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

2020 Final Crab SAFE

Compiled by

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

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Introduction

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

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: https://www.npfmc.org/fishery-management-plan-team/bsai-crab-plan-team/. Due to a process 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. Additionally, based upon consideration of stock prioritization including assessment methods and data availability, some stocks are assessed on an annual basis while others are assessed less frequently. The CPT reviews one assessment in January (Norton Sound red king crab), two assessments in May on a three-year cycle (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, Aleutian Islands golden king crab,) in September (Table 1). Pribilof red king crab is assessed biennially while Pribilof blue king crab is assessed on a three-year cycle. Stocks can be assessed more frequently on a case-by-case basis should data indicate that it is necessary.

Table 1. Ten BSAI crab stocks: Schedule for review by the CPT and SSC and Assessment frequency

Stock	*CPT review and recommendations to SSC*	*SSC review and recommendations to Council*	*Assessment frequency*	*Year of next Assessment*
Norton Sound red king crab (NSRKC)	January	February	Annual	2021
Aleutian Is. golden king crab (AIGKC)	May	June	Annual	2021
Pribilof Is. blue king crab (PIBKC)	May	June	Biennial	2021
Pribilof Is. golden king crab (PIGKC)	May	June	Triennial	2023
Western Aleutian Is. red king crab (WAIRKC)	May	June	Triennial	2023
EBS snow crab	September	October	Annual	2021
Bristol Bay red king crab (BBRKC)	September	October	Annual	2021
EBS Tanner crab	September	October	Annual	2021
Pribilof Is. red king crab (PIRKC)	September	October	Biennial	2021
Saint Matthew blue king crab (SMBKC)	September	October	Annual	2021

Based upon the assessment frequency described in Table 1, 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 (WAIRKC, PIGKC, PIBKC, AIGKC) and October (BBRKC, EBS Snow crab, EBS Tanner crab, SMBKC, PIRKC). 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 that 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 14-17, 2020 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 2020 Crab SAFE report contains recommendations for all 10 stocks including those whose OFL and ABC were previously determined in February and June 2020. This SAFE report will be presented to the NPFMC in October 2020 for their annual review of the status of BSAI Crab stocks.

This review was attended by the entire membership of the CPT: Martin Dorn (Co-Chair), Katie Palof (Co-Chair), James Armstrong (Coordinator), William Bechtol, Ben Daly, Ginny Eckert, Erin Fedewa, Brian Garber-Yonts, Krista Milani, André Punt, Shareef Siddeek, William Stockhausen, Cody Szuwalski, Miranda Westphal, and Jie Zheng.

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 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 for most stocks are annually formulated. The ACL for each stock equals the ABC for that stock. Each crab stock is annually assessed to determine its status and whether (1) overfishing is occurring or the rate or level of fishing mortality for the stock is approaching overfishing, (2) the stock is overfished, or the stock is approaching an overfished condition, and (3) the catch has exceeded the ACL.

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

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

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

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

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

Optimum yield is defined in Chapter 4 of the FMP. Information pertaining to economic, social and ecological factors relevant to the determination of optimum yield is provided in several sections of the

FMP, including sections 7.2 (Management Objectives), Chapter 11, Appendix D (Biological and Environmental Characteristics of the Resource), and Appendix H (Community Profiles).

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

Five-Tier System

The OFL and ABC for each stock are estimated for the upcoming crab fishing year using the five-tier system, detailed in Table 2 and Table 3. 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 2). 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.

First, 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.

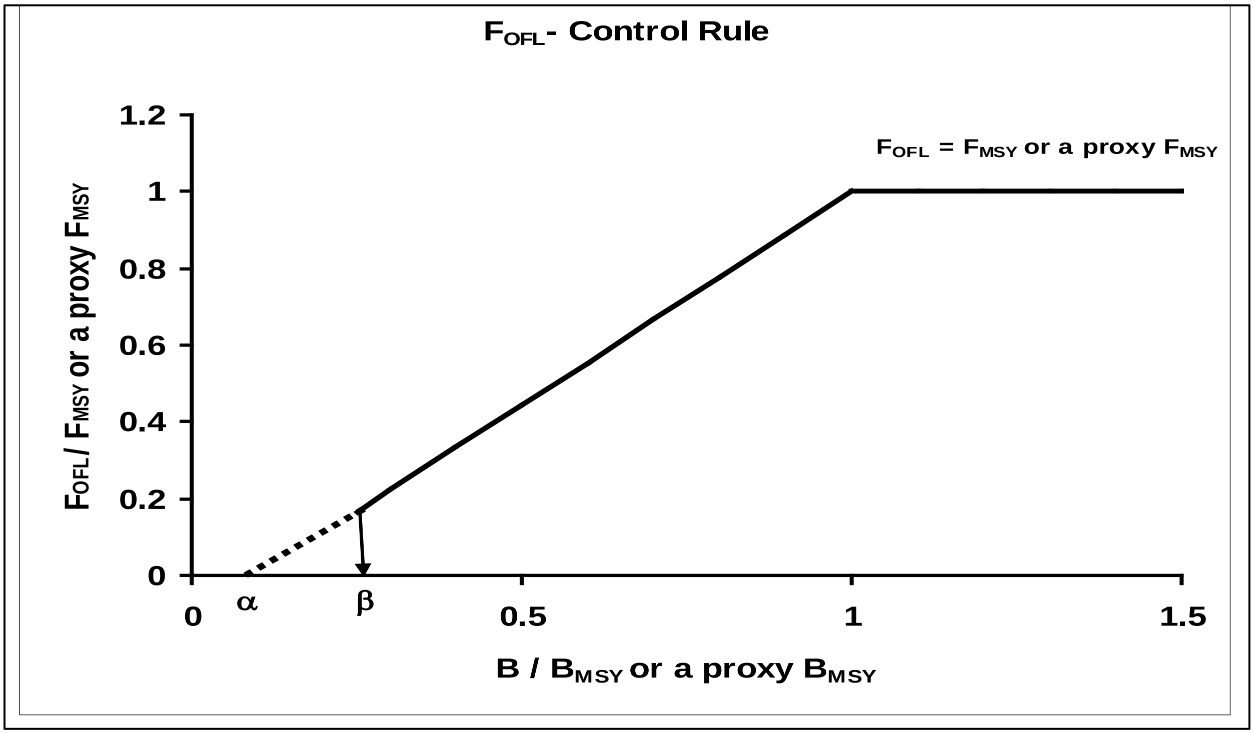

Figure 1. Overfishing control rule for Tiers 1 through 4. Directed fishing mortality is 0 below β.

Table 2. 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 3 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 3. A guide for understanding the five-tier system.

- F_{OFL} — the instantaneous fishing mortality (F) from the directed fishery that is used in the calculation of the overfishing limit (OFL). F_{OFL} is determined as a function of:
  - F_{MSY} — the instantaneous F that will produce MSY at the MSY-producing biomass
    - A proxy of F_{MSY} may be used; e.g., $F_{x\%}$, the instantaneous F that results in x% of the equilibrium spawning per recruit relative to the unfished value
  - B — a measure of the productive capacity of the stock, such as spawning biomass or fertilized egg production.
    - A proxy of B may be used; e.g., mature male biomass
  - B_{MSY} — the value of B at the MSY-producing level
    - A proxy of B_{MSY} may be used; e.g., mature male biomass at the MSY-producing level
  - β — a parameter with restriction that $0 \le \beta < 1$.
  - α — a parameter with restriction that $0 \le \alpha \le \beta$.
- The maximum value of F_{OFL} is F_{MSY}. $F_{OFL} = F_{MSY}$ when $B > B_{MSY}$.
- F_{OFL} decreases linearly from F_{MSY} to $F_{MSY} \cdot (\beta-\alpha)/(1-\alpha)$ as B decreases from B_{MSY} to $\beta \cdot B_{MSY}$
- When $B \le \beta \cdot B_{MSY}$, F = 0 for the directed fishery and $F_{OFL} \le F_{MSY}$ for the non-directed fisheries, which will be determined in the development of the rebuilding plan.
- The parameter, β, determines the threshold level of B at or below which directed fishing is prohibited.
- The parameter, α, determines the value of F_{OFL} when B decreases to $\beta \cdot B_{MSY}$ and the rate at which F_{OFL} decreases with decreasing values of B when $\beta \cdot B_{MSY} < B \le B_{MSY}$.
  - Larger values of α result in a smaller value of F_{OFL} when B decreases to $\beta \cdot B_{MSY}$.
  - Larger values of α result in F_{OFL} decreasing at a higher rate with decreasing values of B when $\beta \cdot B_{MSY} < B \le B_{MSY}$.
- The parameter, b_y, is the value for the annual buffer calculated from a P* of 0.49 and a probability distribution for the OFL that accounts for scientific uncertainty in the estimate of OFL and provides the maximum permissible ABC.
- 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 2019/2020 on Tier assignments, model parameterizations, time periods for reference biomass estimation or appropriate catch averages, OFLs and ABCs. The team recommends four stocks be placed in Tier 3 (EBS snow crab, Bristol Bay red king crab, EBS Tanner crab and Aleutian Island golden king 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 two stocks in Tier 5 (Pribilof Islands golden king crab, and Western Aleutian Islands red king crab). Stock status in relation to status determination criteria are evaluated in this report (Table 4). Status of stocks in relation to status determination criteria for stocks in Tiers 3 and 4 are shown in Figure 2. Table 5 lists those stocks for which the team recommends an ABC less than the maximum permissible ABC for 2019/20. Aleutian Islands golden king crab, EBS snow crab, and Pribilof Island red king crab are estimated to be above B_{MSY} for 2019/20 while EBS Tanner crab, Bristol Bay red king crab, and Norton Sound red king crab are estimated below B_{MSY}. Saint Matthew blue king crab was declared to be overfished in October 2018. Pribilof Islands blue king crab stock remains overfished and is 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 next scheduled assessment. 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 2019 CPT Report).

General Recommendations for all Assessments

1. 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. 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. 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 pounds (lb) and metric tons (t) in the 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 2019/20 was 20,800 t (with discard mortality rates applied), while the retained catch in the directed fishery was 15,400 t. Because the total catch mortality for this stock was below the 2019/20 OFL of 54,900 t, **overfishing did not occur**. 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.

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 account is taken of a terminal molt. The model is fitted to biomass 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 2020 assessment include retained and total catch and length frequencies from the 2019/20 directed fishery, and discard catch and length frequencies from the 2019/20 groundfish fisheries. There were no new survey data because there was no 2020 NMFS trawl survey.

The 2019 and earlier assessments were based on a bespoke model coded in ADMB. The assessment author provided the CPT and SSC with a preliminary version of a model implemented using GMACS in May 2020, and the CPT endorsed its use for the 2020 assessment. The assessment author developed GMACS further after the May 2020 CPT meeting to enable reference points to be calculated.

The assessment author examined four model scenarios for this assessment. Scenario 19.1 was the final model from 2019 with updated bycatch data, Scenario 20.1 was the same as Scenario 19.1 except that the 2019/20 directed fishery and groundfish data were included, Scenario 20.2 was the same as Scenario 20.1 but implemented in GMACS; and Scenario 20.3 was the same as Scenario 20.1, but with extra weight placed on the BSFRF data to force the estimated catchability coefficient to equal the catchability implied by the BSFSF data. The assessment author preferred Scenario 20.2 because it fit the data better than the 2019 model for most data sources, including the survey estimates of male biomass. In addition to fitting the data better, the GMACS model also led to more realistic estimates of fishing mortality during the 1980s and early 1990s, more realistic estimates of growth for females and estimates of immature *M* that are higher than mature *M*. The assessment author preferred Scenario 20.2 to model 20.3 because Scenario 20.2 led to more realistic estimates of biomass and fishing mortality.

The CPT recommends the author's preferred model scenario, 20.2, to determine stock status and set the OFL and ABC for 2020/21 because of the improved fits to the data, and the more realistic estimates of growth, natural mortality and fishing mortality. The CPT recommends that GMACS be used to conduct the 2021 assessment, and form the basis for additional model development work.

Stock biomass and recruitment trends

Observed mature male biomass in the NMFS EBS bottom trawl survey, based on applying a maturity ogive, decreased from a peak of 167,100 t in 2011 to 97,500 t in 2013, increased to 163,500 t in 2014, fell to 63,200 t in 2016, then increased once again to 84,000 t in 2017, 198,400 t in 2018, and 169,100 t in 2019. Observed survey mature female biomass rose quickly from a low of 52,200 t in 2009 to 175,800 t in 2011, its highest value since 1991, decreased steadily to 55,400 t in 2016, then increased to 106,800 t in 2017 and to a peak of 165,900t in 2018. Observed survey mature female biomass decreased in 2019 to 110,400 t.

The model estimates for mature male biomass-at-mating (MMB) declined from a 10-year high of 209,600 t in 2009/10 to a low in 2015/16 of 66,900 t. MMB increased in subsequent years and was estimated to be 560,200 t in 2020/21. Model-estimated mature female biomass-at-mating (MFB) began to decline somewhat later, from a peak in 2011/12 (546,700 t) to a low in 2016/17 (201,200 t), followed by increases to 432,900 t in 2019/20. MFB declined to 352,800t in 2020/21.

Estimated recruitment to the population has been episodic, with peaks in recruitment generally preceding peaks in mature biomass by a few years. The most recent peaks were in 2008/09 (1,370,000 crab), preceding peaks in MMB and MFB in 2009/08 and 2011/12, respectively, and in 2015/16 (15,720,000 crab), preceding the increases in MMB and MFB that began in 2015/16. The estimate of 2015/16 recruitment is substantially higher in this year's assessment than the 2019 assessment.

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 (113.7 kt) based on average recruitment over 1982 to 2018. Consequently, the minimum stock size threshold (MSST) is 56.8 kt. Projected MMB for 2020/21 (276.7kt) is above the MSST, so **the stock is not overfished**. The CPT recommends that the ABC be less than maximum permissible ABC. The buffer between the ABC and OFL was 20% for 2017, 2018 and 2019 assessments, reflecting uncertainty about model misspecification (growth) and parameter confounding, the ongoing evidence for retrospective patterns, and the uncertainty surrounding rates of natural mortality. There is less concern about growth in the 2020 assessment, but the CPT was concerned about the reasons for the substantial increase in 2015/16 recruitment, which may be a consequence of GMACS imposing only weak penalties on the recruitment deviations. Thus ignoring the effect of the lack of a 2020 survey, the CPT recommends a buffer of 25% based only on uncertainties related to the model fit.

The 2020 NMFS bottom trawl surveys were cancelled due to concerns related to the COVID-19pandemic, and this stock assessment is missing survey data for the terminal year. The 2020 assessment of EBS snow crab is the most sensitive of the 2020 model-based assessments to the lack of terminal year survey data, with a median relative over-estimate of the OFL of close to 25%. The CPT therefore recommends an additional 25% buffer resulting in a total buffer of 50% between the OFL and ABC for the 2020/21 fishing year.

Status and catch specifications (1000 t) for snow crab. 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
2016/17	75.8	96.1	9.7	9.7	11.0	23.7	21.3
2017/18	71.4	99.6	8.6	8.6	10.5	28.4	22.7
2018/19	63.0	123.1	12.5	12.5	15.4	29.7	23.8
2019/20	56.8	167.3	15.4	15.4	20.8	54.9	43.9
2020/21		276.7				184.9	92.5

Status and catch specifications (million lb) for snow crab. 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
2016/17	167.1	211.9	21.4	21.4	24.3	52.3	47.0
2017/18	157.4	219.6	19.0	19.0	23.2	62.6	50.0
2018/19	138.9	271.4	27.6	27.6	34.0	65.5	52.5
2019/20	125.2	368.8	34.0	34.0	45.9	121.0	96.8
2020/21		610.0				407.6	203.8

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. 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 58.9 kt 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 thresholds of 8.4 million mature-sized (≥90 mm CL) females and 6.6 kt of effective spawning biomass (ESB) to prosecute a fishery. Annual non-retained catch of female and sublegal male RKC during the fishery has averaged less than 8.6 kt since data collection began in 1990. Total catch (retained and bycatch mortality) increased from 7.6 kt in 2004/05 to 10.6 kt in 2007/08 but has decreased since then; retained catch in 2019/20 was 1.78 kt and total catch mortality was 2.22 kt.

Data and assessment methodology

The stock assessment is based on a sex- and size-structured population dynamics model incorporating data from the NMFS eastern Bering Sea trawl survey, the Bering Sea Fisheries Research Foundation (BSFRF) trawl survey, landings of commercial catch, at-sea observer sampling, and dockside retained catch sampling. In the model recommended by the CPT, annual stock abundance was estimated for male and female crabs ≥ 65-mm CL from 1975 to July 1, 2020 and mature male (males ≥120 mm CL) biomass was projected to 15 February 2021. 2019/20 fishery data on retained catch in the directed fishery were obtained from ADF&G fish tickets and reports (retained catch numbers, retained catch weight, and pot lifts by statistical area and landing date), on bycatch in the red king crab and Tanner crab fisheries from the ADF&G observer database, and on bycatch in the groundfish trawl fisheries from the NMFS groundfish observer database. The 2020 NMFS EBS shelf bottom trawl survey was cancelled due to safety concerns associated with the COVID-19 pandemic; consequently, the model was fit using 1975-2019 NMFS trawl survey dataset, which included sex-specific area-swept estimates of abundance, biomass, and size composition.

Three principal model scenarios were evaluated using GMACS for the 2020 assessment. Model 19.0a was identical to the 2019 assessment model (19.0), except that an error specifying the reference period for the mean sex ratio required to calculate $B_{35\%}$ was corrected. Scenario 19.3 was the same as 19.0a except for the way natural mortality (M) was treated: a constant M estimated for males during 1980-1984, M fixed to $0.18yr^{-1}$ for males during other years, and an estimated constant multiplier applied to male M to obtain female M. Finally, scenario 19.3b was the same as model 19.3 except that the CV of the prior for trawl survey catchability was doubled to reduce its effect . Because estimates for the terminal year recruitment in all of these models were extremely uncertain due to the absence of data from the cancelled 2020 NMFS EBS bottom trawl survey, two scenarios otherwise identical to 19.0a and 19.3 (19.0b and 19.3a, respectively) were defined such that recruitment in the terminal year was fixed to the mean recruitment during the previous seven years (thus reducing the uncertainty in the estimate of terminal year recruitment). This allowed multi-year projections with reasonable values for future recruitment to be run for scenarios 19.0a and 19.3 (projections were not run for 19.3b).

As expected, results (other than projections) for scenarios 19.0a and 19.0b were nearly identical, as were those from scenarios 19.3 and 19.3a. Also as expected, scenario 19.3b estimated an unreasonably high catchability for the trawl survey (>1.0), resulting in overall lower biomass estimates. Biomass estimates from 19.0a were greater for recent years, compared with those from 19.3 and 19.3b. The differences were largely explained by differences in estimated natural mortality rates between the 19.0 and 19.3 scenarios. All models fit the fishery catch and bycatch biomass data extremely well. Model scenario 19.3 fit the data somewhat better than 19.0a with one fewer parameter and was the CPT's preliminary choice for the recommended model scenario during its May 2020 meeting. Scenario 19.3b was primarily a sensitivity run, while the CPT found the 7-year averaging period for the estimate of terminal recruitment in scenarios 19.0b and 19.3a rather arbitrary. Thus, the CPT selected the author's preferred model scenario, 19.3, as its recommended model for status determination and OFL setting.

Stock biomass and recruitment trends

Based on the CPT-recommended scenario, 19.3, the MMB at the time of mating is estimated to have been highest early in the late 1970s (approximately 120 kt), with secondary peaks in 1989 (27 kt) and 2002/03 (~33 kt), followed by a gradual decline. The estimated MMB at time of mating in 2019/20 was 14.24 kt. The projection for the 2020/21 time of mating, which assumes the fishing mortality in 2020/21 matches that corresponding to the OFL, is 14.93 kt. Estimates of recruitment since 1985 have been generally low relative to those estimated for the period prior to 1985 and intermittent peaks in 1995, 2002, and 2005 (61, 52, and 42 million crab, respectively). The relatively low estimate of recruitment for 2019 (3.8 million crab) was the second lowest since 1994. The estimate for 2020, 18.9 million, was the largest since 2010 but was highly uncertain due to the lack of 2020 survey data to inform the model.

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

Bristol Bay red king crab is in Tier 3. Based on previous discussion at the January and May 2018 CPT meetings regarding an apparent reduction in stock productivity associated with the 1976/77 climate regime shift in the EBS, the CPT concurred with the author's recommendation to drop the terminal year recruitment from the time period for average recruitment when calculating $B_{35\%}$ because it is highly uncertain. The CPT recommends computing average recruitment as has been done in recent assessments (i.e., based on model recruitment using the time period 1984 and corresponding to fertilization in 1977) to the penultimate year of the assessment. Based on scenario 19.3, the estimated $B_{35\%}$ is 25.4 kt. MMB projected for 2020/21 is 14.93 kt, 59% of $B_{35\%}$. Consequently, the BBRKC stock is in Tier 3b for 2020/21. The corresponding OFL is 2.14 kt.

Last year, the CPT recommended setting the ABC below the maximum permissible, using a 20% buffer on the OFL to account for additional uncertainty in the assessment associated with the model's lack of fit to the 2018 and 2019 NMFS EBS bottom trawl survey data and recent environmental conditions (e.g., elevated bottom temperatures, lack of a cold pool). This year, the CPT considers the absence of the 2020 NMFS EBS bottom trawl survey from the data used to fit the model to be a potentially substantial additional source of uncertainty to be considered when determining the ABC. The CPT adopted a two-stage approach to characterizing additional uncertainty in the context of determining the ABC. The first stage was to discuss whether or not, ignoring the issue of the cancelled 2020 NMFS bottom trawl survey, the level of uncertainty associated with the assessment differed substantially (either better or worse) from last year's model and thus warranted changing the buffer used last year. The second stage would consider whether the canceled survey introduced enough additional uncertainty to warrant expanding the buffer.

After substantial discussion, the CPT concluded that the level of uncertainty associated with the assessment, ignoring the issue of the cancelled 2020 NMFS survey, had not changed substantially from last year. Although scenario 19.3 fit female survey biomass in 2018 and 2019 much better than 19.0a did, it still overpredicted male survey biomass in these years. In addition, continued concern over poor environmental conditions (as reflected in the BBRKC ESP) and lack of recent recruitment was expressed by several CPT members. However, members agreed that the uncertainty associated with these issues was already included in the 20% buffer previously adopted and did not warrant further increase.

The additional uncertainty associated with the cancelled 2020 NMFS survey was addressed by the assessment author using: 1) results from a pair of retrospective analyses in which the terminal year survey was either included or excluded from the model fits, 2) comparison of CV's for management-related quantities from the 2019 assessment run with and without the 2019 NMFS survey included in the model fit, and 3) comparison of management-related quantities from scenarios (19.3l and 19.3h) using simulated 2020 survey biomass data based on the predicted 2020 survey biomass from scenario 19.3 and the 25th and 75th quantiles for relative errors in the fits to the survey biomass time series. For 1), management-related quantities (e.g., B_{MSY}, OFL) from the survey-included/excluded model runs were compared for each retrospective peel. Results from these comparisons indicate the likely additional uncertainty introduced by the cancelled survey is approximately 5%. The CPT was concerned that the stock in 2021 was estimated to be at 59% of B_{MSY}, which is close to the overfished threshold. The CPT concluded that the cancelled survey in 2020 reduced the ability to reliably determine stock status, which warrants the additional buffer. The CPT recommends an additional buffer of 5% based on the retrospective analysis that indicated the OFL tended to be over-estimated by about 5% when there was no survey in the terminal year. This recommendation would result in a total buffer of 25%.

MMB for 2019/20 was estimated to be 14.24 kt and above MSST (10.62 kt); hence the stock was not overfished in 2019/20. The total catch mortality in 2019/20 (2.22 kt) was less than the 2019/20 OFL (3.40 kt); hence overfishing did not occur in 2019/20. However, several CPT members expressed concern that the stock will be overfished in a few years and that king crab stocks do not seem to rebuild easily, once an overfished condition is reached. It was suggested that it may be time to review the use of $F_{35\%}$ as a proxy for F_{MSY} for this and other Alaskan crab stocks.

Status and catch specifications (1000 t) for Bristol Bay red king crab. 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
2016/17	12.53	25.81	3.84	3.92	4.28	6.64	5.97
2017/18	12.74	24.86	2.99	3.09	3.48	5.60	5.04
2018/19	10.62	16.92	1.95	2.03	2.65	5.34	4.27
2019/20	12.72	14.24	1.72	1.78	2.22	3.40	2.72
2020/21		14.93				2.14	1.61

Status and catch specifications (million lb) for Bristol Bay red king crab. 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
2016/17	27.6	56.9	8.47	8.65	9.63	14.63	13.17
2017/18	28.1	54.8	6.60	6.82	7.93	12.35	11.11
2018/19	23.4	37.3	4.31	4.31	5.85	11.76	9.41
2019/20	28.0	31.4	3.80	3.91	4.89	7.50	6.00
2020/21		32.9				4.72	3.54

Note: The relatively low MSST in 2018/19 (and B_{MSY} in 2019/20) in the tables above was the result of a problem in the previous GMACS application, which used the sex ratio of recruitment in the terminal year to calculate $B_{35\%}$. A low estimate for the male recruitment ratio in the terminal year in the 2019 assessment resulted in a lower mean male recruitment for $B_{35\%}$ in 2019/20. The current version of GMACS uses the average sex ratio at recruitment during the reference period to estimate $B_{35\%}$, which results in a much more stable sex ratio (about 50%) for the reference point calculation.

3 Eastern Bering Sea Tanner crab

Fishery information relative to OFL setting

Eastern Bering Sea (EBS) Tanner crab are caught in directed Tanner crab fisheries, as bycatch in the groundfish and scallop fisheries, as bycatch in 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. 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 fishery was closed from 2010/11 through 2012/13 crab fishery years.

NMFS determined the stock was rebuilt in 2012 based on a new assessment model with a revised estimate of B_{MSY}. The directed fishery was open for the 2013/14 to 2015/16 seasons with a total allowable catch (TAC) of 1,410 t in 2013/14, 6,850 t in 2014/15, and 8,920 t in 2015/16. The total retained catch in 2015/16 (8,910 t) was the largest taken in the fishery since 1992/93. In 2016/17, ADF&G determined that mature female biomass did not meet the criteria for opening a fishery according to the regulatory harvest strategy, and the TAC was set at zero. Consequently, there was no directed harvest in 2016/17. In 2017/18, ADF&G determined that a directed fishery could occur in the area west of 166°W longitude. The TAC was set at 1,110 t for 2018/19, of which 100% was taken. In 2019/20, mature female biomass again did not meet ADF&G criteria for opening a fishery, and there was no directed harvest.

In March 2020, the harvest control rule for Tanner crab was changed by the Alaska Board of Fisheries based on results from an extensive management strategy evaluation (MSE) conducted with input from industry stakeholders, NMFS and academic scientists, and ADF&G managers. The current HCR defines the period for calculating average mature biomass as 1982-2018, and determines exploitation rates on mature males using sliding scale functions of the ratios of MMB and mature female biomass to their long-term averages.

Data and assessment methodology

The SSC accepted a size-structured assessment model for use in harvest specifications in 2012 and classified the EBS Tanner stock as a Tier 3 stock. This year's assessment used the modeling framework, TCSAM02, which was endorsed by the SSC in June 2017. The model is structured by crab size, sex, shell condition, and maturity. The model uses available data on quantity and size-composition from: the NMFS trawl survey; landings and discards by the directed fishery; and 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. There was limited new information for Tanner crab this year due to a closed directed fishery and a cancelation of 2020 NMFS EBS trawl survey. Input data sets were updated with the most recent information on bycatch and size composition data from other 2019/20 crab fisheries, as well as data on Tanner crab bycatch in the groundfish fisheries in 2019/20.

The model recommended by the CPT to set the OFL and the ABC is a revised model (Model 20.07) that incorporates the BSFRF trawl survey data from its cooperative "side-by-side" (SBS) catch comparison studies with the NMFS EBS shelf bottom trawl survey to better fix the scale of the NMFS survey data. Empirical availability curves for the BSFRF were estimated outside the assessment model using a generalized additive model with cubic splines. These were used in the model to relate the BSFRF estimates of absolute abundance (at spatial scales smaller than the stock distribution) and the stock abundance estimated by the assessment model. The CPT regarded this model as an improvement over last year's model because it made robust use of data from BSFRF catch comparison studies, which had not been used previously for Tanner crab.

Stock biomass and recruitment trends

The MMB at the time of mating is estimated to have been highest in the early 1970s (approximately 400 kt), with secondary peaks in 1991 (99 kt), 2008 (108 kt), and in 2014 (111 kt). The estimated MMB at time of mating in 2019/20 was 56.15 kt and the projection for 2020/21 is 35.33 kt. Estimates of recruitment since 1999 have been generally low relative to the peaks estimated for the period prior to 1990. There was a relatively strong recruitment estimated for 2016, 2017, and 2018, but these estimates remain uncertain and will need to be confirmed by subsequent assessments.

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

The CPT 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 average recruitment corresponding to B_{MSY} under prevailing environmental conditions. This recommended time period is 1982 – 2019. The 1982-and-onwards time period had been used in previous OFL determinations, but this year a decision was made to exclude the recruitment estimate for the terminal year in this calculation. This estimate is extremely uncertain this year due to the lack of survey information.

Based on the estimated biomass at 15 February 2020, the stock is at 96% of B_{MSY}, and therefore is in Tier 3b. The F_{MSY} proxy ($F_{35\%}$) is 0.98 yr^{-1}, and the 2020/21 F_{OFL} is 0.94 yr^{-1} under the Tier 3b OFL Control Rule, which results in a total OFL of 21.13 kt. The CPT recommends a 20% buffer to account for model uncertainty and stock productivity uncertainty be applied to the OFL to set ABC = 16.90 kt. The 20% buffer is the same that the SSC recommended for determination of the 2019/20 ABC. The CPT concluded that no additional buffer was needed to account for the cancelled NMFS EBS bottom trawl survey in 2020.

Status and catch specifications (1000 t) for Tanner crab. 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
2016/17	14.58	77.96	0.00	0.00	1.14	25.61	20.49
2017/18	15.15	64.09	1.13	1.13	2.37	25.42	20.33
2018/19	20.54	82.61	1.11	1.11	1.90	20.87	16.70
2019/20	18.31	56.15	0.00	0.00	0.54	28.86	23.09
2020/21		35.31				21.13	16.90

Status and catch specifications (million lb) for Tanner crab. 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
2016/17	32.15	171.87	0.00	0.00	2.52	56.46	45.17
2017/18	33.40	95.49	2.50	2.50	5.22	56.03	44.83
2018/19	45.27	182.09	2.44	2.44	4.18	46.01	36.82
2019/20	40.36	123.77	0.00	0.00	1.20	63.62	50.89
2020/21		77.84				46.58	37.26

4 Pribilof Islands red king crab

The Pribilof Islands red king crab (PIRKC) assessment is on a biennial cycle. This year (2020) is an 'off' year in the cycle, so an update to determine whether or not overfishing occurred in 2019/20 is presented here. The next full assessment will occur in 2021.

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 bycatch has been well below the OFL, ranging from 1.0 to 17.0 t in 2012/13–2018/19.

Data and assessment methodology

The 2019 assessment is based on trends in male mature biomass (MMB) from NMFS bottom trawl survey and commercial catch and trawl bycatch data through 2018/19. Three assessment methods using a Tier 4 harvest control rule 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, and the third was a GMACS integrated method. The GMACS integrated model was presented with five variations: 1) model 19.1: M from BBRKC, 2) model 19.2: 19.1+ more of the population selected in the trawl bycatch, 3) model 19.3: 19.1+ molting probability shifted to the left, 4) model 19.4: 19.1+ increased M (by Hamel method), and 5) model 19.5: 19.1+ increased M (by the Then and Hoenig method).

Stock biomass and recruitment trends

GMACS model fit to mature male biomass identified two peaks of biomasses. In recent years, observed mature male biomass (>120 mm CL) peaked in 2015 and has steadily declined since then. The mature male biomass varied widely over the history of the survey time series and uncertainty around area-swept estimates of biomass were largely due to relatively low sample sizes. Recruitment estimated by the GMACS integrated model appeared to be episodic. Survey length composition data suggest a new year-class has been established recently, but its size is unclear. Numbers at length vary dramatically from year to year; however, two cohorts can be seen moving through the length frequencies over time. GMACS model estimated MMB peaked during 1999 to 2003 and systematically declined since then. However, the 2019 MMB (4,024 t) increased over that in 2018 (2,293 t).

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

The CPT recommended the Tier 4 stock status determination and selected the GMACS model 19.4. This model was selected because it incorporates all available information for the stock and uses a more defensible prior for M. The CPT also recommended use of a modified method of B_{MSY} estimation, which is equal to 0.35*average MMB for 2000 to present, during which no directed fishery occurred. For 2019/20 the B_{MSY} = 1,733 t derived as the 0.35*mean MMB from 2000/01 to 2018/19 from the GMACS model 19.4. Male mature biomass at the time of mating for 2018/19 was estimated at 5,368 t. The B/B_{MSY} = 3.1 and F_{OFL}= 0.21. $B/B_{MSY\ Proxy}$ is > 1, therefore the stock status level is Tier 4*a*. For the 2019/20 fishery, the OFL is 864 t. The CPT recommended a 25% buffer for an ABC from the OFL as in previous years.

Status and catch specifications (1000 t) for Pribilof Islands red king crab. 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
2015/16	2,756	9,062	0	0	4.32	2,119	1,467
2016/17	2,751	4,788	0	0	0.94	1,492	1,096
2017/18	2,751	3,439	0	0	1.41	404	303
2018/19	866	5,368	0	0	7.22	404	303
2019/20	866	6,431	0	0	3.84	864	648
2020/21		6,431				864	648

Status and catch specifications (million lb) for Pribilof Islands red king crab. 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
2015/16	6.08	19.98	0	0	0.01	4.67	3.23
2016/17	6.06	10.56	0	0	0	3.29	2.42
2017/18	6.06	7.58	0	0	0	0.89	0.67
2018/19	1.91	11.83	0	0	0.02	0.89	0.67
2019/20	1.91	14.18	0	0	0.01	1.9	1.43
2020/21		14.18				1.9	1.43

The most recent full assessment was conducted in September 2019 and the stock was above MSST in 2018/19 and was not overfished. Overfishing did not occur for PIRKC during 2019/20 because the total catch mortality did not exceed the OFL.

5 Pribilof Islands blue king crab

The Pribilof Islands blue king crab assessment is biennial with the last assessment conducted in 2017. Information listed below summarizes the 2019 assessment.

Fishery information relative to OFL setting.

The Pribilof Islands 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 for the 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 is 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, ADF&G also implements closure areas for the commercial crab fisheries to reduce the blue king crab bycatch. NMFS has implemented procedures to account for blue king crab bycatch in the groundfish fisheries and take action to prevent overfishing.

Data and assessment methodology

The calculation of the 2018/19 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 uses the 2016/17 methodology to project MMB and calculate B_{MSY}. Prior to 2016/17, MMB 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 current methodology to calculate MMB and B_{MSY} uses a random effects model to smooth the survey time series.

In 2017, the assessment was moved from September to May, which has required that several data inputs to the model (assessment year MMB at the time of the survey and retained catch and bycatch values from the crab fishery year prior to the assessment year) be estimated in some fashion. For the 2019 assessment, MMB at the time of survey (July 2019) was estimated from the observed time series using the random effects as a 1-step ahead prediction. The values of year-to-date bycatch in the crab and groundfish fisheries on April 1, 2019 were taken as estimates of the 2018/19 year-end values for rebuilding status determination. These values were updated in September 2019 to evaluate overfishing status, which did not occur.

Stock biomass and recruitment trends

The 2019/20 MMB at mating is projected to be 175 t, which is approximately 4% 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 4,106 t for 2019/20.

Because the projected 2019/20 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. For this stock, the F_{OFL} is based on average groundfish bycatch between 1999/2000 and 2005/06, a time period determined as part of the rebuilding plan. The recommended OFL for 2019/20 is 1.16 t.

The CPT continues to recommend 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
2015/16	2,058	361	Closed	0	1.18	1.16	0.87
2016/17	2,053	232	Closed	0	0.38	1.16	0.87
2017/18	2,053	230	Closed	0	0.33	1.16	0.87
2018/19	2,053	230	Closed	0	0.41	1.16	0.87
2019/20	2,053	175	Closed	0	0.42	1.16	0.87
2020/21		175				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
2015/16	4.537	0.796	Closed	0	0.0026	0.0026	0.002
2016/17	4.526	0.511	Closed	0	0.0008	0.0026	0.002
2017/18	4.526	0.507	Closed	0	0.0007	0.0026	0.002
2018/19	4.526	0.507	Closed	0	0.0009	0.0026	0.002
2019/20	4.526	0.386	Closed	0	0.0009	0.0026	0.002
2020/21		0.386				0.0026	0.002

The most recent full assessment was conducted in May 2019 and the stock was above MSST in 2018/19 and was not overfished. Overfishing did not occur for PIBKC during 2019/20 because the total catch mortality did not exceed the OFL.

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 (9.453 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 (3.298 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 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 identified 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, closed in 2013/14, opened from 2014/15 – 2015/16, and has been closed since 2016/17. Bycatch of non-retained blue king crab has occurred in the St. Matthew blue king crab fishery, the eastern Bering Sea snow crab fishery, and trawl and fixed-gear groundfish fisheries. The stock declined below the minimum stock size threshold in 2018 and was declared overfished. A rebuilding plan is under development.

Data and assessment methodology

This assessment is conducted in GMACS, which was first accepted for use by the SSC in June 2016. This assessment uses the same model configuration as last year. The model incorporates the following data: (1) commercial catch data; (2) annual trawl survey data; (3) triennial pot survey data; (4) bycatch data in the groundfish trawl and groundfish fixed-gear fisheries; and (5) ADF&G crab-observer composition data.

Stock biomass and recruitment trends

Following a period of low values after the stock was declared overfished in 1999, trawl-survey indices of stock abundance and biomass generally increased to well above average during 2007–2012. In 2013 survey biomass declined (~40% of the mean value) but was followed by average biomass estimates in 2014 and 2015, but with survey CVs of 77% and 45%, respectively). The 2016 survey biomass fell to 3,485 t, followed by continued declines to the 2018 survey estimate of 1,731 t. The 2019 survey estimate of 3,170 t represents an increase of 83% from 2018 but remains low in a historical context.

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 CL size class in each year. The 2019 trawl-survey area-swept estimate of 0.403 million males in this size class is the twelfth lowest in the 42-year time series since 1978 and follows two of the lowest observed recruitments in 2017 and 2018.

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

The stock assessment examines four model configurations: (1) Model 16.0 - the 2019 recommended model; (2) Model 16.0 – the base model, i.e., last year's model updated with new data; (3) Model 16.0a, which fixes the estimate of the terminal year of recruitment as the average of the past seven years; and (4) Model 20.1, which excludes the ADF&G pot survey.

The CPT concurs with the author's recommendation to use the base model 16.0 for the 2020/21 crab year. This stock is in Tier 4. The CPT recommends that the full assessment period (1978/79–2019/20) be used to define the proxy for B_{MSY} in terms of average estimated MMB_{mating}. The projected MMB estimated for 2020/21 under the recommended model is 1,120 t and the F_{MSY} proxy is the natural mortality rate (0.18^{-1} year) and F_{OFL} is 0.047, resulting in a mature male biomass OFL of 0.05 kt. The MMB/B_{MSY} ratio is 0.34.

The author recommended and the CPT concurred with a 25% buffer on the OFL for the ABC which was a return to the correct buffer from a mistakenly applied 20% last year. The ABC based on this buffer is 0.04 kt.

Status and catch specifications (1000 t) for St Matthew blue king crab. 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
2016/17	1.97	2.23	0.00	0.00	0.001	0.14	0.11
2017/18	1.85	2.05	0.00	0.00	0.003	0.12	0.10
2018/19	1.74	1.15	0.00	0.00	0.001	0.04	0.03
2019/20	1.67	1.06	0.00	0.00	0.001	0.04	0.03
2020/21		1.12				0.05	0.04

Status and catch specifications (million lb) for Saint Matthew blue king crab. 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
2016/17	4.30	4.91	0.00	0.000	0.002	0.31	0.25
2017/18	4.10	2.85	0.00	0.000	0.007	0.27	0.22
2018/19	3.84	2.54	0.00	0.000	0.002	0.08	0.07
2019/20	3.68	2.34	0.00	0.000	0.002	0.096	0.08
2020/21		2.48				0.112	0.08

The stock was found to be below MSST in 2017/18 and was declared overfished, and the Council's recommended rebuilding plan will be effective by October 22, 2020. Total catch was less than the OFL in 2019/20 and hence overfishing did not occur.

7 Norton Sound red king crab

Fishery information relative to OFL setting

The Norton Sound red king crab (NSRKC) stock supports three fisheries: summer commercial, winter commercial, and subsistence. The summer commercial fishery, which accounts for most of the catch, reached a peak in the late 1970s at a little over 1.313 kt retained catch. Retained catches since 1982 have been below 0.227 kt, averaging 0.136 kt., including several low years in the 1990s. As the crab population rebounded, retained catches increased to 0.231 kt in 2016, but decreased 69% to 0.073 kt. in 2019.

Data and assessment methodology

Four types of surveys for NSRKC have occurred periodically during the last three decades: summer trawl, summer pot, winter pot, and preseason summer pot. The assessment is based on a length-based model of male crab abundance that combines multiple sources of data. A maximum likelihood approach was used to estimate quantities relevant in management. The model has been updated to include the following data: total catch, catch length composition, discard length composition data from the 2019 summer and winter commercial fisheries (retained size composition data were not collected for the winter fishery due to low harvest). The standardized commercial catch CPUE indices were updated based on data for 1977-2019 and 14 new tag recoveries were included in the assessment. The current model assumes a constant M=0.18 yr-1 for all length classes except the >123mm CL length-class, which had an estimated value of 0.58 yr-1. Logistic functions are used to describe fishery and survey selectivities, except for a dome-shaped function used for the winter pot fishery.

The assessment author presented six model alternatives, including a base model (model 19.0) that was adopted in 2018 and several other models that examine the influence of tagging data on estimated molting probability, the validity of assumptions about trawl survey q, and the assumptions of size-dependent natural mortality.

The CPT recommended the base model 19.0.

Stock biomass and recruitment trends

Estimated mature male biomass was at an historic low in 1982 following a sharp decline from the peak biomass in 1977. MMB increased from a low in 1997 to a peak in 2010, after which it fluctuated about the B_{MSY} proxy. Estimated MMB is currently near the low in 1982. Estimated recruitment has generally been variable and the most recent recruitment estimate is one of the largest since the late 1970s, but will not be corroborated until it enters the fishery in several years.

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

The team continues to recommend Tier 4 for Norton Sound red king crab. The B_{MSY} proxy, calculated as the average of mature male biomass on February 1 during 1980-2019 was 2.068 kt The estimated 2020 mature male biomass on February 1 using Model 19.0 is 1,660 t which is below the B_{MSY} proxy for this stock, placing Norton Sound red king crab in status category 4b. The FMSY proxy is M =0.18 yr-1 and the F_{OFL}=0.141yr-1, because the 2020 mature male biomass is less than B_{MSY} proxy using the default gamma =1.0.

The CPT recommends model 19.0 to set the OFL for 2020, resulting in an OFL of 0.287 million lb. (0.13 thousand t). The team recommends that the ABC for 2020 be set below the maximum permissible ABC. The team recommends that the SSC-endorsed buffer of 20% from the OFL be increased to 25% given very low fishery CPUE and unusually large numbers of old-shell males in the fishery. The resulting ABC is 0.100 kt. The OFL is a retained catch OFL. The author calculated a total catch OFL as part of the assessment, but it is not used because no way to estimate discards from the fishery monitoring program has been adopted.

Status and catch specifications (1000t). 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 Commercial Catch	Total Retained Catch	Retained Catch OFL	Retained catch ABC
2016	1.03	2.66	0.24	0.23	0.24	0.32	0.26
2017	1.05	2.33	0.23	0.22	0.24	0.30	0.24
2018	1.09	1.85	0.13	0.14	0.15	0.20	0.16
2019	1.03	1.41	0.07	0.04	0.04	0.11	0.09
2020	1.04	1.66				0.13	0.10

Status and catch specifications (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 Commercial Catch	Total Retained Catch	Retained Catch OFL	Retained catch ABC
2016	2.26	5.87	0.52	0.51	0.52	0.71	0.57
2017	2.31	5.14	0.50	0.49	0.50	0.67	0.54
2018	2.41	4.08	0.30	0.31	0.34	0.43	0.35
2019	2.24	3.12	0.15	0.08	0.08	0.24	0.19
2020	2.28	3.67				0.29	0.22

Total retained catch during 2019 did not exceed the OFL for this stock, thus overfishing is not occurring. Stock biomass is above MSST; thus, the stock is not overfished.

8 Aleutian Islands Golden King Crab

Fishery information relative to OFL setting

The directed fishery has been prosecuted annually since the 1981/82 season. Management based on a formally established GHL began with the 1996/97 season. The Alaska Board of Fisheries adopted an abundance-based harvest strategy for the stock in March 2019. This fishery has been managed under the Crab Rationalization Program since 2005. Total mortality of AI golden king crab includes retained catch in the directed fishery, mortality of discarded catch, and bycatch in fixed-gear and trawl groundfish fisheries, though bycatch in other fisheries is low compared to mortality in the directed fishery. Total mortality in the post-rationalized fishery has ranged from 2,506 t in 2006/07 to 3,735t in 2019/20.

Data and assessment methodology

The assessment for AI golden king crab establishes a single OFL and ABC for the whole stock. However, separate models are evaluated for the EAG and the WAG owing to different abundance trends in each area. The current modeling framework was recommended by the CPT in September 2016 and approved by the SSC in October 2016.

The model-based stock assessment involves fitting male-only population dynamics models to data on catches and discards in the directed fishery, discards in the groundfish fishery, standardized indices of abundance based on observer data, fish ticket data, length-frequency data for the directed fishery (landings and total catch), and mark-recapture data. This is the only crab assessment that relies solely on fishery CPUE as an index of abundance, with the CPUE index standardization process subject to past CPT and SSC review.

The assessment authors examined six model scenarios for the EAG and three model scenarios for the WAG in this assessment cycle. Model 19.1 was last year's base model. Model 20.1b was the same as Model 19.1 except that the standardization of the Fish Ticket CPUE was based on a negative binomial error model. Model 20.1b is an improvement over last year's base model because it better accounts for the noise in the base model. The CPT recommends Model 20.1b with mean recruitment based on the estimates for years 1987-2012 for OFL and ABC determination for 2020/21.

Stock biomass and recruitment trends

Estimated mature male biomass (MMB) for the EAG decreased from high levels until the 1990s after which the trend has been increasing. In contrast, the MMB for the WAG increased from a low in the 1990s until 2007/08 and then declined again, and has since recovered to the MMB levels of those in the mid-2000s. Recruitment for the EAG was variable and high during 2014-2016 while recruitment for the WAG was lower in recent years than during the 1980s. Stock trends reflected the fishery standardized CPUE trends in both areas.

Summary of major changes

The assessment model recommended by the CPT is similar to the model used in the previous assessment. There were minor changes in the CPUE standardization for the Fish Ticket data that had minor effects on assessment results.

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

The CPT recommends that this stock be managed as a Tier 3 stock in 2020/21. A single OFL and ABC is defined for AIGKC. However, separate models are available by area. The CPT recommends that stock status be determined by adding the estimates of current MMB and B_{MSY} by area. This stock status is then used to determine the ratio of F_{OFL} to $F_{35\%}$ by area, which is then used to calculate the OFLs by area, which are then added together to calculate an OFL for the entire stock. The SSC has concurred with this approach. The stock is currently estimated to be above B_{MSY} in both areas therefore no adjustment is needed to the F_{OFL} to determine the combined OFL for both areas. As in 2019, the CPT recommends that the B_{MSY} proxy for the Tier 3 harvest control rule be based on the average recruitment from 1987-2012, years for which recruitment estimates are relatively precise.

Status and catch specifications (1000 t) for Aleutian Islands golden king crab. 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
2016/17	N/A	N/A	2.515	2.593	2.947	5.69	4.26
2017/18	6.044	14.205	2.515	2.585	2.942	6.048	4.536
2018/19	5.880	17.848	2.883	2.965	3.355	5.514	4.136
2019/20	5.909	16.323	3.257	3.319	3.735	5.249	3.937
2020/21		14.774				4.798	3.599

Status and catch specifications (million lb) for Aleutian Islands golden king crab. 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
2016/17	N/A	N/A	5.545	5.716	6.497	12.53	9.40
2017/18	13.325	31.315	5.545	5.699	6.487	13.333	10.000
2018/19	12.964	39.348	6.356	6.536	7.396	12.157	9.118
2019/20	13.027	35.985	7.180	7.317	8.234	11.572	8.679
2020/21		32.571				10.579	7.934

The total fishery mortality in 2019/20 was 3,735 t, less than the OFL of 5,249 t, thus overfishing has not occurred. The mature male biomass was 16,323 t, above MSST of 5,909 t, hence the stock was not overfished.

Additional Plan Team recommendations

The CPT recommended additional development of fishery CPUE standardization, including further development of how to account for year-area interactions when constructing indices of abundance and their uncertainty. Work should continue to obtain an index using the cooperative pot survey data for use in the EAG assessment model. Finally, GMACS for the AIGKC assessment should be explored.

9 Pribilof District Golden King Crab

In accordance with the approved schedule, the Pribilof Islands golden king crab assessment is conducted triennially with the previous assessment in 2017. Therefore, a full stock assessment was conducted in 2020 with results to be applied for the 2021–2023 specifications. Additional information listed below summarizes the 2020 assessment.

Fishery information relative to OFL setting

The Pribilof Islands golden king crab fishery began in the 1981/82 season but is currently managed by calendar year. The directed fishery mainly occurs in Pribilof Canyon of the continental slope. Peak directed harvest was 388 t by 50 vessels during the 1983/84 season; fishery participation has since been sporadic and retained catches vary from 0 to 155 t. A guideline harvest level (GHL) was first established in 1999 at 91 t and the fishery was managed with a GHL of 68 t from 2000 to 2014, and reduced to 59 t in 2015. Discarded (non-retained) catch has occurred in the directed golden king crab fishery, the eastern Bering Sea snow crab fishery, the Bering Sea grooved Tanner crab fishery, and in Bering Sea groundfish fisheries. Estimates of annual total fishery mortality during 2001–2019 due to crab fisheries range from 0 to 73 t. Estimates of annual fishery mortality during 1991/92–2019 due to groundfish fisheries range from negligible to 9 t. Total fishery mortality in groundfish fisheries during the 2019 crab fishing year was 4 t.

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. A random effects model for moving toward a Tier 4 assessment was explored; however, several model aspects needed better documentation to understand the model. The CPT was encouraged by these efforts and would like to see future development of this model in 2021.

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 2021. The CPT concurs with the author's recommended status quo OFL of 93 t and an ABC of 70 t. 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 2021 OFL calculation is the same as recommended by the SSC for 2013−2020:

$$OFL_{2021} = (1+R_{2001\text{–}2010})*RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,1992/93\text{–}1998/99}$$

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) for Pribilof Islands golden king crab. 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
2016	N/A	N/A	59	0	0.24	91	68
2017	N/A	N/A	59	Conf.	Conf.	93	70
2018	N/A	N/A	59	Conf.	Conf.	93	70
2019	N/A	N/A	59	Conf.	Conf.	93	70
2020	N/A	N/A	59			93	70
2021	N/A	N/A				93	70

Status and catch specifications (lb) for Pribilof Islands golden king crab. 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
2016	N/A	N/A	130,000	0	<0.001	0.20	0.15
2017	N/A	N/A	130,000	Conf.	Conf.	0.20	0.15
2018	N/A	N/A	130,000	Conf.	Conf.	0.20	0.15
2019	N/A	N/A	130,000	Conf.	Conf.	0.20	0.15
2020	N/A	N/A	130,000			0.20	0.15
2021	N/A	N/A				0.20	0.15

10 Western Aleutian Islands red king crab

In accordance with the approved schedule, the Western Aleutian Islands king crab assessment is conducted triennially with the previous assessment in 2017. Therefore, a full stock assessment was conducted in 2020 with results to be applied for the 2020/21specifications. Additional information listed below summarizes the 2020 assessment.

Fishery information relative to OFL and ABC setting

After 1995/96, the fishery was opened only occasionally. There was an exploratory fishery 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 in 2002/03 and 2003/04 in the Petrel Bank area. The fishery has been closed since 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 annual total fishing mortality from 1995/96 to 2019/20 averaged 30 t. The average retained catch during that period was 23 t. 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 2019/20 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 2019/20 and from groundfish fisheries from 1993/94 to 2019/20 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, recruitment trends, and current levels relative to virgin or historic levels are not available for this stock. 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. A cooperative red king crab survey was performed by the Aleutian Islands King Crab Foundation and ADF&G in the Petrel Bank area in November 2016 averaged less than one crab per pot lift suggesting that the stock is in poor condition.

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

The CPT recommends that this stock be managed under Tier 5 for the 2020/21season. 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 2020/21 of 56 t.

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 14 t for 2020/21 which is equivalent to a 75% buffer on OFL. The recommended ABC is less than that which was recommended by the SSC for 2012/13 – 2016/17 because 1) the industry has not expressed interest in a small test fishery, and 2) because the stock is severely depressed as indicated by the 2016 Petrel survey (CPT minutes for May 2017).

Status and catch specifications (t) for Western Aleutian Islands red king crab. 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.

Fishing Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2016/17	N/A	N/A	Closed	0	<1	56	34
2017/18	N/A	N/A	Closed	0	<1	56	34
2018/19	N/A	N/A	Closed	0	<1	56	14
2019/20	N/A	N/A	Closed	0	<1	56	14
2020/21	N/A	N/A				56	14

Status and catch specifications (million lb) for Western Aleutian Islands red king crab. 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.

Fishing Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2016/17	N/A	N/A	Closed	0	0.00045	0.12387	0.07432
2017/18	N/A	N/A	Closed	0	0.00075	0.12387	0.03097
2018/19	N/A	N/A	Closed	0	0.00031	0.12387	0.03097
2019/20	N/A	N/A	Closed	0	0.00164	0.12387	0.03097
2020/21	N/A	N/A				0.12387	0.03097

Figures and Tables

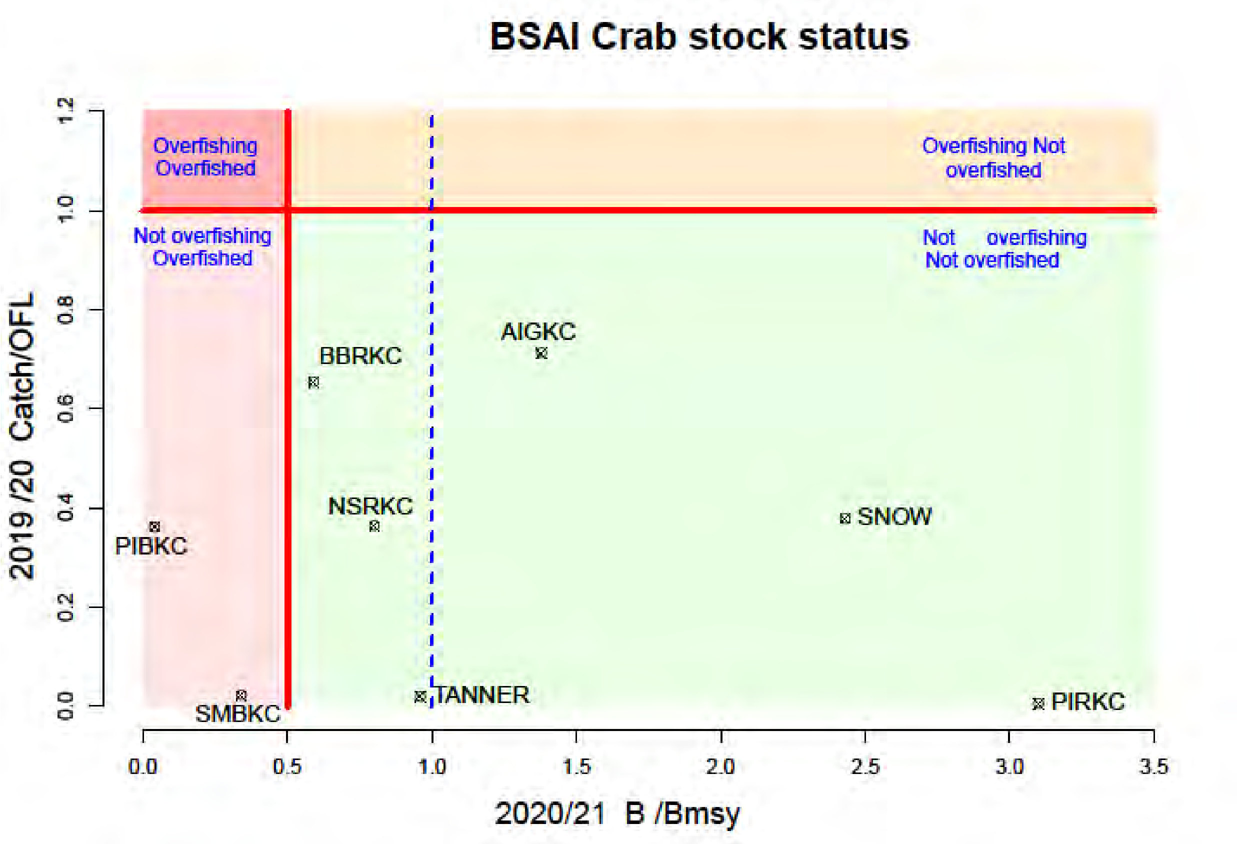

Figure 2. Status of eight Bering Sea and Aleutian Islands crab stocks in relation to status determination criteria (B_{MSY}, MSST, overfishing) for 2020. Note that information is insufficient to assess Tier 5 stocks according to these criteria (WAIRKC, PIGKC).

Table 4. Summary recommendations for each BSAI crab stock from the final 2020 SAFE. Hatched areas indicate parameters not applicable for that tier. Biomass values are in thousand metric tons (kt).

SAFE Chapt.	Stock	Tier	F_{OFL}	B_{MSY} or $B_{MSYproxy}$	B_{MSY} basis years[1]	2020/21[2] MMB	2020/21 MMB / MMB_{MSY}	γ	Natural Mortality (M)	2020/21 [3] OFL	2020/21 ABC[3]	ABC Buffer	Add'l 2020 Buffer[4]
1	E. Bering Sea snow crab	3a	1.65	113.7	1982-2019 [recruitment]	276.7	2.43		0.34 (mat.fem) 0.36 (imm.). 0.36 (mat.male)	184.90	92.5	25%	25%
2	Bristol Bay red king crab	3b	0.16	25.4	1984-2019 [recruitment]	14.93	0.59		0.18	2.14	1.61	20%	5%
3	E. Bering Sea Tanner crab	3b	0.93	36.62	1982-2018 [recruitment]	35.31	0.96		0.32 (mat.fem) 0.24 (imm.) 0.29 (mat.male)	21.13	16.90	20%	**0%**
4	Pribilof Is. red king crab	4a	0.21	1.73	2001-2018 [MMB]	6.43	3.72	1	0.18	0.86	0.65	25%	
5	Pribilof Is. blue king crab	4c	0.18	4.11	1980/81-1984/85 & 1990/91-1997/98 [MMB]	0.175	0.04	1	0.18	0.00116	0.00087	25%	
6	St. Matthew blue king crab	4c	0.047	3.34	1978-2019 [MMB]	1.12	0.34	1	0.18	0.05	0.04	25%	0%
7	Norton Sound red king crab	4b	0.141	2.07	1980-2019 [MMB]	1.66	0.80	1	0.18	0.13	0.10	25%	
8	Aleutian Is. golden king crab	3a	EAG (0.61) WAG (0.56)	11.82	1987/88-2012/13	14.77	1.25		0.21	4.798	3.599	25%	
9	Pribilof Is. golden king crab	5	-	-	See intro chapter	-	-	-	-	0.093	0.070	25%	
10	W. Aleutian Is. red king crab	5	-	-	1995/96-2007/08	-	-	-	-	0.056	0.014	75%	

1 For Tiers 3, 4 where BMSY proxy is estimable, the years refer to the time period over which the estimate is made. For Tier 5 stocks it is the years upon which the catch average for OFL is obtained.
2 MMB as projected in Feb of this year for Norton Sound red king crab, and June of this year for AIGKC.
3 AIGKC OFL and ABC calculated by author outside the chapter for using the Approach 2 combination of EAG and WAG and 25% buffer between OFL and ABC
4 Additional ABC buffer added for some stock to address added uncertainty in OFL due to absence of 2020 trawl survey data

Table 5. Maximum permissible ABCs for 2020/21 and SSC recommended ABCs for three stocks where the SSC recommendation is below the maximum permissible ABC, as defined by Amendment 38 to the Crab FMP. Values are in thousand metric tons (kt).

Stock	Tier	2020/21 *Max* ABC	2020/21 ABC
EBS Snow Crab[1]	3	184.2	92.5
Bristol Bay RKC[2]	3	2.13	1.61
Tanner Crab[3]	3	20.87	16.90
Pribilof Islands RKC[1]	4	0.857	0.648
Pribilof Islands BKC[4]	4	0.00104	0.00087
Saint Matthew BKC[2]	4	0.05	0.04
Norton Sound RKC[2]	4	0.129	0.10
Aleutian Islands GKC[2]	3	4.773	3.599
Pribilof Islands GKC[4]	5	0.092	0.070
Western Aleutian Islands RKC[4]	5	0.056	0.014

Basis for P* calculation of Max ABC:

[1]CV on terminal year biomass
[2]CV on OFL
[3]MCMC
[4]90%OFL (Tier 5)

A stock assessment for eastern Bering Sea snow crab

Cody Szuwalski

September 20, 2020

Contents

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 11.85 kt during 1982) to historical highs in 1990s (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 2019 was relatively low (15.43 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 1992 at 17.06 kt which was 16% of the retained catch during that year. The most recent estimated discard mortality was 5.07 kt, which was 33% of the retained catch (the highest fraction on record).

3. Stock Biomass:

Observed mature male biomass (MMB) at the time of the survey increased from an average of 234.14 kt in the early to mid-1980s to historical highs 1990s (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 1999 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, after 2011, the stock declined and the observed MMB at the time of survey dropped to an all time low in 2016 of 63.21 kt. Recently, MMB is increasing again as a large recruitment moves through the size classes and is currently estimated to be above $B_{35\%}$.

4. Recruitment

Estimated recruitment shifted from a period of high recruitment to a period of low recruitment in the mid-1990s (late 1980s when lagged to fertilization). Recently, a large year class recruited to the survey gear and is beginning to be seen in the biomass vulnerable to the directed fishery.

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
2015/2016	75.8	91.6	18.4	18.4	21.4	83.1	62.3
2016/2017	69.7	96.1	9.7	9.7	11	23.7	21.3
2017/2018	71.4	99.6	8.6	8.6	10.5	28.4	22.7
2018/2019	63	123.1	12.5	12.5	15.4	29.7	23.8
2019/2020	56.8	167.3	15.4	15.4	20.8	54.9	43.9
2020/2021		276.7				184.9	92.5

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

Year	MSST	Biomass (MMB)	TAC	Retained catch	Total catch	OFL	ABC
2015/2016	167.11	201.94	40.57	40.57	47.18	183.2	137.35
2016/2017	153.66	211.86	21.38	21.38	24.25	52.25	46.96
2017/2018	157.41	219.58	18.96	18.96	23.15	62.61	50.04
2018/2019	138.89	271.39	27.56	27.56	33.95	65.48	52.47
2019/2020	125.22	368.83	33.95	33.95	45.86	121.03	96.78
2020/2021		610.02				407.63	203.93

6. Basis for the OFL

The OFL for crab year 2020 from the chosen model 20.2 was 184.91 kt fishing at $F_{OFL} = 1.65$, which was 100% of the calculated $F_{35\%}$. The projected ratio of MMB at the time of mating in 2020 (crab year) to $B_{35\%}$ is 2.43 .

7. Probability Density Function of the OFL

The probability density function of the OFL was characterized for all models by using maximum likelihood estimates of the OFL and associated standard errors.

8. Basis for ABC

The ABC for the chosen model was 92.45 kt, calculated by subtracting a 50% buffer from the OFL as recommended by the CPT. The buffer was increased from 20% (used in 2019) to 25% to account for model uncertainty around the 2015 recruitment event and an additional 25% was added to account for uncertainty related to missing the terminal year of survey data.

A. Summary of Major Changes

1. Management: None

2. Input data:

Data added to this assessment included: 2019 directed fishery retained and discard catch, and length composition for retained and discard catch (calculated via the 'subtraction' method; see below), and groundfish discard length frequency and discard from 2019. Importantly, no new survey data were available for 2020.

3. Assessment methodology:

Management quantities were derived from maximum likelihood estimates of model parameters in a size-based, integrated assessment method. Jittering was not performed because of the shift to GMACS, but will be implemented in the next cycle. Retrospective analyses were performed for selected model configurations.

4. Assessment results

The updated estimate of MMB (February 15, 2020) was 207.19kt which placed the stock at 182% of $B_{35\%}$. Projected MMB on February 15, 2021 from this assessment's chosen model was 276.71 kt after fishing at the OFL, which will place the stock at 243% of $B_{35\%}$. Fits to all data sources were acceptable for the chosen model and most estimated population processes were credible (see discussion below).

B. Comments, responses and assessment summary

SSC and CPT Comments + author responses

SSC comment: The stock assessment author recommended bringing forward three model variants for consideration this fall: status quo, "free q" GMACS, and "prior q" GMACS models. The CPT agreed, and the SSC concurs. The GMACS models fit both NMFS and BSFRF survey data better than the status quo model. Both the stock assessment author and the CPT recommended postponing the use of VAST estimates for assessment until diagnostics could be more fully analyzed. The team offered other suggestions about the assessment, with which the SSC agrees.

Author response: These recommendations are included in the models considered, plus additional exercises necessary to address uncertainty resulting from cancelled NMFS summer surveys.

CPT comments: Identify cause of the 'pigtails' in the retained catch size compositions

Author response: I have not identified why the pigtails occur. Currently, the problem only exists in 1982-1984, so it should not influence management advice arising from the terminal year estimates of MMB. I plan to spend more time understanding this result in the fall.

CPT comments: Implement reference point calculations in GMACS for status determination and OFL calculation

Author response: Reference point calculations were modified in GMACS to accommodate terminally molting life histories with differing natural mortalities between immature and mature life stages. The resulting reference points are similar to the reference points calculated in the status quo assessment and a more thorough comparison is made in the supplementary document titled "A comparison of the status quo stock assessment for eastern Bering Sea snow crab to an assessment developed in GMACS." The conclusion in that document is that, in the opinion of the author, GMACS satisfactorily produces reference points and should be adopted for use in management.

Summary of assessment scenarios for September 2020

Five models are presented here:

- 19.1 – Last year's accepted model fit to last year's data
- 20.1 – 19.1 fit to this year's data, with revised trawl data
- 20.2 – GMACS fit to the same data as 20.1
- 20.3 – 20.2 + extra weight on BSFRF data to force the estimated catchability coefficient to equal the implied catchability by the BSFRF data

Model 20.2 was the author preferred model based on model fits and the use of GMACS. Model 20.1 was not preferred because it did not fit the terminal years of survey MMB and the GMACS modeling platform is an improvement over the status quo model. Model 20.3 was not preferred because it did not converge and resulted in doubling of the stock size.

Given the potential uncertainty added by missing the survey data for this year, several additional analyses were performed. Retrospective analyses, an imputed survey data exercise, and a projection to the year 2025 under two different harvest scenarios were undertaken with the author preferred model. A sequential addition of catch data was performed to understand the impact of the new catch data. An exercise that varied the size of the smoothing penalties placed on estimated recruitment deviations is presented to explore the impact of the penalties on the size of the 2015 estimated recruitment and the resulting management quantities.

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 ~200 meters (Figure 1 & Figure 2). Smaller crabs tend to occupy more inshore northern regions (Figure 3) and mature crabs occupy 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

Relatively few targeted studies exist to determine natural mortality for snow crab in the Bering Sea. In one of these studies, Nevissi, et al. (1995) used radiometric techniques to estimate shell age from last molt (Figure 6). 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 National Marine Fishery Service (NMFS) Bering Sea survey. Representative samples for the 5 shell condition categories were collected from the available crab. 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; carapace width of 110 mm). 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). 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.

In recent years, the mean for the prior for natural mortality used in the eastern Bering Sea snow crab assessment was based on the assumption that longevity would be at least 20 years in a virgin population of snow crab, informed by the studies above. 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. For the base model in this assessment cycle, the means of the prior on natural mortality for immature males and females, mature males, and mature females were also set to 0.23 yr^{-1}.

In contrast to the implied natural mortalities from the methodology used above, Murphy et al. (2018) estimated time-varying natural mortality for eastern Bering Sea snow crab with a mean of 0.49 for females and 0.36 for males (based on the output of state-space models fit to NMFS survey data; Figure 7). Further, natural mortality estimates produced from empirical analyses by Then et al. (2015) and Hamel (2015) using similar assumed maximum ages as the methodology above produce natural mortalities larger than 0.23 (Table 3). Then et al. (2015) compared several major empirical estimation methods for M (including Hoenig's method) with an updated data set and found that maximum age was the best available predictor. A maximum age of 20 years corresponded to an M of ~0.315 in Then et al.'s analysis. Hamel (2015) developed priors in a similar manner to Then et al., but forced the regression of observed natural mortality onto maximum age through the intercept, which resulted in an M of ~0.27 for an assumed maximum age of 20 years.

Table 3: Empirical estimates of natural mortality for a range of methods over a range of assumed maximum ages (column header).

	23	20	17
Then	0.277	0.315	0.365
Hoenig (1983)	0.19	0.212	0.257
Hoenig (2015)	0.194	0.223	0.261
Hamel	0.235	0.271	0.318

In addition to the results of empirical estimates of M from updated methodologies and state-space modeling by Murphy et al. (2018), inspection of the survey data suggests that natural mortality for mature individuals is higher than assumed. A fraction of the mature population (which are assumed not to grow, given evidence for a terminal molt) are not selected in the fishery (e.g. sizes 50-80 mm; Figure 8). Consequently, all mortality observed is 'natural'. The collapse in recruitment in the 1990s can be used as an instrument to understand natural mortality for mature individuals. The last large recruitment enters these size classes in the mid- to late-1990s and numbers of crab in these size classes return to low levels in less than 5 years. It would be useful to perform radiometric aging on old shell crab that are not selected in the fishery to better understand natural mortality for mature crab.

Natural mortality is one of the major axes of uncertainty considered in the assessment scenarios presented in this assessment. The median value of the priors used in some scenarios were changed to values resulting from assuming a maximum age of 20 years and applying Then et al.'s or Hamel's methodology. A standard error of 0.054 was used for all priors and was estimated using the 95% CI of +-1.7 years on maximum age estimates from dactal wear and tag return analysis in Fonseca, et al. (2008). Another potential, but unexplored, option for developing a prior is to apply all of the methods to the range of possible maximum ages, develop a probability density function for maximum age given the observed data, then calculate a weighted average of the natural mortalities using the pdf for weights and use the standard error from that weighted average to define the breadth of the prior.

Weight at length

Weight at length is calculated by a power function, the parameters for which were recalculated by the Shellfish Assessment Program in August 2016 and resulted in very small changes in weight at length for males, but rather large changes for females. New weight at length parameters were applied to all years of data, rather than just the most recent observations and were used starting in 2016 for calculation of the OFL. To provide context for the change, a juvenile female crab of carapace width 52.5 mm was previously estimated to weigh 65 g and is now 48 g; a mature female crab of carapace width 57.5 mm was estimated to previously weigh 102 g and is 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. 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 probability of maturing (which is different from the fraction mature at length) is a freely estimated (but smoothed) function of length for both sexes within the assessment model.

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 4 years old and would be expected to molt annually. Information for the probability of molting comes from the split in numbers at length between immature and mature individuals by sexes.

Mating ratio and reproductive success

Bering Sea snow crabs are managed using mature male biomass (MMB) as a proxy for reproductive potential. MMB is used as the currency for management because the fishery only retains large male crabs. Male snow crabs 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 difficult. 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, 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 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, NMFS 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 euthanized 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 euthanized. Indices of fertilized females based on the visual inspection method of assessing clutch fullness and percent unmated females may overestimate fertilized females and may not be an accurate index of reproductive success.

Growth

Historically, little information was available on growth for Bering Sea snow crab. However, many new data points have been added in recent years (Table 5). These studies include:

1. Transit study (2003); 14 crab
2. Cooperative seasonality study; 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
6. NMFS Kodiak holding study 2017; 70 crab.
7. BSFRF/NMFS holding study 2018; 4 crab.

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 post-molt width (L. 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 the seasonal study were excluded that were measured less than 3 days after molting due to difficulty in measuring soft crab accurately (L. Rugolo, pers. comm.). 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 58% harvest rate 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 only accepts crab 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 et al. (2002) using 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 Alaska Department of Fish and Game (ADFG) 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 is one half B_{MSY}. The harvest rate begins at 0.10 when total mature biomass exceeds 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).

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

Where *TMB* is the total mature biomass and TMB_{BMSY} is the *TMB* associated with maximum sustainable yield. 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}. 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 unfished 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. The range of years of recruitment used to calculate biomass reference points is from 1982 to the present assessment year, minus 1.

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 11.85 kt during 1982) to historical highs in the early and mid-1990s (retained catches during 1991, 1992, and 1998 were 143.02, 104.68, and 88.09 kt, respectively; Table 6). 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 2019 was low (15.43 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 1992 at 17.06 kt, which was 16% of the retained catch. The most recent estimated discard biomass was 5.07 kt, which was 25% of the total catch.

Discard from the directed pot fishery has been estimated from observer data since 1992 and has ranged from 11-100% of the magnitude of retained catch by numbers . In recent years, discards have reached 50-100% of the magnitude of retained catch because of the large year class entering the population. Female discard catch has been very low compared to male discard catch and has not been a significant source of mortality. Discard of snow crab in groundfish fisheries has been highest in the yellowfin sole trawl fishery, and decreases down through the flathead sole trawl fishery, Pacific cod bottom trawl fishery, rock sole trawl fishery, and the Pacific cod hook-and-line and pot fisheries, respectively (Figure 9). Bycatch in fisheries other than the groundfish trawl fishery has historically been relatively low. 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 require on pots used in the snow crab fishery to prevent ghost fishing. Escape panels consist 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 provisions for undersized 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

No new NMFS survey data were available this year due to cancellation of the surveys. Bycatch data (biomass and size composition) were updated for 1986-present after a change in the AKFIN database (Figure 10). This resulted primarily in a scaling down of the bycatch mortality, though the trend of the time series was largely maintained. 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 composition of retained crab from the directed snow crab pot fishery from survey year 1982 to 2019 were used in this analysis (Table 6). Discard size composition data from 1992 to 2017 were estimated from observer data and then combined with retained catch size compositions to become the 'total catch' size composition data, which are fit in the assessment. In 2018, observer data collection changed and only total catch size composition data and retained size composition data are produced. This is a sensible step in data collection, but the current formulation of the snow crab model accepts discarded size composition data as an input. So, in 2018 the discarded size compositions were calculated by subtracting the retained size compositions from the total size compositions. This mismatch of input data types will be addressed in an upcoming data overhaul for the assessment.

The discard male catch was estimated for survey year 1982 to 1991 in the model using the estimated fishery selectivities based on the observer data for the period of survey year 1992 to 2018. The discard catch estimate was multiplied by the assumed mortality of discards from the pot fishery. The assumed mortality of discarded crab was 30% for all model scenarios. This estimate differs from the strategy used since 2001 to the present by ADFG to set the TAC, which assumes a discard mortality of 25% (Zheng, et al. 2002). The discards prior to 1992 may be underestimated due to the lack of escape mechanisms for undersized crab in the pots before 1997. See Table 4 for a summary of catch data.

Table 4: Data included in the assessment. Dates indicate survey year.

Data component	Years
Retained male crab pot fishery size frequency by shell condition	1982 - 2019
Discarded Males and female crab pot fishery size frequencey	1992 - 2019
Trawl fishery bycatch size frequencies by sex	1991 - 2019
Survey size frequencies by sex and shell condition	1982 - 2019
Retained catch estimates	1982 - 2019
Discard catch estimates from crab pot fishery	1992 - 2019
Trawl bycatch estimates	1993 - 2019
Total survey biomass estimates and coefficients of variation	1982 - 2019

Data component	Years
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

Estimates from the annual eastern Bering Sea (EBS) bottom trawl survey conducted by NMFS serve as the primary index of abundance in this assessment (see Lang et al., 2018). In 1982 the survey net was changed resulting in a potential change in catchability and additional survey stations were added in 1989. Consequently, survey selectivity has been historically modeled in two 'eras' in the assessment (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 the assessments presented. In the status quo assessment, total survey numbers 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. In the GMACS models, MMB and FMB were input directly via the .DAT file and the size composition data were input by sex and maturity state (e.g. Figure 11 & Figure 12), cutting out the steps necessary within the code to calculate the data to which the model is ultimately fit.

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 input for the status quo assessment model (Table 7).

The NMFS summer surveys were cancelled in 2020 due to the coronavirus pandemic.

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 have been more prevalent on the southwest portion of the shelf (Figure 4) while smaller males have been more prevalent on the northwest portion of the shelf (Figure 1). Females have exhibited a similar pattern (compare Figure 2 to Figure 5). In addition to changing spatially over the shelf and by size class, distributions of crab by size and maturity have also changed temporally. The centroids of abundance in the summer survey have moved over time (Figure 13 & Figure 14). Centroids of mature female abundance early in the history of the survey were farther south, but moved north during the 1990s. Since the late 1990s and early 2000s, the centroids moved south again, but not to the extent seen in the early 1980s. This phenomenon was mirrored in centroids of abundance for large males (Figure 14).

Centroids of the catch have generally been 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. In general, the majority of catch was taken west and north of the Pribilof Islands, but this rule has had exceptions.

The observed distribution of large males during the summer survey and the fishery catch have historically been different, and the origin of this difference is unknown. It is possible that crab move between the fishery and the survey, but it is also possible that fishers do not target all portions of the distribution of large male crab equally. 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 appear to move south and west as they age (Parada et al., 2010); however, little tagging data exists to fully characterize the ontogenetic or annual migration patterns of this stock (Murphy et al. 2010).

Experimental study of survey selectivity

The Bering Sea Fisheries Research Foundation (BSFRF) has conducted supplementary surveys in the Bering Sea in which snow crab were caught during 2009, 2010, 2016, 2017, and 2018. The location and extent of these surveys varied over the years as the survey goals changed. In 2009, the survey consisted of 108 tows around 27 survey stations and the goal was to improve understanding snow crab densities and the selectivity of NMFS survey gear (Figure 15). In 2010, the survey area was larger and still focused on snow crab. The mature biomass and size composition data gleaned from each of these experiments (and their complimentary NMFS survey observations; Figure 16 & Figure 17) 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 and B for a description of the way in which the surveys are related in the assessment models–the approach is similar for both). Abundances estimated by the industry surveys were generally higher than the NMFS estimates, which suggests that the catchability of the NMFS survey gear is less than 1.

In 2016, 2017, and 2018, snow crab were not the focus of the BSFRF surveys, yet were still caught in the BSFRF gear. Comparing the ratio of the number of crab caught at length in the BSFRF gear (which is assumed to have a catchability/selectivity of 1 over all size classes) to the number of crab caught at length within the same area in the NMFS survey gear (which is assumed to have a catchability/selectivity <= to 1 for at least some of the size classes) can provide an empirical estimate of catchability/selectivity (Figure 18). Empirical estimates of catchability/selectivity vary by year and size class across the different BSFRF data sets (Figure 19). The number of snow crab used to develop estimates of numbers at length probably contribute to these differences among years (Figure 20), but there are likely other factors that influence catchability/selectivity at size of the NMFS survey gear (e.g. Somerton et al. 2013 show substrate type can influence selectivity). Further understanding the implications of these experiments is a research priority for snow crab.

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 total allowable catch, 'TAC', since 2009) by 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 (20.1), 364 parameters were estimated. Parameters estimated within the assessment included those associated with the population processes recruitment, growth, natural mortality (historically subject to a fairly informative prior), fishing mortality, selectivity (fishery and survey), catchability, and maturity. 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.

In the past, each assessment author for crab stocks in the Bering Sea developed an assessment model to provide management advice, and this has lead to some heterogeneity among assessment methodologies. Recently the General Model for Assessing Crustacean Stocks (GMACS) was developed to promote consistency and comparability among assessments. Several crab assessments have been developed in GMACS and subsequently approved for use in management by the Crab Plan Team. GMACS was developed with king crab-like life histories in mind, but has recently been modified to accommodate terminally molting life histories. The structure of the population dynamics model in GMACS is now very similar to the status quo assessment model and can reproduce the dynamics of the male component of the status quo model precisely with the correct configuration (see May 2020 CPT opilio document).

A 'jittering' approach has been historically used to find the estimated parameter vector that produced the smallest negative log likelihood for the assessment model (Turnock, 2016). Jittering was not implemented here because the functionality in GMACS is still in development.

Three models are presented here for consideration: the status quo model, a GMACS implementation in which the BSFRF data are given the same weight as in the status quo assessment, and a GMACS implementation in which the BSFRF data are given a much higher weight to force catchability in the model to align with the implied catchability from the BSFRF experiments.

Retrospective analyses were performed in which the terminal year of data was removed sequentially from the model fitting for the author preferred model. Then estimated management quantities (like MMB) were compared between the most recent model and successive 'peels' of the data to identify retrospective patterns. A retrospective pattern is a consistent directional change in assessment estimates of management quantities (e.g. MMB or the OFL) in a given year when additional years of data are added to an assessment. Mohn's rho (which computes the average difference between the reference case and the peels) was calculated for each retrospective analysis (i.e. including and excluding the terminal year survey data) to quantify the retrospective patterns. A second retrospective analysis was performed in which the terminal year of survey data was removed from the assessment to explore the impact of a missed survey in 2020.

The estimated recruitment in 2015 produced from the author's preferred model nearly doubled when adding the 2019/20 catch data, and this was unexpected. The size of this recruitment strongly impacts the management quantities and the OFL, so additional models runs in which the catch data were added sequentially and the magnitude of the recruitment penalty was varied were performed to explore the behavior of the model with respect to this estimated recruitment.

Model selection and evaluation

Models were evaluated based on their fit to the data, the credibility of the estimated population processes, stability of the model, the magnitude of retrospective patterns, and the strength of the influence of the assumptions of the model on the outcomes of the assessment. Input data, functional forms of population processes, initial values, projections specification, and maximum likelihood estimates of parameters can be seen for the author preferred model in the appendices containing the .DAT, .CTL, .PROJ, and .PAR files.

Comparison between the output of the status quo model and GMACS is difficult because the likelihoods and weighting schemes are different. The mean absolute relative errors (relative error being the observed data minus the predicted value, all divided by the observed data) were calculated for the survey indices and catch data. Mean absolute errors were calculated for the size composition data. Both these metrics provide a quantitative measure of goodness of fit, but are not ideal because they do not consider the uncertainty in the data. Model comparison will be less of a problem when the only GMACS models are considered.

Results

Model 20.2 is the only model that incorporated the most recent catch data, provided passable fits to the recent survey MMB, and converged. Given the total allowable catches are often based on survey derived quantities and no survey was performed this year, projected values of survey MMB could be important to management of the fishery. Model 20.2 fit the survey data the best (Figure 21 & Figure 22), but it also displayed a retrospective pattern (Figure 23), which has been a persistent issue with the snow crab assessment. Retrospective patterns suggest that a process is varying over time that is not allowed to vary within the model (e.g. catchability) or the data are incomplete (e.g. not all catch is reported). This particular pattern appears to be driven by an anomalously high observation of survey MMB in 2014. Below, the fits to data and estimated population processes for all considered models are described.

Fits to data

Survey biomass data

The GMACS models generally fit the survey MMB and FMB better than the status quo model (Figure 24). The status quo model (20.1) did not fit the last two years of available MMB well, in spite of relatively good fits to the data from models without the new data (i.e. 19.1).

Growth data

All GMACS models provided roughly the same fit to the male growth data, which is a line with a slightly larger slope than the line fit by the status quo models (Figure 25). All GMACS models fit a linear relationship between premolt length and growth increment for females, whereas status quo models retained the kinked growth curve.

Catch data

Retained catch data were fit by all models well, but the status quo models fit the data slightly better than GMACS (Figure 26). Female discard data were fit more closely by GMACS, which is a reflection of the transition to CVs that force greater precision than the weights used in the status quo assessment. Male discard data during the period for which data exist (early 1990s to the present) were well fit by every model (Figure 26).

Size composition data

Total and retained catch size composition were similarly fit by both GMACS and the status quo model. However, GMACS predicted larger numbers of animals in the largest size bins for the first few model years (Figure 27). This phenomenon disappeared in later years with fits to the data that were indiscernible among models. Total catch and bycatch size composition data were both similarly fit by the models, with total catch size composition being fit more closely than the bycatch data (Figure 28 & Figure 29).

Fits to size composition data for the BSFRF survey selectivity experiments produced some notable runs of positive and negative residuals for males (Figure 30). GMACS fit the data in 2010 (which are most important for informing catchability) better than the status quo assessment, but which model best fit the 2009 data was less clear.

Notable differences in fits to NMFS survey size composition data existed (Figure 31, Figure 32, Figure 33 & Figure 34). GMACS fit the immature female size composition data better in many years (e.g. 1984, 1986, 1996, 1997, 2007); GMACS fit the immature males more similarly to the status quo model than the immature females. Fits to mature male size composition data were also similar between models and the few differences seemed to favor GMACS (e.g. 1984, 1990, 2017-18). Differences between models for fits to mature female size composition data were the smallest for survey size composition data. The shift in how growth and natural mortality from the status quo model to GMACS likely contributed to the changes in fits to the size composition data.

A potentially important lack of fit is apparent in the mature males NMFS size composition data in 2019. All models predicted fewer mature males >~70mm carapace size than observed (Figure 35). There is a conflict in the two terminal years of the survey which may warrant caution in extrapolating the fitted trend to the year of survey data required for management advice. This issue was not apparent for mature females (Figure 36).

Estimated population processes and derived quantities

Estimated population processes and derived quantities varied among models. Projected MMB for 2020 ranged from 165 to 517 kt (Figure 37). Model 20.3 produced the largest estimates of MMB, resulting from forcing the catchability coefficient to reflect the implied q from the BSFRF studies. For the author preferred model, estimated fishing mortality has exceeded $F_{35\%}$ in the recent past (Figure 38). Estimated MMB has been less than $B_{35\%}$ from 2011 to 2018, and estimates suggest that the population may have recently been beneath MSST (Figure 38). However, the most recent estimated MMB exceeds $B_{35\%}$ for the author preferred model 20.2.

Both status quo and GMACS models estimated lower catchability in survey era 1 (1982-1988) relative to era 2 (1989-present). The shapes of the NMFS selectivity curves were similar among all models; the largest changes were seen in the catchability coefficient (Figure 39). GMACS model 20.2 estimated a higher catchability coefficient than the status quo model during selectivity era 2; model 20.3 estimated catchability at the value implied by the BSFRF data. These differences in catchabilities contributed to the differences in scale of estimated MMB between the models.

Predicted availability curves for the BSFRF experimental surveys were similar across assessments in years with similar configurations (Figure 40). The status quo assessment historically used a logistic curve for the availability for females in 2009, but this is likely overly restrictive. All implementations of GMACS estimated a vector of availabilities for both years and sexes of BSFRF data, which more closely reflect the empirical availabilities.

The shape of the estimated curve representing the probability of maturing for both sexes were similar within sex, but the magnitude of the probabilities varied, most strongly for females (Figure 41). The GMACS-estimated probability of maturing at smaller sizes was consistently higher for females and this is related to the change from a kinked growth curve to a linear growth model. The 'hump' at 32.5 mm carapace width for females is likely related to the specified curve that determines what fraction of incoming recruitment is placed in which length bin, which has a peak at the same spot as the probability of maturing. Model 20.3 (in which survey q was low) estimated a higher probability of maturing for intermediately sized male crab than other models.

Estimated fishing mortality scaled with estimated population size across models (Figure 42). GMACS models generally estimated fishing mortality lower than the status quo models during survey era 1. This difference is a result of differences in estimated MMB in the early years of the fishery. Estimated fishery and discard selectivity were dissimilar between model type (i.e. GMACS vs. status quo), which is related to how selectivity and fishing mortality are treated in the code (discussed in the May 2020 snow crab document). GMACS estimates of female discard mortality were lower than the status quo, but, when balanced with changes in estimated selectivity, the estimated catches were similar to the status quo (Figure 26).

Patterns in estimated recruitment by sex were similar for both models, but GMACS estimates were more variable than the status quo estimates (Figure 43). Further, the estimated 2015 recruitment was larger in GMACS than the status quo model and the size of this recruitment is a strong driver of the terminal year MMB and OFL. Part of the variation in estimated recruitment appears to be related to differences in the relative weight of smoothing penalties placed on estimated recruitment deviations (Figure 44). These differences in recruitment are translated to the MMB and OFL (Figure 45 & Figure 46). The penalties in both the status quo and GMACS model were first difference penalties with a weight of 1, but, given the differences in likelihood and model structure, the relative strength of the smoothness penalties appear to be stronger in the status quo model. The estimated recruitment in GMACS sharply increases from the estimates with only the 2019 assessment year data when the discard data are added and then again with the addition of the trawl data to the final estimate in 20.2 (not shown).

In general, a period of high recruitment was estimated in which 2 or 3 large male cohorts passed through the population during the 1980s and into the early 1990s. Following that, a period of low recruitment persisted from the early 1990s to the mid-2010s. All models indicated a large (relative to the past) recruitment to the survey gear occurred around 2015 for males. Peaks in female recruitment were roughly coincident across models, but the magnitudes could be mismatched. Recruitment entering the model was placed primarily in the first three size bins, and the parameters determining the process were fixed in both models.

Estimated natural mortality from GMACS model for immature crab was higher than the status quo models, in spite of identical priors (Figure 47). Estimated immature natural mortality was generally higher than mature natural mortality in GMACS, which was not seen in the status quo model. The relationship between estimates of immature and mature natural mortality produced using GMACS is more consistent with a 'U-shaped' natural mortality curve with respect to size/age that is posited to be a better reflection of exposure to predation at smaller sizes and increased senescence at older ages.

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 'unfished' 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 unfished 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 Tier 3 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).

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

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).

Calculated OFLs and interpretation

OFLs calculated from maximum likelihood estimates of parameters from the suite of presented models ranged from 95.4 to 448.38 (Table 8). Differences in OFLs were a result of differences in estimated MMB (see above), calculated $B_{35\%}$ (which ranged from 113.66 to 183.95 kt; Table 8), $F_{35\%}$ (which ranged from 1.6 to 2.61 yr^{-1}; Table 8), and F_{OFL} (which ranged from 1.6 to 2.61 yr^{-1}; Table 8). Changes in estimated catchability, natural mortality, and the probability of maturing determine the reference points calculated within a given assessment.

Projections under harvest strategies

G. Calculation of the ABC

The acceptable biological catch (ABC) was set by subtracting a 50% buffer from the OFL to account for scientific uncertainty, as recommended by the CPT. The 2019 buffer was 20%, recommended by the CPT and SSC. For this year's buffer, 5% of the increase was attributed to model uncertainty related to changes in recruitment estimates and 25% of the additional buffer was attributed to retrospective analyses with and without the terminal year of survey data showing large increases in the OFL when the terminal year of survey data was excluded.

Uncertainty in the ABC

Several aspects of this year's assessment contributed to the consideration of an additional buffer. First, the retrospective analyses performed showed that the retrospective patterns were worse when the terminal year of survey biomass was not included in the model. A Mohn's rho of 0.66 vs. 1.04 in MMB was produced by the author preferred model, including and excluding terminal survey data, respectively (Figure 23) & Figure 48). These retrospective patterns would have often translated to higher OFLs (i.e. overharvesting of the stock) when the terminal year of survey data was unavailable (Figure 49). Part of the differences in MMB and OFL arise from changes in estimated survey q (Figure 50).

Second, runs using an imputed survey for 2020 based on the prediction of the survey data and error associated with the 25th and 75th quantiles of the residuals produced a large range of OFL (154 to 203 kt). This coupled with conflict in the 2018 and 2019 survey data is troubling. The survey numbers in 2019 decreased much more rapidly than would be expected based on estimates of natural mortality. If the decline is 'real' and not an artifact of sampling, the larger magnitude of the predicted survey MMB with respect to the observed survey MMB in 2019 could result in a larger OFL than appropriate. All models had a difficult time fitting the observed composition of mature males in these years and, without a survey in 2020 to corroborate the survey numbers and size composition from either 2018 or 2019, additional uncertainty will exist in projections that is difficult to incorporate into assessment output directly.

Finally, the large differences in the estimated recruitment in 2015 with the addition of the 2019/2020 catch data is concerning because it is not clear why the estimates should increase as much as they did. Estimates of the 2015 recruitment from the GMACS model were already somewhat larger than those from the status quo before adding the 2019/20 data. However, once the 2019/20 discard and bycatch data were in the model, the GMACS estimate of the 2015 recruitment nearly doubled.

Projections were performed for the author preferred model to the year 2025, harvesting at $F_{35\%}$ and at a fishing mortality defined by the most recent five year average of the estimated directed fishing mortality.

Recruitment in these projections were a random draws from estimates of historical recruitments. The projections suggest that, given the estimated 2019 size composition and estimates of growth, maturity, natural mortality, and stock size, MMB will peak either this year or next at levels similar to the maximum historically estimated MMB before declining precipitously (Figure 51). Projections beyond 4 years become uncertain because the stochasticity introduced by randomly drawn recruitment enters the model. These projections should be considered exploratory and not an absolute reflection of the future of the stock.

Author recommendations

Model 20.2 is the author preferred model, based on fits to the data (particularly the survey MMB), the credibility of the estimated populations processes (growth and natural mortality, importantly), and the strength of the influence of assumptions of the model on the outcomes of the assessment (e.g. assumptions about BSFRF availability and growth functional forms). The CPT elected to increase the buffer to 50% for this year, given model uncertainties and the impacts of a missing terminal year of survey data.

Although the author preferred model fit the data as well or better than the status quo model in most instances, there were exceptions. The overestimation of the retained size length composition data in the initial model years by GMACS should be further examined, but it ultimately does not appear to influence the model appreciably in recent years. The GMACS estimates of population processes were at least as credible as the status quo model, given what we know about snow crab biology and the fishery (perhaps more so for processes like growth). The resulting changes in reference points and other quantities used in management were readily explained by the observed changes in estimates of parameters determining population processes. Given the improvements in GMACS model structure and following the need to standardize assessment methodologies across platforms, the author recommends adoption of the GMACS platform for the use of assessment and management of snow crab.

H. Data gaps and research priorities

Methodology

Refining the code base and transparency of the newly minted assessment for snow crab in GMACS is the next priority.

Data sources

The supplementary analyses included in this document confirm that yearly survey data are very important to the assessment and management of snow crab in the eastern Bering Sea. The author is pleased to hear from collaborators at ADFG that an automated system for producing the catch data used in assessment is being developed. This will improve confidence in the input data, which should bolster confidence in the assessment output.

Modeling

Although GMACS appears to be a satisfactory platform with which to assess eastern Bering Sea snow crab, more work exists to address data inputs, model structure, and assumptions about population processes. Future work will include reexamining catchability and the functional form of selectivity of the NMFS survey gear. The estimated change in catchability between survey eras is rather large and it is not clear if the changes in survey gear and area surveyed are sufficient to explain these changes. Based on the BSFRF survey selectivities, it is possible that survey selectivity is not logistic, as assumed, and perhaps a more flexible functional form would incorporate the BSFRF data more effectively into the model. Time varying catchability is also a strong potential culprit behind some years of poorly fit survey data (e.g. 2014).

The concept of a kinked growth curve should not be entirely abandoned because the biological reasoning holds merit. However, the current growth data and growth function does not capture the hypothesized process well. A potentially more realistic growth model may fit two growth curves: one for immature crab and one for maturing crab. However, this would require the growth increment data to be split between ‘immature’ and ‘maturing’ growth increments, which are not currently available.

It is not clear in practice which parameters can be reliably estimated with the currently available data and assessment model. Different weightings of likelihood components can have drastic impacts on the management advice provided from an assessment. 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. Simulations may be useful to understand both the estimability of the parameters in the current model with the current data and the impact of the weights assigned to different data sources. 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 and population processes, but is poorly known. Tagging studies targeted at estimating natural mortality could be useful to the assessment 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 regardless of the centroid of large male abundance? The answer to this question could influence priors on catchability.) Lacking tagging studies, studies aimed at aging old shell crab protected from the fishery by selectivity could provide better estimates of maximum age for use in empirical estimates of M.

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 (e.g. Murphy et al. 2017). In general, exploring the spatial dynamics of the population may allow for patterns and influences of the fishery and environment on the productivity of the stock to be more easily identified.

Previous analyses suggested that retrospective patterns may be a problem for the snow crab assessment (Szuwalski and Turnock, 2016; Szuwalski, 2017), which was supported by this analysis. Retrospective patterns can result from unaccounted for time-varying processes in the population dynamics of the model (Hurtado et al., 2015). The retrospective patterns in MMB for snow crab appears to be at least partially a result of large estimates of survey MMB in 2014 and 2018. The large estimated survey MMB may have been caused by a change in catchability during those years and focused research on time-variation in important population processes for snow crab should be pursued to confront retrospective biases. Efforts to address catchability and the spatial dynamics of the snow crab fishery are currently underway.

I. Ecosystem Considerations

Historically, recruitment for snow crab could be divided into two periods via regime shift algorithms (e.g. Rodionov, 2004). Szuwalski and Punt (2013) reported that the shift in recruitment corresponded with a change in the winter Pacific Decadal Oscillation (Szuwalski and Punt, 2013), but also with a period of intense fishing mortality. The recent observed large recruitments may suggest a new 'regime' has begun (though it could also be a one-off large recruitment event).

Checking the new estimates of recruitment against the winter PDO showed that the relationship has broken down with the addition of new data (which is a common phenomenon; Myers 1998). However, the PDO is correlated with the Arctic Oscillation (AO) and the AO is very significantly correlated with estimated snow crab recruitment (Figure 52; though one data point has high leverage in this relationship). Negative values of the AO are associated with high pressure in the polar region and greater movement of polar air into lower latitudes. This relationship may be another clue in the search for mechanistic explanations for changes in snow crab recruitment.

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 (Restrepo et al., 1998). 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. The most recent large recruitment events will likely divide the recruitment time series into three periods and present an intriguing opportunity for further study of the relationship between environmental variables and recruitment success.

Appendix A: Status quo assessment model 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, $\lambda_{s,m,l\psi}$ 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.

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

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

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

The dynamics after the initial year were described by:

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

Where ${}_{s,l\psi}$ 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), $\kappa_{s,l'}$ 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:

$$Q_{s,m,y,l\psi} = \sum_{v\psi} N_{s,v,m,y,l} e^{Z_{s,v,m,y,l}} \quad (6)$$

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. $Z_{s,v,m,y,l}$ 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 selectivity 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 $\gamma_{natM,m\psi}$ was estimated subject to constraints (see 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 occurred 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 2 eras in the base model: 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. Immature crab were assumed to molt every year with an estimated probability 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 variability around that relationship was characterized by a discretized and renormalized gamma function, $Y_{s,l,l'}$.

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

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

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

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

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

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

$\hat{L}^{post,1}_{s,l\psi}$ and $\hat{L}^{post,2}_{s,l\psi}$ were predicted post-molt lengths from each piece of the piece-wise relationship, and $\Phi()$ was a cumulative normal distribution in which $\delta_{a,x\psi}$ was an estimated change point. The model in which linear growth was estimated removed equations 26 and 27 from the model.

An average recruitment for the assessment period (1982-present) and yearly deviations around this average were estimated within the assessment for models in which only a single vector of recruitment deviations was estimated. 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.

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

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

For models in which separate vectors of recruitment deviations were estimated for males and females, a separate average recruitment was also estimated (in log space). Each vector of deviations was also subject to a smoothing penalty, but were not linked directly in any way (e.g. priors on the ratio of estimated male to female average recruitment).

Three general types of likelihood components were used to fit to the available data. 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:

$$L_{x\psi} = \lambda_{x\psi} \sum_{y} N^{eff\psi}_{x,y\psi} \sum_{l\psi} p^{obs\psi}_{x,y,l} ln(\hat{p}_{x,y,l}/p^{obs\psi}_{x,y,l}) \tag{31}$$

L_x was the likelihood associated with data component x, where $\lambda_{x\psi}$ represented an optional additional weighting factor for the likelihood, $N^{eff\psi}_{x,y\psi}$ was the effective sample sizes for the likelihood, $p^{obs\psi}_{x,y,l\psi}$ was the observed proportion in size bin l during year y for data component x, and $\hat{p}_{x,y,l\psi}$ was the predicted proportion in size bin l during year y for data component x.

Log normal likelihoods were implemented in the form:

$$L_{x\psi} = \lambda_{x\psi} \sum_{y\psi} \frac{(ln(\hat{I}_{x,y\psi}) - ln(I_{x,y\psi}))^2}{2(ln(CV^2_{x,y\psi} + 1))} \tag{32}$$

$L_{x\psi}$ was the contribution to the objective function of data component x, $\lambda_{x\psi}$ was any additional weighting applied to the component, $\hat{I}_{x,y\psi}$ 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.

Normal likelihoods were implemented in the form:

$$L_{x\psi} = \lambda_{x\psi} \sum_{y\psi} (\hat{I}_{x,y\psi} - I_{x,y\psi})^2 \tag{33}$$

L_x was the contribution 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, $\mathrm{I}_{x,y}$ was the observed value of quantity I from data component x during year y.

Smoothing penalties were also placed on some estimated vectors of parameters in the form of normal likelihoods on the second differences of the vector.

Appendix B: GMACS basic population dynamics

The basic dynamics of GMACS account for growth, mortality, maturity state, and shell condition (although most of the equations omit these indices for simplicity):

$$N_{hji} = ((\mathbf{I} - \mathbf{P}_{hji-1}) + \mathbf{X}_{hji-1}\mathbf{P}_{hji-1})\,\mathbf{S}_{hji-1}N_{hji-1} + \widetilde{R}_{hji} \tag{34}$$

where N_{hji} is the number of animals by size-class of sex h at the start of season j of year i, $\mathbf{P}_{hji}$ is a matrix with diagonals given by vector of molting probabilities for animals of sex h at the start of season j of year i, $\mathbf{S}_{hji}$ is a matrix with diagonals given by the vector of probabilities of surviving for animals of sex h during time-step j of year i (which may be of zero duration):

$$S_{hjil} = exp(-Z_{hjil}) \tag{35}$$

$$S_{hjil} = 1 - \frac{Z_{hjil}}{\widetilde{Z}_{hjil}}(1 - exp(-Z_{hjil})) \tag{36}$$

$\mathbf{X}_{hji}$ is the size-transition matrix (probability of growing from one size-class to each of the other size-classes or remaining in the same size class) for animals of sex h during season j of year i, $\widetilde{R}_{hji}$ is the recruitment (by size-class) to gear g during season j of year i (which will be zero except for one season – the recruitment season), Z_{hjil} is the total mortality for animals of sex h in size- class l during season j of year i, and $\tilde{Z}_{hjil}$ is the probability of encountering the gear for animals of sex h in size-class l during season j of year i. Equation 34 applies when mortality is continuous across a time-step and equation 35 applies when a time-step is instantaneous. Equation 33 can be modified to track old and new shell crab (under the assumption that both old and new shell crab molt), i.e.:

$$N_{hji}^{new} = \mathbf{X}_{hji-1}\mathbf{P}_{hji-1}\mathbf{S}_{hji-1}\left(N_{hji-1}^{new} + N_{hji-1}^{old}\right) + \widetilde{R}_{hji} \tag{37}$$

$$N_{hji}^{old} = (\mathbf{I} - \mathbf{P}_{hji-1})\,\mathbf{S}_{hji-1}\mathbf{P}_{hji-1}\left(N_{hji-1}^{new} + N_{hji-1}^{old}\right) \tag{38}$$

Equation 33 can be also be modified to track mature and immature shell crab (under the assumption that immature crab always molt and mature crab never molt and $\mathbf{P}_{hji}$ now represents the probability of molting to maturity), i.e.:

$$N_{hji}^{mat} = \mathbf{X}_{hji-1}\mathbf{S}_{hji-1}\mathbf{P}_{hji-1}N_{hji-1}^{imm} + \mathbf{S}_{hji-1}N_{hji-1}^{mat} N_{hji}^{imm} = \mathbf{X}_{hji-1}\mathbf{S}_{hji-1}(\mathbf{I} - \mathbf{P}_{hji-1})N_{hji-1}^{imm} + \mathbf{S}_{hji-1}N_{hji-1}^{mat} \tag{39}$$

There are several ways to specify the initial conditions for the model (i.e., the numbers-at- size at the start of the first year, i_1).

- An equilibrium size-structure based on constant recruitment and either no fishing for any of the fleets or (estimated or fixed) fishing mortality by fleet. The average recruitment is an estimated parameter of the model.

- An individual parameter for each size- class, i.e.: $N_{hi_1 1} = exp(\delta_{hi_1 l})$
- An overall total recruitment multiplied by offsets for each size-class, i.e.:

$$N_{hi_1 1} = \frac{R_{init} exp(\delta_{hi_1 l})}{\sum_{h'} \sum_{l'} exp(\delta_{hi_1 l'})} \tag{40}$$

Recruitment occurs once during each year. Recruitment by sex and size-class is the product of total recruitment, the split of the total recruitment to sex and the assignment of sex-specific recruitment to size-classes, i.e.:

$$\widetilde{R}_{hjil} = \bar{R} e^{\epsilon_i} \begin{cases} (1+e^{\theta_i})^{-1} p_{hl} & \text{if h = males} \\ \theta_i (1+e^{\theta_i})^{-1} p_{hl} & \text{if h = females} \end{cases} \tag{41}$$

where $\bar{R}$ is median recruitment, θ_i determines the sex ratio of recruitment during year i, and p_{hl} is the proportion of the recruitment (by sex) that recruits to size-class l:

$$p_{hil} = \int_{L_{low}}^{L_{high}} \frac{\frac{l e^{-l/\beta_h}}{\beta_h}^{(\alpha^h/\beta^h)-1}}{\Gamma(\alpha_h/\beta h)} dl \tag{42}$$

where α_h and β_h are the parameters that define a gamma function for the distribution of recruits to size-class l. Equation 41 can be restricted to a subset of size-classes, in which case the results from Equation 41 are normalized to sum to 1 over the selected size-classes.

Total mortality is the sum of fishing mortality and natural mortality, i.e.:

$$Z_{hijl} = \rho_{ij} M_{hi} \tilde{M}_l + \sum_f S_{fhijl} (\lambda_{fhijl} + \;_{fhijl} (1 - \lambda_{fhijl})) F_{fhijl} \tag{43}$$

where ρ_{ij} is the proportion of natural mortality that occurs during season j for year i, M_{hi} is the rate of natural mortality for year i for animals of sex h (applies to animals for which $\tilde{M}_l = 1$), $\tilde{M}_l$ is the relative natural mortality for size-class l, S_{fhijl} is the (capture) selectivity for animals of sex h in size- class l by fleet f during season j of year i, λ_{fhijl} is the probability of retention for animals of sex h in size-class l by fleet f during season j of year i, $_{fhijl}$ is the mortality rate for discards of sex h in size-class l by fleet f during season j of year i, and F_{fhijl} is the fully-selected fishing mortality for animals of sex h by fleet f during season j of year i.

The probability of capture (occurs instantaneously) is given by:

$$\widetilde{Z}_{hijl} = \sum_f S_{fhijl} F_{fhij} \tag{44}$$

Note that Equation 43 is computed under the premise that fishing is instantaneous and hence that there is no natural mortality during season j of year i. The logarithms of the fully-selected fishing mortalities by season are modelled as:

$$ln(F_{fhij}) = ln(F_{fh}) + \epsilon_{fhij} \text{ if h = males} \tag{45}$$

$$ln(F_{fhij}) = ln(F_{fh}) + \theta_f + \epsilon_{fhij} \text{ if h = females} \tag{46}$$

where $F_{fh\psi}$ is the reference fully-selected fishing mortality rate for fleet f, $\theta_{f\psi}$ is the offset between female and male fully-selected fishing mortality for fleet f, and $\epsilon_{fhij\psi}$ are the annual deviation of fully-selected fishing mortality for fleet $f\psi$ (by sex). Natural mortality can depend on time according to several functional forms:

- Natural mortality changes over time as a random walk, i.e.:

$$M_{hi\psi} = \begin{cases} M_{hi_1} & \text{if i} = i_1 \\ M_{hi-1} e^{\psi_{hi}} & \text{otherwise} \end{cases} \tag{47}$$

where M_{hi_1} is the rate of natural mortality for sex $h\psi$ for the first year of the model, and $_{hi\psi}$ is the annual change in natural mortality.

- Natural mortality changes over time as a spline function. This option follows Equation 46, except that the number of knots at which $_{hi\psi}$ is estimated is specified.

- Blocked changes. This option follows Equation 46, except that $_{hi\psi}$ changes between 'blocks' of years, during which $_{hi\psi}$ is constant.

- Blocked natural mortality (individual parameters). This option estimates natural mortality as parameters by block, i.e.:

$$M_{hi\psi} = e^{\psi_{hi}} \tag{48}$$

where $_{hi\psi}$ changes in blocks of years.

- Blocked offsets (relative to reference). This option captures the intent of the previous option, except that the parameters are relative to natural mortality in the first year, i.e.:

$$M_{hi\psi} = M_{hi_1} e^{\psi_{hi}} \tag{49}$$

It is possible to 'mirror' the values for the $_{hi\psi}$ parameters (between sexs and between blocks), which allows male and female natural mortality to be the same, and for natural mortality to be the same for discontinuous blocks (based on Equations 47 and 48). The deviations in natural mortality can also be penalized to avoid unrealistic changes in natural mortality to fit 'quirks' in the data.

The model keeps track of (and can be fitted to) landings, discards, total catch by fleet, whose computation depends on whether the fisheries in season t are continuous or instantaneous.

$$C^{Land\psi}_{fhijl\psi} = \begin{cases} \frac{\lambda_{fhijl} S_{fhijl} F_{fhijl}}{Z_{hijl}} N_{fhijl}(1 - e^{-\hat{Z}_{hijl}}) & \text{if continuous} \\ \frac{\lambda_{fhijl} S_{fhijl} F_{fhijl}}{Z_{hijl}} N_{fhijl}(1 - e^{-Z_{hijl}}) & \text{if instantaneous} \end{cases} \tag{50}$$

$$C^{Disc\psi}_{fhijl\psi} = \begin{cases} \frac{(1-\lambda_{fhijl}) S_{fhijl} F_{fhijl}}{Z_{hijl}} N_{fhijl}(1 - e^{-\hat{Z}_{hijl}}) & \text{if continuous} \\ \frac{(1-\lambda_{fhijl}) S_{fhijl} F_{fhijl}}{Z_{hijl}} N_{fhijl}(1 - e^{-Z_{hijl}}) & \text{if instantaneous} \end{cases} \tag{51}$$

$$C^{Tot\psi}_{fhijl\psi} = \begin{cases} \frac{S_{fhijl}F_{fhijl}}{\hat{Z}_{hijl}} N_{fhijl}(1 - e^{-\hat{Z}_{hijl}}) & \text{if continuous} \\ \frac{S_{fhijl}F_{fhijl}}{Z_{hijl}} N_{fhijl}(1 - e^{-Z_{hijl}}) & \text{if instantaneous} \end{cases} \quad (52)$$

Landings, discards, and total catches by fleet can be aggregated over sex (e.g., when fitting to removals reported as sex-combined). Equations 49-51 are extended naturally for the case in which the population is represented by shell condition and/or maturity status (given the assumption that fishing mortality, retention and discard mortality depend on sex and time, but not on shell condition nor maturity status). Landings, discards, and total catches by fleet can be reported in numbers (Equations 49-51) or in terms of weight. For example, the landings, discards, and total catches by fleet, season, year, and sex for the total (over size-class) removals are computed as:

$$C^{Land\psi}_{fhij\psi} = \sum_{l\psi} C^{Land\psi}_{fhijl} w_{hil\psi} \quad (53)$$

$$C^{Disc\psi}_{fhij\psi} = \sum_{l\psi} C^{Disc\psi}_{fhijl} w_{hil\psi} \quad (54)$$

$$C^{Total\psi}_{fhij\psi} = \sum_{l\psi} C^{Total\psi}_{fhijl\psi} w_{hil\psi} \quad (55)$$

$$(56)$$

where $C^{Land\psi}_{fhij\psi}$, $C^{Disc\psi}_{fhij\psi}$ and $C^{Total\psi}_{fhij\psi}$ are respectively the landings, discards, and total catches in weight by fleet, season, year, and sex for the total (over size-class) removals, and $w_{hil\psi}$ is the weight of an animal of sex h in size-class l during year i.

Many options exist related to selectivity (the probability of encountering the gear) and retention (the probability of being landed given being captured). The options for selectivity are:

- Individual parameters for each size-class (in log-space); normalized to a maximum of 1 over all size-classes (if indicated).
- Individual parameters for a subset of the size-classes (in log-space). Selectivity must be specified for a contiguous range of size-classes starting with the first size-class. Selectivity for any size-classes outside of the specified range is set to that for last size-class for which selectivity is treated as estimable.
- Logistic selectivity. Two variants are available depending of the parametrization:

$$S_{l\psi} = \frac{1}{1 + exp(\frac{ln19(\bar{L}_l - S_{50})}{S_{95} - S_{50}})} \quad (57)$$

$$S_{l\psi} = \frac{1}{1 + exp(\frac{(\bar{L}_l - S_{50})}{\sigma_S})} \quad (58)$$

where S_{50} is the size corresponding to 50% selectivity, S_{95} is the size corresponding to 95% selectivity, $\sigma_{S\psi}$ is the "standard deviation" of the selectivity curve, and $\bar{L}_{l\psi}$ is the midpoint of size-class l.

- All size-classes are equally selected.
- Selectivity is zero for all size-classes.

It is possible to assume that selectivity for one fleet is the product of two of the selectivity patterns. This option is used to model cases in which one survey is located within the footprint of another survey. The options to model retention are the same as those for selectivity, except that it is possible to estimate an asymptotic parameter, which allows discard of animals that would be "fully retained" according to the standard options for (capture) selectivity. Selectivity and retention can be defined for blocks of contiguous years. The blocks need not be the same for selectivity and retention, and can also differ between fleets and sexs.

Growth is a key component of any size-structured model. It is modelled in terms of molt probability and the size-transition matrix (the probability of growing from each size-class to each of the other size-classes, constrained to be zero for sizes less than the current size). Note that the size-transition matrix has entries on its diagonal, which represent animals that molt but do not change size-classes

There are four options for modelling the probability of molting as a function of size:

- Pre-specified probability
- Individual parameters for each size-class (in log-space)
- Constant probability
- Logistic probability, i.e.:

$$P_{l,l\psi} = \frac{1}{1-(1+exp(\frac{\bar{L}_l - P_{50}}{\sigma_P}))} \tag{59}$$

where P_{50} is the size at which the probability of molting is 0.5 and $\sigma_{P\psi}$is the "standard deviation" of the molt probability function. Molt probability is specified by sex and can change in blocks.

The proportion of animals in size-class $l\psi$that grow to be in size-class l' $(X_{l,l'})$ can either be pre-specified by the user or determined using a parametric form:

- The size-increment is gamma-distributed:

$$X_{l,l'} = \int_{L_{low}}^{L_{high}} \frac{((l-\bar{L}_l)/\tilde{\beta})^{I_l/\tilde{\beta}-1} e^{-(l-\bar{L}_l)/\tilde{\beta}\psi}}{\Gamma(I_l/\tilde{\beta})} dl\psi \tag{60}$$

- The size after increment is gamma-distributed, i.e.:

$$X_{l,l'} = \int_{L_{low}}^{L_{high}} \frac{(l/\tilde{\beta})^{(\bar{L}_l+I_l)/\tilde{\beta}-1} e^{-(l/\tilde{\beta})}}{\Gamma((\bar{L}_{l\psi}+I_l)/\tilde{\beta})} dl\psi \tag{61}$$

- The size-increment is normally-distributed, i.e.:

$$X_{l,l'} = \int_{L_{low}}^{L_{high}} \frac{e^{-(l-\bar{L}_l-I_l)^2/(2\tilde{\beta}^2)}}{\sqrt{2\pi}\tilde{\beta}\psi} dl\psi \tag{62}$$

- There is individual variation in the growth parameters L_∞ and $k\psi$(equivalent to the parameters of a linear growth increment equation given the assumption of von Bertlanffy growth), i.e.:

$$X_{l,l'} = \int_{L_{low}}^{L_{high}} \int_{L_{low}}^{L_{high}} \int_{0}^{\infty} \int_{0}^{\infty} \frac{1}{L_{hi,l\psi} - L_{low_l}} \frac{e^{-(ln(L_\infty)-\bar{L}_{\psi\infty})^2/(2\sigma^2_{L_\infty})}}{\sqrt{2\pi}\sigma^2_{L_\infty}} \frac{e^{-(ln(k)-\bar{k})^2/(2\sigma^2_k)}}{\sqrt{2\pi}\sigma^2_{L_k}} dL_{L_\infty} dk dl_{l'} dl_{l\psi} \quad (63)$$

- There is individual variation in the growth parameter L_∞:

$$X_{l,l'} = \int_{L_{low}}^{L_{high}} \int_{L_{low}}^{L_{high}} \int_{0}^{\infty} \frac{1}{L_{hi,l\psi} - L_{low_l}} \frac{e\bar{\psi}^{(ln(L_\infty)-\bar{L}_{\psi\infty})^2/(2\sigma^2_{L_\infty})}}{\sqrt{2\pi}\sigma^2_{L_\infty}} dL_{L_\infty} dl_{l'} dl_{l\psi} \quad (64)$$

- There is individual variation in the growth parameters k:

$$X_{l,l'} = \int_{L_{low}}^{L_{high}} \int_{L_{low}}^{L_{high}} \int_{0}^{\infty} \frac{1}{L_{hi,l\psi} - L_{low_l}} \frac{e^{-(ln(k)-\bar{k})^2/(2\sigma^2_k)}}{\sqrt{2\pi}\sigma^2_{k\psi}} dk dl_{l'} dl_{l\psi} \quad (65)$$

The size-transition matrix is specified by sex and can change in blocks.

Table 5: Observed growth increment data by sex

Female premolt length (mm)	Female postmolt length (mm)	Male premolt length (mm)	Male postmolt length (mm)
20.7	27	57.63	68.6
25.2	32	20.6	28.9
28.7	37.1	25.6	31.4
28.2	36.22	25.9	31.1
25.9	32.7	20	26.3
26.9	34.4	25.2	32.8
26.4	31.8	21	27.8
29	36.7	20.3	26.4
23	31.2	21.9	28.4
21.6	27.7	20.7	27.7
24.2	30.9	20.1	28
20.8	27.3	19.8	26.5
20.3	26.2	26	32.2
22.2	29.7	62.3	81.8
21.4	28	56.5	70
19.3	25.2	57	70
26.9	34.5	58.7	72.5
25.7	32.5	60.8	78.4
19.8	26.9	59.3	75.1
27.4	35.1	64	84.7
20.4	26.4	60.3	75.1
25.5	34.6	20.7	29.2
34.9	44.8	24	32.3
18.6	25.2	16.1	23
28.2	35.8	19.2	26.6
22.8	29.6	21.23	26.41
26.5	33.9	22.2	28.1
25.5	32.9	23.48	28.27
24.2	31.4	29.9	39.9
24.4	30.7	30.3	40.3
22.3	29.4	30.7	40.5
20.8	27.3	44.2	58.7
22.8	30.2	44.7	57.3
26.2	32.6	64.7	82.7
29.4	36.7	67.6	86
20.2	24.9	67.9	85.3
27.5	34.8	74.5	93.9
20.4	26.7	79.9	97.8
25.4	31.7	89.8	110
28.1	34.5	89.9	112.1
28.7	36	89.9	112.3
29.5	38.4	93.8	117.6
30.9	38.4	20	26.3
26	33.1		
29.1	38.4		
19.37	24.24		
20.7	27.4		
21.25	28.73		
21.94	28.71		
23.09	29.26		

Female premolt length (mm)	Female postmolt length (mm)	Male premolt length (mm)	Male postmolt length (mm)
32.8	44.9		
35.3	47.6		
38.3	50.9		
38.9	53		
41	55.8		
42.1	54.6		
44.2	59.5		
44.3	59.3		
44.8	59.7		
45.2	59.6		
46.9	60.4		
47	61.4		
47.9	61.4		
20.6	25.1		
20.8	27.6		
22	28.2		
22.9	28.6		

Table 6: Observed retained catches, discarded catch, and bycatch. Discards and bycatch have assumed mortalities applied.

Survey year	Retained catch (kt)	Discarded females (kt)	Discarded males (kt)	Trawl bycatch (kt)
1982	11.85	0.02	1.33	0.37
1983	12.16	0.01	1.3	0.47
1984	29.94	0.01	2.89	0.5
1985	44.45	0.01	4.21	0.43
1986	46.22	0.02	4.45	0
1987	61.4	0.03	5.79	0
1988	67.79	0.04	6.1	0
1989	73.4	0.05	7.01	0.1
1990	149.1	0.05	15.95	0.71
1991	143	0.06	12.58	1.5
1992	104.7	0.12	17.06	2.28
1993	67.94	0.08	5.32	1.57
1994	34.13	0.06	4.03	2.67
1995	29.81	0.02	5.75	1.01
1996	54.22	0.07	7.44	0.66
1997	114.4	0.01	5.73	0.82
1998	88.09	0.01	4.67	0.54
1999	15.1	0	0.52	0.47
2000	11.46	0	0.62	0.41
2001	14.8	0	1.89	0.31
2002	12.84	0	1.47	0.17
2003	10.86	0	0.57	0.46
2004	11.29	0	0.51	0.63
2005	16.77	0	1.36	0.2
2006	16.49	0	1.78	0.42
2007	28.59	0.01	2.53	0.18
2008	26.56	0.01	2.06	0.18
2009	21.78	0.01	1.23	0.47
2010	24.61	0.01	0.62	0.14
2011	40.29	0.18	1.69	0.15
2012	30.05	0.03	2.32	0.22
2013	24.49	0.07	3.27	0.11
2014	30.82	0.17	3.52	0.13
2015	18.42	0.07	2.96	0.13
2016	9.67	0.02	1.31	0.06
2017	8.6	0.02	1.93	0.04
2018	12.51	0.02	2.86	0.23
2019	15.43	0.02	5.07	0.24

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 (kt)	Males >101mm (million)
1982	144.4	0.15	176.8	0.14	33.34	60.91
1983	90.13	0.2	161.6	0.13	38.09	70.09
1984	42.32	0.19	177.7	0.12	88.73	151.8
1985	6.12	0.2	71.84	0.11	43.39	72.84
1986	15.74	0.18	89.81	0.11	46.7	77.91
1987	122.6	0.16	194.6	0.11	74.44	128.6
1988	169.9	0.17	259.4	0.15	104.7	173.1
1989	264.2	0.25	299.2	0.11	92.31	158.9
1990	182.9	0.19	443.8	0.14	224.7	386.4
1991	214.9	0.19	466.6	0.15	292.2	452.9
1992	131.4	0.18	235.5	0.09	143.9	227.3
1993	132.1	0.16	183.9	0.1	78.11	126.7
1994	126.2	0.15	171.3	0.08	44.78	72.57
1995	168.7	0.14	220.5	0.13	37.75	65.18
1996	107.3	0.14	288.4	0.12	87.57	155.2
1997	103.8	0.2	326.8	0.1	168.7	280.6
1998	72.73	0.25	206.4	0.09	126.7	209.7
1999	30.89	0.21	95.85	0.09	52.53	85.2
2000	96.46	0.52	96.39	0.14	41.88	69.83
2001	77.24	0.28	136.5	0.12	41.51	70.69
2002	30.22	0.28	93.17	0.23	36.56	64.16
2003	41.71	0.31	79.07	0.12	32.57	55.61
2004	50.16	0.26	79.57	0.14	35.99	57.42
2005	64.85	0.17	123.5	0.11	40.67	63.26
2006	51.93	0.17	139.3	0.26	71.13	120.9
2007	55.89	0.22	153.1	0.15	73.62	127.5
2008	57.15	0.19	142	0.1	66.56	113.6
2009	52.16	0.21	148.2	0.13	78.92	129.9
2010	98.01	0.17	162.8	0.12	88.35	138.3
2011	175.8	0.18	167.1	0.11	94.67	147.6
2012	149.4	0.2	122.2	0.12	53.17	85.35
2013	131.4	0.17	97.46	0.12	42.93	71.79
2014	119.7	0.19	163.5	0.16	81.39	138.8
2015	85.13	0.17	80.04	0.12	35.77	56.11
2016	55.39	0.21	63.21	0.11	21.96	36.51
2017	106.8	0.21	83.96	0.13	20.52	35.02
2018	165.9	0.18	198.4	0.17	26.75	48.08
2019	110.4	0.2	169.1	0.17	28.12	51.27

Table 8: Changes in management quantities for each scenario considered. Reported management quantities are derived from maximum likelihood estimates. Reported natural mortality is for mature males and average recruitment is for males.

Model	MMB	B35	F35	FOFL	OFL	M	avg_rec
19.1	109.56	123.71	1.80	1.80	54.05	0.30	113.68
20.1	144.29	120.51	1.60	1.60	95.40	0.30	109.55
20.2	207.19	113.66	1.65	1.65	184.91	0.36	169.96
20.3	517.13	183.95	2.61	2.61	448.38	0.36	265.31

Table 9: Maximum likelihood estimates of predicted mature male (MMB), mature female (FMB), and males >101mm biomass (1000 t) and numbers (in millions) at the time of the survey from the chosen model. Columns 2-5 are subject to survey selectivity; columns 6-9 are the population values (i.e. the numbers at length are not modified by multiplying them by a selectivity curve–they are estimates of the underlying population).

Survey year	FMB	MMB	Male >101 biomass	Male >101 (millions)	FMB	MMB	Male >101 biomass	Male >101 (millions)
1982	87.91	118.2	38.25	62.01	434.7	292.2	92.14	149.4
1983	74.56	117	40.31	62.84	364.3	288.8	97.11	151.4
1984	54.86	117.1	48.08	77.5	268.2	289	115.8	186.7
1985	41.28	112.9	48.5	79	201.9	279.9	116.8	190.3
1986	34.9	107.3	42.46	69.87	171.2	267.6	102.3	168.3
1987	115	115.5	41.65	70.27	572.9	289.4	100.3	169.3
1988	193	141.6	55.06	92.64	956.3	354.4	132.7	223.2
1989	411.4	362	141.7	237.4	904.1	417.4	162.6	272.4
1990	314.9	427.6	193	323.9	690.5	492.6	221.5	371.6
1991	232.4	385.3	177.1	295.1	509.5	443.6	203.3	338.6
1992	193.8	293.6	123.8	205.8	426.2	338.2	142.1	236.1
1993	196.1	210.5	73.82	123.2	432.5	242.9	84.71	141.4
1994	203	183.1	48.47	80.4	447.4	211.8	55.62	92.27
1995	214.2	210.1	53.54	91.63	472.5	242.8	61.44	105.2
1996	201.2	284.7	109.7	186.7	442.8	328.1	125.8	214.2
1997	157.4	327.7	164.3	273.3	345.3	377.1	188.5	313.6
1998	114	257	132.2	216.8	249.9	295.6	151.8	248.8
1999	87.56	154.9	67.71	110.5	192.3	178.4	77.7	126.8
2000	93.06	118.1	48.33	78.31	205.5	136.1	55.46	89.87
2001	99.2	95.25	32.38	53.26	218.8	109.8	37.15	61.12
2002	83.99	90.71	31.2	53.33	184.5	104.5	35.81	61.2
2003	62.53	100.1	45.57	75.87	137.1	115.3	52.3	87.07
2004	45.3	99.28	46.93	76.48	99.33	114.5	53.86	87.77
2005	89.17	97.93	39.51	64.74	198.4	113.1	45.35	74.29
2006	126.7	111.8	39.98	67.52	280.3	129.2	45.88	77.48
2007	109.7	146.8	60.95	102.4	240.9	169.2	69.95	117.5
2008	80.49	169.7	78.07	130.2	176.5	195.4	89.59	149.4
2009	61.18	182.1	94.81	156.7	134.3	209.6	108.8	179.8
2010	158.6	174.2	98.11	159.9	353.5	200.4	112.6	183.6
2011	247	144.5	78.12	126.4	546.7	166.4	89.65	145.1
2012	229.2	102.5	42.39	70.3	503.9	118.1	48.65	80.68
2013	189.2	89.51	34.35	58.49	415.8	103.1	39.42	67.12
2014	151.5	82.62	35.74	59.73	332.8	95.16	41.02	68.54
2015	113	58.02	21.27	35.36	247.9	66.89	24.41	40.58
2016	91.54	44.36	12.44	20.85	201.2	51.28	14.27	23.93
2017	124.1	61.66	12.1	20.41	275	72.04	13.89	23.42
2018	184.8	127.4	15.49	26.47	409.2	148.8	17.78	30.37
2019	196.4	251.9	44.67	79.07	432.9	291.6	51.27	90.74
2020	160.7	486.5	204.5	352.3	352.8	560.2	234.7	404.3

Table 10: Maximum likelihood estimates of predicted mature male biomass at mating, male recruitment (millions) from the chosen model, and estimated fully-selected total fishing mortaltiy.

Survey year	Mature male biomass	Male recruits	Fishing mortality
1982	218.9	4.4	0.19
1983	212.2	1.75	0.19
1984	193.9	3.82	0.45
1985	171.2	6.49	0.72
1986	161.9	0.95	0.86
1987	170.5	3.08	1.13
1988	210.7	0.3	0.97
1989	253.4	0.64	0.83
1990	235.7	2.47	1.64
1991	203.8	5.12	1.79
1992	147.7	2.5	2.44
1993	127.9	0.39	1.82
1994	127.8	0.1	1.39
1995	155.3	0.14	1.02
1996	198.8	0.15	0.85
1997	193.5	1.76	1.14
1998	144.6	0.22	1.24
1999	124.5	0.36	0.29
2000	93.13	0.3	0.35
2001	67.75	1.63	0.87
2002	68.09	1.45	0.64
2003	79.21	1.8	0.32
2004	77.46	1.54	0.34
2005	70.01	0.4	0.72
2006	83.24	0.17	0.66
2007	102.8	0.63	0.77
2008	125.3	1.37	0.51
2009	141.5	0.23	0.32
2010	134.8	0.4	0.31
2011	89.63	0.15	0.87
2012	61.98	0.45	1.36
2013	54.34	0.35	1.52
2014	41.65	2.07	2.33
2015	31.32	15.73	2.64
2016	29.79	0.78	1.75
2017	48.04	0.18	1.79
2018	101.1	0.14	1.69
2019	207.2	0.18	0.54

Table 11: Maximum likelihood estimates of predicted total numbers (billions), not subject to survey selectivity at the time of the survey.

Survey year	Total females	Total males	Total numbers
1982	6.053	3.591	9.643
1983	4.885	6.881	11.77
1984	3.73	6.52	10.25
1985	4.485	8.305	12.79
1986	38.71	12.19	50.89
1987	34.08	9.346	43.42
1988	24.35	9.477	33.83
1989	17.74	6.774	24.52
1990	13.27	5.223	18.49
1991	13.87	5.839	19.71
1992	15.62	8.929	24.55
1993	15.08	8.492	23.57
1994	17.29	6.18	23.47
1995	12.55	4.332	16.89
1996	8.911	3.087	12
1997	6.368	2.192	8.561
1998	5.673	3.118	8.791
1999	8.511	2.256	10.77
2000	6.872	1.908	8.78
2001	4.933	1.604	6.537
2002	3.521	2.718	6.24
2003	2.577	3.321	5.898
2004	12.4	4.087	16.48
2005	8.906	4.366	13.27
2006	6.322	3.402	9.724
2007	4.522	2.509	7.031
2008	3.878	2.327	6.204
2009	23.54	2.949	26.49
2010	18.55	2.245	20.8
2011	14.16	1.933	16.09
2012	12.46	1.435	13.89
2013	8.896	1.397	10.29
2014	6.416	1.274	7.69
2015	6.442	2.895	9.337
2016	13.5	17.7	31.2
2017	17.12	13.06	30.18
2018	12.91	9.232	22.14
2019	9.39	6.527	15.92
2020	6.892	4.681	11.57

Table 12: Differences between GMACS and the status quo model.

Process	GMACS	Status quo
Recruitment	Yearly recruitment estimate + parameter to divide recruitment between sexes	Separate estimated recruitment deviations and average recruitment for both sexes
Fishing mortality	Total mortality and female discards treated consistently (see May CPT document)	Total mortality and female discards treated inconsistently (see May CPT document)
Growth	Linear growth for both males and females	Linear growth for males; kinked growth for females
BSFRF	Freely estimated availability curves for all sex/year combinations	Logistic availability curves for some sex/year combinations
Natural mortality	Estimated M for mature males, mature females, immature males, immature females (n=4)	Estimated M for mature males, mature females, immature males and females (n=3)

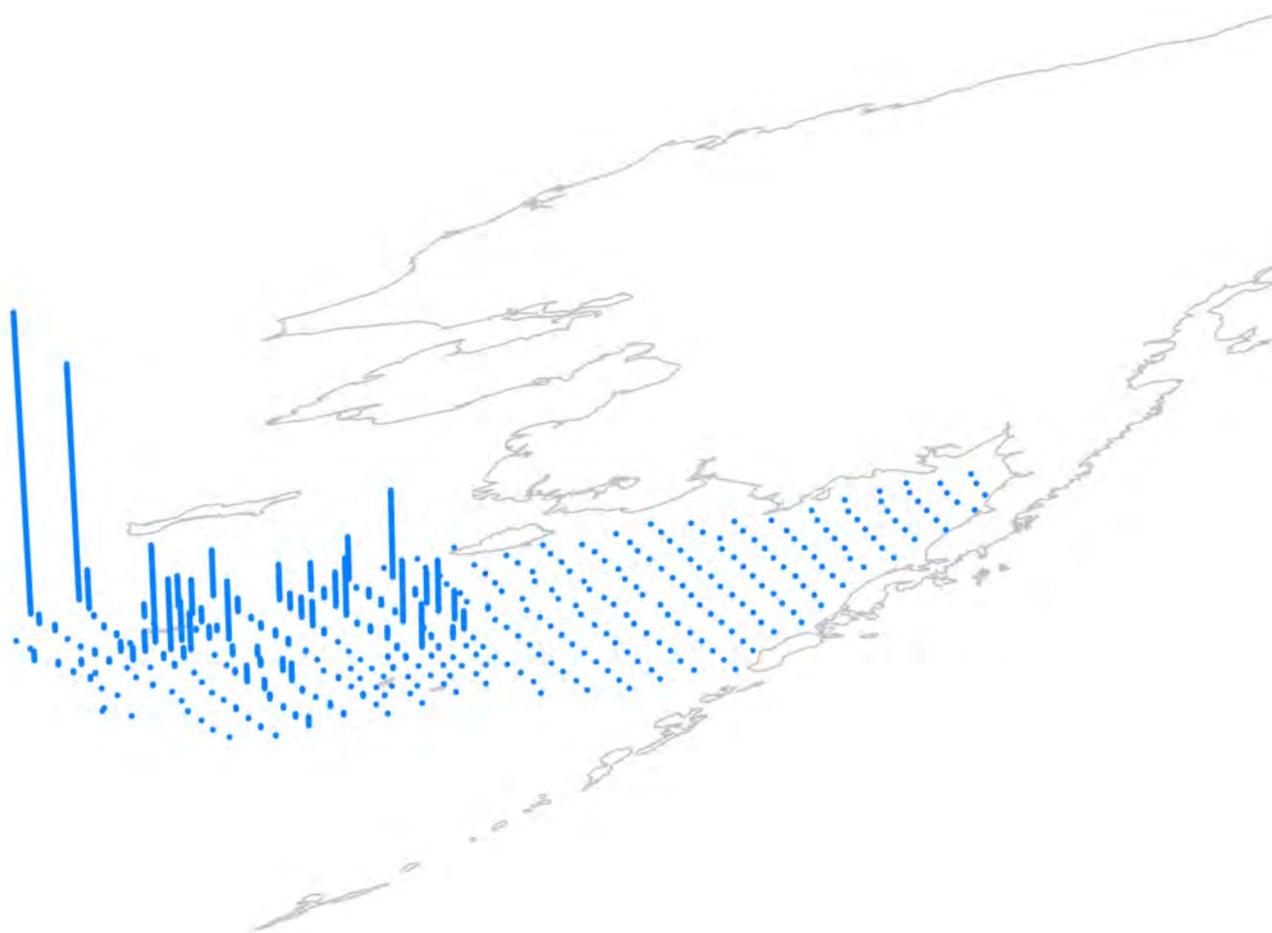

Figure 1: Observed relative density of all males at the time of the 2019 NMFS summer survey

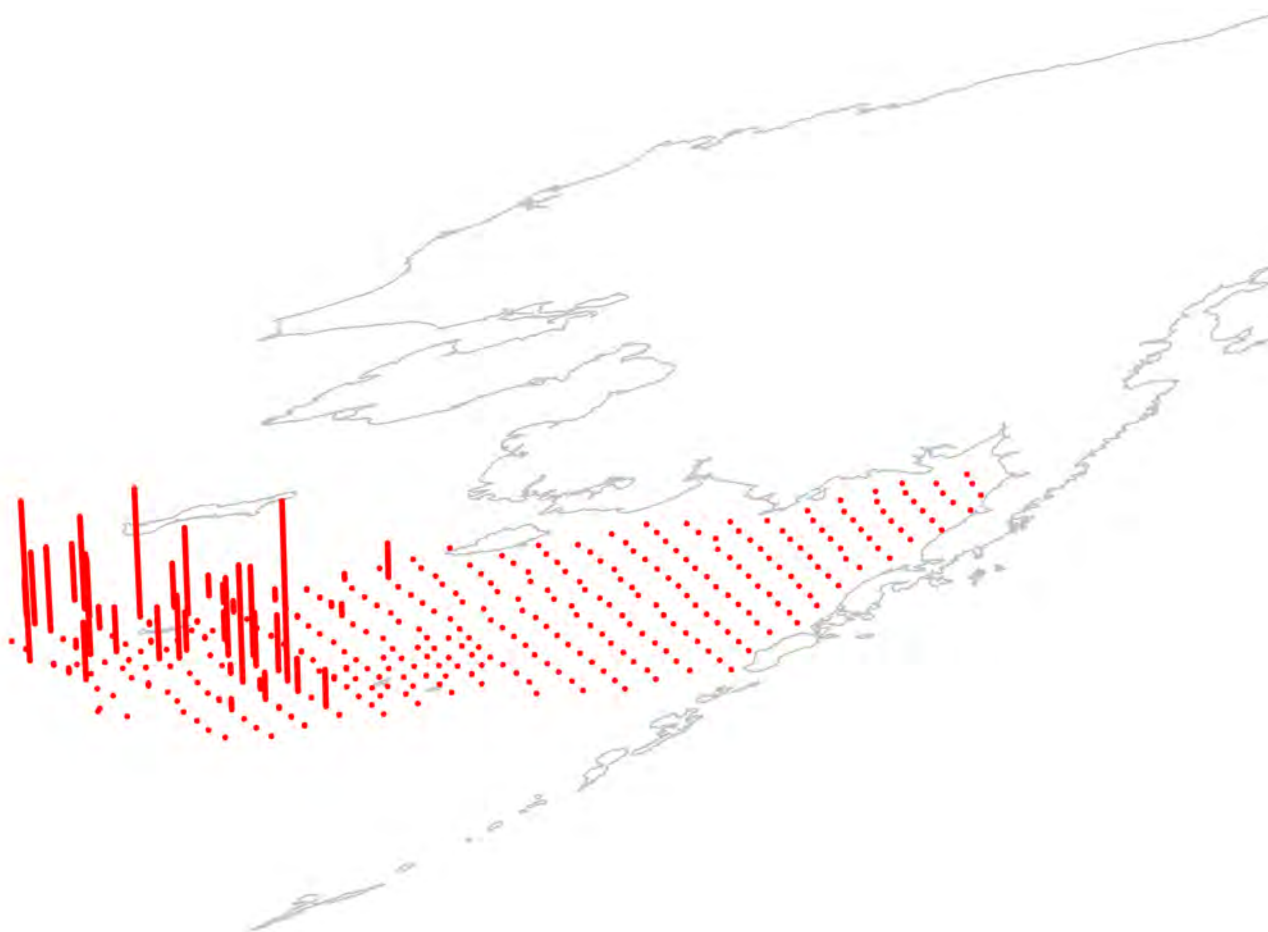

Figure 2: Observed relative density of all females at the time of the 2019 NMFS summer survey

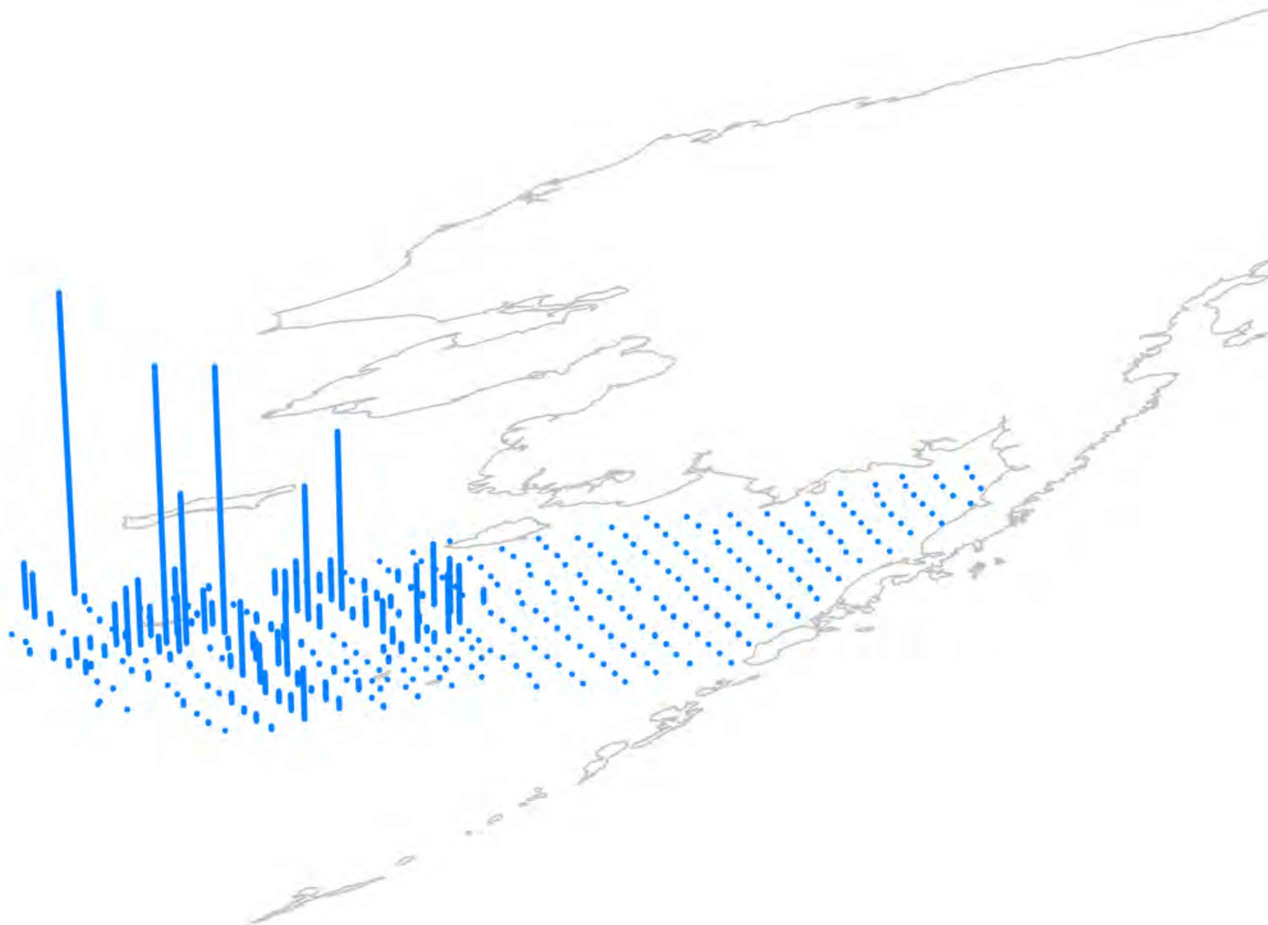

Figure 3: Observed relative density of males >77mm carapace width at the time of the 2019 NMFS summer survey

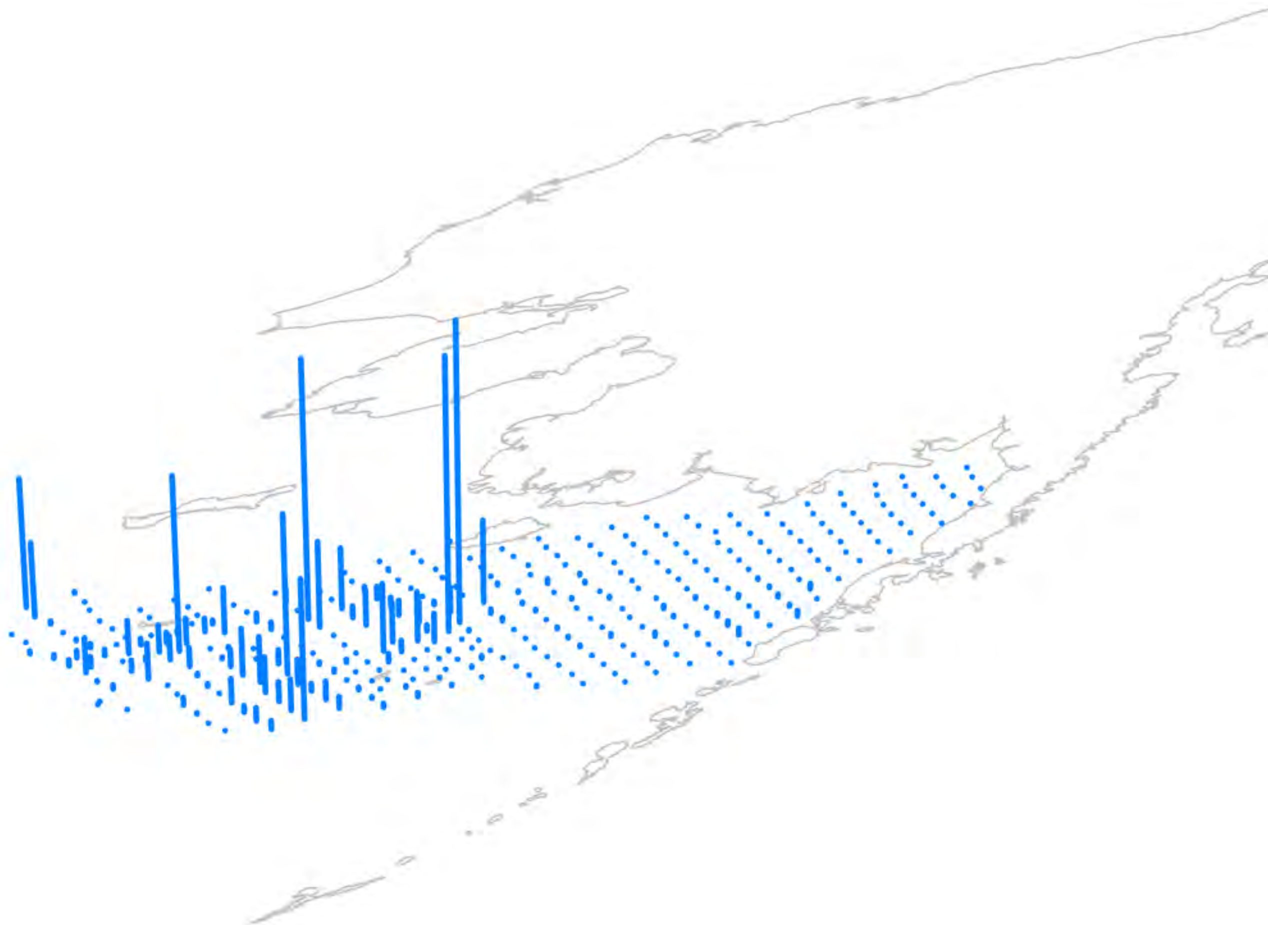

Figure 4: Observed relative density of males >101mm carapace width at the time of the 2019 NMFS summer survey

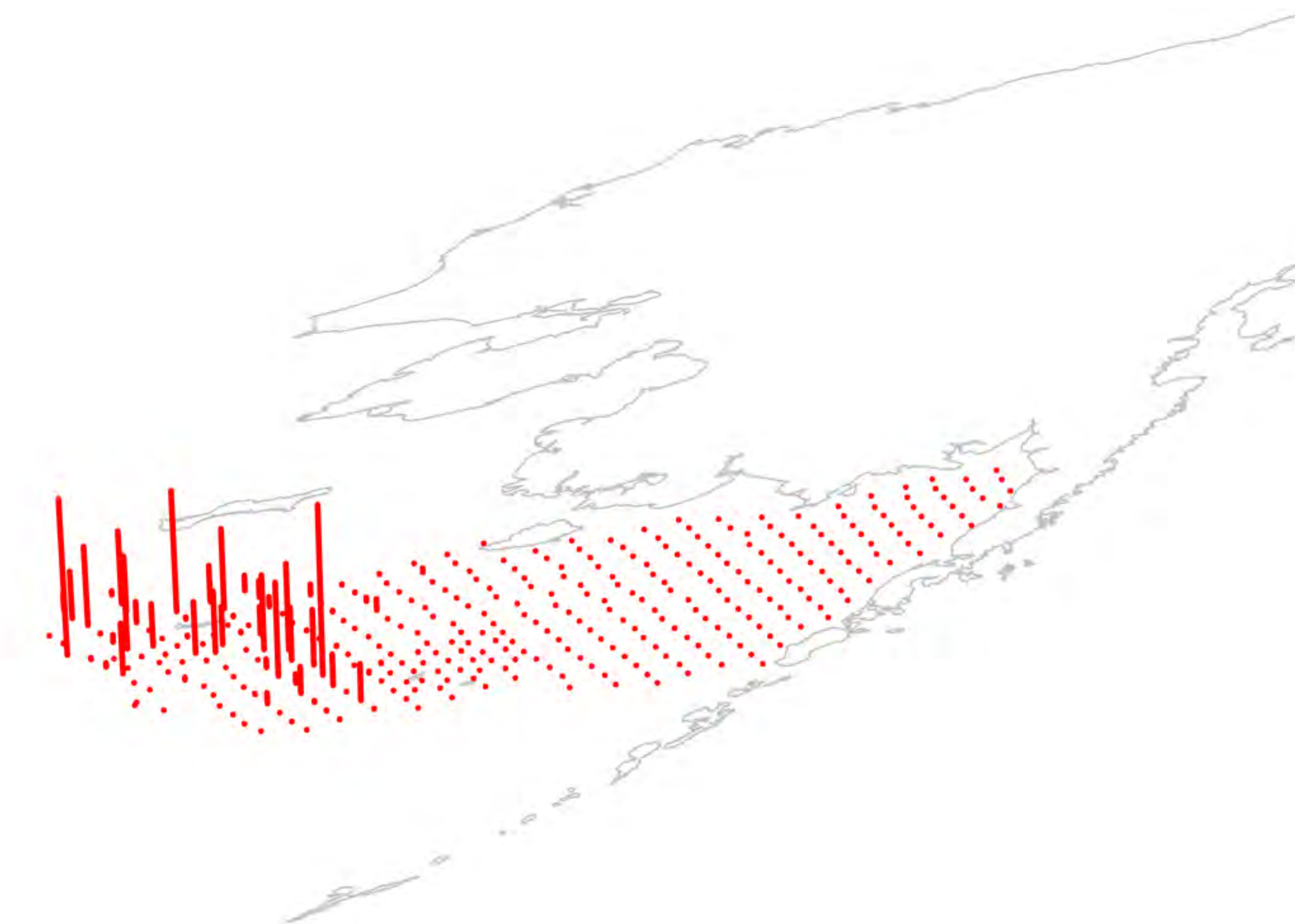

Figure 5: Observed relative density of mature females at the time of the 2019 NMFS summer survey

Shell condition	CW (mm)	Age (years)	Error (years)	Coordinates	Depth (m)	Species
0^+	121	0.05	0.26	59°20′N, 171°49′W	43	*C. opilio*
0^+	110	0.11	0.27	59°20′N, 171°49′W	43	*C. opilio*
0^+	132	0.11	0.19	59°20′N, 171°49′W	43	*C. opilio*
1	118	0.15	0.26	59°20′N, 171°49′W	43	*C. opilio*
1	130	0.23	0.27	59°20′N, 171°49′W	43	*C. opilio*
1	116	0.25	0.24	59°20′N, 171°49′W	43	*C. opilio*
2^+	93	0.33	0.28	57°00′N, 167°43′W	42	*C. bairdi*
2^+	122	0.42	0.26	57°00′N, 167°43′W	42	*C. bairdi*
2^+	97	0.66	0.30	59°00′N, 171°47′W	46	*C. opilio*
2^+	123	0.78	0.32	59°00′N, 171°47′W	46	*C. opilio*
2^+	121	0.85	0.27	57°00′N, 167°43′W	42	*C. opilio*
2^+	66	1.07	0.29	59°00′N, 171°47′W	46	*C. opilio*
3	117	0.92	0.34	59°00′N, 171°47′W	46	*C. opilio*
3	69	1.04	0.28	59°00′N, 171°47′W	46	*C. opilio*
3	78	1.10	0.30	59°00′N, 171°47′W	46	*C. opilio*
4	100	4.43	0.33	57°21′N, 167°45′W	39	*C. opilio*
4	93	4.89	0.37	58°20′N, 171°38′W	52	*C. bairdi*
4	100	6.60	0.33	57°00′N, 167°43′W	42	*C. opilio*
5	111	2.70	0.44	58°60′N, 169°12′W	28	*C. opilio*
5	100	4.21	0.34	59°00′N, 171°47′W	46	*C. bairdi*
5	110	6.85	0.58	58°60′N, 169°12′W	28	*C. opilio*

Figure 6: Radiometric estimates of shell age in male snow and tanner crabs collected during the NMFS survey of 1992. Reproduced from Ernst et al. 2005's presentation of Nevissi et al. 1995.

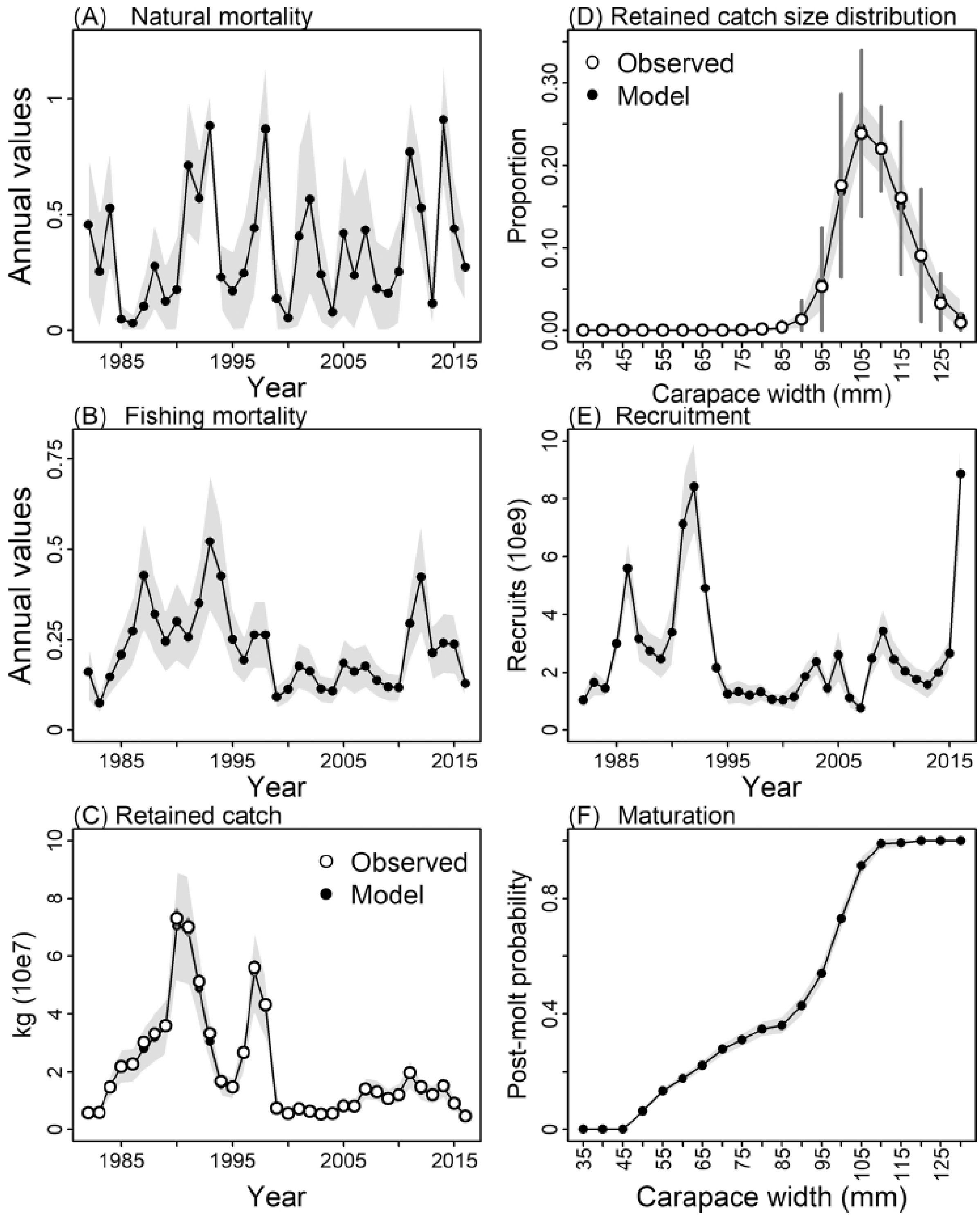

Figure 7: Murphy et al.'s (2018) estimates of natural mortality (and time-variation in M) from a state-space modeling framework.

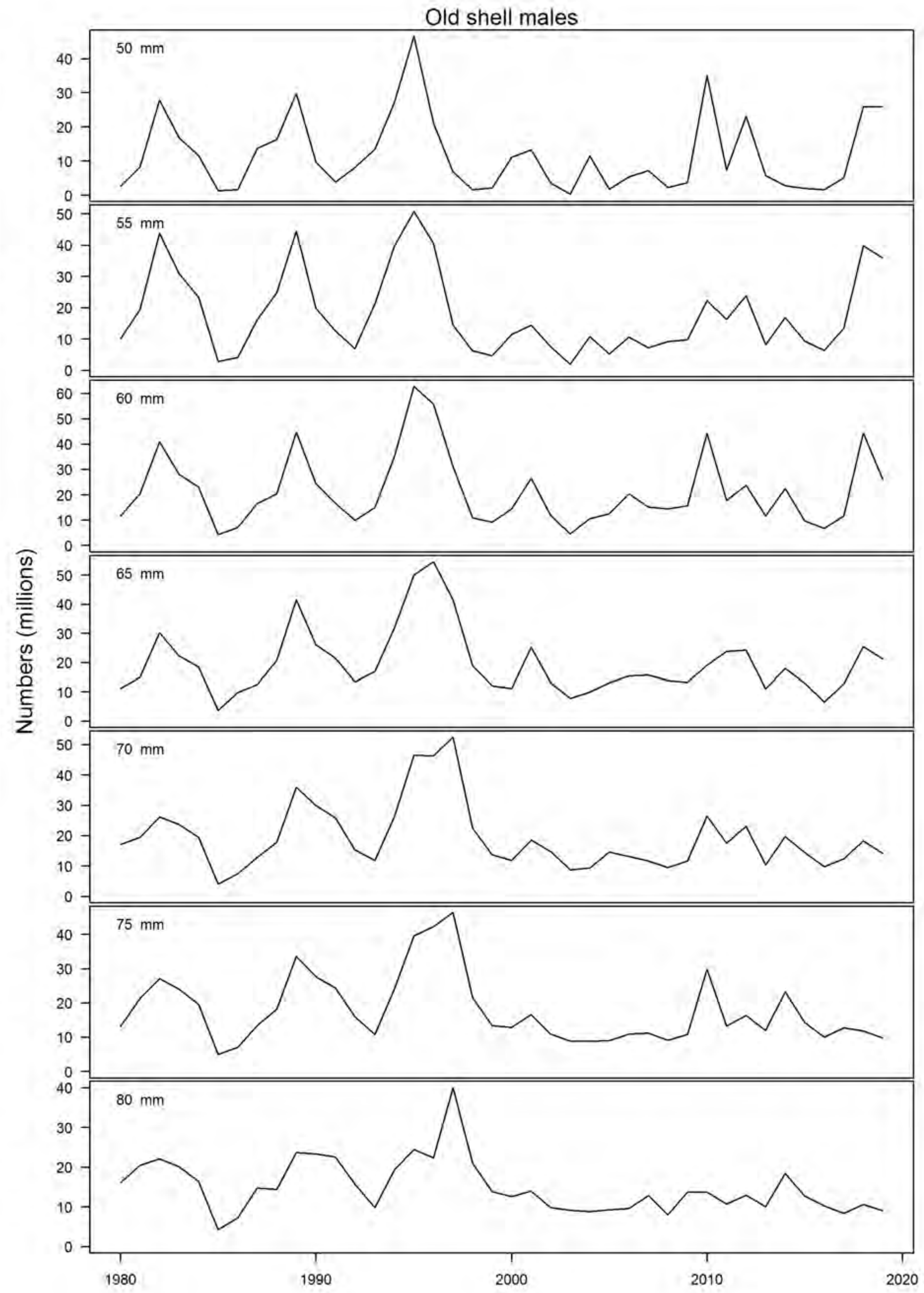

Figure 8: Observed numbers at length of old shell mature males by size class. The presented size bins are not vulnerable to the fishery, so all mortality is 'natural'. The decline in numbers in a size class after the recruitment collapse in the early 1990s demonstrates expected natural mortality for mature male individuals.

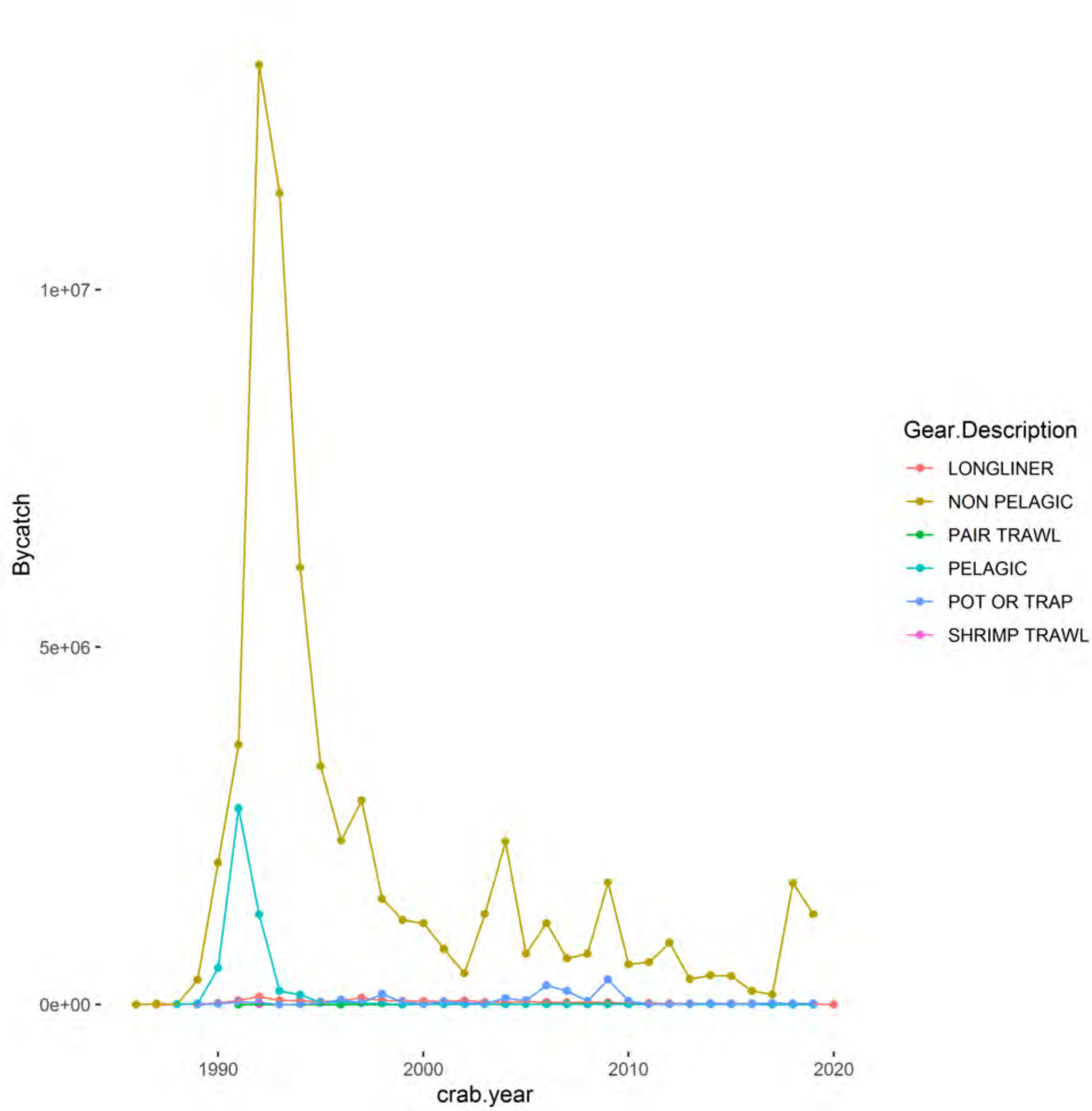

Figure 9: Bycatches in other fishing fleets.

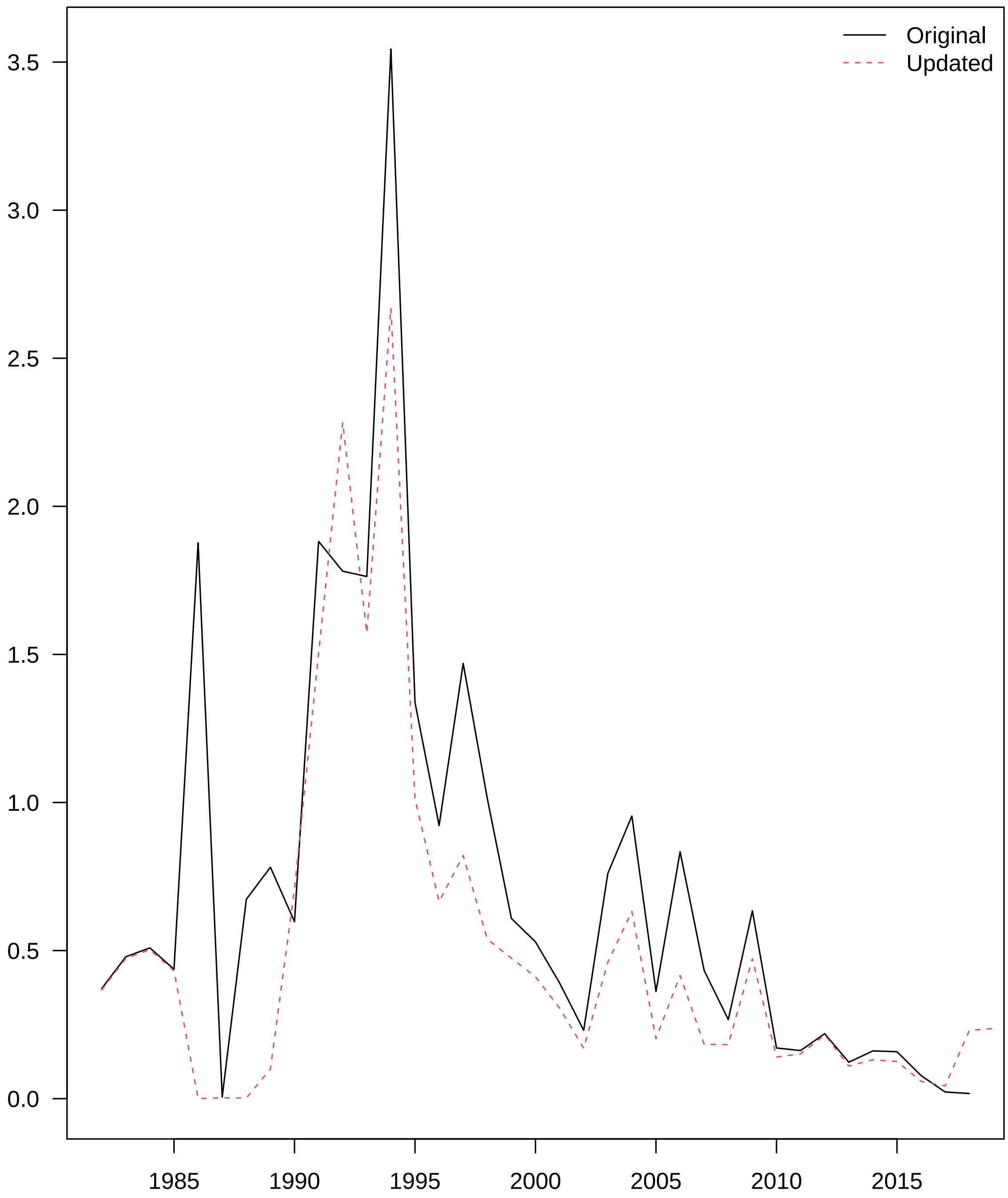

Figure 10: Change in trawl data.

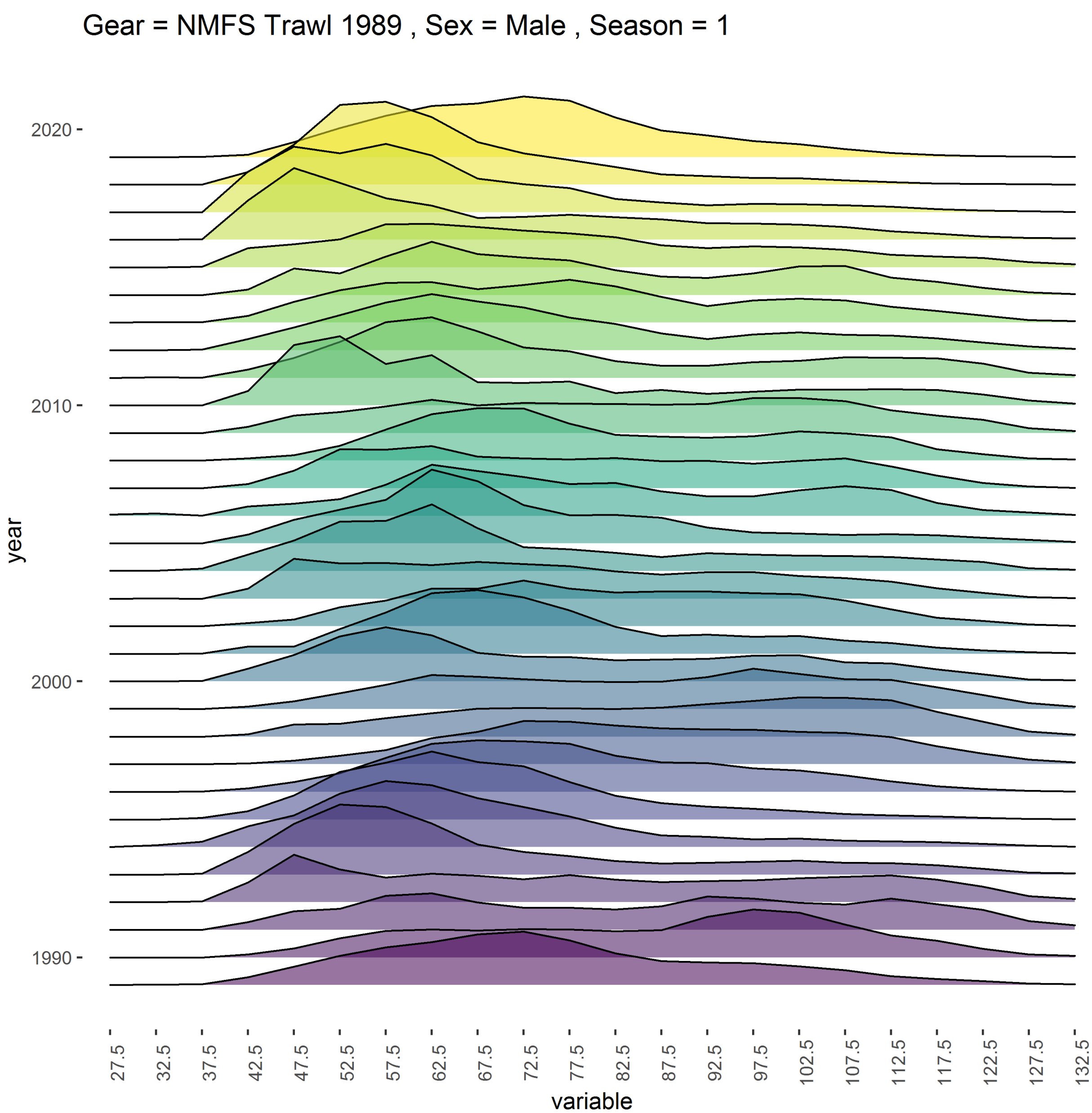

Figure 11: Observed size composition of mature males from th NMFS summer survey.

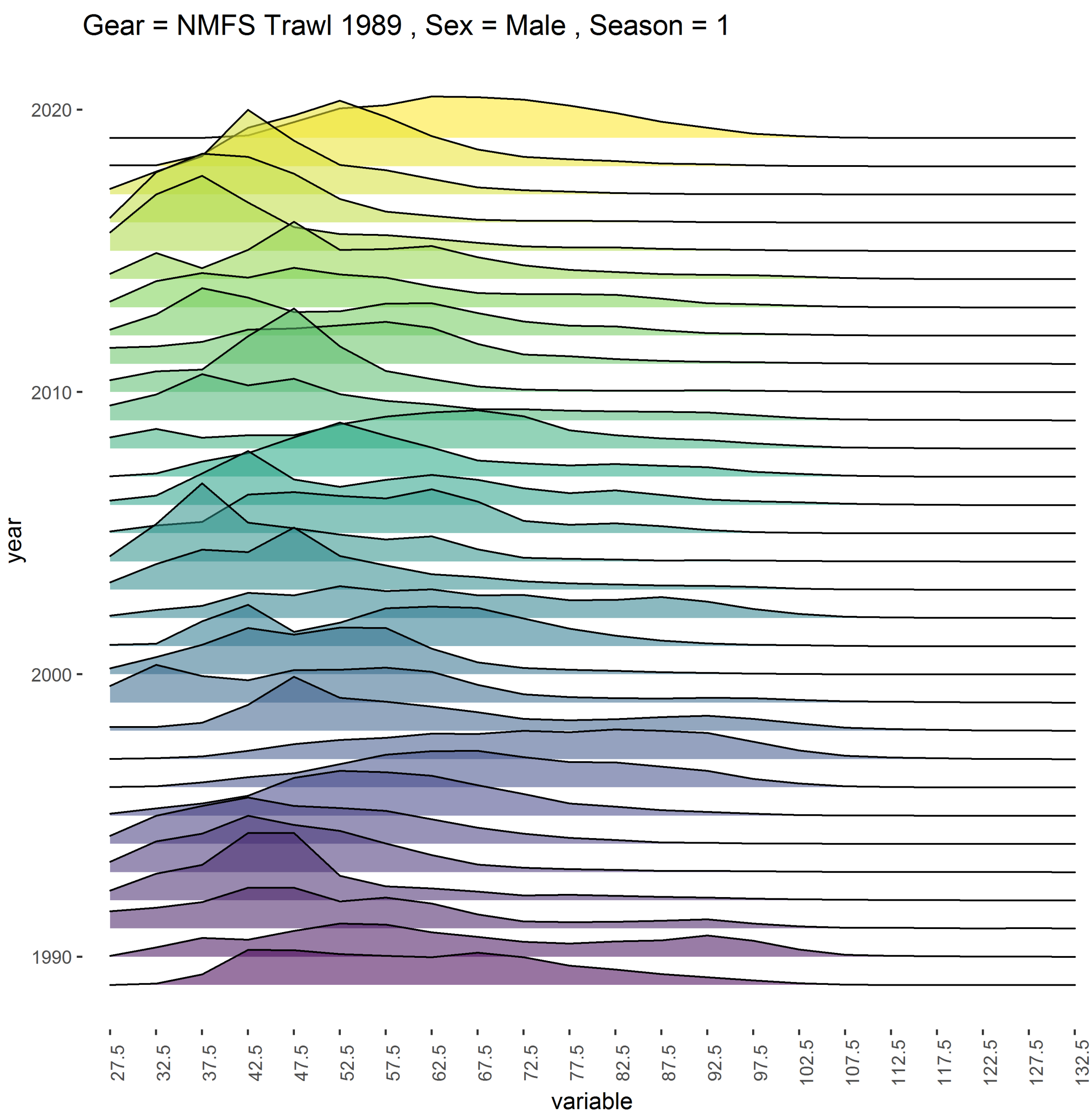

Figure 12: Observed size composition of immature males from th NMFS summer survey.

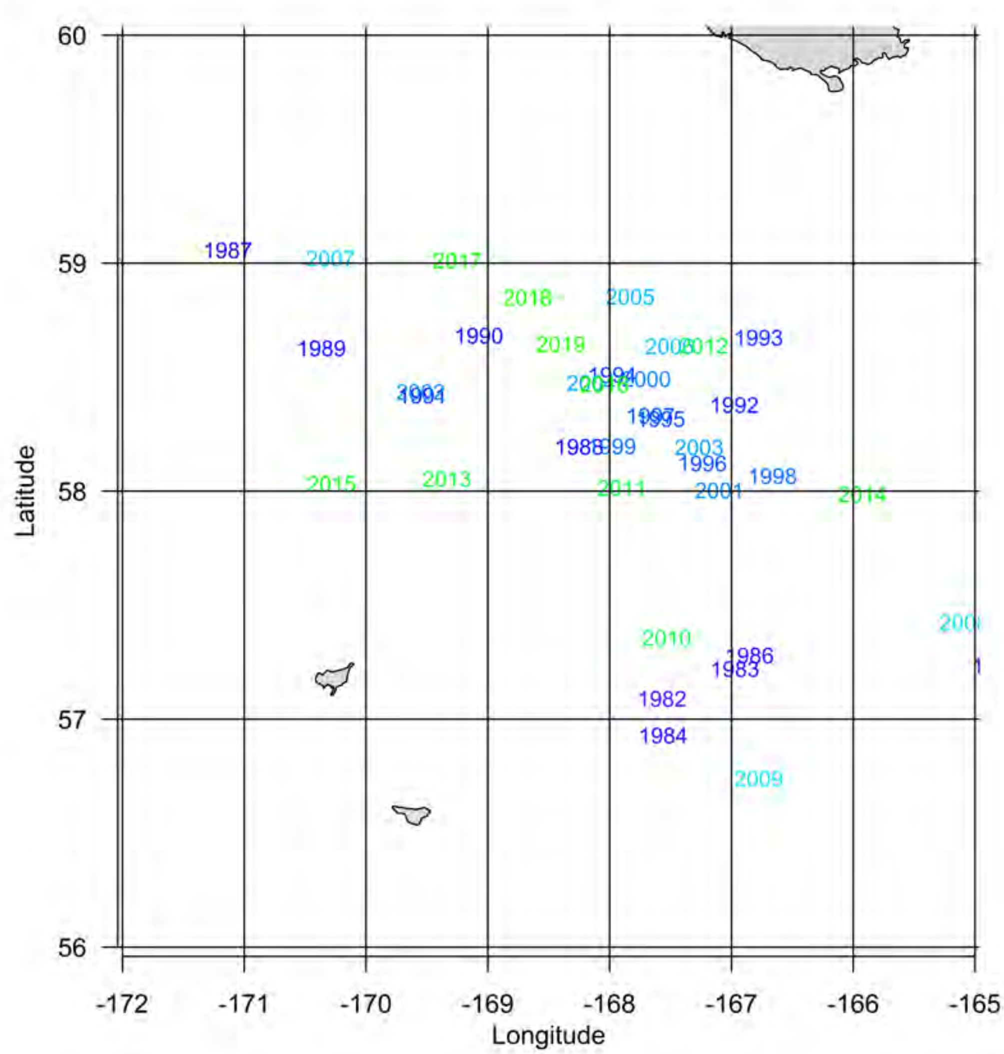

Figure 13: Centroid of mature females observed in the survey over time. Dark blue indicates years early in the time series; green are the most recent years in the time series.

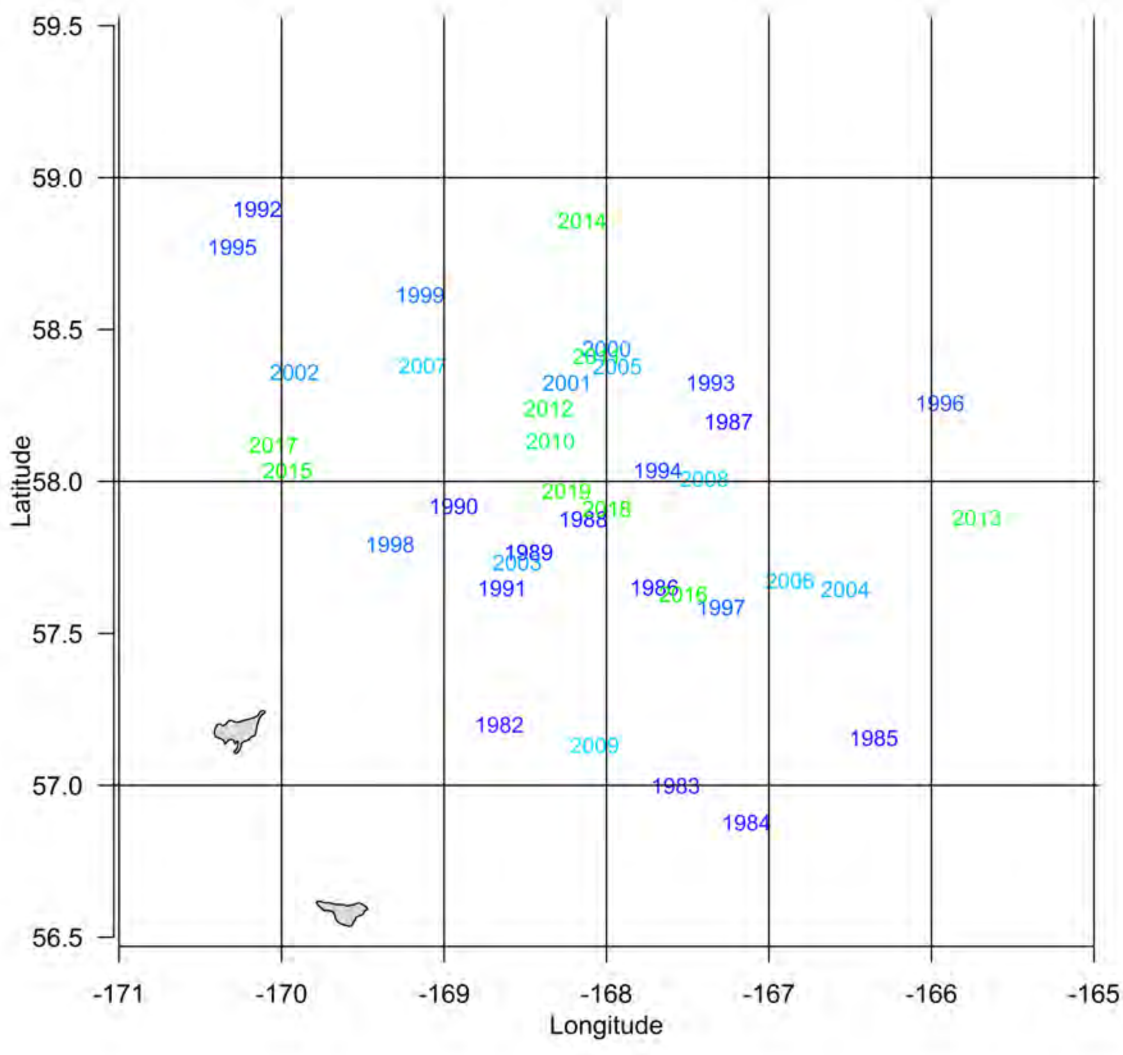

Figure 14: Centroid of large males observed in the survey over time. Dark blue indicates years early in the time series; green are the most recent years in the time series.

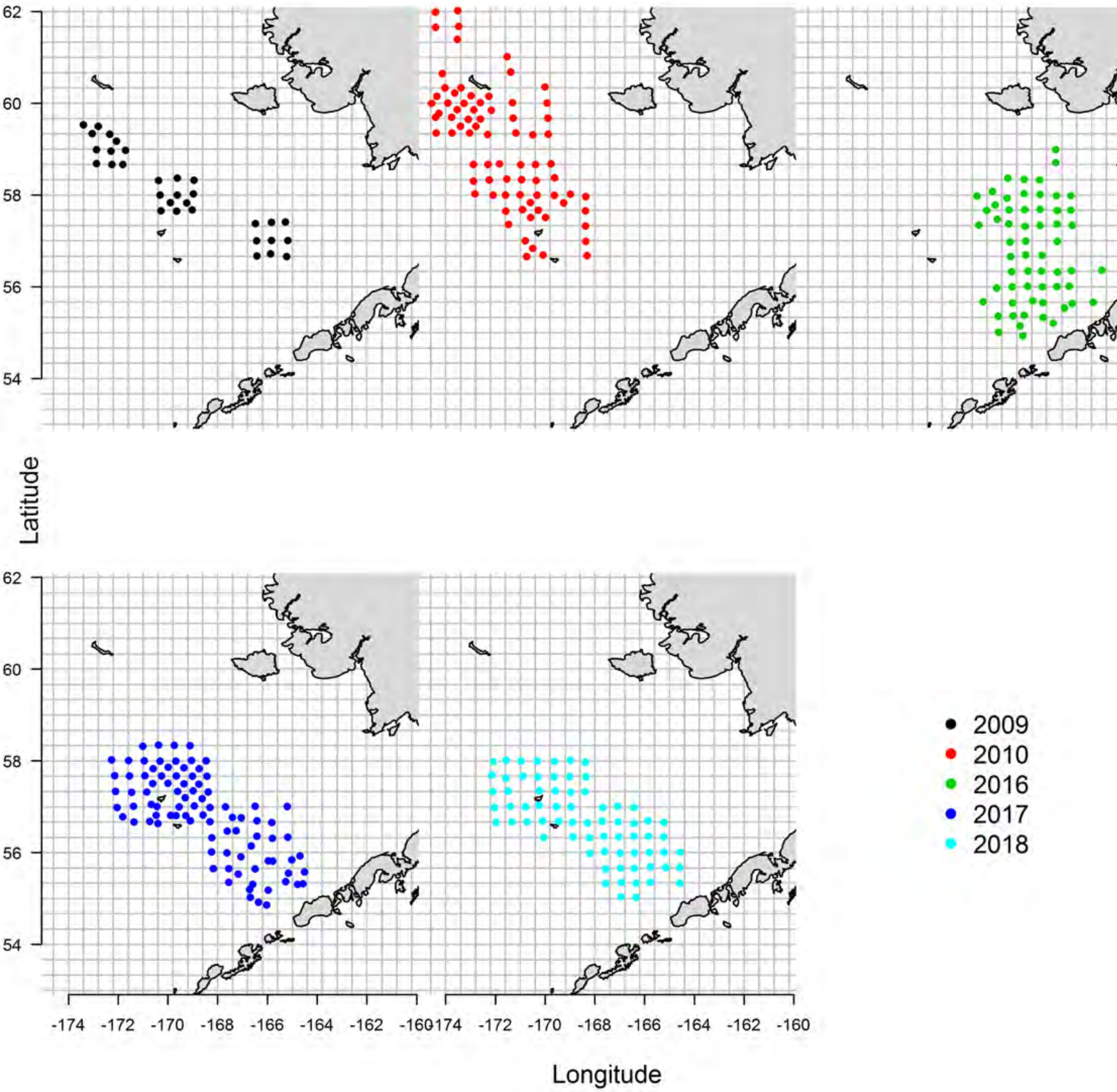

Figure 15: Location of BSFRF survey selectivity experiments.

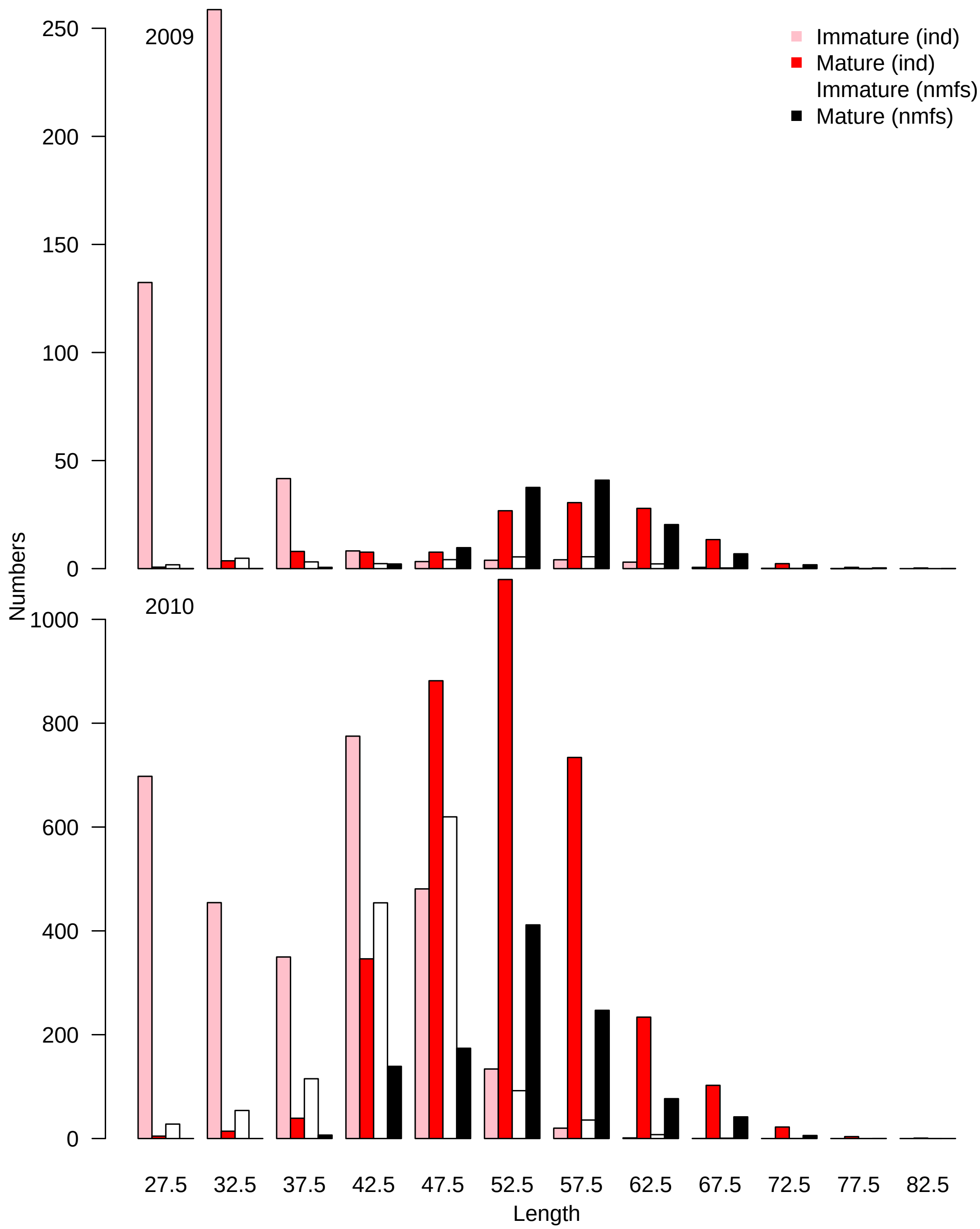

Figure 16: Raw female numbers from BSFRF survey selectivity experiments (2009 & 2010). Note a change in scale on the y-axis from 2009 to 2010

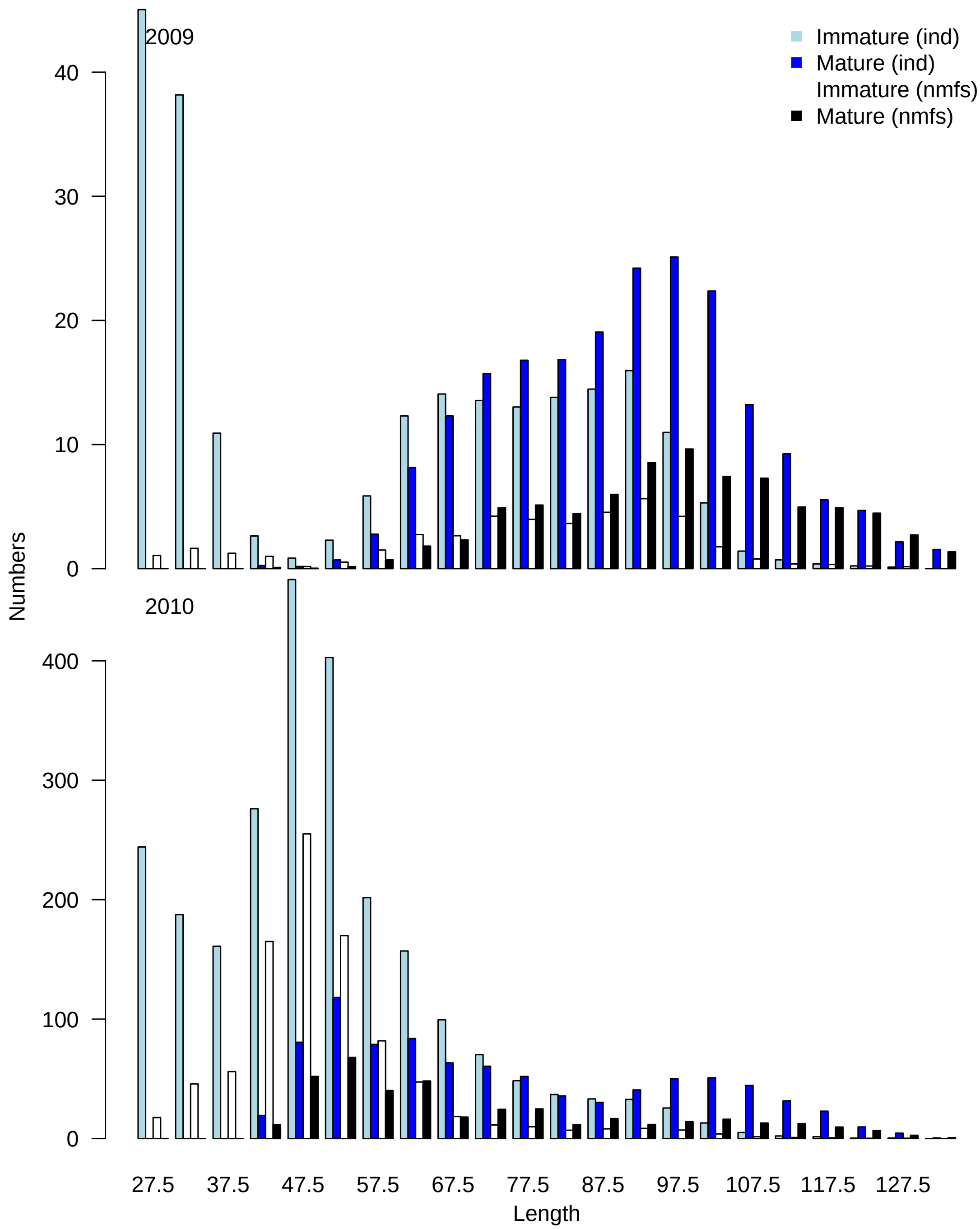

Figure 17: Raw male numbers from BSFRF survey selectivity experiments (2009 & 2010). Note a change in scale from 2009 to 2010 on the y-axis.

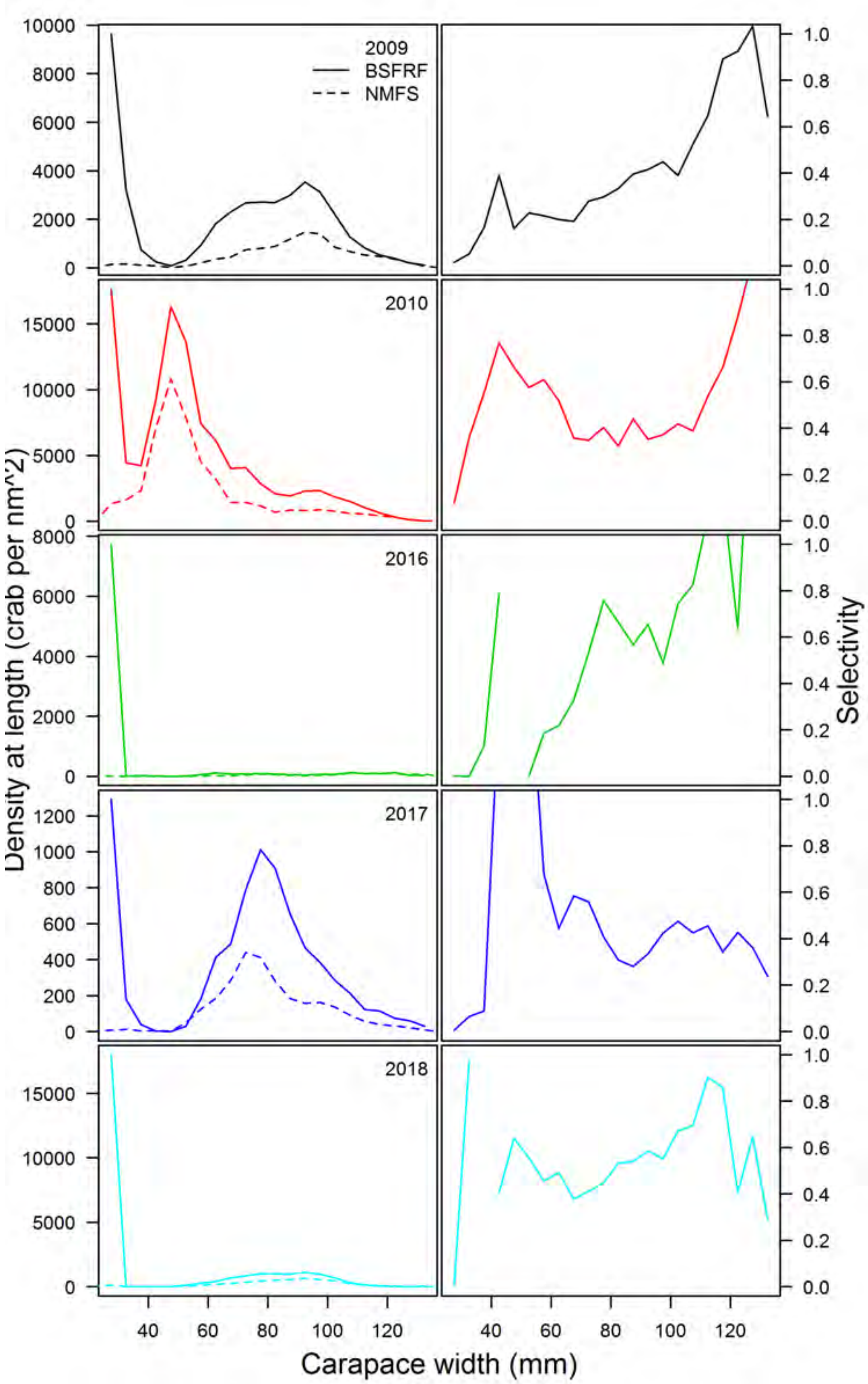

Figure 18: Observed numbers at length extrapolated from length composition data and estimates of total numbers within the survey selectivity experimental areas by year (left). Inferred selectivity (i.e. the ratio of crab at length in the NMFS gear to crab at length in the BSFRF gear.

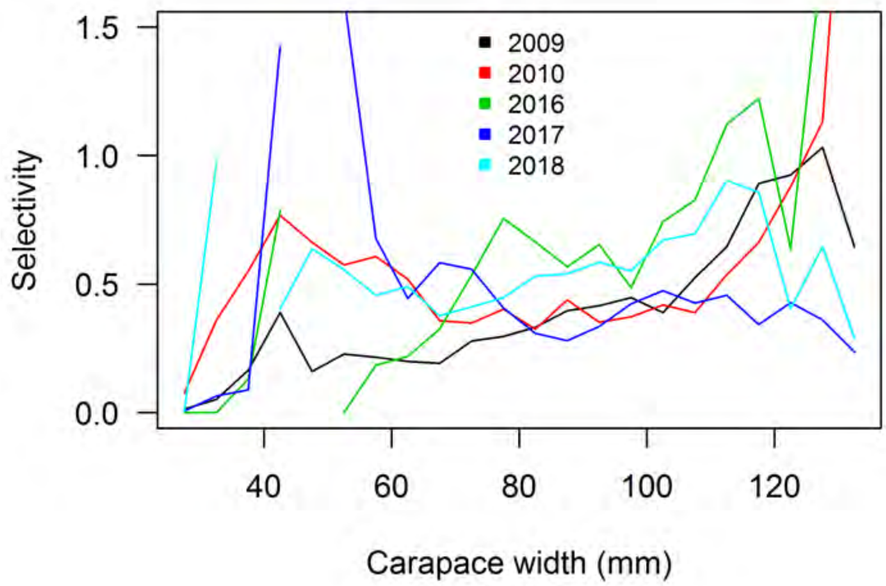

Figure 19: Inferred selectivity for all available years of BSFRF data.

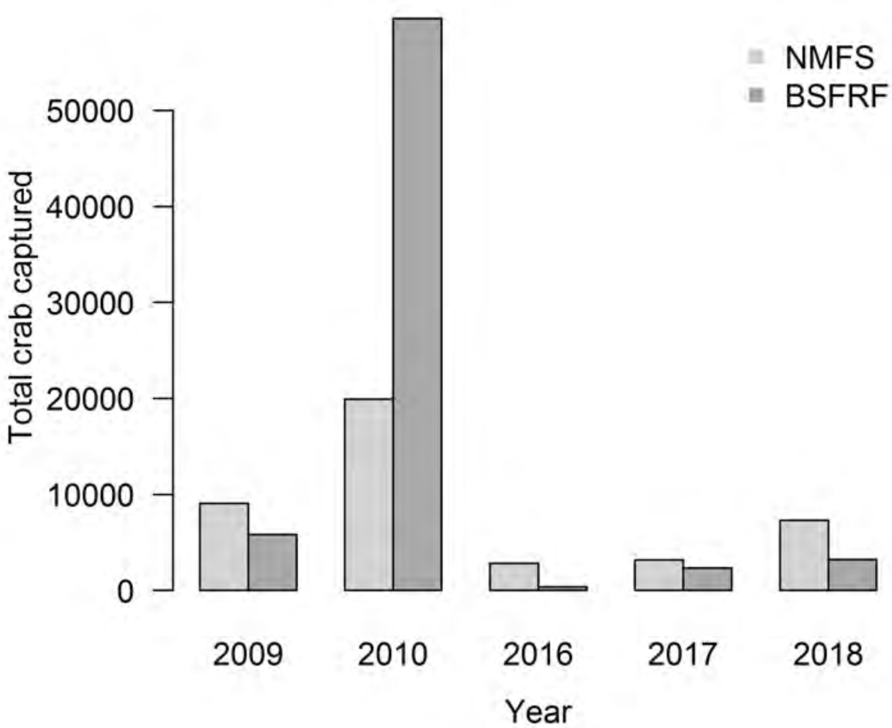

Figure 20: Number of crab from which estimates of biomass and length composition data were inferred within the survey selectivity experimental area.

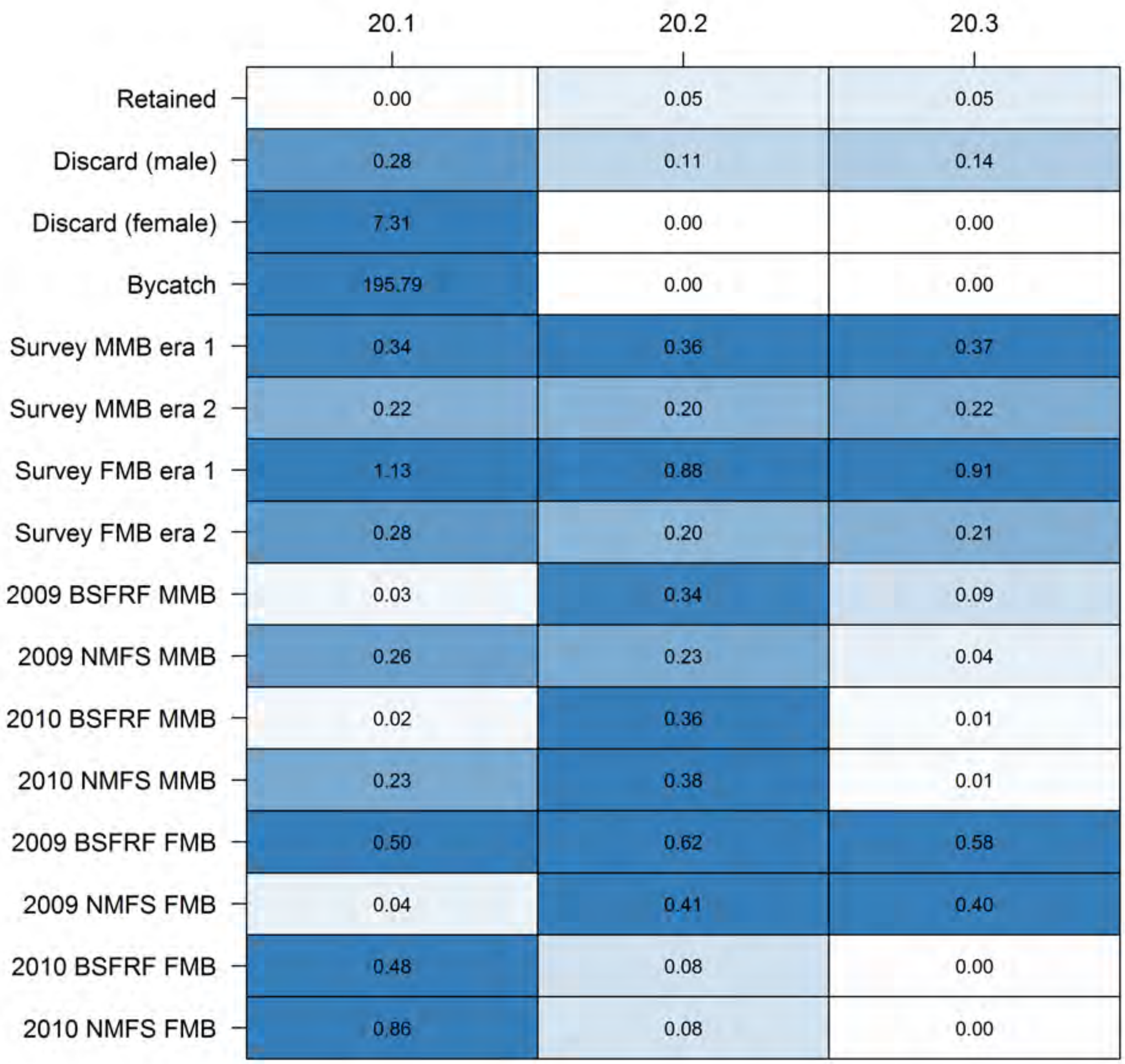

Figure 21: Mean absolute relative error by data type (row) and model (column). A MARE of zero is perfect prediction. Dark colors indicate poorer fits .

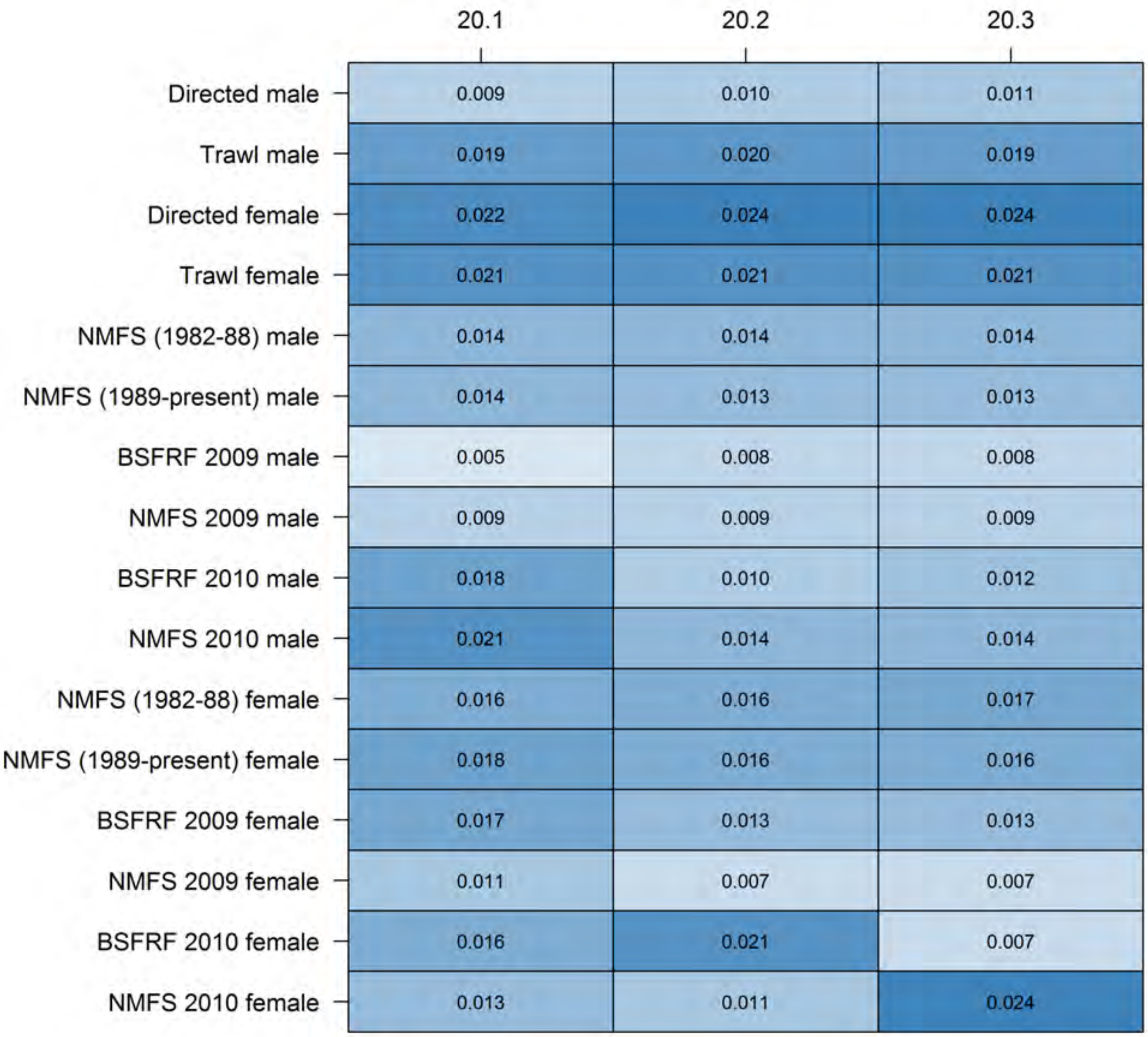

Figure 22: Mean absolute error by data type (row) and model (column). A MAE of zero is perfect prediction. Dark colors indicate poorer fits .

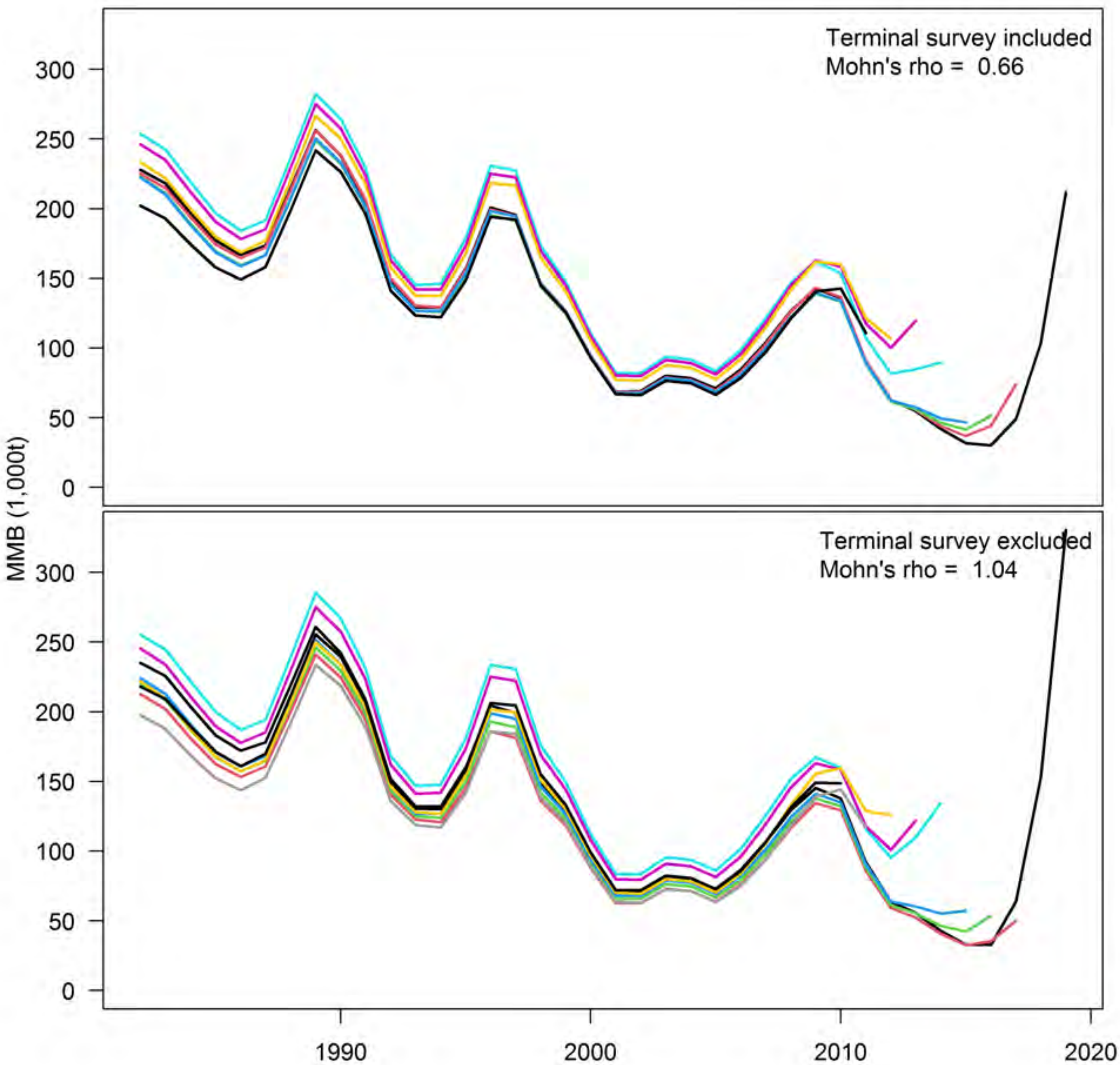

Figure 23: Retrospective analysis of mature male biomass (MMB) for the author's preferred model. Top model represents retrospective analysis including the terminal year of survey data; bottom represents analysis excluding terminal year of survey data

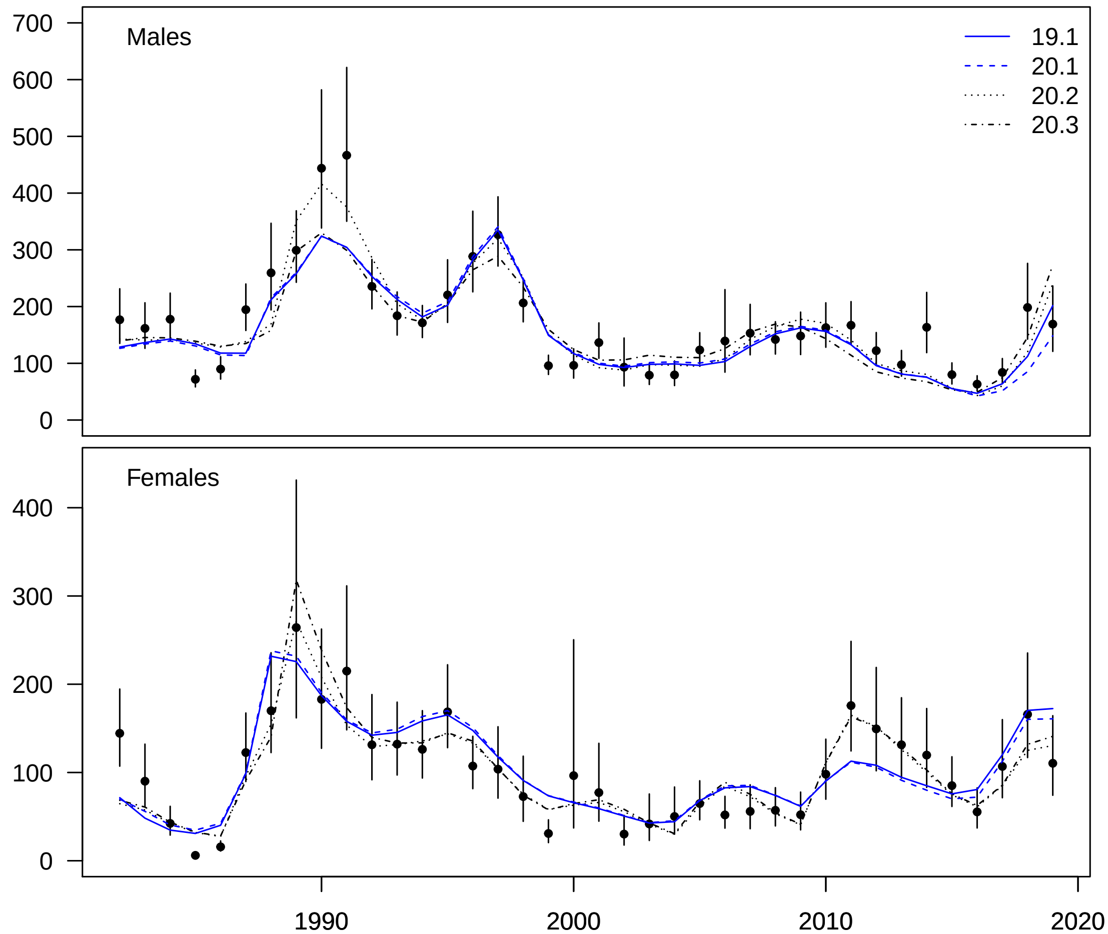

Figure 24: Model fits to the observed mature biomass at survey

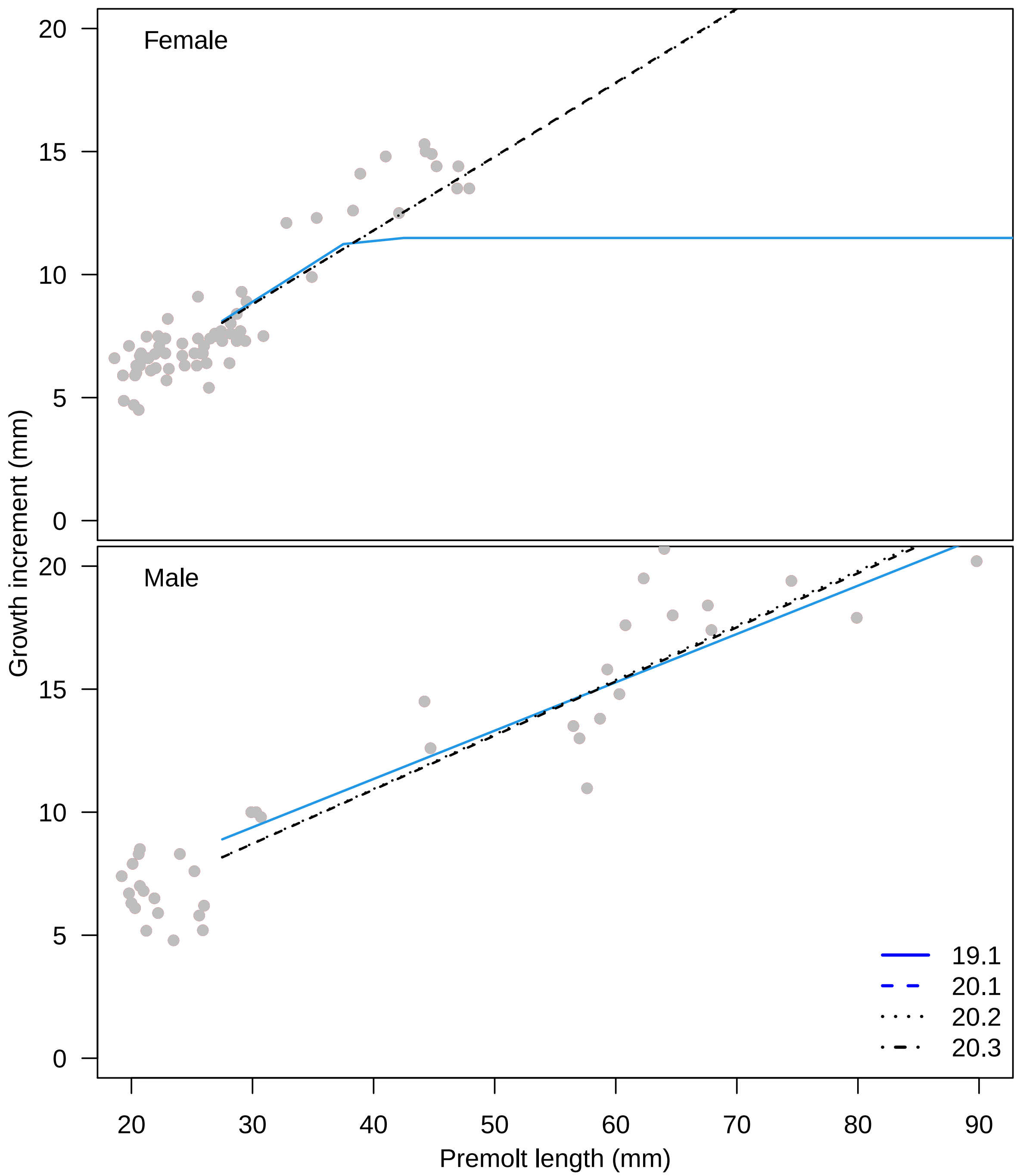

Figure 25: Model fits to the growth data

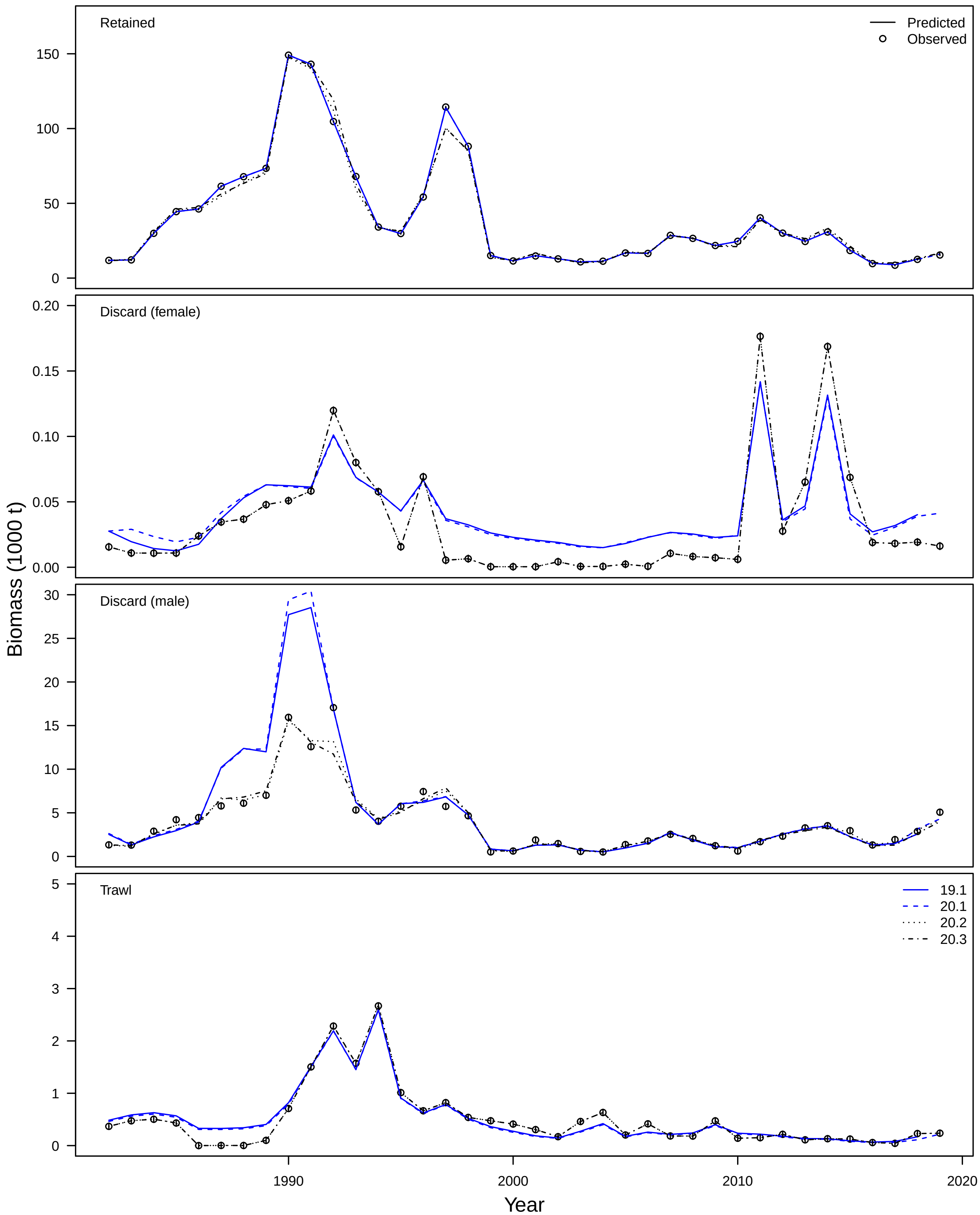

Figure 26: Model fits to catch data

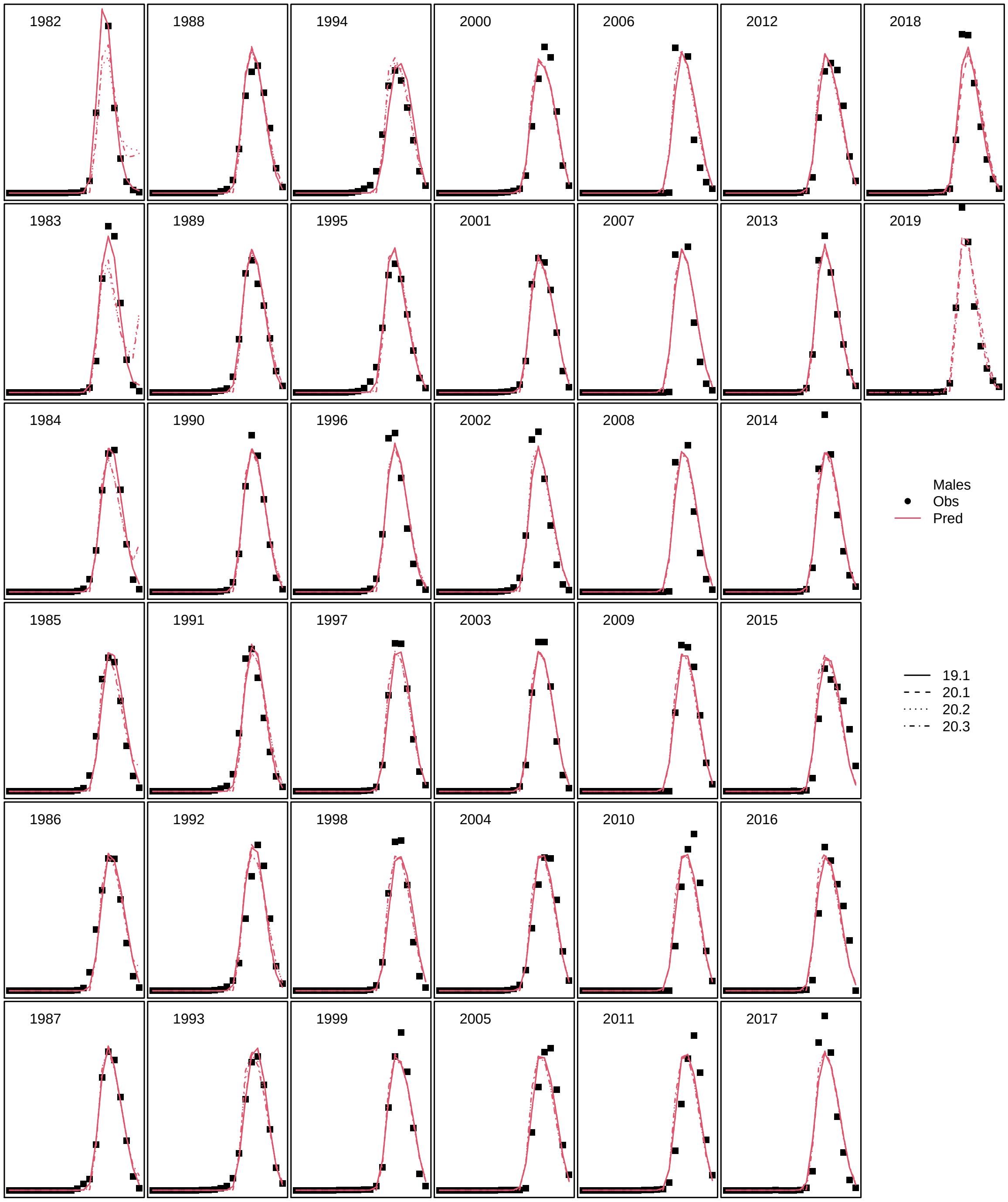

Figure 27: Model fits to retained catch size composition data

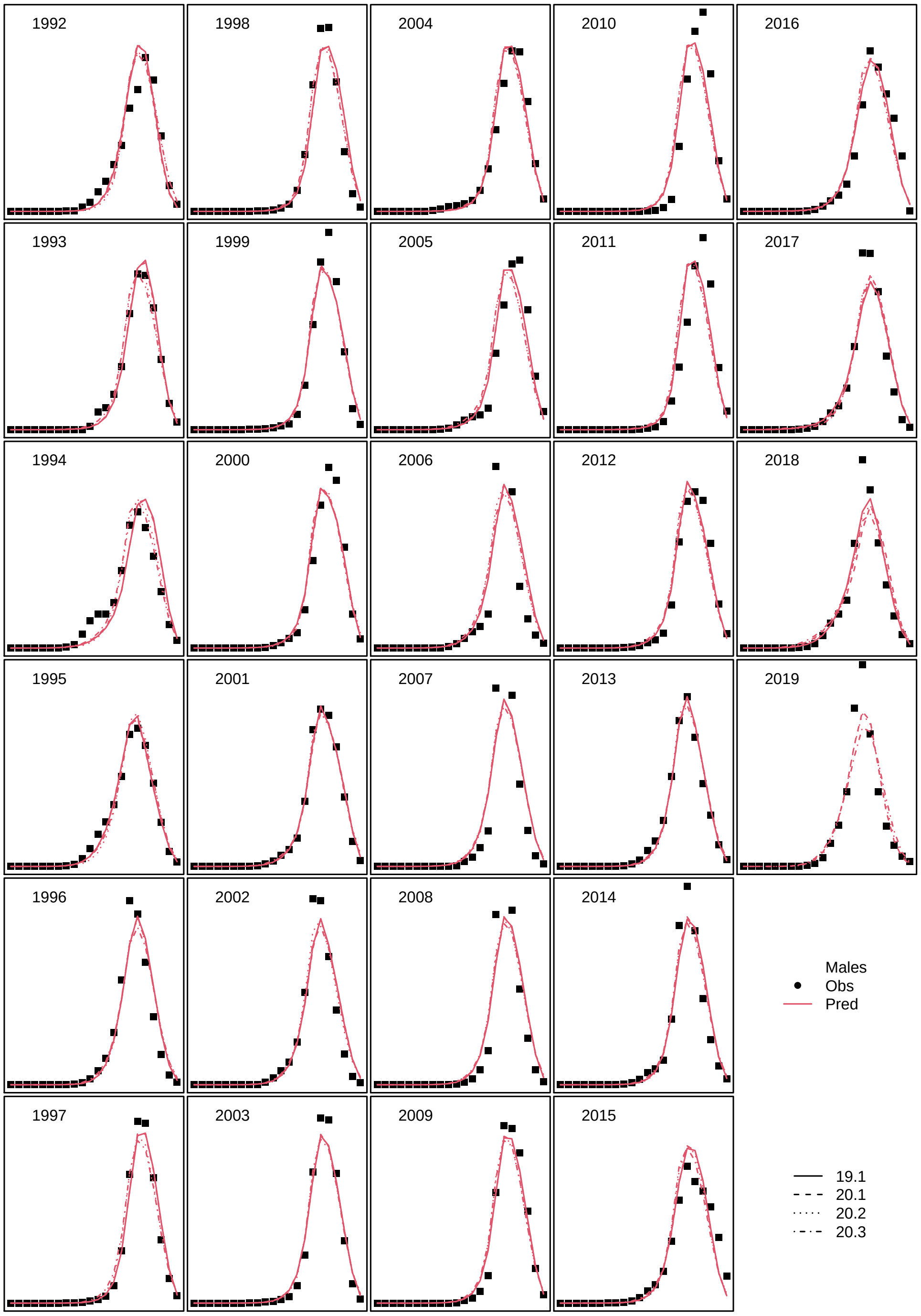

Figure 28: Model fits to total catch size composition data

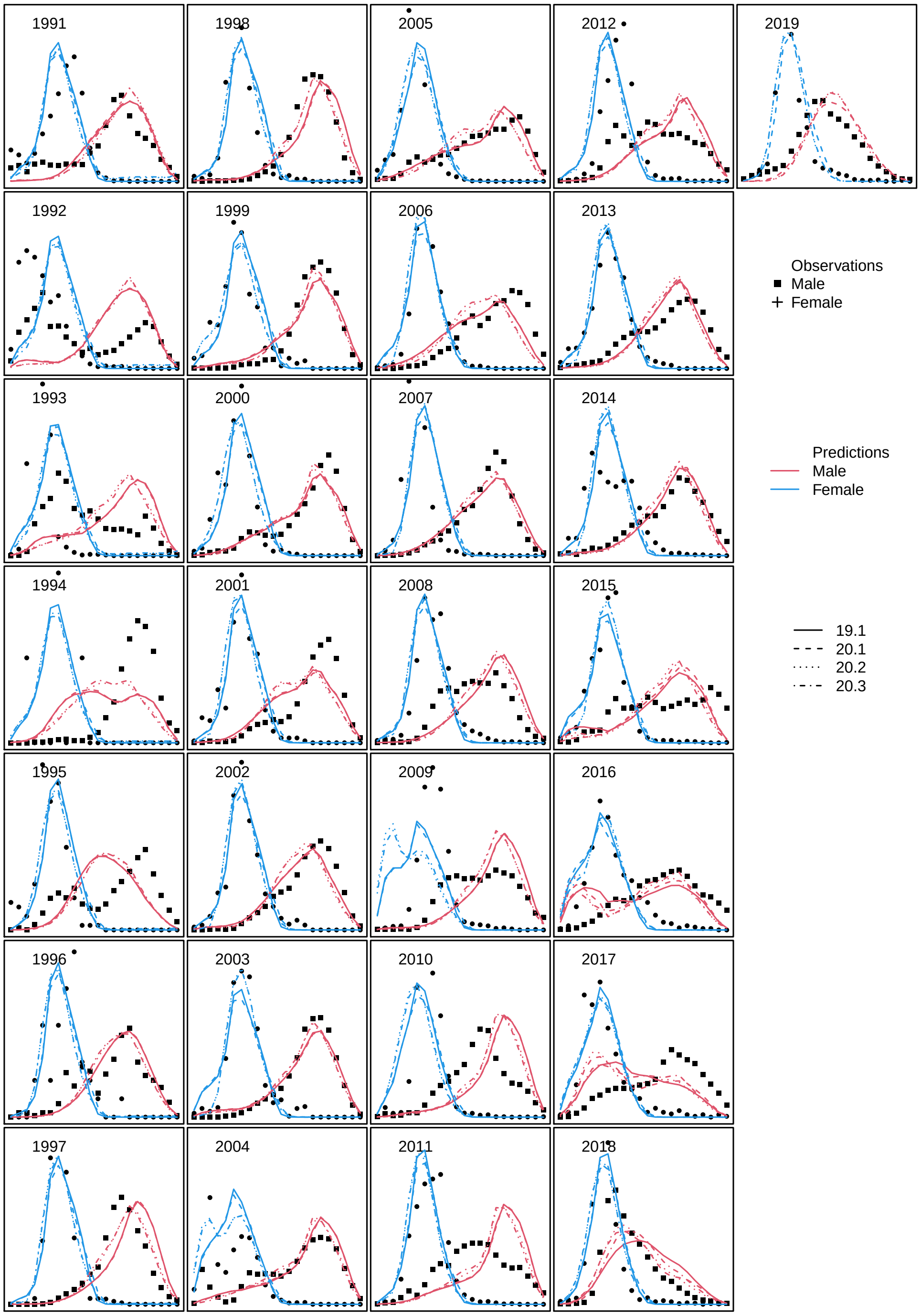

Figure 29: Model fits to trawl catch size composition data

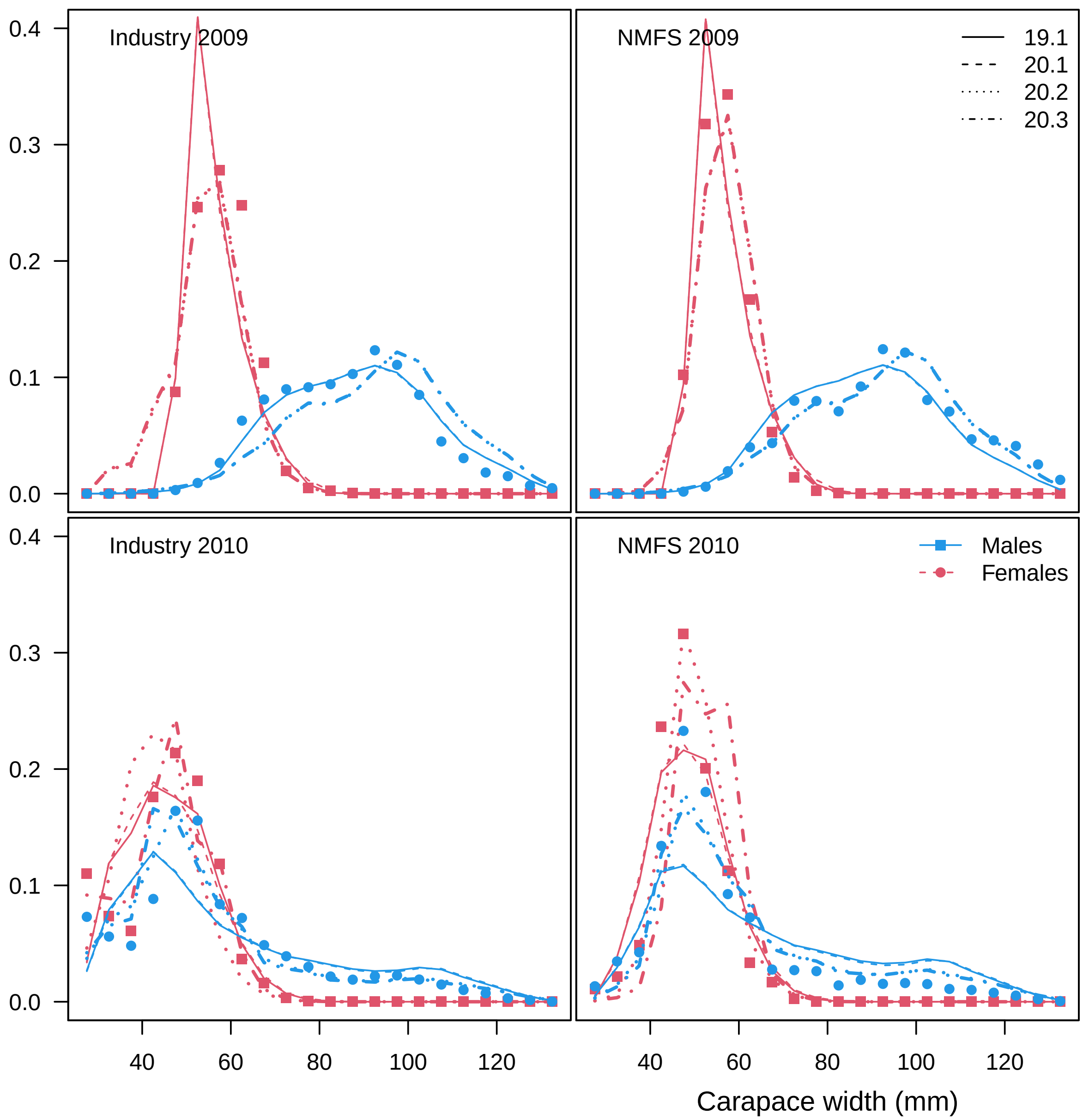

Figure 30: Model fits to size composition data from summer survey experiments (2009 & 2010)

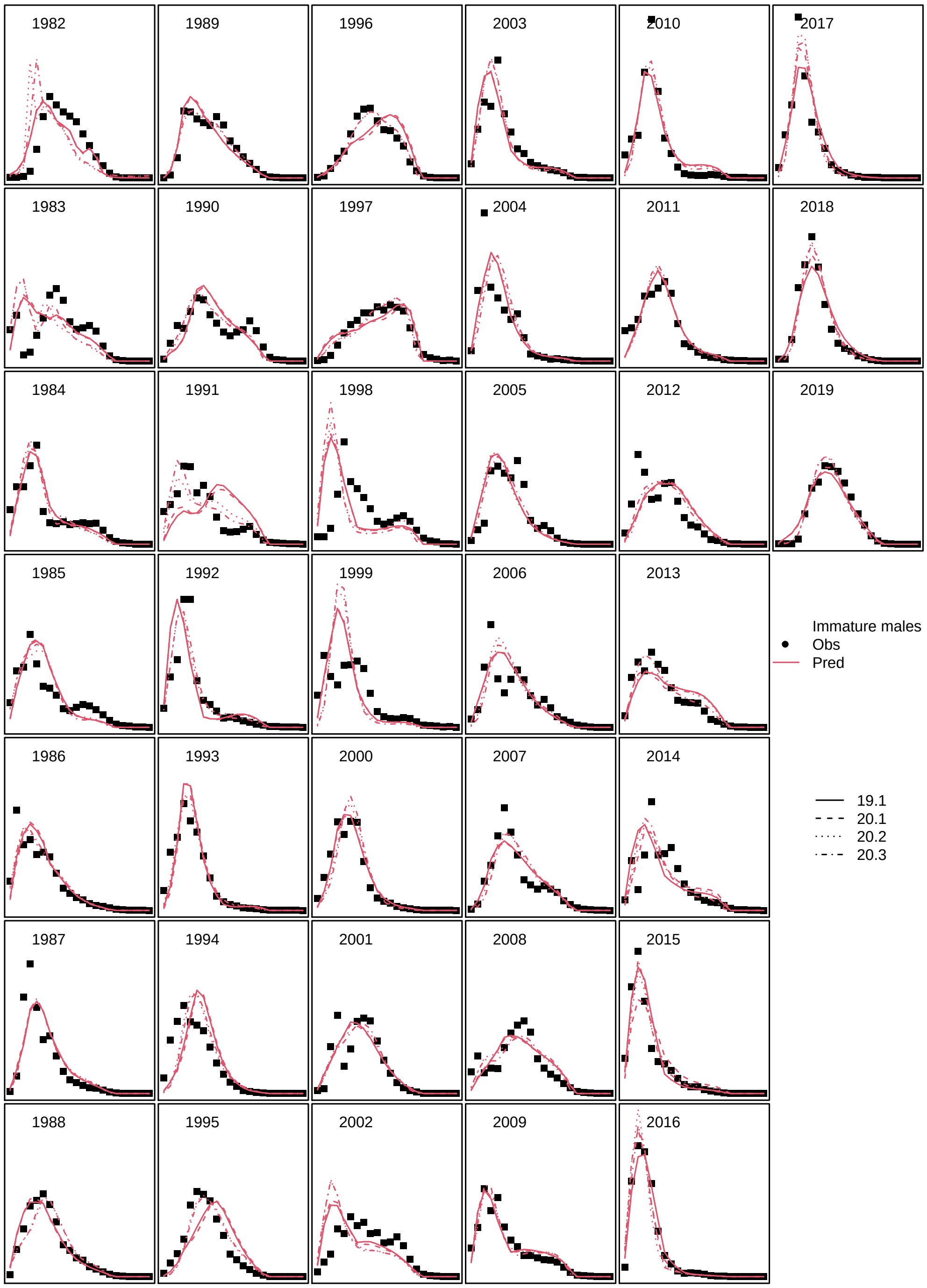

Figure 31: Model fits to immature male survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

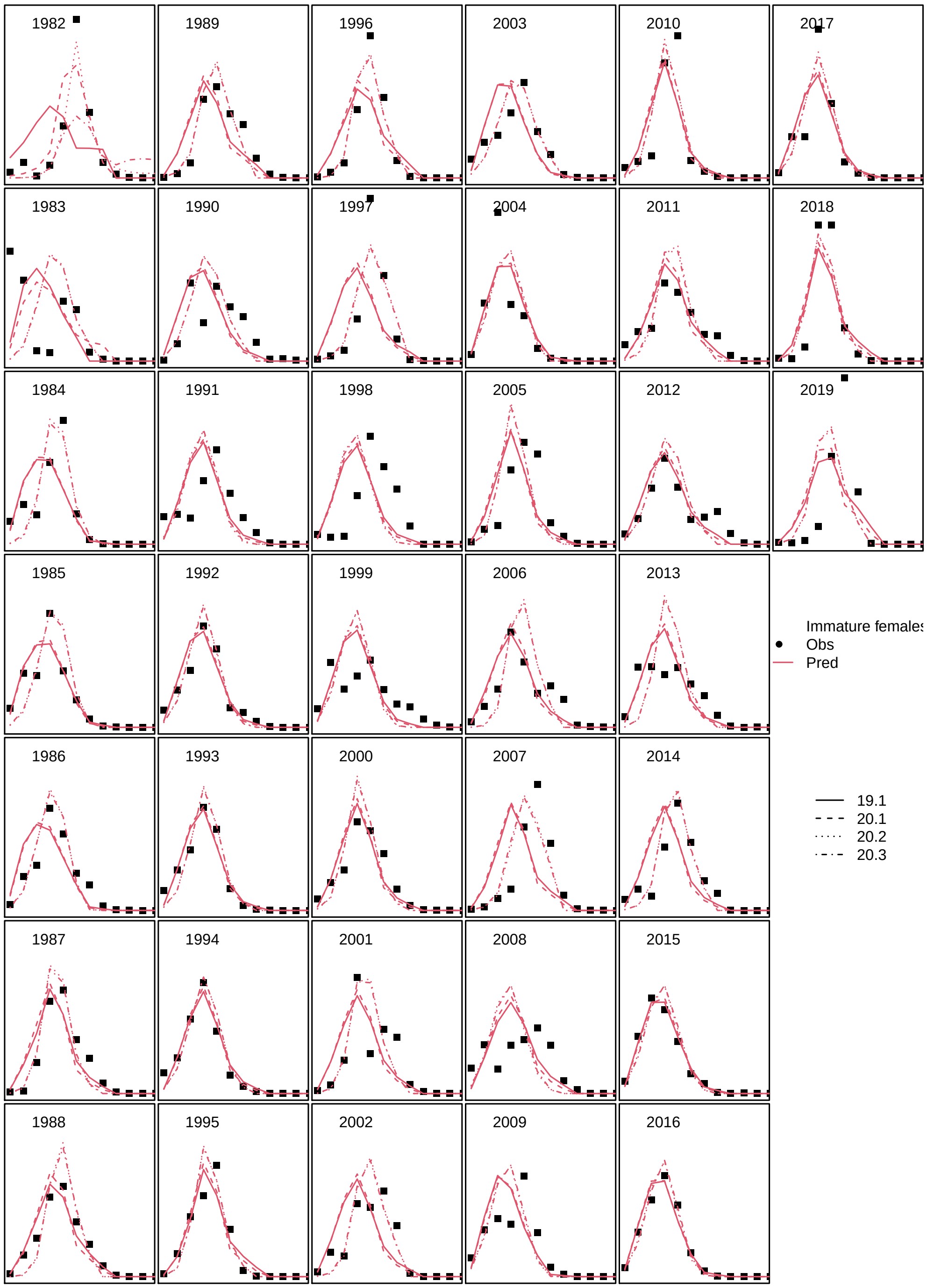

Figure 32: Model fits to immature female survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

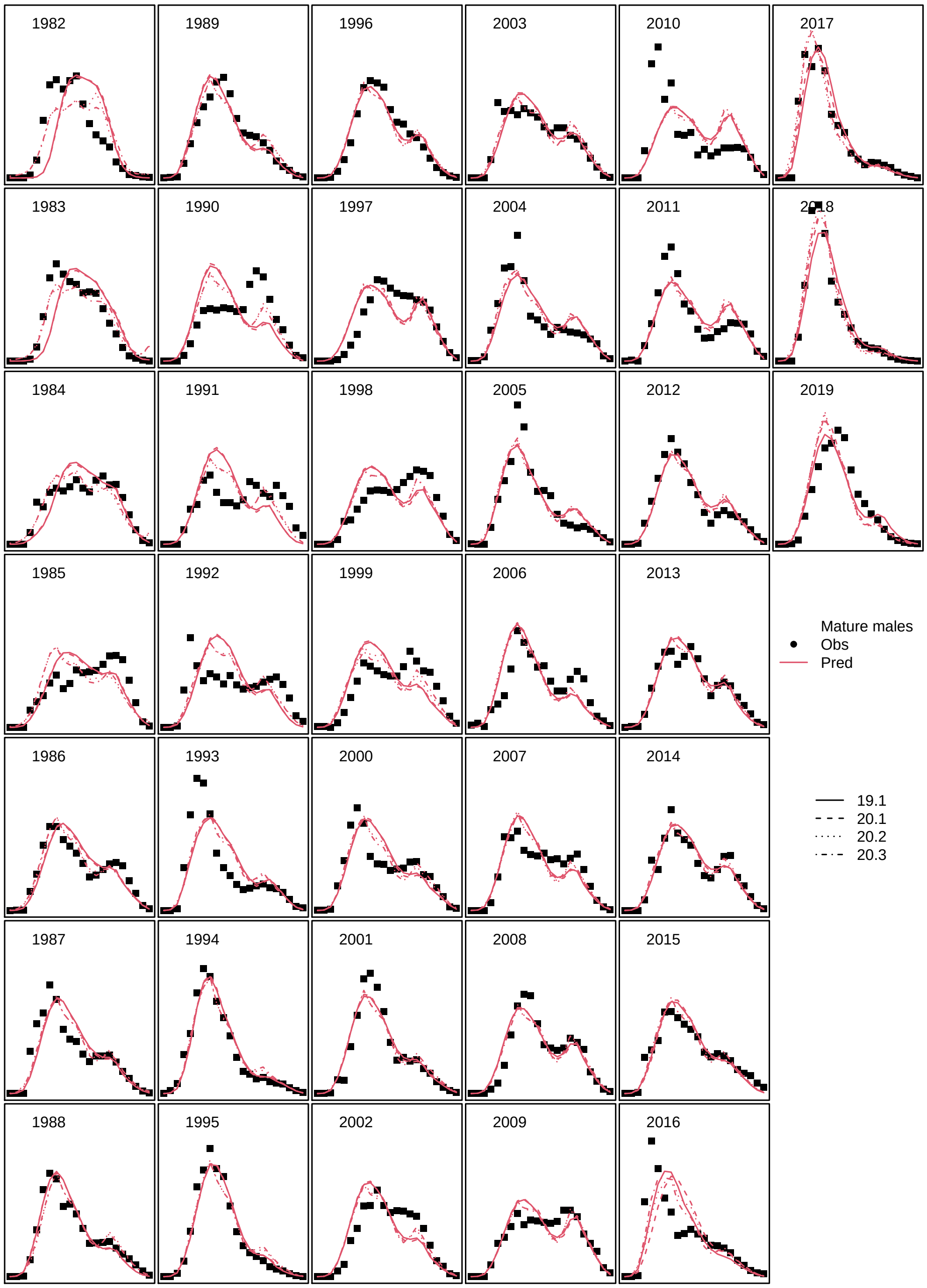

Figure 33: Model fits to mature male survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

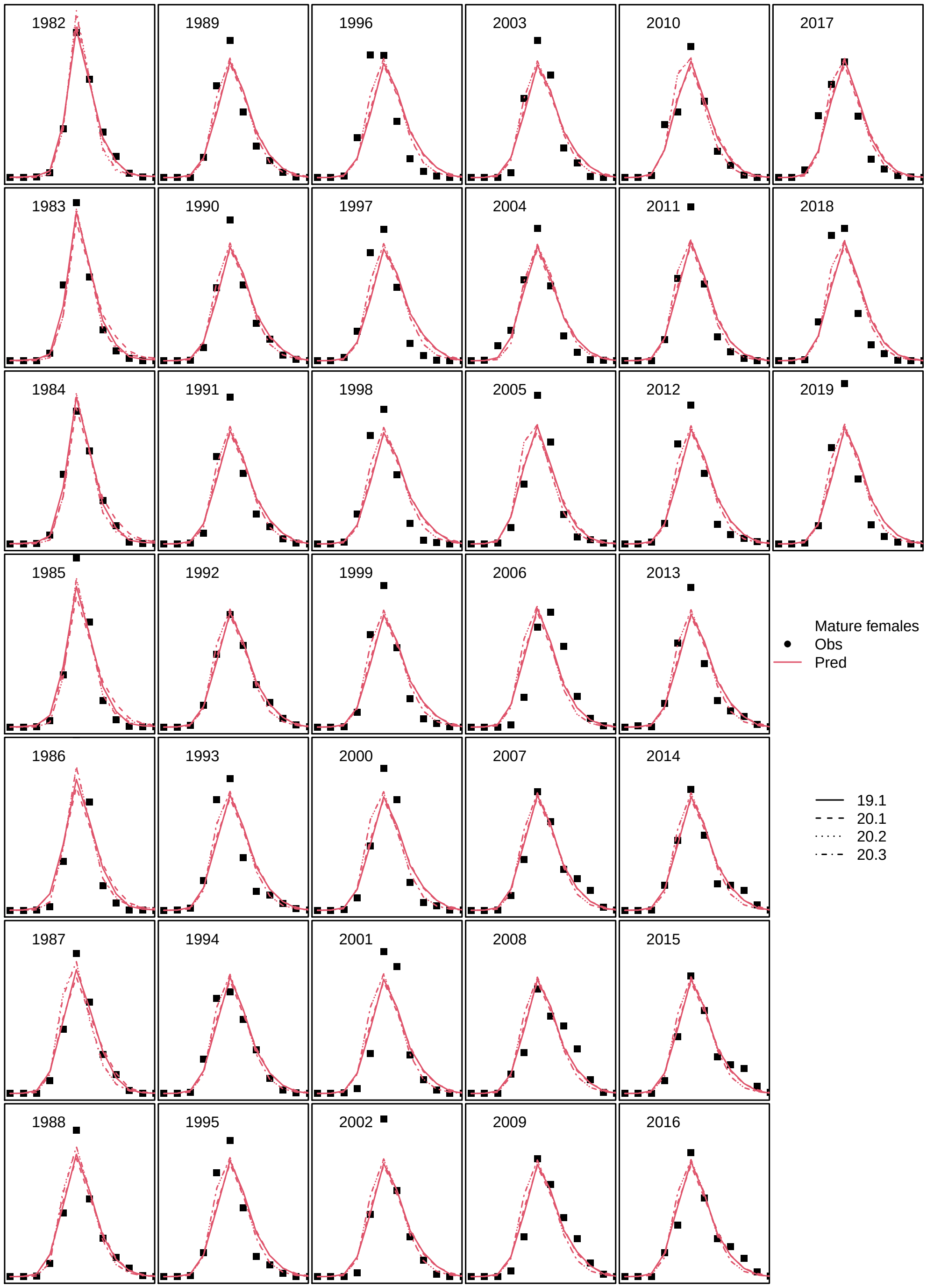

Figure 34: Model fits to mature female survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

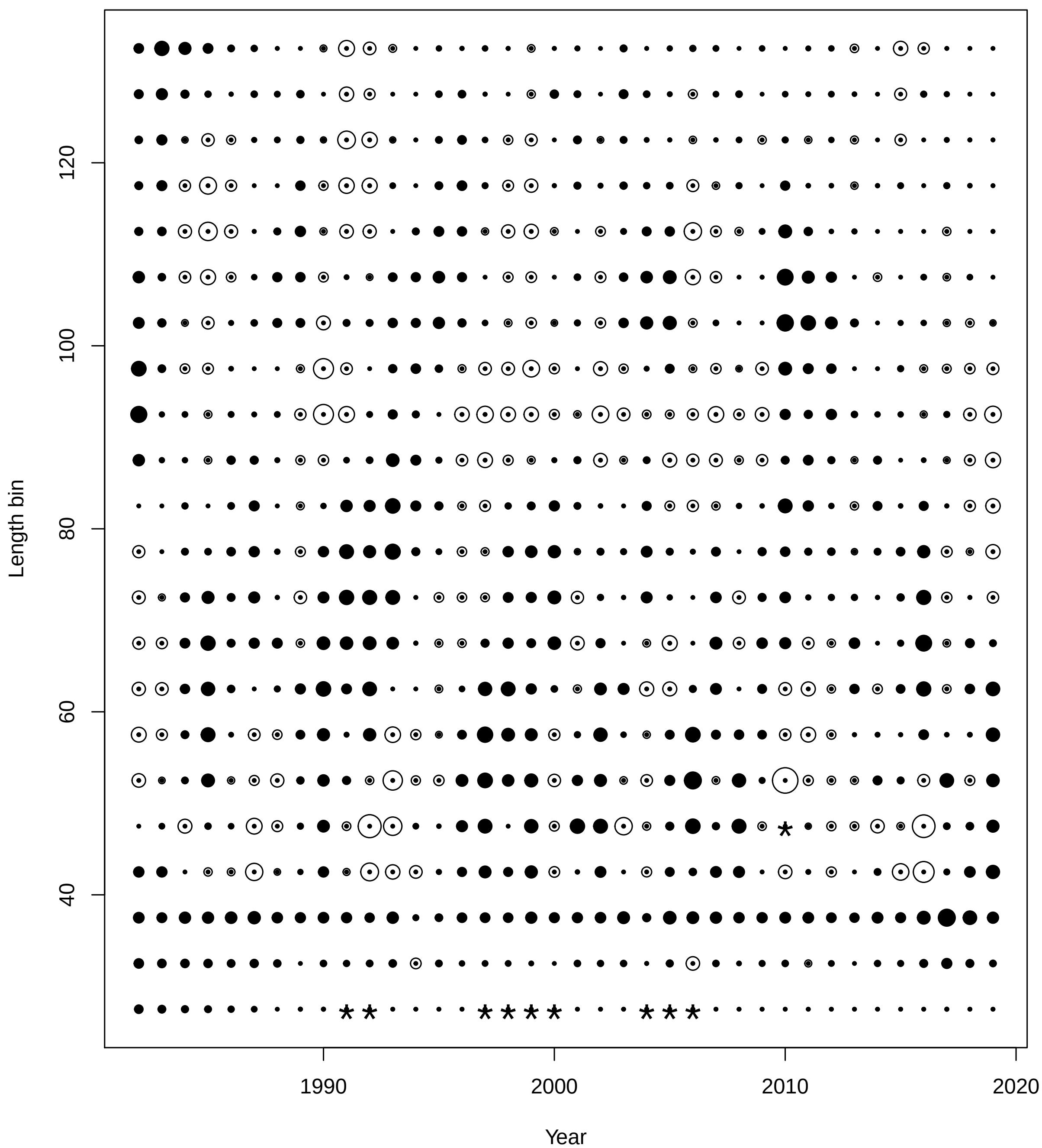

Figure 35: Residual bubble plot of the fits to the NMFS mature male for the authors chosen model. Open circles represent positive residuals; close circles represent negative residuals.

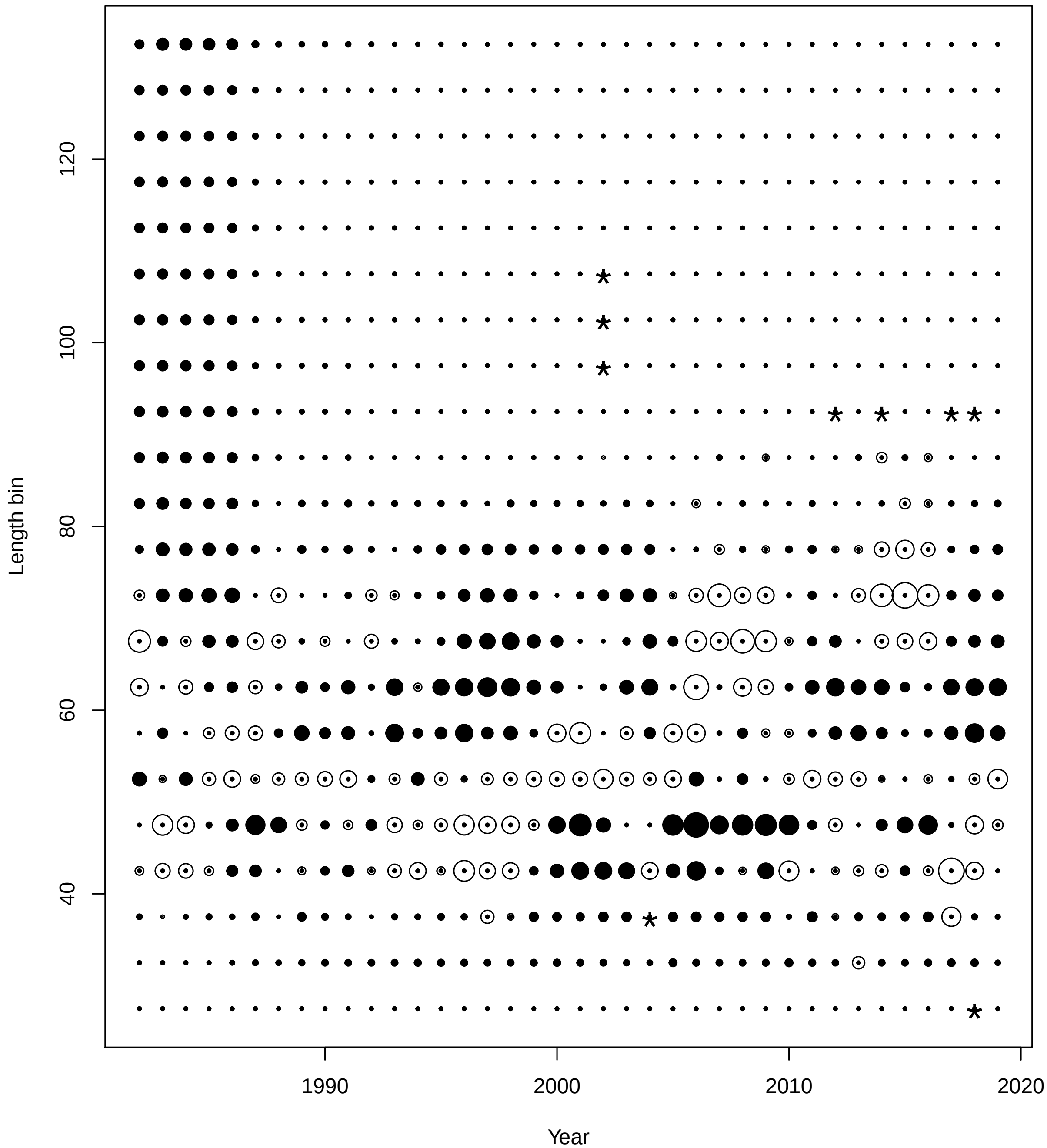

Figure 36: Residual bubble plot of the fits to the NMFS mature female for the authors chosen model. Open circles represent positive residuals; close circles represent negative residuals.

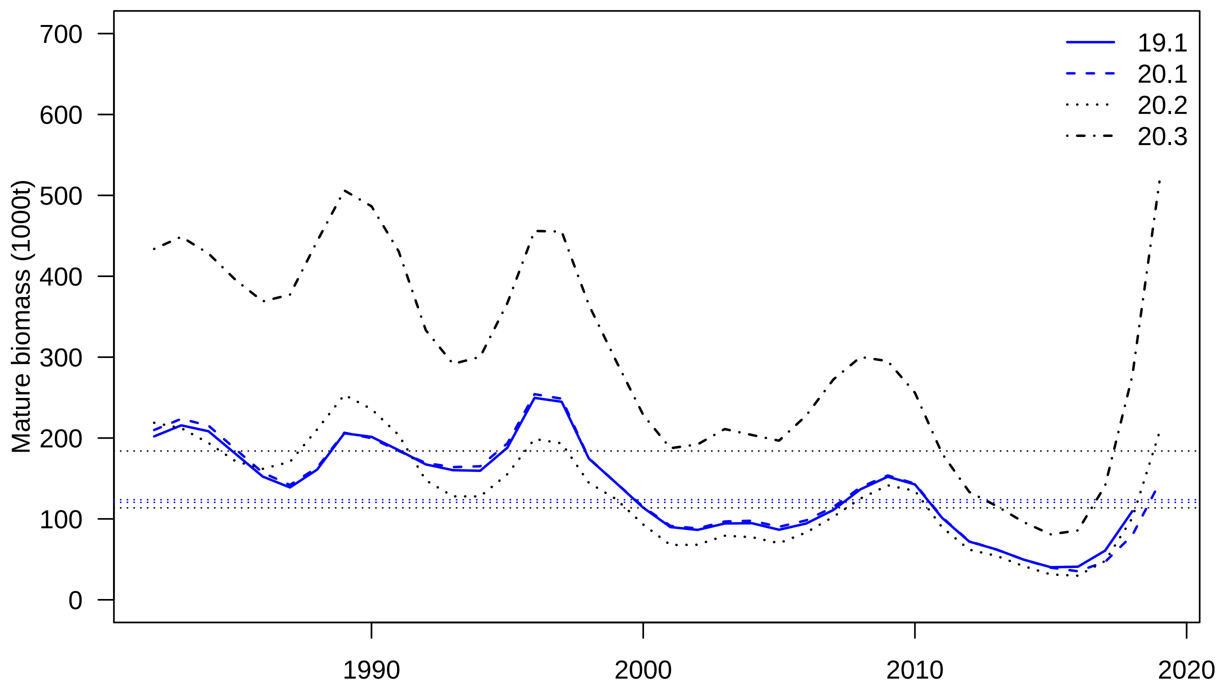

Figure 37: Model predicted mature biomass at mating time. Dotted horizontal lines are target biomasses.

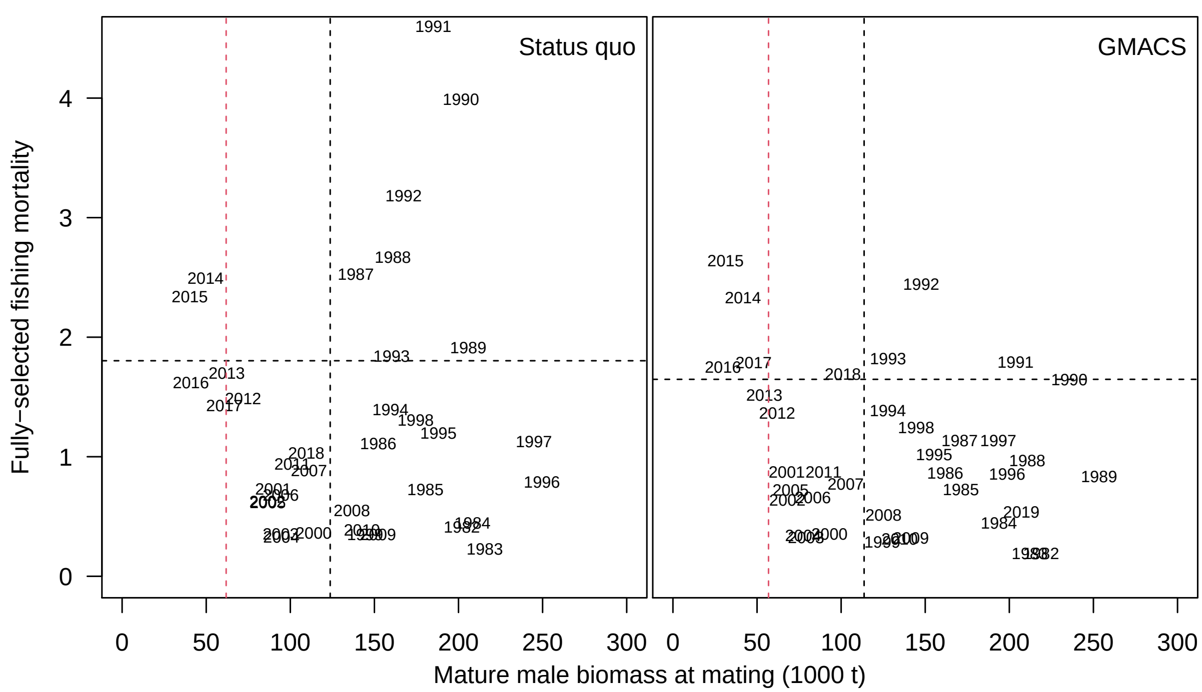

Figure 38: Kobe plot for the author's preferred model. Vertical dashed black line represents the MLE value for B35; Vertical dashed red line represents the overfished level, horizontal dashed black line represents F35

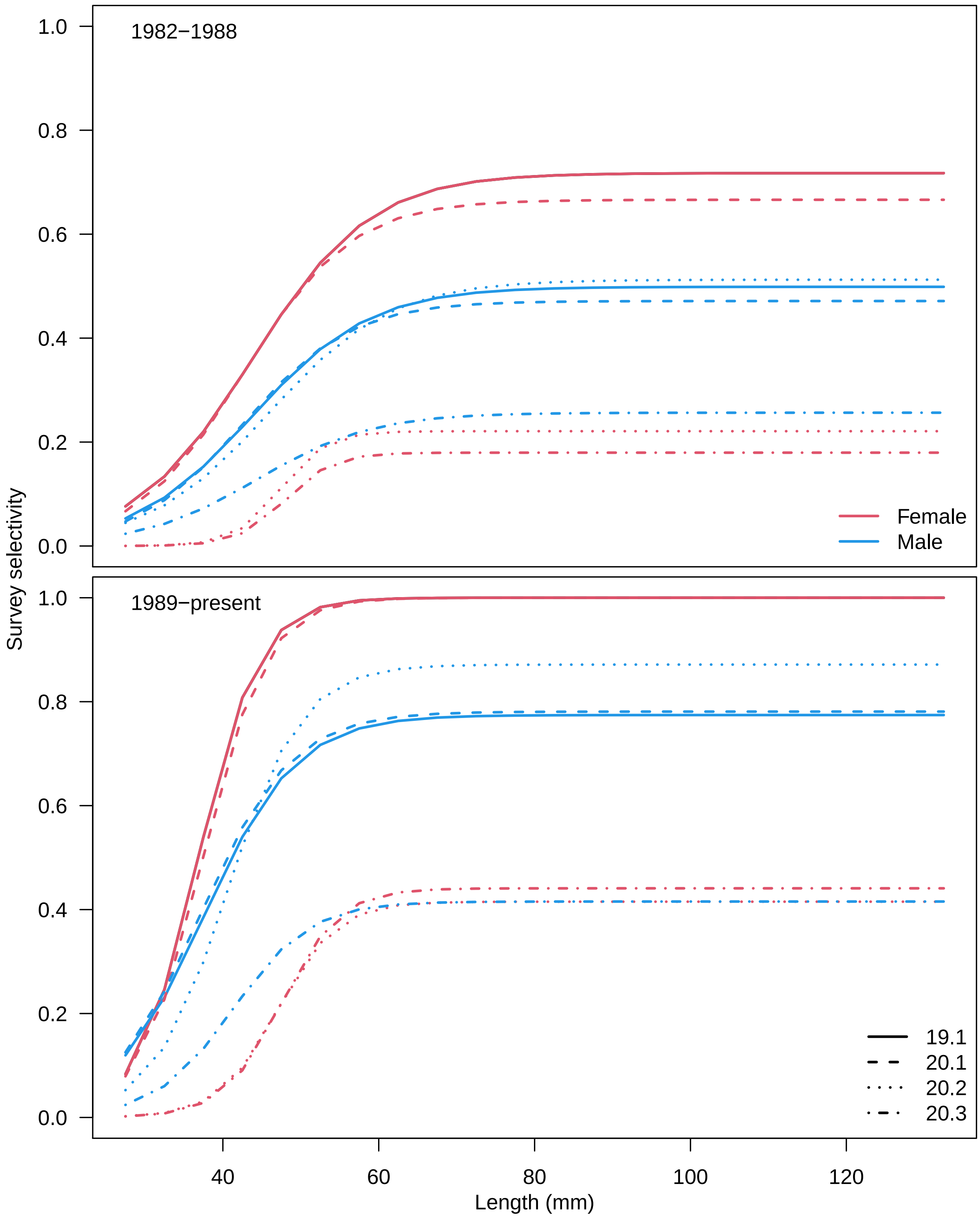

Figure 39: Estimated survey selectivity

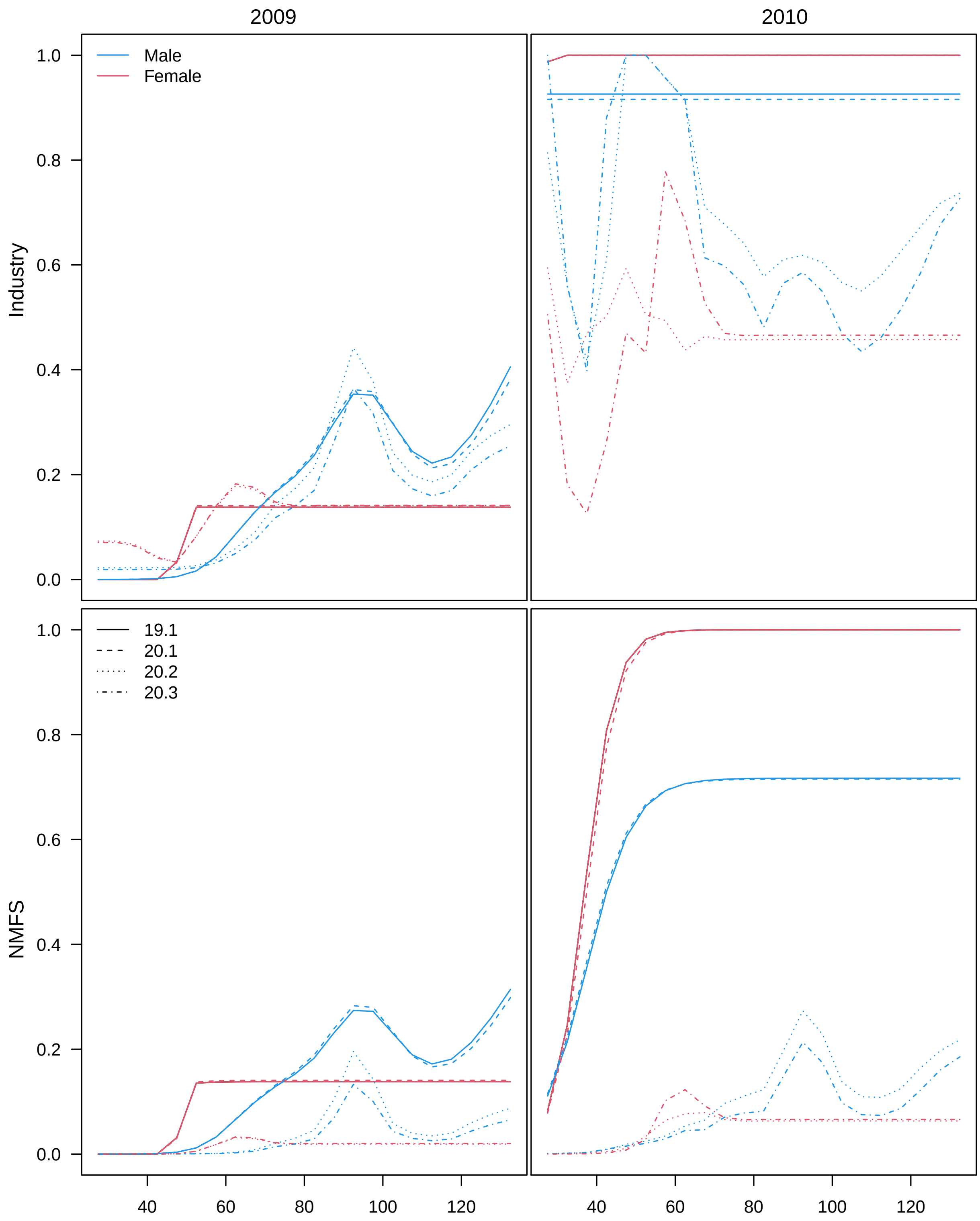

Figure 40: Estimated experimental survey selectivity (availability * survey selectivity)

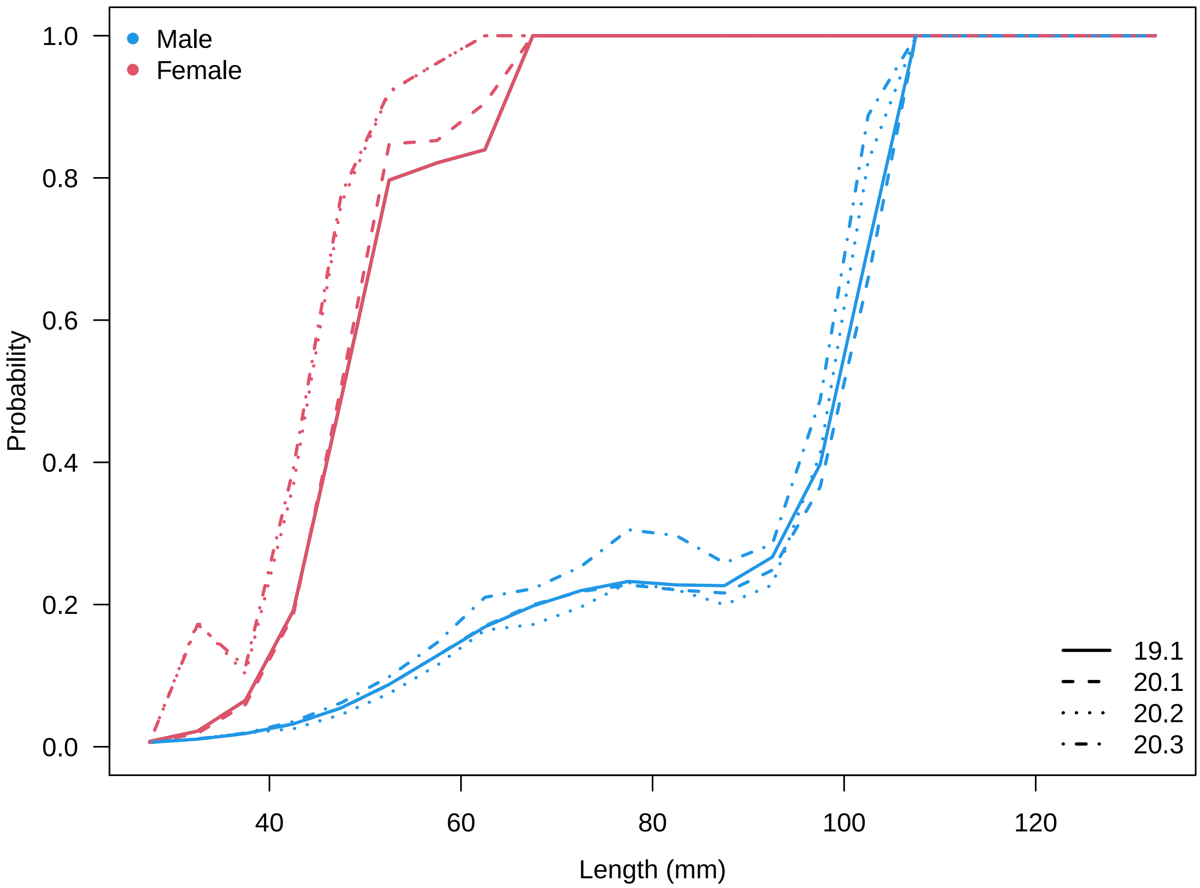

Figure 41: Estimated probability of maturing

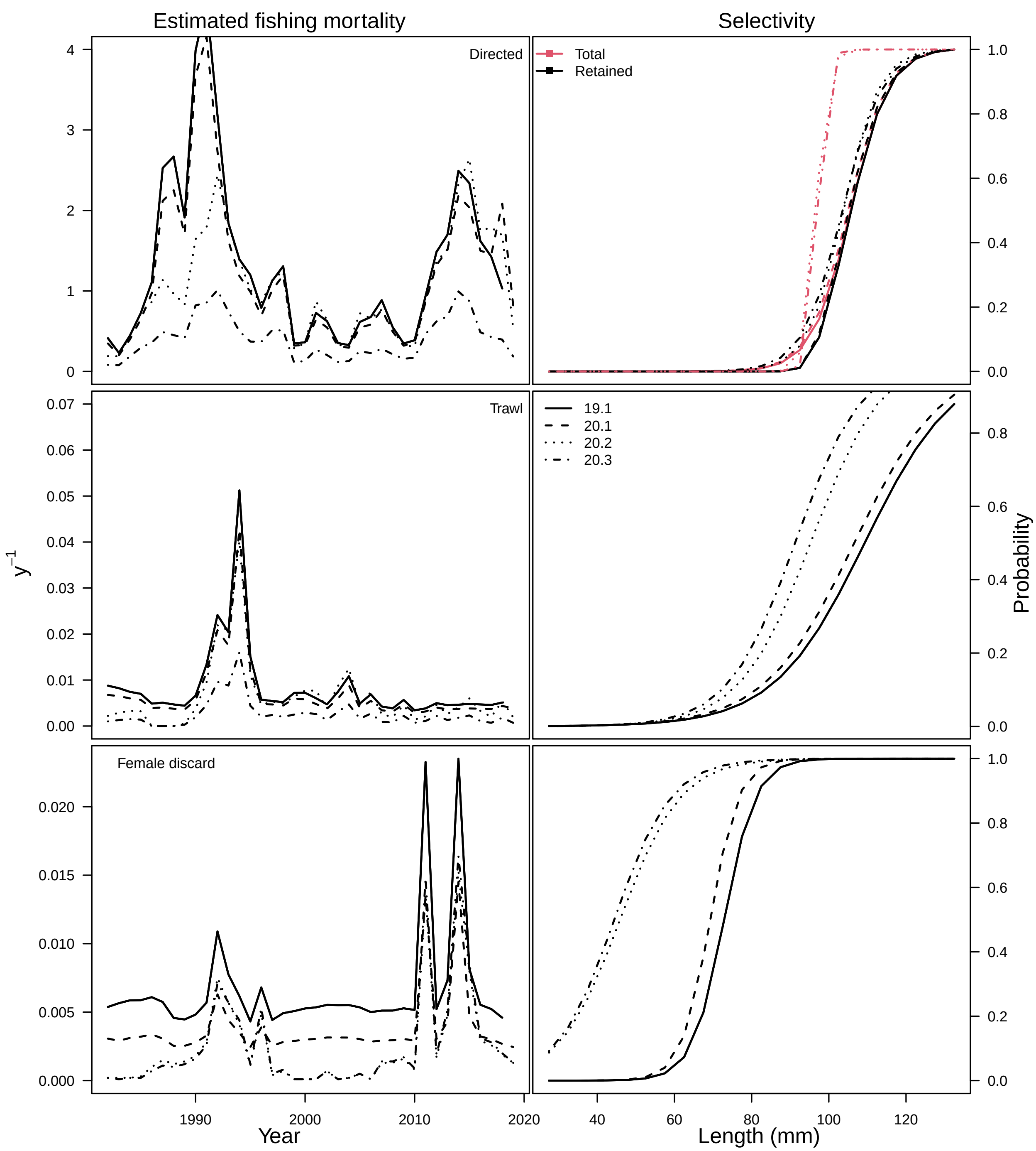

Figure 42: Model predicted fishing mortalities and selectivities for all sources of mortality

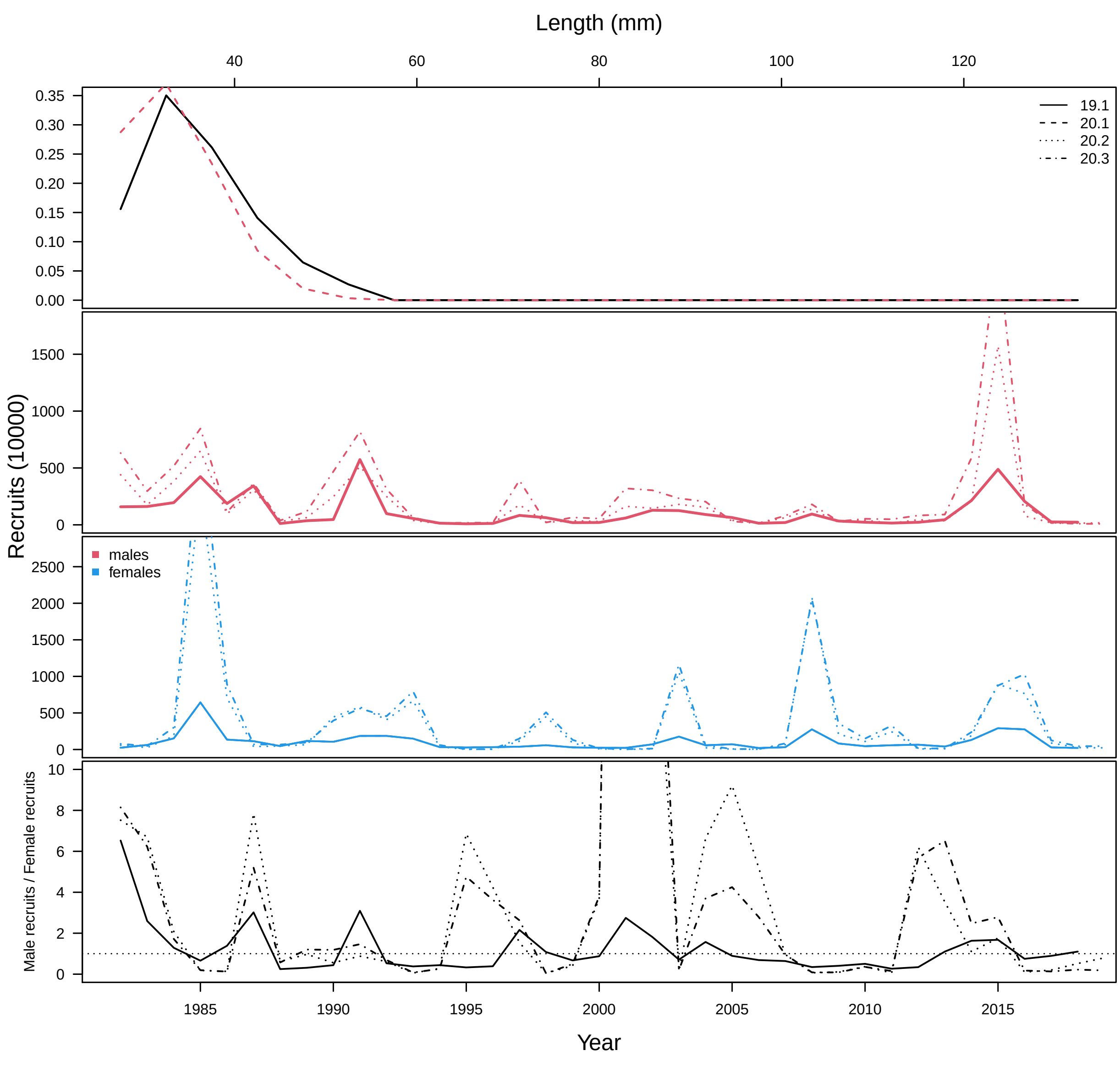

Figure 43: Estimated recruitment and proportions recruiting to length bin.

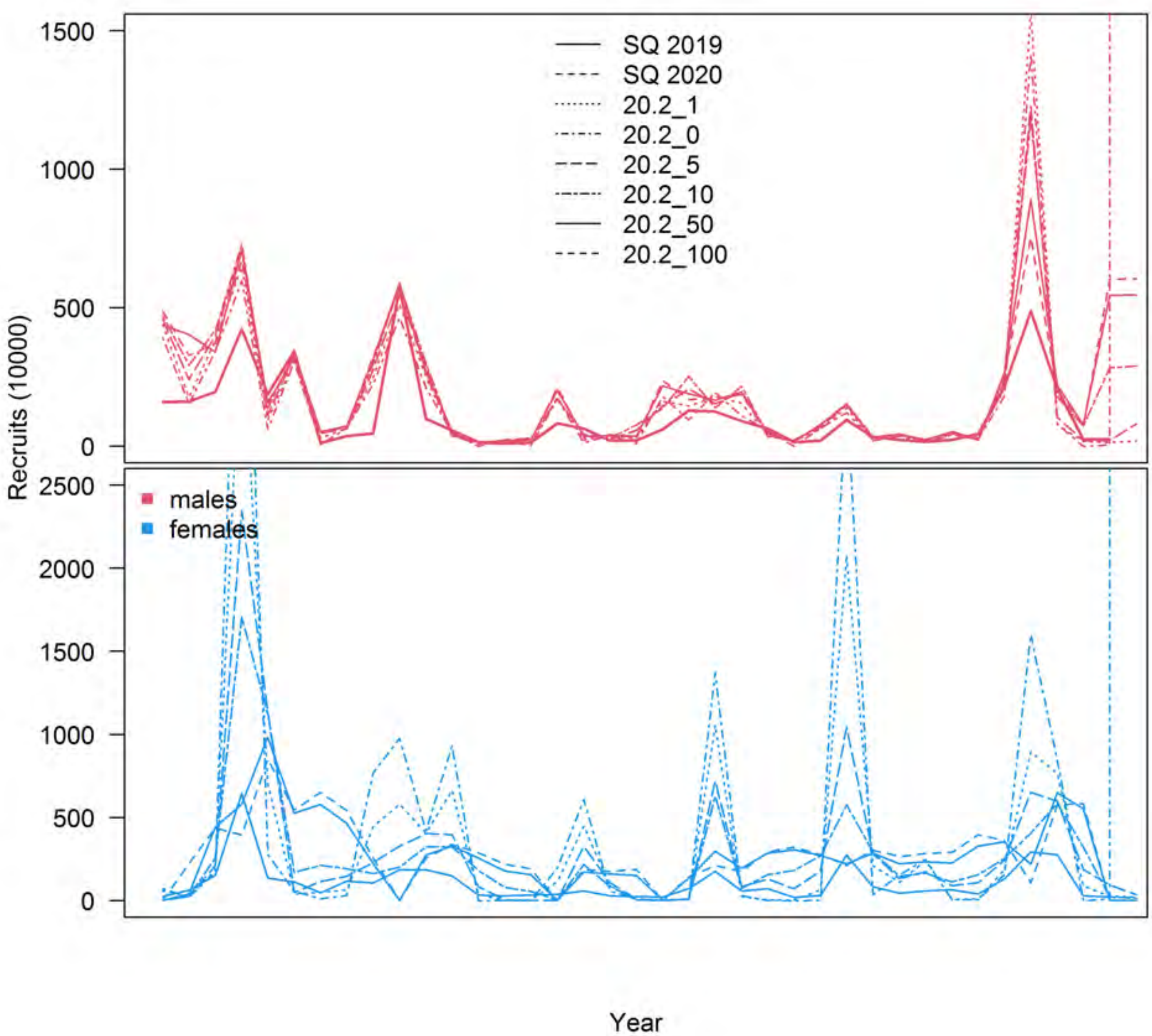

Figure 44: Estimated recruitment from model runs in which the recruitment penalty in GMACS was varied. The size of the penalty is equal to the final number following the last underscore.

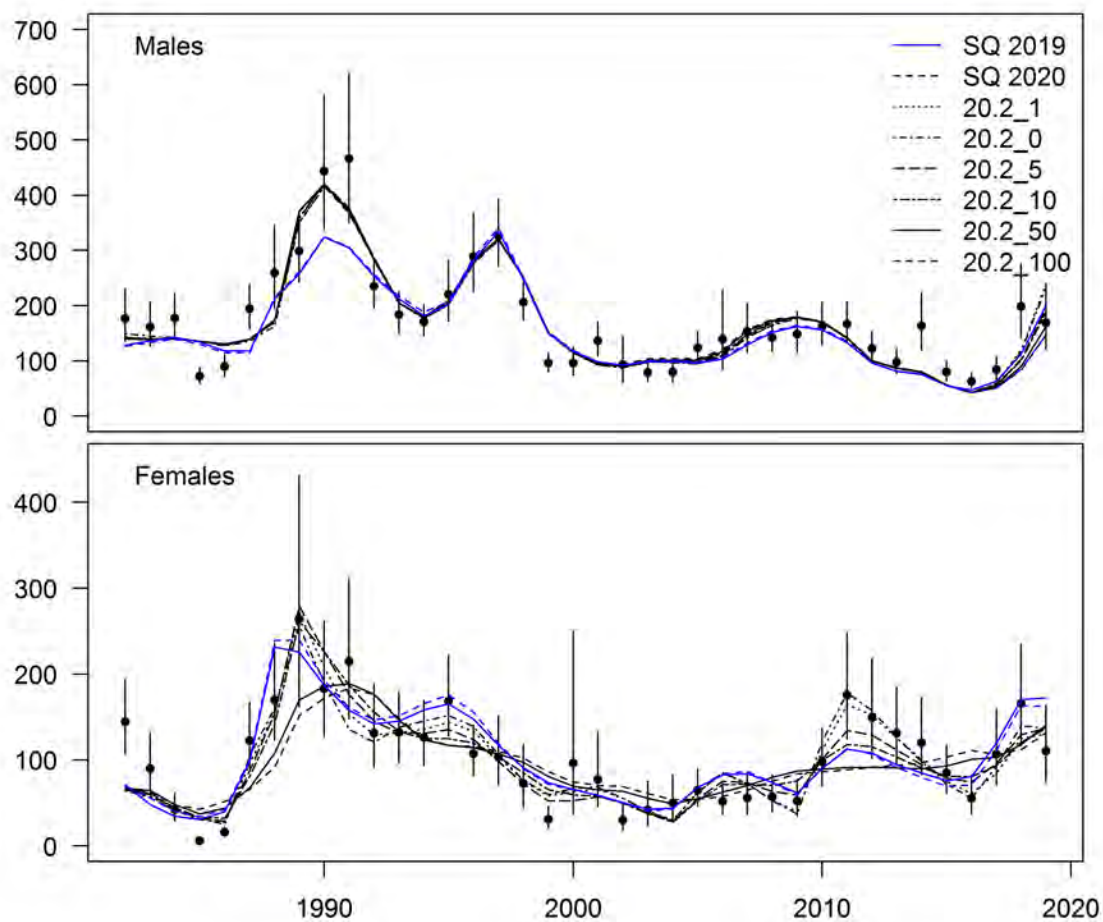

Figure 45: Estimated MMB from model runs in which the recruitment penalty in GMACS was varied. The size of the penalty is equal to the final number following the last underscore.

Table 1: Changes in management quantities for each scenario considered. Reported management quantities are derived from maximum likelihood estimates.

Model	MMB	B35	F35	FOFL	OFL
SQ 2019	109.56	123.71	1.80	1.80	54.05
SQ 2020	142.85	151.25	1.63	1.63	93.63
20.2_1	207.19	113.66	1.65	1.65	184.91
20.2_0	202.46	115.00	1.61	1.61	183.83
20.2_5	164.37	103.58	1.68	1.68	146.10
20.2_10	162.90	104.30	1.71	1.71	142.94
20.2_50	140.26	100.32	1.70	1.70	119.49
20.2_100	127.52	99.08	1.69	1.69	107.27

Figure 46: Management quantities from models in which the recruitment penalty as varied for the author preferred model.

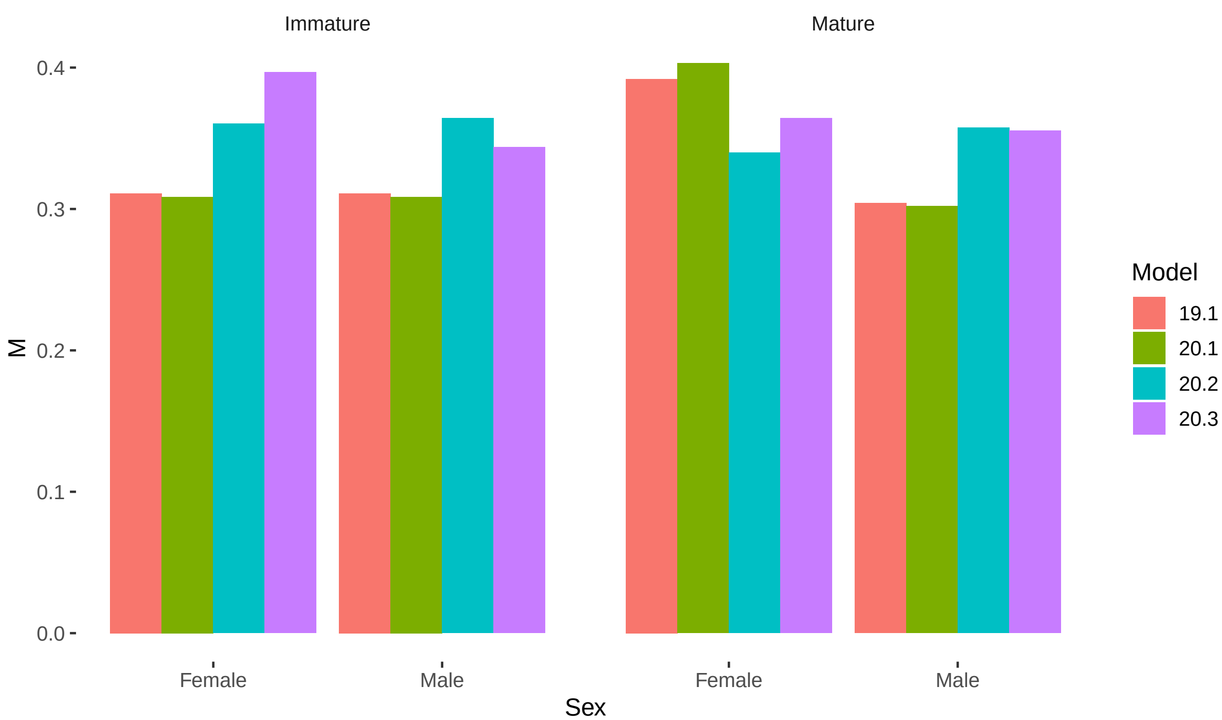

Figure 47: Estimated natural mortality by sex and maturity state.

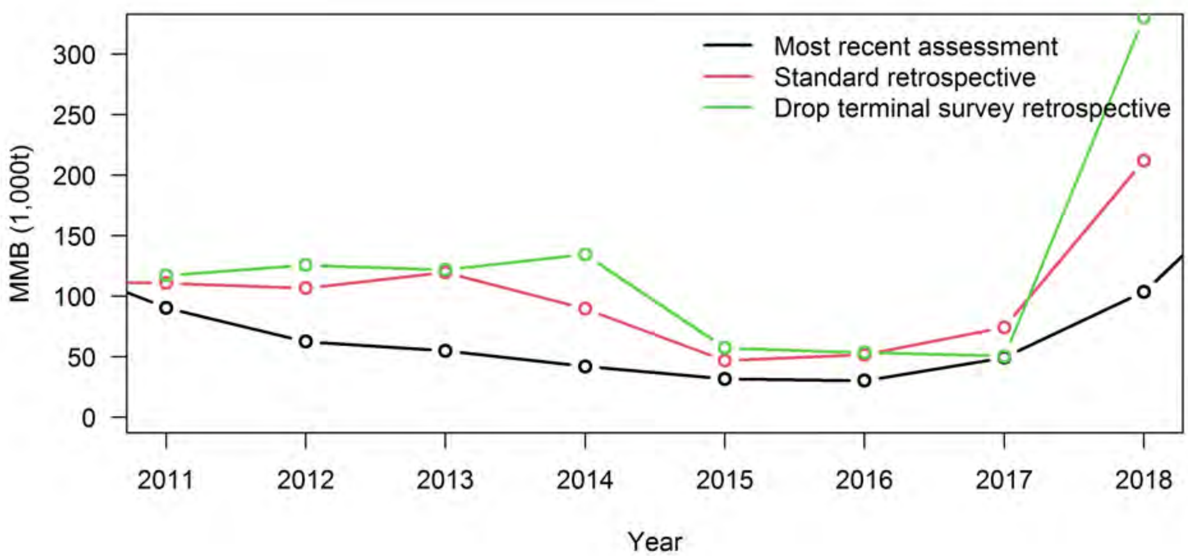

Figure 48: Retrospective analysis of the terminal year of mature male biomass (MMB) for the author's preferred model.

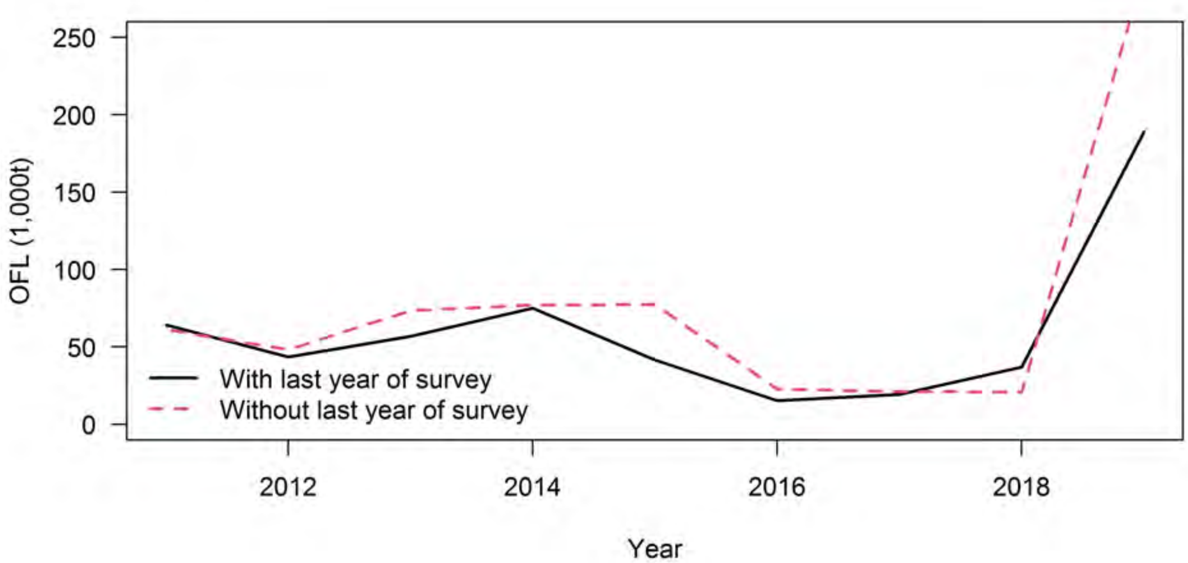

Figure 49: Retrospective analysis of the overfishing level (OFL) for the author's preferred model.

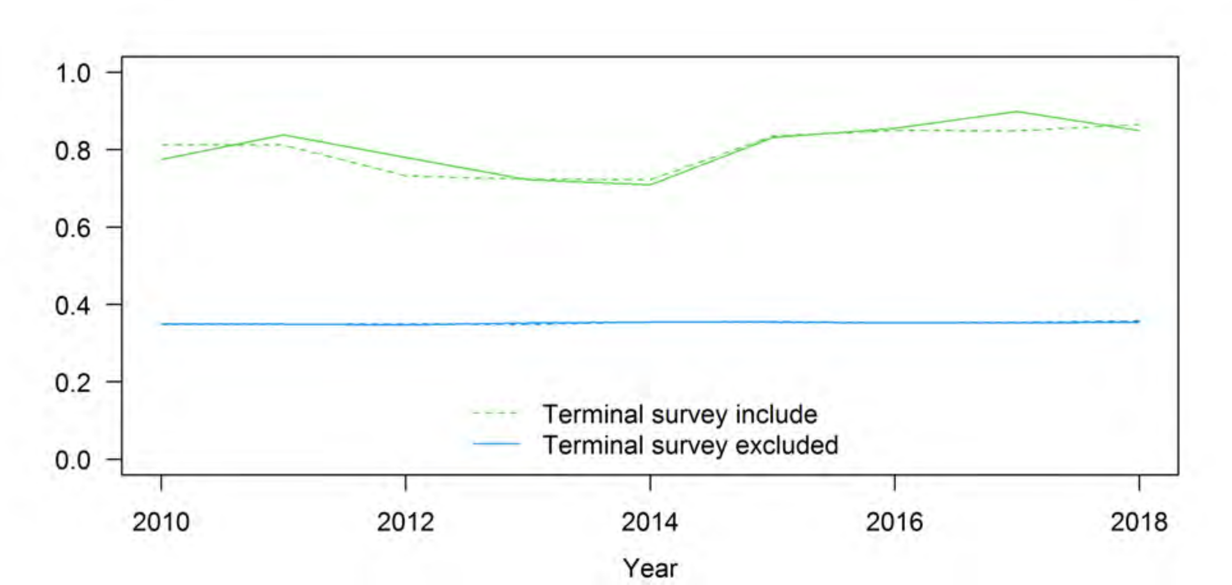

Figure 50: Retrospective analysis of catchability and natural mortality for the author's preferred model.

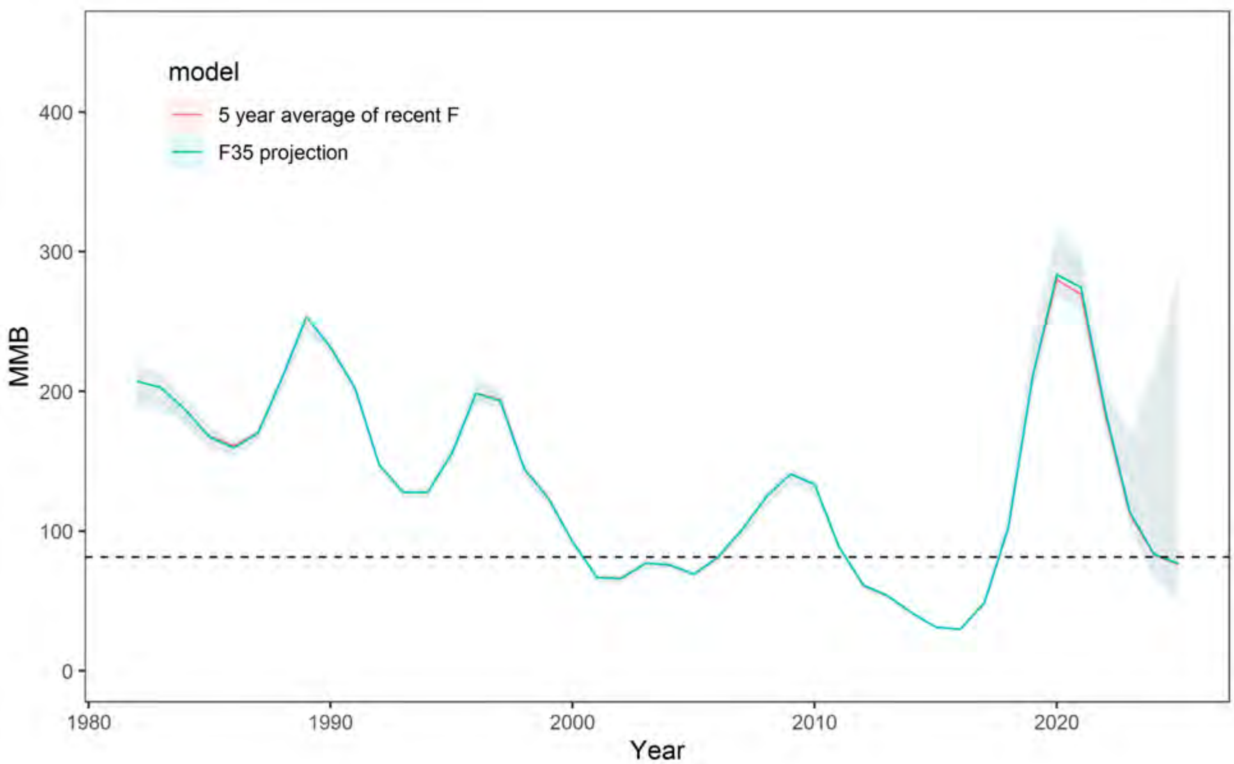

Figure 51: Projection to 2025 of the author's preferred model under harvest at F35 and the average estimated fishing mortality over the terminal 5 years of the fishery.

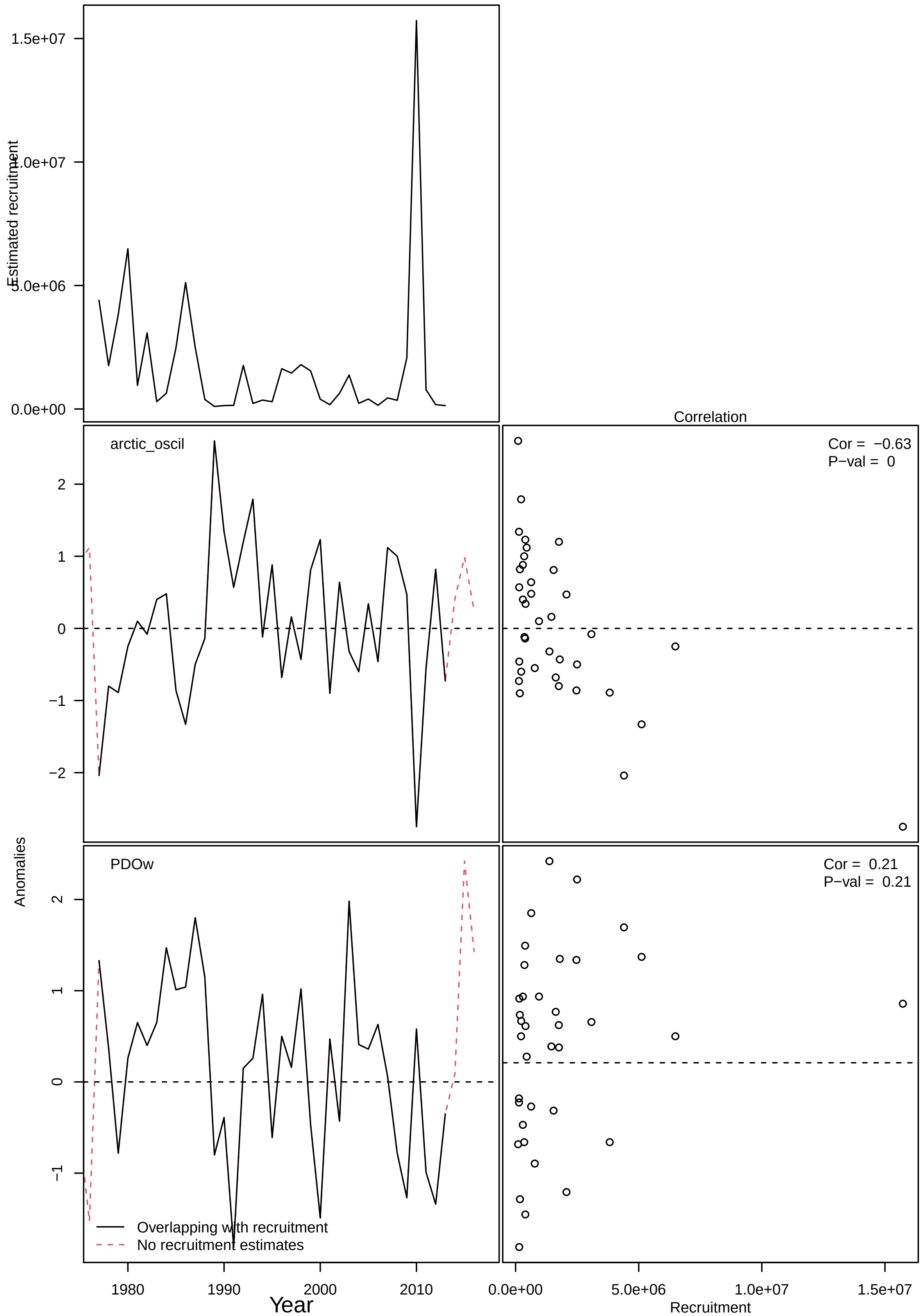

Figure 52: Comparison of estimated recruitment from GMACS with the Pacific Decadal Oscillation and the Arctic Oscillation

BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN FALL 2020

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Executive Summary

1. Stock: Red king crab (RKC), *Paralithodes camtschaticus,* in Bristol Bay, Alaska.
2. Catches: The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lb (58,943 t). The catch declined dramatically in the early 1980s and remained at low levels during the last three decades. After rationalization, catches were relatively high before the 2010/11 season and have been on a declining trend since 2014. The retained catch in 2019/20 was approximately 3.9 million lb (1,775 t), compared to 4.5 million lb (2,027 t) in 2018/19, following a reduction in total allowable catch (TAC). The magnitude of bycatch from groundfish trawl and fixed gear 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 the 1970s and early 1980s and has generally been low since 1985 (1979-year class). During 1984-2019, estimated recruitment was above the historical average (1976-2019 reference years) only in 1984, 1986, 1995, 1999, 2002 and 2005. Estimated recruitment was extremely low during the last 12 years. Estimated recruitment for 2020 is not reliable due to the lack of trawl survey data.
5. Management performance:

Status and catch specifications (1,000 t) (model 19.3):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2016/17	12.53[A]	25.81[A]	3.84	3.92	4.37	6.64	5.97
2017/18	12.74[B]	24.86[B]	2.99	3.09	3.60	5.60	5.04
2018/19	10.62[C]	16.92[C]	1.95	2.03	2.65	5.34	4.27
2019/20	12.72[D]	14.24[D]	1.72	1.78	2.22	3.40	2.72
2020/21		14.93[D]				2.14	1.61

The stock was above MSST in 2019/20 and hence was not overfished. Since total catch was below OFL, overfishing did not occur. The relatively low MSST in 2018/19 and B_{MSY} in 2019/20 below was caused by a problem of the previous GMACS version using the only sex ratio of recruitment in the terminal year for $B_{35\%}$ computation in 2019. The lower estimated male recruitment ratio in the terminal year in 2019 resulted in a lower mean male recruitment for $B_{35\%}$ computation. The current version of GMACS uses average of sex ratios of recruitment during the reference period to estimate $B_{35\%}$, which results in a much more stable sex ratio (about 50%) for the reference point calculation.

Status and catch specifications (million lb):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2016/17	27.6[A]	56.9[A]	8.47	8.65	9.63	14.63	13.17
2017/18	28.1[B]	54.8[B]	6.60	6.82	7.93	12.35	11.11
2018/19	23.4[C]	37.3[C]	4.31	4.31	5.85	11.76	9.41
2019/20	28.0[D]	31.4[D]	3.80	3.91	4.89	7.50	6.00
2020/21		32.9[D]				4.72	3.54

Notes:
A – Calculated from the assessment reviewed by the Crab Plan Team in September 2017
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2018
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2019
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2020

6. Basis for the OFL: Values in 1,000 t (model 19.3):

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2016/17	3b	25.8	24.0	0.93	0.27	1984-2016	0.18
2017/18	3b	25.1	21.3	0.85	0.24	1984-2017	0.18
2018/19	3b	25.5	20.8	0.82	0.25	1984-2017	0.18
2019/20	3b	21.2	16.0	0.75	0.22	1984-2018	0.18
2020/21	3b	25.4	14.9	0.59	0.16	1984-2019	0.18

Basis for the OFL: Values in million lb:

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2016/17	3b	56.8	52.9	0.93	0.27	1984-2016	0.18
2017/18	3b	55.2	47.0	0.85	0.24	1984-2017	0.18
2018/19	3b	56.2	45.9	0.82	0.25	1984-2017	0.18
2019/20	3b	46.8	35.2	0.75	0.22	1984-2018	0.18
2020/21	3b	56.1	32.9	0.59	0.16	1984-2019	0.18

A. Summary of Major Changes

1. Changes to management of the fishery: None.

2. Changes to the input data:

a. No trawl survey was conducted in 2020.

b. Updated directed pot fishery catch and bycatch data through 2019 (i.e., completed 2019/20 fishery).

c. Updated groundfish fisheries bycatch data during 2014-2019.

3. Changes to the assessment methodology:

a. Uncertainty of estimated management qualities without trawl survey data in 2020 is examined (Appendix D).

b. The analyses of terminal years of recruitment is updated.

c. Seven models are compared in this report (See Section E.3.a for details):

19.0a: the model 19.0 in September 2019 except with mean recruitment sex ratio during the reference period to estimate $B_{35\%}$. This model replaces the previous GMACS version that had the sex ratio only in the terminal year to estimate $B_{35\%}$.

19.0b: the same as model 19.0a except for fixing the recruitment in the terminal year to be the mean recruitment during the seven years prior to the terminal year.

19.3: the same as model 19.0a except for a constant *M* being estimated for males during 1980-1984, a constant *M* of 0.18 for males during the other years, and an estimated constant multiplier being used to multiply male *M* for female *M*. That is, *M* for females is relative to *M* for males each year.

19.3a: the same as model 19.3 except for fixing the recruitment in the terminal year to be the mean recruitment during the seven years prior to the terminal year.

19.3b: the same as model 19.3 except for doubling the CV of the prior for trawl survey catchability.

19.3l: the same as model 19.3 except for adding a low trawl survey biomass for 2020 (at 25 percentile) (Appendix D).

19.3h: the same as model 19.3 except for adding a high trawl survey biomass for 2020 (at 75 percentile) (Appendix D).

4. Changes to assessment results:

The population biomass estimates in 2020 are slightly higher than those in 2019. Among the seven models, model estimated relative NMFS survey biomasses and mature biomasses are similar, especially for models 19.0a and 19.0b, and for models 19.3 and 19.3a. Biomass estimates for model 19.0a and 19.0b are higher during recent years than the other five model scenarios. As expected, model 19.3b estimates a higher trawl survey catchability (>1.0), thus resulting in overall lower absolute biomass estimates. Differences of biomass estimates between models 19.0a and 19.0b and models 19.3, 19.3a, 19.3l and 19.3h can largely be explained by different structures of *M*. All seven models fit the catch and bycatch biomasses extremely well. Among the seven models, models 19.0b and 19.3a are respectively models 19.0a and 19.3 with a reasonable terminal year recruitment estimate for potential forward projections. Model 19.3b is just a sensitivity run for a trawl survey catchability prior, and models 19.3l and 19.3h are used for examining the uncertainty without the trawl survey in 2020. Model 19.3 is the preferred model by the CPT in May 2020 and fits the data better with one less parameter than model 19.0a, thus being our preferred model for overfishing definition determination. The CPT adopted GMACS for overfishing definition determination for September 2019.

Like the results of model 19.0 in September 2019, the terminal year recruitment analysis with model 19.3 also suggests the estimated recruitment in the last year should not be used for estimating $B_{35\%}$.

B. Responses to SSC and CPT Comments

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

Response to SSC Comments (from October 2019):

"The SSC reminds authors to use the model numbering protocols that allows the SSC to understand the year in which a particular version of the model was first introduced. Also, when reporting bycatch in tables in each SAFE chapter, the SSC requests authors to be clear whether they report bycatch or bycatch mortality (DMRs have been applied). Further, when reporting bycatch mortality, it would be helpful to report the DMR values used."

Response: We have followed these recommendations.

"The SSC requests that the CPT consider developing a standard approach for projecting the upcoming year's biomass that does not include removing the entire OFL for stocks where recent mortality has been substantially below the OFL. This may appreciably change the projected biomass levels for stocks such as Tanner crab, where actual catch mortality has been less than 10% of the OFL."

Response: Agree to this request and will follow the standard approach developed by the CPT.

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

Response to CPT Comments (from May 2020):

"Given the above discussion, the CPT selected model 19.3 as the priority model (in addition to the status quo model, 19.0a) for presentation in September, understanding that time schedules for producing data used in the assessment may be compressed as a result of the global pandemic. Model 19.3 estimated male natural mortality in an early block (1980-1984) and then specified M as 0.18 thereafter. Female natural mortality was estimated as an offset from males in both periods. Survey selectivity was estimated separately for sexes, but a single catchability was estimated (still with a strong prior). If time allows, a model building from 19.3 in which the prior on catchability is relaxed and estimated separately by sex (and revisited in light of the catchability implied by the BSFRF data) would be useful for comparison."

Response: We used model 19.3b to examine the sensitivity of trawl survey catchability estimate when the CV of the prior on catchability was doubled. The resulting catchability estimate was greater than 1.0. Different catchabilities for males and females in the NMFS survey were examined in model 19.5 in May 2020.

"Produce the empirical survey selectivity diagnostics that were produced for Tanner crab at this meeting, but for BBRKC. Specifically, display the ratio of NMFS to BSFRF (rather than NMFS/(NMFS+BSFRF)) numbers at size to provide a direct comparison to estimated survey selectivity."

Response: Ratios of NMFS to BSFRF numbers at size are plotted in Figure 7 (a, b, and c). Note that the ratios are from combined all haul data due to small amount of crab caught. The abundance-weighted average ratio is 0.891 for crab ≥135 mm carapace length from all four years (2013-2016) of data, about the same as the double-bag experiment (0.896 at 162.5 mm carapace length), although the ratios changed greatly from year to year.

"Describe how the sex ratios for OFL calculations were averaged. It is the same as the recruitments, but was difficult to confirm in the document."

Response: We added text to explain the sex ratios for OFL calculations in Appendix A (B (b) (2) The proxy for B_{MSY}).

"Check the calculation of total male directed fishery catch as inputted to GMACS to ensure accounting for discard mortality is appropriate. Check the tables for correct numbers and that they match the .DAT files provided. Consider splitting the tables needed by the State of Alaska from those presenting the data used in the assessment. CPT suggests that the methodology for how total catches are calculated should be added to the terms of reference for all assessments."

Response: Total male directed fishery catch data in the GMACS input data file are correct. Table 2 is added to include all observer catch and discard data. Methods of bycatch estimation are added to Table 1a caption.

"Highlight the 'PriorDensity' row in the table listing the contribution of likelihoods to the objective function value. Make sure that it is clear that differences in likelihood comparability are well represented in the tables. It appears that modifications will need to be made to the way that GMACS includes or does not include prior densities so that the objective function values from models with different numbers of parameters (but fitting to identical data) are comparable."

Response: The "PriorDensity" row is highlighted, and a new row is added for total negative log likelihood values without prior densities for easy comparison.

"Include diagnostics for VAST indices of abundance and provide rationale for accepting or rejecting the index in future iterations (but not for September 2020)."

Response: Will include this in May 2021.

"Provide justification for the assumed natural mortality for males of 0.18 yr-1. How does the 1% rule assumed in the assessment compare to empirical studies on natural mortality and longevity (e.g. Then et al. 2016)?"

Response: The 1% rule was accepted after very long, several year difficult discussions among the crab overfishing working group, CPT, and SSC. The base *M* for females is also higher than 0.18 for model 19.3 and the related models. We will examine it again in May 2021.

Response to CPT Comments (from September 2019):

"Explore the cause of the residual pattern for female fits for the largest size class in the bottom trawl survey."

Response: The patterns could be due to changes in maturities-at-size, growths, and natural mortalities. The patterns have been improved in many models in May 2020 and September 2020.

"Provide a plot of the empirical BSFRF vs. NMFS selectivity values."

Response: We plot NMFS/(NMFS+BSFRF) as well as NMFS/BSFRF in Figure 7.

"Consider a scenario with different catchabilities for males and females in the NMFS survey to address the discrepancies in the respective selectivity curves."

Response: We added model 19.5 with different catchabilities for males and females in the NMFS survey in May 2020.

"Investigate the discrepancies in historical assessment, e.g., by retrospective plots, and estimation of Mohn's rho."

Response: These have been plotted in Figures 27-29 in our SAFE report since September 2019.

Response to SSC Comments specific to this assessment (from June 2020):

"The SSC agrees with the CPT's model recommendations for September. Though promising, it is advisable to postpone the use of VAST estimates for this stock assessment until diagnostics for VAST can be more fully analyzed and better-fitting error distributions identified. The SSC also supports the other recommendations on this assessment offered by the CPT."

Response: We follow these suggestions.

Response to SSC Comments specific to this assessment (from October 2019):

"The SSC recommends evaluating the use of one selectivity curve for both sexes, since the selectivity is length based and the gear is the same. If the authors believe that one sex is less available to the survey, please provide evidence. If evidence exists, consider using two catchabilities (as recommended by the CPT) with one selectivity curve."

Response: This is a very good suggestion. New models 19.4, 19.4a, 19.4b and 19.5 have the same selectivity curve for both sexes in May 2020. In model 19.5, different survey catchabilities are used for each sex.

"The SSC requests that these large differences in length predictions between the models be investigated, given what appear to be similar selectivities."

Response: GMACS has been improved since September 2019, including rewriting selectivity function codes, and six out of the current eight models in May 2020 have reasonable fits to these large female length compositions. Models 19.1 and 19.2 do not fit well primarily due to *M* assumptions.

"The SSC recommends that details on the reference point calculations should be investigated and reported on for the next assessment. The SSC also requests that the addition of new data be consistently evaluated by comparing the results from the preceding year to the same model with the addition of new data. Note, these models will retain the same model number (e.g., Model 19.0 with 2019 data and Model 19.0 with 2020 data)."

Response: We found a problem of the previous GMACS version using the sex ratio of recruitment in the terminal year only for $B_{35\%}$ computation. The current version of GMACS uses average of sex ratios of recruitment during the reference period to estimate $B_{35\%}$, which results in a much more stable sex ratio for the reference point calculation. Details on the reference point calculations are provided in Appendix A. In this SAFE report (September 2020) as well as past reports, we always did retrospective analysis to compare a model with different year's data. We also plot trawl survey biomass estimates under model 19.3 (2020 data) and model 19.3 (2019 data) alone for comparison (Figure 10b).

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 (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 tens of thousands to 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 (Stevens 1990; Loher et al. 2001) and may live >20 years (Matsuura and Takeshita 1990). Males and females attain a maximum size of 227 mm 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 pot fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lb (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 (Tables 1a and 1b). 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) frameworked 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 lb and 15% when ESB is at or above 55.0 million lb (Zheng et al. 1996). The maximum harvest rate cap of legal males was changed from 60% to 50%. A threshold of 14.5 million lb of ESB was also added. In 1997, a minimum threshold of 4.0 million lb 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 in 2003 by adding a mature harvest rate of 12.5% when the ESB is between 34.75 and 55.0 million lb and in 2012 eliminated the minimum GHL threshold. The current harvest strategy is illustrated in Figure 1.

D. Data

1. Summary of New Information

a. No trawl survey was conducted in 2020.

b. Updated the directed pot fishery catch and bycatch data through 2019 (i.e., completed 2019/20 fishery).

c. Updated groundfish fisheries bycatch data during 2014-2019.

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 Alaska Department of Fish and Game from 1974 to 2019 (Tables 1a and 1b). Bycatch data are available starting from 1990 and were obtained from the ADF&G observer database and reports (Gaeuman 2013) (Table 2). Sample sizes for catch by length and shell condition are summarized in Table 3. 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 Tables 1a and 1b, and illustrated in Figure 3. 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. The years in Tables 1a and 1b are defined as crab year from July 1 to June 30. 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 and fixed gear fisheries are groundfish fisheries. Observers did not separate legal retained and discarded catch after 2017 in the directed pot fishery, so the male discarded biomass from the directed fishery has been estimated by the subtraction method since 2018 (B. Daly, ADF&G, personal communication).

(ii). Catch Size Composition

Retained catches by length and shell condition and bycatches 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 1b). 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 the 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 conducted 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 1975-2019 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). 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, 5a, and 5b 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 2019. The VAST estimated biomasses are compared to area-swept biomasses in Figure 6.

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, 2006-2012, and 2017 to better assess mature female abundance. 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 densities. The resurveys were necessary because a high proportion of mature females had not yet molted or mated when sampled during 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, presumably 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 (S. Goodman, BSFRF, pers. com.). The surveys occurred at similar times as the NMFS standard surveys and covered about 97% of the Bristol Bay survey area. Few Bristol Bay RKC were found outside the BSFRF survey area. Because of the small mesh size, the BSFRF surveys were expected to catch more 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 million crab (CV = 0.0634) in 2007 and 19.747 million crab (CV = 0.0765) in 2008. BSFRF also conducted a side-by-side survey concurrent with the NMFS trawl survey during 2013-2016 in Bristol Bay. In May 2017, survey biomass and size composition estimates from 2016 BSFRF side-by-side trawl survey data were updated. Ratios of NMFS survey abundances/total NMFS and BSFRF side-by-side trawl survey abundances are illustrated in Figure 7a, and ratios of NMFS survey abundances/BSFRF side-by-side trawl survey abundances are shown in Figures 7b and 7c.

As a comparison to the estimated NMFS survey catchability (0.896) at 162.5 mm carapace length by the double-bag experiment, we computed an overall ratio (q=0.891) of NMFS survey abundances/BSFRF side-by-side trawl survey abundances for legal crab (≥135 mm carapace length) as follow:

$$q = \sum_{y=2013,l=135mm}^{y=2016,l=\infty} r_{y,l}\ n_{y,l} / \sum_{y=2013,l=135mm}^{y=2016,l=\infty} n_{y,l} \qquad (1)$$

where $r_{y,l}$ is the ratio of NMFS survey abundance/BSFRF side-by-side trawl survey abundance in year y and length group l, and $n_{y,l}$ is the combined survey abundance of side-by-side surveys in year y and length group l. Due to small catch, all haul data were combined to compute the ratios for each length group and year.

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 crab to determine federal overfishing limits. Given that 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 base constant natural mortality during 1976-1993. In this report, we present only the research model that was fit to the data from 1975 to 2020.

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. Since 2019, GMACS (General Model for Alaska Crab Stocks) has been used for assessments. 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 kept constant at $0.18yr^{-1}$ over sex, 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 may or may not be a function of sex except for groundfish fisheries bycatch selectivities, which are the same for both sexes. Two different NMFS survey selectivities were estimated: (1) 1975-1981 and (2) 1982-2020, 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 are estimated for three periods (1975-1982, 1983-1993, and 1994-2020) based on sizes at maturity. Once mature, female red king crab have 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 NMFS survey catchability (*Q*) is estimated to be 0.896 with a standard deviation of 0.025 for some models, based on a trawl experiment by Weinberg et al. (2004); *Q* is assumed to be constant over time and is estimated in the model. The BSFRF survey catchability is assumed to be 1.0. The prior of 0.896 for NMFS survey *Q* (at 162.5 mm carapace length) is also close to the abundance-weighted average ratio of 0.891 for crab ≥135 mm carapace length across four years of side-by-side NMFS and BSFRF survey data (Figure 7c).

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

viii. Measurement errors are assumed to be normally distributed for length compositions and are 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: Assessment results by GMACS has been compared to the previous assessment models, and the code is online and available from the first author.

3. Model Selection and Evaluation

a. Alternative model configurations (models):

19.0a: the model 19.0 in September 2019 except with mean recruitment sex ratio during the reference period to estimate $B_{35\%}$.

Basic features of this model include:

(1) Base $M = 0.18\text{yr}^{-1}$, 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. Additional mortalities are estimated in the model.

(2) Including BSFRF survey data during 2007-2008 and 2013-2016.

(3) Estimating a constant NMFS survey catchability over time in the model and assuming BSFRF survey catchability to be 1.0.

(4) Assuming the BSFRF survey selectivities as the availability to the NMFS trawl survey because the BSFRF survey gear has very small mesh sizes and has tighter contact to the sea floor. This implies that crab occurring in nearshore areas are not available to trawl survey gears.

(5) 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.

(6) Estimating effective sample size from observed sample sizes. Stage-1 effective sample sizes are estimated as min(0.25*n, N) for trawl surveys and min(0.05*n, N) for catch and bycatch, where n is the sum of observed sample sizes for two sexes, and N is the maximum sample size (200 for trawl surveys, 100 for males from the pot fishery and 50 for females from the pot fishery and for both males and females from the groundfish fisheries). There is justification for enforcing a maximum limit to effective sample sizes because the number of length measurements is large (Fournier et al. 1998).

(7) Standard survey data for males and NMFS survey re-tow data (during cold years) for females.

(8) Estimating initial year length compositions.

(9) Using the total observer male biomass and total observer male length composition data in the directed pot fishery to replace discarded male biomass and discarded male length composition data.

(10) Using total male selectivity and retained proportions in the directed pot fishery to replace retained selectivity and discarded male selectivity; and due to high grading problems in some years since rationalization, estimating two logistic curves for retained proportions: one before rationalization (before 2005) and another after 2004.

(11) Equal annual effective sample sizes of male and female length compositions.

19.0b: the same as model 19.0a except for fixing the recruitment in the terminal year to be the mean recruitment during the seven years prior to the terminal year. This model scenario is used for forward projection if needed.

19.3: the same as model 19.0a except for a constant *M* being estimated for males during 1980-1984, a constant *M* of 0.18 for males during the other years, and an estimated constant multiplier being used to multiply male *M* to estimate *M* for females. That is, *M* for females is relative to *M* for males each year.

19.3a: the same as model 19.3 except for fixing the recruitment in the terminal year to be the mean recruitment during the seven years prior to the terminal year. These seven years have the lowest recruitment level. This model scenario is used for forward projection if needed.

19.3b: the same as model 19.3 except for doubling the CV of the prior for trawl survey catchability.

19.3l: the same as model 19.3 except for adding a low trawl survey biomass for 2020 (25th percentile) (Appendix D).

19.3h: the same as model 19.3 except for adding a high trawl survey biomass for 2020 (75th percentile) (Appendix D).

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 3.

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

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

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

i. Model evaluation is provided under Results, below.

j. Jittering: The Stock Synthesis Approach is used to perform 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:

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

with the final jittered starting parameter value back-transformed as:

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

where P_{max} and P_{min} are upper and lower bounds of parameters and P_{val} is the estimated parameter value before the jittering. Jittering results are not updated and presented in this report.

4. Results

a. Effective sample sizes and weighting factors.

i. CVs are assumed to be 0.03 for retained catch biomass, 0.04 for total male biomass, 0.07 for pot bycatch biomasses, 0.10 for groundfish bycatch biomasses, and 0.23 for recruitment sex ratio. Models also estimate sigmaR for recruitment variation and have a penalty *M* variation and many prior-densities.

ii. 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 (Weinberg et al. 2004). These values are used to set a prior for estimating *Q* in all models.

b. Tables of estimates.

i. Negative log-likelihood values and parameter estimates are summarized in Tables 4 and 5 for all seven models.

ii. Abundance and biomass time series are provided in Tables 6a and 6b for models 19.0a and 19.3.

iii. Recruitment time series for models 19.0a and 19.3 are provided in Tables 6a and 6b.

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

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 groundfish fisheries bycatch are low due to low bycatch and handling mortality rates less than 1.0. Estimated recruits varied greatly among years (Tables 6a and 6b). Estimated selectivities for female pot bycatch are close to 1.0 for all mature females, and the estimated full fishing mortalities for female pot bycatch are lower than for male retained catch and bycatch (Tables 5a and 5b for models 19.0a and 19.3).

c. Graphs of estimates.

i. Estimated selectivities and molting probabilities by length are provided in Figures 8a and 8b and 9a and 9b for models 19.0a and 19.3.

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

For all models, estimated molting probabilities during 1975-2020 (Figures 9a ad 9b) are 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 shown for NMFS surveys (Figure 10a) and BSFRF surveys (Figure 10c). Absolute mature male biomasses are illustrated in Figure 11.

The population biomass estimates in 2020 are slightly higher than those in 2019. Estimated population biomass increased dramatically in the mid-1970s then decreased precipitously in the early 1980s. Estimated biomass had increased during 1985-2009, declined since 2009, and then have steadily declined since the late 2000s (Figures 10a-10c and 11). Absolute mature male biomasses for all models have a similar trend over time (Figure 11). Among the seven models, model estimated relative NMFS survey biomasses and mature biomasses are similar, especially for models 19.0a and 19.0b and for models 19.3 and 19.3a. Biomass estimates for model 19.0a and 19.0b are higher during recent years than the other 5 model scenarios. As expected, model 19.3b estimates a higher trawl survey catchability (>1.0), thus resulting in overall lower absolute biomass estimates. Differences of biomass estimates between models 19.0a and 19.0b and models 19.3, 19.3a, 19.3l and 19.3h can largely be explained by different structures of natural mortality. All seven models fit the catch and bycatch biomasses very well. Among the seven models, models 19.0b and 19.3a are basically models 19.0a and 19.3 with a reasonable terminal year recruitment estimate for potential forward projections. Model 19.3b is just for a sensitivity run for trawl survey catchability prior, and models 19.3l and 19.3h are used for examining the uncertainty without the trawl survey in 2020. Model 19.3 is the preferred model by the CPT from May 2020 and fits the data better with one less parameter than model 19.0a, thus being our preferred model for overfishing definition determination.

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

Like the results of model 19.0 in September 2019, the terminal year recruitment analysis with model 19.3 also suggests the estimated recruitment in the last year should not be used for estimating $B_{35\%}$.

iii. Estimated recruitment time series are plotted in Figure 12a and recruitment length distributions in Figure 12b for models 19.0a and 19.3. Recruitment is estimated at the end of year in GMACS and is moved up one year for the beginning of next year.

iv. Estimated fishing mortality rates are plotted against mature male biomass in Figures 13a and 13b and estimated M and directed pot fishing mortality values over time are illustrated in Figure 13c for models 19.0a and 19.3.

The average of estimated male recruits from 1984 to 2019 (Figure 12a) and mature male biomass per recruit are used to estimate $B_{35\%}$. The full fishing mortalities for the directed pot fishery at the time of fishing are plotted against mature male biomass on Feb. 15 (Figures 13a and 13b). Estimated fishing mortalities in most years before the current harvest strategy was adopted in 1996 were above $F_{35\%}$ (Figures 13a and 13b). Under the current harvest strategy, estimated fishing mortalities were at or above the

$F_{35\%}$ limits in 1998-1999, 2005, 2007-2010, and 2016-2017 for models 19.0a, and in 1998-1999, 2005, 2007-2010, 2014-2019 for model 19.3, but below the $F_{35\%}$ limits in the other post-1995 years.

For model 19.0a, estimated full pot fishing mortalities ranged from 0.00 to 2.87 during 1975-2019. Estimated values were greater than 0.40 during 1975-1976, 1978-1982, 1984-1987, 1990-1991, 1993, 1998 and 2007-2008 (Table 5a, Figure 13a). For model 19.3, estimated full pot fishing mortalities ranged from 0.00 to 2.24 during 1975-2019, with estimated values over 0.40 in the same years as model 19.0a (Table 5b, Figure 13b). Estimated fishing mortalities for pot female and groundfish fisheries bycatches are generally less than 0.07.

For model 19.0a, estimated *M* values are 0.7459 during 1980-1984 and 0.18 for the other years for males, and 1.172 during 1980-1984 and 0.3124 during 1976-1979 and 1985-1993 and 0.18 for the other years for females (Figure 13c). For model 19.3, estimated *M* values are 0.8966 during 1980-1984 and 0.18 for the other years for males, and 1.1802 during 1980-1984 and 0.2369 for the other years for females, with estimated female *M* values equaling to 1.3163 times male *M* values (Figure 13c). Biologically, females mature earlier than males and likely have higher *M* values.

v. Estimated mature male biomass and recruitment are plotted to illustrate their relationships with model 19.3 (Figure 14a). Annual stock productivities are illustrated in Figure 14b.

Stock productivity (recruitment/mature male biomass) is generally lower during the last 20 years (Figure 14b). However, there are high variations for the relation of stock productivity against mature male biomass.

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 are 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 is similar for these two periods (Figure 15). Egg clutch fullness during 2016-2018 was relatively low, then increased in 2019.

d. Graphic evaluation of the fit to the data.

i. Observed vs. estimated catches are plotted in Figure 16a, with bycatch mortalities from different sources shown in Figure 16b.

ii. Model fits to total survey biomass are shown in Figure 10 with a standardized residual plot in Figures 17a and 17b for models 19.0a and 19.3.

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.

All seven models 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, pot female bycatch, and trawl and fixed gear bycatch, the deviations of observed and predicted (estimated) fishery biomass are mainly due to size composition differences. Model 19.3 fits the 2019 and 2020 data almost identical (Figure 10b), partly due to lack of trawl survey data in 2020.

The models also fit the length composition data well (Figures 18-24). Modal progressions are tracked well in the trawl survey data, particularly beginning in 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 bycatch data provide little information to track modal progression (Figures 23 and 24).

Residuals of survey biomasses and proportions of length are plotted to examine their patterns. Residuals were calculated as observed minus predicted and standardized by the estimated standard deviation. Residuals of survey biomasses did not show any consistent patterns for model 19.3 and showed mostly negative residuals for females during the last eight years for model 19.0a (Figures 17a and 17b). Generally, residuals of proportions of survey males and females appear to be random over length and year for models 19.0a and (Figures 25 and 26).

e. Retrospective and historic analyses.

Two kinds of retrospective analyses were conducted for this report: (1) the 2020 model (model 19.3) hindcast results and (2) historical results. The 2020 model hindcast 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 2020 estimates as the baseline values, we can evaluate how well the model had done in the past.

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

The performance of the 2020 model includes sequentially excluding one-year of data. Model 19.3 produced some upward biases during 2009-2019 with higher terminal year estimates of mature male biomass in 2009-2010 and 2014-2019 (Figures 27-28). Higher than expected BSFRF survey biomass during 2007-2008 and 2013-2016 and NMFS survey biomass in 2014 likely caused these biases. Also, much lower than expected NMFS survey biomass during 2018-2019 results in lower biomass estimates in 2020. The biases for total abundance are much smaller than mature male biomass.

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 17 historical assessments for comparison with the 2020 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 did 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 weighting 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 consistency with 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. In 2014 and 2015, the trawl survey time series were re-estimated and a trawl survey catchability was estimated for some models.

Model 19.3 with GMACS was used for 2020. Among many differences from previous models, one main difference is natural mortality structure. Natural mortalities for females are proportional to natural mortalities for males for model 19.3, and one less natural mortality parameter is estimated for females than the previous models. Model 19.3 results in relatively low abundance estimates in recent years.

Overall, both historical results (historic analysis) and the 2020 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).

Ratios of estimated retrospective recruitments to terminal estimates in 2020 as a function of number of years estimated in the model show converging to 1.0 as the number of years increases (Figure 28). Standard deviations of the ratios drop sharply from one year estimated in the model to two years (Figure 28), showing great uncertainty of recruitment estimates for terminal years. Based on these results, we suggest not using recruitment estimates in a terminal year for overfishing/overfished determination.

f. Uncertainty and sensitivity analyses

i. Estimated standard deviations of parameters are summarized in Table 5 for models 19.0a and 19.3. Estimated standard deviations of mature male biomass are listed in Table 6.

ii. Probabilities for mature male biomass and OFL in 2020 were illustrated in Figures 30 and 31 for model 19.3 using the MCMC approach. The confidence intervals are quite narrow.

iii. Sensitivity analysis for handling mortality rate was included 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 respectively reduced or increased. Overall, estimated biomasses were similar 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 models

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) resulted in a better fit of survey length compositions at an expense of 36 more parameters than model 1. Abundance and biomass estimates with model 1a were similar between models. Using only standard survey data (scenario 1b) resulted 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 had the lowest likelihood value. Although the likelihood value was 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 were almost identical. The higher likelihood value for scenario 1 over scenario 1c was due to trawl bycatch length compositions.

In this report (September 2020), seven models are compared. The population biomass estimates in 2020 are slightly higher than those in 2019. Absolute mature male biomasses for all models have a similar trend over time (Figure 11). Among the seven models, model estimated relative NMFS survey biomasses and mature biomasses are similar, especially for models 19.0a and 19.0b and for models 19.3 and 19.3a. Biomass estimates for model 19.0a and 19.0b are higher during recent years than the other five model scenarios. As expected, model 19.3b estimates a higher trawl survey catchability (>1.0), thus resulting in overall lower absolute biomass estimates. Differences of biomass estimates between models 19.0a and 19.0b and models 19.3, 19.3a, 19.3l and 19.3h can largely be explained by different structures of natural mortality. All seven models fit the catch and bycatch biomasses very well.

For negative likelihood value comparisons (Tables 4b and 4c), models 19.0a and 19.0b have lower likelihood values than the other models. Model 19.3b has the highest likelihood value due to reduced influence of the prior on the trawl survey catchability. Interestingly, model 19.3a with two less parameters has a slightly higher likelihood value than model 19.3, due to the recruitment sex ratio component; however, model 19.3 fits the trawl survey data slightly better. The differences are very small.

Among the seven models, models 19.0b and 19.3a are basically models 19.0a and 19.3 with a reasonable terminal year recruitment estimate for potential forward projections. Model 19.3b is just for a sensitivity run for trawl survey catchability prior, and models 19.3l and 19.3h are used for examining the uncertainty without the trawl survey in 2020. Model 19.3 is the preferred model by the CPT in May 2020 and fits the data better with one less parameter than model 19.0a, thus being our preferred model for overfishing definition determination for September 2020.

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 are used to conduct mature male biomass-per-recruit analysis.
3. Specification of the OFL:

   The Tier 3 control rule formula is as follows:

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

   b) $\beta < \frac{B}{B^*} \le 1$ $\qquad F_{OFL} = F^*\left(\frac{B/B^* - \alpha}{1-\alpha}\right)$ (2)

   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 is MMB estimated at the time of primiparous female mating (February 15).

   $F^* = F_{35\%}$, 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 a restriction that $0 \le \beta < 1$. A default value of 0.25 is used.

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

Because trawl bycatch fishing mortality is not related to pot fishing mortality, average trawl bycatch fishing mortality during 2015 to 2019 is used for the per recruit analysis as well as for projections in the next section. Some discards of legal males occurred after the Individual Fishery Quota (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 high proportions of large oldshell males, the discard rate increased greatly in 2014. The current models estimate two levels of retained proportions before 2005 and after 2004. The retained proportions after 2004 and total male selectivities are used to represent current trends for per recruit analysis and projections. Average molting probabilities during 2014-2019 are used for per recruit analysis and projections. For the models in 2020, the averages are the same since they are constant over time during at least last 15 years.

Average recruitment during 1984-2019 is used to estimate $B_{35\%}$ (Figure 12a). Estimated $B_{35\%}$ is compared with historical mature male biomass in Figure 13a. The period of 1984-2019 corresponds to the 1976/77 regime shift, and the 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.

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/B_{MSY} or B/B_{MSY}-proxy equals or declines below β, then the stock productivity is severely depleted, and the directed fishery is closed.

The estimated probability distribution of MMB in 2020 is illustrated in Figure 30. Based on SSC suggestions in 2011, ABC = 0.9*OFL and in October 2018, ABC = 0.8*OFL. The CPT then recommended ABC = 0.8*OFL in May 2018 (accepted by the SSC), which is used to estimate ABC in this report. Due to the stock close to overfished and lack of survey in 2020, the CPT recommended additional 5% buffer in September 2020, resulting in ABC = 0.75*OFL for 2020.

Status and catch specifications (1,000 t) (model 19.3):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2016/17	12.53[A]	25.81[A]	3.84	3.92	4.37	6.64	5.97
2017/18	12.74[B]	24.86[B]	2.99	3.09	3.60	5.60	5.04
2018/19	10.62[C]	16.92[C]	1.95	2.03	2.65	5.34	4.27
2019/20	12.72[D]	14.24[D]	1.72	1.78	2.22	3.40	2.72
2020/21		14.93[D]				2.14	1.61

The stock was above MSST in 2019/20 and hence was not overfished. Since total catch was below OFL, overfishing did not occur. The relatively low MSST in 2018/19 and B_{MSY} in 2019/20 below was caused by a problem of the previous GMACS version using the only sex ratio of recruitment in the terminal year for $B_{35\%}$ computation in 2019. The lower estimated male recruitment ratio in the terminal year in 2019 resulted in a lower mean male recruitment for $B_{35\%}$ computation. The current version of GMACS uses average of sex ratios of recruitment during the reference period to estimate $B_{35\%}$, which results in a much more stable sex ratio (about 50%) for the reference point calculation.

Status and catch specifications (million lb):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2016/17	27.6[A]	56.9[A]	8.47	8.65	9.63	14.63	13.17
2017/18	28.1[B]	54.8[B]	6.60	6.82	7.93	12.35	11.11
2018/19	23.4[C]	37.3[C]	4.31	4.31	5.85	11.76	9.41
2019/20	28.0[D]	31.4[D]	3.80	3.91	4.89	7.50	6.00
2020/21		32.9[D]				4.72	3.54

Notes:

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2017
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2018
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2019
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2020

Basis for the OFL: Values in 1,000 t (model 19.3):

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2016/17	3b	25.8	24.0	0.93	0.27	1984-2016	0.18
2017/18	3b	25.1	21.3	0.85	0.24	1984-2017	0.18
2018/19	3b	25.5	20.8	0.82	0.25	1984-2017	0.18
2019/20	3b	21.2	16.0	0.75	0.22	1984-2018	0.18
2020/21	3b	25.4	14.9	0.59	0.16	1984-2019	0.18

Basis for the OFL: Values in million lb:

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2016/17	3b	56.8	52.9	0.93	0.27	1984-2016	0.18
2017/18	3b	55.2	47.0	0.85	0.24	1984-2017	0.18
2018/19	3b	56.2	45.9	0.82	0.25	1984-2017	0.18
2019/20	3b	46.8	35.2	0.75	0.22	1984-2018	0.18
2020/21	3b	56.1	32.9	0.59	0.16	1984-2019	0.18

4. Based on the $B_{35\%}$ estimated from the average male recruitment during 1984-2019, the biological reference points and OFL are illustrated in Table 4.

5. Based on the CPT/SSC recommendation of 20% buffer rule in May 2018 and an additional buffer of 5% for 2020 due to lack of survey by the CPT, ABC = 0.75*OFL (Table 4).

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,
   h. A better understanding of larval distribution and subsequent recruit distribution.
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 is a random selection from estimated recruitments during 2012-2019, a low recruitment period. Four levels of fishing mortality for the directed pot fishery are used in the projections: 0, 0.083, 0.167 and 0.25. Fishing mortality of 0.167 corresponds to estimated F_{ofl} in 2020. MCMC runs with 400,000 replicates and 500 draws are used for projection.

As expected, projected mature male biomasses are much higher without the directed fishing mortality than under other positive mortality values. At the end of 10 years, projected mature male biomass is below $B_{35\%}$ for all models due to low recruitments (Table 7; Figure 32). Due to the poor recruitment in recent years, the projected biomass and retained catch are expected to decline during the next few years with fishing mortalities of 0.167 and 0.25.

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 33). 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 33). No strong cohorts were observed in the survey data after this cohort through 2010 (Figure 33). A huge tow of juvenile crab of size 45-55 mm in 2011 was not tracked during 2012-2019 surveys and is unlikely to be 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 also inconsistent with the 2016-2019 survey results (Figure 33). Due to lack of recruitment, mature and legal crab should continue to decline next year. Current crab abundance is still low relative to the late 1970s, and without favorable environmental conditions, recovery to the high levels of the late 1970s is unlikely.

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Table 1a. Bristol Bay red king crab annual catch and bycatch mortality biomass (t) from July 1 to June 30. A handling mortality rate of 20% for the directed pot, 25% for the Tanner fishery, 80% for trawl, and 50% or fixed gear was assumed to estimate bycatch mortality biomass. Pot bycatch and Tanner crab fishery bycatch are estimated through expanding the mean observer bycatch per pot to total fishery pot. The pot male bycatch after 2017 is estimated through the subtraction method (B. Daly, ADF&G, personal communication). The trawl and fixed gear fishery bycatches are obtained from the NMFS database. The directed pot bycatch before 1990 and Tanner crab fishery bycatch before 1991 are not available from the observer data and thus not included in this table.

Year	Retained Catch				Pot Bycatch		Trawl Bycatch	Fixed 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			598.4			3949.4
1989	4656.0		0	4656.0			175.2			4831.2
1990	9236.2	36.6	0	9272.8	526.9	648.0	259.9			10707.6
1991	7791.8	93.4	0	7885.1	407.8	47.3	349.4		1401.8	10091.5
1992	3648.2	33.6	0	3681.8	552.0	400.2	293.5		244.4	5172.0
1993	6635.4	24.1	0	6659.6	763.2	634.9	401.4		54.6	8513.6
1994	0.0	42.3	0	42.3	3.8	1.9	87.3		10.8	146.2
1995	0.0	36.4	0	36.4	3.3	1.6	82.1		0.0	123.3
1996	3812.7	49.0	0	3861.7	164.6	1.0	90.8	41.4	0.0	4159.6
1997	3971.9	70.2	0	4042.1	244.7	37.0	57.5	22.5	0.0	4403.7
1998	6693.8	85.4	0	6779.2	959.7	579.4	186.1	18.5	0.0	8522.8
1999	5293.5	84.3	0	5377.9	314.2	5.6	150.5	50.1	0.0	5898.3
2000	3698.8	39.1	0	3737.9	360.8	166.7	81.7	4.7	0.0	4351.9

2001	3811.5	54.6	0	3866.2	417.9	122.3	192.8	35.3	0.0	4634.4
2002	4340.9	43.6	0	4384.5	442.7	9.2	151.2	29.2	0.0	5016.8
2003	7120.0	15.3	0	7135.3	918.9	360.9	136.9	12.7	0.0	8564.7
2004	6915.2	91.4	0	7006.7	345.5	174.6	173.5	15.2	0.0	7715.5
2005	8305.0	94.7	0	8399.7	1359.5	410.3	124.7	19.9	0.0	10314.1
2006	7005.3	137.9	0	7143.2	563.8	37.5	151.7	19.6	3.8	7919.6
2007	9237.9	66.1	0	9303.9	1001.3	163.3	154.1	32.3	1.8	10656.8
2008	9216.1	0.0	0	9216.1	1165.5	146.9	136.6	15.6	4.0	10684.6
2009	7226.9	45.5	0	7272.5	888.1	93.7	95.1	5.8	1.6	8356.9
2010	6728.5	33.0	0	6761.5	797.5	121.8	83.3	2.4	0.0	7766.5
2011	3553.3	53.8	0	3607.1	395.0	24.7	56.3	10.9	0.0	4093.9
2012	3560.6	61.1	0	3621.7	205.2	12.0	34.2	18.4	0.0	3891.5
2013	3901.1	89.9	0	3991.0	310.6	102.9	67.1	55.5	28.5	4555.5
2014	4530.0	8.6	0	4538.6	584.7	72.4	34.8	118.8	42.0	5391.3
2015	4522.3	91.4	0	4613.7	266.1	216.3	45.3	77.4	84.2	5303.1
2016	3840.4	83.4	0	3923.9	237.4	105.4	67.3	28.9	0.0	4362.9
2017	2994.1	99.6	0	3093.7	225.2	53.3	91.8	127.6	0.0	3591.6
2018	1954.1	72.4	0	2026.5	279.6	114.8	78.3	148.0	0.0	2647.2
2019	1719.8	55.5	0	1775.3	273.8	43.3	80.8	45.1	0.0	2218.3

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		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	
2016					1.281	38	
2017					0.997	20	
2018					0.630	20	
2019					0.549	16	

Table 2. Total observer catch and bycatch (metric ton) of Bristol Bay red king crab. No handling mortality rates are applied.

Year	Total Males	Pot Bycatch Males	Pot Bycatch Females	Trawl Bycatch	Fixed Bycatch	Tanner Bycatch
1975				0.000		
1976				853.494		
1977				1,562.313		
1978				1,650.775		
1979				1,664.925		
1980				1,295.625		
1981				274.229		
1982				718.610		
1983				525.554		
1984				1,367.550		
1985				487.576		
1986				250.758		
1987				233.045		
1988				747.996		
1989				219.023		
1990	11,782.900	2,634.570	3,240.200	324.883		
1991	9,974.000	2,039.120	236.600	436.783		5,607.344
1992	6,013.700	2,760.045	2,001.200	366.816		977.750
1993	9,667.700	3,815.785	3,174.400	501.770		218.570
1994	42.300	19.060	9.383	109.129		43.366
1995	36.400	16.369	8.058	102.623		0.000
1996	3,902.300	823.180	5.200	113.495	82.859	0.000
1997	3,847.200	1,223.435	184.800	71.862	44.979	0.000
1998	17,681.400	4,798.560	2,897.100	232.580	36.916	0.000
1999	12,245.200	1,570.855	28.200	188.101	100.242	0.000
2000	6,672.300	1,804.165	833.700	102.161	9.446	0.000
2001	5,797.000	2,089.375	611.400	241.011	70.553	0.000
2002	7,065.300	2,213.290	46.100	189.018	58.382	0.000
2003	12,300.600	4,594.290	1,804.700	171.114	25.351	0.000
2004	10,816.800	1,727.745	873.000	216.889	30.422	0.000
2005	13,753.300	6,797.650	2,051.400	155.924	39.802	0.000
2006	9,170.400	2,818.755	187.700	189.660	39.134	15.232
2007	13,956.600	5,006.550	816.700	192.571	64.655	7.169
2008	15,068.700	5,827.550	734.400	170.754	31.158	15.938
2009	12,300.300	4,440.620	468.500	118.906	11.616	6.499
2010	10,087.400	3,987.380	609.200	104.086	4.736	0.000
2011	5,732.600	1,974.810	123.400	70.419	21.706	0.000
2012	4,568.100	1,025.775	59.800	42.786	36.895	0.000
2013	5,260.700	1,552.895	514.300	83.868	110.970	113.848
2014	8,312.700	2,923.280	362.200	43.460	237.651	168.080
2015	6,706.400	1,330.705	1,081.600	56.686	154.810	336.715
2016	5,557.200	1,187.083	527.000	84.127	57.896	0.000
2017	4,075.760	1,126.025	266.546	114.784	255.155	0.000
2018	3,060.344	1,398.089	574.045	97.891	295.916	0.000
2019	3,143.250	1,369.039	216.739	101.001	90.109	0.000

Table 3. Annual sample sizes (>64 mm CL) in numbers of crab for trawl surveys, retained catch, directed pot, Tanner crab, trawl and fixed gear fishery bycatches of Bristol Bay red king crab.

Year	Trawl Survey		Retained Catch	Pot Total	Pot Bycatch	Trawl & Fixed Gear Bycatch		Tanner Fishery Bycatch	
	Males	Females		Males	Females	Males	Females	Males	Females
1975	2,815	2,042	29,570						
1976	2,699	1,466	26,450			676	2,327		
1977	2,734	2,424	32,596			689	14,014		
1978	2,735	2,793	27,529			1,456	8,983		
1979	1,158	1,456	27,900			2,821	7,228		
1980	1,917	1,301	34,747			39,689	47,463		
1981	591	664	18,029			49,634	42,172		
1982	1,911	1,948	11,466			47,229	84,240		
1983	1,343	733	0			104,910	204,464		
1984	1,209	778	4,404			147,134	357,981		
1985	790	414	4,582			30,693	169,767		
1986	959	341	5,773			1,199	927		
1987	1,123	1,011	4,230			723	275		
1988	708	478	9,833			437	194		
1989	764	403	32,858			3,140	1,566		
1990	729	535	7,218	2,571	1,416	756	375		
1991	1,180	490	36,820	5,024	366	236	90	885	2,198
1992	509	357	23,552	4,769	3,238	212	228	280	685
1993	725	576	32,777	10,334	6,187	24	3	232	265
1994	416	239	0	0	0	327	245		
1995	685	407	0	0	0	120	40		
1996	755	753	8,896	1,778	11	1,035	971		
1997	1,280	702	15,747	11,089	939	1,200	445		
1998	1,067	1,123	16,131	31,432	10,236	1,623	913		
1999	765	618	17,666	13,519	57	2,025	843		
2000	734	730	14,091	32,711	8,470	957	661		
2001	599	736	12,854	26,460	5,474	3,444	2,406		
2002	972	826	15,932	32,612	714	3,262	1,435		
2003	1,360	1,250	16,212	45,583	12,971	1,518	1,008		
2004	1,852	1,271	20,038	38,782	6,667	1,656	1,508		
2005	1,198	1,563	21,938	94,794	26,824	1,814	1,871		
2006	1,178	1,432	18,027	66,529	3,646	1,461	1,979		
2007	1,228	1,305	22,387	111,575	12,457	1,018	1,099		
2008	1,228	1,183	14,567	90,331	8,737	1,794	979		
2009	837	941	16,708	92,616	6,050	1,424	853		
2010	708	1,004	20,137	66,659	6,862	612	843		
2011	531	912	10,706	40,226	1,752	563	1,071		
2012	585	707	8,956	20,161	562	1,507	1,752		
2013	647	569	10,197	30,261	6,070	4,806	4,198	218	596
2014	1,107	1,257	9,618	28,540	1,953	1,966	2,580	256	381
2015	615	681	11,746	22,022	5,927	1,150	3,731	726	2,163
2016	378	812	10,811	26,510	4,315	1,935	3,011		
2017	385	508	9,867	27,219	3,834	996	1,137		
2018	285	359	7,626	22,480	7,386	2,806	3,389		
2019	273	299	8,034	21,712	2,819	713	909		

Table 4a. Number of parameters for the model (Models 19.0a, 19.0b, 19.3, 19.3a, 19.3b, 19.3l, and 19.3h). Red values indicate different values among models.

Parameter counts	**19.0a**	**19.0b**	**19.3**	**19.3a**	**19.3b**	**19.3l**	**19.3h**
Fixed growth parameters	9	9	9	9	9	9	9
Fixed recruitment parameters	2	2	2	2	2	2	2
Fixed length-weight relationship parameters	6	6	6	6	6	6	6
Fixed mortality parameters	4	4	4	4	4	4	4
Fixed survey catchability parameter	1	1	1	1	1	1	1
Fixed high grading parameters	0	0	0	0	0	0	0
Total number of fixed parameters	22	22	22	22	22	22	22
Free survey catchability parameter	1	1	1	1	1	1	1
Free growth parameters	6	6	6	6	6	6	6
Initial abundance (1975)	1	1	1	1	1	1	1
Recruitment-distribution parameters	2	2	2	2	2	2	2
Mean recruitment parameters	1	1	1	1	1	1	1
Male recruitment deviations	45	44	45	44	45	45	45
Female recruitment deviations	45	44	45	44	45	45	45
Natural mortality parameters	3	3	2	2	2	2	2
Mean & offset fishing mortality parameters	6	6	6	6	6	6	6
Pot male fishing mortality deviations	45	45	45	45	45	45	45
Bycatch mortality from the Tanner crab fishery	50	50	50	50	50	50	50
Pot female bycatch fishing mortality deviations	30	30	30	30	30	30	30
Trawl bycatch fishing mortality deviations	44	44	44	44	44	44	44
Fixed gear bycatch fishing mortality deviations	24	24	24	24	24	24	24
Initial (1975) length compositions	35	35	35	35	35	35	35
Survey extra CV	1	1	1	1	1	1	1
Free selectivity parameters	28	28	28	28	28	28	28
Total number of free parameters	367	365	366	364	366	366	366
Total number of fixed and free parameters	389	387	388	386	388	388	388

Table 4b. Negative log likelihood components for Models 19.0a, 19.0b, 19.3, 19.3a, 19.3b, 19.3l, and 19.3h and some management quantities. Highlighted cells in yellow color show prior density values and total negative likelihood values without prior density.

	Models						
	19.0a	19.0b	19.3	19.3a	19.3b	19.3l	19.3h
Pot-ret-catch	-62.15	-62.13	-59.87	-59.88	-60.83	-59.90	-59.84
Pot-totM-catch	23.63	23.71	25.90	25.90	24.03	25.78	25.97
Pot-F-discC	-52.23	-52.23	-52.21	-52.21	-52.20	-52.21	-52.21
Trawl-discC	-60.97	-60.97	-60.98	-60.98	-60.98	-60.98	-60.98
Tanner-M-discC	-43.54	-43.54	-43.54	-43.54	-43.54	-43.54	-43.54
Tanner-F-discC	-43.54	-43.54	-43.49	-43.49	-43.48	-43.49	-43.49
Fixed-discC	-33.27	-33.27	-33.27	-33.27	-33.27	-33.27	-33.27
Traw-suv-bio	-21.28	-20.05	-33.82	-33.72	-35.18	-36.61	-36.21
BSFRF-sur-bio	-6.55	-6.69	-4.80	-4.83	-3.09	-4.50	-4.97
Pot-ret-comp	-3639.55	-3639.50	-3643.89	-3643.93	-3643.96	-3643.77	-3643.96
Pot-totM-comp	-2147.56	-2147.19	-2150.62	-2150.62	-2151.87	-2150.59	-2150.64
Pot-discF-comp	-1358.90	-1358.34	-1353.14	-1353.08	-1353.04	-1353.20	-1353.11
Trawl-disc-comp	-5565.24	-5565.06	-5583.78	-5583.87	-5583.70	-5583.16	-5584.09
TC-disc-comp	-780.10	-780.35	-790.17	-790.29	-790.83	-789.98	-790.25
Fixed-disc-comp	-3163.15	-3163.84	-3168.76	-3168.87	-3167.87	-3168.68	-3168.83
Trawl-sur-comp	-6723.19	-6722.98	-6717.35	-6717.38	-6720.93	-6718.67	-6716.47
BSFRF-sur-comp	-843.49	-843.11	-851.44	-851.43	-852.66	-851.47	-851.41
Recruit-dev	61.54	62.17	67.03	67.50	67.10	67.28	66.91
Recruit-sex-R	74.99	72.73	73.72	72.08	73.71	73.73	73.73
Log_fdev=0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
M-deviation	51.88	51.99	44.12	44.11	44.15	44.05	44.16
Sex-specific-R	0.94	0.84	0.06	0.07	0.06	0.06	0.05
Ini-size-struct.	29.81	29.91	31.46	31.48	31.96	31.42	31.49
PriorDensity	258.01	257.81	297.16	297.53	301.13	297.94	296.55
Tot-likelihood	-24043.9	-24043.6	-24051.7	-24052.7	-24055.3	-24053.8	-24054.4
Tot-likeli-no-PD	-24301.9	-24301.4	-24348.9	-24350.2	-24356.4	-24351.7	-24351.0
Tot-parameter	367	365	366	364	366	366	366
MMB35%	25142.33	24961.21	25444.68	25438.31	24559.29	25324.34	25523.27
MMB-terminal	16561.25	16684.07	14928.39	14988.25	13463.40	14422.21	15219.53
F35%	0.295	0.295	0.291	0.291	0.288	0.290	0.291
Fofl	0.183	0.187	0.157	0.158	0.144	0.152	0.160
OFL	2763.44	2831.42	2140.72	2158.13	1766.99	1997.27	2223.67
ABC	2072.58	2123.56	1605.54	1618.60	1325.24	1497.95	1667.76
Q-1982-now	0.940	0.936	0.959	0.958	1.053	0.960	0.959

Table 4c. Differences of negative log likelihood components and some management quantities between model 19.3 and models 19.0a, 19.3b, 19.3l, and 19.3h.

	19.3 - 19.0a	19.3 - 19.3b	19.3 - 19.3l	19.3 - 19.3h
Pot-ret-catch	2.286	0.967	0.029	-0.026
Pot-totM-catch	2.275	1.870	0.124	-0.066
Pot-F-discC	0.020	-0.007	0.001	-0.001
Trawl-discC	-0.014	-0.001	0.000	0.000
Tanner-M-discC	-0.001	0.000	0.000	0.000
Tanner-F-discC	0.051	-0.010	0.002	-0.001
Fixed-discC	0.000	0.000	0.000	0.000
Traw-suv-bio	-12.544	1.354	2.786	2.391
BSFRF-sur-bio	1.758	-1.709	-0.295	0.169
Pot-ret-comp	-4.340	0.070	-0.120	0.070
Pot-totM-comp	-3.060	1.250	-0.030	0.020
Pot-discF-comp	5.760	-0.100	0.060	-0.030
Trawl-disc-comp	-18.540	-0.080	-0.620	0.310
Tanner-disc-comp	-10.071	0.661	-0.186	0.082
Fixed-disc-comp	-5.610	-0.890	-0.080	0.070
Trawl-sur-comp	5.840	3.580	1.320	-0.880
BSFRF-sur-comp	-7.949	1.221	0.032	-0.032
Recruit-dev	5.485	-0.072	-0.252	0.114
Recruit-sex-R	-1.276	0.009	-0.009	-0.010
Log_fdev=0	0.000	0.000	0.000	0.000
M-deviation	-7.757	-0.033	0.066	-0.045
Sex-specific-R	-0.881	0.002	0.003	0.015
Ini-size-structure	1.653	-0.500	0.049	-0.024
PriorDensity	39.151	-3.973	-0.787	0.605
Tot-likelihood	-7.800	3.600	2.100	2.700
Tot-like-no-PD	-46.951	7.573	2.887	2.095
Tot-parameter	-1.000	0.000	0.000	0.000
MMB35%	302.35	885.39	120.34	-78.59
MMB-terminal	-1632.86	1464.99	506.18	-291.13
F35%	-0.004	0.002	0.000	0.000
Fofl	-0.026	0.014	0.006	-0.003
OFL	-622.72	373.73	143.45	-82.95
ABC	-467.04	280.30	107.59	-62.21
Q-1982-now	0.019	-0.094	-0.001	0.000

Table 5a. Summary of estimated model parameter values and standard deviations for model 19.0a for Bristol Bay red king crab.

index	name	value	std.dev	index	name	value	std.dev
1	theta[2]	0.2749	0.0173	47	log_slx_pars[1]	4.7444	0.0083
2	theta[4]	19.8860	0.0569	48	log_slx_pars[2]	2.1890	0.0583
3	theta[5]	16.3000	0.1429	49	log_slx_pars[3]	4.5081	0.0295
4	theta[7]	0.6590	0.1257	50	log_slx_pars[4]	2.0856	0.1812
5	theta[9]	-0.4401	0.2572	51	log_slx_pars[5]	5.1519	0.0566
6	theta[13]	0.9628	0.3826	52	log_slx_pars[6]	2.8465	0.0460
7	theta[14]	0.6174	0.4329	53	log_slx_pars[7]	4.6374	0.0651
8	theta[15]	0.8052	0.3219	54	log_slx_pars[8]	2.1786	0.6064
9	theta[16]	0.6510	0.3010	55	log_slx_pars[9]	4.5128	0.0168
10	theta[17]	0.4889	0.2941	56	log_slx_pars[10]	0.9159	0.4156
11	theta[18]	0.4465	0.2788	57	log_slx_pars[11]	4.7991	0.0261
12	theta[19]	0.3027	0.2819	58	log_slx_pars[12]	2.3519	0.0920
13	theta[20]	0.3306	0.2712	59	log_slx_pars[13]	4.0859	0.5844
14	theta[21]	0.3533	0.2661	60	log_slx_pars[14]	3.1951	1.5504
15	theta[22]	0.1478	0.2865	61	log_slx_pars[15]	4.1851	0.2052
16	theta[23]	0.1432	0.2807	62	log_slx_pars[16]	3.1842	0.3813
17	theta[24]	0.0240	0.2912	63	log_slx_pars[17]	4.0735	0.2493
18	theta[25]	0.0904	0.2740	64	log_slx_pars[18]	2.1854	0.4853
19	theta[26]	-0.0117	0.2182	65	log_slx_pars[19]	3.7549	236.6700
20	theta[27]	-0.2226	0.2111	66	log_slx_pars[20]	0.3179	410.7200
21	theta[28]	-0.3853	0.2138	67	log_slx_pars[21]	4.3551	0.0450
22	theta[29]	-0.7165	0.2288	68	log_slx_pars[22]	2.3047	0.1459
23	theta[30]	-1.1582	0.2498	69	log_slx_pars[23]	4.4858	0.0145
24	theta[31]	-1.1849	0.2518	70	log_slx_pars[24]	2.4915	0.0696
25	theta[52]	1.2533	0.9311	71	log_slx_pars[25]	4.9217	0.0016
26	theta[53]	1.5687	0.5268	72	log_slx_pars[26]	0.6855	0.0650
27	theta[54]	1.5399	0.4050	73	log_slx_pars[27]	4.9283	0.0022
28	theta[55]	1.2891	0.3561	74	log_slx_pars[28]	0.6763	0.1275
29	theta[56]	1.1377	0.3118	75	log_fbar[1]	-1.5043	0.0428
30	theta[57]	0.6097	0.3388	76	log_fbar[2]	-4.2897	0.0775
31	theta[58]	0.2224	0.3645	77	log_fbar[3]	-5.4585	0.0989
32	theta[59]	-0.0187	0.3664	78	log_fbar[4]	-6.6075	0.0837
33	theta[60]	-0.2084	0.3541	79	log_fdev[1]	0.6427	0.1226
34	theta[61]	-0.5465	0.3714	80	log_fdev[1]	0.6494	0.0929
35	theta[62]	-0.9352	0.3819	81	log_fdev[1]	0.5870	0.0750
36	theta[63]	-1.1947	0.3863	82	log_fdev[1]	0.7065	0.0617
37	theta[64]	-1.4263	0.3848	83	log_fdev[1]	0.9335	0.0553
38	theta[65]	-1.8059	0.3740	84	log_fdev[1]	1.8165	0.0614
39	theta[66]	-1.9123	0.3701	85	log_fdev[1]	2.3108	0.1365
40	theta[67]	-1.8529	0.3494	86	log_fdev[1]	0.6701	0.1759
41	Grwth[21]	0.8870	0.1854	87	log_fdev[1]	-9.0309	0.1185
42	Grwth[42]	1.4192	0.1224	88	log_fdev[1]	1.0063	0.1052
43	Grwth[85]	140.970	1.7806	89	log_fdev[1]	1.1137	0.0932
44	Grwth[86]	0.0596	0.0103	90	log_fdev[1]	1.2936	0.0756
45	Grwth[87]	140.110	0.6511	91	log_fdev[1]	0.8411	0.0661
46	Grwth[88]	0.0729	0.0037	92	log_fdev[1]	-0.0909	0.0545
93	log_fdev[1]	0.0275	0.0490	143	log_fdev[2]	-0.8520	0.1036
94	log_fdev[1]	0.6682	0.0405	144	log_fdev[2]	-0.7779	0.1038

95	log_fdev[1]	0.6733	0.0433	145	log_fdev[2]	-1.2343	0.1037
96	log_fdev[1]	0.1482	0.0476	146	log_fdev[2]	0.0863	0.1042
97	log_fdev[1]	0.8191	0.0517	147	log_fdev[2]	-0.1993	0.1040
98	log_fdev[1]	-4.3245	0.0493	148	log_fdev[2]	-0.9709	0.1032
99	log_fdev[1]	-4.7230	0.0425	149	log_fdev[2]	-0.2103	0.1031
100	log_fdev[1]	-0.2379	0.0413	150	log_fdev[2]	-0.5125	0.1028
101	log_fdev[1]	-0.1767	0.0419	151	log_fdev[2]	-0.6062	0.1026
102	log_fdev[1]	0.7894	0.0451	152	log_fdev[2]	-0.3762	0.1025
103	log_fdev[1]	0.3819	0.0438	153	log_fdev[2]	-0.6571	0.1024
104	log_fdev[1]	-0.2162	0.0423	154	log_fdev[2]	-0.4930	0.1021
105	log_fdev[1]	-0.3014	0.0417	155	log_fdev[2]	-0.4231	0.1022
106	log_fdev[1]	-0.1917	0.0406	156	log_fdev[2]	-0.4598	0.1025
107	log_fdev[1]	0.2737	0.0393	157	log_fdev[2]	-0.8254	0.1027
108	log_fdev[1]	0.2300	0.0393	158	log_fdev[2]	-0.9867	0.1029
109	log_fdev[1]	0.5087	0.0397	159	log_fdev[2]	-1.4550	0.1028
110	log_fdev[1]	0.2488	0.0388	160	log_fdev[2]	-1.9816	0.1032
111	log_fdev[1]	0.6134	0.0388	161	log_fdev[2]	-1.2798	0.1037
112	log_fdev[1]	0.7772	0.0409	162	log_fdev[2]	-1.8574	0.1045
113	log_fdev[1]	0.5760	0.0419	163	log_fdev[2]	-1.5055	0.1061
114	log_fdev[1]	0.4312	0.0421	164	log_fdev[2]	-1.0216	0.1086
115	log_fdev[1]	-0.2039	0.0416	165	log_fdev[2]	-0.6217	0.1119
116	log_fdev[1]	-0.2809	0.0412	166	log_fdev[2]	-0.7132	0.1150
117	log_fdev[1]	-0.1157	0.0419	167	log_fdev[2]	-0.6279	0.1185
118	log_fdev[1]	0.2040	0.0440	168	log_fdev[3]	-0.0389	0.0685
119	log_fdev[1]	0.2318	0.0486	169	log_fdev[3]	-0.0388	0.0685
120	log_fdev[1]	0.1762	0.0559	170	log_fdev[3]	1.7536	0.0685
121	log_fdev[1]	0.0390	0.0652	171	log_fdev[3]	1.4488	0.0685
122	log_fdev[1]	-0.2324	0.0743	172	log_fdev[3]	1.6753	0.0685
123	log_fdev[1]	-0.2629	0.0820	173	log_fdev[3]	2.5538	0.0685
124	log_fdev[2]	0.1418	0.1261	174	log_fdev[3]	1.4425	0.0685
125	log_fdev[2]	0.6032	0.1168	175	log_fdev[3]	1.6003	0.0685
126	log_fdev[2]	0.6008	0.1111	176	log_fdev[3]	-0.2471	0.0685
127	log_fdev[2]	0.6844	0.1094	177	log_fdev[3]	0.9278	0.0685
128	log_fdev[2]	1.3961	0.1135	178	log_fdev[3]	0.4542	0.0685
129	log_fdev[2]	1.1126	0.1313	179	log_fdev[3]	0.9392	0.0685
130	log_fdev[2]	2.3962	0.1289	180	log_fdev[3]	1.6522	0.0685
131	log_fdev[2]	2.1357	0.1170	181	log_fdev[3]	1.6600	0.0685
132	log_fdev[2]	3.3701	0.1155	182	log_fdev[3]	2.9993	0.0720
133	log_fdev[2]	2.1852	0.1123	183	log_fdev[3]	1.0492	0.0729
134	log_fdev[2]	1.1270	0.1121	184	log_fdev[3]	0.3264	0.0792
135	log_fdev[2]	0.6761	0.1096	185	log_fdev[3]	-2.9934	0.0685
136	log_fdev[2]	1.4522	0.1052	186	log_fdev[3]	-3.9508	0.0685
137	log_fdev[2]	0.0183	0.1042	187	log_fdev[3]	-3.7276	0.0685
138	log_fdev[2]	0.4656	0.1043	188	log_fdev[3]	-3.7276	0.0685
139	log_fdev[2]	0.8772	0.1056	189	log_fdev[3]	-4.6439	0.0685
140	log_fdev[2]	0.7061	0.1056	190	log_fdev[3]	-1.1276	0.0702
141	log_fdev[2]	1.1851	0.1081	191	log_fdev[3]	-0.2264	0.0723
142	log_fdev[2]	-0.5717	0.1051	192	log_fdev[3]	0.2395	0.0772
193	log_fdev[4]	0.6887	0.1037	243	log_fdov[1]	-0.3031	0.0796
194	log_fdev[4]	0.0364	0.1022	244	log_fdov[1]	0.8545	0.0812
195	log_fdev[4]	-0.1681	0.1028	245	log_fdov[1]	0.2983	0.0841
196	log_fdev[4]	0.7408	0.1019	246	log_fdov[1]	-0.1485	0.0875

197	log_fdev[4]	-1.6971	0.1013	247	log_fdov[1]	0.9944	0.0918
198	log_fdev[4]	0.2552	0.1009	248	log_fdov[1]	0.1632	0.0959
199	log_fdev[4]	-0.0024	0.1005	249	log_fdov[3]	-0.0002	0.0967
200	log_fdev[4]	-0.8381	0.1004	250	log_fdov[3]	-0.0004	0.0967
201	log_fdev[4]	-0.6665	0.1001	251	log_fdov[3]	0.0002	0.0967
202	log_fdev[4]	-0.3943	0.0999	252	log_fdov[3]	0.0006	0.0967
203	log_fdev[4]	-0.4464	0.0996	253	log_fdov[3]	0.0006	0.0967
204	log_fdev[4]	0.0951	0.0996	254	log_fdov[3]	-0.0016	0.0966
205	log_fdev[4]	-0.6118	0.1001	255	log_fdov[3]	-0.0007	0.0967
206	log_fdev[4]	-1.6194	0.0999	256	log_fdov[3]	-0.0003	0.0967
207	log_fdev[4]	-2.5090	0.0995	257	log_fdov[3]	-0.0005	0.0967
208	log_fdev[4]	-0.9955	0.0992	258	log_fdov[3]	0.0002	0.0967
209	log_fdev[4]	-0.4479	0.0993	259	log_fdov[3]	0.0003	0.0967
210	log_fdev[4]	0.6876	0.0995	260	log_fdov[3]	0.0015	0.0967
211	log_fdev[4]	1.5158	0.1000	261	log_fdov[3]	0.0026	0.0967
212	log_fdev[4]	1.1726	0.1010	262	log_fdov[3]	0.0038	0.0967
213	log_fdev[4]	0.2879	0.1025	263	log_fdov[3]	0.5057	0.0988
214	log_fdev[4]	1.8747	0.1047	264	log_fdov[3]	0.7525	0.0978
215	log_fdev[4]	2.0949	0.1067	265	log_fdov[3]	-0.4482	0.1022
216	log_fdev[4]	0.9467	0.1090	266	log_fdov[3]	-0.0006	0.0967
217	log_foff[1]	-2.8529	0.0537	267	log_fdov[3]	-0.0006	0.0967
218	log_foff[3]	0.5009	0.0929	268	log_fdov[3]	-0.0006	0.0967
219	log_fdov[1]	2.0679	0.0841	269	log_fdov[3]	-0.0006	0.0967
220	log_fdov[1]	-0.5974	0.0832	270	log_fdov[3]	-0.0006	0.0967
221	log_fdov[1]	2.0825	0.0847	271	log_fdov[3]	0.0182	0.0966
222	log_fdov[1]	1.9121	0.0858	272	log_fdov[3]	-0.7141	0.0973
223	log_fdov[1]	-0.3400	0.0844	273	log_fdov[3]	-0.1175	0.0997
224	log_fdov[1]	-0.1270	0.0827	274	rec_dev_est	1.0794	0.2976
225	log_fdov[1]	-3.6240	0.0827	275	rec_dev_est	0.7311	0.2950
226	log_fdov[1]	-0.2733	0.0845	276	rec_dev_est	1.1263	0.2445
227	log_fdov[1]	1.4941	0.0829	277	rec_dev_est	1.7291	0.2113
228	log_fdov[1]	-2.7279	0.0813	278	rec_dev_est	1.9904	0.2231
229	log_fdov[1]	1.2165	0.0805	279	rec_dev_est	1.1519	0.2681
230	log_fdov[1]	0.9443	0.0805	280	rec_dev_est	2.3399	0.1690
231	log_fdov[1]	-1.8064	0.0798	281	rec_dev_est	1.3687	0.1839
232	log_fdov[1]	1.2767	0.0805	282	rec_dev_est	0.9960	0.1708
233	log_fdov[1]	0.4918	0.0809	283	rec_dev_est	-0.8590	0.2556
234	log_fdov[1]	1.0262	0.0796	284	rec_dev_est	0.2556	0.1674
235	log_fdov[1]	-1.1644	0.0791	285	rec_dev_est	-0.8849	0.2447
236	log_fdov[1]	-0.1117	0.0793	286	rec_dev_est	-1.3230	0.2789
237	log_fdov[1]	-0.3832	0.0795	287	rec_dev_est	-1.1210	0.2339
238	log_fdov[1]	-0.5928	0.0798	288	rec_dev_est	-0.1322	0.1713
239	log_fdov[1]	-0.1359	0.0803	289	rec_dev_est	-0.5997	0.1933
240	log_fdov[1]	-1.0767	0.0793	290	rec_dev_est	-2.0873	0.3716
241	log_fdov[1]	-1.7165	0.0787	291	rec_dev_est	-1.0340	0.2076
242	log_fdov[1]	0.3028	0.0788	292	rec_dev_est	-2.3004	0.5003
293	rec_dev_est	0.9320	0.1518	339	logit_rec_prop_es	1.4330	0.7775
294	rec_dev_est	-1.0433	0.2655	340	logit_rec_prop_es	0.6054	0.6934
295	rec_dev_est	-1.6231	0.3342	341	logit_rec_prop_es	0.4621	0.3267
296	rec_dev_est	-0.6536	0.2037	342	logit_rec_prop_es	-0.1146	0.1462
297	rec_dev_est	0.3285	0.1611	343	logit_rec_prop_es	0.2329	0.3548
298	rec_dev_est	-0.5955	0.2220	344	logit_rec_prop_es	-0.4851	0.3715

299	rec_dev_est	-0.5981	0.2419	345	logit_rec_prop_es	-0.5161	0.1317
300	rec_dev_est	0.7746	0.1599	346	logit_rec_prop_es	-0.3856	0.4374
301	rec_dev_est	-0.7101	0.2737	347	logit_rec_prop_es	-0.0832	0.4245
302	rec_dev_est	-0.6874	0.2618	348	logit_rec_prop_es	-0.4556	0.1413
303	rec_dev_est	0.5600	0.1615	349	logit_rec_prop_es	-0.0760	0.2474
304	rec_dev_est	-0.1755	0.1895	350	logit_rec_prop_es	0.1947	0.2815
305	rec_dev_est	-0.5592	0.1953	351	logit_rec_prop_es	-0.2368	0.3697
306	rec_dev_est	-1.1078	0.2414	352	logit_rec_prop_es	-0.3192	0.3748
307	rec_dev_est	-1.0323	0.2465	353	logit_rec_prop_es	-0.8485	0.1925
308	rec_dev_est	-0.0045	0.1799	354	logit_rec_prop_es	-0.3224	0.3105
309	rec_dev_est	-0.5554	0.2233	355	logit_rec_prop_es	-0.5481	0.3173
310	rec_dev_est	-0.9540	0.2248	356	logit_rec_prop_es	-0.0122	0.3469
311	rec_dev_est	-1.3618	0.2286	357	logit_rec_prop_es	-0.2385	0.4730
312	rec_dev_est	-1.9292	0.2923	358	logit_rec_prop_es	-0.1864	0.3287
313	rec_dev_est	-1.4162	0.2269	359	logit_rec_prop_es	0.2586	0.2467
314	rec_dev_est	-0.8414	0.1882	360	logit_rec_prop_es	0.6521	0.5618
315	rec_dev_est	-1.6911	0.2850	361	logit_rec_prop_es	0.4341	0.4426
316	rec_dev_est	-1.2456	0.2701	362	logit_rec_prop_es	0.7423	0.9166
317	rec_dev_est	-1.8541	0.4577	363	logit_rec_prop_es	-0.3395	1.6742
318	rec_dev_est	-0.2405	1.3063	364	m_dev_est[1]	1.6056	0.0288
319	logit_rec_prop_es	-0.1738	0.4779	365	survey_q[1]	0.9592	0.0280
320	logit_rec_prop_es	-0.7552	0.4696	366	log_add_cv[2]	-0.9615	0.2885
321	logit_rec_prop_es	-0.2946	0.3618	367	sd_rbar	16133000	521640.0
322	logit_rec_prop_es	-0.5530	0.2706	368	sd_ssbF0	72699.0	2135.600
323	logit_rec_prop_es	-0.0626	0.2743	369	sd_Bmsy	25445.0	747.4400
324	logit_rec_prop_es	0.0951	0.3784	370	sd_depl	0.5867	0.0405
325	logit_rec_prop_es	0.3407	0.1569	371	sd_fmsy	0.2907	0.0043
326	logit_rec_prop_es	0.3958	0.2409	372	sd_fmsy	0.0059	0.0006
327	logit_rec_prop_es	-0.0992	0.1810	373	sd_fmsy	0.0011	0.0001
328	logit_rec_prop_es	0.5050	0.4900	374	sd_fmsy	0.0059	0.0006
329	logit_rec_prop_es	-0.4662	0.1645	375	sd_fmsy	0.0000	0.0000
330	logit_rec_prop_es	0.2581	0.4222	376	sd_fmsy	0.0000	0.0000
331	logit_rec_prop_es	-0.0528	0.4617	377	sd_fofl	0.1572	0.0137
332	logit_rec_prop_es	0.4767	0.4221	378	sd_fofl	0.0059	0.0006
333	logit_rec_prop_es	-0.1924	0.1754	379	sd_fofl	0.0011	0.0001
334	logit_rec_prop_es	0.1362	0.2614	380	sd_fofl	0.0059	0.0006
335	logit_rec_prop_es	0.9226	0.8947	381	sd_fofl	0.0000	0.0000
336	logit_rec_prop_es	0.0337	0.2920	382	sd_fofl	0.0000	0.0000
337	logit_rec_prop_es	-0.0668	0.8645	383	sd_ofl	2140.7000	334.4400
338	logit_rec_prop_es	-0.2947	0.0904				

Table 5b. Summary of estimated model parameter values and standard deviations for model 19.3 for Bristol Bay red king crab.

index	name	value	std.dev	index	name	value	std.dev
1	theta[2]	0.2749	0.0173	47	log_slx_pars[1]	4.7444	0.0083
2	theta[4]	19.8860	0.0569	48	log_slx_pars[2]	2.1890	0.0583
3	theta[5]	16.3000	0.1429	49	log_slx_pars[3]	4.5081	0.0295
4	theta[7]	0.6590	0.1257	50	log_slx_pars[4]	2.0856	0.1812
5	theta[9]	-0.4401	0.2572	51	log_slx_pars[5]	5.1519	0.0566
6	theta[13]	0.9628	0.3826	52	log_slx_pars[6]	2.8465	0.0460
7	theta[14]	0.6174	0.4329	53	log_slx_pars[7]	4.6374	0.0651
8	theta[15]	0.8052	0.3219	54	log_slx_pars[8]	2.1786	0.6064
9	theta[16]	0.6510	0.3010	55	log_slx_pars[9]	4.5128	0.0168
10	theta[17]	0.4889	0.2941	56	log_slx_pars[10]	0.9159	0.4156
11	theta[18]	0.4465	0.2788	57	log_slx_pars[11]	4.7991	0.0261
12	theta[19]	0.3027	0.2819	58	log_slx_pars[12]	2.3519	0.0920
13	theta[20]	0.3306	0.2712	59	log_slx_pars[13]	4.0859	0.5844
14	theta[21]	0.3533	0.2661	60	log_slx_pars[14]	3.1951	1.5504
15	theta[22]	0.1478	0.2865	61	log_slx_pars[15]	4.1851	0.2052
16	theta[23]	0.1432	0.2807	62	log_slx_pars[16]	3.1842	0.3813
17	theta[24]	0.0240	0.2912	63	log_slx_pars[17]	4.0735	0.2493
18	theta[25]	0.0904	0.2740	64	log_slx_pars[18]	2.1854	0.4853
19	theta[26]	-0.0117	0.2182	65	log_slx_pars[19]	3.7549	236.6700
20	theta[27]	-0.2226	0.2111	66	log_slx_pars[20]	0.3179	410.7200
21	theta[28]	-0.3853	0.2138	67	log_slx_pars[21]	4.3551	0.0450
22	theta[29]	-0.7165	0.2288	68	log_slx_pars[22]	2.3047	0.1459
23	theta[30]	-1.1582	0.2498	69	log_slx_pars[23]	4.4858	0.0145
24	theta[31]	-1.1849	0.2518	70	log_slx_pars[24]	2.4915	0.0696
25	theta[52]	1.2533	0.9311	71	log_slx_pars[25]	4.9217	0.0016
26	theta[53]	1.5687	0.5268	72	log_slx_pars[26]	0.6855	0.0650
27	theta[54]	1.5399	0.4050	73	log_slx_pars[27]	4.9283	0.0022
28	theta[55]	1.2891	0.3561	74	log_slx_pars[28]	0.6763	0.1275
29	theta[56]	1.1377	0.3118	75	log_fbar[1]	-1.5043	0.0428
30	theta[57]	0.6097	0.3388	76	log_fbar[2]	-4.2897	0.0775
31	theta[58]	0.2224	0.3645	77	log_fbar[3]	-5.4585	0.0989
32	theta[59]	-0.0187	0.3664	78	log_fbar[4]	-6.6075	0.0837
33	theta[60]	-0.2084	0.3541	79	log_fdev[1]	0.6427	0.1226
34	theta[61]	-0.5465	0.3714	80	log_fdev[1]	0.6494	0.0929
35	theta[62]	-0.9352	0.3819	81	log_fdev[1]	0.5870	0.0750
36	theta[63]	-1.1947	0.3863	82	log_fdev[1]	0.7065	0.0617
37	theta[64]	-1.4263	0.3848	83	log_fdev[1]	0.9335	0.0553
38	theta[65]	-1.8059	0.3740	84	log_fdev[1]	1.8165	0.0614
39	theta[66]	-1.9123	0.3701	85	log_fdev[1]	2.3108	0.1365
40	theta[67]	-1.8529	0.3494	86	log_fdev[1]	0.6701	0.1759
41	Grwth[21]	0.8870	0.1854	87	log_fdev[1]	-9.0309	0.1185
42	Grwth[42]	1.4192	0.1224	88	log_fdev[1]	1.0063	0.1052
43	Grwth[85]	140.970	1.7806	89	log_fdev[1]	1.1137	0.0932
44	Grwth[86]	0.0596	0.0103	90	log_fdev[1]	1.2936	0.0756
45	Grwth[87]	140.110	0.6511	91	log_fdev[1]	0.8411	0.0661
46	Grwth[88]	0.0729	0.0037	92	log_fdev[1]	-0.0909	0.0545
93	log_fdev[1]	0.0275	0.0490	143	log_fdev[2]	-0.8520	0.1036
94	log_fdev[1]	0.6682	0.0405	144	log_fdev[2]	-0.7779	0.1038

95	log_fdev[1]	0.6733	0.0433	145	log_fdev[2]	-1.2343	0.1037
96	log_fdev[1]	0.1482	0.0476	146	log_fdev[2]	0.0863	0.1042
97	log_fdev[1]	0.8191	0.0517	147	log_fdev[2]	-0.1993	0.1040
98	log_fdev[1]	-4.3245	0.0493	148	log_fdev[2]	-0.9709	0.1032
99	log_fdev[1]	-4.7230	0.0425	149	log_fdev[2]	-0.2103	0.1031
100	log_fdev[1]	-0.2379	0.0413	150	log_fdev[2]	-0.5125	0.1028
101	log_fdev[1]	-0.1767	0.0419	151	log_fdev[2]	-0.6062	0.1026
102	log_fdev[1]	0.7894	0.0451	152	log_fdev[2]	-0.3762	0.1025
103	log_fdev[1]	0.3819	0.0438	153	log_fdev[2]	-0.6571	0.1024
104	log_fdev[1]	-0.2162	0.0423	154	log_fdev[2]	-0.4930	0.1021
105	log_fdev[1]	-0.3014	0.0417	155	log_fdev[2]	-0.4231	0.1022
106	log_fdev[1]	-0.1917	0.0406	156	log_fdev[2]	-0.4598	0.1025
107	log_fdev[1]	0.2737	0.0393	157	log_fdev[2]	-0.8254	0.1027
108	log_fdev[1]	0.2300	0.0393	158	log_fdev[2]	-0.9867	0.1029
109	log_fdev[1]	0.5087	0.0397	159	log_fdev[2]	-1.4550	0.1028
110	log_fdev[1]	0.2488	0.0388	160	log_fdev[2]	-1.9816	0.1032
111	log_fdev[1]	0.6134	0.0388	161	log_fdev[2]	-1.2798	0.1037
112	log_fdev[1]	0.7772	0.0409	162	log_fdev[2]	-1.8574	0.1045
113	log_fdev[1]	0.5760	0.0419	163	log_fdev[2]	-1.5055	0.1061
114	log_fdev[1]	0.4312	0.0421	164	log_fdev[2]	-1.0216	0.1086
115	log_fdev[1]	-0.2039	0.0416	165	log_fdev[2]	-0.6217	0.1119
116	log_fdev[1]	-0.2809	0.0412	166	log_fdev[2]	-0.7132	0.1150
117	log_fdev[1]	-0.1157	0.0419	167	log_fdev[2]	-0.6279	0.1185
118	log_fdev[1]	0.2040	0.0440	168	log_fdev[3]	-0.0389	0.0685
119	log_fdev[1]	0.2318	0.0486	169	log_fdev[3]	-0.0388	0.0685
120	log_fdev[1]	0.1762	0.0559	170	log_fdev[3]	1.7536	0.0685
121	log_fdev[1]	0.0390	0.0652	171	log_fdev[3]	1.4488	0.0685
122	log_fdev[1]	-0.2324	0.0743	172	log_fdev[3]	1.6753	0.0685
123	log_fdev[1]	-0.2629	0.0820	173	log_fdev[3]	2.5538	0.0685
124	log_fdev[2]	0.1418	0.1261	174	log_fdev[3]	1.4425	0.0685
125	log_fdev[2]	0.6032	0.1168	175	log_fdev[3]	1.6003	0.0685
126	log_fdev[2]	0.6008	0.1111	176	log_fdev[3]	-0.2471	0.0685
127	log_fdev[2]	0.6844	0.1094	177	log_fdev[3]	0.9278	0.0685
128	log_fdev[2]	1.3961	0.1135	178	log_fdev[3]	0.4542	0.0685
129	log_fdev[2]	1.1126	0.1313	179	log_fdev[3]	0.9392	0.0685
130	log_fdev[2]	2.3962	0.1289	180	log_fdev[3]	1.6522	0.0685
131	log_fdev[2]	2.1357	0.1170	181	log_fdev[3]	1.6600	0.0685
132	log_fdev[2]	3.3701	0.1155	182	log_fdev[3]	2.9993	0.0720
133	log_fdev[2]	2.1852	0.1123	183	log_fdev[3]	1.0492	0.0729
134	log_fdev[2]	1.1270	0.1121	184	log_fdev[3]	0.3264	0.0792
135	log_fdev[2]	0.6761	0.1096	185	log_fdev[3]	-2.9934	0.0685
136	log_fdev[2]	1.4522	0.1052	186	log_fdev[3]	-3.9508	0.0685
137	log_fdev[2]	0.0183	0.1042	187	log_fdev[3]	-3.7276	0.0685
138	log_fdev[2]	0.4656	0.1043	188	log_fdev[3]	-3.7276	0.0685
139	log_fdev[2]	0.8772	0.1056	189	log_fdev[3]	-4.6439	0.0685
140	log_fdev[2]	0.7061	0.1056	190	log_fdev[3]	-1.1276	0.0702
141	log_fdev[2]	1.1851	0.1081	191	log_fdev[3]	-0.2264	0.0723
142	log_fdev[2]	-0.5717	0.1051	192	log_fdev[3]	0.2395	0.0772
193	log_fdev[4]	0.6887	0.1037	243	log_fdov[1]	-0.3031	0.0796
194	log_fdev[4]	0.0364	0.1022	244	log_fdov[1]	0.8545	0.0812
195	log_fdev[4]	-0.1681	0.1028	245	log_fdov[1]	0.2983	0.0841
196	log_fdev[4]	0.7408	0.1019	246	log_fdov[1]	-0.1485	0.0875

197	log_fdev[4]	-1.6971	0.1013	247	log_fdov[1]	0.9944	0.0918
198	log_fdev[4]	0.2552	0.1009	248	log_fdov[1]	0.1632	0.0959
199	log_fdev[4]	-0.0024	0.1005	249	log_fdov[3]	-0.0002	0.0967
200	log_fdev[4]	-0.8381	0.1004	250	log_fdov[3]	-0.0004	0.0967
201	log_fdev[4]	-0.6665	0.1001	251	log_fdov[3]	0.0002	0.0967
202	log_fdev[4]	-0.3943	0.0999	252	log_fdov[3]	0.0006	0.0967
203	log_fdev[4]	-0.4464	0.0996	253	log_fdov[3]	0.0006	0.0967
204	log_fdev[4]	0.0951	0.0996	254	log_fdov[3]	-0.0016	0.0966
205	log_fdev[4]	-0.6118	0.1001	255	log_fdov[3]	-0.0007	0.0967
206	log_fdev[4]	-1.6194	0.0999	256	log_fdov[3]	-0.0003	0.0967
207	log_fdev[4]	-2.5090	0.0995	257	log_fdov[3]	-0.0005	0.0967
208	log_fdev[4]	-0.9955	0.0992	258	log_fdov[3]	0.0002	0.0967
209	log_fdev[4]	-0.4479	0.0993	259	log_fdov[3]	0.0003	0.0967
210	log_fdev[4]	0.6876	0.0995	260	log_fdov[3]	0.0015	0.0967
211	log_fdev[4]	1.5158	0.1000	261	log_fdov[3]	0.0026	0.0967
212	log_fdev[4]	1.1726	0.1010	262	log_fdov[3]	0.0038	0.0967
213	log_fdev[4]	0.2879	0.1025	263	log_fdov[3]	0.5057	0.0988
214	log_fdev[4]	1.8747	0.1047	264	log_fdov[3]	0.7525	0.0978
215	log_fdev[4]	2.0949	0.1067	265	log_fdov[3]	-0.4482	0.1022
216	log_fdev[4]	0.9467	0.1090	266	log_fdov[3]	-0.0006	0.0967
217	log_foff[1]	-2.8529	0.0537	267	log_fdov[3]	-0.0006	0.0967
218	log_foff[3]	0.5009	0.0929	268	log_fdov[3]	-0.0006	0.0967
219	log_fdov[1]	2.0679	0.0841	269	log_fdov[3]	-0.0006	0.0967
220	log_fdov[1]	-0.5974	0.0832	270	log_fdov[3]	-0.0006	0.0967
221	log_fdov[1]	2.0825	0.0847	271	log_fdov[3]	0.0182	0.0966
222	log_fdov[1]	1.9121	0.0858	272	log_fdov[3]	-0.7141	0.0973
223	log_fdov[1]	-0.3400	0.0844	273	log_fdov[3]	-0.1175	0.0997
224	log_fdov[1]	-0.1270	0.0827	274	rec_dev_est	1.0794	0.2976
225	log_fdov[1]	-3.6240	0.0827	275	rec_dev_est	0.7311	0.2950
226	log_fdov[1]	-0.2733	0.0845	276	rec_dev_est	1.1263	0.2445
227	log_fdov[1]	1.4941	0.0829	277	rec_dev_est	1.7291	0.2113
228	log_fdov[1]	-2.7279	0.0813	278	rec_dev_est	1.9904	0.2231
229	log_fdov[1]	1.2165	0.0805	279	rec_dev_est	1.1519	0.2681
230	log_fdov[1]	0.9443	0.0805	280	rec_dev_est	2.3399	0.1690
231	log_fdov[1]	-1.8064	0.0798	281	rec_dev_est	1.3687	0.1839
232	log_fdov[1]	1.2767	0.0805	282	rec_dev_est	0.9960	0.1708
233	log_fdov[1]	0.4918	0.0809	283	rec_dev_est	-0.8590	0.2556
234	log_fdov[1]	1.0262	0.0796	284	rec_dev_est	0.2556	0.1674
235	log_fdov[1]	-1.1644	0.0791	285	rec_dev_est	-0.8849	0.2447
236	log_fdov[1]	-0.1117	0.0793	286	rec_dev_est	-1.3230	0.2789
237	log_fdov[1]	-0.3832	0.0795	287	rec_dev_est	-1.1210	0.2339
238	log_fdov[1]	-0.5928	0.0798	288	rec_dev_est	-0.1322	0.1713
239	log_fdov[1]	-0.1359	0.0803	289	rec_dev_est	-0.5997	0.1933
240	log_fdov[1]	-1.0767	0.0793	290	rec_dev_est	-2.0873	0.3716
241	log_fdov[1]	-1.7165	0.0787	291	rec_dev_est	-1.0340	0.2076
242	log_fdov[1]	0.3028	0.0788	292	rec_dev_est	-2.3004	0.5003
293	rec_dev_est	0.9320	0.1518	339	logit_rec_prop_es	1.4330	0.7775
294	rec_dev_est	-1.0433	0.2655	340	logit_rec_prop_es	0.6054	0.6934
295	rec_dev_est	-1.6231	0.3342	341	logit_rec_prop_es	0.4621	0.3267
296	rec_dev_est	-0.6536	0.2037	342	logit_rec_prop_es	-0.1146	0.1462
297	rec_dev_est	0.3285	0.1611	343	logit_rec_prop_es	0.2329	0.3548
298	rec_dev_est	-0.5955	0.2220	344	logit_rec_prop_es	-0.4851	0.3715

299	rec_dev_est	-0.5981	0.2419	345	logit_rec_prop_es	-0.5161	0.1317
300	rec_dev_est	0.7746	0.1599	346	logit_rec_prop_es	-0.3856	0.4374
301	rec_dev_est	-0.7101	0.2737	347	logit_rec_prop_es	-0.0832	0.4245
302	rec_dev_est	-0.6874	0.2618	348	logit_rec_prop_es	-0.4556	0.1413
303	rec_dev_est	0.5600	0.1615	349	logit_rec_prop_es	-0.0760	0.2474
304	rec_dev_est	-0.1755	0.1895	350	logit_rec_prop_es	0.1947	0.2815
305	rec_dev_est	-0.5592	0.1953	351	logit_rec_prop_es	-0.2368	0.3697
306	rec_dev_est	-1.1078	0.2414	352	logit_rec_prop_es	-0.3192	0.3748
307	rec_dev_est	-1.0323	0.2465	353	logit_rec_prop_es	-0.8485	0.1925
308	rec_dev_est	-0.0045	0.1799	354	logit_rec_prop_es	-0.3224	0.3105
309	rec_dev_est	-0.5554	0.2233	355	logit_rec_prop_es	-0.5481	0.3173
310	rec_dev_est	-0.9540	0.2248	356	logit_rec_prop_es	-0.0122	0.3469
311	rec_dev_est	-1.3618	0.2286	357	logit_rec_prop_es	-0.2385	0.4730
312	rec_dev_est	-1.9292	0.2923	358	logit_rec_prop_es	-0.1864	0.3287
313	rec_dev_est	-1.4162	0.2269	359	logit_rec_prop_es	0.2586	0.2467
314	rec_dev_est	-0.8414	0.1882	360	logit_rec_prop_es	0.6521	0.5618
315	rec_dev_est	-1.6911	0.2850	361	logit_rec_prop_es	0.4341	0.4426
316	rec_dev_est	-1.2456	0.2701	362	logit_rec_prop_es	0.7423	0.9166
317	rec_dev_est	-1.8541	0.4577	363	logit_rec_prop_es	-0.3395	1.6742
318	rec_dev_est	-0.2405	1.3063	364	m_dev_est[1]	1.6056	0.0288
319	logit_rec_prop_es	-0.1738	0.4779	365	survey_q[1]	0.9592	0.0280
320	logit_rec_prop_es	-0.7552	0.4696	366	log_add_cv[2]	-0.9615	0.2885
321	logit_rec_prop_es	-0.2946	0.3618	367	sd_rbar	16133000	521640
322	logit_rec_prop_es	-0.5530	0.2706	368	sd_ssbF0	72699.0	2135.60
323	logit_rec_prop_es	-0.0626	0.2743	369	sd_Bmsy	25445.0	747.440
324	logit_rec_prop_es	0.0951	0.3784	370	sd_depl	0.5867	0.0405
325	logit_rec_prop_es	0.3407	0.1569	371	sd_fmsy	0.2907	0.0043
326	logit_rec_prop_es	0.3958	0.2409	372	sd_fmsy	0.0059	0.0006
327	logit_rec_prop_es	-0.0992	0.1810	373	sd_fmsy	0.0011	0.0001
328	logit_rec_prop_es	0.5050	0.4900	374	sd_fmsy	0.0059	0.0006
329	logit_rec_prop_es	-0.4662	0.1645	375	sd_fmsy	0.0000	0.0000
330	logit_rec_prop_es	0.2581	0.4222	376	sd_fmsy	0.0000	0.0000
331	logit_rec_prop_es	-0.0528	0.4617	377	sd_fofl	0.1572	0.0137
332	logit_rec_prop_es	0.4767	0.4221	378	sd_fofl	0.0059	0.0006
333	logit_rec_prop_es	-0.1924	0.1754	379	sd_fofl	0.0011	0.0001
334	logit_rec_prop_es	0.1362	0.2614	380	sd_fofl	0.0059	0.0006
335	logit_rec_prop_es	0.9226	0.8947	381	sd_fofl	0.0000	0.0000
336	logit_rec_prop_es	0.0337	0.2920	382	sd_fofl	0.0000	0.0000
337	logit_rec_prop_es	-0.0668	0.8645	383	sd_ofl	2140.700	334.4400
338	logit_rec_prop_es	-0.2947	0.0904				

Table 6a. Annual abundance estimates (million 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 (model 19.0a) during 1975-2020. Mature male biomass for year *t* is on Feb. 15, year *t*+1. Size measurements are mm carapace length. The highlighted cell shows a very unreliable recruitment estimate.

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	59.824	31.215	92.553	9.555	58.594		248.677	202.731
1976	68.579	37.909	106.416	8.908	100.154	76.287	290.527	331.868
1977	73.255	42.679	115.195	7.524	125.875	48.646	302.138	375.661
1978	76.379	45.716	116.397	5.794	120.830	65.402	293.370	349.545
1979	65.788	44.991	92.239	3.980	108.793	115.358	270.123	167.627
1980	46.636	34.415	25.805	1.563	105.213	134.085	241.483	249.322
1981	13.368	7.387	5.145	0.855	47.721	63.839	97.474	132.669
1982	5.883	1.820	5.799	0.782	22.102	183.294	57.006	143.740
1983	5.857	2.034	7.493	0.663	13.924	86.260	51.731	49.320
1984	6.062	2.433	5.719	0.506	13.405	72.749	49.328	155.312
1985	8.088	2.094	10.729	0.750	10.751	11.824	37.416	34.535
1986	12.931	4.990	16.517	1.117	15.488	36.908	48.489	48.158
1987	15.153	7.135	21.972	1.335	18.964	11.309	54.502	70.263
1988	15.108	8.916	26.534	1.386	23.315	7.405	57.188	55.372
1989	16.101	10.128	29.168	1.319	20.984	6.872	58.417	55.941
1990	15.479	10.733	25.099	1.234	17.291	23.484	57.063	60.321
1991	11.917	8.891	19.279	1.157	15.592	11.005	50.829	85.055
1992	9.532	6.679	17.893	1.105	15.987	2.876	44.857	37.687
1993	10.518	6.287	16.053	1.147	13.477	7.534	42.823	53.703
1994	10.167	5.955	21.482	1.226	10.519	2.505	37.024	32.335
1995	10.549	7.689	24.259	1.203	10.436	48.931	42.900	38.396
1996	10.615	8.240	22.253	1.134	15.001	7.606	52.092	44.649
1997	9.823	7.325	20.477	1.102	22.353	4.023	58.159	85.277
1998	15.429	7.117	23.323	1.327	20.545	11.426	62.526	85.176
1999	16.628	9.125	27.396	1.514	18.140	27.734	61.594	65.604
2000	14.404	10.189	27.831	1.516	19.616	11.335	63.927	68.102
2001	14.162	9.876	28.252	1.483	22.355	12.120	68.102	53.188
2002	16.914	10.037	32.202	1.515	22.610	41.904	73.568	69.786
2003	17.932	11.608	32.023	1.496	27.359	10.072	80.213	116.794
2004	16.268	11.321	29.821	1.426	33.334	10.177	82.398	131.910
2005	18.415	10.639	30.879	1.420	32.206	37.840	84.577	107.341
2006	17.644	11.387	31.638	1.401	33.678	16.686	86.182	95.676
2007	16.043	11.263	26.972	1.332	38.705	12.550	89.508	104.841
2008	16.779	9.718	26.327	1.403	37.383	6.747	87.662	114.430
2009	16.961	9.906	27.918	1.510	34.371	7.862	83.287	91.673
2010	15.886	10.368	27.557	1.507	31.285	20.681	79.648	81.642
2011	13.583	9.921	27.373	1.437	31.169	12.733	76.660	67.053
2012	12.260	9.403	25.955	1.360	33.395	7.941	76.409	61.248
2013	12.323	8.704	25.253	1.321	32.456	5.753	75.007	62.410
2014	12.405	8.536	23.881	1.319	29.870	3.258	71.455	114.103
2015	11.132	8.099	21.576	1.330	26.593	5.697	65.526	64.240
2016	9.515	7.229	19.033	1.352	23.537	10.641	59.572	61.231
2017	7.879	6.259	16.525	1.357	21.796	4.455	54.975	52.922
2018	7.070	5.327	15.365	1.387	20.335	7.204	51.678	28.932
2019	7.856	5.047	16.287	1.542	18.337	4.619	49.595	28.744
2020	8.222	5.540	16.561	1.185	16.969	57.313		

Table 6b. Annual abundance estimates (million 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 (model 19.3) during 1975-2020. Mature male biomass for year *t* is on Feb. 15, year *t*+1. Size measurements are mm carapace length. The highlighted cell shows a very unreliable recruitment estimate.

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	57.510	30.033	88.074	9.093	57.640		233.362	202.731
1976	66.807	36.605	102.546	8.584	91.349	70.625	272.161	331.868
1977	73.512	41.868	114.496	7.479	124.005	49.849	294.567	375.661
1978	78.735	46.378	120.111	5.979	128.207	74.012	299.709	349.545
1979	69.672	47.182	100.043	4.316	123.110	135.246	291.714	167.627
1980	52.117	37.842	30.293	1.835	126.594	175.629	280.477	249.322
1981	15.211	8.130	6.866	1.141	55.764	75.931	112.334	132.669
1982	7.114	2.252	6.873	0.927	24.830	249.089	69.540	143.740
1983	6.447	2.252	7.689	0.680	15.709	94.311	59.842	49.320
1984	6.169	2.354	5.258	0.465	14.618	64.973	51.154	155.312
1985	7.520	1.854	9.605	0.671	9.902	10.165	34.527	34.535
1986	12.079	4.594	14.870	1.005	13.818	30.986	45.010	48.158
1987	14.241	6.584	20.087	1.220	17.184	9.906	50.786	70.263
1988	14.314	8.328	24.736	1.292	21.684	6.391	54.268	55.372
1989	15.555	9.606	27.738	1.255	20.408	7.822	57.078	55.941
1990	15.152	10.379	24.181	1.188	18.069	21.026	57.209	60.321
1991	11.710	8.694	18.709	1.122	17.428	13.175	52.137	85.055
1992	9.364	6.555	17.471	1.079	18.700	2.976	47.443	37.687
1993	10.405	6.199	15.788	1.128	17.408	8.533	46.767	53.703
1994	10.172	5.936	21.438	1.224	14.799	2.405	41.945	32.335
1995	10.677	7.764	24.504	1.215	13.665	60.942	47.884	38.396
1996	10.786	8.388	22.669	1.155	19.834	8.454	57.153	44.649
1997	10.056	7.500	21.044	1.132	29.204	4.734	63.220	85.277
1998	15.657	7.336	23.885	1.358	25.554	12.482	67.192	85.176
1999	16.755	9.402	27.888	1.542	21.571	33.329	65.731	65.604
2000	14.529	10.426	28.358	1.544	23.110	13.230	67.546	68.102
2001	14.323	10.074	28.833	1.513	26.337	13.196	71.214	53.188
2002	17.013	10.241	32.689	1.538	25.600	52.068	76.387	69.786
2003	17.939	11.804	32.330	1.510	31.356	11.798	82.650	116.794
2004	16.252	11.448	30.031	1.436	38.727	12.068	84.330	131.910
2005	18.170	10.707	30.673	1.410	35.976	42.013	85.769	107.341
2006	17.287	11.331	31.150	1.379	36.928	20.136	86.267	95.676
2007	15.646	11.114	26.295	1.299	41.524	13.719	88.489	104.841
2008	16.198	9.486	25.265	1.346	39.154	7.926	85.461	114.430
2009	16.245	9.567	26.531	1.435	34.624	8.548	79.898	91.673
2010	15.168	9.939	26.053	1.425	30.370	23.889	75.264	81.642
2011	12.925	9.459	25.889	1.359	29.952	13.771	71.252	67.053
2012	11.643	8.947	24.502	1.283	32.030	9.244	70.123	61.248
2013	11.670	8.256	23.728	1.241	30.405	6.148	67.944	62.410
2014	11.658	8.069	22.187	1.225	27.191	3.486	63.732	114.103
2015	10.360	7.575	19.786	1.220	23.252	5.823	57.246	64.240
2016	8.772	6.674	17.238	1.224	19.789	10.346	50.807	61.231
2017	7.197	5.709	14.783	1.214	17.900	4.423	45.776	52.922
2018	6.362	4.800	13.580	1.226	16.240	6.906	42.167	28.932
2019	6.983	4.493	14.237	1.348	14.118	3.758	39.853	28.744
2020	7.305	4.896	14.928	1.185	12.471	18.867		

Table 7. Comparison of projected mature male biomass (1000 t) on Feb. 15 and their 95% limits with four levels of fishing mortality during 2020-2030. Parameter estimates with model 19.3a are used for the projection with recruitments randomly drawn from estimated recruitments from 2012 to 2019. Fishing mortality of 0.167 is about estimated F_{ofl} for Model 19.3a for 2020.

	F=0			F=0.083		
	Mean	2.5% limit	97.5% limit	Mean	2.5% limit	97.5% limit
2020	16.559	15.055	17.985	15.562	14.142	16.896
2021	18.365	16.408	20.181	16.365	14.543	18.058
2022	19.274	17.074	21.720	16.340	14.399	18.530
2023	19.876	17.551	22.607	16.136	14.145	18.508
2024	20.567	18.082	23.657	16.154	13.986	18.811
2025	21.251	18.268	24.662	16.273	13.670	19.145
2026	21.883	18.439	25.880	16.425	13.441	19.680
2027	22.451	18.484	26.760	16.579	13.304	20.149
2028	22.906	18.886	27.598	16.678	13.385	20.426
2029	23.305	19.103	28.054	16.772	13.439	20.390
2030	23.677	19.278	28.473	16.881	13.420	20.644

	F=0.167			F=0.250		
	Mean	2.5% limit	97.5% limit	Mean	2.5% limit	97.5% limit
2020	14.638	13.299	15.885	13.780	12.514	14.939
2021	14.629	12.942	16.223	13.122	11.551	14.613
2022	13.950	12.205	15.930	11.996	10.410	13.832
2023	13.267	11.564	15.364	11.051	9.580	12.925
2024	12.951	10.999	15.183	10.597	8.846	12.625
2025	12.833	10.581	15.242	10.409	8.396	12.557
2026	12.809	10.170	15.613	10.346	8.016	12.819
2027	12.829	10.086	15.747	10.340	7.946	12.939
2028	12.821	10.045	15.907	10.314	7.852	12.899
2029	12.833	10.068	15.891	10.312	7.945	12.854
2030	12.877	10.035	16.016	10.346	7.908	12.898

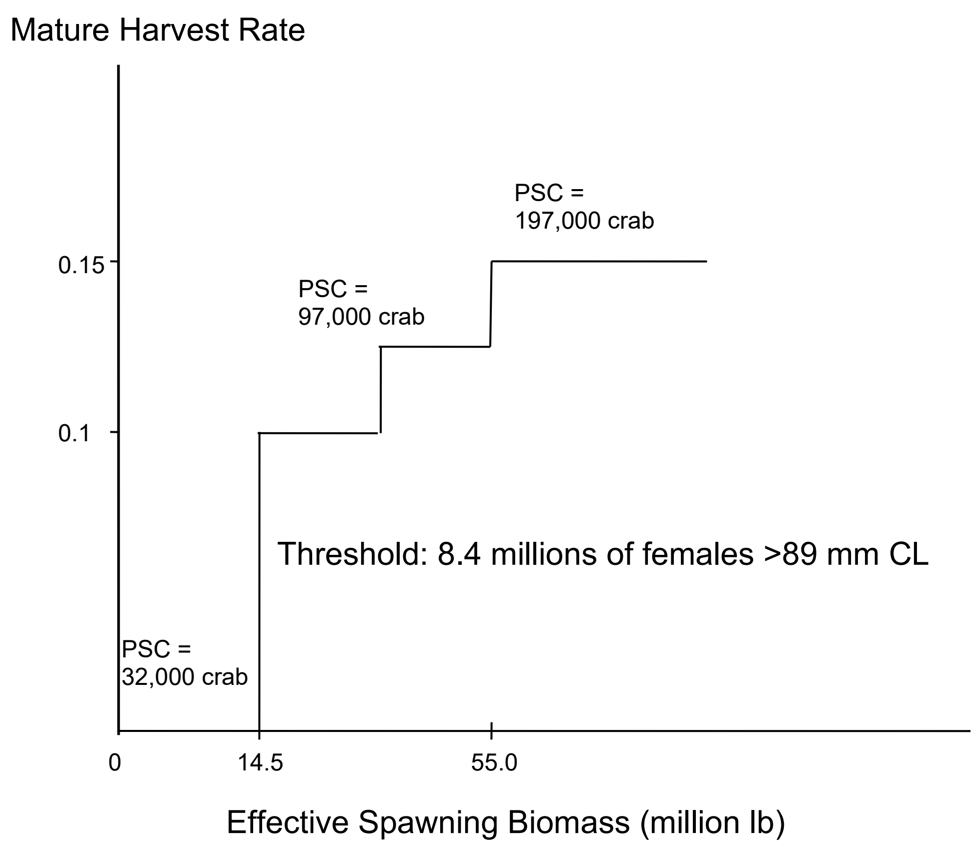


Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crab) of Bristol Bay red king crab in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates of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

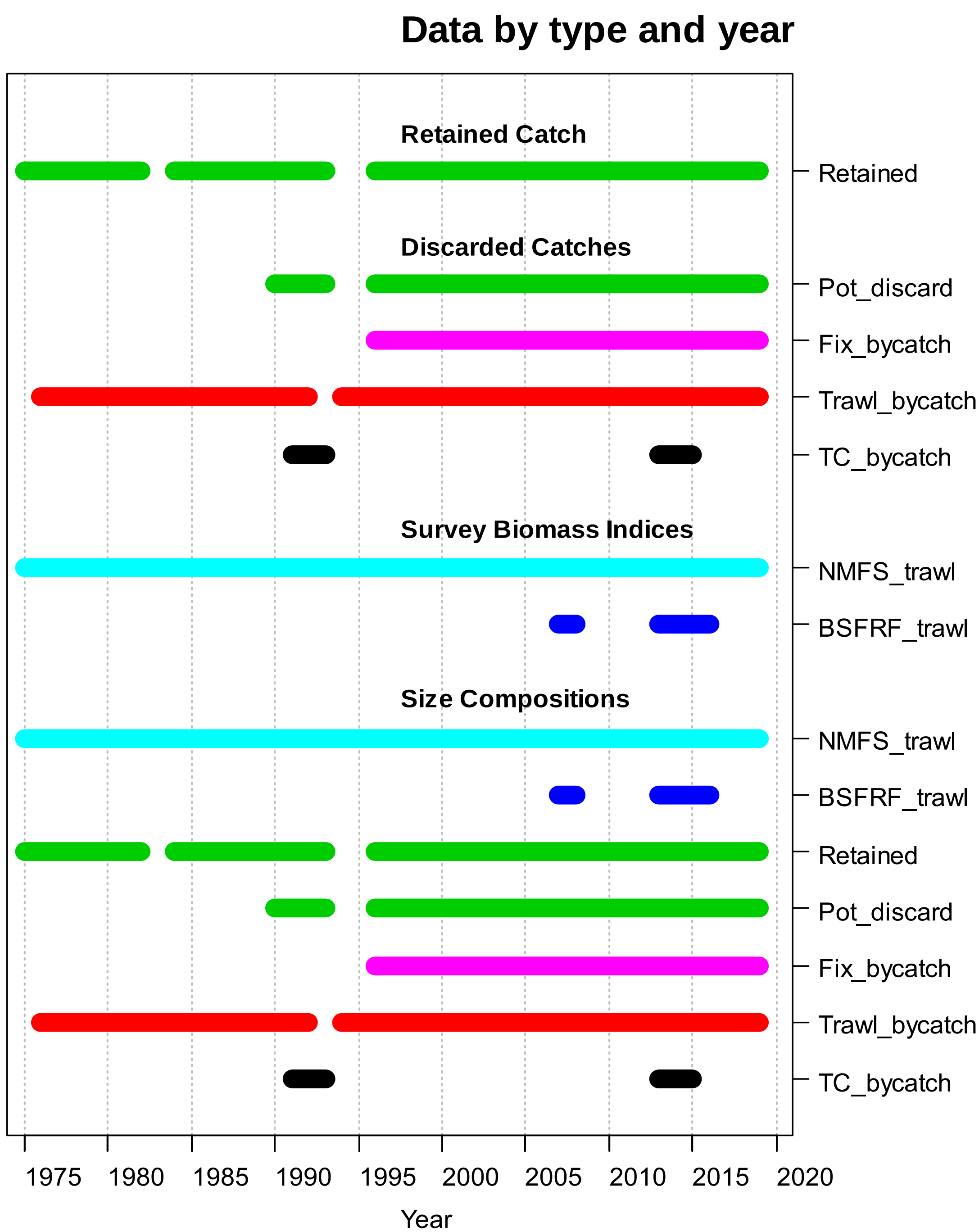


Figure 2. Data types and ranges used for the stock assessment.

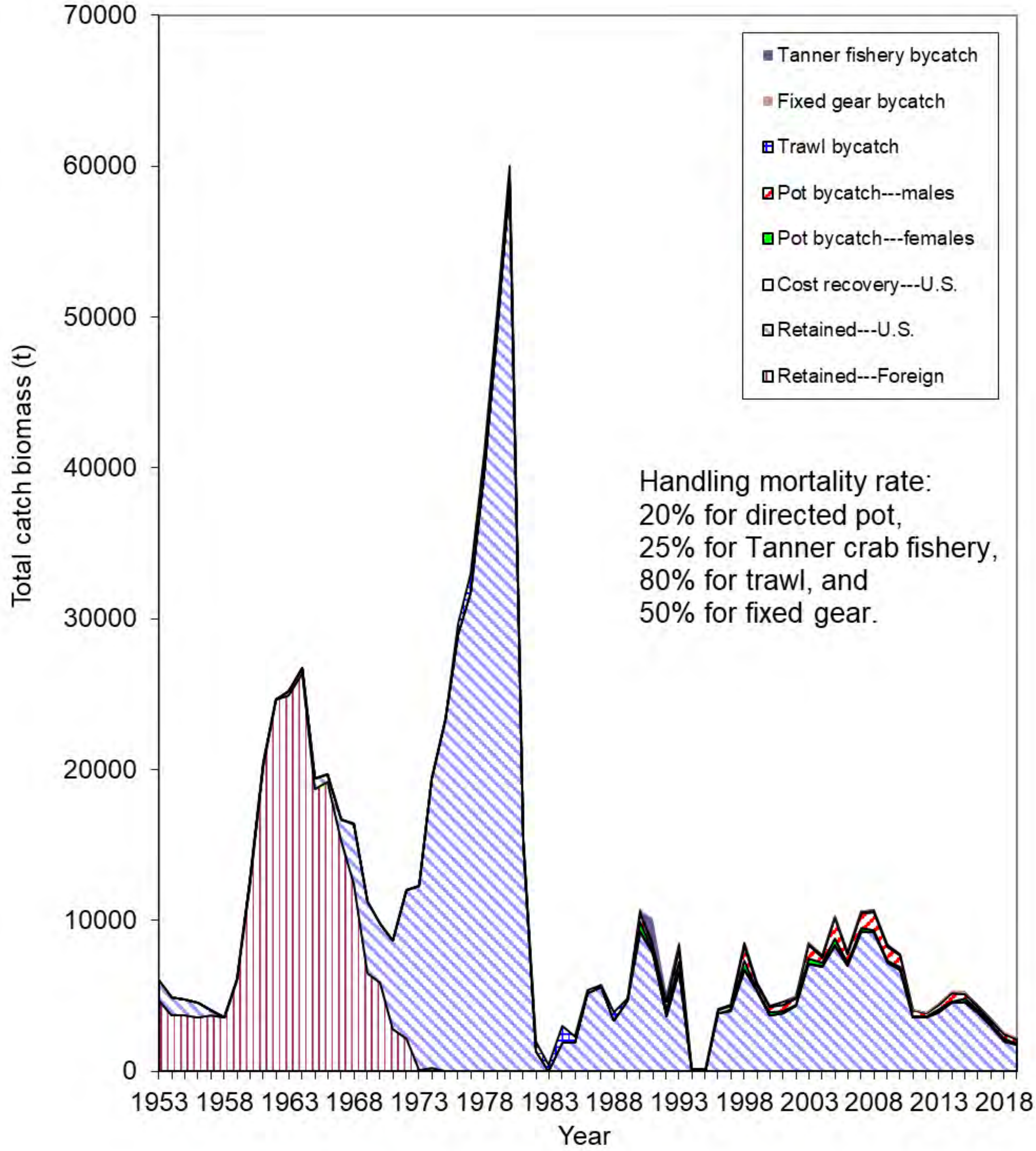


Figure 3. Retained catch biomass and bycatch mortality biomass (t) for Bristol Bay red king crab from 1953 to 2019. Directed pot bycatch data were not available from the observer program before 1990 and are not included in this figure.

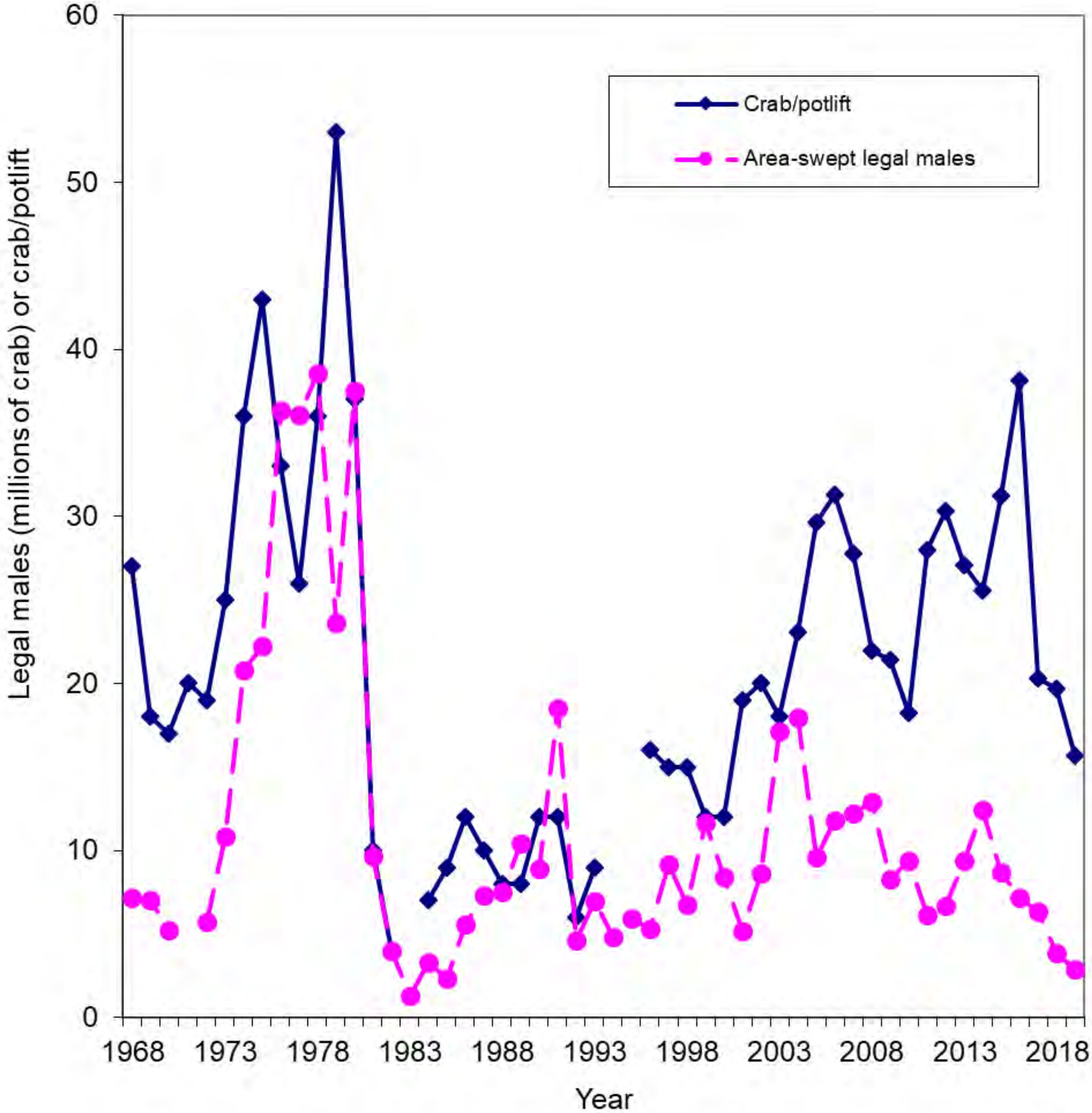


Figure 4. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2019.

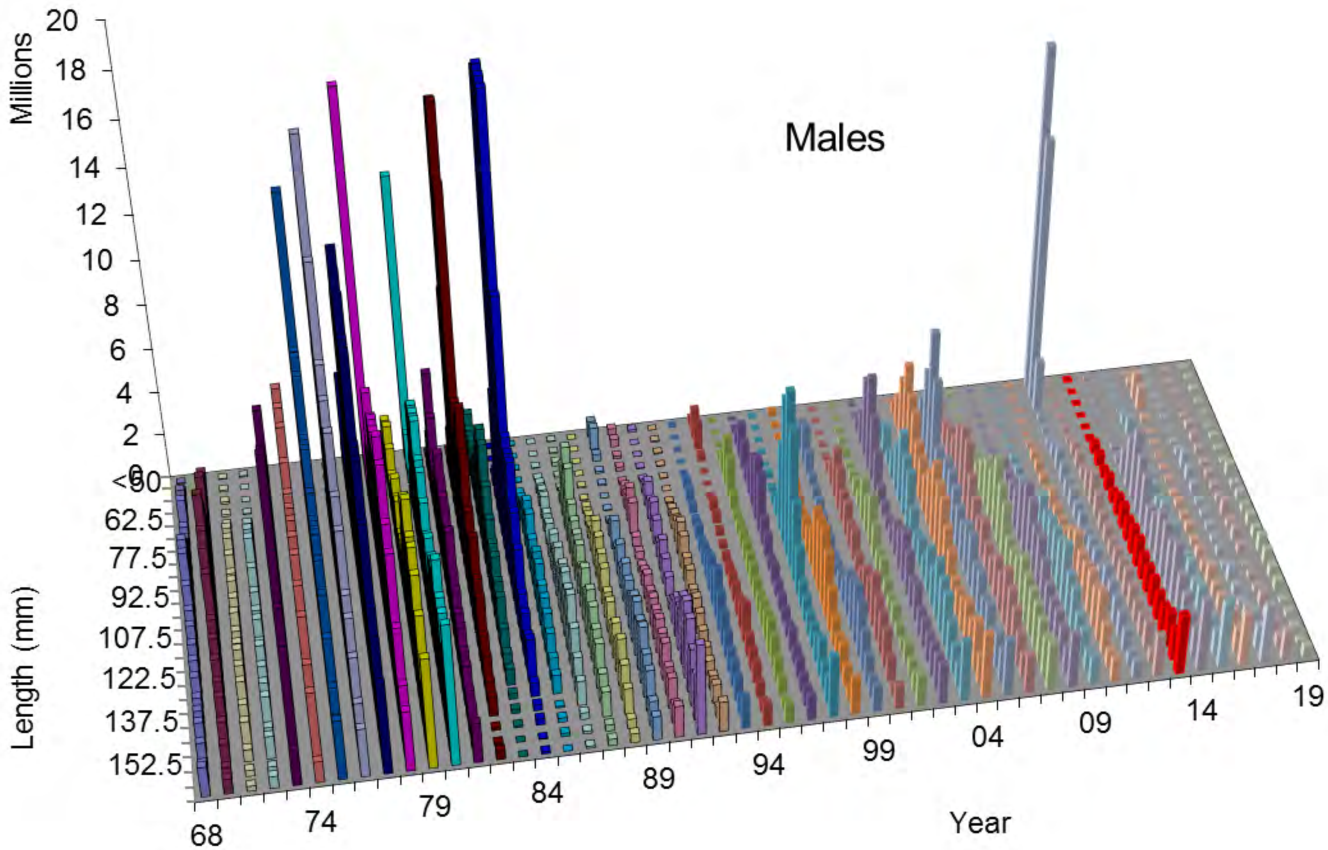


Figure 5a. Survey abundances by 5-mm carapace length bin for male Bristol Bay red king crab from 1968 to 2019.

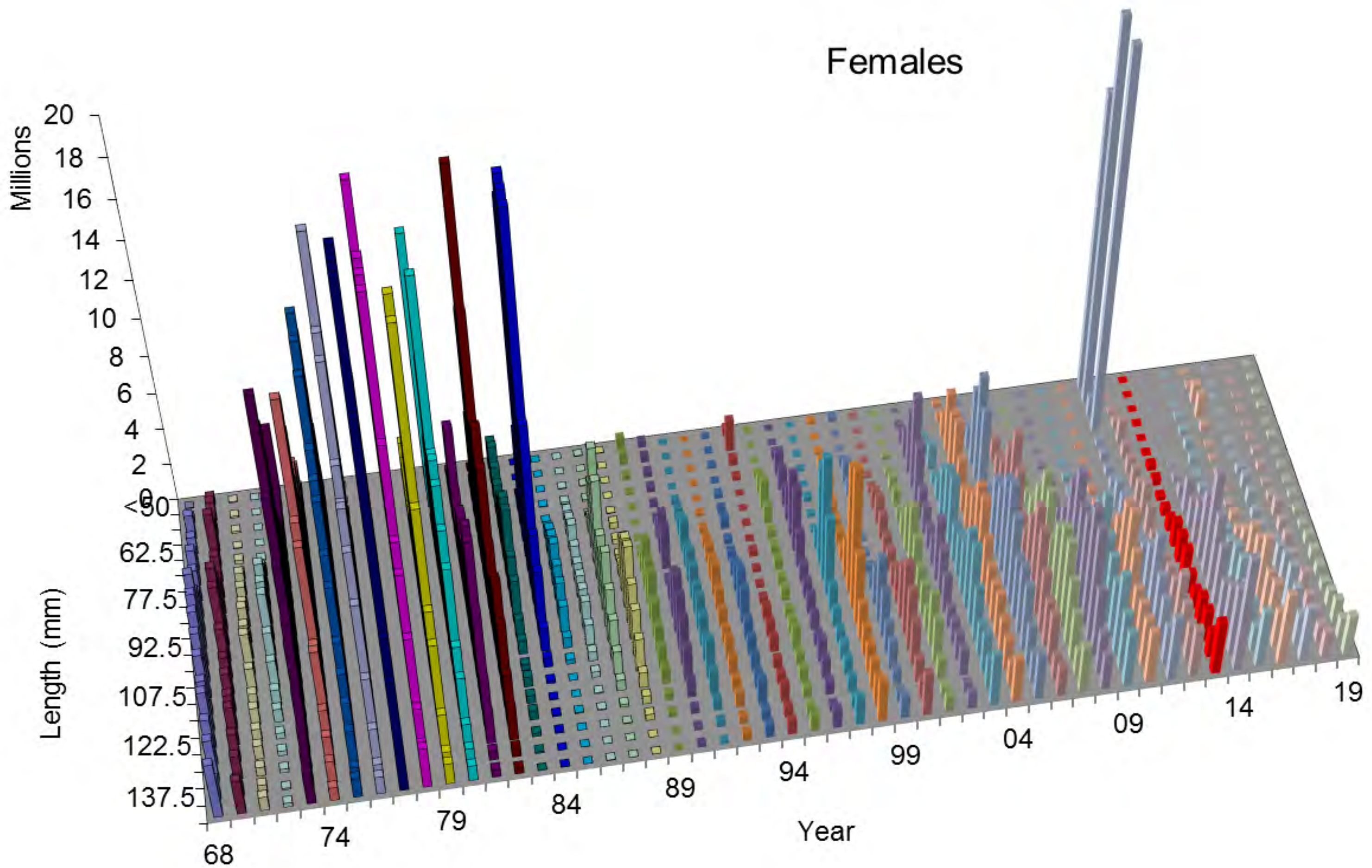


Figure 5b. Survey abundances by 5 mm carapace length bin for female Bristol Bay red king crab from 1968 to 2019.

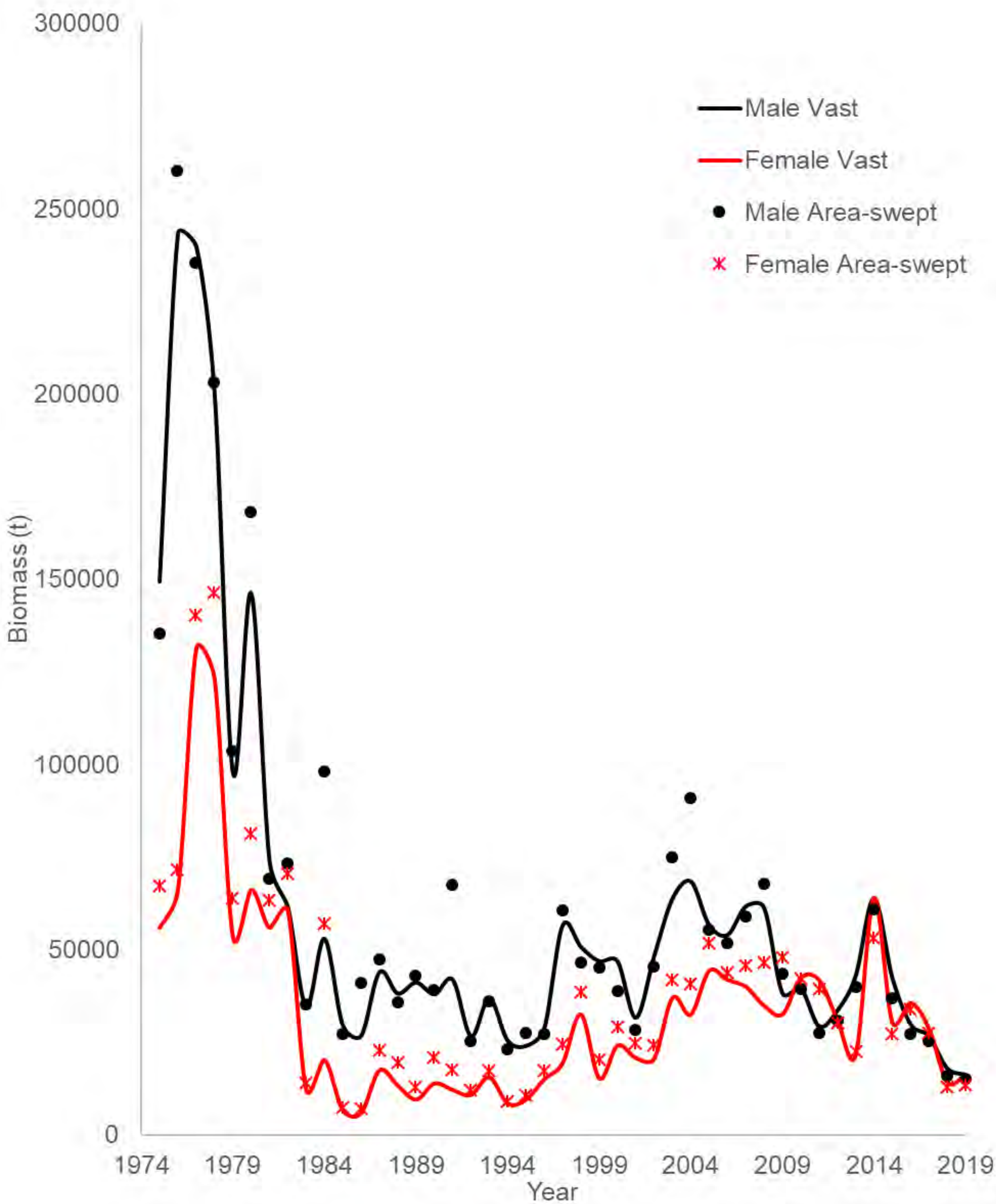


Figure 6. Comparison of area-swept and VAST-estimated survey biomasses for Bristol Bay red king crab from 1975 to 2019.

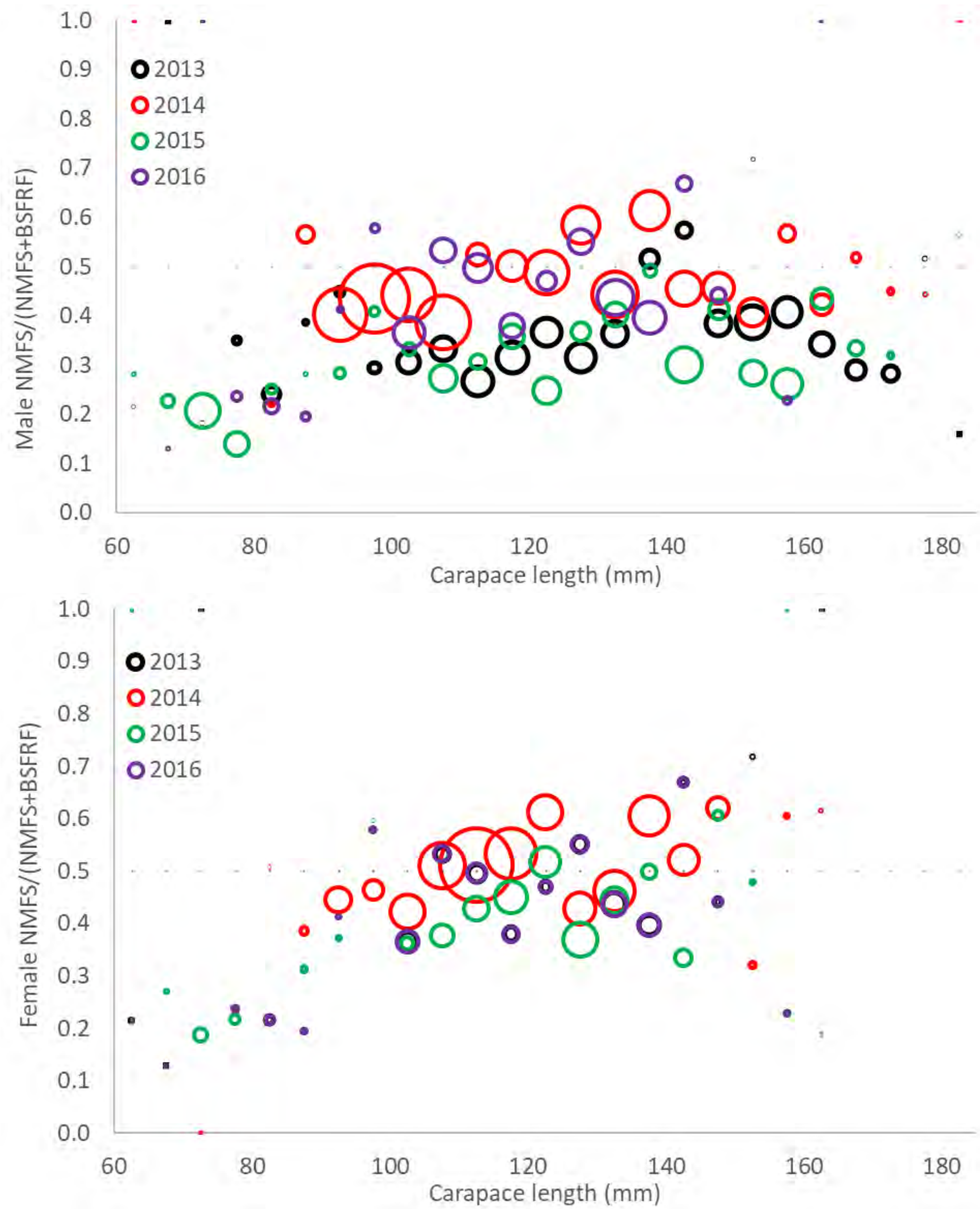
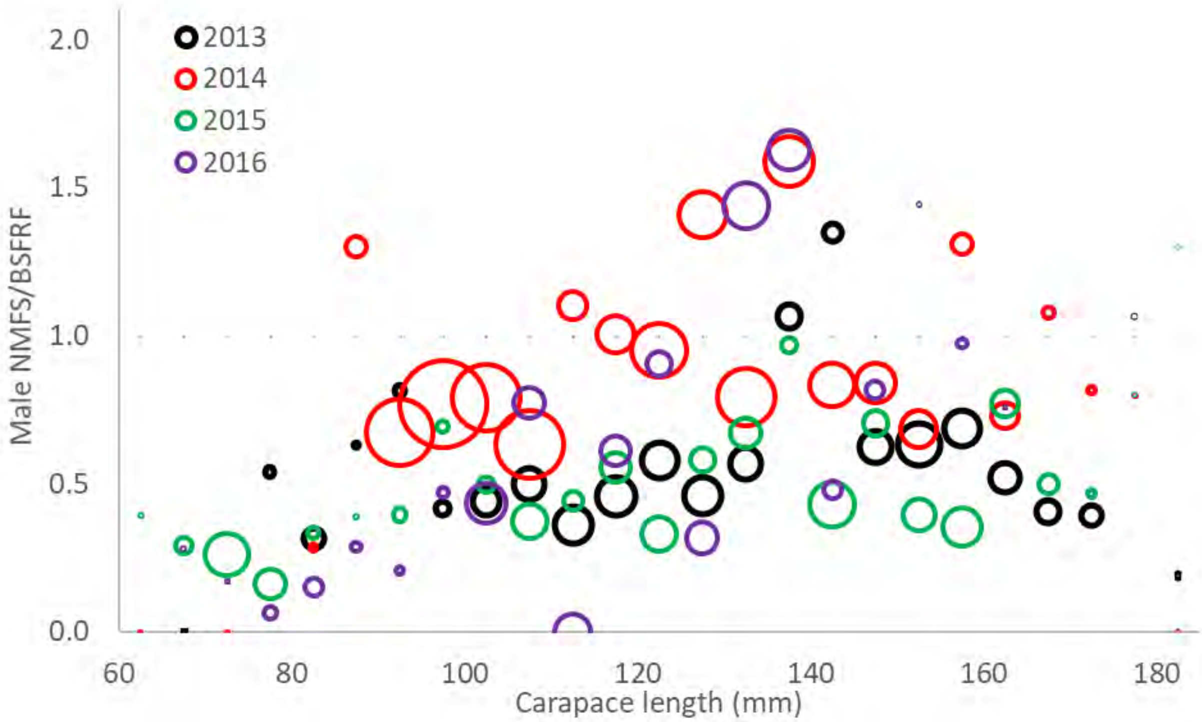


Figure 7a. Comparison of NMFS survey abundance proportions of total NMFS and BSFRF side-by-side trawl surveys during 2013-2016 for Bristol Bay red king crab. Sizes of circles are proportional to total abundances.



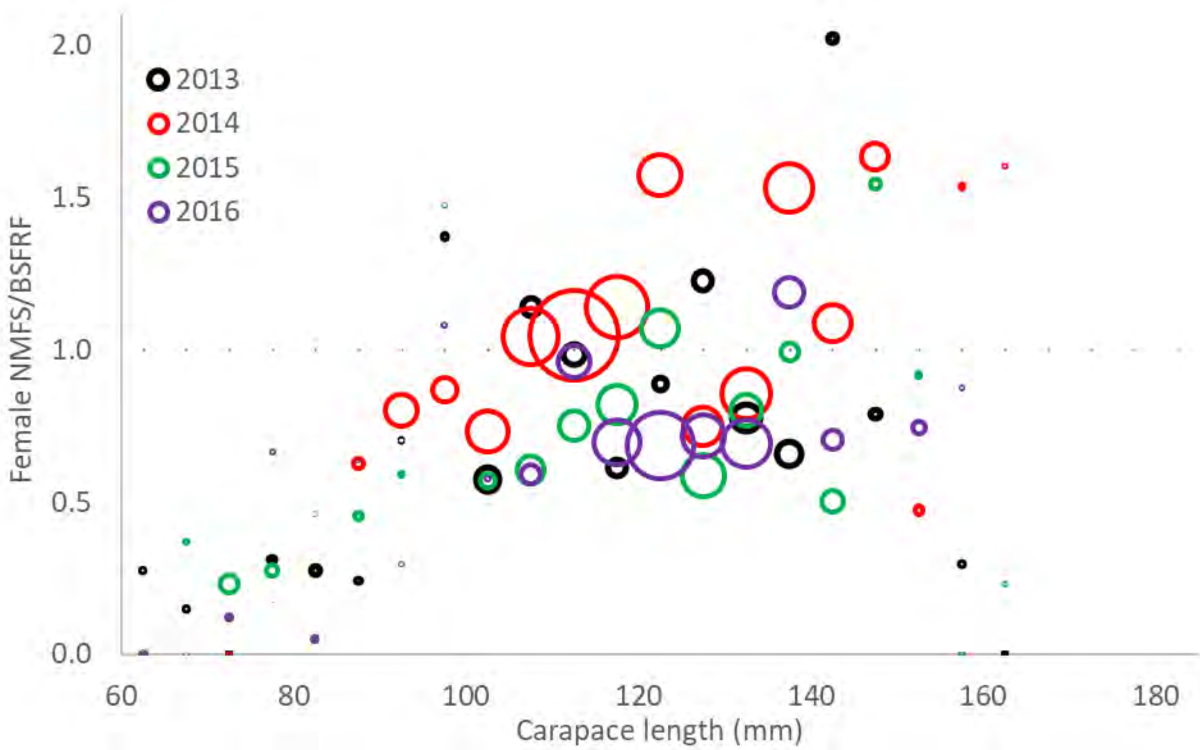


Figure 7b. Comparison of ratios of NMFS survey abundances to BSFRF side-by-side survey abundances during 2013-2016 for Bristol Bay red king crab. Sizes of circles are proportional to total abundances.

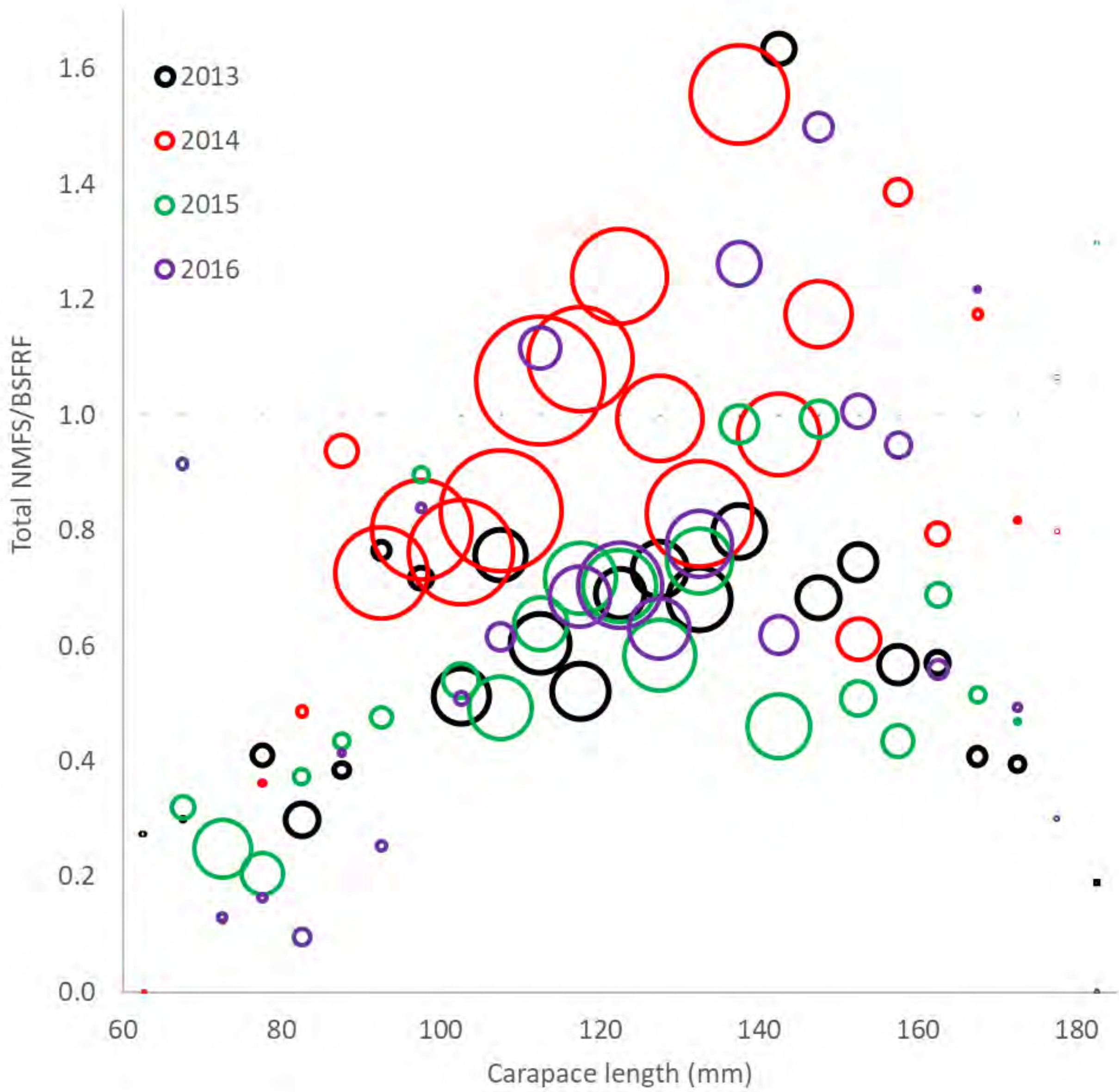


Figure 7c. Comparison of ratios of NMFS survey abundances to BSFRF side-by-side survey abundances during 2013-2016 for Bristol Bay red king crab. Sizes of circles are proportional to total abundances. The abundance-weighted average ratio is 0.891 for crab ≥135 mm carapace length from all four years of data. The approach to compute this overall ratio is documented in section D. Data, 4. Bering Sea Fisheries Research Foundation Survey Data.

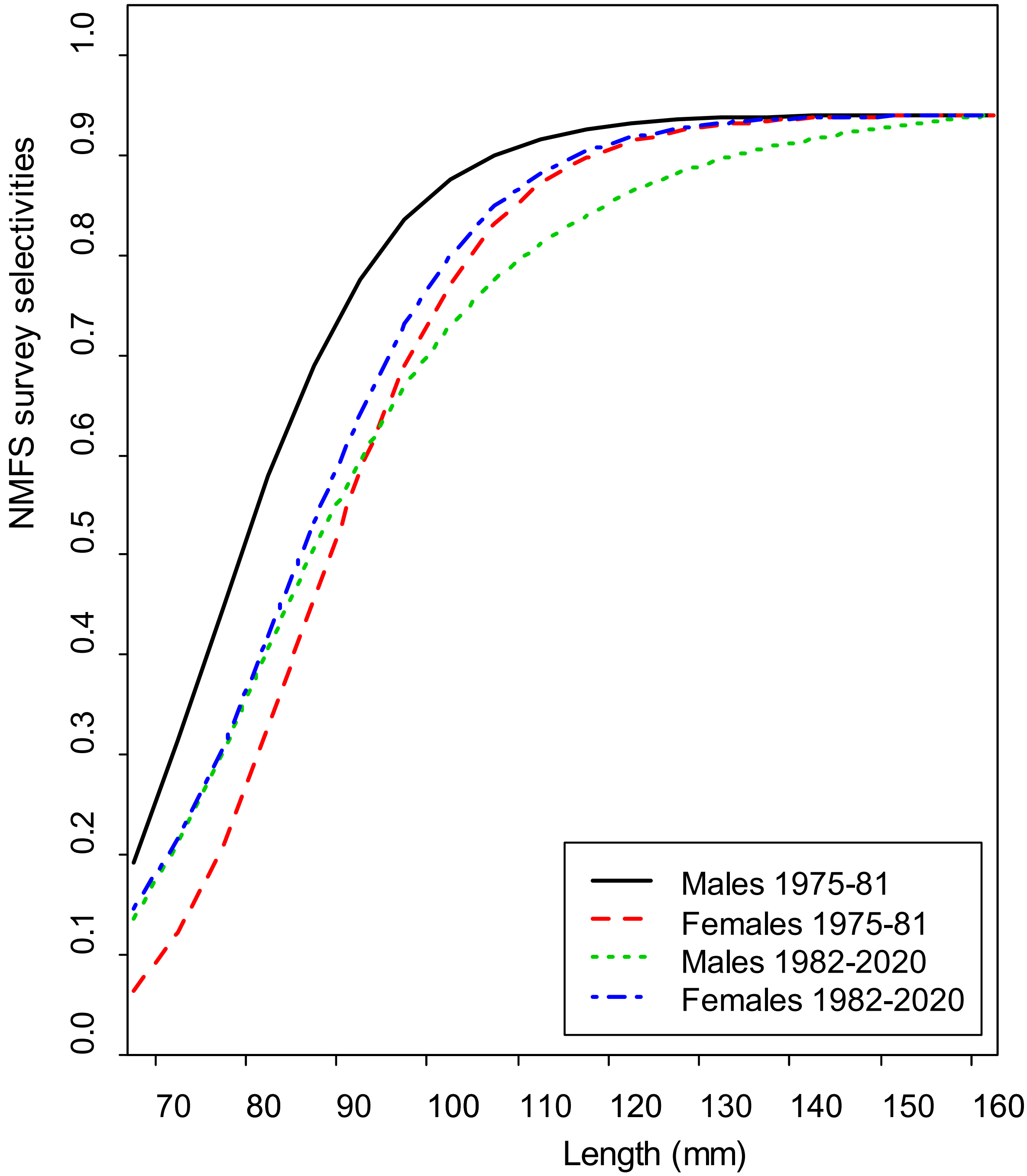


Figure 8a. Estimated NMFS trawl survey selectivities under model 19.0a.

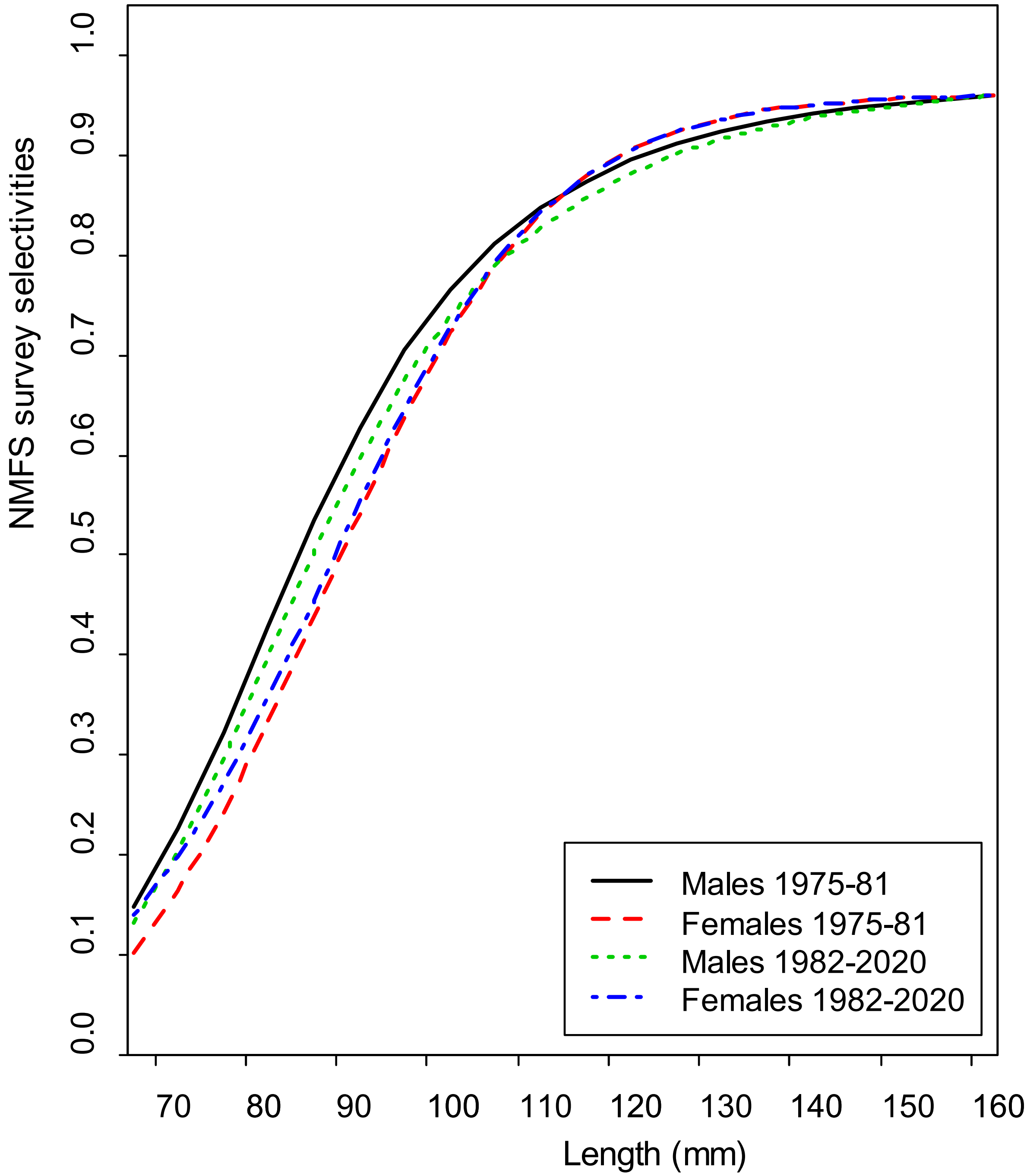


Figure 8b. Estimated NMFS trawl survey selectivities under model 19.3.

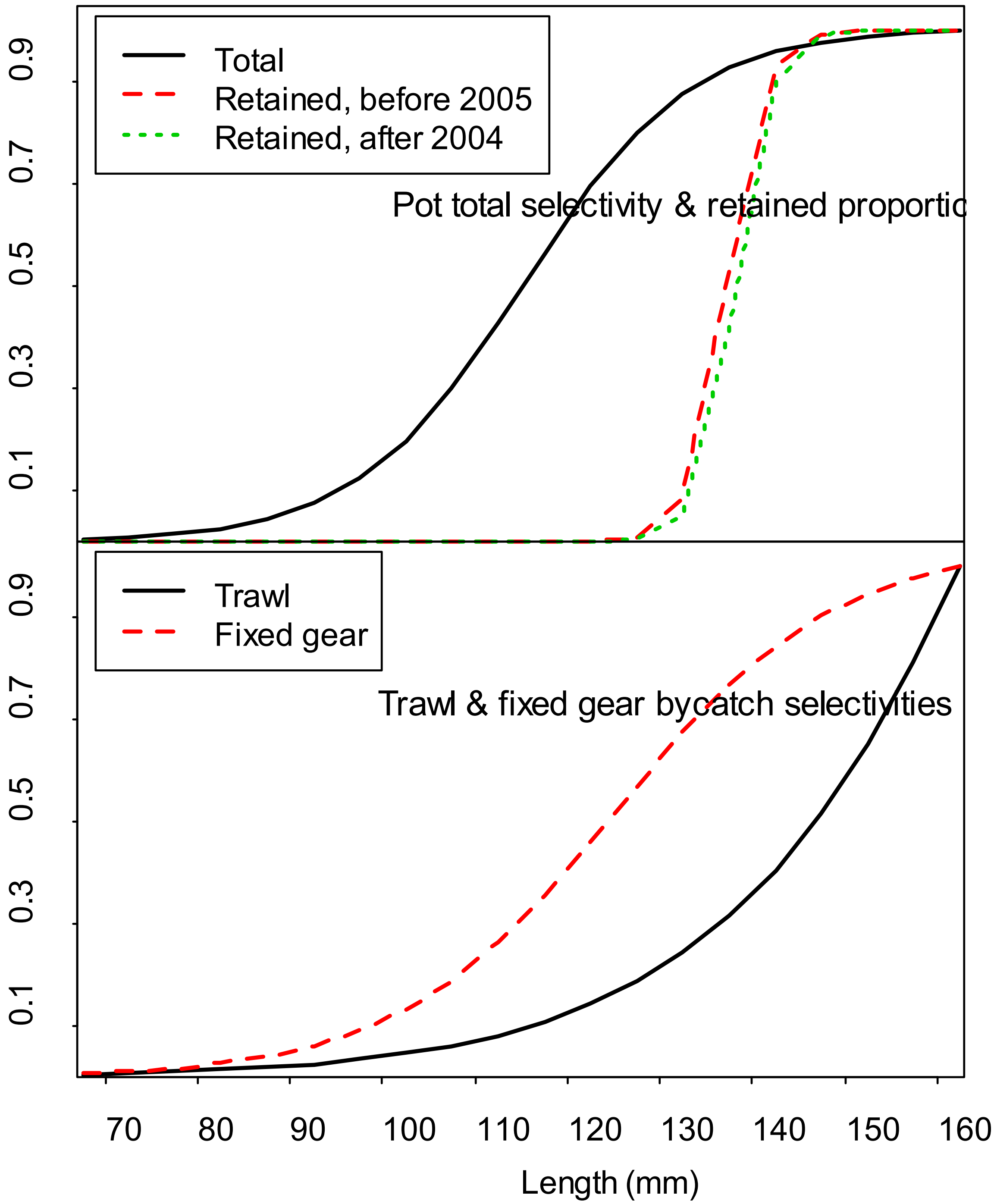


Figure 8c. Estimated total pot fishery selectivities and retained proportions and groundfish fisheries bycatch selectivities under model 19.0a.

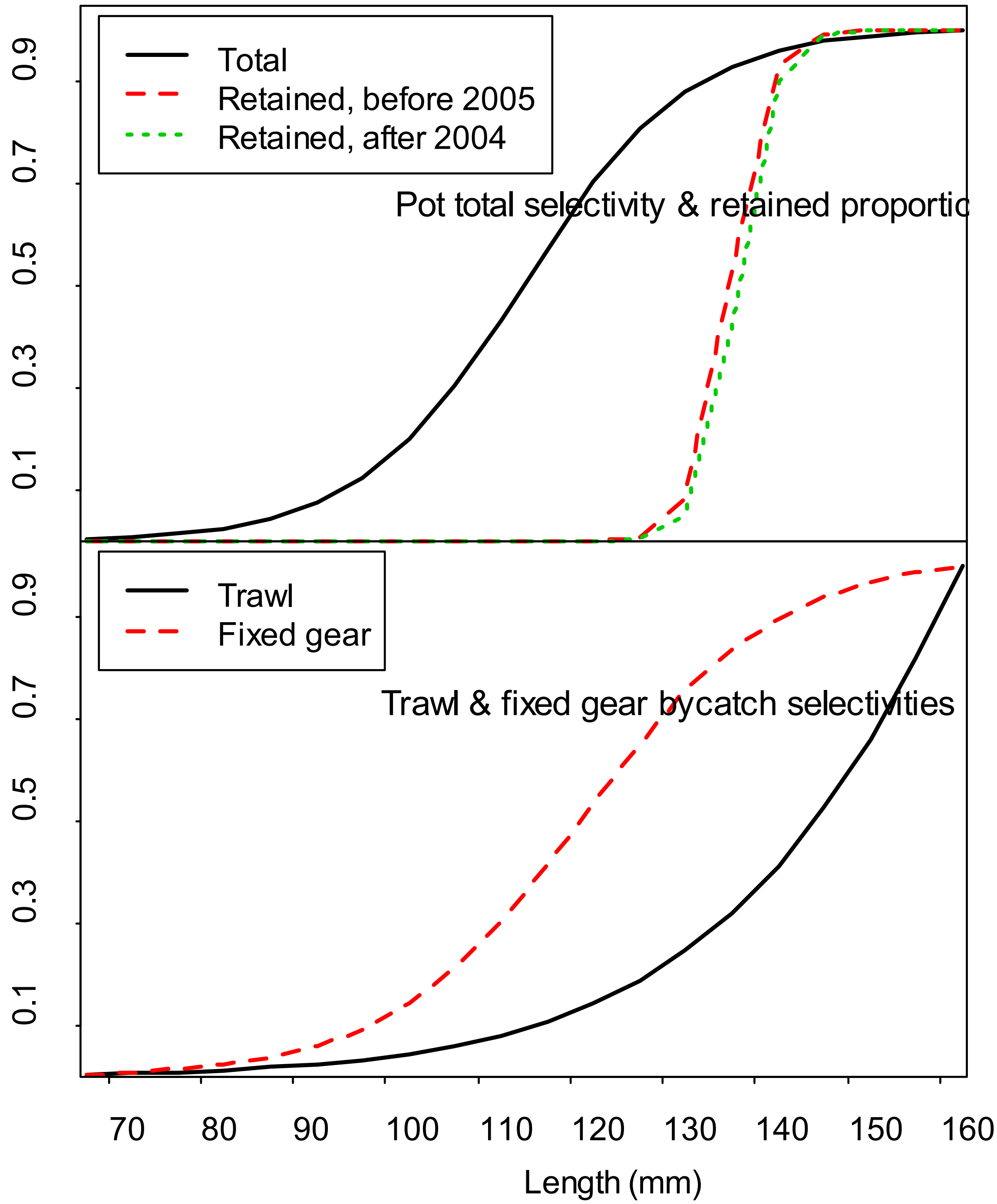


Figure 8d. Estimated total pot fishery selectivities and retained proportions and groundfish fisheries bycatch selectivities under model 19.3.

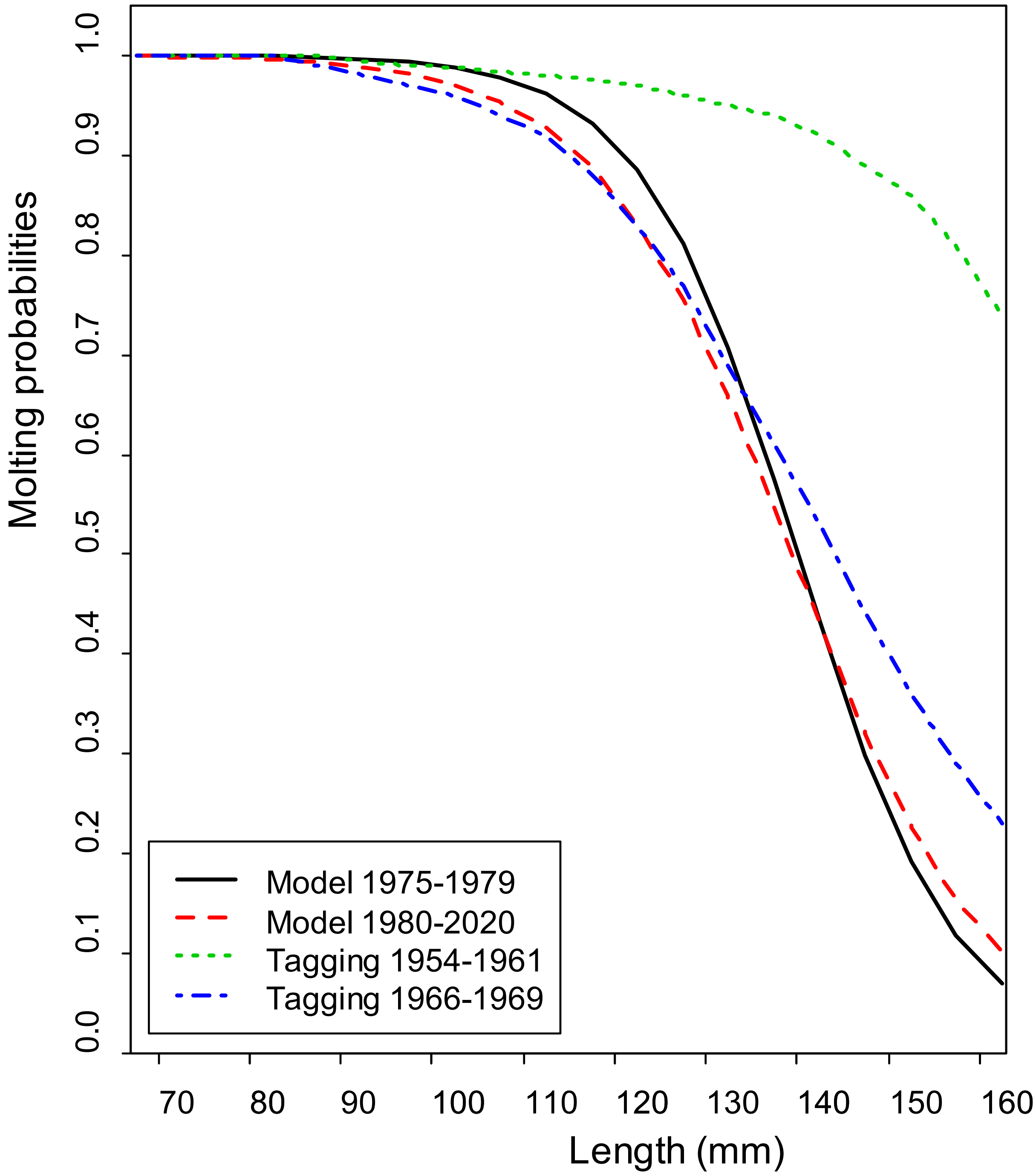


Figure 9a. Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods with model 19.0a. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-1979 and 1980-2020 were estimated with a length-based model.

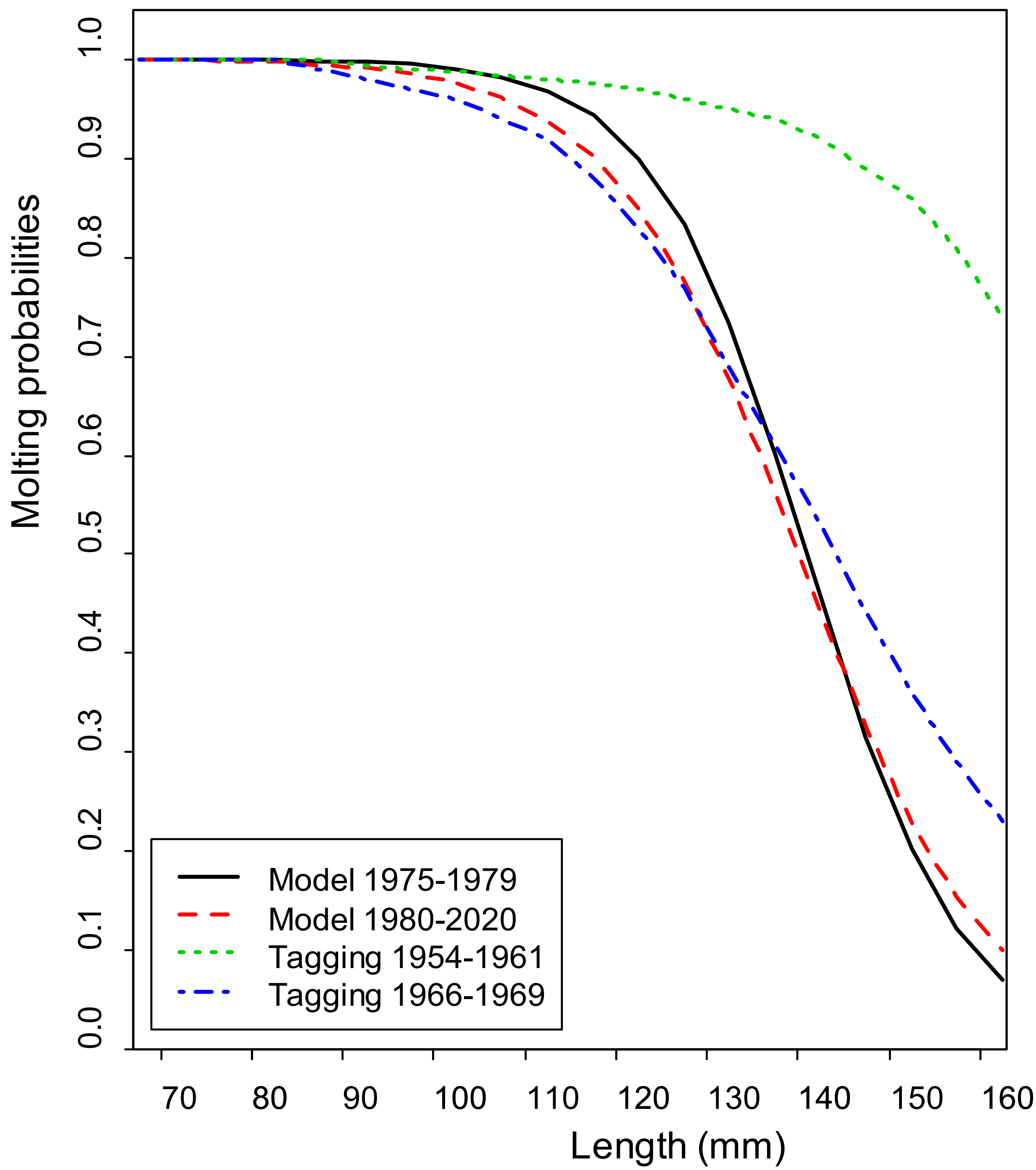


Figure 9b. Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods with model 19.3. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-1979 and 1980-2020 were estimated with a length-based model.

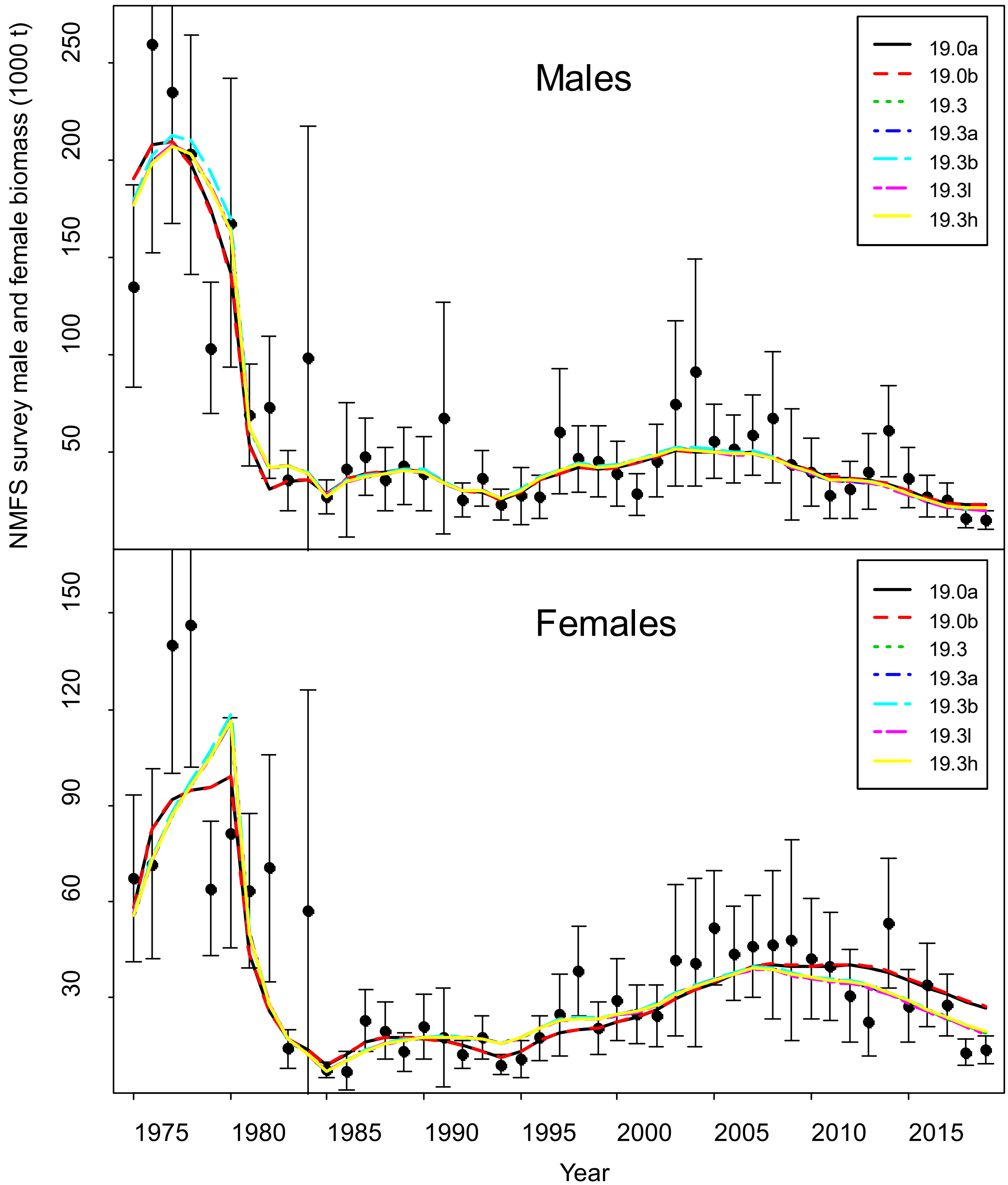


Figure 10a. Comparisons of area-swept estimates of total NMFS survey biomass and model prediction for model estimates in 2020 under models 19.0a, 19.0b, 19.3, 19.3a, 19.3b, 19.3l, and 19.3h. The error bars are plus and minus 2 standard deviations of model 19.3.

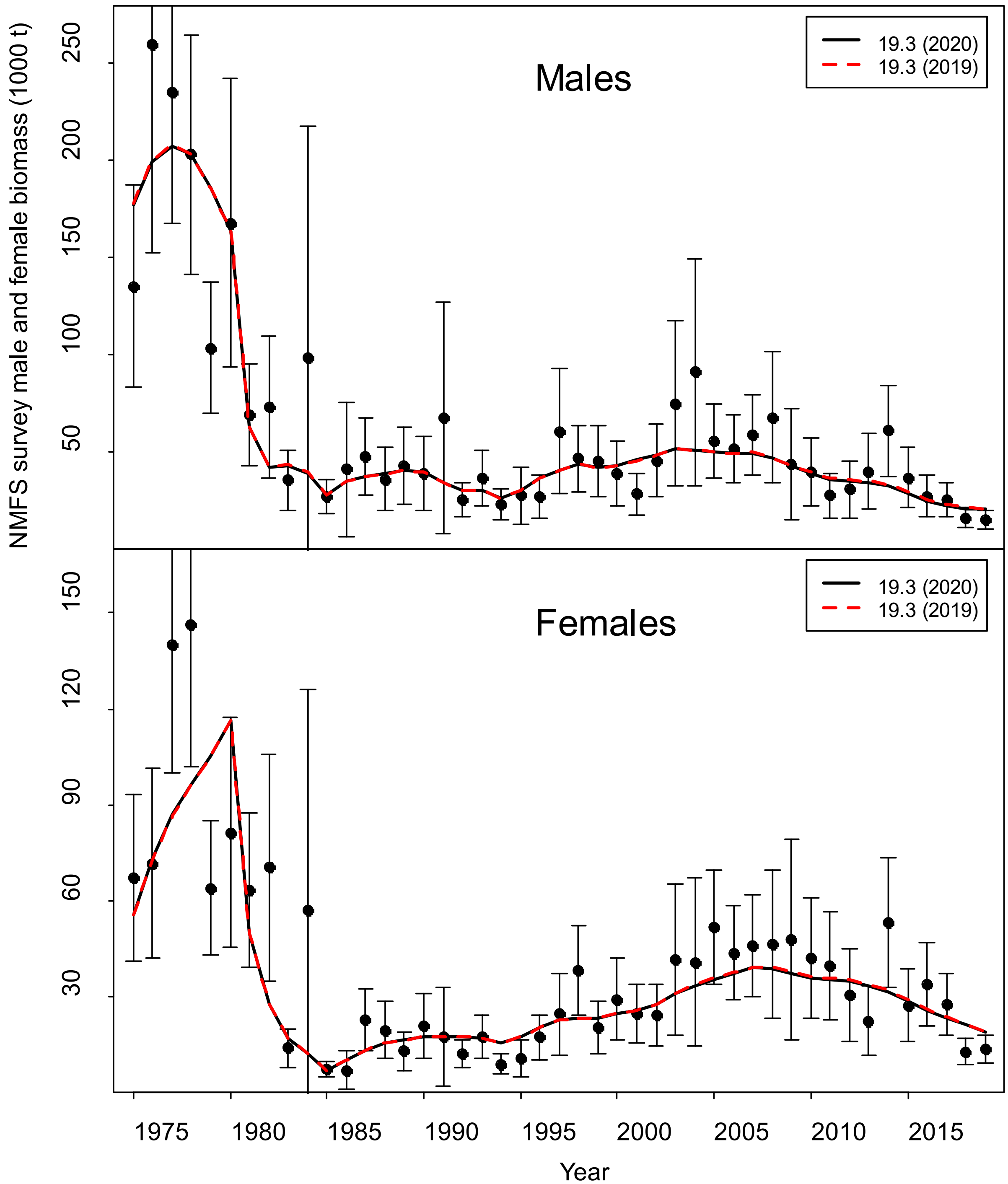


Figure 10b. Comparisons of area-swept estimates of total NMFS survey biomass and model prediction for model estimates under model 19.3 (2019 data) and (2020 data). The error bars are plus and minus 2 standard deviations of model 19.3.

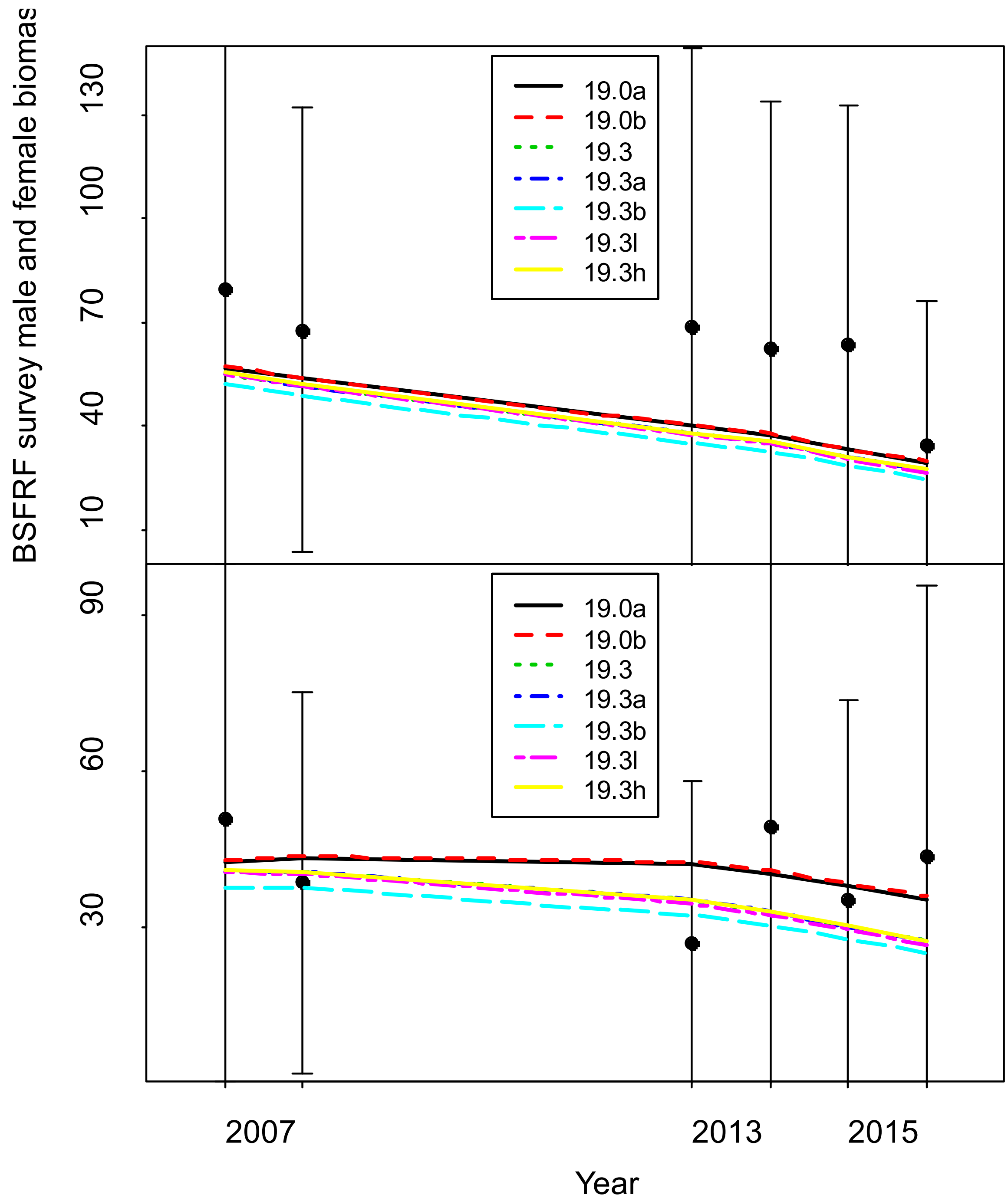


Figure 10c. Comparisons of survey biomass estimates by sex (upper plot for males and lower plot for females) by the BSFRF survey and the model for model estimates in 2020 (models 19.0a, 19.0b, 19.3, 19.3a, 19.3b, 19.3l, and 19.3h). The error bars are plus and minus 2 standard deviations of model 19.3.

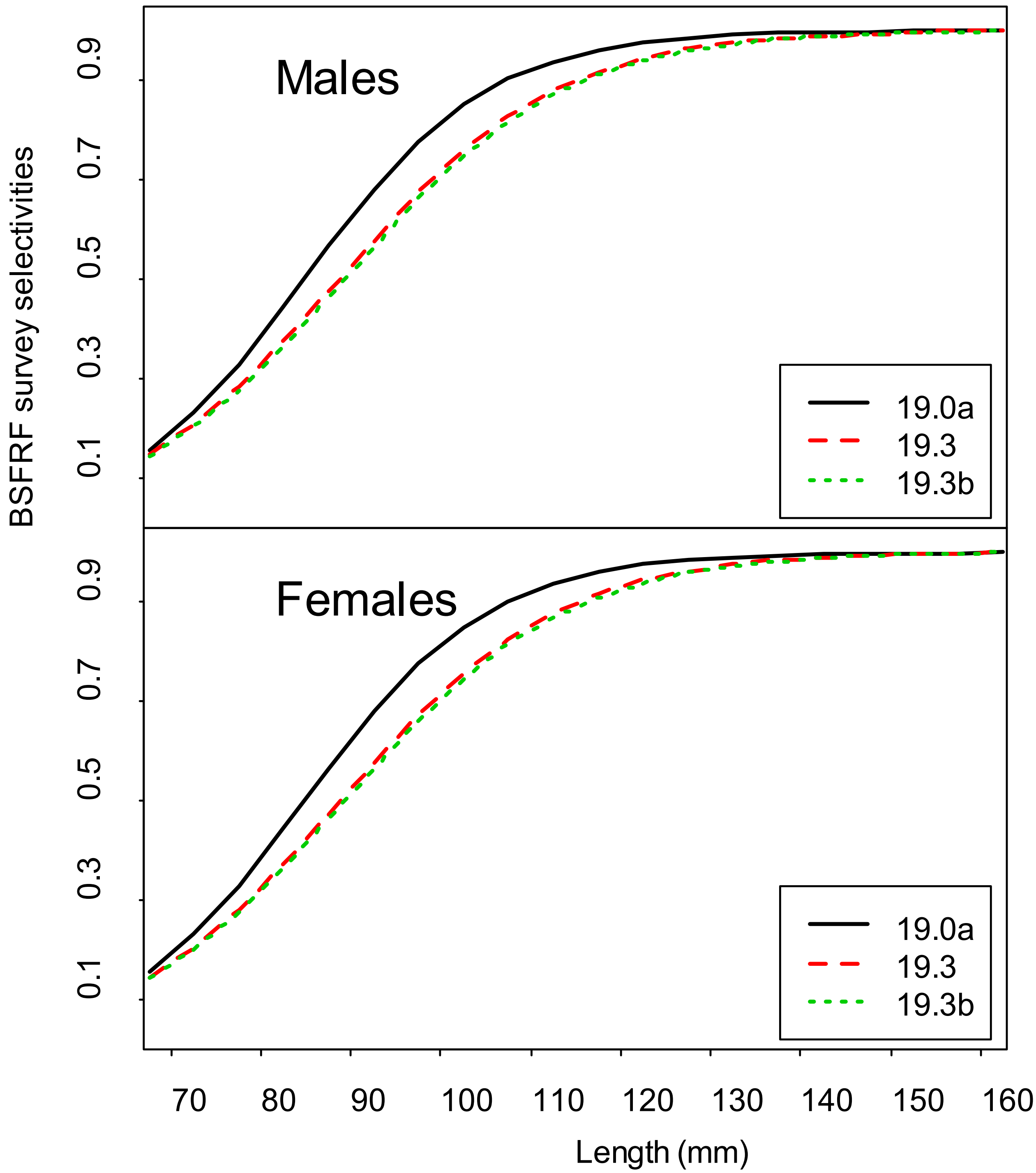


Figure 10d. Comparisons of estimated BSFRF survey selectivities with models 19.0a, 19.3, and 19.3b. The catchability is assumed to be 1.0.

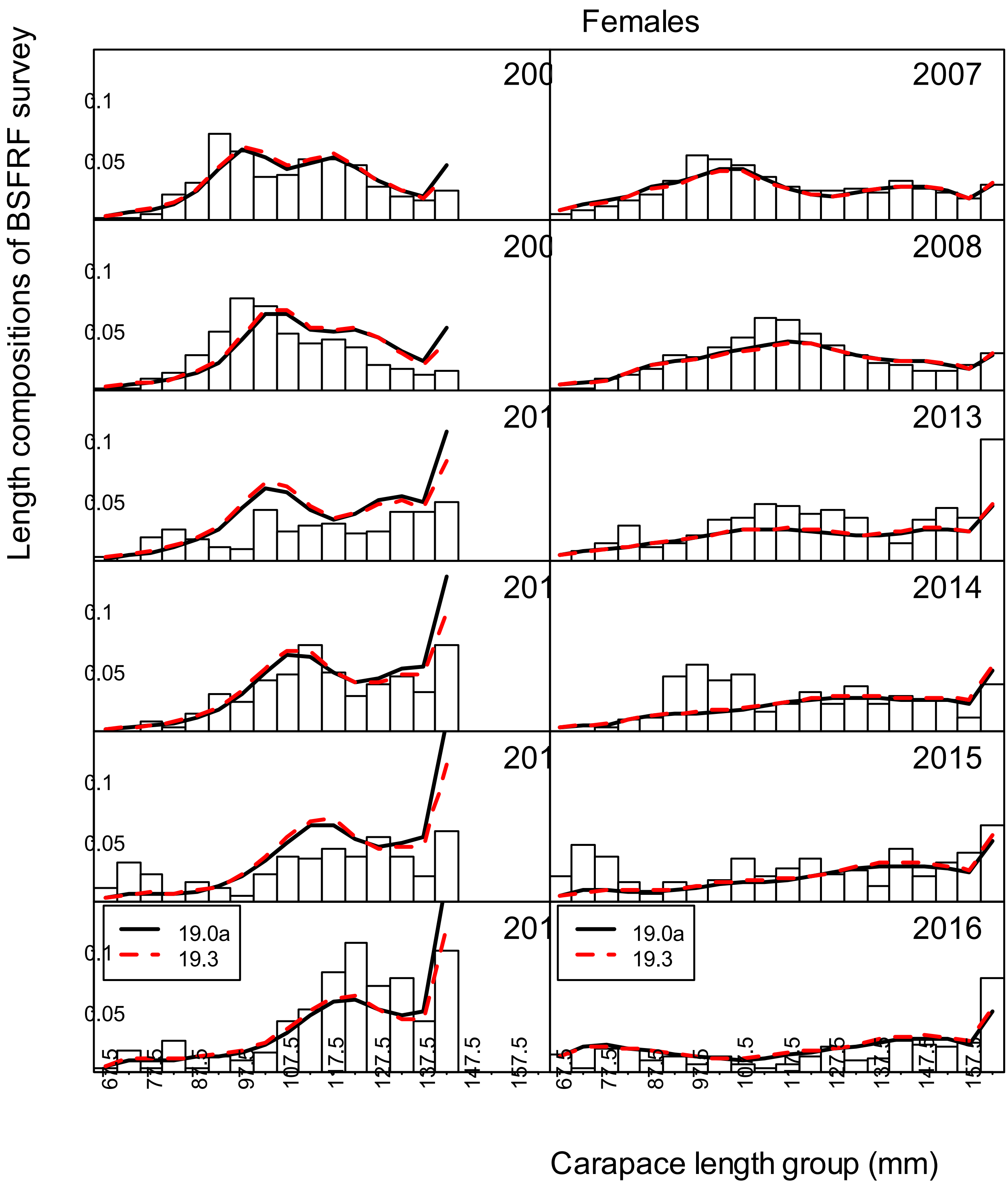


Figure 10e. Comparisons of length compositions by the BSFRF survey and the model estimates during 2007-2008 and 2013-2016 with models 19.0a and 19.3.

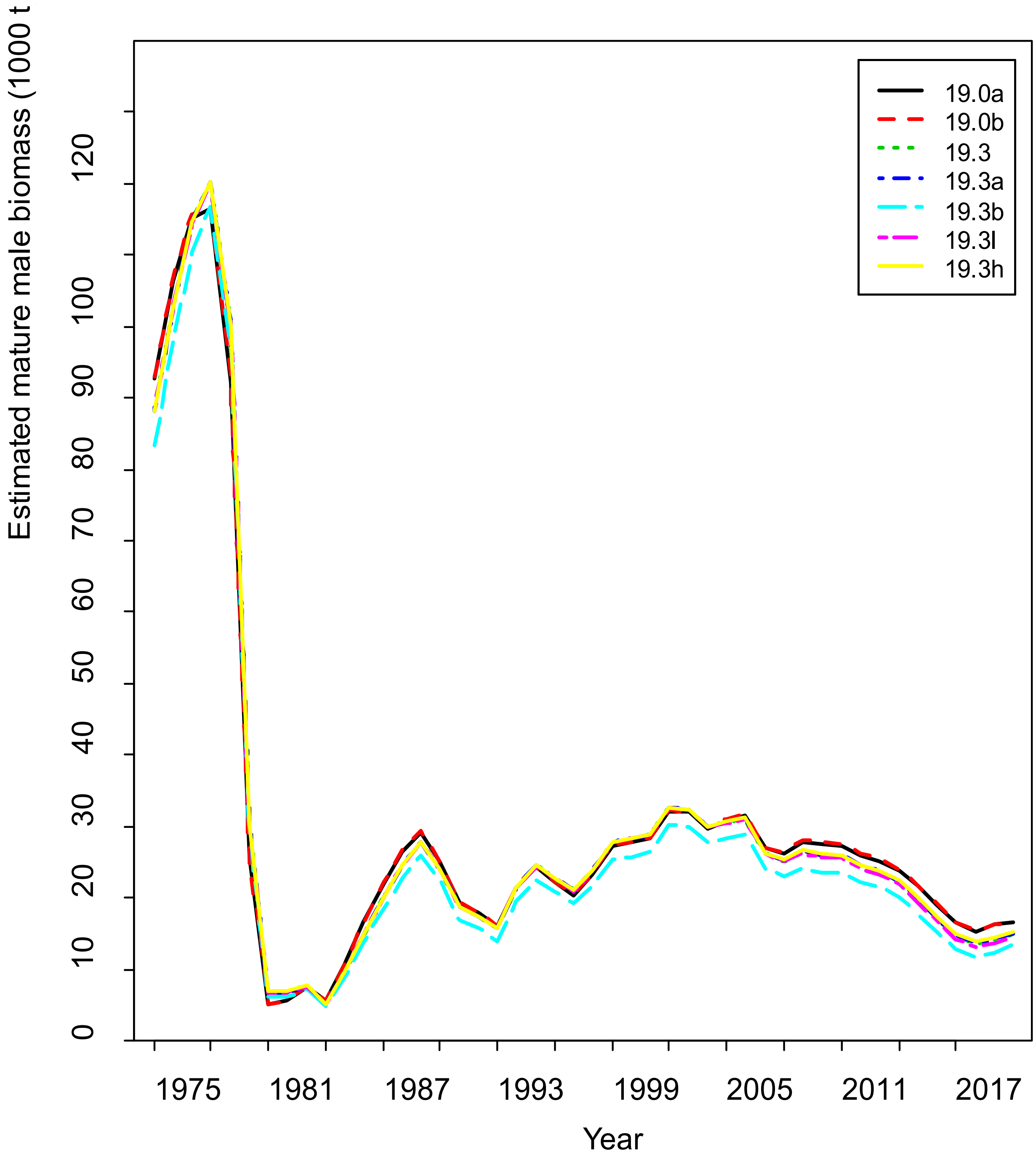


Figure 11. Estimated absolute mature male biomasses during 1975-2020 for models 19.0a, 19.0b, 19.3, 19.3a, 19.3b, 19.3l, and 19.3h.

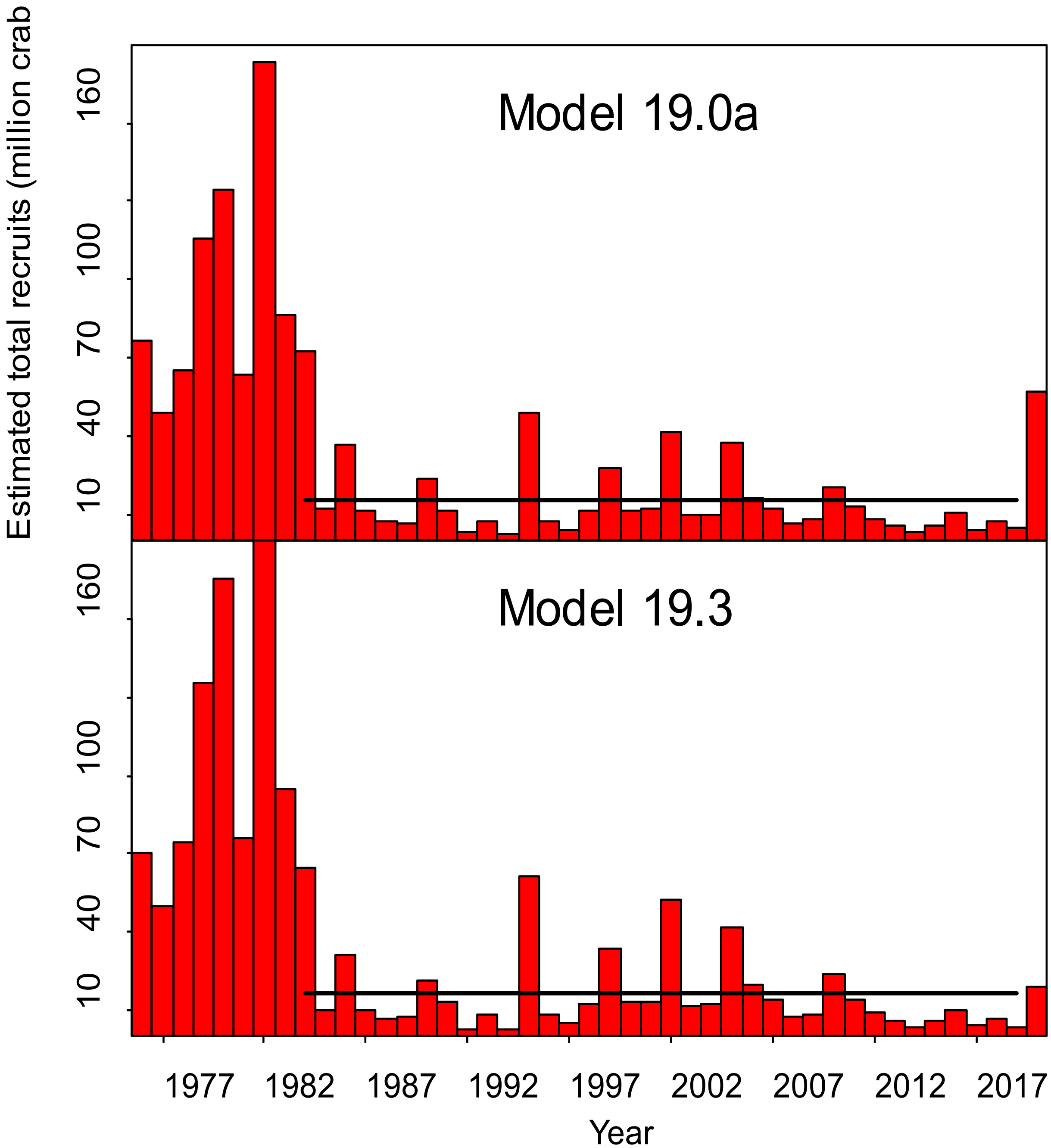


Figure 12a. Estimated recruitment time series during 1976-2020 with models 19.0a and 19.3. Mean male recruits during 1984-2019 was used to estimate $B_{35\%}$.

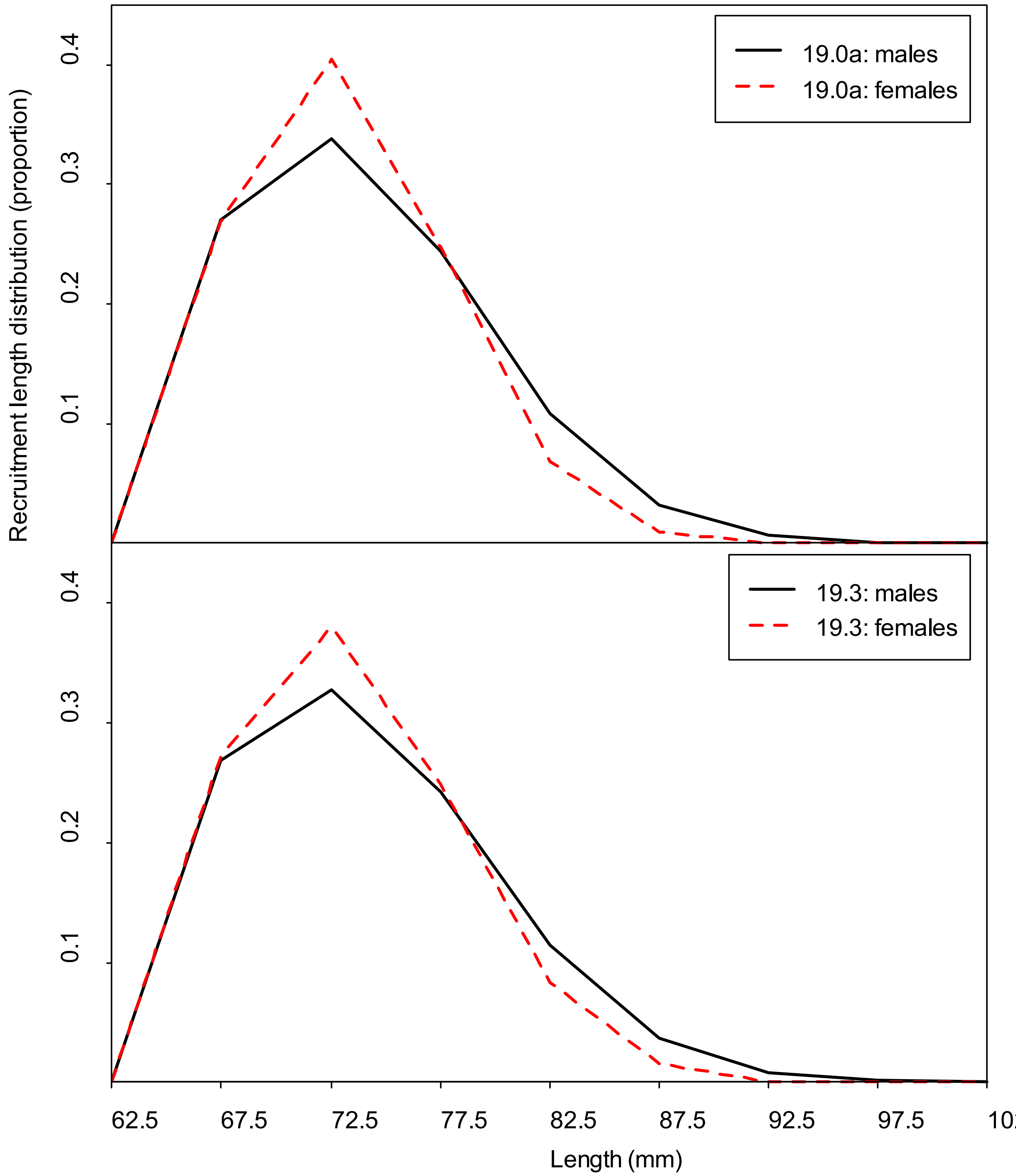


Figure 12b. Estimated recruitment length distributions with models 19.0a and 19.3.

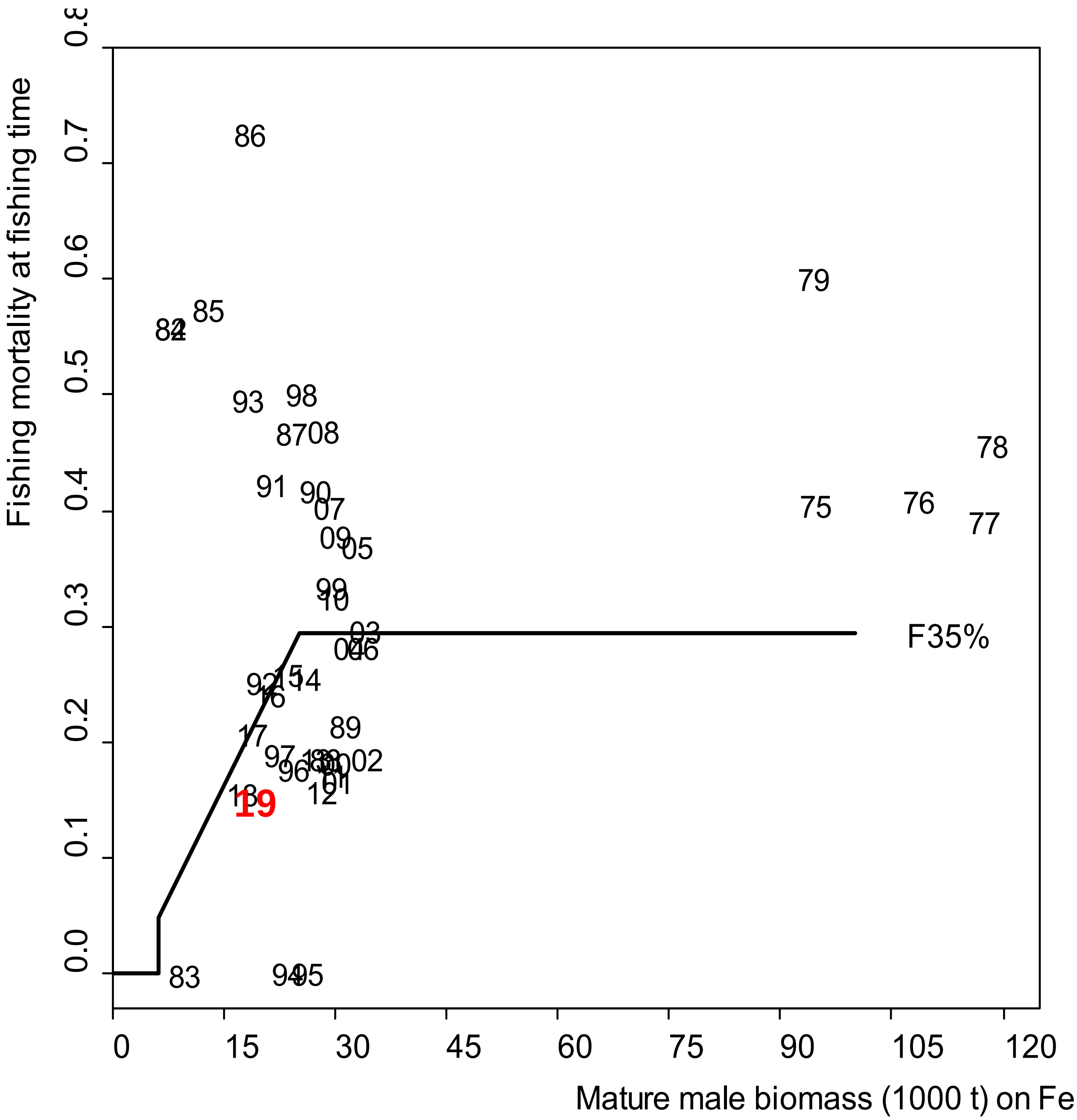


Figure 13a. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2019 under model 19.0a. Average of recruitment from 1984 to 2019 was used to estimate B_{MSY}.

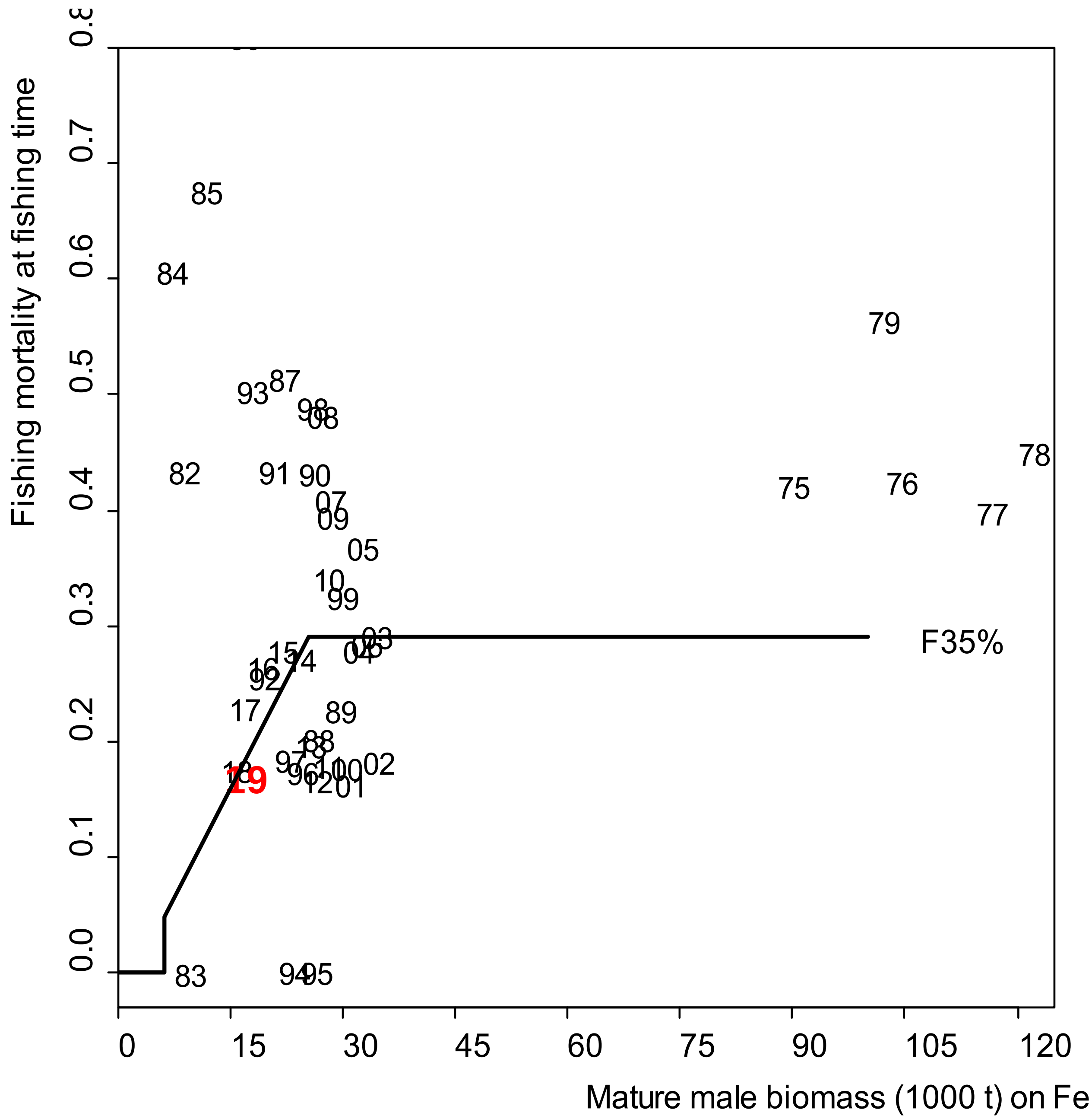


Figure 13b. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2019 under model 19.3. Average of recruitment from 1984 to 2019 was used to estimate B_{MSY}.

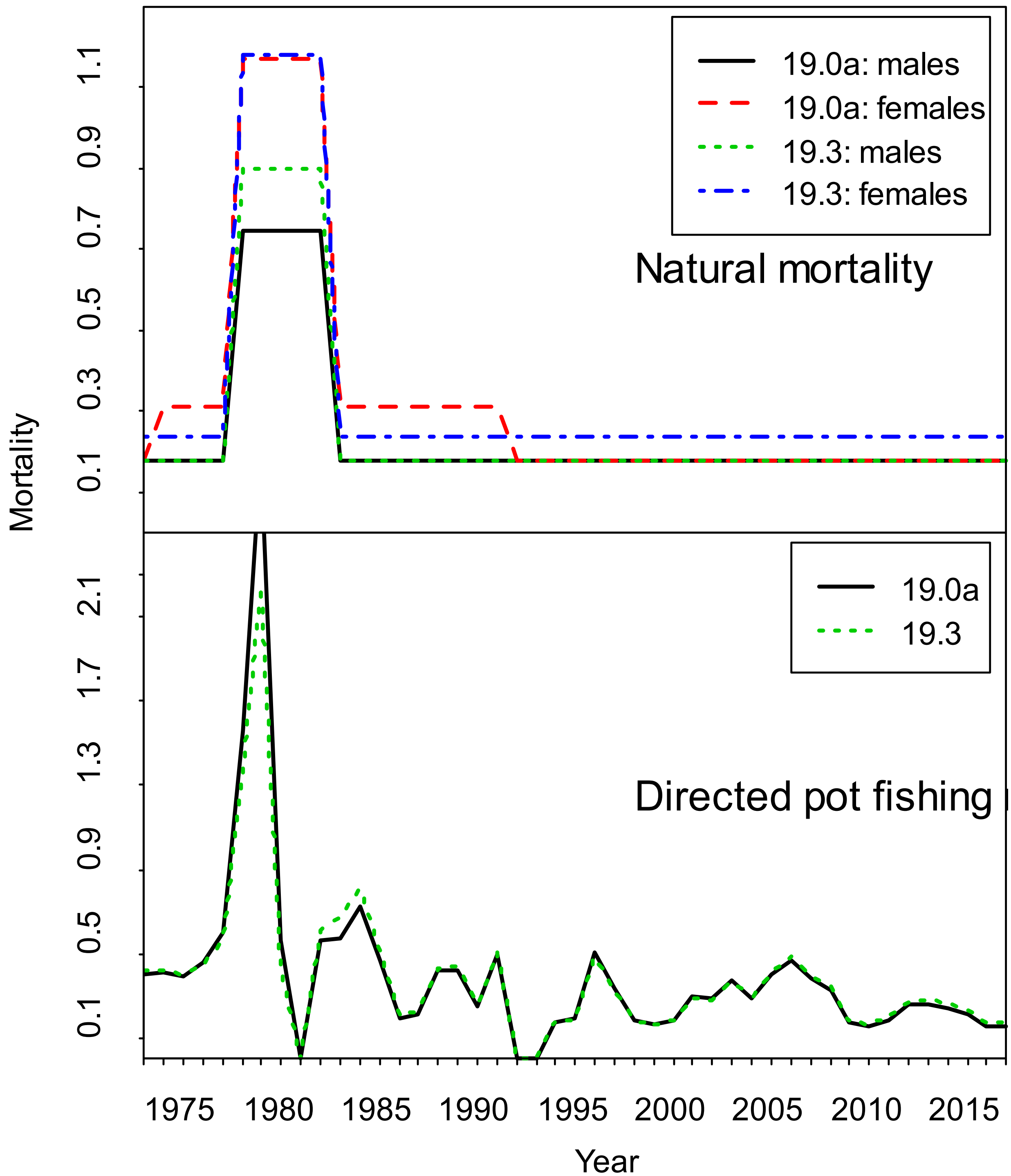


Figure 13c. Comparison of estimated natural mortality and directed pot fishing mortality for models models 19.0a and 19.3.

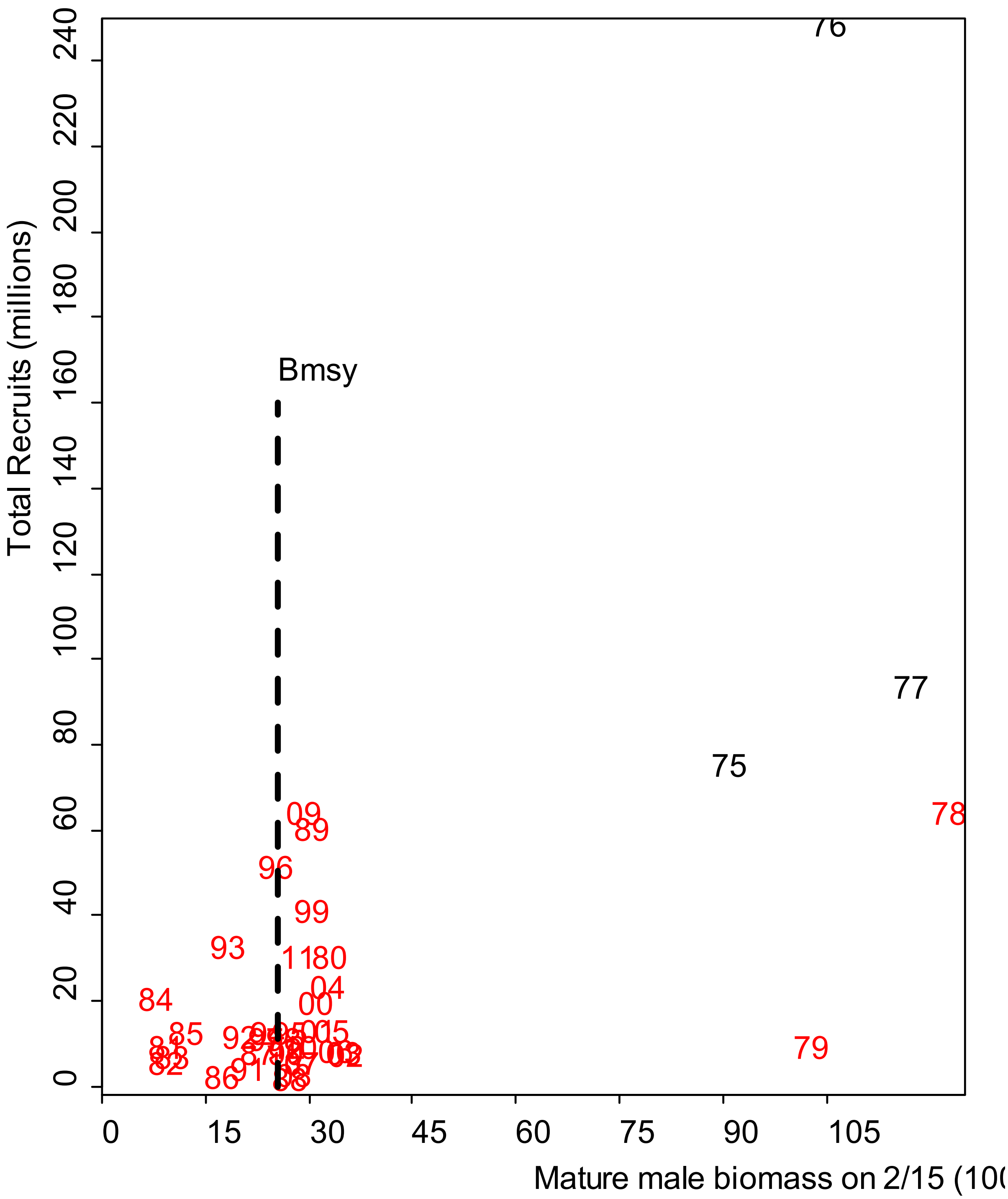


Figure 14a. Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab under model 19.3. Numerical labels are years of mating, and the vertical dotted line is the estimated $B_{35\%}$ based on the mean recruitment level during 1984 to 2019.

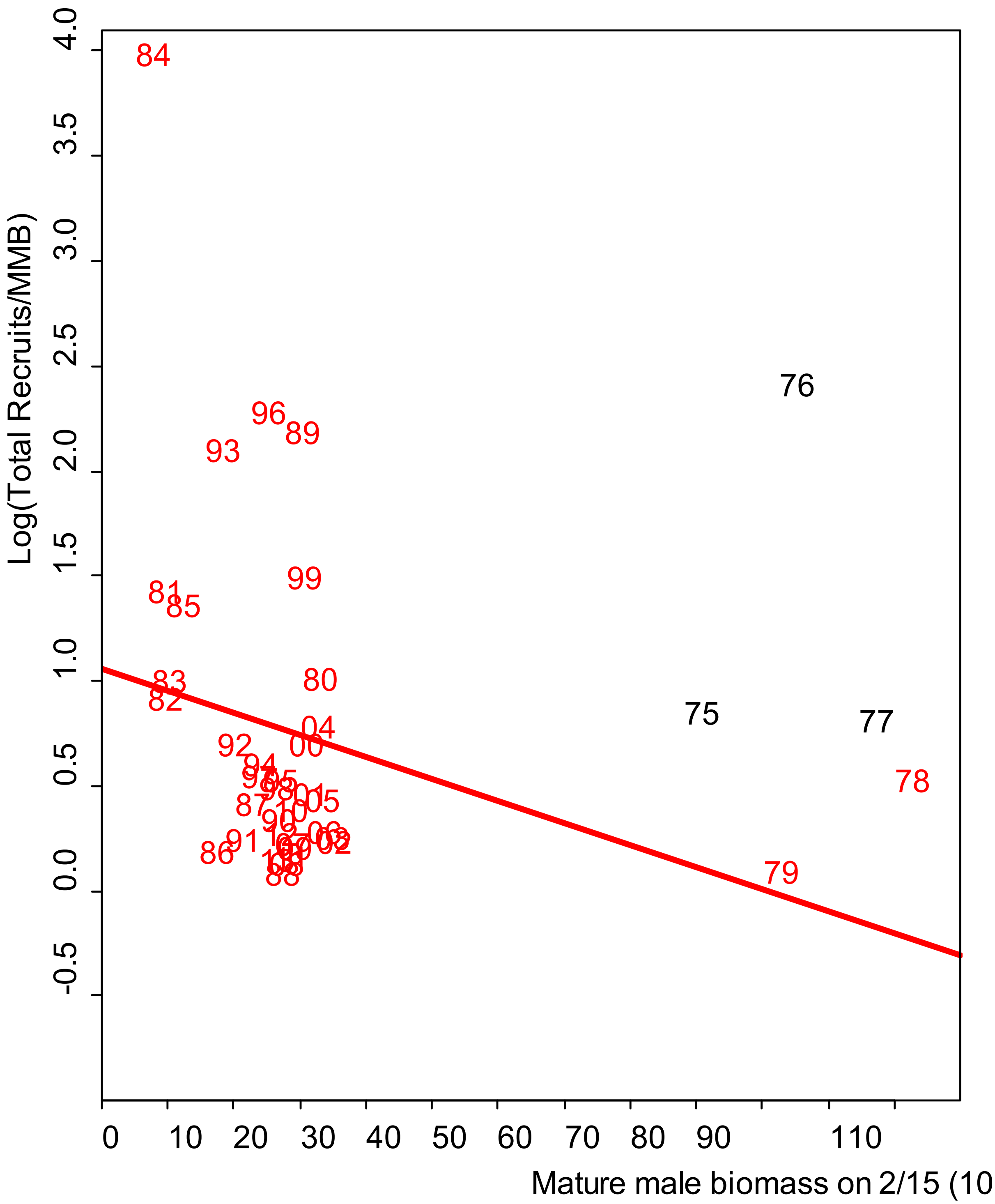


Figure 14b. Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab under model 19.3. Numerical labels are years of mating, and the line is the regression line for data of 1978-2013.

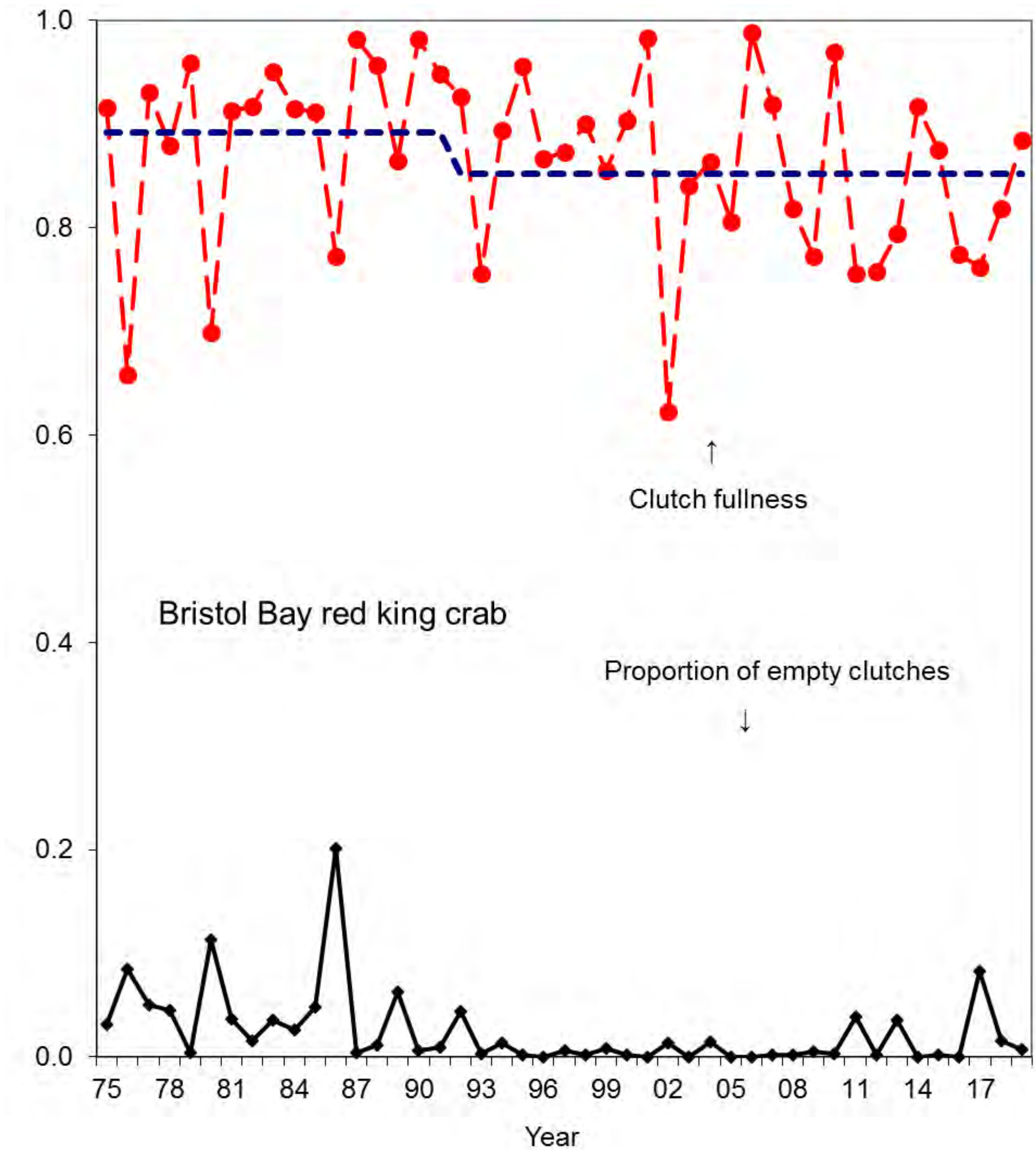


Figure 15. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crab >89 mm CL from 1975 to 2019 from survey data. Oldshell females were excluded. The blue dashed line is the mean clutch fullness during two periods before 1992 and after 1991.

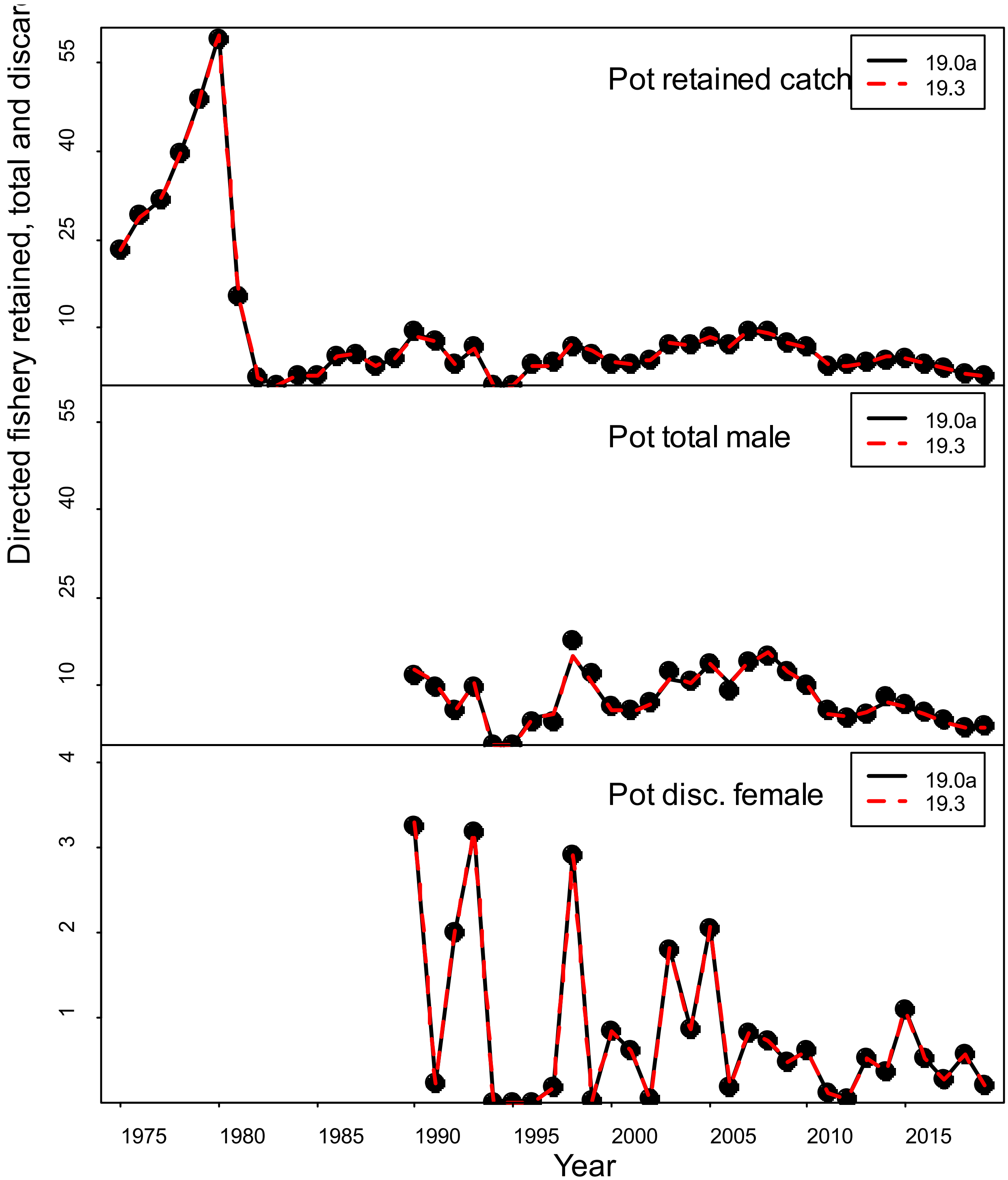


Figure 16a. Observed (dots) and predicted (lines) RKC catch and bycatch biomass under models 19.0a and 19.3.

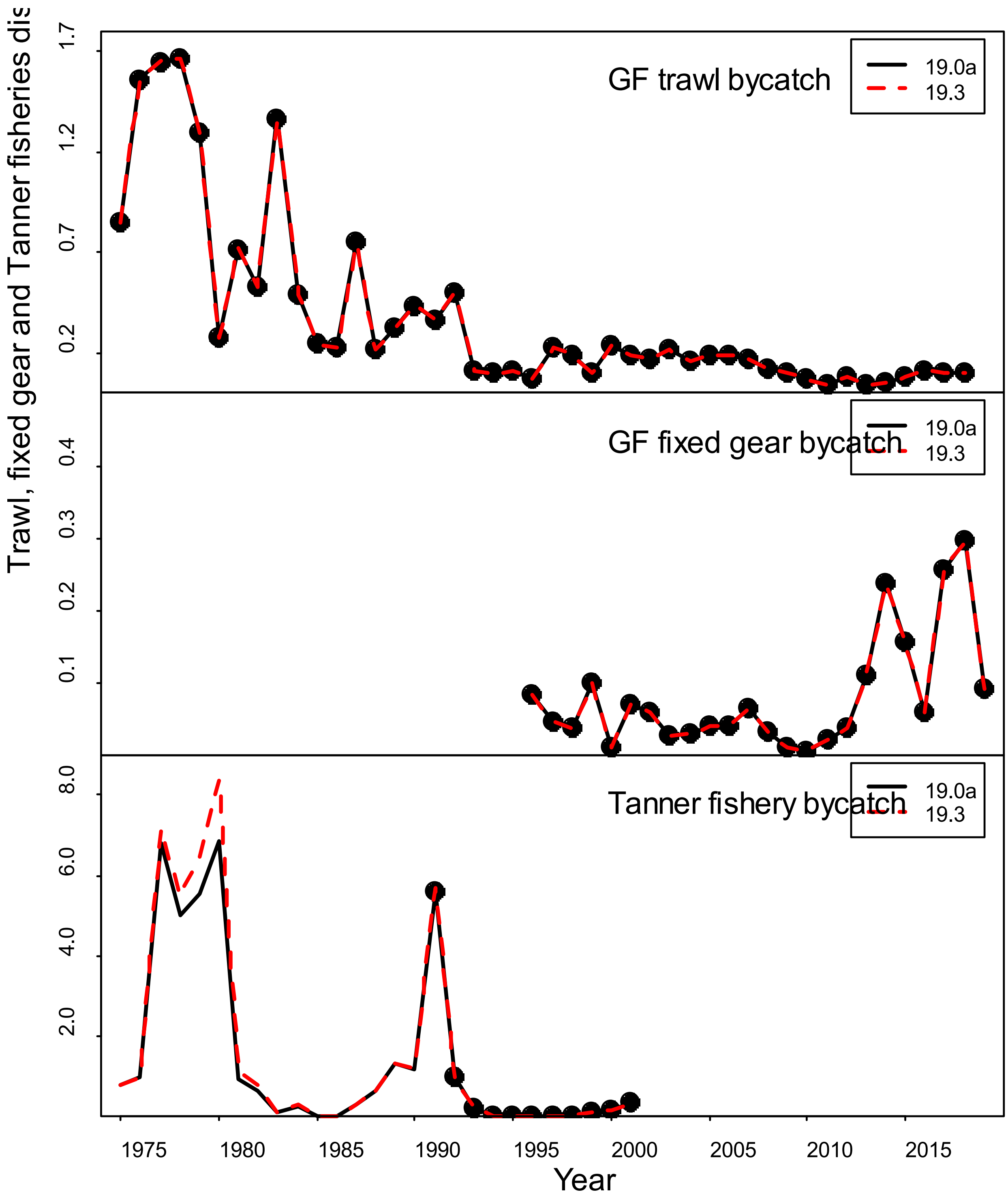


Figure 16b. Observed (dots) and predicted (lines) RKC bycatch biomass from groundfish fisheries and the Tanner crab fishery under models 19.0a and 19.3. Trawl bycatch biomass was 0 before 1976.

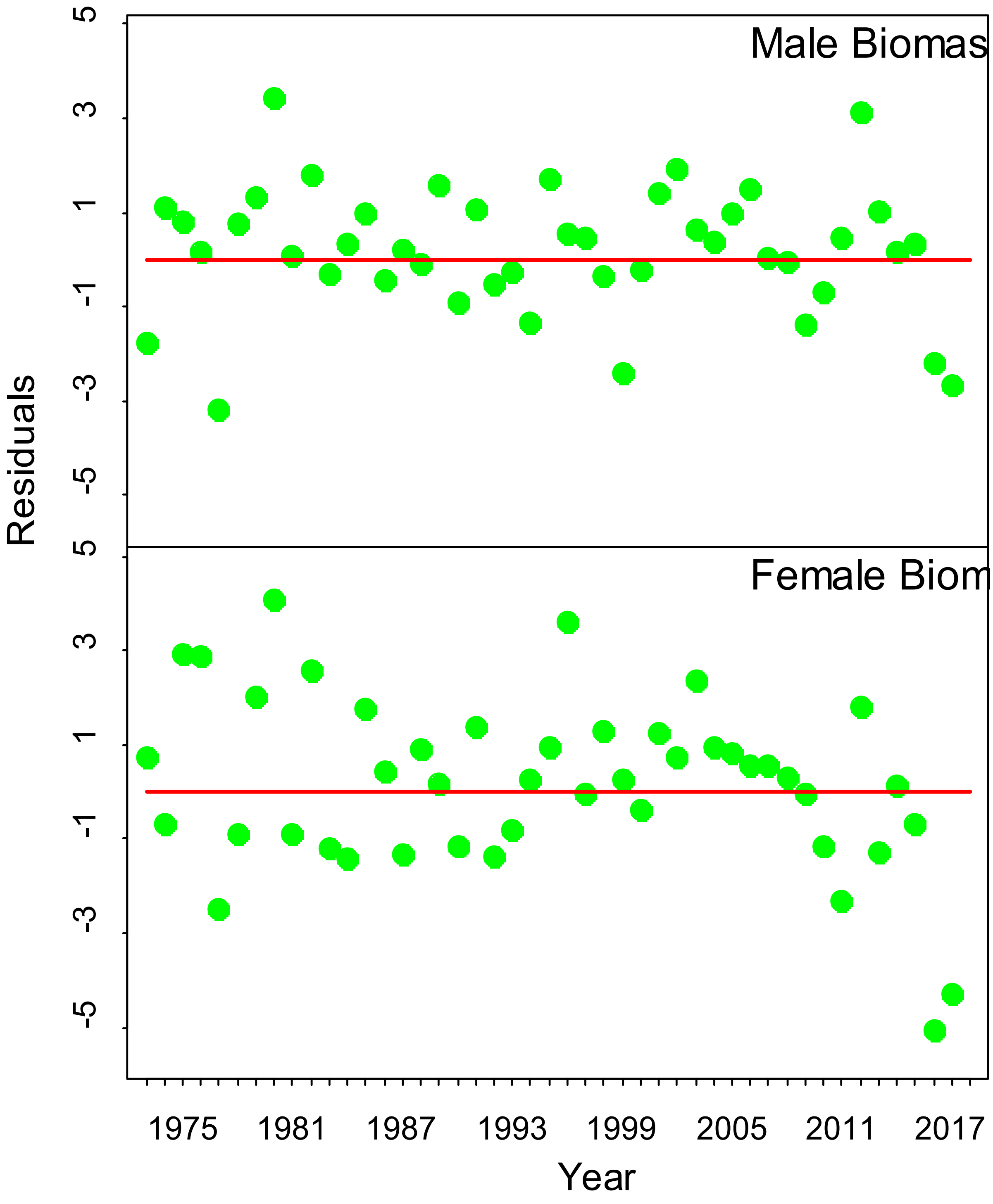


Figure 17a. Standardized residuals of NMFS survey biomass under model 19.0a.

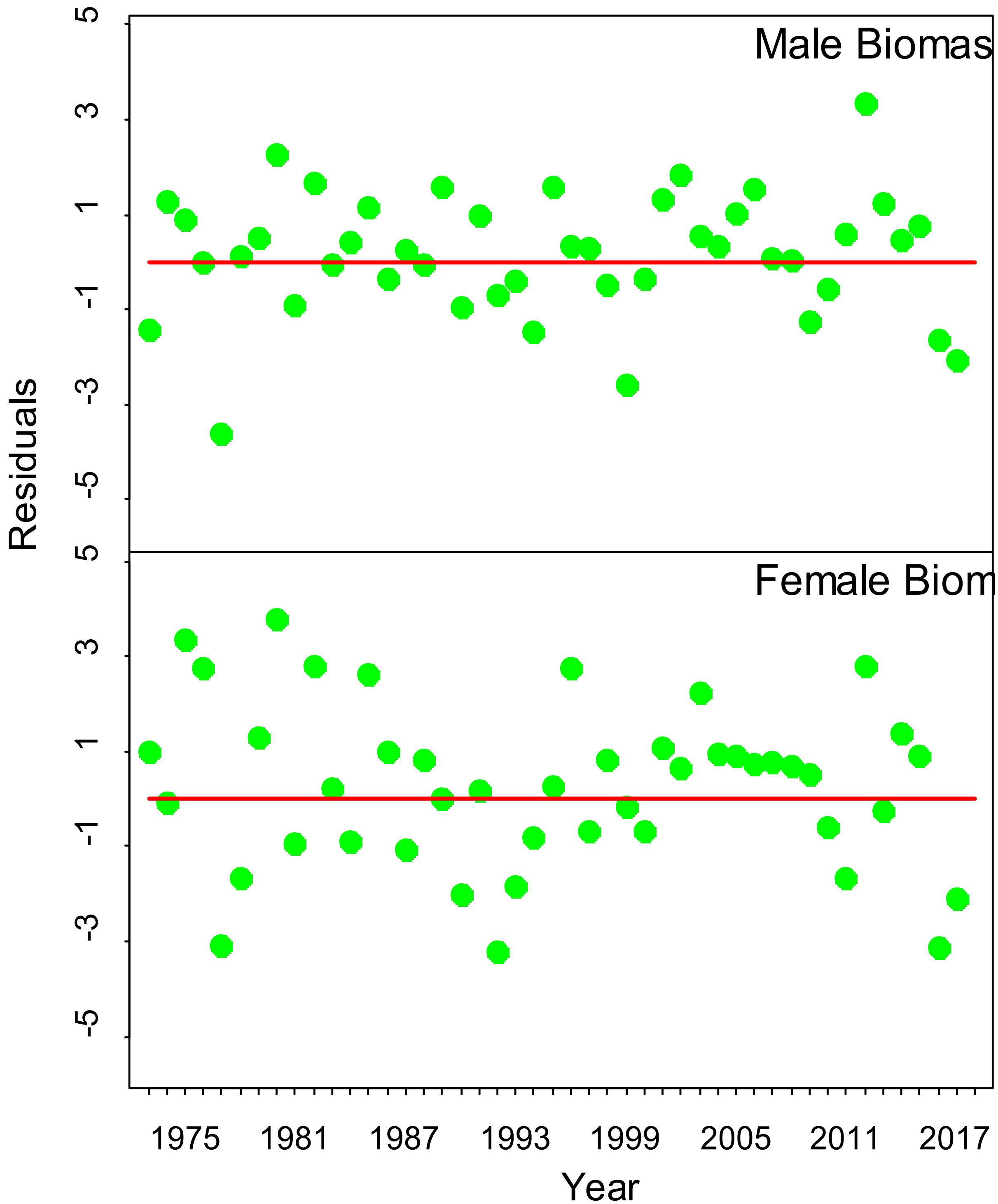


Figure 17b. Standardized residuals of NMFS survey biomass under model 19.3.

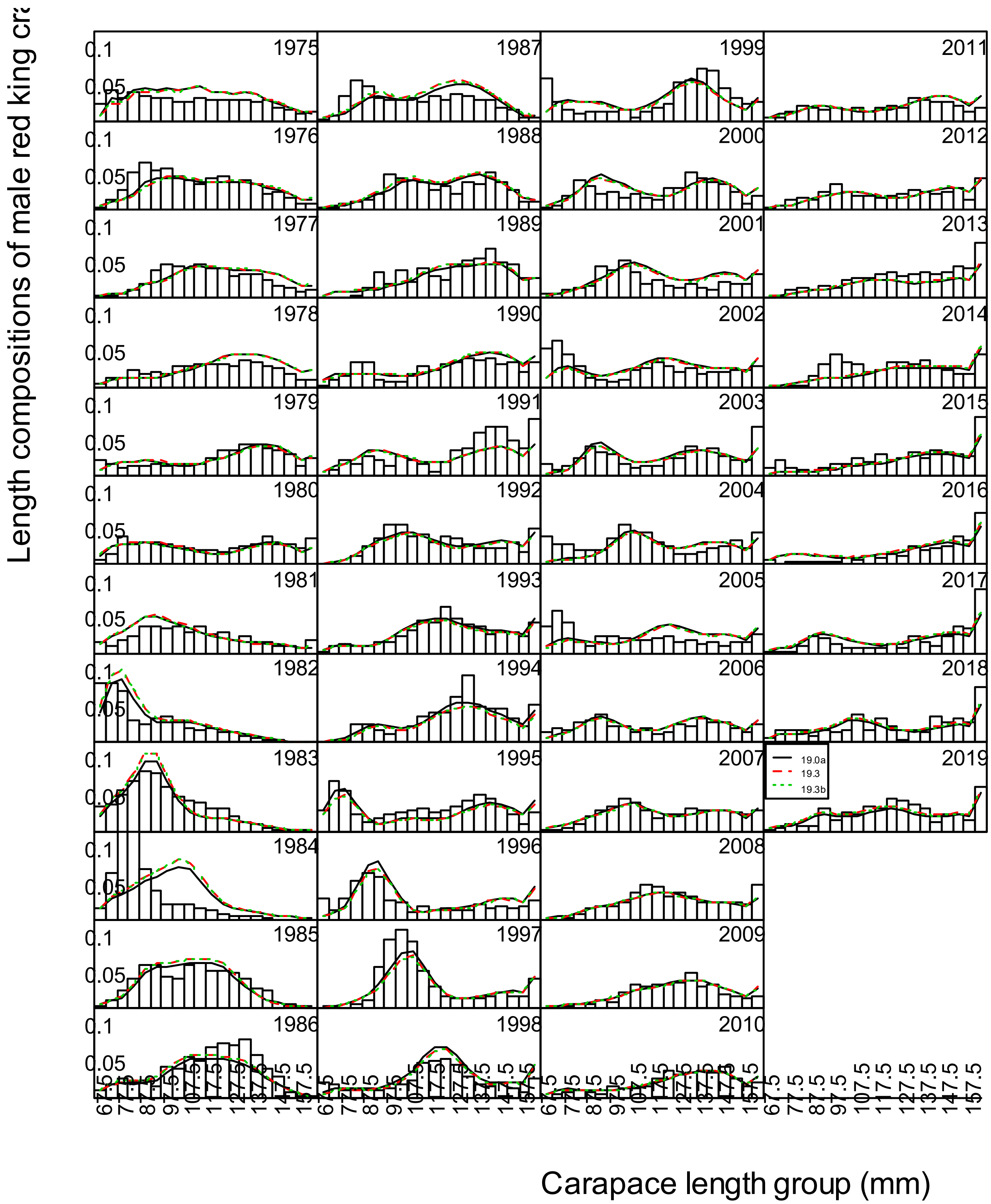


Figure 18. Comparison of area-swept and model estimated NMFS survey length frequencies of Bristol Bay male red king crab by year under models 19.0a, 19.3, and 19.3b.

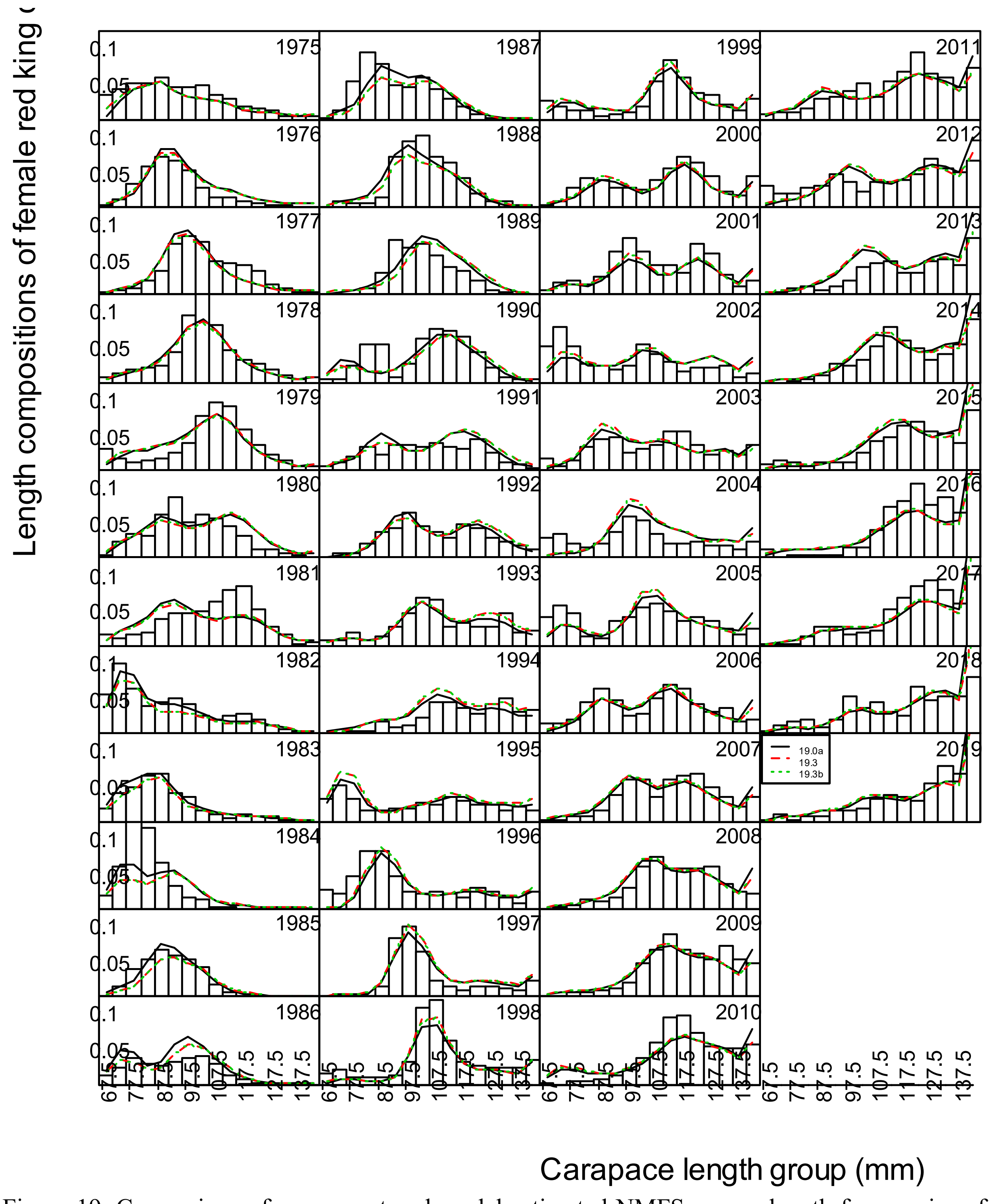


Figure 19. Comparison of area-swept and model estimated NMFS survey length frequencies of Bristol Bay female red king crab by year under models 19.0a, 19.3, and 19.3b.

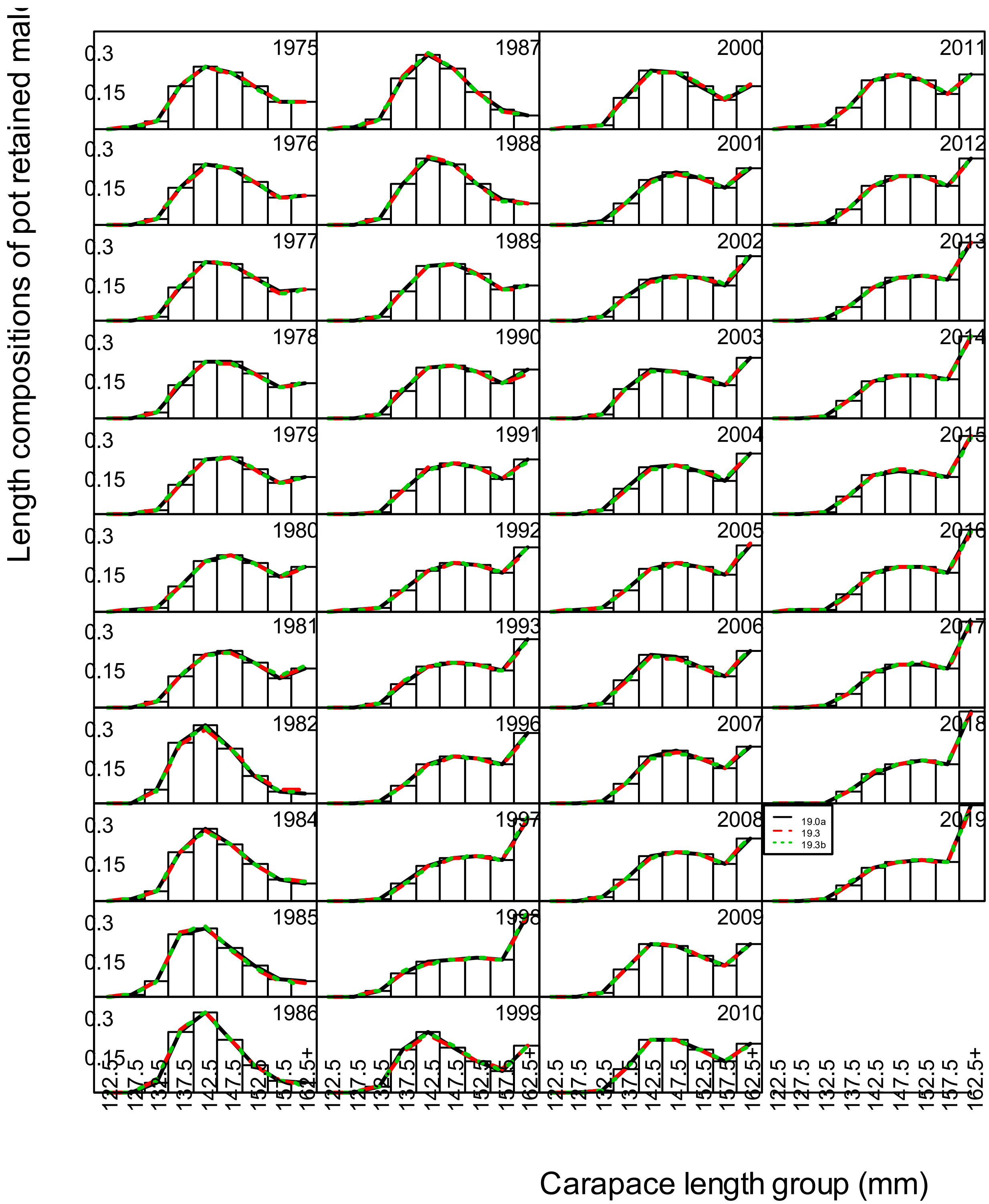


Figure 20. Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under models 19.0a, 19.3, and 19.3b.

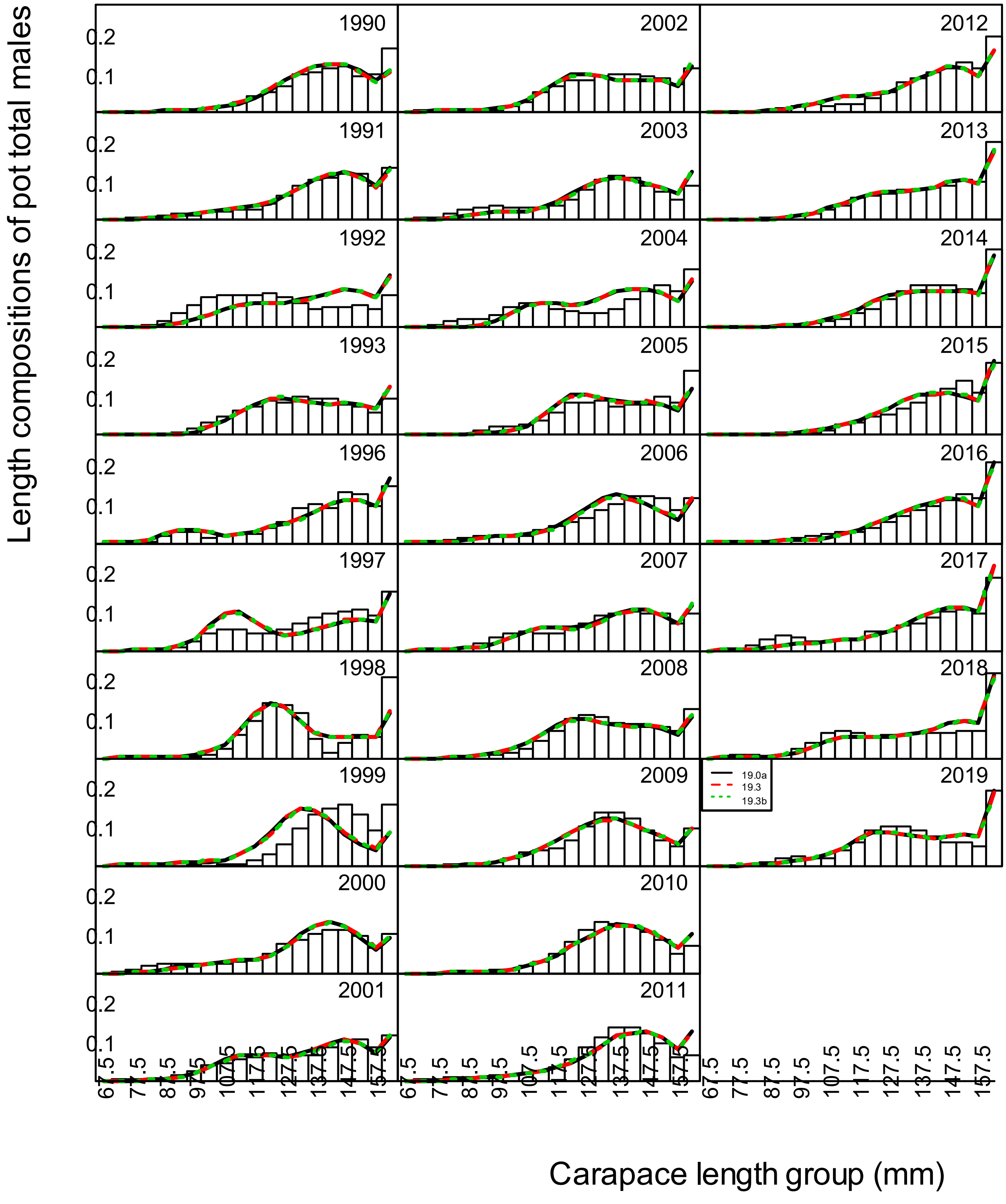


Figure 21. Comparison of observer and model estimated total observer length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under models 19.0a, 19.3, and 19.3b.

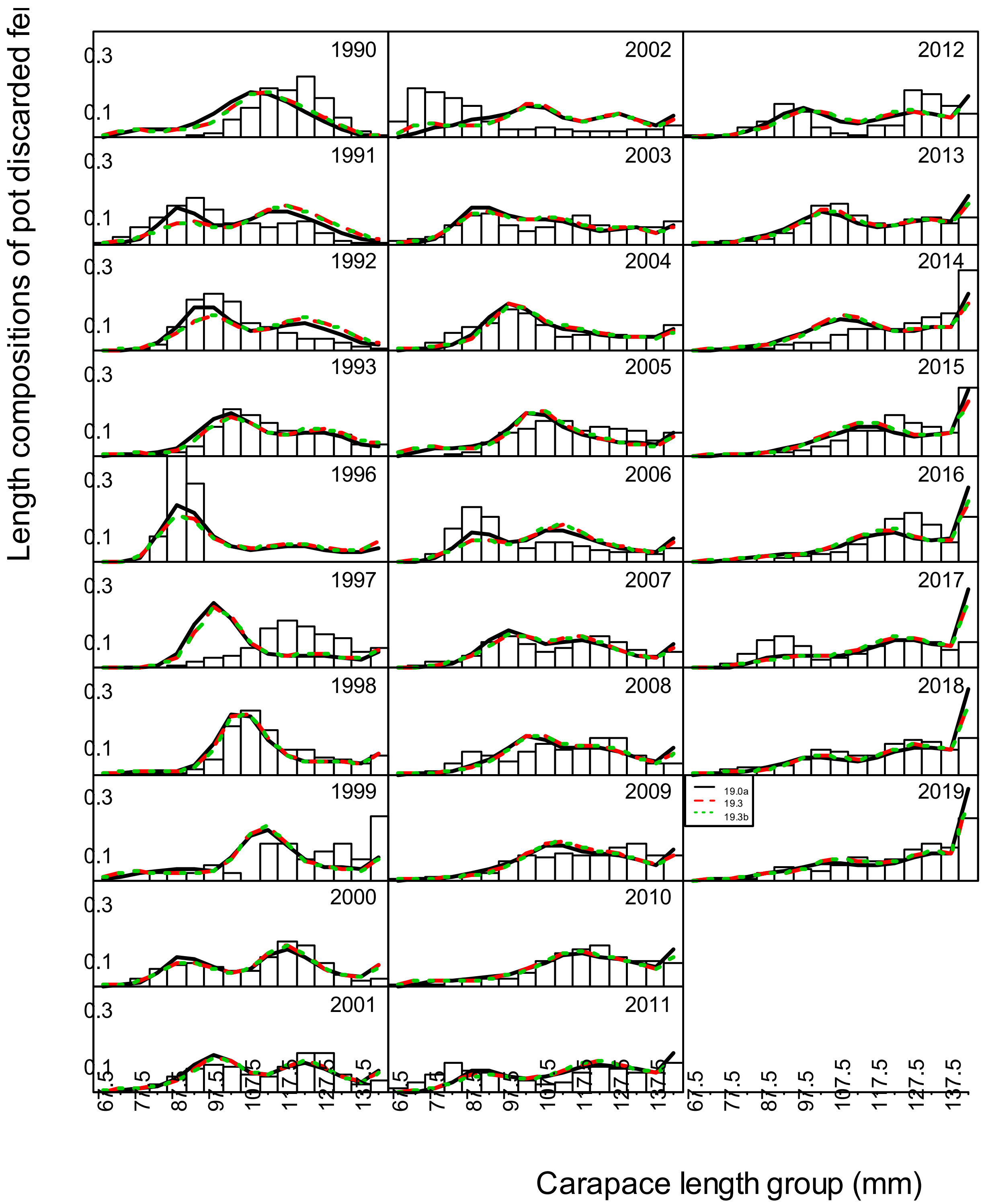


Figure 22. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the directed pot fishery under models 19.0a, 19.3, and 19.3b.

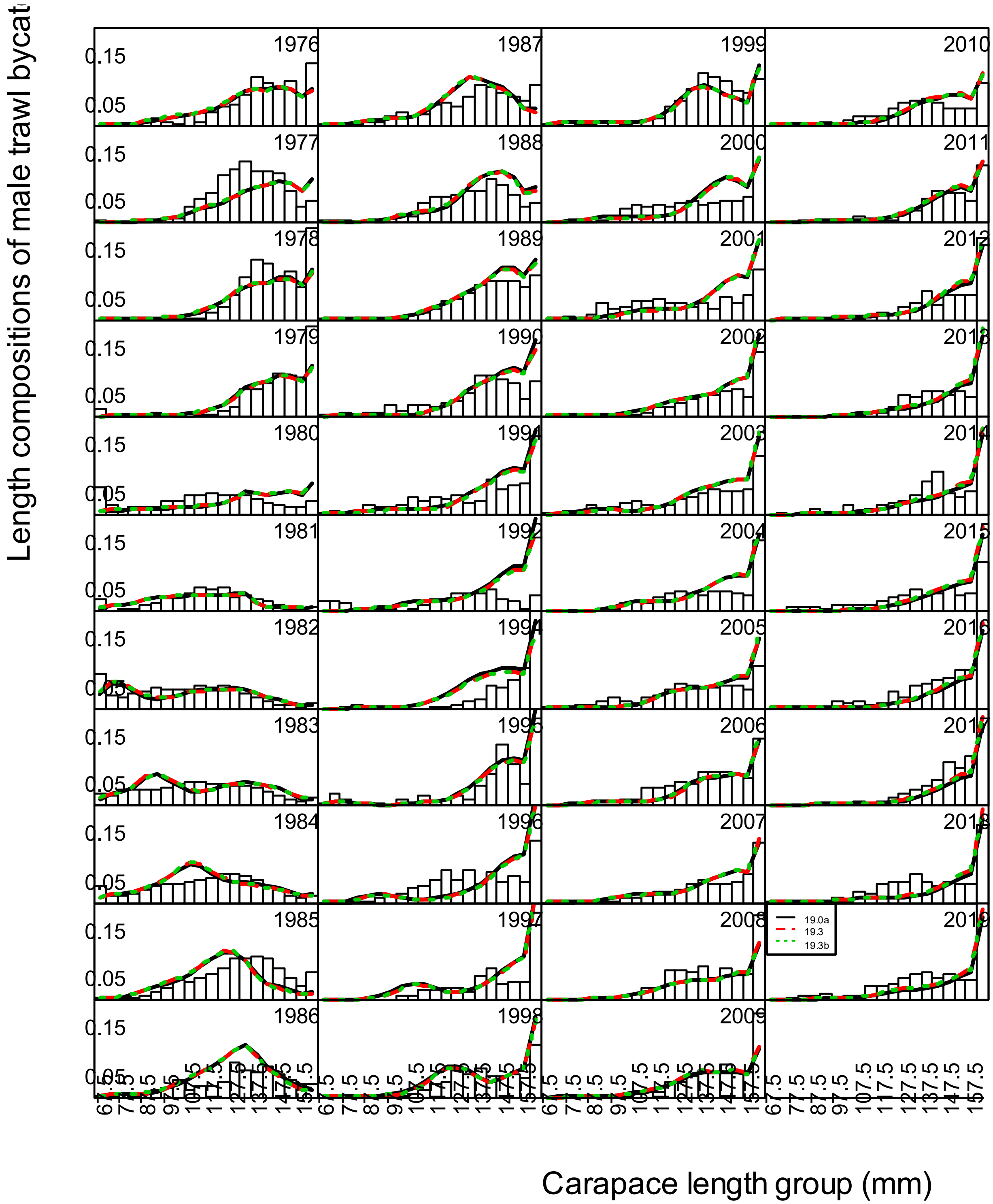


Figure 23a. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish trawl fisheries under models 19.0a, 19.3, and 19.3b.

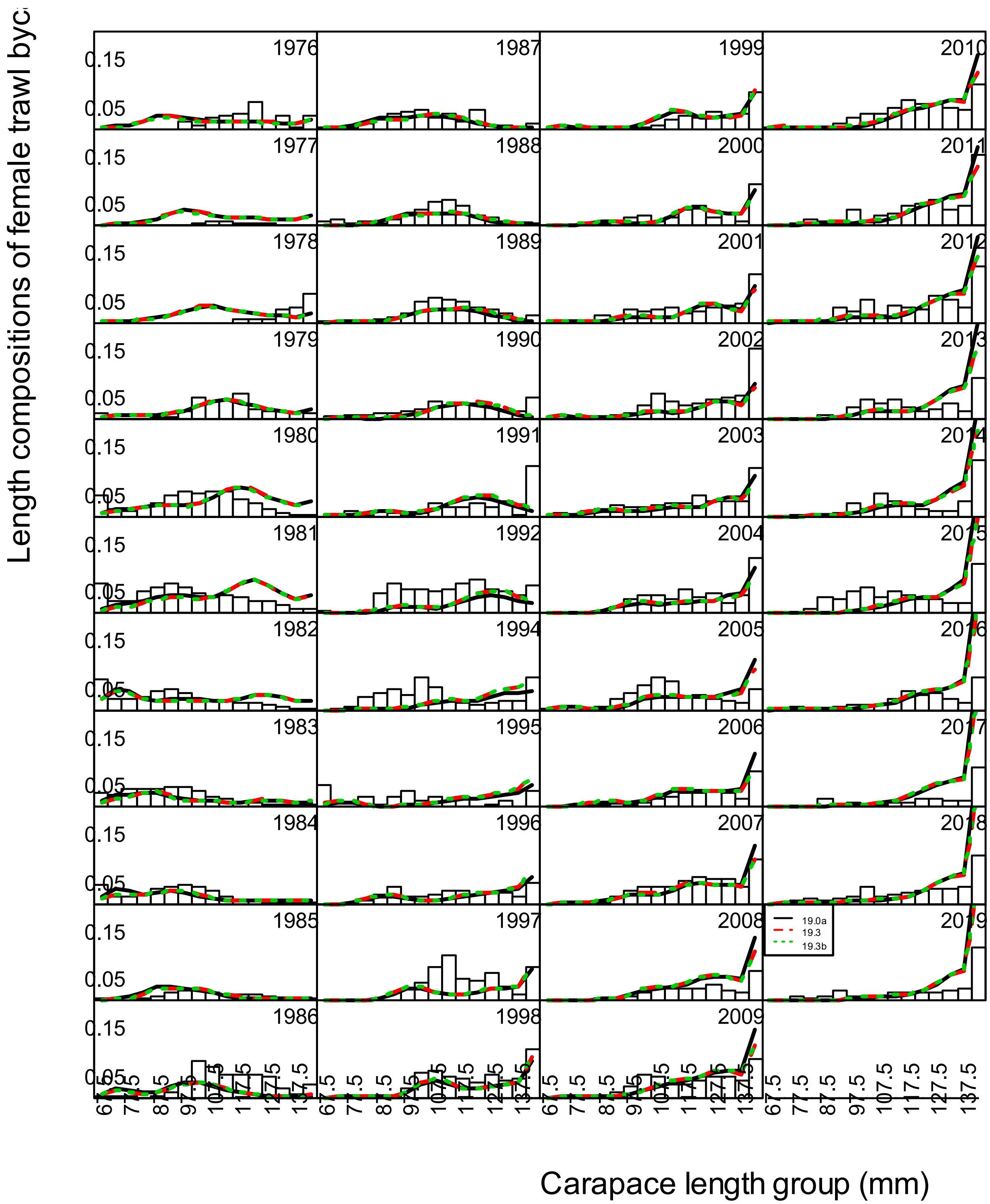


Figure 23b. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish trawl fisheries under models 19.0a, 19.3, and 19.3b.

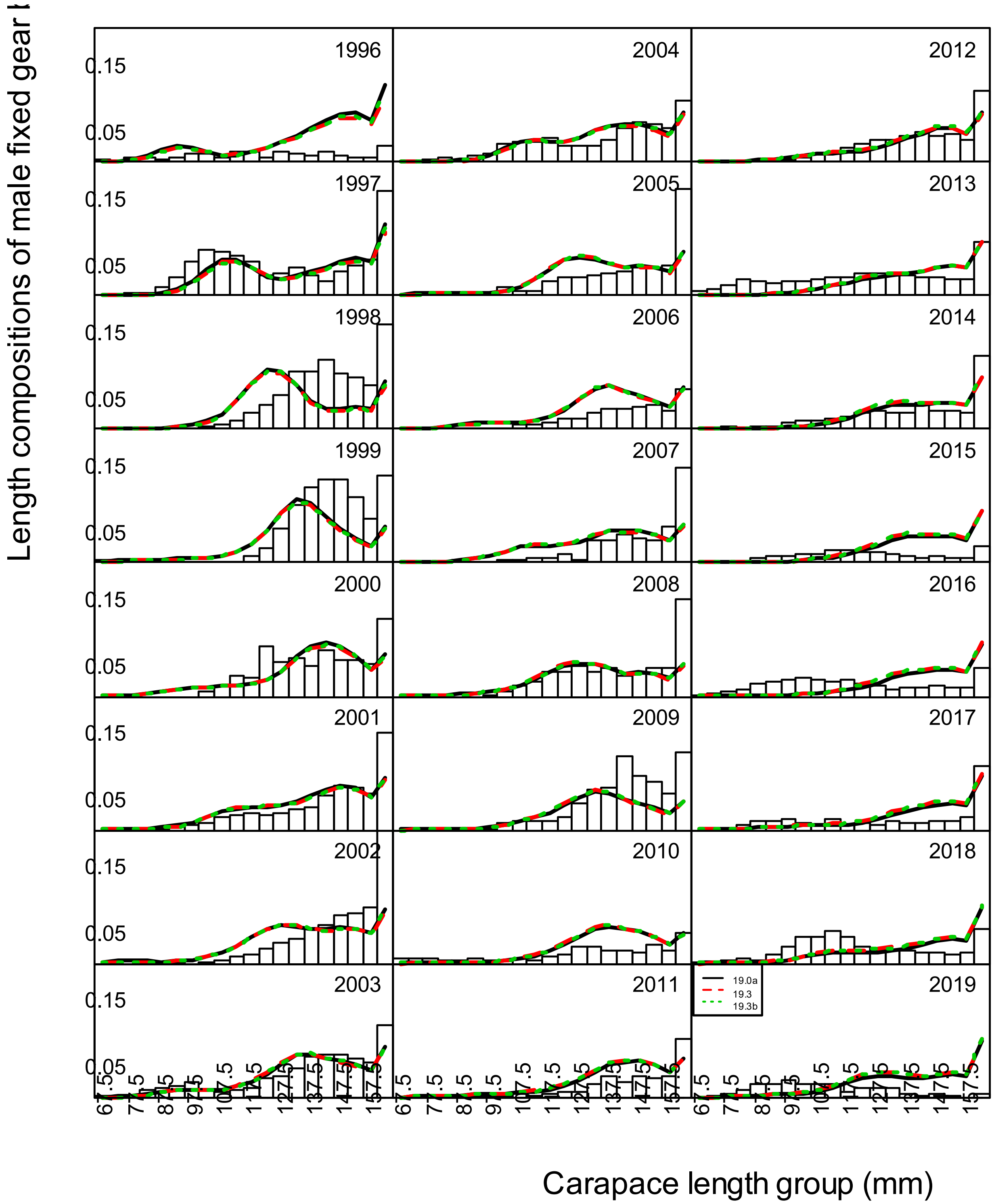


Figure 24a. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish fixed gear fisheries under models 19.0a, 19.3, and 19.3b.

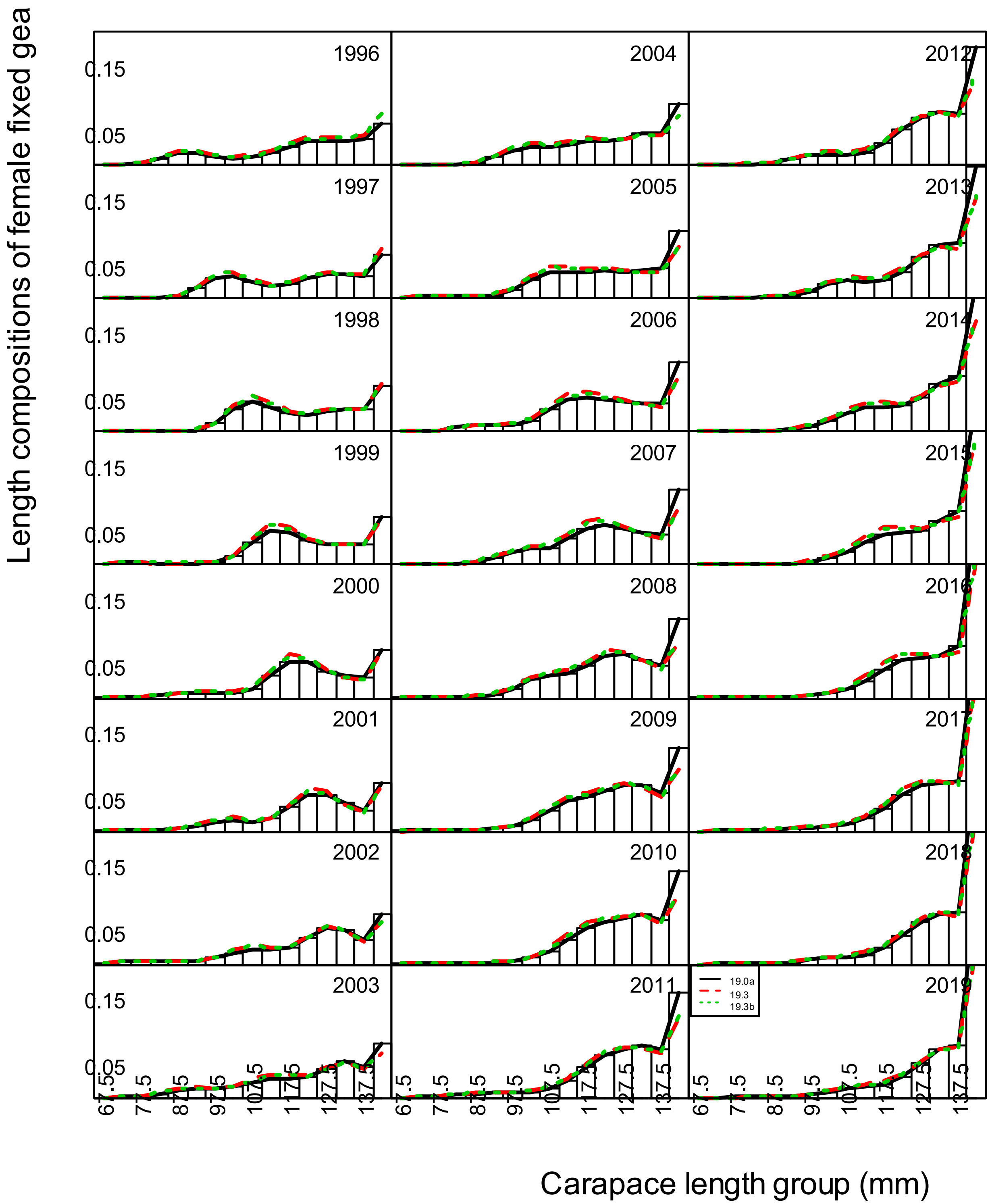


Figure 24b. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish fixed gear fisheries under models 19.0a, 19.3, and 19.3b.

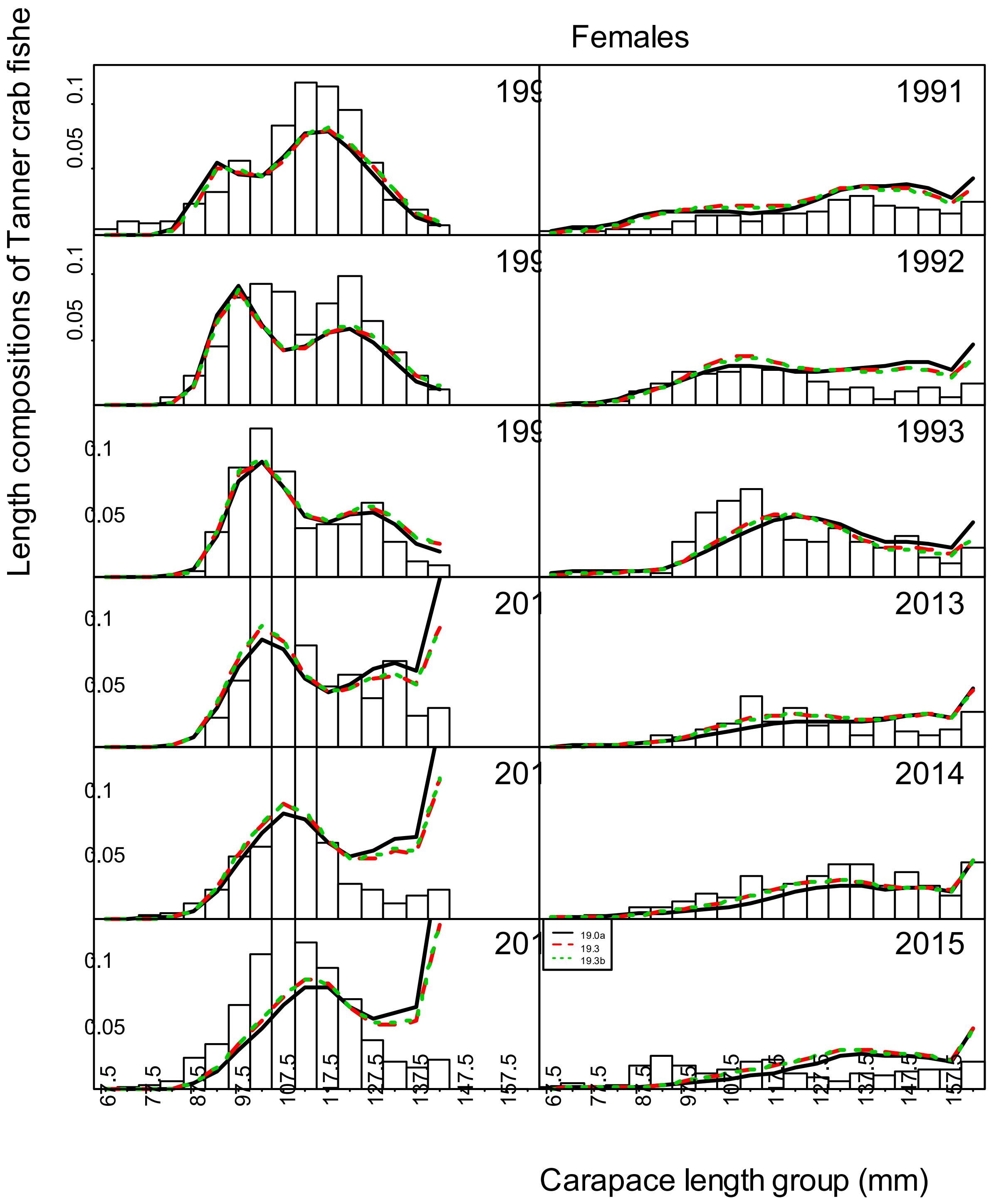


Figure 24c. Comparison of observer and model estimated discarded length frequencies of Bristol Bay red king crab by year in the Tanner crab fishery under models 19.0a, 19.3, and 19.3b.

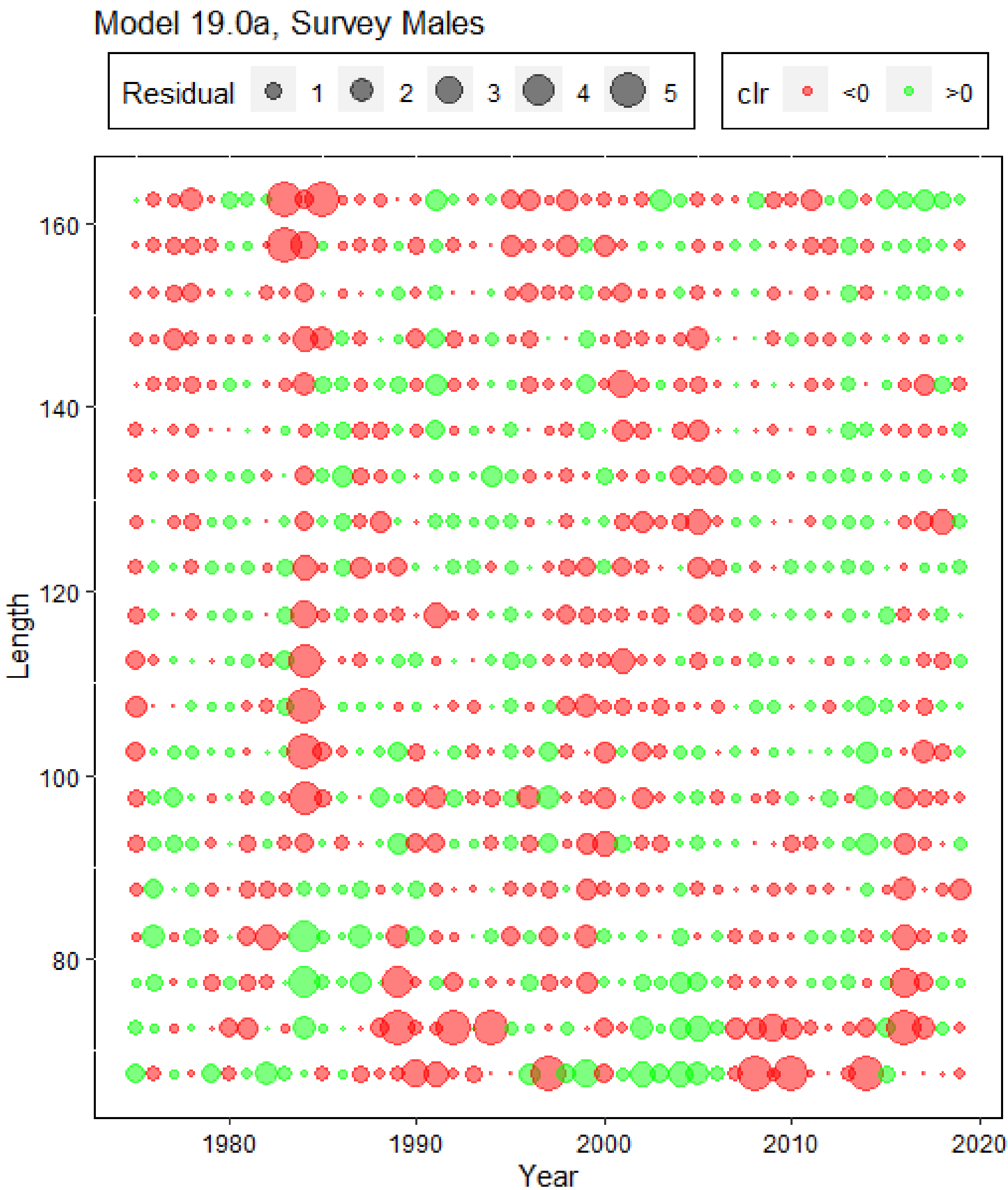


Figure 25a. Residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 19.0a. Green circles are positive residuals, and red circles are negative residuals.

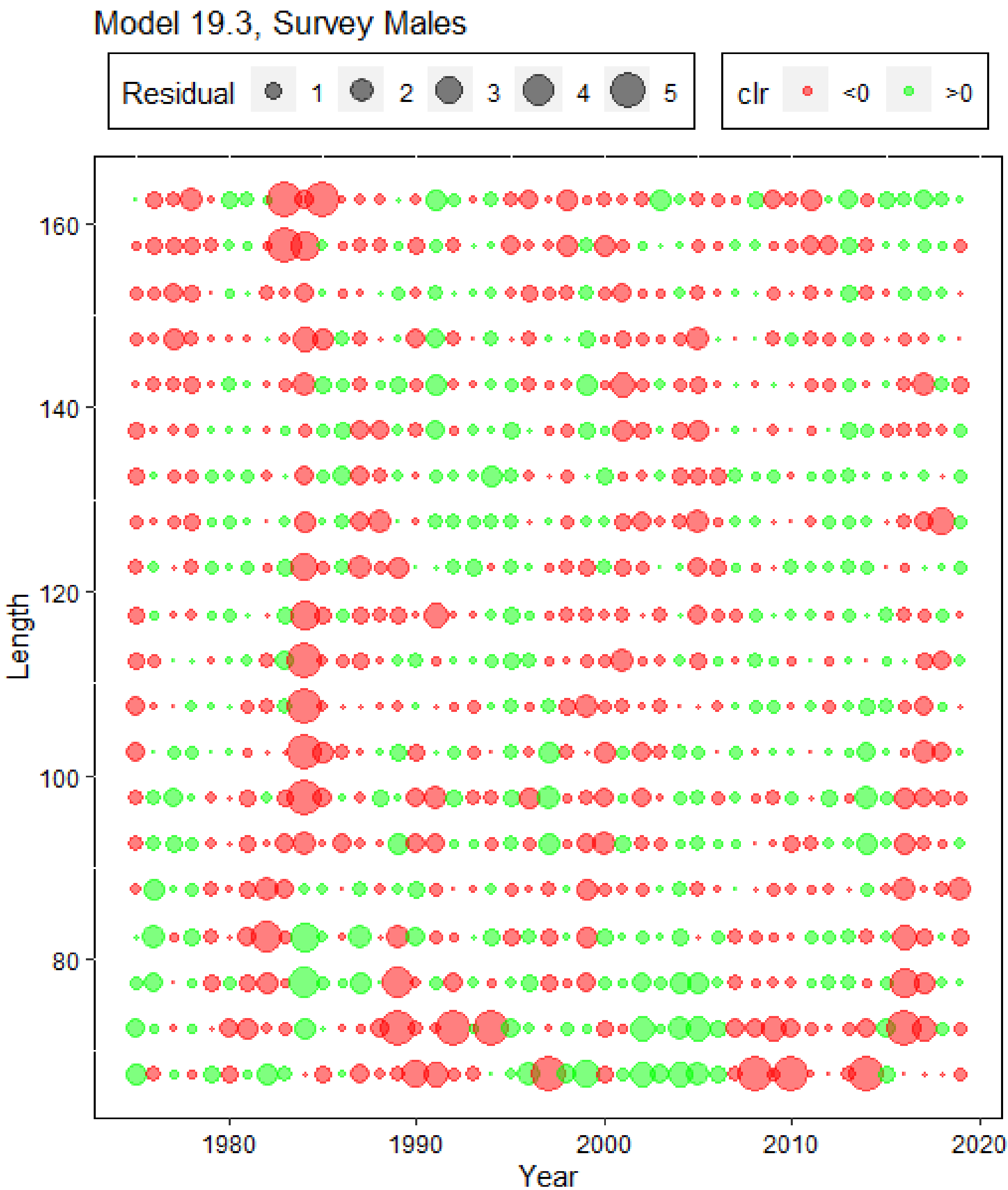


Figure 25b. Residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 19.3. Green circles are positive residuals, and red circles are negative residuals.

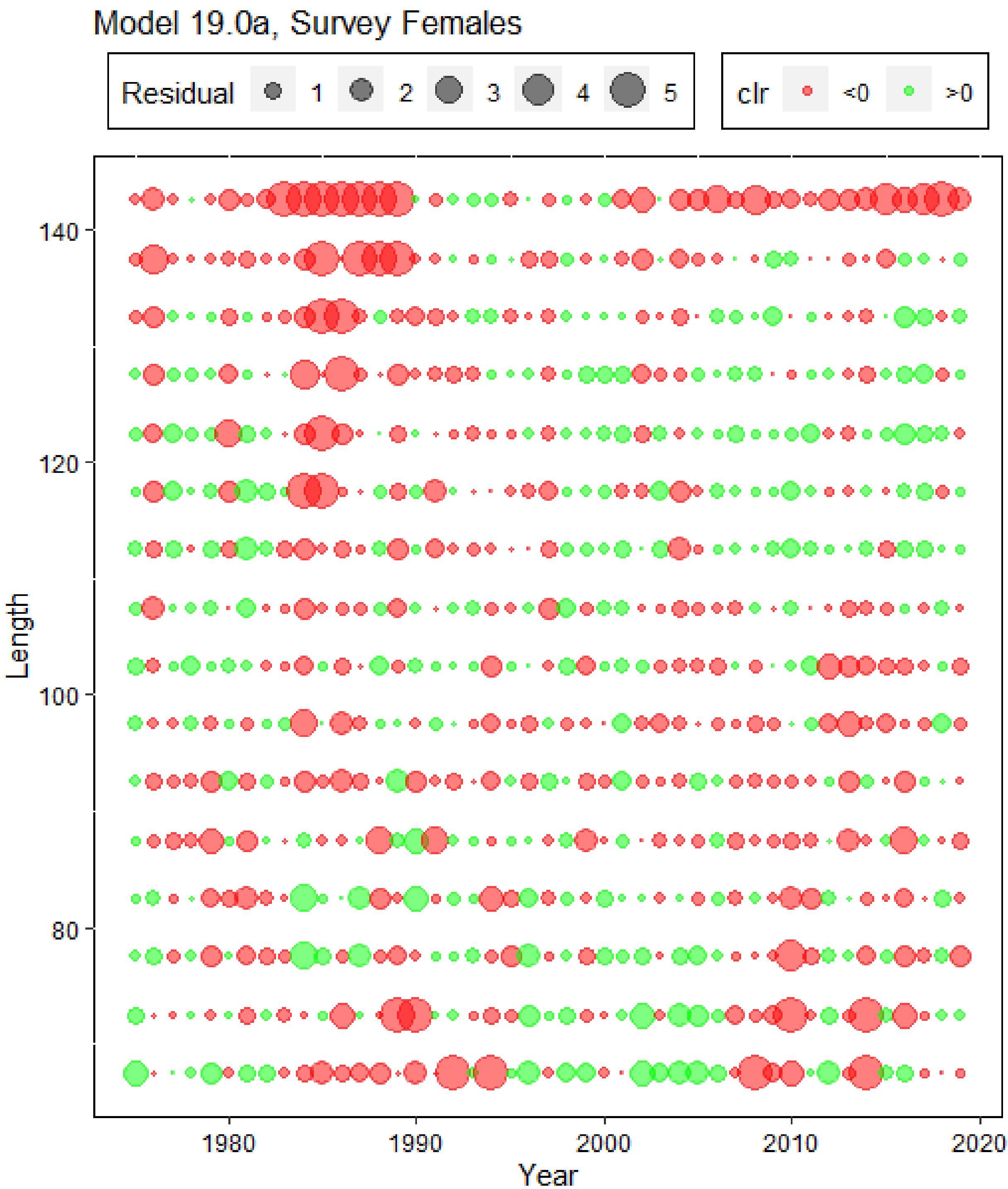


Figure 26a. Residuals of proportions of NMFS survey female red king crab by year and carapace length (mm) under model 19.0a. Green circles are positive residuals, and red circles are negative residuals.

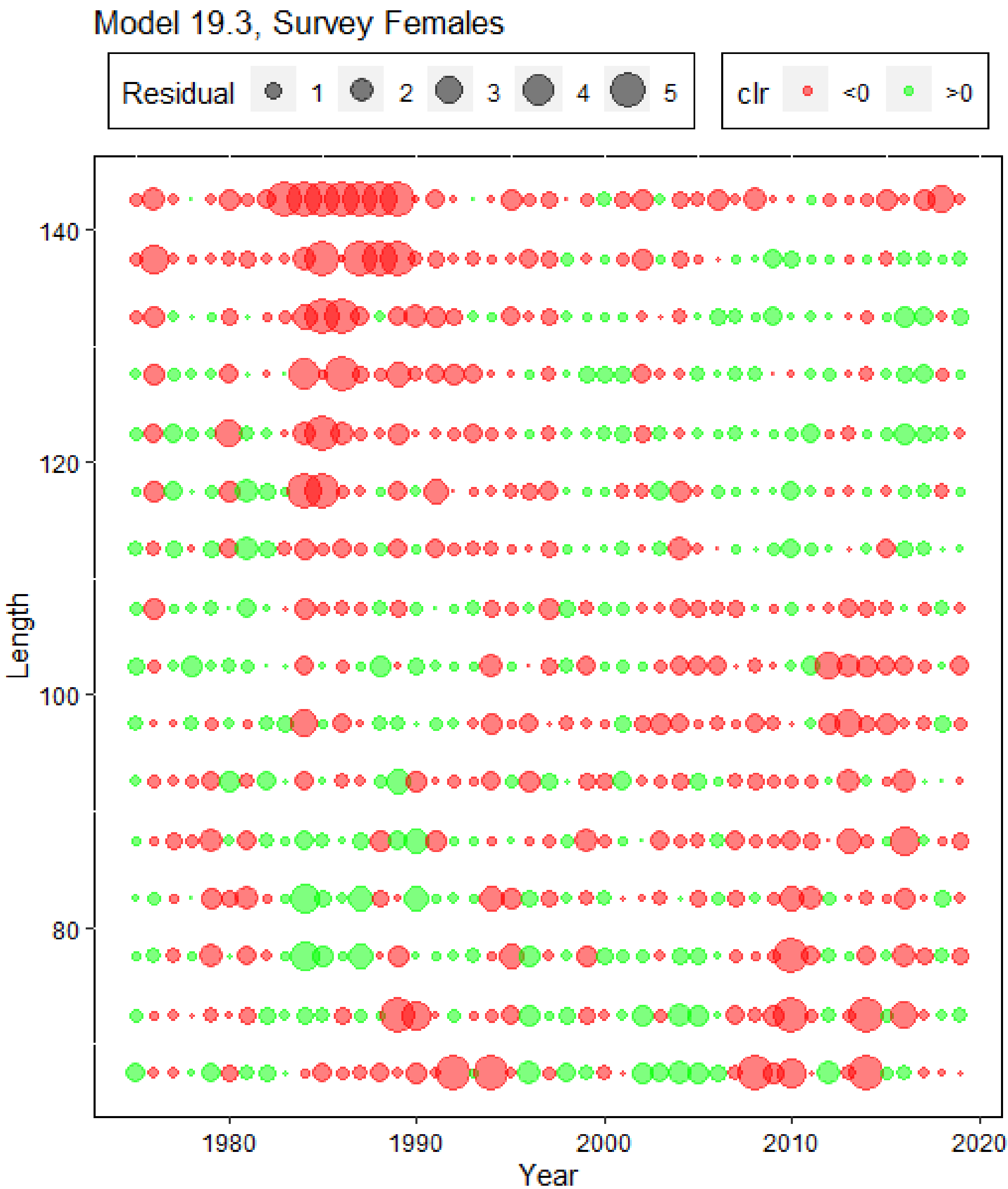


Figure 26b. Residuals of proportions of NMFS survey female red king crab by year and carapace length (mm) under model 19.3. Green circles are positive residuals, and red circles are negative residuals.

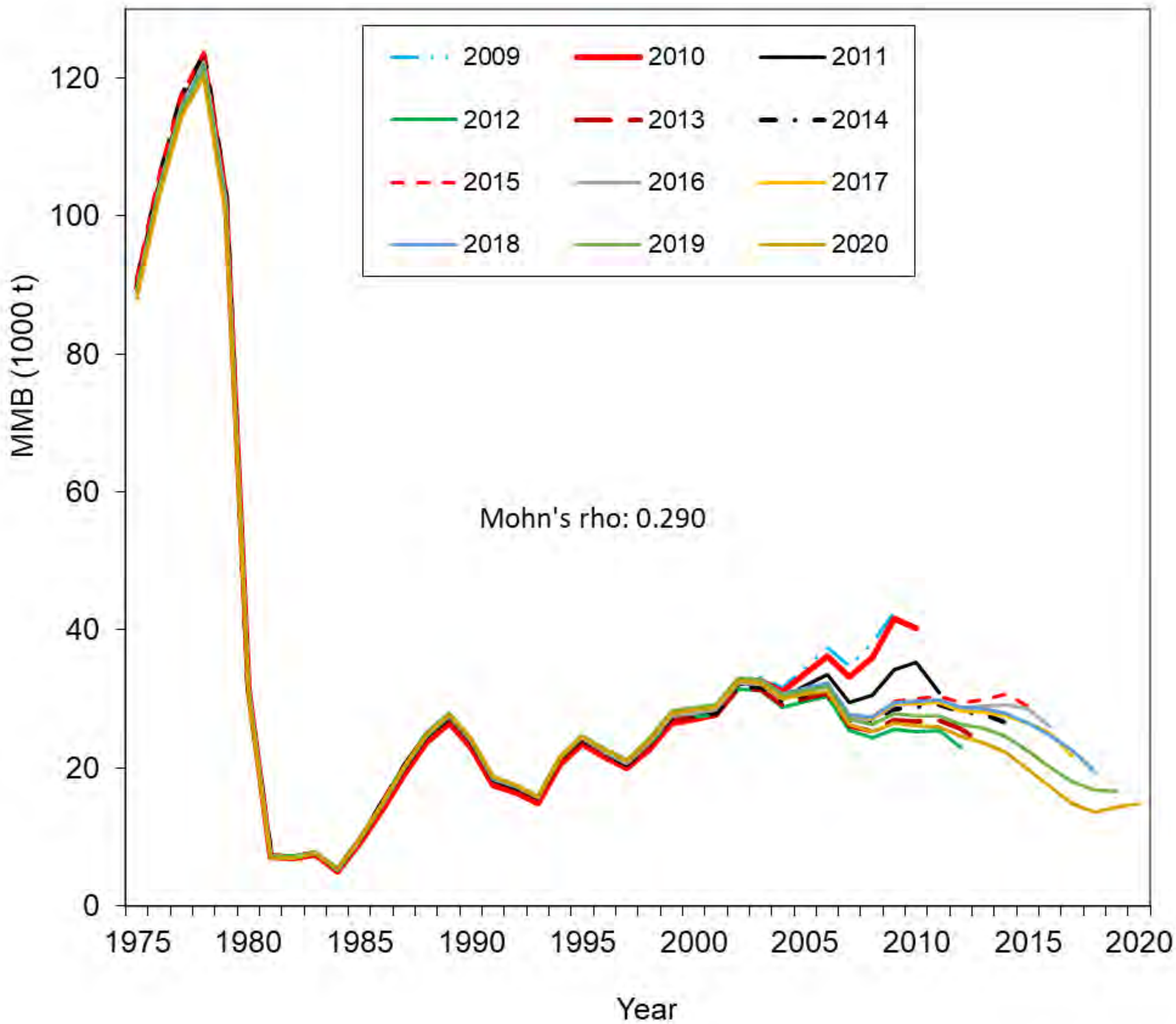


Figure 27. Comparison of hindcast estimates of mature male biomass on Feb. 15 of Bristol Bay red king crab from 1975 to 2020 made with terminal years 2009-2020 with model 19.3. These are results of the 2020 model. Legend shows the terminal year.

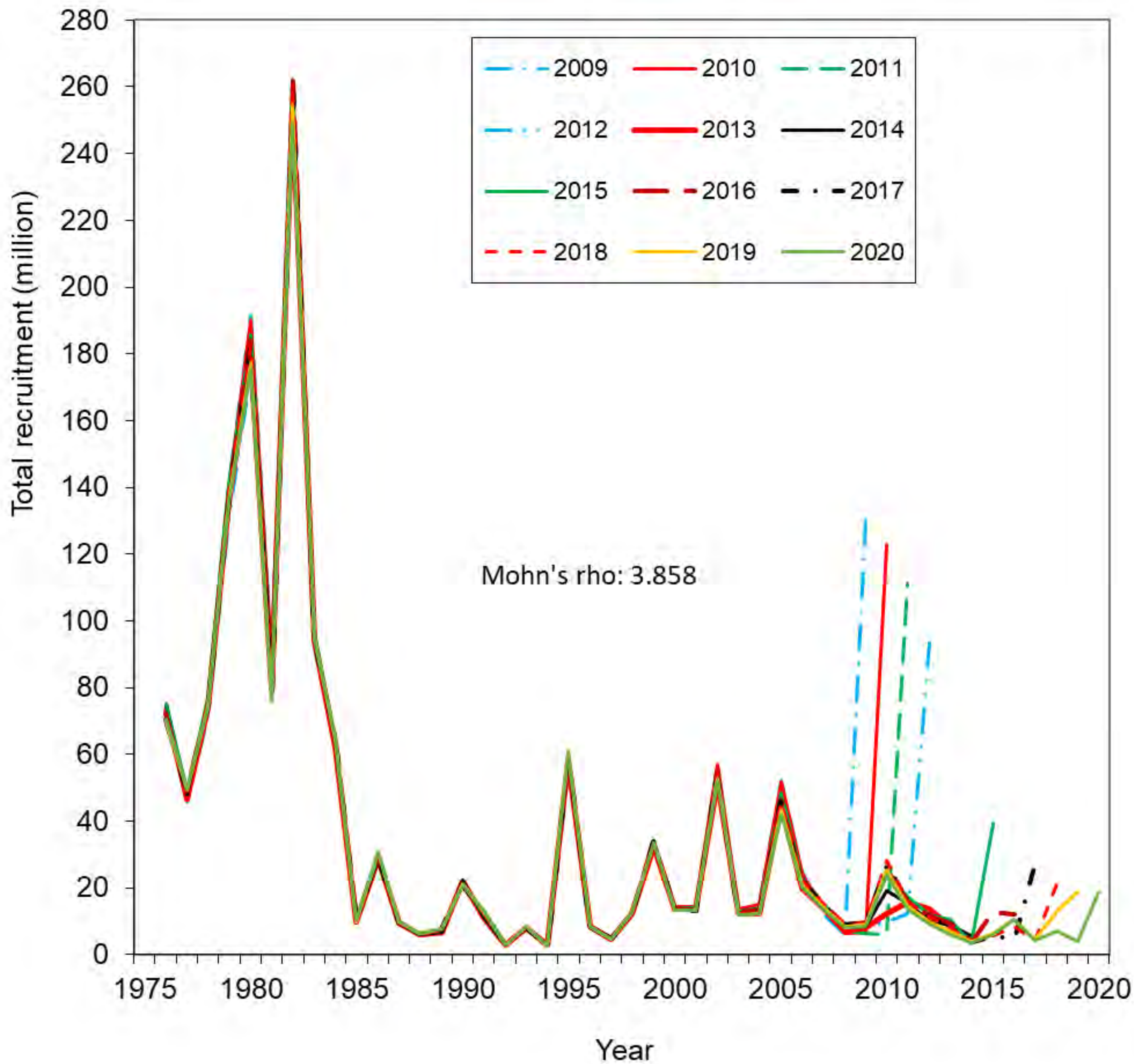


Figure 28a. Comparison of hindcast estimates of total recruitment for model 19.3 of Bristol Bay red king crab from 1976 to 2020 made with terminal years 2009-2020. These are results of the 2020 model. Legend shows the terminal year.

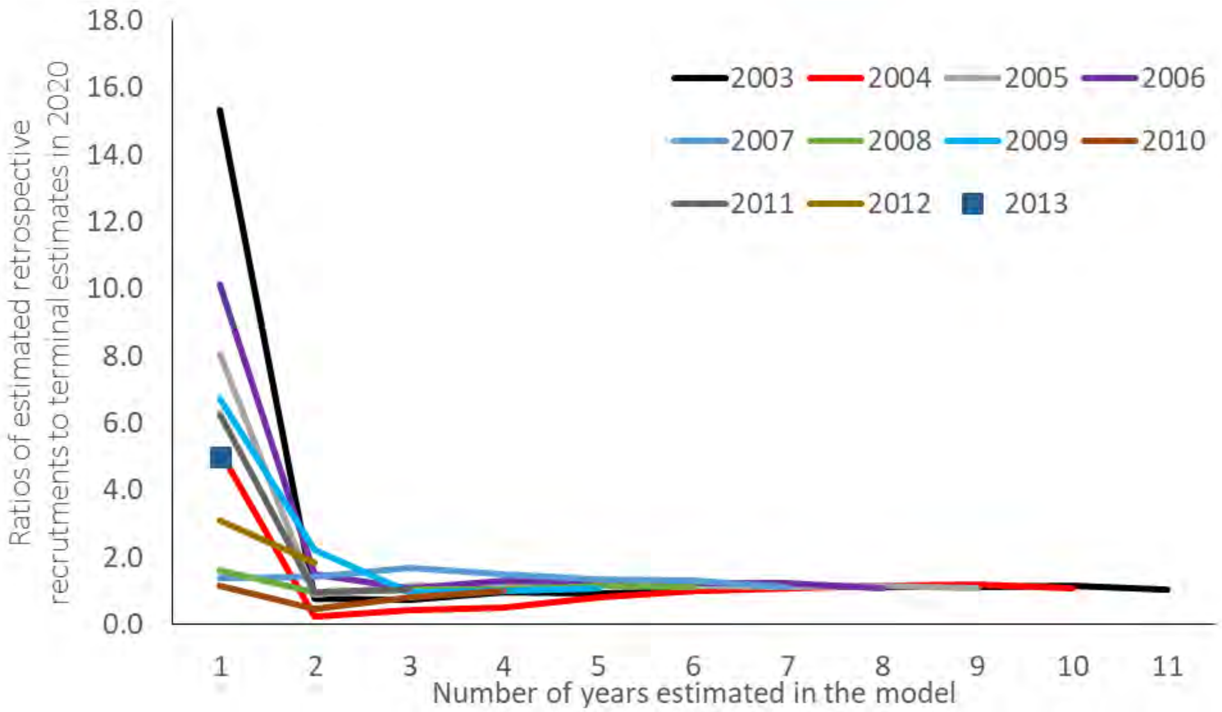


Figure 28b. Evaluation of Bristol Bay red king crab retrospective errors on recruitment estimates as a function of the number of years in the model for model 19.3.

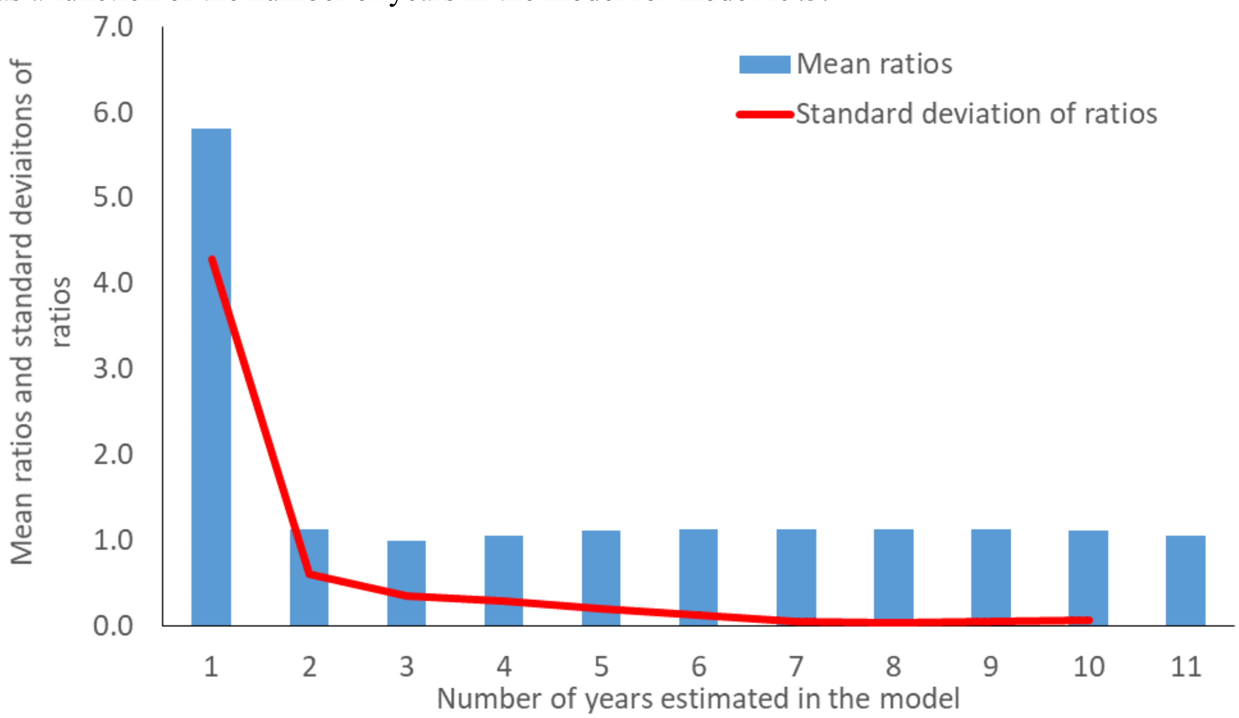


Figure 28c. Mean ratios of retrospective estimates of recruitments to those estimated in the most recent year (2020) and standard deviations of the ratios as a function of the number of years in the model for model 19.3.

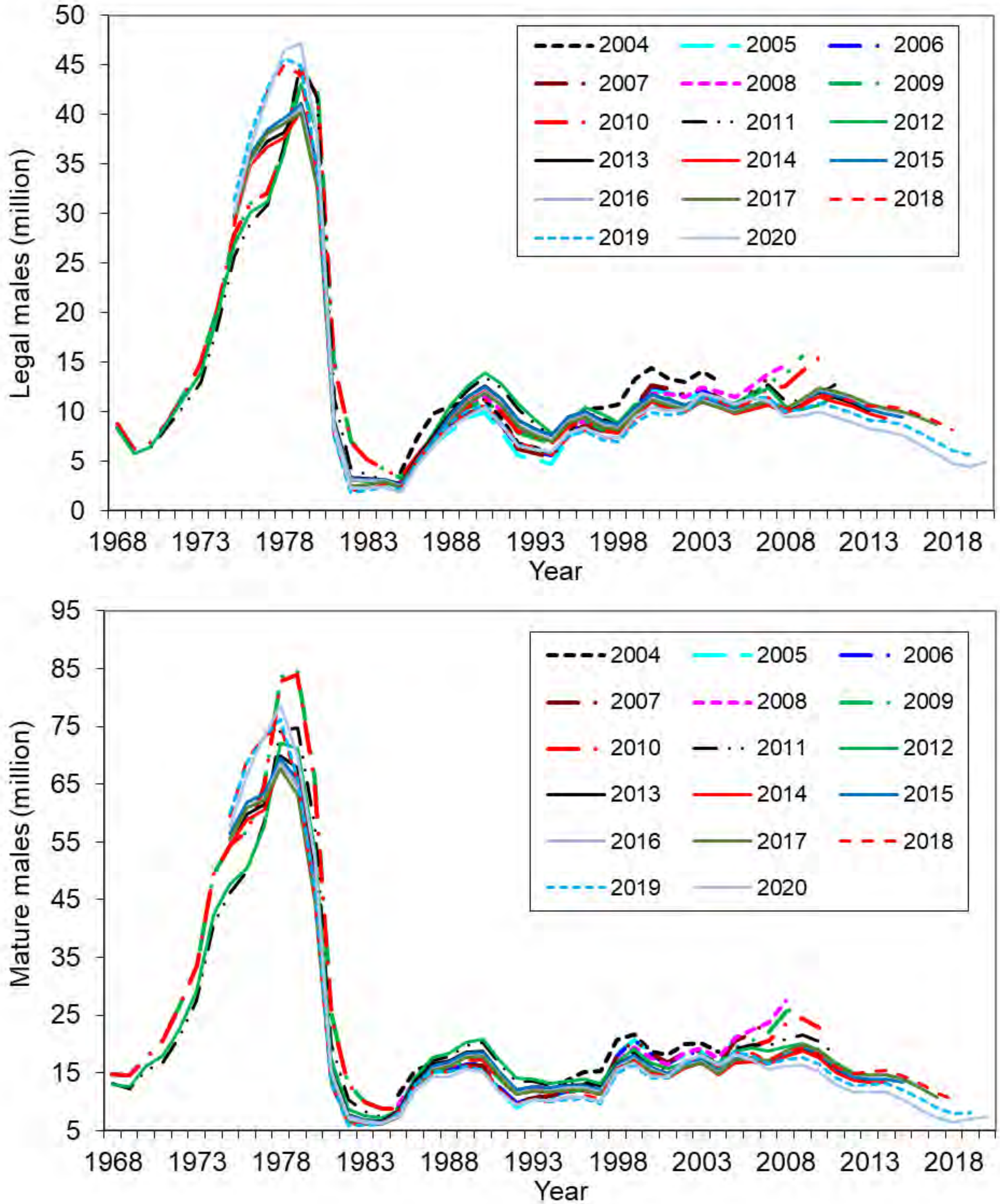


Figure 29. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1968 to 2020 made with terminal years 2004-2020 with the base models. Model 19.3 is used for 2020. These are results of historical assessments. Legend shows the year in which the assessment was conducted.

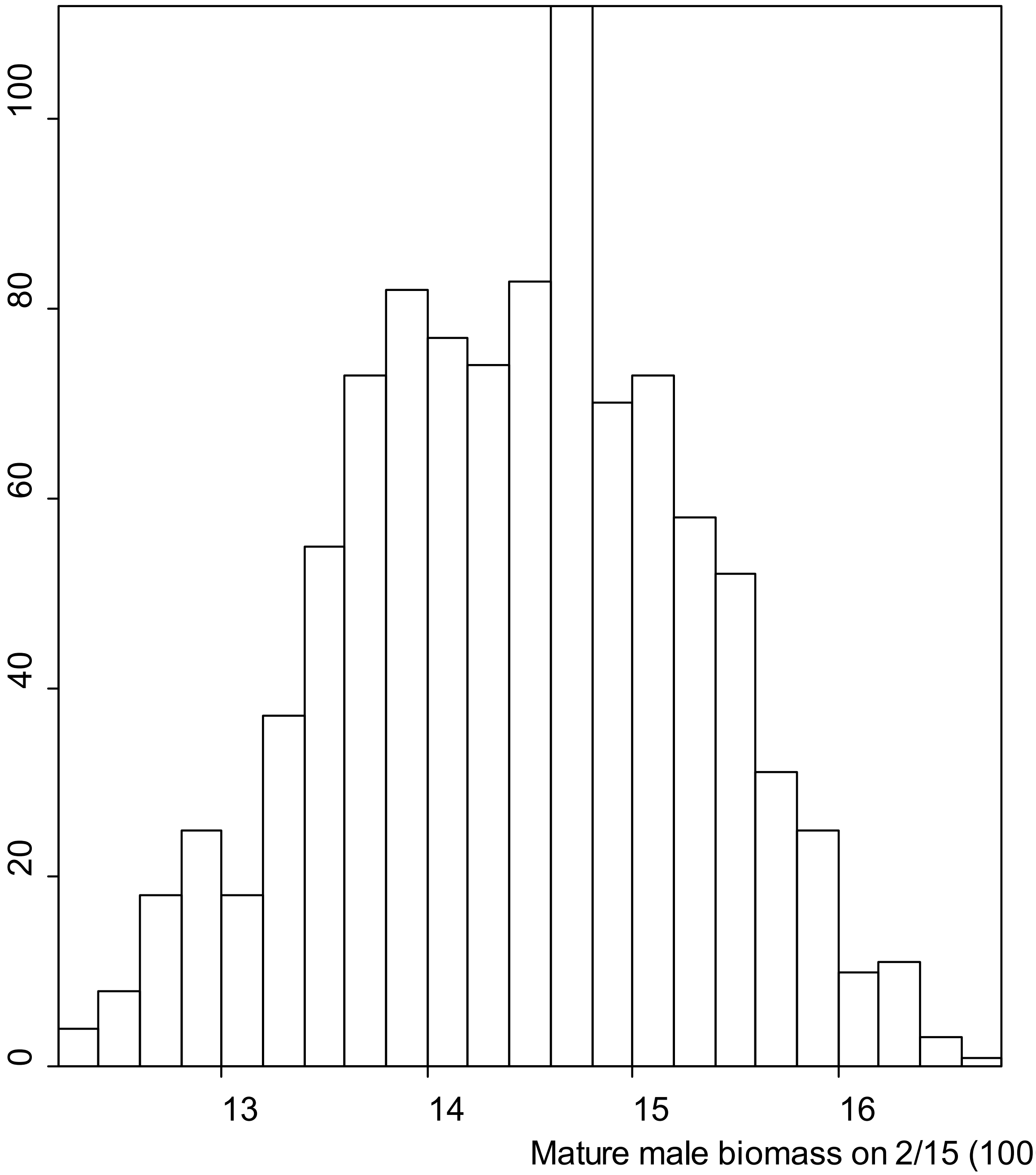


Figure 30. Histogram of estimated mature male biomass on Feb. 15, 2021 under model 19.3 with the MCMC approach.

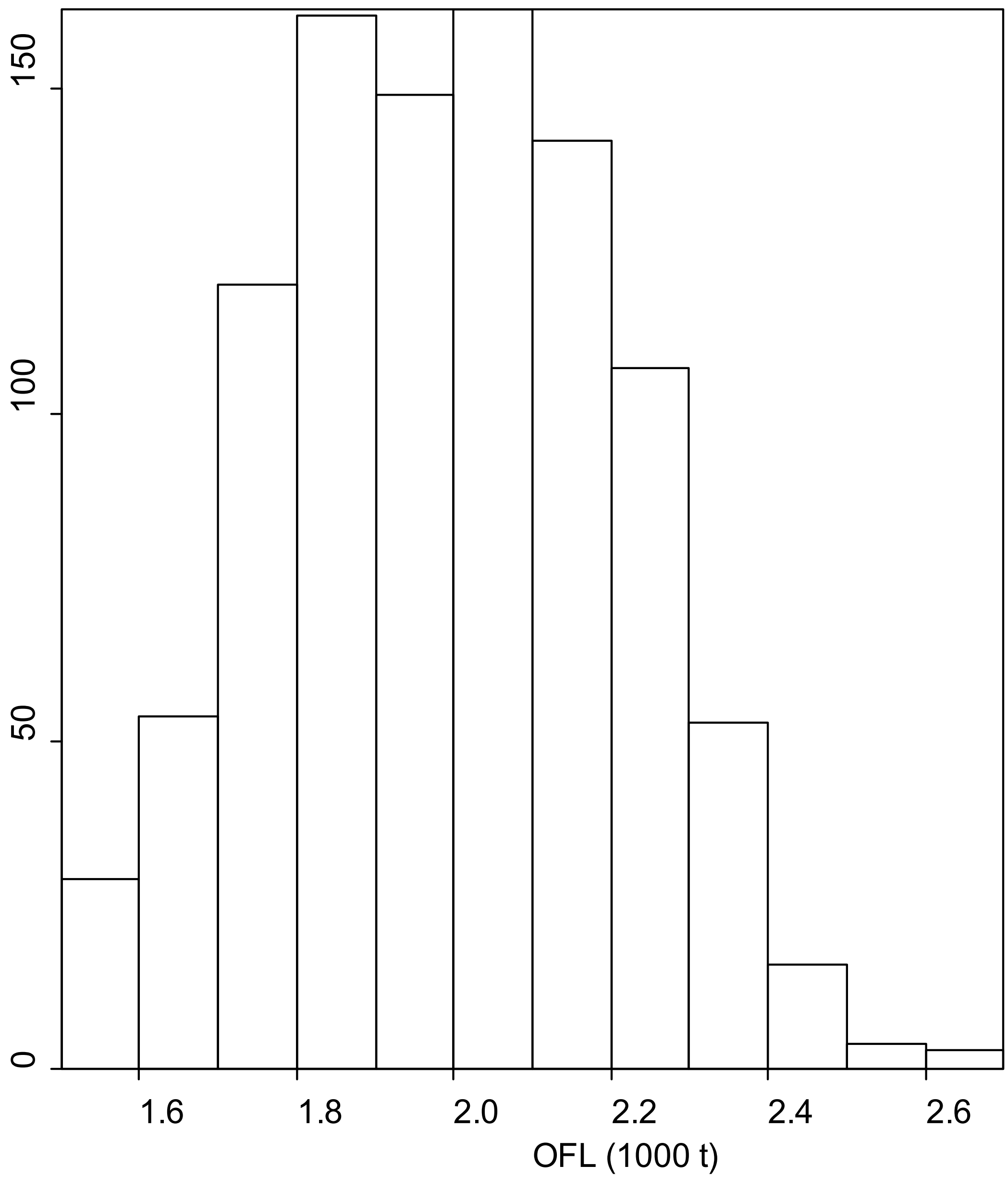


Figure 31. Histogram of the 2020 estimated OFL under model 19.3 with the MCMC approach.

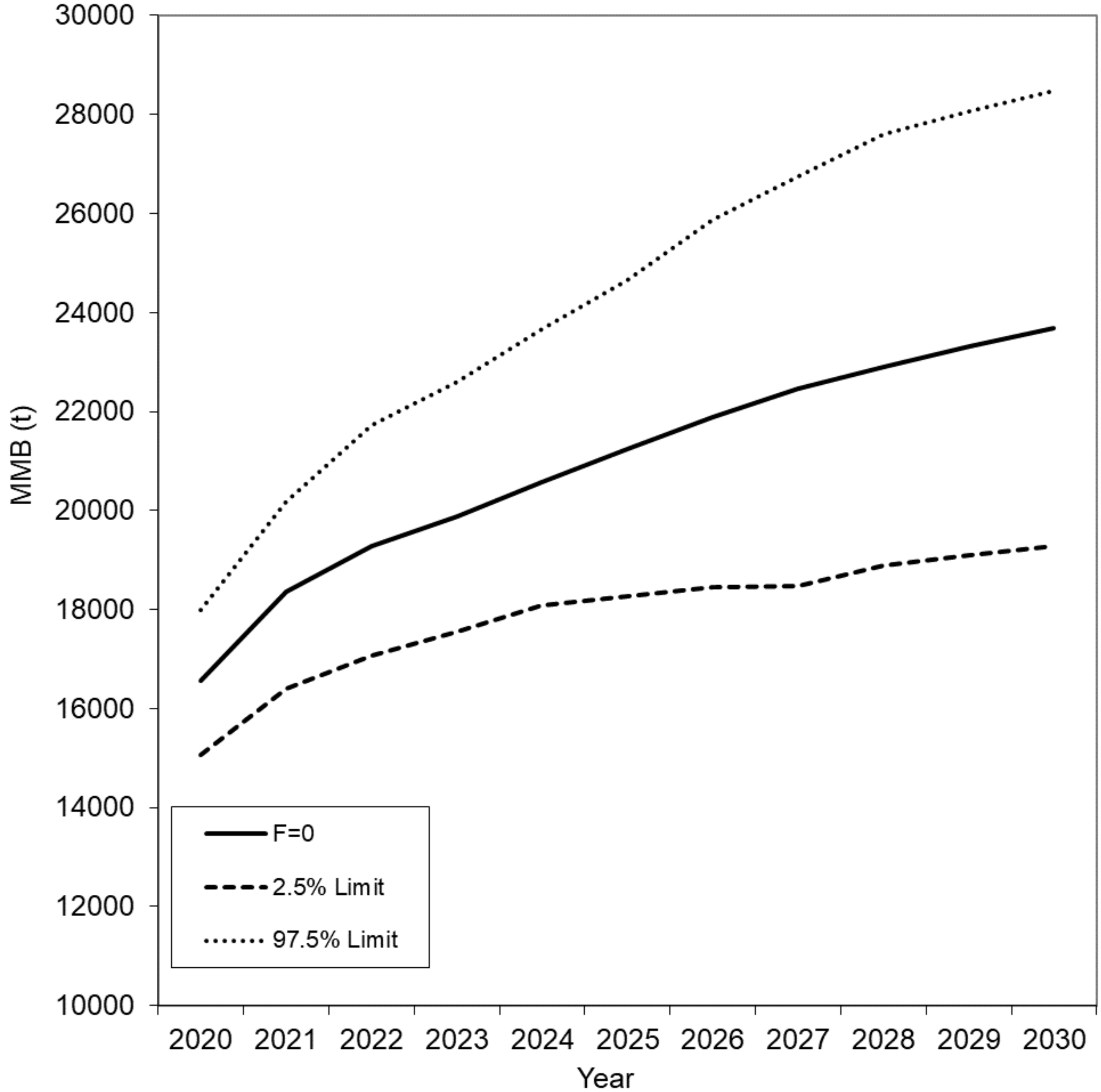


Figure 32a. Projected mature male biomass on Feb. 15 with $F = 0$ harvest strategy during 2020-2030. Input parameter estimates are based on model 19.3a.

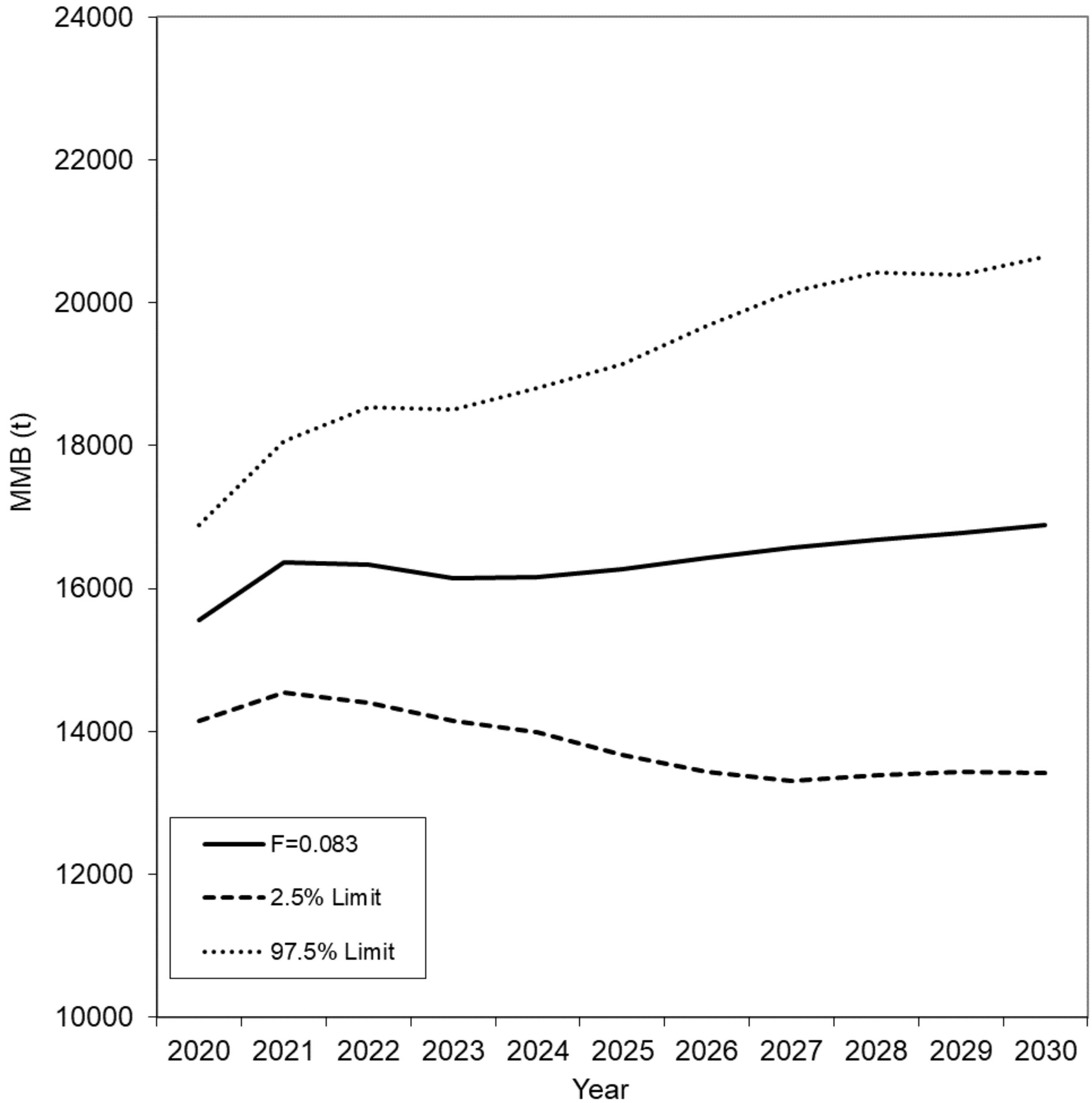


Figure 32b. Projected mature male biomass on Feb. 15 with F = 0.083 harvest strategy during 2020-2030. Input parameter estimates are based on model 19.3a.

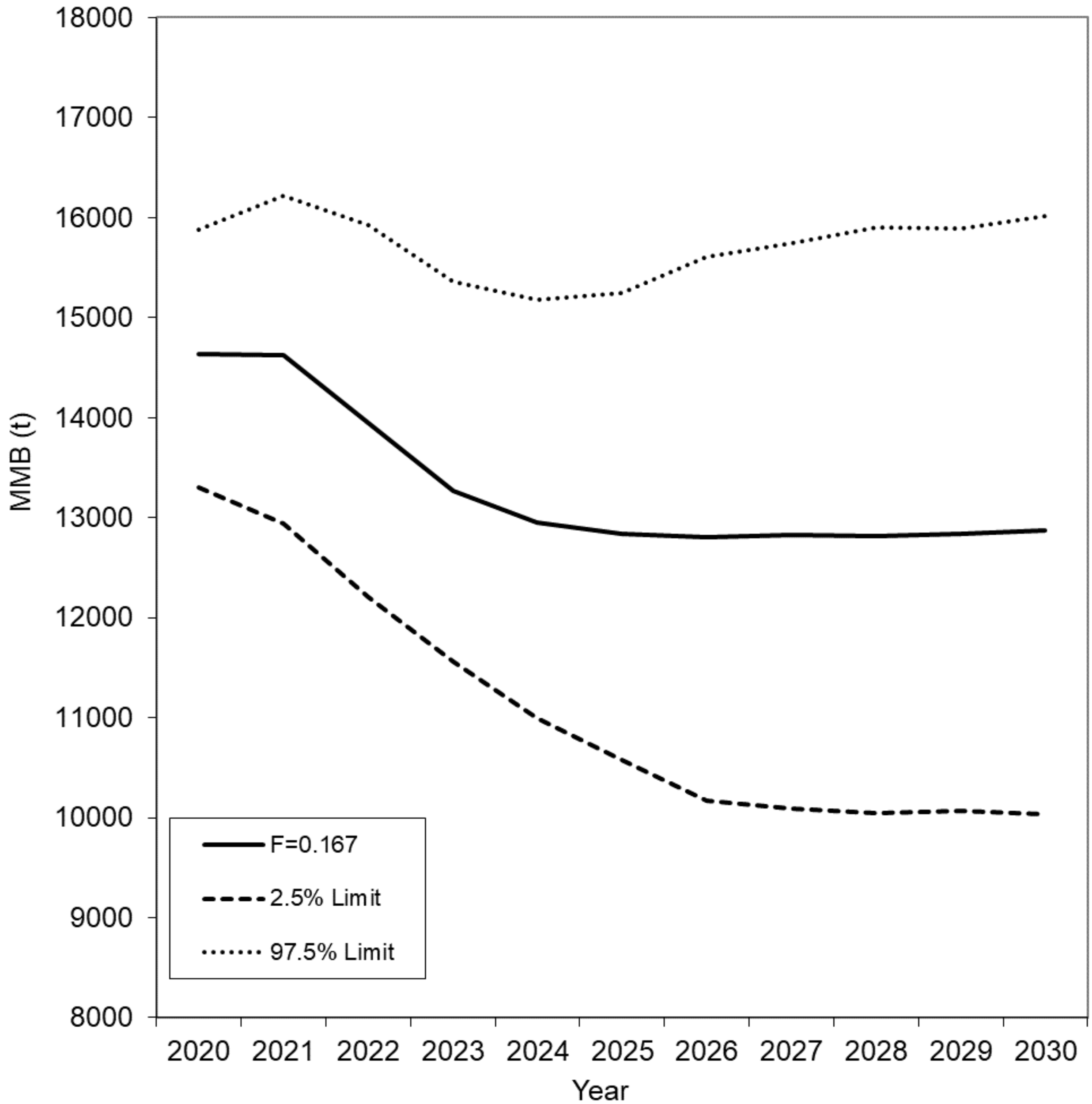


Figure 32c. Projected mature male biomass on Feb. 15 with F = 0.167 harvest strategy during 2020-2030. Input parameter estimates are based on model 19.3a.

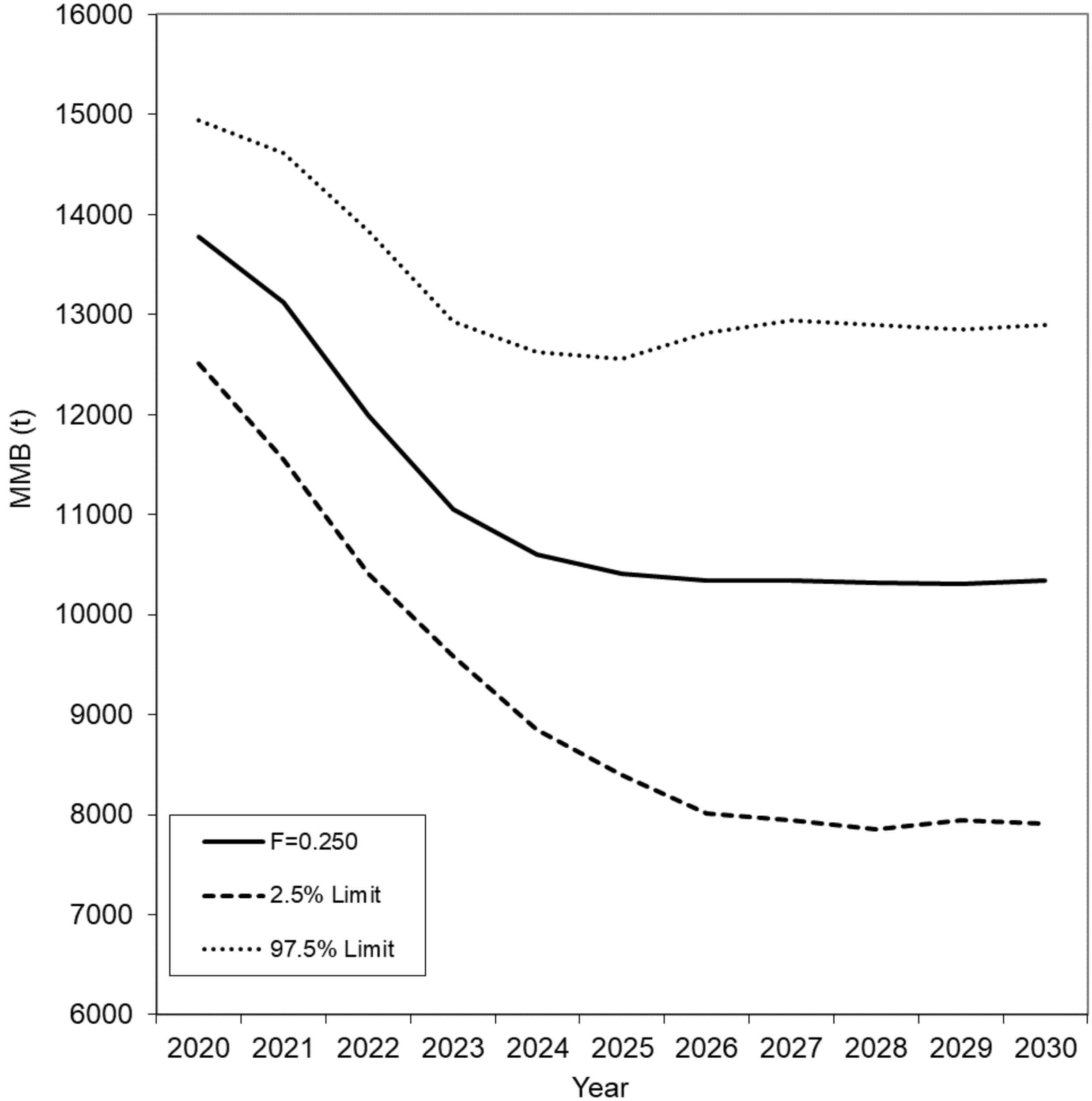


Figure 32d. Projected mature male biomass on Feb. 15 with F = 0.250 harvest strategy during 2020-2030. Input parameter estimates are based on model 19.3a.

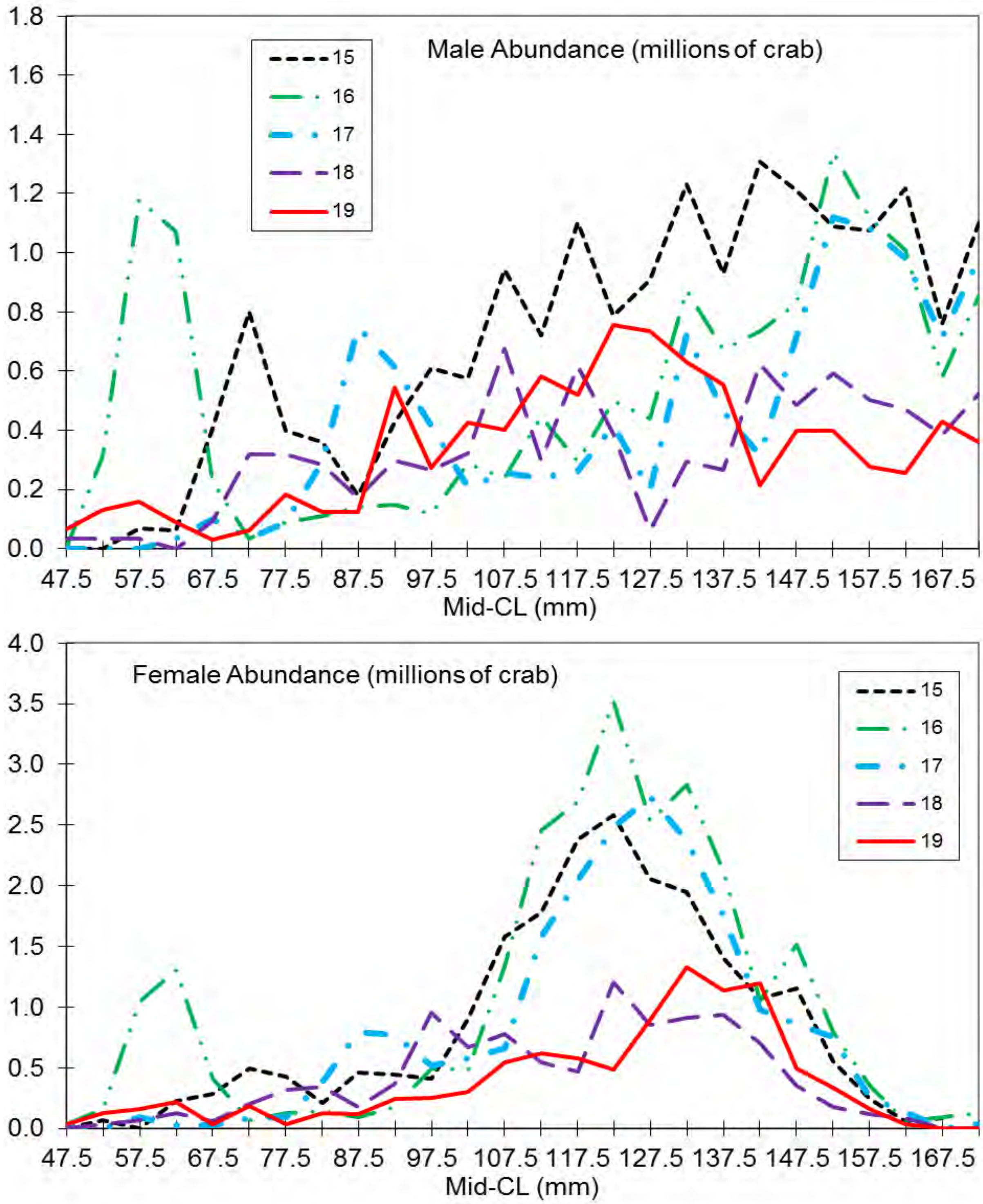


Figure 33. Length frequency distributions of male (top panel) and female (bottom panel) red king crab in Bristol Bay from NMFS trawl surveys during 2015-2019. For purposes of these graphs, abundance estimates are based on area-swept methods.

Appendix A. Description of GMACS with Bristol Bay Red King Crab Options (mainly from the GMACS document)

A. Model Description

a. Population model

The basic dynamics account for growth, mortality, maturity state and shell condition (although most of the equations below do not explicitly refer to maturity state and shell condition). For the case in which shell condition is not distinguished:

$$\underline{N}^g_{y,t} = ((\mathbf{I} - \mathbf{P}^g_{y,t-1}) + \mathbf{X}^g_{y,t-1}\mathbf{P}^g_{y,t-1})\,\mathbf{S}^g_{y,t-1}\,\underline{N}^g_{y,t-1} + \underline{\tilde{R}}^g_{y,t} \tag{A.1}$$

where $\underline{N}^g_{y,t}$ is the number of animals by size-class of gender g at the start of season t of year y, $\mathbf{P}^g_{y,t}$ is a matrix with diagonals given by vector of molting probabilities for animals of gender g at the start of season t of year y, $\mathbf{S}^g_{y,t}$ is a matrix with diagonals given by the vector of probabilities of surviving for animals of gender g during time-step t of year y (which may be of zero duration):

$$S^g_{y,t,l,l} = \exp\left(-Z^g_{y,t,l}\right) \tag{A.2}$$

$\mathbf{X}^g_{y,t}$ is the size-transition matrix (probability of growing from one size-class to each of the other size-classes or remains in the same size class) for animals of gender g during season t of year y, $\underline{\tilde{R}}^g_{y,t}$ is the recruitment (by size-class) to gear g during season t of year y (which will be zero except for one season – the recruitment season), and $Z^g_{y,t,l}$ is the total mortality for animals of gender g in size-class l during season t of year y. Note that mortality is continuous across a time-step.

The initial conditions for the model (i.e., the numbers-at-size at the start of the first year, y_1) is specified with an overall total recruitment multiplied by offsets for each size-class, i.e.:

$$N^g_{y_1,l} = R_{\text{Init}} e^{\delta^g_{y_1,l}} / \sum_{g'}\sum_{l'} e^{\delta^{g'}_{y_1,l'}} \tag{A.3}$$

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.

b. Recruitment

Recruitment occurs once during each year. Recruitment by sex and size-class is the product of total recruitment, the split of the total recruitment to sex and the assignment of sex-specific recruitment to size-classes, i.e.:

$$\tilde{R}^g_{y,t,l} = \bar{R}e^{\varepsilon_y}\begin{cases}(1+e^{\phi_y})^{-1}\,p^{\text{r,mal}}_l & \text{if } g\text{=males}\\ \phi_y(1+e^{\phi_y})^{-1}\,p^{\text{r,fem}}_l & \text{if } g\text{=females}\end{cases} \tag{A.4}$$

where $\bar{R}$ is median recruitment, ϕ_y determines the sex ratio of recruitment during year y, and $p_l^{r,g}$ is the proportion of the recruitment (by gender and year) that recruits to size-class l:

$$p_l^{r,g} = \int_{L_l^{\text{low}}}^{L_l^{\text{hi}}} \frac{1}{\Gamma(\alpha^{r,g}/\beta^{r,g})}(l/\beta^{r,g})^{((\alpha^{r,g}/\beta^{r,g})-1)} e^{-l/\beta^{r,g}} dl \tag{A.5}$$

where $\alpha^{r,g}$ and $\beta^{r,g}$ are the parameters that define a gamma function for the distribution of recruits to size-class. Equation A.5 can be restricted to a subset of size-classes, in which case the results from Equation A.5 are normalized to sum to 1 over the selected size-classes.

c. Total mortality / probability of encountering the gear

Total mortality is the sum of fishing mortality and natural mortality, i.e.:

$$Z_{y,t,l}^g = \rho_{y,t}^{\text{M}} M_y^g \tilde{M}_l + \sum_f S_{y,t,l}^{f,g}(\lambda_{y,t,l}^{f,g} + \Omega_{y,t,l}^{f,g}(1-\lambda_{y,t,l}^{f,g}))F_{y,t}^{f,g} \tag{A.6}$$

where $\rho_{y,t}^{\text{M}}$ is the proportion of natural mortality that occurs during season t for year y, M_y^g is the rate of natural mortality for year y for animals of gender g (applies to animals for which $\tilde{M}_l = 1$), $\tilde{M}_l$ is the relative natural mortality for size-class l, $S_{y,t,l}^{f,g}$ is the (capture) selectivity for animals of gender g in size-class l by fleet f during season t of year y, $\lambda_{y,t,l}^{f,g}$ is the probability of retention for animals of gender g in size-class l by fleet f during season t of year y, $\Omega_{y,t,l}^{f,g}$ is the mortality rate for discards of gender g in size-class l by fleet f during season t of year y, and $F_{y,t}^{f,g}$ is the fully-selected fishing mortality for animals of gender g by fleet f during season t of year y.

The probability of encountering the gear (occurs instantaneously) is given by:

$$\tilde{Z}_{y,t,l}^g = \sum_f S_{y,t,l}^{f,g} F_{y,t}^{f,g} \tag{A.7}$$

Note that Equation A.7 is computed under the premise that fishing is instantaneous and hence that there is no natural mortality during season t of year y.

The logarithms of the fully-selected fishing mortalities by season are modelled as:

$$\ell\text{n}F_{y,t}^{f,\text{mal}} = \ell\text{n}F^{f,\text{mal}} + \xi_{y,t}^{f,\text{mal}} \tag{A.8}$$

$$\ell\text{n}F_{y,t}^{f,\text{fem}} = \ell\text{n}F_{y,t}^{f,\text{mal}} + \phi^f + \xi_{y,t}^{f,\text{fem}} \tag{A.9}$$

where $F^{f,\text{mal}}$ is the reference fully-selected fishing mortality rate for fleet f, ϕ^f is the offset between female and male fully-selected fishing mortality for fleet f, and $\xi_{y,t}^{f,g}$ are the annual deviation of fully-selected fishing mortality for fleet f (by gender).

Natural mortality can depend on time with blocked natural mortality (individual parameters). This option estimates natural mortality as parameters by block, i.e.:

$$M_y^g = e^{\psi_y^g} \quad \text{(A.10)}$$

where $M_{y_1}^g$ is the rate of natural mortality for gender g for the first year of the model, and ψ_y^g is the annual change in natural mortality and changes in blocks of years.

It is possible to 'mirror' the values for the ψ_y^g parameters (between genders and between blocks), which allows male and female natural mortality to be the same, and for natural mortality to be the same for discontinuous blocks (based on Equation A.10). It is also possible to estimate a ratio of natural mortality between genders. The deviations in natural mortality can also be penalized to avoid unrealistic changes in natural mortality to fit 'quirks' in the data.

d. Landings, discards, total catch

The model keeps track of (and can be fitted to) landings, discards, total catch by fleet in season with continuous mortality:

Landed catch
$$C_{y,t,l}^{\text{Land},f,g} = \frac{\lambda_{y,t,l}^{f,g} S_{y,t,l}^{f,g} F_{y,t}^{f,g}}{Z_{y,t,l}^g} N_{y,t,l}^{f,g}(1-e^{-Z_{y,t,l}^g}) \quad \text{(A.11)}$$

Discards
$$C_{y,t,l}^{\text{Disc},f,g} = \frac{(1-\lambda_{y,t,l}^{f,g}) S_{y,t,l}^{f,g} F_{y,t}^{f,g}}{Z_{y,t,l}^g} N_{y,t,l}^{f,g}(1-e^{-Z_{y,t,l}^g}) \quad \text{(A.12)}$$

Total catch
$$C_{y,t,l}^{\text{Total}f,g} = \frac{S_{y,t,l}^{f,g} F_{y,t}^{f,g}}{Z_{y,t,l}^g} N_{y,t,l}^{f,g}(1-e^{-Z_{y,t,l}^g}) \quad \text{(A.13)}$$

Landings, discards, and total catches by fleet can be aggregated over gender (e.g., when fitting to removals reported as gender-combined). Equations A.11-13 are extended naturally for the case in which the population is represented by shell condition and/or maturity status (given the assumption that fishing mortality, retention and discard mortality depend on gender and time, but not on shell condition nor maturity status).

Landings, discards, and total catches by fleet can be reported in numbers (Equations A.11–13) or in terms of weight. For example, the landings, discards, and total catches by fleet, season, year, and gender for the total (over size-class) removals are computed as:

$$C_{y,t}^{\text{Land},g,f} = \sum_l C_{y,t,l}^{\text{Land},g,f} w_{y,l}^g \,;\; C_{y,t}^{\text{Disc},g,f} = \sum_l C_{y,t,l}^{\text{Disc},g,f} w_{y,l}^g \,;\; C_{y,t}^{\text{Total},g,f} = \sum_l C_{y,t,l}^{\text{Total},g,f} w_{y,l}^g \quad \text{(A.14)}$$

where $C_{y,t}^{\text{Land},g,f}$, $C_{y,t}^{\text{Disc},g,f}$, and $C_{y,t}^{\text{Total},g,f}$ are respectively the landings, discards, and total catches in weight by fleet, season, year, and gender for the total (over size-class) removals, and $w_{y,l}^g$ is the weight of an animal of gender g in size-class l during year y.

e. Selectivity / retention

Selectivity (the probability of encountering the gear) and retention (the probability of being landed given being captured) are logistic function:

$$S_l = 1 - (1 + exp((\bar{L}_l - S_{50})/\sigma^S))^{-1} \qquad \text{(A.15)}$$

where S_{50} is the size corresponding to 50% selectivity, σ^S is the "standard deviation" of the selectivity curve, and $\bar{L}_l$ is the midpoint of size-class *l*.

It is possible to assume that selectivity for one fleet is the product of two of the selectivity patterns. This option is used to model cases in which one survey (NMFS trawl survey) is located within the footprint of another survey (BSFRF trawl survey).

The options to model retention are the same as those for selectivity, except that it is possible to estimate an asymptotic parameter, which allows discard of animals that would be "fully retained" according to the standard options for (capture) selectivity.

Selectivity and retention can be defined for blocks of contiguous years. Two blocks are used for NMFS survey selectivity (before 1982 and after 1981) due to gear modifications and two blocks are used for the directed pot fishery retention (before 2005 and after 2004) due to the fishery rationalization.

f. Growth

Growth is a key component of any size-structured model. It is modelled in terms of molt probability and the size-transition matrix (the probability of growing from each size-class to each of the other size-classes, constrained to be zero for sizes less than the current size). Note that the size-transition matrix has entries on its diagonal, which represent animals that molt but do not change size-classes.

(1) Molt probability

There are two options for modelling the probability of molting as a function of size, $P_{l,l}$:

- Constant probability (1 for females)
- Logistic probability (for males), i.e.:

$$P_{l,l} = 1 - (1 + \exp((\bar{L}_l - P_{50}) / \sigma^P))^{-1} \qquad \text{(A.16)}$$

where P_{50} is the size at which the probability of molting is 0.5, and σ^S is the "standard deviation" of the molt probability function.

Molt probability is specified by gender and can change in blocks (one block before 1981 and one block after 1980 for males).

(2) Size-transition

The proportion of animals in size-class *j* that grow to be in size-class *i* ($X_{i,j}$) can be pre-specified as gamma-distributed size-increments:

$$X_{i,j} = \int_{L_j^{\text{low}}}^{L_j^{\text{hi}}} \frac{1}{\Gamma(I_i/\tilde{\beta})} ((l - \bar{L}_i) / \tilde{\beta})^{(I_i/\tilde{\beta})-1} e^{-(l-\bar{L}_i)/\tilde{\beta}} dl \qquad \text{(A.17)}$$

where I_i is the 'expected' growth increment for an animal in size-class *i* (a linear function of the mid-point of size-class *i*), $\tilde{\beta}$ determines the variation in growth among individuals, and L_j^{low} and L_j^{hi} are respectively the lower and upper bounds of size-class *j*.

The size-transition matrix is specified by gender and can change in blocks (one block for males and three blocks for females (1975-1982, 1983-1993, and 1994-present based on changes in sizes at maturity).

B. Outputs, Projections and OFL Calculation

a. Core model outputs

The core model outputs are the N-matrix, the matrix of fully-selected fishing mortalities, the time-series of spawning stock biomass, mature male biomass (SSB), the values for the model parameters, and the predictions related to the observations. The spawning stock biomass (and hence mature male biomass) is defined according to:

$$SSB_y = \sum_g p^{\text{SSB},g} \sum_l N^g_{y,t^*,l} \quad \text{(A.18)}$$

where $p^{\text{SSB},g}$ is the relative contribution of gender *g* to spawning biomass ($p^{\text{SSB,mal}} = 1$; $p^{\text{SSB,fem}} = 0$ corresponds to spawning stock biomass equating to mature male biomass), and *t** is the season in which spawning takes place (spawning occurs at the start of the season).

Definition of model outputs:

(1) 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.
(2) 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).
(3) Fishing mortality: full-selected instantaneous annual fishing mortality rate at the time of fishery.

b. Biological reference points

The key biological reference points are the proxy for F_{MSY}, the proxy for B_{MSY} and the Overfishing Level (OFL).

(1) The proxy for F_{MSY}

The specification for the proxy for F_{MSY} depends on the tier in which the stock is placed. BBRKC belongs to Tier 3, and the proxy for F_{MSY} is $F_{35\%}$, the value of a multiplier on the fully-selected fishing mortality rates for directed fisheries in the final year of the assessment such that spawning biomass-per-recruit is 35% of the unfished level. The fully-selected fishing mortality rates for non-directed fisheries are set to recent averages (recent 5 years for BBRKC). The unfished spawning biomass-per-recruit, $SSBPR(\underline{0})$, is calculated by projecting the population model forward where fishing mortality is zero for all fleets, and recruitment is constant (and ideally equal to 1). $F_{35\%}$ is then computed (using Newtons' method) such that:

$$SSBPR(\underline{\alpha}\underline{\bar{F}}) = 0.35\,SSBPR(\underline{0}) \qquad (A.19)$$

where $\underline{\bar{F}}$ is the vector of recent average fully-selected fishing mortalities, and $\underline{\alpha}$ is a vector with 1 for the non-directed fisheries and a calculated constant for the directed fisheries.

(2) The proxy for B_{MSY}

The specification for the proxy for B_{MSY} depends on the tier in which the stock is placed. For stocks in Tier 4, the proxy for B_{MSY} is the average spawning stock biomass over a pre-specified number of years. For Tier 3, the proxy for B_{MSY} is $0.35\,SSBPR(\underline{0})$ multiplied by the mean recruitment over a pre-specified number of years. GMACS estimates annual recruitments by sex through estimating annual recruitment deviations and annual recruitment proportions by sex. Pre-specified numbers of years are needed in the control file for recruitment average and for mean recruitment sex ratio, respectively.

(3) Calculating the OFL

The OFL is the total catch (in weight) encountered by the gear that dies either due to being landed or due to being discarded when fully-selected fishing mortality is computed using the OFL control rule. The total catch

$$OFL = \sum_g \sum_t w^g_{y_2,l} \frac{S^{f,g}_{y_2,t,l}(\lambda^{f,g}_{y_2,t,l} + \Omega^{f,g}_{y_2,t,l}(1-\lambda^{f,g}_{y_2,t,l})\,S^{f,g}_{y_2,t,l})\alpha^{*,f}\bar{F}^{f,g}_t}{Z^g_{y_2+1,t,l}} N^{f,g}_{y_2+1,t,l}(1-e^{-Z^g_{y_2+1,t,l}}) \qquad (A.20)$$

where y_2 is the final year of the assessment, $\alpha^{*,f}$ is the multiplier on average fully-selected fishing mortality for fleet f (1 for non-directed fisheries and a value computed from the OFL control rule for the directed fisheries), $\bar{F}^{f,g}_t$ is recent average fully-selected fishing mortality for fleet f and gender g during season t, and $Z^g_{y_2+1,t,l}$ is the total mortality on animals of gender g in size-class l during season t of year y_2+1:

$$Z^g_{y_2+1,t,l} = \rho^{\mathrm{M}}_{y_2,t} M^g_{y_2} \tilde{M}_l + \sum_f S^{f,g}_{y_2,t,l}(\lambda^{f,g}_{y_2,t,l} + \Omega^{f,g}_{y_2,t,l}(1-\lambda^{f,g}_{y_2,t,l}))\alpha^{*,f}\bar{F}^{f,g}_t \qquad (A.21)$$

The values for entries of the vector α^* for the directed fisheries are determined using the OFL control rule:

- If the projected spawning stock biomass in year y_2+1 when $\underline{\alpha}^* = \underline{\alpha}$ exceeds the proxy for B_{MSY}, then $\alpha^{*,f} = \alpha^f$.
- If the projected spawning stock biomass in year y_2+1 when $\underline{\alpha}^* = \underline{\alpha}$ is less than 25% of the proxy for B_{MSY}, then $\alpha^{*,f} = 0$.
- If the projected spawning stock biomass in year y_2+1, $SSB^*_{y_2}$ when $\underline{\alpha}^* = \underline{\alpha}$ lies between less than 25% and 100% of the proxy for B_{MSY}, then $\alpha^{*,f}$ is tuned according to $\alpha^{*,f} = \alpha^f(SSB^*_{y_2}/B_{MSY} - 0.1)/0.9$ until convergence.

c. Projections

The specifications for the projections relate to:

- The duration of the projection.
- Whether the fully-selected fishing mortalities for the non-directed fisheries are set to zero or to recent averages by fleet.
- The way in which future recruitment is generated. The options available are:
  - Select a recruitment from a set of historical recruitments at random.
  - Generate a future recruitment from a Ricker stock-recruitment relationship, i.e.:

$$R_y^g = SSB_{y-a^*} / SSB_0 e^{-1.25\ell n h(SSB_{y-a^*}/SSB_0 - 1)} e^{\varepsilon_y - \sigma_R^2/2}\ ;\ \varepsilon_y \sim N(0;\sigma^2) \qquad \text{(A.22)}$$

    where a^* is the time-lag between spawning and entering the first size-class in the model, SSB_0 is unfished spawning stock biomass, h is the steepness of the stock-recruitment relationship, σ_R is the variation in recruitment about the stock-recruitment relationship.
  - Generate a future recruitment from a Beverton-Holt stock-recruitment relationship, i.e.:

$$R_y^g = \frac{4R_0\, SSB_{y-a^*} / SSB_0}{(1-h)+(5h-1)SSB_{y-a^*} / SSB_0} e^{\varepsilon_y - \sigma_R^2/2} \qquad \varepsilon_y \sim N(0;\sigma^2) \qquad \text{(A.23)}$$

    where R_0 is unfished recruitment (i.e.. $SSB_0 / SSBPR(\underline{0})$).
- The control rule used to set fully-selected fishing mortality for the directed fisheries. The options are available
  - Pre-specified values for fully-selected fishing mortality for each fishery.
  - Pre-specified values subject to the dead catch not exceeding that corresponding to the OFL.
  - Pre-specified values subject to the dead catch not exceeding that corresponding to the OFL and the landed catch not exceeding that corresponding to the State of Alaska harvest control rule.

The value for the steepness of the stock-recruitment relationship is computed such that the maximum sustainable yield occurs at $F_{35\%}$, i.e.:

$$\left.\frac{dC(\underline{F})}{dF}\right|_{\underline{F}=\underline{\alpha}^* \overline{F}} \qquad \text{(A.24)}$$

where $C(\underline{F})$ is the equilibrium landed catch when the population model is projected forward deterministically under one of the two stock-recruitment relationships.

C. Parameter Estimation

a. *Estimating Bycatch Fishing Mortalities for Years without Observer Data*

Observer data are not available for the directed pot fishery before 1990 and the Tanner crab fishery before 1991. There are also extremely low observed bycatches in the Tanner crab fishery in 1994 and during 2006-2009. Bycatch fishing mortalities for male and females during 1975-1989 in the directed pot fishery were estimated as

$$F_t^{disc,s} = r^s \ F_t^{dir} \tag{A.25}$$

where r^s is the mean ratio of estimated bycatch discard fishing mortalities to the estimated directed pot fishing mortalities during 1990-2004 for sex s. Directed pot fishing practice has changed after 2004 due to fishery rationalization.

We used pot fishing effort (potlifts) east of 163° W in the Tanner crab fishery to estimate red king crab bycatch discard fishing mortalities in that fishery when observer data are not available (1975-1990, 1994, 2006-2009):

$$F_t^{Tanner,s} = a^s \ E_t \tag{A.26}$$

where a^s is the mean ratio of estimated Tanner crab fishery bycatch fishing mortalities to fishing efforts during 1991-1993 for sex s, and E_t is Tanner crab fishery fishing efforts east of 163° W in year t. Due to fishery rationalization after 2004, we used the data only during 1991-1993 to estimate the ratio.

b. Likelihood Components

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

$$Rf = \prod_{l=1}^{L} \prod_{t=1}^{T} \coprod_{s=1}^{2} \prod_{sh=1}^{2} \frac{\left\{ exp\left[-\frac{\left(p_{l,t,s,sh} - \hat{p}_{l,t,s,sh}\right)^2}{2\sigma_{l,t,s,sh}^2} \right] + 0.01 \right\}}{\sqrt{2\pi\sigma_{l,t,s,sh}^2}} \tag{A.27}$$

$$\sigma_{l,t,s,sh}^2 = \frac{\left[p_{l,t,s,sh}\left(1 - p_{l,t,s,sh}\right) + \frac{0.1}{L}\right]}{n_t}$$

where L is the number of length groups, T the number of years, and n_t the effective sample size in year t, which was estimated for trawl survey, pot retained catch, total directed pot male catch, directed pot female discard, groundfish trawl discard, groundfish fixed gear discard, and Tanner crab fishery discard length composition data. $p_{l,t,s,sh}$ is the observed proportion of crab in length-class l, year t, sex s and shell condition sh, and $\hat{p}_{l,t,s,sh}$ is the model-estimate corresponding to $p_{l,t,s,sh}$.

The weighted negative log likelihood functions are:

$$
\begin{aligned}
&Length\ compositions:\ -\sum \ln(Rf_i) \\
&Catch\ and\ bycatch\ biomasses:\ \sum\left[ln\left(\frac{C_t}{\hat{C}_t}\right)^2/(2\ln(cv_t^2+1))\right] \\
&NMFS\ survey\ biomass:\ \sum\left[ln\left(ln\left(CV_t^{\,2}+1\right)\right)^{0.5}+\frac{ln\left(\frac{B_t}{\hat{B}_t}\right)^2}{\left(2ln\left(CV_t^{\,2}+1\right)\right)}\right] \\
&BSFRF\ survey\ biomass:\ \sum\left[ln\left(ln\left(CV_t^{\,2}+AV^2+1\right)\right)^{0.5}+\frac{ln\left(\frac{B_t}{\hat{B}_t}\right)^2}{\left(2ln\left(CV_t^{\,2}+AV^2+1\right)\right)}\right] \\
&R\ variation:\ \lambda_R\sum\left[ln\left(\frac{R_t}{\bar{R}}\right)^2\right] \\
&R\ sex\ ratio:\ \lambda_s\sum\left[ln\left(\frac{\bar{R}_M}{\bar{R}_F}\right)^2\right] \\
&Groundfish\ bycatch\ fishing\ mortalities:\ \lambda_t\sum\left[ln\left(\frac{F_{t,gf}}{\bar{F}_{gf}}\right)^2\right] \\
&Pot\ female\ bycatch\ fishing\ mortalities:\ \lambda_p\sum\left[ln\left(\frac{F_{t,f}}{\bar{F}_f}\right)^2\right] \\
&Trawl\ survey\ catchability:\ \frac{(Q-\hat{Q})^2}{2\sigma^2}
\end{aligned}
\tag{A.28}
$$

where R_t is the recruitment in year t, $\bar{R}$ the mean recruitment, $\bar{R}_M$ the mean male recruitment, $\bar{R}_F$ the mean female recruitment, AV is additional CV and estimated in the model, $\bar{F}_{gf}$ the mean groundfish bycatch fishing mortality (this is separated into trawl and fixed gear fishery bycatch), $\bar{F}_f$ the mean pot female bycatch fishing mortality, Q summer trawl survey catchability, and σ the estimated standard deviation of Q (all models).

Weights λ_j are assumed to be 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 correspond to CV values of 0.53, 0.23, 3.34, and 12.14, respectively.

c. Population State in Year 1.

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

d. Parameter estimation framework:

(1) 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. Handling mortality rates were set to 0.2 for the directed pot fishery, 0.25 for the Tanner crab fishery, 0.5 for the groundfish fixed gear fishery, and 0.8 for the groundfish trawl fishery.

i. 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/or females. Natural mortality in a given year, M_t, may equal to $M + Mm_t$ (for males) or $M + Mf_t$ (females), or may be estimated. Different model scenarios estimate Mm_t and Mf_t differently.

ii. Length-weight Relationship

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

$$\text{Immature Females:} \quad W = 0.000408\ L^{3.127956}$$
$$\text{Ovigerous Females:} \quad W = 0.003593\ L^{2.666076} \qquad (A.29)$$
$$\text{Males:} \quad W = 0.0004031\ L^{3.141334}$$

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

iii. 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 1994-2020, respectively, and the data presented in Gray (1963) were used to estimate those for mature females for model scenarios (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 1994-2020, 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).

iv. 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 1994-2020).

v. 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.

vi. 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 1980-1984 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° W. No absolute red king crab bycatch estimates are available until 1991. So there are insufficient data to fully evaluate the impact. Retained catch and potlifts from the eastern Bering Sea Tanner crab fishery are illustrated in Figure A5. The observed red king crab bycatch in the Tanner crab fishery during 1991-1993 and total potlifts east of 163° W during 1968 to 2005 were used to estimate the bycatch mortality in the current model. Because winter sea surface temperatures and air temperatures were warmer (which means a lower handling mortality rate) and there were fewer potlifts during the early 1980s than during the early 1990s, bycatch in the Tanner crab fishery is unlikely to have been a main factor for the sharp decline of Bristol Bay red king crab.

Several factors may have caused increases in natural mortality. Crab diseases in the early 1980s were documented by Sparks and Morado (1985), but inadequate data were collected to examine their effects on the stock. Stevens (1990) speculated that senescence may be a factor because many crab in the early 1980s were very old due to low temperatures in the

1960s and early 1970s. The biomass of the main crab predator, Pacific cod, increased about 10 times during the late 1970s and early 1980s. Yellowfin sole biomass also increased substantially during this period. Predation is primarily on juvenile and molting/softshell crab. But we lack stomach samples in shallow waters (juvenile habitat) and during the period when red king crab molt. Also cannibalism occurs during molting periods for red king crab. High crab abundance in the late 1970s and early 1980s may have increased the occurrence of cannibalism.

Overall, the likely causes for the sharp decline in the early 1980s are combinations of the above factors, such as pot fisheries on legal males, bycatch, and predation on females and juvenile and sublegal males, senescence for older crab, and disease for all crab. In our model, we estimated one mortality parameter for males and another for females during 1980-1984. We also estimated a mortality parameter for females during 1976-1979 and 1985-1993. These three mortality parameters are additional to the basic natural mortality of $0.18 yr^{-1}$, 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.

(2) 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 2020), 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 different sets of β and L_{50} for total selectivity and retained proportions, 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 and fixed gear discarded selectivities, and different sets of β and L_{50} for NMFS trawl survey male and female selectivities separately. The NMFS survey catchabilities Q for some models were also estimated. Different sets of β and L_{50} for 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 (1975-2019), pot-discarded females from the directed fishery (1990-2019), pot-discarded males and females from the eastern Bering Sea Tanner crab fishery (1991-93, 2013-15), groundfish trawl discarded males and females (1976-2019), and groundfish fixed gear discarded males and females (1996-2019). Three additional mortality parameters for Mm_t and Mf_t were also estimated for some model scenarios. 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.

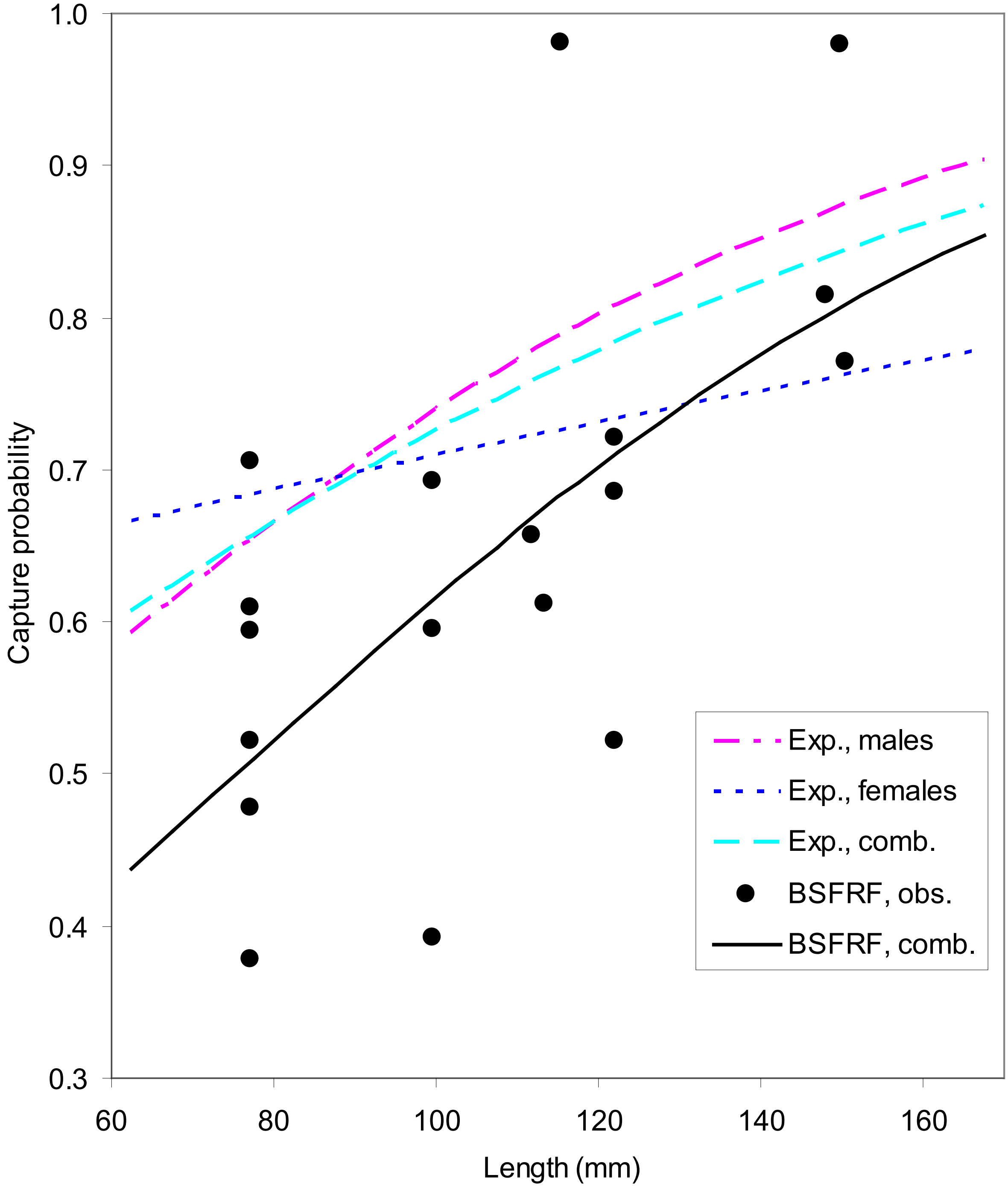
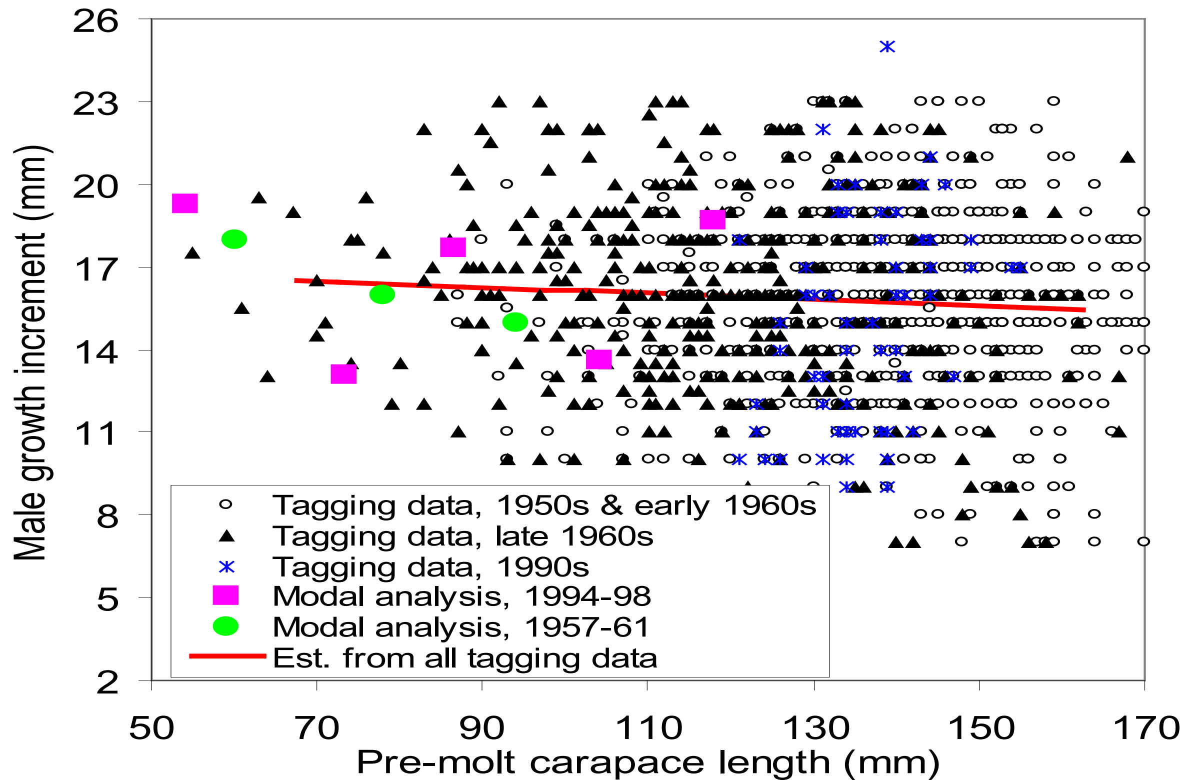


Figure A1. Estimated capture probabilities for NMFS Bristol Bay red king crab trawl surveys by Weinberg et al. (2004) and the Bering Sea Fisheries Research Foundation surveys.



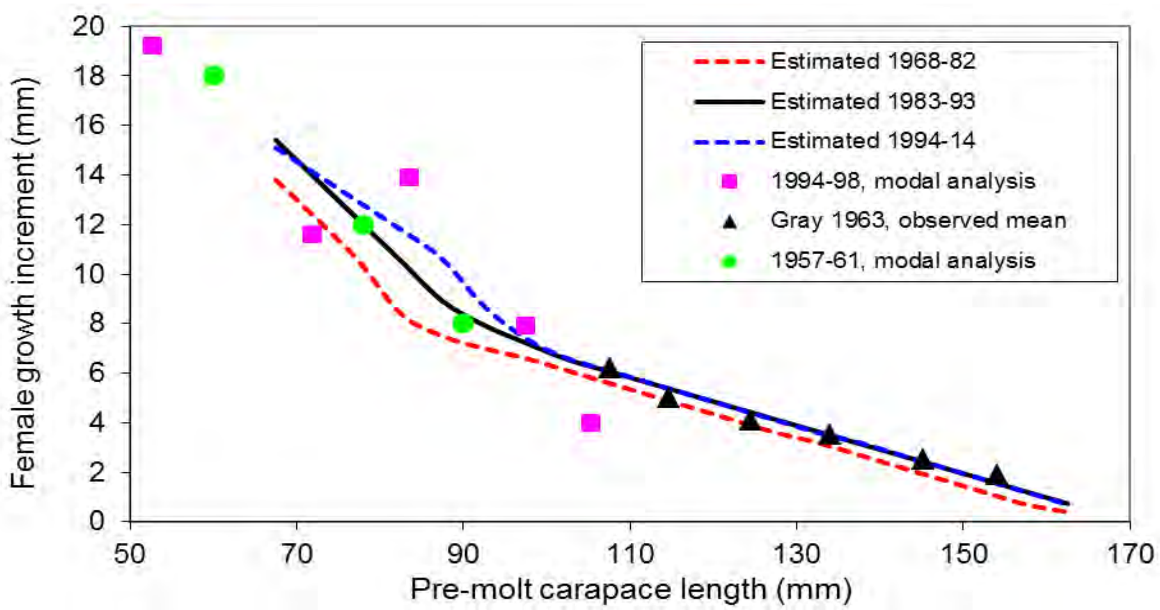


Figure A2. Mean growth increments per molt for Bristol Bay red king crab. Note: "tagging"---based on tagging data; "mode"---based on modal analysis. The female growth increments per molt are for different model scenarios.

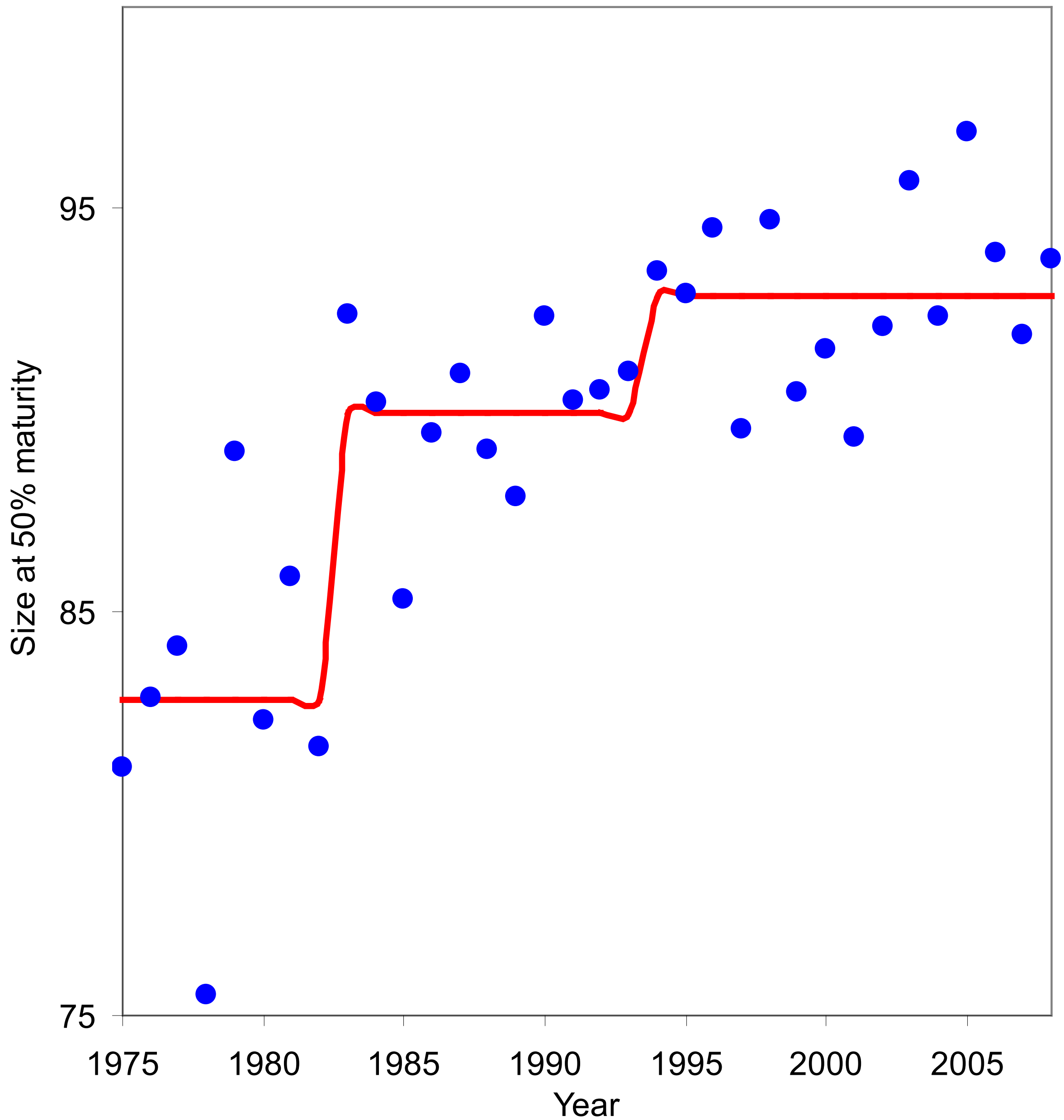


Figure A3. Estimated sizes at 50% maturity for Bristol Bay female red king crab from 1975 to 2008. Averages for three periods (1975-82, 1983-93, and 1994-08) are plotted with a line.

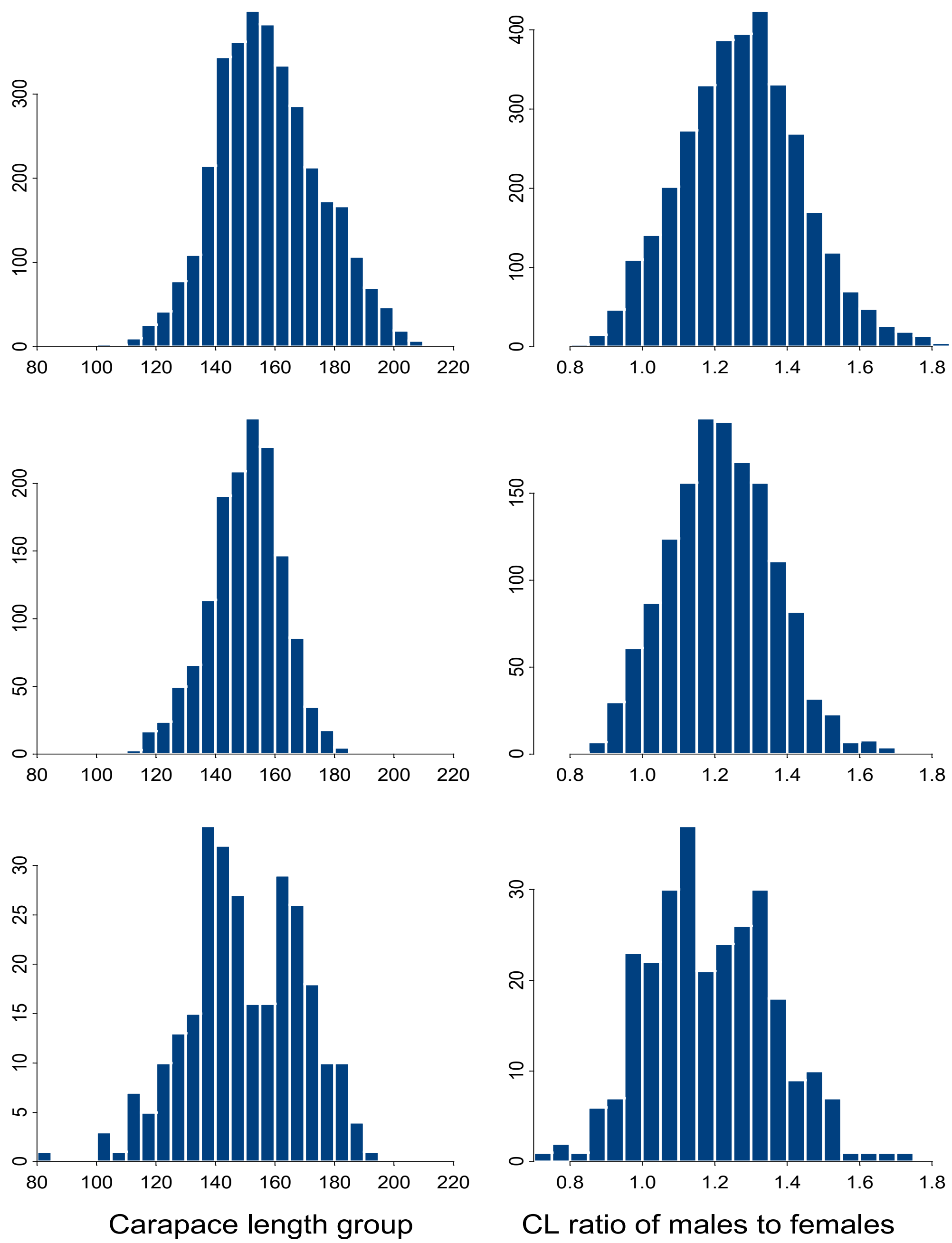
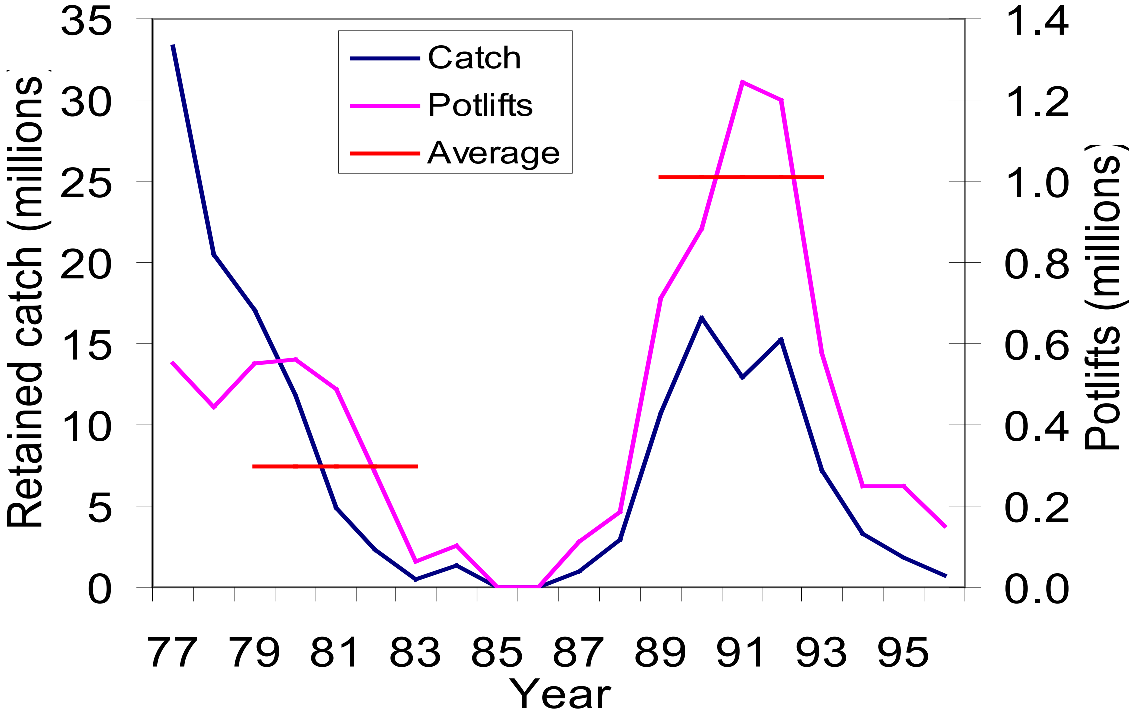


Figure A4. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages ≤13 months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak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



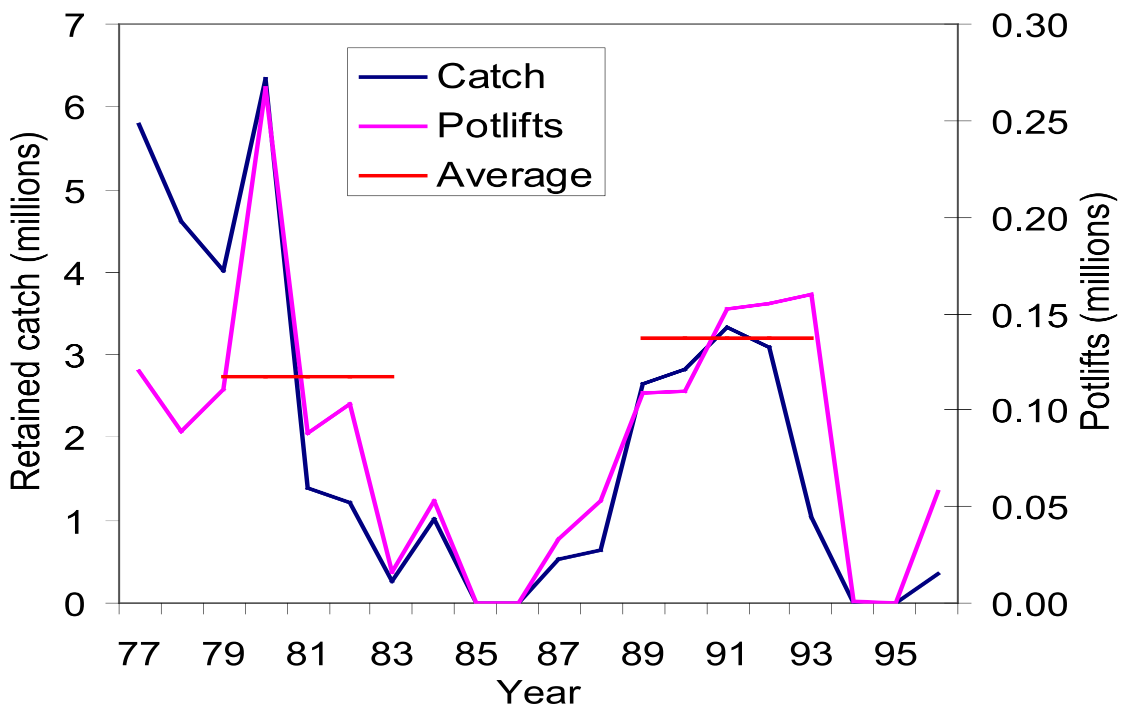


Figure A5. Retained catch and potlifts for total eastern Bering Sea Tanner crab fishery (upper plot) and the Tanner crab fishery east of 163° W (bottom).

Appendix B. Input Data File for Models 19.0a-19.3 (all seven models)

#===

Gmacs Main Data File Version 1.1: BBRKC Example
GEAR_INDEX DESCRIPTION
1 : Pot fishery retained catch.
1 : Pot fishery with discarded catch.
2 : Trawl bycatch
3 : Trawl survey
Fisheries: 1 Pot Fishery, 2 Pot Discard, 3 Trawl by-catch, 4 Tanner bycatch 5 fixed gear
Surveys: 6 NMFS Trawl Survey,7 BSFRF Survey
#===
1975 # Start year
2019 # End year
7 # Number of seasons
6 # Number of fleets (fishing fleets and surveys)
2 # Number of sexes
2 # Number of shell condition types
1 # Number of maturity types
20 # Number of size-classes in the model
7 # Season recruitment occurs
7 # Season molting and growth occurs
6 # Season to calculate SSB
1 # Season for N output
maximum size-class (males then females)
20 16
size_breaks (a vector giving the break points between size intervals, dim=nclass+1)
65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165
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
0.0000 0.2329 0.0000 0.2671 0.000 0.194 0.306 #1975
0.0000 0.2795 0.0000 0.2205 0.000 0.194 0.306 #1976
0.0000 0.3233 0.0000 0.1767 0.000 0.194 0.306 #1977
0.0000 0.2548 0.0000 0.2452 0.000 0.194 0.306 #1978
0.0000 0.2493 0.0000 0.2507 0.000 0.194 0.306 #1979
0.0000 0.2493 0.0000 0.2507 0.000 0.194 0.306 #1980
0.0000 0.2493 0.0000 0.2507 0.000 0.194 0.306 #1981
0.0000 0.2356 0.0000 0.2644 0.000 0.194 0.306 #1982
0.0000 0.2400 0.0000 0.2600 0.000 0.194 0.306 #1983
0.0000 0.2712 0.0000 0.2288 0.000 0.194 0.306 #1984
0.0000 0.2438 0.0000 0.2562 0.000 0.194 0.306 #1985

0.0000	0.2521	0.0000	0.2479	0.000	0.194	0.306	#1986
0.0000	0.2493	0.0000	0.2507	0.000	0.194	0.306	#1987
0.0000	0.2438	0.0000	0.2562	0.000	0.194	0.306	#1988
0.0000	0.2493	0.0000	0.2507	0.000	0.194	0.306	#1989
0.0000	0.3507	0.0000	0.1493	0.000	0.194	0.306	#1990
0.0000	0.3425	0.0000	0.1575	0.000	0.194	0.306	#1991
0.0000	0.3425	0.0000	0.1575	0.000	0.194	0.306	#1992
0.0000	0.3452	0.0000	0.1548	0.000	0.194	0.306	#1993
0.0000	0.3400	0.0000	0.1600	0.000	0.194	0.306	#1994
0.0000	0.3400	0.0000	0.1600	0.000	0.194	0.306	#1995
0.0000	0.3400	0.0000	0.1600	0.000	0.194	0.306	#1996
0.0000	0.3400	0.0000	0.1600	0.000	0.194	0.306	#1997
0.0000	0.3400	0.0000	0.1600	0.000	0.194	0.306	#1998
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#1999
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2000
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2001
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2002
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2003
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2004
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2005
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2006
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2007
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2008
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2009
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2010
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2011
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2012
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2013
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2014
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2015
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2016
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2017
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2018
0.0000	0.3000	0.0000	0.2000	0.000	0.194	0.306	#2019

```
# Fishing fleet names (delimited with: no spaces in names)
Pot_Fishery Trawl_Bycatch Bairdi_Fishery_Bycatch Fixed_Gear
# Survey names (delimited with: no spaces in names)
NMFS_Trawl BSFRF
# Are the seasons instantaneous (0) or continuous (1)
1 1 1 1 1 1 1
# Number of catch data frames
7
# Number of rows in each data frame
45 30 30 44 25 25 24
## ——————————————————————————————————— ##
## CATCH DATA
## Type of catch: 1 = retained, 2 = discard, 0 = total
## Units of catch: 1 = biomass, 2 = numbers
## for BBRKC Units are in 1000 mt for landed & discards.
## ——————————————————————————————————— ##
## Male retained pot fishery (tonnes)
#year seas fleet sex obs cv type units mult effort discard_mortality
1975 3 1 1 23281.2 0.03 1 1 1 0 0.2
1976 3 1 1 28993.6 0.03 1 1 1 0 0.2
1977 3 1 1 31736.9 0.03 1 1 1 0 0.2
1978 3 1 1 39743 0.03 1 1 1 0 0.2
1979 3 1 1 48910 0.03 1 1 1 0 0.2
1980 3 1 1 58943.6 0.03 1 1 1 0 0.2
1981 3 1 1 15236.8 0.03 1 1 1 0 0.2
1982 3 1 1 1361.3 0.03 1 1 1 0 0.2
1983 3 1 1 0.1 0.03 1 1 1 0 0.2 #AEP
1984 3 1 1 1897.1 0.03 1 1 1 0 0.2
1985 3 1 1 1893.8 0.03 1 1 1 0 0.2
1986 3 1 1 5168.2 0.03 1 1 1 0 0.2
1987 3 1 1 5574.2 0.03 1 1 1 0 0.2
1988 3 1 1 3351.1 0.03 1 1 1 0 0.2
1989 3 1 1 4656 0.03 1 1 1 0 0.2
1990 3 1 1 9272.8 0.03 1 1 1 0 0.2
1991 3 1 1 7885.1 0.03 1 1 1 0 0.2
1992 3 1 1 3681.8 0.03 1 1 1 0 0.2
1993 3 1 1 6659.6 0.03 1 1 1 0 0.2
1994 3 1 1 42.3 0.03 1 1 1 0 0.2
1995 3 1 1 36.4 0.03 1 1 1 0 0.2
1996 3 1 1 3861.7 0.03 1 1 1 0 0.2
1997 3 1 1 4042.1 0.03 1 1 1 0 0.2
1998 3 1 1 6779.2 0.03 1 1 1 0 0.2
1999 3 1 1 5377.9 0.03 1 1 1 0 0.2
2000 3 1 1 3737.9 0.03 1 1 1 0 0.2
2001 3 1 1 3866.2 0.03 1 1 1 0 0.2
2002 3 1 1 4384.5 0.03 1 1 1 0 0.2
```

2003	3	1	1	7135.3	0.03	1	1	1	0	0.2
2004	3	1	1	7006.7	0.03	1	1	1	0	0.2
2005	3	1	1	8399.7	0.03	1	1	1	0	0.2
2006	3	1	1	7143.2	0.03	1	1	1	0	0.2
2007	3	1	1	9303.9	0.03	1	1	1	0	0.2
2008	3	1	1	9216.1	0.03	1	1	1	0	0.2
2009	3	1	1	7272.5	0.03	1	1	1	0	0.2
2010	3	1	1	6761.5	0.03	1	1	1	0	0.2
2011	3	1	1	3607.1	0.03	1	1	1	0	0.2
2012	3	1	1	3621.7	0.03	1	1	1	0	0.2
2013	3	1	1	3991	0.03	1	1	1	0	0.2
2014	3	1	1	4538.6	0.03	1	1	1	0	0.2
2015	3	1	1	4613.7	0.03	1	1	1	0	0.2
2016	3	1	1	3923.9	0.03	1	1	1	0	0.2
2017	3	1	1	3093.7	0.03	1	1	1	0	0.2
2018	3	1	1	2026.5	0.03	1	1	1	0	0.2
2019	3	1	1	1775.3	0.03	1	1	1	0	0.2

##	Total Male		pot	fishery (t)							
#year	seas	fleet	sex	obs	cv	type	units	mult	effort	discard_mortality	
1990	3	1	1	11782.9		0.04	0	1	1	0	0.2
1991	3	1	1	9974	0.04	0	1	1	0	0.2	
1992	3	1	1	6013.7	0.04	0	1	1	0	0.2	
1993	3	1	1	9667.7	0.04	0	1	1	0	0.2	
1994	3	1	1	62.3	0.04	0	1	1	0	0.2	
1995	3	1	1	52.8	0.04	0	1	1	0	0.2	
1996	3	1	1	3902.3	0.04	0	1	1	0	0.2	
1997	3	1	1	3847.2	0.04	0	1	1	0	0.2	
1998	3	1	1	17681.4		0.04	0	1	1	0	0.2
1999	3	1	1	12245.2		0.04	0	1	1	0	0.2
2000	3	1	1	6672.3	0.04	0	1	1	0	0.2	
2001	3	1	1	5797	0.04	0	1	1	0	0.2	
2002	3	1	1	7065.3	0.04	0	1	1	0	0.2	
2003	3	1	1	12300.6		0.04	0	1	1	0	0.2
2004	3	1	1	10816.8		0.04	0	1	1	0	0.2
2005	3	1	1	13753.3		0.04	0	1	1	0	0.2
2006	3	1	1	9170.4	0.04	0	1	1	0	0.2	
2007	3	1	1	13956.6		0.04	0	1	1	0	0.2
2008	3	1	1	15068.7		0.04	0	1	1	0	0.2
2009	3	1	1	12300.3		0.04	0	1	1	0	0.2
2010	3	1	1	10087.4		0.04	0	1	1	0	0.2
2011	3	1	1	5732.6	0.04	0	1	1	0	0.2	
2012	3	1	1	4568.1	0.04	0	1	1	0	0.2	
2013	3	1	1	5260.7	0.04	0	1	1	0	0.2	
2014	3	1	1	8312.7	0.04	0	1	1	0	0.2	
2015	3	1	1	6706.4	0.04	0	1	1	0	0.2	

2016	3	1	1	5557.2	0.04	0	1	1	0	0.2
2017	3	1	1	4075.76	0.04	0	1	1	0	0.2
2018	3	1	1	3060.34	0.04	0	1	1	0	0.2
2019	3	1	1	3143.25	0.04	0	1	1	0	0.2

Female discards Pot fishery

#year	seas	fleet	sex	obs	cv	type	units	mult	effort	discard_mortality
1990	3	1	2	3240.20	0.07	0	1	1	0	0.2
1991	3	1	2	236.600	0.07	0	1	1	0	0.2
1992	3	1	2	2001.20	0.07	0	1	1	0	0.2
1993	3	1	2	3174.40	0.07	0	1	1	0	0.2
1994	3	1	2	1.877	0.07	0	1	1	0	0.2
1995	3	1	2	1.612	0.07	0	1	1	0	0.2
1996	3	1	2	5.200	0.07	0	1	1	0	0.2
1997	3	1	2	184.800	0.07	0	1	1	0	0.2
1998	3	1	2	2897.10	0.07	0	1	1	0	0.2
1999	3	1	2	28.200	0.07	0	1	1	0	0.2
2000	3	1	2	833.700	0.07	0	1	1	0	0.2
2001	3	1	2	611.400	0.07	0	1	1	0	0.2
2002	3	1	2	46.100	0.07	0	1	1	0	0.2
2003	3	1	2	1804.70	0.07	0	1	1	0	0.2
2004	3	1	2	873.000	0.07	0	1	1	0	0.2
2005	3	1	2	2051.40	0.07	0	1	1	0	0.2
2006	3	1	2	187.700	0.07	0	1	1	0	0.2
2007	3	1	2	816.700	0.07	0	1	1	0	0.2
2008	3	1	2	734.400	0.07	0	1	1	0	0.2
2009	3	1	2	468.500	0.07	0	1	1	0	0.2
2010	3	1	2	609.200	0.07	0	1	1	0	0.2
2011	3	1	2	123.400	0.07	0	1	1	0	0.2
2012	3	1	2	59.800	0.07	0	1	1	0	0.2
2013	3	1	2	514.300	0.07	0	1	1	0	0.2
2014	3	1	2	362.200	0.07	0	1	1	0	0.2
2015	3	1	2	1081.60	0.07	0	1	1	0	0.2
2016	3	1	2	527.000	0.07	0	1	1	0	0.2
2017	3	1	2	266.546	0.07	0	1	1	0	0.2
2018	3	1	2	574.047	0.07	0	1	1	0	0.2
2019	3	1	2	216.739	0.07	0	1	1	0	0.2

Trawl fishery discards (t, without applying to handling mortality rate)

#year	seas	fleet	sex	obs	cv	type	units	mult	effort	discard_mortality
1976	5	2	0	853.494	0.10	2	1	1	0	0.8
1977	5	2	0	1562.313	0.10	2	1	1	0	0.8
1978	5	2	0	1650.775	0.10	2	1	1	0	0.8
1979	5	2	0	1664.925	0.10	2	1	1	0	0.8
1980	5	2	0	1295.625	0.10	2	1	1	0	0.8
1981	5	2	0	274.229	0.10	2	1	1	0	0.8
1982	5	2	0	718.610	0.10	2	1	1	0	0.8

1983	5	2	0	525.554	0.10	2	1	1	0	0.8
1984	5	2	0	1367.550	0.10	2	1	1	0	0.8
1985	5	2	0	487.576	0.10	2	1	1	0	0.8
1986	5	2	0	250.758	0.10	2	1	1	0	0.8
1987	5	2	0	233.045	0.10	2	1	1	0	0.8
1988	5	2	0	747.996	0.10	2	1	1	0	0.8
1989	5	2	0	219.023	0.10	2	1	1	0	0.8
1990	5	2	0	324.883	0.10	2	1	1	0	0.8
1991	5	2	0	436.783	0.10	2	1	1	0	0.8
1992	5	2	0	366.816	0.10	2	1	1	0	0.8
1993	5	2	0	501.770	0.10	2	1	1	0	0.8
1994	5	2	0	109.129	0.10	2	1	1	0	0.8
1995	5	2	0	102.623	0.10	2	1	1	0	0.8
1996	5	2	0	113.495	0.10	2	1	1	0	0.8
1997	5	2	0	71.862	0.10	2	1	1	0	0.8
1998	5	2	0	232.580	0.10	2	1	1	0	0.8
1999	5	2	0	188.101	0.10	2	1	1	0	0.8
2000	5	2	0	102.161	0.10	2	1	1	0	0.8
2001	5	2	0	241.011	0.10	2	1	1	0	0.8
2002	5	2	0	189.018	0.10	2	1	1	0	0.8
2003	5	2	0	171.114	0.10	2	1	1	0	0.8
2004	5	2	0	216.889	0.10	2	1	1	0	0.8
2005	5	2	0	155.924	0.10	2	1	1	0	0.8
2006	5	2	0	189.660	0.10	2	1	1	0	0.8
2007	5	2	0	192.571	0.10	2	1	1	0	0.8
2008	5	2	0	170.561	0.10	2	1	1	0	0.8
2009	5	2	0	118.906	0.10	2	1	1	0	0.8
2010	5	2	0	104.086	0.10	2	1	1	0	0.8
2011	5	2	0	70.419	0.10	2	1	1	0	0.8
2012	5	2	0	42.786	0.10	2	1	1	0	0.8
2013	5	2	0	83.868	0.10	2	1	1	0	0.8
2014	5	2	0	43.460	0.10	2	1	1	0	0.8
2015	5	2	0	56.686	0.10	2	1	1	0	0.8
2016	5	2	0	84.127	0.10	2	1	1	0	0.8
2017	5	2	0	114.784	0.10	2	1	1	0	0.8
2018	5	2	0	97.891	0.10	2	1	1	0	0.8
2019	5	2	0	101.001	0.10	2	1	1	0	0.8

Tanner crab fishery discards males

#year	seas	fleet	sex	obs	cv	type	units	mult	potlifts	discard_mortality
1975	5	3	1	0	0.07	2	1	1	20	0.25
1976	5	3	1	0	0.07	2	1	1	20	0.25
1977	5	3	1	0	0.07	2	1	1	120.031	0.25
1978	5	3	1	0	0.07	2	1	1	88.489	0.25
1979	5	3	1	0	0.07	2	1	1	110.989	0.25
1980	5	3	1	0	0.07	2	1	1	267.154	0.25

1981	5	3	1	0	0.07	2	1	1	87.951	0.25		
1982	5	3	1	0	0.07	2	1	1	102.987		0.25	
1983	5	3	1	0	0.07	2	1	1	16.239	0.25		
1984	5	3	1	0	0.07	2	1	1	52.598	0.25		
#1985	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#1986	5	3	1	0	0.07	2	1	1	0.0001	0.25		
1987	5	3	1	0	0.07	2	1	1	32.75	0.25		
1988	5	3	1	0	0.07	2	1	1	53.203	0.25		
1989	5	3	1	0	0.07	2	1	1	108.519		0.25	
1990	5	3	1	0	0.07	2	1	1	109.371		0.25	
1991	5	3	1	1890.9	0.07	2	1	1	152.541		0.25	
1992	5	3	1	269.526		0.07	2	1	1	154.976		0.25
1993	5	3	1	117.643		0.07	2	1	1	159.922		0.25
1994	5	3	1	0	0.07	2	1	1	1.042	0.25		
#1995	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#1996	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#1997	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#1998	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#1999	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#2000	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#2001	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#2002	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#2003	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#2004	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#2005	5	3	1	0	0.07	2	1	1	0.0001	0.25		
2006	5	3	1	0	0.07	2	1	1	0.4	0.25		
2007	5	3	1	0	0.07	2	1	1	0.5	0.25		
2008	5	3	1	0	0.07	2	1	1	0.5	0.25		
2009	5	3	1	0	0.07	2	1	1	0.2	0.25		
#2010	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#2011	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#2012	5	3	1	0	0.07	2	1	1	0.0001	0.25		
2013	5	3	1	37.4687		0.07	2	1	1	2	0.25	
2014	5	3	1	83.5014		0.07	2	1	1	2	0.25	
2015	5	3	1	116.404		0.07	2	1	1	139.171		0.25
#2016	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#2017	5	3	1	0	0.07	2	1	1	0.0001	0.25		
#	Tanner crab		fishery	discards		females						
#year	seas	fleet	sex	obs	cv	type	units	mult	potlifts	discard_mortality		
1975	5	3	2	0	0.07	2	1	1	20	0.25		
1976	5	3	2	0	0.07	2	1	1	20	0.25		
1977	5	3	2	0	0.07	2	1	1	120.031		0.25	
1978	5	3	2	0	0.07	2	1	1	88.489	0.25		
1979	5	3	2	0	0.07	2	1	1	110.989		0.25	
1980	5	3	2	0	0.07	2	1	1	267.154		0.25	
1981	5	3	2	0	0.07	2	1	1	87.951	0.25		

1982	5	3	2	0	0.07	2	1	1	102.987	0.25
1983	5	3	2	0	0.07	2	1	1	16.239	0.25
1984	5	3	2	0	0.07	2	1	1	52.598	0.25
#1985	5	3	2	0	0.07	2	1	1	0.0001	0.25
#1986	5	3	2	0	0.07	2	1	1	0.0001	0.25
1987	5	3	2	0	0.07	2	1	1	32.75	0.25
1988	5	3	2	0	0.07	2	1	1	53.203	0.25
1989	5	3	2	0	0.07	2	1	1	108.519	0.25
1990	5	3	2	0	0.07	2	1	1	109.371	0.25
1991	5	3	2	3716.45	0.07	2	1	1	152.541	0.25
1992	5	3	2	708.223	0.07	2	1	1	154.976	0.25
1993	5	3	2	100.927	0.07	2	1	1	159.922	0.25
1994	5	3	2	0	0.07	2	1	1	1.042	0.25
#1995	5	3	2	0	0.07	2	1	1	0.0001	0.25
#1996	5	3	2	0	0.07	2	1	1	0.0001	0.25
#1997	5	3	2	0	0.07	2	1	1	0.0001	0.25
#1998	5	3	2	0	0.07	2	1	1	0.0001	0.25
#1999	5	3	2	0	0.07	2	1	1	0.0001	0.25
#2000	5	3	2	0	0.07	2	1	1	0.0001	0.25
#2001	5	3	2	0	0.07	2	1	1	0.0001	0.25
#2002	5	3	2	0	0.07	2	1	1	0.0001	0.25
#2003	5	3	2	0	0.07	2	1	1	0.0001	0.25
#2004	5	3	2	0	0.07	2	1	1	0.0001	0.25
#2005	5	3	2	0	0.07	2	1	1	0.0001	0.25
2006	5	3	2	0	0.07	2	1	1	0.4	0.25
2007	5	3	2	0	0.07	2	1	1	0.5	0.25
2008	5	3	2	0	0.07	2	1	1	0.5	0.25
2009	5	3	2	0	0.07	2	1	1	0.2	0.25
#2010	5	3	2	0	0.07	2	1	1	0.0001	0.25
#2011	5	3	2	0	0.07	2	1	1	0.0001	0.25
#2012	5	3	2	0	0.07	2	1	1	0.0001	0.25
2013	5	3	2	76.3798	0.07	2	1	1	2	0.25
2014	5	3	2	84.5793	0.07	2	1	1	2	0.25
2015	5	3	2	220.311	0.07	2	1	1	139.171	0.25
#2016	5	3	2	0	0.07	2	1	1	0.0001	0.25
#2017	5	3	1	0	0.07	2	1	1	0.0001	0.25

Fixed gear crab fishery discards (t, without applying to handling mortality rate)

1996	5	4	0	82.859	0.10	2	1	1	0	0.5
1997	5	4	0	44.979	0.10	2	1	1	0	0.5
1998	5	4	0	36.916	0.10	2	1	1	0	0.5
1999	5	4	0	100.242	0.10	2	1	1	0	0.5
2000	5	4	0	9.446	0.10	2	1	1	0	0.5
2001	5	4	0	70.553	0.10	2	1	1	0	0.5
2002	5	4	0	58.382	0.10	2	1	1	0	0.5
2003	5	4	0	25.351	0.10	2	1	1	0	0.5

```
2004 5 4 0 30.422 0.10 2 1 1 0 0.5
2005 5 4 0 39.802 0.10 2 1 1 0 0.5
2006 5 4 0 39.134 0.10 2 1 1 0 0.5
2007 5 4 0 64.655 0.10 2 1 1 0 0.5
2008 5 4 0 31.158 0.10 2 1 1 0 0.5
2009 5 4 0 11.616 0.10 2 1 1 0 0.5
2010 5 4 0 4.736 0.10 2 1 1 0 0.5
2011 5 4 0 21.706 0.10 2 1 1 0 0.5
2012 5 4 0 36.895 0.10 2 1 1 0 0.5
2013 5 4 0 110.970 0.10 2 1 1 0 0.5
2014 5 4 0 237.651 0.10 2 1 1 0 0.5
2015 5 4 0 154.810 0.10 2 1 1 0 0.5
2016 5 4 0 57.896 0.10 2 1 1 0 0.5
2017 5 4 0 255.155 0.10 2 1 1 0 0.5
2018 5 4 0 295.916 0.10 2 1 1 0 0.5
2019 5 4 0 90.109 0.10 2 1 1 0 0.5

## ———————————————————————————————— ##
## RELATIVE ABUNDANCE DATA
## Units of Abundance: 1 = biomass, 2 = numbers
## TODO:add column for maturity for terminal molt life-histories
## for BBRKC Units are in 1000 mt.
## ———————————————————————————————— ##
## Number of relative abundance indicies
2
## Number of rows in each index
102
# Survey data (abundance indices,units are 1000 mt)
#Index Year Season Fleet Sex Abundance CV Units
1 1975 1 5 1 0 135463.3 0.193 1
1 1976 1 5 1 0 260149.5 0.207 1
1 1977 1 5 1 0 235411.4 0.144 1
1 1978 1 5 1 0 203192.7 0.152 1
1 1979 1 5 1 0 103715.0 0.164 1
1 1980 1 5 1 0 168047.2 0.221 1
1 1981 1 5 1 0 69161.2 0.190 1
1 1982 1 5 1 0 73232.9 0.251 1
1 1983 1 5 1 0 35368.0 0.214 1
1 1984 1 5 1 0 98281.5 0.606 1
1 1985 1 5 1 0 27203.7 0.159 1
1 1986 1 5 1 0 41113.6 0.420 1
1 1987 1 5 1 0 47410.5 0.209 1
1 1988 1 5 1 0 35852.6 0.228 1
1 1989 1 5 1 0 42967.7 0.232 1
1 1990 1 5 1 0 39271.6 0.242 1
1 1991 1 5 1 0 67458.4 0.443 1
```

1	1992	1	5	1	0	25442.5	0.176	1
1	1993	1	5	1	0	36217.5	0.198	1
1	1994	1	5	1	0	23285.5	0.174	1
1	1995	1	5	1	0	27670.5	0.266	1
1	1996	1	5	1	0	27277.5	0.203	1
1	1997	1	5	1	0	60719.6	0.264	1
1	1998	1	5	1	0	46693.7	0.182	1
1	1999	1	5	1	0	45126.5	0.204	1
1	2000	1	5	1	0	38787.8	0.216	1
1	2001	1	5	1	0	28367.5	0.187	1
1	2002	1	5	1	0	45597.0	0.202	1
1	2003	1	5	1	0	74997.9	0.283	1
1	2004	1	5	1	0	91090.1	0.321	1
1	2005	1	5	1	0	55471.4	0.171	1
1	2006	1	5	1	0	51948.6	0.169	1
1	2007	1	5	1	0	59064.2	0.174	1
1	2008	1	5	1	0	67945.7	0.249	1
1	2009	1	5	1	0	43692.8	0.326	1
1	2010	1	5	1	0	39555.6	0.223	1
1	2011	1	5	1	0	27529.9	0.213	1
1	2012	1	5	1	0	30830.4	0.237	1
1	2013	1	5	1	0	39833.2	0.244	1
1	2014	1	5	1	0	60859.1	0.191	1
1	2015	1	5	1	0	36919.3	0.208	1
1	2016	1	5	1	0	27302.6	0.194	1
1	2017	1	5	1	0	25344.0	0.173	1
1	2018	1	5	1	0	16064.2	0.161	1
1	2019	1	5	1	0	15127.4	0.157	1
1	1975	1	5	2	0	67267.3	0.193	1
1	1976	1	5	2	0	71718.0	0.207	1
1	1977	1	5	2	0	140249.6	0.144	1
1	1978	1	5	2	0	146351.8	0.152	1
1	1979	1	5	2	0	63911.7	0.164	1
1	1980	1	5	2	0	81275.0	0.221	1
1	1981	1	5	2	0	63507.9	0.190	1
1	1982	1	5	2	0	70506.7	0.251	1
1	1983	1	5	2	0	13951.7	0.214	1
1	1984	1	5	2	0	57030.0	0.606	1
1	1985	1	5	2	0	7330.8	0.159	1
1	1986	1	5	2	0	7044.8	0.420	1
1	1987	1	5	2	0	22852.7	0.209	1
1	1988	1	5	2	0	19519.6	0.228	1
1	1989	1	5	2	0	12973.6	0.232	1
1	1990	1	5	2	0	21049.2	0.242	1
1	1991	1	5	2	0	17596.5	0.443	1
1	1992	1	5	2	0	12244.8	0.176	1

1	1993	1	5	2	0	17485.5	0.198	1
1	1994	1	5	2	0	9049.4	0.174	1
1	1995	1	5	2	0	10725.7	0.266	1
1	1996	1	5	2	0	17371.1	0.203	1
1	1997	1	5	2	0	24557.1	0.264	1
1	1998	1	5	2	0	38482.0	0.182	1
1	1999	1	5	2	0	20477.3	0.204	1
1	2000	1	5	2	0	29314.2	0.216	1
1	2001	1	5	2	0	24820.6	0.187	1
1	2002	1	5	2	0	24188.9	0.202	1
1	2003	1	5	2	0	41796.1	0.283	1
1	2004	1	5	2	0	40819.8	0.321	1
1	2005	1	5	2	0	51869.8	0.171	1
1	2006	1	5	2	0	43727.8	0.169	1
1	2007	1	5	2	0	45777.1	0.174	1
1	2008	1	5	2	0	46484.5	0.249	1
1	2009	1	5	2	0	47980.0	0.326	1
1	2010	1	5	2	0	42086.5	0.223	1
1	2011	1	5	2	0	39523.3	0.213	1
1	2012	1	5	2	0	30417.8	0.237	1
1	2013	1	5	2	0	22576.6	0.244	1
1	2014	1	5	2	0	53243.9	0.191	1
1	2015	1	5	2	0	27320.8	0.208	1
1	2016	1	5	2	0	33928.4	0.194	1
1	2017	1	5	2	0	27577.5	0.173	1
1	2018	1	5	2	0	12868.2	0.161	1
1	2019	1	5	2	0	13616.4	0.157	1

	#	BSFRF						
2	2007	1	6	1	0	79542	0.116	1
2	2008	1	6	1	0	67569	0.094	1
2	2013	1	6	1	0	68384	0.209	1
2	2014	1	6	1	0	62327	0.192	1
2	2015	1	6	1	0	63709	0.161	1
2	2016	1	6	1	0	34417	0.22	1
2	2007	1	6	2	0	50811	0.116	1
2	2008	1	6	2	0	38472	0.094	1
2	2013	1	6	2	0	26633	0.209	1
2	2014	1	6	2	0	49414	0.192	1
2	2015	1	6	2	0	35244	0.161	1
2	2016	1	6	2	0	43399	0.22	1

Number of length frequency matrices
13
Number of rows in each matrix
42 28 28 43 43 6 6 24 24 45 45 6 6
Number of bins in each matrix (columns of size data)
20 20 16 20 16 20 16 20 16 20 16 20 16

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
———————————————————————————————

#Retained males
#Year Season Fleet Sex Type Shell Maturity Nsamp DataVec
1975 3 1 1 1 0 0 100 0 0 0 0 0
0 0 0 0 0 0 0 0.0071 0.0741 0.1721 0.2239
0.2122 0.1464 0.0858 0.0785
1976 3 1 1 1 0 0 100 0 0 0 0 0
0 0 0 0 0 0 0 0.0016 0.029 0.1418 0.2316
0.2199 0.1635 0.1071 0.1055
1977 3 1 1 1 0 0 100 0 0 0 0 0
0 0 0 0 0 0 0 0.0017 0.0192 0.1382 0.2442
0.2226 0.1605 0.104 0.1096
1978 3 1 1 1 0 0 100 0 0 0 0 0
0 0 0 0 0 0 0 0.0012 0.0209 0.1441 0.2588
0.2401 0.1673 0.0966 0.0711
1979 3 1 1 1 0 0 100 0 0 0 0 0
0 0 0 0 0 0 0 0.0013 0.0119 0.0747 0.1649
0.1998 0.2004 0.1556 0.1914
1980 3 1 1 1 0 0 100 0 0 0 0 0
0 0 0 0 0 0 0 0.0008 0.0138 0.0919 0.1771
0.195 0.1792 0.1404 0.2019
1981 3 1 1 1 0 0 100 0 0 0 0 0
0 0 0 0 0 0 0 0.0006 0.0225 0.1164 0.1743
0.1711 0.1584 0.1284 0.2283
1982 3 1 1 1 0 0 100 0 0 0 0 0
0 0 0 0 0 0 0 0 0.0544 0.2576 0.2802
0.1667 0.0837 0.0508 0.1067
1984 3 1 1 1 0 0 100 0 0 0 0 0

		0	0	0	0	0	0	0.0003	0.0023	0.0654	0.311	0.3135
		0.1763	0.0846	0.0321	0.0145							
1985	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0.0005	0.0044	0.079	0.2869	0.3098
		0.1898	0.086	0.0306	0.0129							
1986	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0	0.0016	0.0531	0.2613	0.3289
		0.2084	0.0978	0.0352	0.0137							
1987	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0	0.0013	0.0284	0.1895	0.3045
		0.2522	0.1421	0.0565	0.0255							
1988	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0	0	0.0202	0.1294	0.2646
		0.2471	0.1876	0.1033	0.0477							
1989	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0	0.0005	0.0187	0.1211	0.2209
		0.219	0.1908	0.1197	0.1094							
1990	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0.0003	0	0.0146	0.0887	0.1801
		0.1707	0.1728	0.1431	0.2297							
1991	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0.0001	0.0005	0.0141	0.0848	0.1651
		0.179	0.1739	0.1432	0.2392							
1992	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0.0003	0.0002	0.0005	0.0095	0.0638	0.1317
		0.1673	0.1747	0.1636	0.2886							
1993	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0	0.0014	0.0138	0.094	0.1789
		0.1739	0.1596	0.1331	0.2453							
1996	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0.0006	0.0006	0.0129	0.0779	0.1407
		0.162	0.1771	0.1671	0.2612							
1997	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0.0004	0.0003	0.0138	0.0899	0.1486
		0.1603	0.1699	0.1588	0.258							
1998	3	1	1	1	0	0	100	0	0	0	0	0
		0	0.0001	0.0001	0.0001	0.0001	0.0004	0.0002	0.0008	0.0225	0.1187	0.1596
		0.149	0.1432	0.1394	0.266							
1999	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0.0001	0	0.0001	0.0147	0.1313	0.2575
		0.2292	0.1624	0.0961	0.1087							
2000	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0.0001	0.0001	0	0.0001	0.0003	0.0111	0.0931	0.1945
		0.2111	0.1822	0.1247	0.1826							
2001	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0.0001	0.0001	0.0001	0.0002	0.0002	0.0012	0.0181	0.0836	0.1681

		0.1986	0.1953	0.1506	0.1838							
2002	3	1	1	1	0	0	100	0	0	0	0	0
		0	0.0001	0	0.0001	0.0001	0.0001	0	0.0002	0.0151	0.108	0.1884
		0.1915	0.1683	0.1334	0.1948							
2003	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0.0001	0.0001	0.0002	0.0009	0.0243	0.1464	0.232
		0.1871	0.1497	0.0994	0.1597							
2004	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0	0.0002	0.0064	0.0514	0.1302
		0.1702	0.1971	0.1632	0.2812							
2005	3	1	1	1	0	0	100	0	0	0	0	0
		0	0.0001	0	0	0	0.0001	0.0001	0.0008	0.015	0.0859	0.1543
		0.1661	0.1783	0.1516	0.2475							
2006	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0.0001	0.0001	0.0004	0.0102	0.0739	0.1905
		0.2203	0.1887	0.137	0.1787							
2007	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0.0002	0.0003	0.0067	0.0871	0.1833
		0.1934	0.1846	0.1472	0.1973							
2008	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0.0001	0.0002	0.01	0.0746	0.1457
		0.1619	0.179	0.1625	0.2659							
2009	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0	0.0002	0.0108	0.1152	0.2215
		0.1968	0.1588	0.1084	0.1882							
2010	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0	0.0003	0.0091	0.0986	0.2244
		0.2238	0.1861	0.1144	0.1433							
2011	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0.0003	0.0001	0.0003	0.0114	0.118	0.2436
		0.2292	0.1725	0.1077	0.1169							
2012	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0.0001	0	0.0001	0	0	0.0044	0.0499	0.1249
		0.173	0.1886	0.1654	0.2937							
2013	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0.0001	0.0001	0	0	0.0001	0.0001	0.0054	0.0525	0.1271
		0.1484	0.1657	0.1632	0.3374							
2014	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0	0.0004	0.0117	0.0964	0.1831
		0.1696	0.1454	0.1246	0.2689							
2015	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0.0001	0.0003	0.0067	0.0616	0.1473
		0.1864	0.1947	0.1634	0.2397							
2016	3	1	1	1	0	0	100	0	0	0	0	0
		0	0	0	0	0	0	0	0.0002	0.0062	0.0489	0.127
		0.166	0.1822	0.1689	0.3006							

2017 3 1 1 1 0 0 100 0 0 0 0 0
0 0 0 0.0001 0.0001 0 0 0 0.0044 0.0453 0.1055
0.1441 0.1781 0.1664 0.356
2018 3 1 1 1 0 0 100 0 0 0 0 0
0 0 0 0 0 0 0 0.0001 0.0052 0.0593 0.1370
0.1406 0.1386 0.1239 0.3951
2019 3 1 1 1 0 0 100 0 0 0 0 0 0
0 0 0 0 0 0.0000 0.0004 0.0086 0.0678 0.1360 0.1338
0.1276 0.1139 0.4119

#Total males
#Year Season Fleet Sex Type Shell Maturity Nsamp DataVec
1990 3 1 1 0 0 0 100 0 0 0.0004 0.0028 0.0016
0.0043 0.0024 0.013 0.0173 0.0263 0.0421 0.0523 0.0641 0.0943 0.1018 0.1108
0.1156 0.0924 0.0971 0.1616
1991 3 1 1 0 0 0 100 0.0009 0.0038 0.0075 0.0081 0.0092
0.0149 0.0124 0.0241 0.0236 0.0262 0.0243 0.0428 0.0605 0.0884 0.1014 0.1069
0.1152 0.1161 0.085 0.129
1992 3 1 1 0 0 0 100 0 0.0006 0.0008 0.0075 0.0151
0.0375 0.0591 0.0777 0.0806 0.0838 0.0806 0.0852 0.0756 0.0603 0.0477 0.0503
0.0538 0.0578 0.0448 0.081
1993 3 1 1 0 0 0 100 0.0008 0.0024 0.0031 0.003 0.004
0.0073 0.0176 0.0325 0.0455 0.062 0.0745 0.0854 0.0832 0.0991 0.0909 0.0898
0.0749 0.0725 0.0567 0.0946
1996 3 1 1 0 0 0 100 0 0 0 0.0047 0.0187
0.0296 0.0265 0.0109 0.0171 0.0249 0.0218 0.0358 0.053 0.0872 0.0981 0.0888
0.1277 0.1246 0.0903 0.1402
1997 3 1 1 0 0 0 100 0 0.0001 0.0002 0.0003 0.0006
0.0081 0.0227 0.0446 0.0519 0.0534 0.0422 0.041 0.0522 0.0701 0.0832 0.0938
0.0967 0.1035 0.0886 0.1467
1998 3 1 1 0 0 0 100 0.0001 0.0002 0.0004 0.0021 0.0037
0.0054 0.0056 0.0104 0.0246 0.0588 0.0946 0.1362 0.1335 0.1122 0.0476 0.0117
0.0386 0.0565 0.0525 0.2052
1999 3 1 1 0 0 0 100 0 0 0 0.0013 0.0013
0.0006 0.0017 0.0013 0.0025 0.006 0.0138 0.0264 0.0537 0.0923 0.1302 0.1444
0.1518 0.1301 0.091 0.1515
2000 3 1 1 0 0 0 100 0.0002 0.002 0.0071 0.0185 0.0234
0.0242 0.0256 0.0262 0.0254 0.0291 0.0349 0.0507 0.0718 0.0843 0.1001 0.1083
0.1114 0.0943 0.0638 0.0988
2001 3 1 1 0 0 0 100 0.0004 0.0023 0.0037 0.005 0.0066
0.0139 0.0249 0.0381 0.0447 0.0539 0.0605 0.0696 0.0659 0.0647 0.0652 0.0843
0.0982 0.1023 0.0824 0.1133
2002 3 1 1 0 0 0 100 0.0017 0.0046 0.0044 0.0051 0.0043
0.0054 0.0066 0.0151 0.0272 0.0504 0.0684 0.0822 0.083 0.0901 0.0939 0.0985
0.0913 0.0881 0.0689 0.1108
2003 3 1 1 0 0 0 100 0.0034 0.0053 0.0065 0.0144 0.0257

0.0323 0.0355 0.0335 0.0315 0.0322 0.036 0.0526 0.0756 0.1021 0.1115 0.108
0.0867 0.0715 0.0494 0.0863
2004 3 1 1 0 0 0 100 0.0001 0.0019 0.0061 0.016 0.021
0.0231 0.0316 0.0519 0.0613 0.0616 0.0486 0.0411 0.035 0.0389 0.0474 0.0731
0.0927 0.1087 0.0917 0.1482
2005 3 1 1 0 0 0 100 0.0001 0.0005 0.0008 0.0017 0.0044
0.0128 0.0199 0.0243 0.0264 0.0383 0.0556 0.0801 0.0806 0.0849 0.0723 0.0769
0.0794 0.0949 0.0818 0.1643
2006 3 1 1 0 0 0 100 0.0001 0.0006 0.0019 0.0065 0.014
0.0171 0.0166 0.0154 0.02 0.0334 0.0412 0.0506 0.0611 0.0815 0.098 0.1153
0.1191 0.113 0.0806 0.1138
2007 3 1 1 0 0 0 100 0.0006 0.0021 0.0034 0.0051 0.0089
0.0191 0.0341 0.044 0.0477 0.044 0.0423 0.0513 0.0676 0.0899 0.0952 0.0974
0.0929 0.0907 0.0691 0.0946
2008 3 1 1 0 0 0 100 0.0001 0.0002 0.0007 0.0025 0.0059
0.0078 0.0088 0.0118 0.0242 0.0444 0.0697 0.0985 0.1095 0.1038 0.0868 0.0768
0.0766 0.0772 0.0703 0.1244
2009 3 1 1 0 0 0 100 0.0002 0.0005 0.0009 0.0016 0.0021
0.0038 0.0093 0.0213 0.033 0.0371 0.0428 0.0638 0.0978 0.1348 0.1354 0.1172
0.0895 0.0659 0.0499 0.0931
2010 3 1 1 0 0 0 100 0.0004 0.0006 0.0013 0.0028 0.0044
0.0061 0.0077 0.0113 0.0179 0.0286 0.0504 0.0807 0.107 0.1302 0.1264 0.121
0.1031 0.0821 0.0512 0.067
2011 3 1 1 0 0 0 100 0.0008 0.0031 0.0055 0.0096 0.0099
0.0089 0.0128 0.0147 0.0192 0.0264 0.0358 0.0564 0.0822 0.1114 0.1321 0.1357
0.1212 0.0926 0.0583 0.0633
2012 3 1 1 0 0 0 100 0.0002 0.0003 0.0008 0.0014 0.0037
0.0088 0.014 0.0188 0.0178 0.0192 0.0236 0.0359 0.0519 0.0746 0.0861 0.099
0.112 0.1276 0.1127 0.1915
2013 3 1 1 0 0 0 100 0.0001 0.0007 0.0017 0.0022 0.0047
0.0059 0.0097 0.0152 0.0261 0.0381 0.0546 0.0609 0.0673 0.0742 0.0761 0.0826
0.0842 0.1033 0.0981 0.1944
2014 3 1 1 0 0 0 100 0.0003 0.0006 0.0008 0.0012 0.0017
0.0038 0.0063 0.0111 0.0155 0.0206 0.0345 0.0474 0.0701 0.0902 0.1051 0.108
0.1051 0.0972 0.0846 0.196
2015 3 1 1 0 0 0 100 0.0001 0.0002 0.0008 0.0017 0.0038
0.0059 0.0063 0.007 0.012 0.0272 0.0337 0.0492 0.0541 0.0675 0.0799 0.107
0.117 0.137 0.1056 0.1841
2016 3 1 1 0 0 0 100 0.0001 0.0002 0.0015 0.0034 0.0046
0.0064 0.0111 0.0188 0.0225 0.028 0.0295 0.04 0.0509 0.0675 0.0814 0.0938
0.1068 0.1214 0.1118 0.2005
2017 3 1 1 0 0 0 100 0.0003 0.0006 0.0034 0.012 0.0258
0.0362 0.0313 0.0248 0.0207 0.0259 0.0306 0.047 0.0505 0.0641 0.0671 0.0809
0.097 0.1032 0.0949 0.1839
2018 3 1 1 0 0 0 100 0.0004 0.0017 0.0065 0.0074 0.0060
0.0100 0.0217 0.0402 0.0630 0.0704 0.0659 0.0551 0.0560 0.0565 0.0621 0.0649

		0.0632	0.0669	0.0698	0.2124							
2019	3	1	1	0	0	0	100	0.0000	0.0001	0.0002	0.0021	0.0094
		0.0186	0.0241	0.0214	0.0212	0.0383	0.0591	0.0896	0.0975	0.0981	0.0889	0.0736
		0.0608	0.0588	0.0503	0.1879							

#Total females

#Year	Season	Fleet	Sex	Type	Shell	Maturity		Nsamp	DataVec			
1990	3	1	2	0	0	0	50	0	0.0014	0.0029	0.0029	0.0057
		0.0072	0.0143	0.0672	0.1016	0.1731	0.1688	0.2132	0.1359	0.0715	0.0243	0.01
1991	3	1	2	0	0	0	37.5	0.0027	0.024	0.0613	0.096	0.1333
		0.16	0.1227	0.072	0.0693	0.056	0.0693	0.08	0.0347	0.0107	0.0053	0.0027
1992	3	1	2	0	0	0	50	0	0.0013	0.0029	0.0177	0.0803
		0.1765	0.195	0.1698	0.0958	0.0815	0.0572	0.0404	0.0395	0.0256	0.0118	0.0046
1993	3	1	2	0	0	0	50	0.0013	0.0023	0.0047	0.006	0.0137
		0.033	0.1017	0.1606	0.1446	0.1136	0.09	0.0849	0.0829	0.0735	0.043	0.0442
1996	3	1	2	0	0	0	1.1	0	0	0	0.0909	0.6364
		0.2727	0	0	0	0	0	0	0	0	0	0
1997	3	1	2	0	0	0	50	0	0	0.0011	0.0011	0.0099
		0.0265	0.0364	0.0464	0.0695	0.1391	0.1667	0.1435	0.117	0.1082	0.0607	0.074
1998	3	1	2	0	0	0	50	0.0002	0.0004	0.0009	0.0024	0.0062
		0.0165	0.0519	0.168	0.2191	0.1527	0.0862	0.0853	0.0578	0.0533	0.0362	0.0628
1999	3	1	2	0	0	0	3.6	0	0	0	0.025	0.025
		0.025	0.05	0.025	0	0.125	0.125	0.075	0.1	0.125	0.075	0.225
2000	3	1	2	0	0	0	50	0	0.0044	0.0256	0.0607	0.0744
		0.0816	0.0701	0.0543	0.055	0.0998	0.1541	0.146	0.0799	0.042	0.0224	0.0296
2001	3	1	2	0	0	0	50	0.0007	0.0042	0.0129	0.0307	0.0568
		0.0844	0.0986	0.0909	0.0646	0.0568	0.0883	0.1407	0.14	0.0638	0.0269	0.0396
2002	3	1	2	0	0	0	30.2	0.0595	0.1714	0.1601	0.1388	0.1091
		0.0581	0.0297	0.0326	0.0382	0.0326	0.0241	0.0241	0.0198	0.0269	0.0283	0.0467
2003	3	1	2	0	0	0	50	0.012	0.0164	0.0231	0.0635	0.102
		0.1075	0.0682	0.043	0.06	0.0866	0.0984	0.0675	0.054	0.0596	0.0572	0.0811
2004	3	1	2	0	0	0	50	0.0003	0.0056	0.0258	0.0575	0.0774
		0.0918	0.1413	0.1308	0.0876	0.0449	0.0503	0.0611	0.0531	0.0446	0.0431	0.0851
2005	3	1	2	0	0	0	50	0.0004	0.0013	0.0022	0.005	0.0146
		0.05	0.0788	0.0931	0.1233	0.1212	0.0871	0.1021	0.0958	0.0885	0.0519	0.0848
2006	3	1	2	0	0	0	50	0.0003	0.004	0.0256	0.1183	0.1939
		0.1616	0.0692	0.0519	0.0672	0.0704	0.0576	0.0403	0.0358	0.0323	0.0256	0.0461
2007	3	1	2	0	0	0	50	0.0029	0.0124	0.0214	0.0235	0.0461
		0.0886	0.1116	0.0832	0.0556	0.0739	0.1005	0.1146	0.0942	0.0671	0.0437	0.0604
2008	3	1	2	0	0	0	50	0.0004	0.0018	0.0097	0.0362	0.0775
		0.0662	0.0472	0.0772	0.1071	0.0871	0.0954	0.126	0.1254	0.067	0.0391	0.0368
2009	3	1	2	0	0	0	50	0.0036	0.0083	0.0099	0.0144	0.0164
		0.0282	0.0652	0.0867	0.0803	0.0912	0.0857	0.09	0.1141	0.1308	0.0875	0.0877
2010	3	1	2	0	0	0	50	0.0036	0.0051	0.0052	0.0199	0.0276
		0.0292	0.0269	0.0444	0.0882	0.1135	0.1315	0.1423	0.1011	0.0917	0.0879	0.0816
2011	3	1	2	0	0	0	50	0.013	0.037	0.0604	0.101	0.076

		0.0698	0.0583	0.0411	0.0266	0.0359	0.0693	0.0911	0.0823	0.0667	0.0672	0.1042
2012	3	1	2	0	0	0	50	0.0089	0.0107	0.0124	0.0337	0.0604
		0.1155	0.0941	0.0391	0.0178	0.0124	0.0409	0.0426	0.1652	0.151	0.1101	0.0853
2013	3	1	2	0	0	0	50	0.0005	0.0017	0.0083	0.0109	0.0187
		0.037	0.0716	0.1327	0.1428	0.0967	0.0716	0.0637	0.0851	0.0904	0.0731	0.0952
2014	3	1	2	0	0	0	50	0.0011	0.0053	0.0068	0.0086	0.0086
		0.021	0.0282	0.0274	0.0526	0.0713	0.0755	0.0762	0.0965	0.1142	0.1303	0.2764
2015	3	1	2	0	0	0	50	0	0.0011	0.0018	0.0051	0.012
		0.0164	0.0197	0.0354	0.0556	0.0869	0.0889	0.1404	0.1126	0.1031	0.0833	0.2377
2016	3	1	2	0	0	0	50	0	0.0003	0.0073	0.0122	0.0187
		0.0181	0.0213	0.0312	0.0377	0.0617	0.0994	0.1535	0.1739	0.1341	0.0712	0.1594
2017	3	1	2	0	0	0	50	0.0005	0.003	0.0137	0.0526	0.0983
		0.1093	0.0806	0.0333	0.0371	0.0497	0.0747	0.0959	0.0991	0.0937	0.0655	0.0929
2018	3	1	2	0	0	0	50	0.0003	0.0046	0.0171	0.0233	0.0221
		0.0338	0.0542	0.0839	0.0766	0.0658	0.0674	0.1078	0.1178	0.1126	0.0839	0.1288
2019	3	1	2	0	0	0	50	0.0000	0.0000	0.0018	0.0053	0.0263
		0.0458	0.0362	0.0337	0.0564	0.0777	0.0702	0.0770	0.1057	0.1302	0.1153	0.2185

#Trawl	bycatch		male									
#Year	Season	Fleet	Sex	Type	Shell	Maturity		Nsamp	DataVec			
1976	5	2	1	0.0	0	0	50	0.0000	0.0000	0.0000	0.0000	0.0000
		0.0130	0.0087	0.0043	0.0216	0.0087	0.0260	0.0390	0.0433	0.0649	0.0996	0.0866
		0.0736	0.0909	0.0649	0.1299							
1977	5	2	1	0.0	0	0	50	0.0036	0.0009	0.0009	0.0009	0.0026
		0.0035	0.0079	0.0097	0.0317	0.0485	0.0599	0.0996	0.1084	0.1251	0.1040	0.1057
		0.1004	0.0634	0.0326	0.0441							
1978	5	2	1	0.0	0	0	50	0.0000	0.0000	0.0000	0.0000	0.0000
		0.0000	0.0000	0.0025	0.0012	0.0025	0.0149	0.0274	0.0511	0.0872	0.1245	0.1158
		0.0797	0.0984	0.0672	0.1880							
1979	5	2	1	0.0	0	0	50	0.0178	0.0013	0.0025	0.0013	0.0025
		0.0076	0.0038	0.0025	0.0013	0.0063	0.0051	0.0114	0.0228	0.0556	0.0582	0.0708
		0.0898	0.0860	0.0809	0.1858							
1980	5	2	1	0.0	0	0	50	0.0531	0.0207	0.0096	0.0135	0.0142
		0.0163	0.0274	0.0263	0.0380	0.0375	0.0422	0.0394	0.0368	0.0377	0.0313	0.0231
		0.0207	0.0142	0.0131	0.0265							
1981	5	2	1	0.0	0	0	50	0.0262	0.0028	0.0045	0.0066	0.0112
		0.0175	0.0279	0.0349	0.0386	0.0504	0.0434	0.0480	0.0287	0.0334	0.0241	0.0212
		0.0112	0.0064	0.0051	0.0087							
1982	5	2	1	0.0	0	0	50	0.0701	0.0268	0.0247	0.0326	0.0356
		0.0443	0.0409	0.0403	0.0401	0.0475	0.0426	0.0479	0.0405	0.0326	0.0218	0.0153
		0.0084	0.0052	0.0038	0.0099							
1983	5	2	1	0.0	0	0	50	0.0231	0.0214	0.0336	0.0344	0.0311
		0.0319	0.0377	0.0445	0.0473	0.0471	0.0457	0.0437	0.0409	0.0414	0.0371	0.0283
		0.0204	0.0129	0.0096	0.0180							
1984	5	2	1	0.0	0	0	50	0.0366	0.0156	0.0147	0.0199	0.0270
		0.0342	0.0399	0.0407	0.0431	0.0476	0.0511	0.0596	0.0594	0.0563	0.0473	0.0355

		0.0264	0.0170	0.0109	0.0146							
1985	5	2	1	0.0	0	0	50	0.0051	0.0014	0.0034	0.0059	0.0100
		0.0164	0.0256	0.0396	0.0357	0.0446	0.0538	0.0636	0.0843	0.0862	0.0883	0.0843
		0.0638	0.0455	0.0299	0.0578							
1986	5	2	1	0.0	0	0	50	0.0038	0.0019	0.0085	0.0019	0.0056
		0.0136	0.0193	0.0357	0.0160	0.0249	0.0221	0.0320	0.0710	0.0555	0.0527	0.0635
		0.0456	0.0362	0.0259	0.0282							
1987	5	2	1	0.0	0	0	49.9	0.0020	0.0000	0.0010	0.0020	0.0050
		0.0080	0.0190	0.0271	0.0170	0.0220	0.0441	0.0491	0.0401	0.0581	0.0852	0.0812
		0.0671	0.0611	0.0511	0.0842							
1988	5	2	1	0.0	0	0	31.55	0.0048	0.0048	0.0063	0.0016	0.0032
		0.0000	0.0095	0.0175	0.0127	0.0397	0.0524	0.0540	0.0571	0.0635	0.0651	0.0889
		0.0794	0.0587	0.0349	0.0397							
1989	5	2	1	0.0	0	0	50	0.0047	0.0026	0.0019	0.0006	0.0019
		0.0019	0.0045	0.0047	0.0097	0.0142	0.0237	0.0379	0.0439	0.0534	0.0710	0.0809
		0.0798	0.0783	0.0678	0.0897							
1990	5	2	1	0.0	0	0	50	0.0051	0.0041	0.0071	0.0020	0.0081
		0.0071	0.0234	0.0142	0.0244	0.0264	0.0224	0.0305	0.0325	0.0508	0.0843	0.0843
		0.0772	0.0681	0.0376	0.0742							
1991	5	2	1	0.0	0	0	16.3	0.0036	0.0072	0.0036	0.0072	0.0181
		0.0144	0.0144	0.0181	0.0361	0.0253	0.0361	0.0325	0.0397	0.0217	0.0289	0.0722
		0.0505	0.0578	0.0650	0.1588							
1992	5	2	1	0.0	0	0	22	0.0210	0.0210	0.0180	0.0000	0.0060
		0.0060	0.0030	0.0000	0.0060	0.0120	0.0240	0.0210	0.0360	0.0390	0.0390	0.0450
		0.0240	0.0210	0.0030	0.0330							
1994	5	2	1	0.0	0	0	28.6	0.0000	0.0000	0.0035	0.0070	0.0018
		0.0000	0.0000	0.0000	0.0000	0.0000	0.0018	0.0018	0.0088	0.0158	0.0210	0.0473
		0.0438	0.0578	0.0841	0.2785							
1995	5	2	1	0.0	0	0	8	0.0067	0.0267	0.0133	0.0067	0.0067
		0.0067	0.0000	0.0133	0.0067	0.0200	0.0000	0.0133	0.0200	0.0133	0.0400	0.0667
		0.1267	0.0867	0.0467	0.2467							
1996	5	2	1	0.0	0	0	50	0.0000	0.0008	0.0000	0.0016	0.0049
		0.0114	0.0147	0.0188	0.0294	0.0343	0.0474	0.0662	0.0466	0.0686	0.0392	0.0645
		0.0425	0.0564	0.0417	0.1266							
1997	5	2	1	0.0	0	0	17.45	0.0000	0.0000	0.0000	0.0000	0.0029
		0.0029	0.0029	0.0088	0.0088	0.0206	0.0206	0.0265	0.0235	0.0176	0.0500	0.0647
		0.0324	0.0382	0.0382	0.1559							
1998	5	2	1	0.0	0	0	50	0.0007	0.0007	0.0007	0.0000	0.0000
		0.0000	0.0035	0.0028	0.0056	0.0133	0.0280	0.0314	0.0566	0.0475	0.0580	0.0419
		0.0419	0.0475	0.0405	0.1097							
1999	5	2	1	0.0	0	0	32.15	0.0016	0.0016	0.0000	0.0016	0.0031
		0.0000	0.0063	0.0031	0.0079	0.0126	0.0142	0.0409	0.0504	0.0756	0.1071	0.1008
		0.0913	0.0709	0.0661	0.0945							
2000	5	2	1	0.0	0	0	36.7	0.0000	0.0000	0.0014	0.0014	0.0014
		0.0068	0.0095	0.0286	0.0368	0.0327	0.0354	0.0313	0.0422	0.0463	0.0354	0.0422
		0.0436	0.0463	0.0518	0.2262							

2001 5 2 1 0.0 0 0 40.1 0.0000 0.0000 0.0050 0.0025 0.0100
0.0339 0.0226 0.0263 0.0402 0.0376 0.0427 0.0351 0.0351 0.0251 0.0351 0.0226
0.0477 0.0351 0.0527 0.1041
2002 5 2 1 0.0 0 0 50 0.0009 0.0009 0.0009 0.0009 0.0018
0.0026 0.0061 0.0044 0.0061 0.0105 0.0219 0.0193 0.0280 0.0368 0.0464 0.0455
0.0517 0.0569 0.0412 0.1322
2003 5 2 1 0.0 0 0 26.25 0.0019 0.0039 0.0058 0.0077 0.0193
0.0097 0.0154 0.0232 0.0251 0.0174 0.0135 0.0193 0.0309 0.0347 0.0425 0.0521
0.0463 0.0483 0.0521 0.1216
2004 5 2 1 0.0 0 0 33.3 0.0015 0.0000 0.0000 0.0015 0.0015
0.0045 0.0060 0.0166 0.0211 0.0166 0.0302 0.0392 0.0407 0.0377 0.0347 0.0407
0.0422 0.0392 0.0347 0.1448
2005 5 2 1 0.0 0 0 50 0.0029 0.0038 0.0019 0.0086 0.0077
0.0134 0.0211 0.0154 0.0125 0.0230 0.0259 0.0393 0.0509 0.0480 0.0422 0.0413
0.0461 0.0480 0.0403 0.0883
2006 5 2 1 0.0 0 0 50 0.0000 0.0000 0.0000 0.0000 0.0017
0.0025 0.0025 0.0127 0.0110 0.0391 0.0365 0.0425 0.0484 0.0467 0.0688 0.0697
0.0688 0.0671 0.0586 0.1393
2007 5 2 1 0.0 0 0 50 0.0000 0.0000 0.0000 0.0016 0.0024
0.0032 0.0048 0.0112 0.0128 0.0136 0.0233 0.0217 0.0289 0.0393 0.0457 0.0401
0.0393 0.0425 0.0586 0.1252
2008 5 2 1 0.0 0 0 50 0.0000 0.0000 0.0006 0.0000 0.0025
0.0025 0.0019 0.0025 0.0131 0.0255 0.0255 0.0597 0.0622 0.0566 0.0715 0.0466
0.0646 0.0547 0.0541 0.1753
2009 5 2 1 0.0 0 0 50 0.0000 0.0000 0.0000 0.0000 0.0008
0.0025 0.0025 0.0033 0.0066 0.0108 0.0116 0.0298 0.0298 0.0431 0.0547 0.0514
0.0671 0.0497 0.0530 0.1740
2010 5 2 1 0.0 0 0 45.95 0.0000 0.0000 0.0022 0.0022 0.0022
0.0054 0.0033 0.0120 0.0185 0.0174 0.0196 0.0348 0.0490 0.0501 0.0566 0.0479
0.0359 0.0337 0.0370 0.0860
2011 5 2 1 0.0 0 0 22.3 0.0000 0.0000 0.0022 0.0067 0.0067
0.0022 0.0022 0.0067 0.0135 0.0090 0.0067 0.0067 0.0224 0.0269 0.0493 0.0650
0.0605 0.0628 0.0448 0.1188
2012 5 2 1 0.0 0 0 14.15 0.0000 0.0035 0.0000 0.0000 0.0000
0.0035 0.0071 0.0071 0.0035 0.0071 0.0141 0.0106 0.0283 0.0353 0.0601 0.0318
0.0495 0.0530 0.0530 0.1696
2013 5 2 1 0.0 0 0 24.2 0.0000 0.0021 0.0000 0.0021 0.0021
0.0000 0.0000 0.0021 0.0041 0.0083 0.0103 0.0227 0.0455 0.0393 0.0517 0.0517
0.0434 0.0517 0.0393 0.2624
2014 5 2 1 0.0 0 0 13.05 0.0000 0.0038 0.0000 0.0038 0.0115
0.0038 0.0000 0.0192 0.0038 0.0115 0.0192 0.0230 0.0268 0.0383 0.0690 0.0881
0.0421 0.0345 0.0460 0.2069
2015 5 2 1 0.0 0 0 20.45 0.0000 0.0000 0.0073 0.0073 0.0073
0.0049 0.0122 0.0147 0.0122 0.0147 0.0220 0.0293 0.0318 0.0440 0.0342 0.0391
0.0513 0.0342 0.0391 0.1002
2016 5 2 1 0.0 0 0 30.85 0.0000 0.0016 0.0032 0.0049 0.0032

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                0.0016 0.0130 0.0097 0.0162 0.0065 0.0113 0.0357 0.0243 0.0470 0.0519 0.0583
                0.0632 0.0794 0.0778 0.2107
2017    5       2      1      0.0    0      0      35.9   0.0000 0.0000 0.0000 0.0000 0.0056
                0.0042 0.0056 0.0056 0.0070 0.0056 0.0084 0.0153 0.0265 0.0320 0.0418 0.0529
                0.0891 0.0766 0.1017 0.3231
2018    5       2      1      0.0    0      0      44.65  0.0011 0.0000 0.0022 0.0000 0.0022
                0.0045 0.0112 0.0045 0.0213 0.0202 0.0403 0.0426 0.0437 0.0594 0.0448 0.0336
                0.0448 0.0403 0.0403 0.1601
2019    5       2      1      0.0    0      0      38.0   0.0013 0.0013 0.0053 0.0079 0.0092
                0.0118 0.0053 0.0092 0.0092 0.0276 0.0303 0.0316 0.0434 0.0553 0.0566 0.0434
                0.0539 0.0421 0.0395 0.2132

#Trawl bycatch         female
#Year   Season  Fleet  Sex    Type   Shell  Maturity        Nsamp  DataVec
1976    5       2      2      0      0      0      0      0.0000 0.0000 0.0000 0.0000 0.0000
                0.0000 0.0130 0.0087 0.0216 0.0260 0.0303 0.0563 0.0130 0.0260 0.0043 0.0260
1977    5       2      2      0      0      0      0      0.0000 0.0009 0.0009 0.0000 0.0000
                0.0009 0.0026 0.0053 0.0070 0.0088 0.0062 0.0053 0.0044 0.0026 0.0009 0.0009
1978    5       2      2      0      0      0      0      0.0000 0.0000 0.0000 0.0000 0.0000
                0.0000 0.0000 0.0000 0.0000 0.0000 0.0075 0.0050 0.0075 0.0262 0.0324 0.0610
1979    5       2      2      0      0      0      0      0.0130 0.0013 0.0000 0.0000 0.0063
                0.0038 0.0152 0.0468 0.0354 0.0392 0.0544 0.0215 0.0164 0.0177 0.0013 0.0139
1980    5       2      2      0      0      0      0      0.0433 0.0160 0.0096 0.0189 0.0281
                0.0409 0.0497 0.0472 0.0489 0.0525 0.0362 0.0265 0.0134 0.0081 0.0039 0.0040
1981    5       2      2      0      0      0      0      0.0612 0.0245 0.0245 0.0437 0.0540
                0.0608 0.0525 0.0425 0.0315 0.0383 0.0312 0.0267 0.0240 0.0158 0.0093 0.0086
1982    5       2      2      0      0      0      0      0.0631 0.0235 0.0237 0.0285 0.0379
                0.0413 0.0332 0.0246 0.0190 0.0177 0.0156 0.0144 0.0104 0.0080 0.0034 0.0049
1983    5       2      2      0      0      0      0      0.0281 0.0233 0.0351 0.0363 0.0358
                0.0407 0.0392 0.0316 0.0222 0.0154 0.0100 0.0087 0.0065 0.0042 0.0030 0.0041
1984    5       2      2      0      0      0      0      0.0400 0.0156 0.0155 0.0211 0.0298
                0.0344 0.0399 0.0359 0.0287 0.0151 0.0085 0.0060 0.0042 0.0031 0.0019 0.0029
1985    5       2      2      0      0      0      0      0.0034 0.0013 0.0024 0.0046 0.0096
                0.0171 0.0195 0.0193 0.0163 0.0128 0.0119 0.0111 0.0108 0.0057 0.0025 0.0066
1986    5       2      2      0      0      0      0      0.0038 0.0014 0.0038 0.0000 0.0038
                0.0099 0.0329 0.0762 0.0630 0.0470 0.0494 0.0466 0.0428 0.0202 0.0085 0.0268
1987    5       2      2      0      0      0      0      0.0020 0.0020 0.0030 0.0100 0.0180
                0.0311 0.0331 0.0401 0.0220 0.0311 0.0160 0.0391 0.0080 0.0080 0.0030 0.0090
1988    5       2      2      0      0      0      0      0.0079 0.0143 0.0032 0.0079 0.0063
                0.0127 0.0222 0.0333 0.0476 0.0524 0.0397 0.0222 0.0175 0.0079 0.0048 0.0063
1989    5       2      2      0      0      0      0      0.0028 0.0024 0.0015 0.0022 0.0065
                0.0108 0.0204 0.0430 0.0504 0.0480 0.0435 0.0295 0.0256 0.0170 0.0065 0.0168
1990    5       2      2      0      0      0      0      0.0020 0.0041 0.0071 0.0081 0.0112
                0.0112 0.0183 0.0203 0.0366 0.0305 0.0335 0.0325 0.0234 0.0173 0.0152 0.0447
1991    5       2      2      0      0      0      0      0.0000 0.0036 0.0108 0.0036 0.0000
                0.0072 0.0036 0.0072 0.0289 0.0181 0.0181 0.0289 0.0181 0.0325 0.0036 0.1047
```

1992	5	2	2	0	0	0	0	0.0030	0.0000	0.0000	0.0030	0.0420
		0.0631	0.0480	0.0480	0.0450	0.0480	0.0631	0.0691	0.0480	0.0450	0.0390	0.0571
1994	5	2	2	0	0	0	0	0.0000	0.0035	0.0088	0.0280	0.0333
		0.0438	0.0298	0.0665	0.0455	0.0175	0.0140	0.0123	0.0140	0.0210	0.0210	0.0683
1995	5	2	2	0	0	0	0	0.0467	0.0000	0.0000	0.0200	0.0067
		0.0200	0.0333	0.0133	0.0200	0.0000	0.0200	0.0000	0.0067	0.0133	0.0000	0.0333
1996	5	2	2	0	0	0	0	0.0000	0.0000	0.0008	0.0090	0.0204
		0.0335	0.0147	0.0163	0.0188	0.0253	0.0253	0.0188	0.0237	0.0212	0.0139	0.0425
1997	5	2	2	0	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0029
		0.0000	0.0265	0.0382	0.0676	0.0941	0.0471	0.0412	0.0559	0.0294	0.0147	0.0676
1998	5	2	2	0	0	0	0	0.0000	0.0000	0.0000	0.0007	0.0014
		0.0042	0.0182	0.0503	0.0545	0.0440	0.0391	0.0321	0.0468	0.0370	0.0398	0.1013
1999	5	2	2	0	0	0	0	0.0000	0.0000	0.0000	0.0016	0.0000
		0.0000	0.0047	0.0047	0.0079	0.0205	0.0252	0.0220	0.0346	0.0236	0.0299	0.0756
2000	5	2	2	0	0	0	0	0.0000	0.0000	0.0000	0.0027	0.0041
		0.0082	0.0150	0.0191	0.0082	0.0163	0.0313	0.0422	0.0177	0.0232	0.0082	0.0845
2001	5	2	2	0	0	0	0	0.0000	0.0000	0.0025	0.0025	0.0138
		0.0125	0.0289	0.0226	0.0251	0.0301	0.0201	0.0238	0.0301	0.0351	0.0376	0.1016
2002	5	2	2	0	0	0	0	0.0000	0.0009	0.0000	0.0018	0.0035
		0.0079	0.0149	0.0271	0.0525	0.0368	0.0280	0.0315	0.0394	0.0438	0.0490	0.1480
2003	5	2	2	0	0	0	0	0.0000	0.0058	0.0039	0.0116	0.0154
		0.0232	0.0174	0.0193	0.0232	0.0270	0.0251	0.0425	0.0309	0.0328	0.0328	0.0985
2004	5	2	2	0	0	0	0	0.0000	0.0000	0.0000	0.0015	0.0015
		0.0136	0.0287	0.0377	0.0392	0.0287	0.0513	0.0332	0.0407	0.0211	0.0362	0.1131
2005	5	2	2	0	0	0	0	0.0010	0.0058	0.0077	0.0048	0.0086
		0.0211	0.0355	0.0499	0.0672	0.0605	0.0259	0.0307	0.0221	0.0192	0.0154	0.0441
2006	5	2	2	0	0	0	0	0.0000	0.0000	0.0008	0.0008	0.0051
		0.0093	0.0068	0.0102	0.0153	0.0229	0.0297	0.0306	0.0340	0.0272	0.0178	0.0731
2007	5	2	2	0	0	0	0	0.0000	0.0000	0.0032	0.0016	0.0032
		0.0144	0.0265	0.0353	0.0353	0.0369	0.0457	0.0554	0.0514	0.0514	0.0353	0.0899
2008	5	2	2	0	0	0	0	0.0000	0.0000	0.0000	0.0006	0.0068
		0.0044	0.0081	0.0168	0.0305	0.0267	0.0267	0.0267	0.0342	0.0199	0.0186	0.0609
2009	5	2	2	0	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0017
		0.0116	0.0232	0.0456	0.0414	0.0257	0.0273	0.0348	0.0423	0.0414	0.0365	0.0779
2010	5	2	2	0	0	0	0	0.0011	0.0011	0.0011	0.0011	0.0044
		0.0120	0.0239	0.0316	0.0326	0.0435	0.0598	0.0511	0.0501	0.0424	0.0392	0.0914
2011	5	2	2	0	0	0	0	0.0000	0.0000	0.0045	0.0135	0.0090
		0.0067	0.0336	0.0090	0.0224	0.0269	0.0426	0.0448	0.0538	0.0336	0.0404	0.1457
2012	5	2	2	0	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0035
		0.0318	0.0212	0.0459	0.0141	0.0353	0.0318	0.0283	0.0565	0.0459	0.0318	0.1166
2013	5	2	2	0	0	0	0	0.0021	0.0000	0.0021	0.0000	0.0083
		0.0062	0.0248	0.0413	0.0331	0.0393	0.0248	0.0186	0.0227	0.0351	0.0186	0.0847
2014	5	2	2	0	0	0	0	0.0000	0.0000	0.0038	0.0038	0.0038
		0.0077	0.0268	0.0153	0.0460	0.0307	0.0268	0.0153	0.0115	0.0115	0.0307	0.1149
2015	5	2	2	0	0	0	0	0.0000	0.0024	0.0024	0.0073	0.0342
		0.0293	0.0465	0.0538	0.0318	0.0465	0.0367	0.0293	0.0293	0.0220	0.0220	0.1002

2016 5 2 2 0 0 0 0 0.0000 0.0000 0.0065 0.0049 0.0016
0.0081 0.0097 0.0097 0.0097 0.0227 0.0373 0.0324 0.0340 0.0243 0.0130 0.0665
2017 5 2 2 0 0 0 0 0.0000 0.0000 0.0028 0.0028 0.0181
0.0056 0.0070 0.0028 0.0056 0.0070 0.0097 0.0153 0.0153 0.0125 0.0125 0.0822
2018 5 2 2 0 0 0 0 0.0000 0.0045 0.0067 0.0112 0.0078
0.0112 0.0157 0.0347 0.0168 0.0202 0.0246 0.0291 0.0314 0.0325 0.0370 0.0997
2019 5 2 2 0 0 0 0 0.0026 0.0026 0.0105 0.0039 0.0092
0.0211 0.0079 0.0105 0.0105 0.0171 0.0158 0.0171 0.0184 0.0197 0.0237 0.1118

#Tanner crab bycatch Male (male and female combined compositons are normalized to be 1)
#Year Season Fleet Sex Type Shell Maturity Nsamp DataVec

1991 5 3 1 0.000 0 0 50 0.0026 0.0049 0.0029 0.0042 0.0052
0.0042 0.0104 0.0143 0.0146 0.0110 0.0159 0.0169 0.0181 0.0269 0.0292 0.0230
0.0211 0.0201 0.0169 0.0249
1992 5 3 1 0.000 0 0 48.25 0.0000 0.0000 0.0010 0.0031 0.0114
0.0166 0.0259 0.0238 0.0259 0.0301 0.0270 0.0270 0.0187 0.0124 0.0145 0.0052
0.0104 0.0135 0.0073 0.0166
1993 5 3 1 0.000 0 0 24.85 0.0000 0.0000 0.0000 0.0000 0.0040
0.0020 0.0261 0.0483 0.0584 0.0664 0.0463 0.0282 0.0261 0.0362 0.0261 0.0221
0.0302 0.0141 0.0101 0.0221
2013 5 3 1 0.000 0 0 40.7 0.0000 0.0012 0.0000 0.0000 0.0000
0.0086 0.0074 0.0135 0.0184 0.0393 0.0197 0.0295 0.0172 0.0197 0.0086 0.0221
0.0123 0.0098 0.0135 0.0270
2014 5 3 1 0.000 0 0 31.85 0.0000 0.0000 0.0016 0.0000 0.0078
0.0078 0.0126 0.0188 0.0157 0.0314 0.0220 0.0267 0.0314 0.0408 0.0408 0.0251
0.0345 0.0251 0.0173 0.0424
2015 5 3 1 0.000 0 0 50 0.0017 0.0038 0.0017 0.0024 0.0180
0.0246 0.0176 0.0114 0.0152 0.0201 0.0215 0.0118 0.0086 0.0066 0.0121 0.0104
0.0135 0.0142 0.0149 0.0211
#Tanner crab bycatch female

#Year Season Fleet Sex Type Shell Maturity Nsamp DataVec
1991 5 3 2 0 0 0 0 0.0052 0.0107 0.0097 0.0103 0.0243
0.0331 0.0567 0.0463 0.0839 0.1160 0.1134 0.0956 0.0548 0.0269 0.0188 0.0071

1992 5 3 2 0 0 0 0 0.0000 0.0000 0.0011 0.0062 0.0228
0.0456 0.0818 0.0933 0.0870 0.0539 0.0777 0.0995 0.0653 0.0404 0.0228 0.0124

1993 5 3 2 0 0 0 0 0.0000 0.0000 0.0000 0.0000 0.0040
0.0342 0.0825 0.1127 0.0805 0.0362 0.0403 0.0403 0.0564 0.0262 0.0121 0.0081

2013 5 3 2 0 0 0 0 0.0000 0.0000 0.0000 0.0000 0.0000
0.0221 0.0504 0.1806 0.1437 0.0774 0.0467 0.0553 0.0368 0.0651 0.0234 0.0307

2014	5	3	2	0	0	0	0	0.0000	0.0000	0.0016	0.0031	0.0110
		0.0220	0.0471	0.0550	0.1428	0.1586	0.0581	0.0267	0.0220	0.0110	0.0173	0.0220
2015	5	3	2	0	0	0	0	0.0004	0.0013	0.0028	0.0052	0.0239
		0.0346	0.0637	0.1032	0.1440	0.1115	0.0921	0.0689	0.0374	0.0201	0.0170	0.0228
# Fixed gear		crab	bycatch		Male							
#Year	season	Fleet	Sex	Type	Shell	Maturity		Nsamp	DataVec			
1996	5	4	1	0	0	0	39	0.0026	0.0013	0.0066	0.0053	0.0026
		0.0053	0.0132	0.0132	0.0079	0.0146	0.0146	0.0079	0.0146	0.0132	0.0106	0.0146
		0.0106	0.0066	0.0066	0.0238							
1997	5	4	1	0	0	0	50	0.0000	0.0000	0.0024	0.0024	0.0134
		0.0284	0.0504	0.0686	0.0654	0.0607	0.0496	0.0315	0.0347	0.0418	0.0315	0.0221
		0.0362	0.0441	0.0528	0.1560							
1998	5	4	1	0	0	0	50	0.0000	0.0000	0.0000	0.0000	0.0000
		0.0019	0.0019	0.0039	0.0077	0.0125	0.0251	0.0367	0.0521	0.0869	0.0849	0.1052
		0.0840	0.0772	0.0666	0.1564							
1999	5	4	1	0	0	0	50	0.0031	0.0006	0.0019	0.0000	0.0000
		0.0000	0.0000	0.0000	0.0000	0.0025	0.0094	0.0218	0.0524	0.0868	0.1142	0.1255
		0.1242	0.0980	0.0674	0.1311							
2000	5	4	1	0	0	0	44.2	0.0000	0.0000	0.0000	0.0000	0.0000
		0.0000	0.0000	0.0085	0.0169	0.0321	0.0271	0.0761	0.0508	0.0575	0.0457	0.0694
		0.0558	0.0541	0.0474	0.1151							
2001	5	4	1	0	0	0	50	0.0000	0.0002	0.0006	0.0004	0.0016
		0.0044	0.0074	0.0111	0.0201	0.0221	0.0239	0.0233	0.0257	0.0298	0.0340	0.0513
		0.0652	0.0638	0.0547	0.1456							
2002	5	4	1	0	0	0	50	0.0000	0.0000	0.0000	0.0003	0.0009
		0.0017	0.0003	0.0020	0.0049	0.0111	0.0151	0.0220	0.0305	0.0365	0.0520	0.0582
		0.0722	0.0748	0.0854	0.2880							
2003	5	4	1	0	0	0	50	0.0011	0.0000	0.0032	0.0117	0.0149
		0.0171	0.0235	0.0107	0.0075	0.0117	0.0128	0.0299	0.0309	0.0421	0.0597	0.0645
		0.0629	0.0581	0.0533	0.1093							
2004	5	4	1	0	0	0	50	0.0000	0.0005	0.0023	0.0059	0.0036
		0.0091	0.0123	0.0282	0.0310	0.0287	0.0346	0.0246	0.0241	0.0241	0.0319	0.0492
		0.0583	0.0556	0.0497	0.0929							
2005	5	4	1	0	0	0	50	0.0005	0.0000	0.0014	0.0000	0.0005
		0.0042	0.0009	0.0116	0.0075	0.0075	0.0205	0.0266	0.0266	0.0312	0.0336	0.0349
		0.0410	0.0433	0.0457	0.1603							
2006	5	4	1	0	0	0	50	0.0000	0.0000	0.0000	0.0000	0.0000
		0.0005	0.0026	0.0016	0.0069	0.0069	0.0106	0.0159	0.0154	0.0244	0.0318	0.0318
		0.0349	0.0355	0.0286	0.0593							
2007	5	4	1	0	0	0	42.6	0.0000	0.0000	0.0000	0.0000	0.0037
		0.0000	0.0000	0.0037	0.0037	0.0074	0.0062	0.0136	0.0049	0.0333	0.0333	0.0432
		0.0358	0.0333	0.0543	0.1432							
2008	5	4	1	0	0	0	50	0.0000	0.0000	0.0000	0.0000	0.0000

0.0000 0.0026 0.0069 0.0172 0.0232 0.0369 0.0378 0.0464 0.0369 0.0438 0.0309
0.0344 0.0421 0.0430 0.1452
2009 5 4 1 0 0 0 50 0.0000 0.0000 0.0000 0.0000 0.0009
0.0009 0.0009 0.0101 0.0129 0.0129 0.0129 0.0202 0.0395 0.0606 0.0634 0.1093
0.0817 0.0735 0.0542 0.1166
2010 5 4 1 0 0 0 27.4 0.0073 0.0091 0.0073 0.0036 0.0036
0.0073 0.0055 0.0000 0.0073 0.0036 0.0109 0.0146 0.0255 0.0255 0.0201 0.0182
0.0164 0.0274 0.0182 0.0456
2011 5 4 1 0 0 0 50 0.0000 0.0000 0.0008 0.0017 0.0000
0.0025 0.0017 0.0025 0.0042 0.0025 0.0050 0.0067 0.0076 0.0185 0.0302 0.0235
0.0302 0.0285 0.0302 0.0865
2012 5 4 1 0 0 0 50 0.0000 0.0000 0.0003 0.0007 0.0013
0.0010 0.0047 0.0074 0.0114 0.0138 0.0225 0.0269 0.0316 0.0326 0.0376 0.0443
0.0376 0.0417 0.0343 0.1058
2013 5 4 1 0 0 0 50 0.0073 0.0097 0.0153 0.0253 0.0210
0.0185 0.0211 0.0215 0.0232 0.0264 0.0275 0.0327 0.0340 0.0303 0.0300 0.0265
0.0272 0.0256 0.0250 0.0798
2014 5 4 1 0 0 0 50 0.0019 0.0026 0.0040 0.0026 0.0033
0.0054 0.0089 0.0128 0.0121 0.0145 0.0191 0.0238 0.0285 0.0261 0.0233 0.0390
0.0289 0.0273 0.0250 0.1102
2015 5 4 1 0 0 0 50 0.0007 0.0011 0.0007 0.0022 0.0063
0.0098 0.0107 0.0130 0.0125 0.0192 0.0177 0.0170 0.0150 0.0143 0.0110 0.0076
0.0103 0.0083 0.0074 0.0262
2016 5 4 1 0 0 0 50 0.0018 0.0032 0.0062 0.0090 0.0192
0.0210 0.0240 0.0291 0.0261 0.0229 0.0247 0.0189 0.0155 0.0118 0.0127 0.0132
0.0159 0.0127 0.0134 0.0430
2017 5 4 1 0 0 0 50 0.0000 0.0014 0.0000 0.0071 0.0141
0.0148 0.0163 0.0120 0.0071 0.0163 0.0085 0.0120 0.0078 0.0141 0.0113 0.0092
0.0148 0.0141 0.0205 0.0961
2018 5 4 1 0 0 0 50 0.0009 0.0021 0.0040 0.0081 0.0045
0.0126 0.0241 0.0396 0.0406 0.0475 0.0390 0.0258 0.0204 0.0206 0.0207 0.0181
0.0153 0.0141 0.0164 0.0507
2019 5 4 1 0 0 0 43.1 0.0000 0.0023 0.0046 0.0104 0.0186
0.0197 0.0255 0.0209 0.0209 0.0197 0.0070 0.0139 0.0139 0.0139 0.0058 0.0035
0.0058 0.0012 0.0000 0.0046

Fixed gear crab bycatch female
#Year Season Fleet Sex Type Shell Maturity Nsamp DataVec
ERROR CHECK
1996 5 4 2 0 0 0 0 0.0066 0.0013 0.0053 0.0040 0.0159
0.0079 0.0238 0.0423 0.0556 0.0860 0.1270 0.1230 0.0847 0.0741 0.0556 0.0913
1997 5 4 2 0 0 0 0 0.0000 0.0000 0.0008 0.0008 0.0047
0.0126 0.0299 0.0260 0.0339 0.0252 0.0165 0.0126 0.0071 0.0071 0.0079 0.0229
1998 5 4 2 0 0 0 0 0.0000 0.0000 0.0010 0.0000 0.0000
0.0000 0.0068 0.0251 0.0309 0.0193 0.0203 0.0097 0.0058 0.0106 0.0174 0.0502
1999 5 4 2 0 0 0 0 0.0000 0.0000 0.0000 0.0000 0.0000

		0.0000	0.0000	0.0000	0.0031	0.0075	0.0131	0.0194	0.0256	0.0237	0.0137	0.0549
2000	5	4	2	0	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000
		0.0017	0.0017	0.0102	0.0152	0.0237	0.0508	0.0440	0.0423	0.0321	0.0321	0.0897
2001	5	4	2	0	0	0	0	0.0004	0.0002	0.0000	0.0016	0.0028
		0.0066	0.0127	0.0195	0.0177	0.0205	0.0441	0.0787	0.0678	0.0380	0.0266	0.0777
2002	5	4	2	0	0	0	0	0.0000	0.0003	0.0009	0.0000	0.0000
		0.0006	0.0000	0.0029	0.0060	0.0106	0.0086	0.0226	0.0340	0.0348	0.0354	0.0876
2003	5	4	2	0	0	0	0	0.0011	0.0005	0.0011	0.0101	0.0197
		0.0155	0.0096	0.0069	0.0149	0.0240	0.0331	0.0336	0.0341	0.0443	0.0427	0.0837
2004	5	4	2	0	0	0	0	0.0005	0.0005	0.0023	0.0032	0.0055
		0.0114	0.0173	0.0328	0.0292	0.0282	0.0474	0.0483	0.0456	0.0428	0.0374	0.0811
2005	5	4	2	0	0	0	0	0.0000	0.0000	0.0000	0.0005	0.0005
		0.0023	0.0056	0.0149	0.0322	0.0503	0.0499	0.0517	0.0718	0.0555	0.0499	0.1174
2006	5	4	2	0	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0011
		0.0016	0.0122	0.0371	0.0736	0.1128	0.1053	0.0969	0.0667	0.0492	0.0392	0.0979
2007	5	4	2	0	0	0	0	0.0000	0.0012	0.0012	0.0012	0.0025
		0.0074	0.0099	0.0321	0.0432	0.0827	0.1173	0.1086	0.0704	0.0420	0.0222	0.0383
2008	5	4	2	0	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000
		0.0043	0.0120	0.0198	0.0438	0.0335	0.0576	0.0653	0.0730	0.0490	0.0301	0.0644
2009	5	4	2	0	0	0	0	0.0000	0.0000	0.0000	0.0000	0.0000
		0.0028	0.0147	0.0184	0.0220	0.0294	0.0340	0.0312	0.0487	0.0395	0.0239	0.0652
2010	5	4	2	0	0	0	0	0.0000	0.0000	0.0000	0.0036	0.0036
		0.0036	0.0109	0.0201	0.0657	0.0657	0.0912	0.1058	0.1077	0.0620	0.0584	0.1241
2011	5	4	2	0	0	0	0	0.0000	0.0025	0.0008	0.0067	0.0076
		0.0176	0.0202	0.0336	0.0579	0.0663	0.0999	0.0907	0.0739	0.0638	0.0428	0.1327
2012	5	4	2	0	0	0	0	0.0000	0.0000	0.0010	0.0027	0.0020
		0.0104	0.0215	0.0262	0.0339	0.0346	0.0339	0.0571	0.0668	0.0648	0.0658	0.1236
2013	5	4	2	0	0	0	0	0.0056	0.0108	0.0224	0.0266	0.0243
		0.0245	0.0249	0.0316	0.0354	0.0272	0.0251	0.0241	0.0296	0.0412	0.0334	0.0853
2014	5	4	2	0	0	0	0	0.0023	0.0061	0.0049	0.0014	0.0042
		0.0056	0.0084	0.0229	0.0422	0.0537	0.0497	0.0502	0.0511	0.0560	0.0597	0.1624
2015	5	4	2	0	0	0	0	0.0002	0.0002	0.0002	0.0045	0.0072
		0.0132	0.0228	0.0512	0.0745	0.0879	0.1082	0.1064	0.0767	0.0557	0.0586	0.1216
2016	5	4	2	0	0	0	0	0.0037	0.0028	0.0044	0.0162	0.0245
		0.0208	0.0231	0.0370	0.0499	0.0695	0.0931	0.0845	0.0640	0.0464	0.0342	0.0815
2017	5	4	2	0	0	0	0	0.0007	0.0007	0.0021	0.0127	0.0155
		0.0261	0.0184	0.0184	0.0240	0.0382	0.0615	0.0912	0.0876	0.1110	0.0671	0.1272
2018	5	4	2	0	0	0	0	0.0006	0.0040	0.0026	0.0049	0.0066
		0.0164	0.0349	0.0621	0.0592	0.0605	0.0573	0.0711	0.0654	0.0507	0.0366	0.0417
2019	5	4	2	0	0	0	0	0.0000	0.0000	0.0012	0.0104	0.0174
		0.0313	0.0290	0.0406	0.0789	0.0824	0.0789	0.0719	0.0638	0.0708	0.0650	0.1462

```
#NMFS		males	combined
#Year	Season	Fleet	Sex	Type	Shell	Maturity		Nsamp	DataVec
1975	1	5	1	0.000	0	0	200	0.0222	0.0411	0.0299	0.0379	0.0342
		0.0299	0.0309	0.0246	0.0264	0.0314	0.0268	0.0292	0.0284	0.0273	0.0244	0.0270
		0.0183	0.0134	0.0097	0.0113
1976	1	5	1	0.000	0	0	200	0.0025	0.0127	0.0268	0.0503	0.0623
		0.0522	0.0559	0.0449	0.0392	0.0329	0.0409	0.0438	0.0369	0.0392	0.0335	0.0221
		0.0236	0.0154	0.0070	0.0077
1977	1	5	1	0.000	0	0	200	0.0040	0.0043	0.0065	0.0102	0.0199
		0.0376	0.0453	0.0441	0.0414	0.0450	0.0409	0.0409	0.0311	0.0324	0.0322	0.0259
		0.0166	0.0140	0.0084	0.0121
1978	1	5	1	0.000	0	0	200	0.0043	0.0120	0.0136	0.0240	0.0172
		0.0191	0.0178	0.0279	0.0296	0.0297	0.0300	0.0304	0.0291	0.0367	0.0346	0.0283
		0.0260	0.0173	0.0108	0.0091
1979	1	5	1	0.000	0	0	200	0.0206	0.0154	0.0103	0.0123	0.0144
		0.0163	0.0137	0.0155	0.0164	0.0157	0.0235	0.0338	0.0333	0.0432	0.0415	0.0378
		0.0359	0.0298	0.0136	0.0235
1980	1	5	1	0.000	0	0	200	0.0067	0.0133	0.0376	0.0287	0.0295
		0.0296	0.0265	0.0262	0.0224	0.0192	0.0208	0.0165	0.0231	0.0251	0.0264	0.0378
		0.0266	0.0268	0.0216	0.0357
1981	1	5	1	0.000	0	0	200	0.0160	0.0113	0.0182	0.0240	0.0366
		0.0362	0.0331	0.0367	0.0291	0.0356	0.0261	0.0285	0.0194	0.0221	0.0156	0.0145
		0.0112	0.0106	0.0085	0.0176
1982	1	5	1	0.000	0	0	200	0.0792	0.0811	0.0682	0.0287	0.0240
		0.0310	0.0353	0.0287	0.0197	0.0171	0.0198	0.0141	0.0131	0.0079	0.0066	0.0043
		0.0039	0.0005	0.0004	0.0018
1983	1	5	1	0.000	0	0	200	0.0325	0.0356	0.0497	0.0665	0.0801
		0.0783	0.0598	0.0468	0.0402	0.0398	0.0320	0.0309	0.0190	0.0119	0.0107	0.0037
		0.0025	0.0012	0.0000	0.0000
1984	1	5	1	0.000	0	0	200	0.0161	0.0626	0.1229	0.1327	0.0682
		0.0389	0.0206	0.0202	0.0208	0.0154	0.0119	0.0072	0.0063	0.0050	0.0065	0.0021
		0.0009	0.0009	0.0001	0.0003
1985	1	5	1	0.000	0	0	200	0.0026	0.0128	0.0244	0.0395	0.0589
		0.0582	0.0424	0.0403	0.0602	0.0614	0.0513	0.0523	0.0497	0.0418	0.0279	0.0237
		0.0018	0.0051	0.0042	0.0000
1986	1	5	1	0.000	0	0	200	0.0112	0.0179	0.0248	0.0201	0.0232
		0.0156	0.0408	0.0400	0.0559	0.0485	0.0675	0.0734	0.0700	0.0788	0.0563	0.0385
		0.0275	0.0073	0.0029	0.0023
1987	1	5	1	0.000	0	0	200	0.0012	0.0071	0.0340	0.0546	0.0469
		0.0317	0.0290	0.0291	0.0310	0.0253	0.0332	0.0270	0.0363	0.0345	0.0290	0.0284
		0.0183	0.0154	0.0038	0.0039
1988	1	5	1	0.000	0	0	200	0.0013	0.0013	0.0066	0.0110	0.0133
		0.0215	0.0469	0.0430	0.0405	0.0374	0.0262	0.0308	0.0210	0.0371	0.0331	0.0495
		0.0368	0.0268	0.0094	0.0093
1989	1	5	1	0.000	0	0	200	0.0017	0.0000	0.0009	0.0024	0.0149
		0.0348	0.0184	0.0376	0.0232	0.0412	0.0288	0.0253	0.0450	0.0523	0.0535	0.0665
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		0.0483	0.0466	0.0283	0.0278							
1990	1	5	1	0.000	0	0	200	0.0013	0.0106	0.0151	0.0348	0.0329
		0.0094	0.0080	0.0084	0.0182	0.0296	0.0219	0.0298	0.0341	0.0401	0.0369	0.0382
		0.0299	0.0344	0.0196	0.0342							
1991	1	5	1	0.000	0	0	200	0.0011	0.0090	0.0224	0.0168	0.0265
		0.0217	0.0137	0.0274	0.0221	0.0172	0.0053	0.0198	0.0347	0.0364	0.0588	0.0674
		0.0658	0.0482	0.0369	0.0757							
1992	1	5	1	0.000	0	0	200	0.0010	0.0000	0.0020	0.0127	0.0252
		0.0355	0.0552	0.0528	0.0382	0.0399	0.0291	0.0378	0.0348	0.0280	0.0234	0.0233
		0.0219	0.0307	0.0169	0.0496							
1993	1	5	1	0.000	0	0	200	0.0021	0.0110	0.0137	0.0105	0.0095
		0.0157	0.0142	0.0235	0.0309	0.0443	0.0417	0.0627	0.0479	0.0390	0.0371	0.0269
		0.0288	0.0298	0.0242	0.0411							
1994	1	5	1	0.000	0	0	163.75	0.0016	0.0000	0.0031	0.0237	0.0235
		0.0152	0.0124	0.0173	0.0213	0.0354	0.0412	0.0403	0.0627	0.0907	0.0474	0.0461
		0.0468	0.0327	0.0229	0.0504							
1995	1	5	1	0.000	0	0	200	0.0283	0.0683	0.0557	0.0220	0.0110
		0.0169	0.0222	0.0255	0.0275	0.0305	0.0263	0.0268	0.0343	0.0402	0.0490	0.0433
		0.0323	0.0238	0.0108	0.0262							
1996	1	5	1	0.000	0	0	200	0.0278	0.0135	0.0298	0.0529	0.0632
		0.0594	0.0276	0.0225	0.0117	0.0179	0.0140	0.0150	0.0139	0.0130	0.0218	0.0165
		0.0190	0.0171	0.0183	0.0252							
1997	1	5	1	0.000	0	0	200	0.0000	0.0036	0.0022	0.0052	0.0127
		0.0564	0.0943	0.1070	0.0910	0.0515	0.0301	0.0162	0.0149	0.0132	0.0142	0.0168
		0.0234	0.0168	0.0173	0.0402							
1998	1	5	1	0.000	0	0	200	0.0209	0.0174	0.0103	0.0127	0.0120
		0.0101	0.0135	0.0169	0.0226	0.0467	0.0485	0.0523	0.0451	0.0291	0.0183	0.0153
		0.0196	0.0135	0.0080	0.0245							
1999	1	5	1	0.000	0	0	200	0.0583	0.0244	0.0134	0.0104	0.0120
		0.0110	0.0121	0.0148	0.0047	0.0132	0.0182	0.0233	0.0520	0.0536	0.0700	0.0688
		0.0435	0.0303	0.0221	0.0252							
2000	1	5	1	0.000	0	0	200	0.0018	0.0047	0.0195	0.0396	0.0310
		0.0200	0.0228	0.0163	0.0201	0.0147	0.0134	0.0296	0.0294	0.0489	0.0416	0.0360
		0.0343	0.0229	0.0085	0.0196							
2001	1	5	1	0.000	0	0	200	0.0069	0.0050	0.0106	0.0149	0.0156
		0.0421	0.0372	0.0523	0.0346	0.0200	0.0253	0.0166	0.0140	0.0202	0.0132	0.0112
		0.0219	0.0191	0.0192	0.0327							
2002	1	5	1	0.000	0	0	200	0.0534	0.0638	0.0436	0.0272	0.0119
		0.0091	0.0076	0.0106	0.0229	0.0266	0.0347	0.0290	0.0203	0.0252	0.0170	0.0193
		0.0195	0.0222	0.0242	0.0274							
2003	1	5	1	0.000	0	0	200	0.0149	0.0069	0.0142	0.0236	0.0392
		0.0320	0.0301	0.0165	0.0112	0.0143	0.0133	0.0251	0.0236	0.0386	0.0348	0.0364
		0.0254	0.0216	0.0212	0.0666							
2004	1	5	1	0.000	0	0	200	0.0371	0.0289	0.0268	0.0195	0.0187
		0.0187	0.0350	0.0535	0.0436	0.0445	0.0293	0.0238	0.0142	0.0150	0.0179	0.0232
		0.0240	0.0327	0.0232	0.0447							

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2005  1  5      1      0.000  0      0      200    0.0353 0.0586 0.0419 0.0160 0.0098
         0.0228 0.0234 0.0215 0.0184 0.0171 0.0219 0.0233 0.0159 0.0189 0.0125 0.0158
         0.0103 0.0155 0.0144 0.0252
2006  1  5      1      0.000  0      0      200    0.0133 0.0197 0.0173 0.0276 0.0291
         0.0369 0.0210 0.0208 0.0129 0.0188 0.0116 0.0128 0.0236 0.0205 0.0329 0.0280
         0.0271 0.0200 0.0144 0.0246
2007  1  5      1      0.000  0      0      200    0.0017 0.0025 0.0053 0.0084 0.0196
         0.0271 0.0345 0.0436 0.0386 0.0288 0.0187 0.0233 0.0236 0.0315 0.0273 0.0288
         0.0277 0.0262 0.0229 0.0290
2008  1  5      1      0.000  0      0      200    0.0000 0.0008 0.0038 0.0068 0.0149
         0.0188 0.0194 0.0239 0.0372 0.0470 0.0453 0.0328 0.0382 0.0317 0.0249 0.0226
         0.0242 0.0236 0.0222 0.0467
2009  1  5      1      0.000  0      0      200    0.0010 0.0005 0.0037 0.0053 0.0053
         0.0104 0.0096 0.0225 0.0330 0.0301 0.0315 0.0328 0.0363 0.0479 0.0312 0.0329
         0.0198 0.0163 0.0148 0.0169
2010  1  5      1      0.000  0      0      200    0.0000 0.0033 0.0080 0.0094 0.0077
         0.0054 0.0161 0.0134 0.0130 0.0153 0.0270 0.0363 0.0302 0.0325 0.0367 0.0348
         0.0423 0.0262 0.0145 0.0200
2011  1  5      1      0.000  0      0      200    0.0036 0.0044 0.0125 0.0204 0.0169
         0.0138 0.0168 0.0151 0.0182 0.0132 0.0181 0.0203 0.0161 0.0295 0.0275 0.0257
         0.0242 0.0204 0.0115 0.0165
2012  1  5      1      0.000  0      0      200    0.0025 0.0040 0.0120 0.0159 0.0128
         0.0227 0.0336 0.0247 0.0174 0.0174 0.0153 0.0196 0.0217 0.0264 0.0234 0.0209
         0.0232 0.0281 0.0132 0.0434
2013  1  5      1      0.000  0      0      200    0.0008 0.0025 0.0123 0.0145 0.0101
         0.0174 0.0134 0.0235 0.0280 0.0261 0.0323 0.0348 0.0303 0.0319 0.0344 0.0324
         0.0340 0.0431 0.0395 0.0749
2014  1  5      1      0.000  0      0      200    0.0000 0.0005 0.0026 0.0030 0.0160
         0.0313 0.0437 0.0348 0.0313 0.0192 0.0231 0.0326 0.0336 0.0309 0.0372 0.0258
         0.0224 0.0189 0.0180 0.0439
2015  1  5      1      0.000  0      0      200    0.0105 0.0207 0.0103 0.0093 0.0047
         0.0110 0.0158 0.0149 0.0244 0.0187 0.0285 0.0203 0.0235 0.0318 0.0240 0.0338
         0.0313 0.0282 0.0278 0.0796
2016  1  5      1      0.000  0      0      200    0.0066 0.0009 0.0026 0.0032 0.0041
         0.0043 0.0034 0.0083 0.0069 0.0129 0.0085 0.0145 0.0127 0.0254 0.0195 0.0213
         0.0241 0.0389 0.0324 0.0709
2017  1  5      1      0.000  0      0      200    0.0032 0.0011 0.0029 0.0095 0.0243
         0.0199 0.0135 0.0068 0.0083 0.0077 0.0086 0.0134 0.0064 0.0234 0.0150 0.0102
         0.0233 0.0363 0.0351 0.0868
2018  1  5      1      0.000  0      0      161    0.0051 0.0173 0.0173 0.0153 0.0093
         0.0161 0.0144 0.0174 0.0367 0.0160 0.0334 0.0210 0.0033 0.0160 0.0145 0.0338
         0.0262 0.0321 0.0272 0.0746
2019  1  5      1      0.000  0      0      143    0.0017 0.0036 0.0106 0.0071 0.0071
         0.0314 0.0157 0.0244 0.0231 0.0336 0.0299 0.0436 0.0424 0.0363 0.0319 0.0124
         0.0229 0.0230 0.0160 0.0602
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#NMFS		female										
#Year	Season	Fleet	Sex	Type	Shell	Maturity		Nsamp	DataVec			
1975	1	5	2	0.000	0	0	0	0.0331	0.0401	0.0481	0.0494	0.0564
		0.0439	0.0444	0.0454	0.0326	0.0289	0.0162	0.0158	0.0116	0.0035	0.0029	0.0034
1976	1	5	2	0.000	0	0	0	0.0029	0.0092	0.0313	0.0563	0.0688
		0.0628	0.0494	0.0269	0.0121	0.0137	0.0066	0.0049	0.0023	0.0015	0.0003	0.0011
1977	1	5	2	0.000	0	0	0	0.0026	0.0068	0.0079	0.0193	0.0337
		0.0701	0.0808	0.0715	0.0453	0.0435	0.0415	0.0316	0.0151	0.0100	0.0033	0.0046
1978	1	5	2	0.000	0	0	0	0.0060	0.0111	0.0187	0.0201	0.0233
		0.0418	0.0920	0.1212	0.0791	0.0440	0.0301	0.0267	0.0176	0.0089	0.0045	0.0075
1979	1	5	2	0.000	0	0	0	0.0286	0.0154	0.0121	0.0147	0.0148
		0.0230	0.0381	0.0734	0.0922	0.0876	0.0565	0.0336	0.0215	0.0123	0.0043	0.0057
1980	1	5	2	0.000	0	0	0	0.0048	0.0219	0.0322	0.0292	0.0597
		0.0820	0.0487	0.0581	0.0540	0.0424	0.0315	0.0130	0.0110	0.0059	0.0035	0.0020
1981	1	5	2	0.000	0	0	0	0.0152	0.0113	0.0151	0.0190	0.0366
		0.0456	0.0443	0.0472	0.0600	0.0774	0.0804	0.0510	0.0252	0.0143	0.0028	0.0042
1982	1	5	2	0.000	0	0	0	0.0536	0.0954	0.0603	0.0378	0.0423
		0.0482	0.0398	0.0232	0.0190	0.0257	0.0281	0.0203	0.0114	0.0063	0.0024	0.0009
1983	1	5	2	0.000	0	0	0	0.0174	0.0383	0.0475	0.0629	0.0647
		0.0398	0.0341	0.0152	0.0107	0.0042	0.0090	0.0056	0.0061	0.0022	0.0013	0.0000
1984	1	5	2	0.000	0	0	0	0.0174	0.0585	0.1229	0.1105	0.0647
		0.0325	0.0159	0.0119	0.0038	0.0017	0.0000	0.0004	0.0001	0.0002	0.0001	0.0000
1985	1	5	2	0.000	0	0	0	0.0009	0.0155	0.0377	0.0521	0.0643
		0.0555	0.0516	0.0397	0.0161	0.0068	0.0000	0.0000	0.0015	0.0000	0.0000	0.0000
1986	1	5	2	0.000	0	0	0	0.0124	0.0224	0.0355	0.0274	0.0263
		0.0313	0.0362	0.0388	0.0274	0.0113	0.0072	0.0008	0.0000	0.0000	0.0008	0.0000
1987	1	5	2	0.000	0	0	0	0.0013	0.0124	0.0525	0.0918	0.0761
		0.0462	0.0445	0.0569	0.0414	0.0292	0.0179	0.0079	0.0018	0.0004	0.0000	0.0000
1988	1	5	2	0.000	0	0	0	0.0006	0.0076	0.0064	0.0062	0.0139
		0.0695	0.0910	0.0979	0.0697	0.0600	0.0407	0.0184	0.0077	0.0077	0.0000	0.0000
1989	1	5	2	0.000	0	0	0	0.0017	0.0000	0.0017	0.0082	0.0310
		0.0740	0.0646	0.0692	0.0531	0.0376	0.0315	0.0194	0.0064	0.0041	0.0000	0.0000
1990	1	5	2	0.000	0	0	0	0.0041	0.0052	0.0235	0.0513	0.0525
		0.0071	0.0256	0.0601	0.0732	0.0708	0.0633	0.0410	0.0215	0.0062	0.0037	0.0037
1991	1	5	2	0.000	0	0	0	0.0042	0.0115	0.0196	0.0320	0.0218
		0.0344	0.0343	0.0310	0.0366	0.0329	0.0281	0.0431	0.0232	0.0110	0.0069	0.0027
1992	1	5	2	0.000	0	0	0	0.0000	0.0053	0.0074	0.0197	0.0364
		0.0414	0.0625	0.0448	0.0353	0.0273	0.0450	0.0407	0.0265	0.0212	0.0162	0.0122
1993	1	5	2	0.000	0	0	0	0.0066	0.0080	0.0175	0.0085	0.0131
		0.0248	0.0437	0.0647	0.0639	0.0269	0.0300	0.0268	0.0271	0.0445	0.0175	0.0219
1994	1	5	2	0.000	0	0	0	0.0000	0.0016	0.0044	0.0030	0.0169
		0.0092	0.0124	0.0213	0.0431	0.0416	0.0362	0.0280	0.0395	0.0469	0.0292	0.0321
1995	1	5	2	0.000	0	0	0	0.0294	0.0482	0.0316	0.0145	0.0139
		0.0182	0.0163	0.0254	0.0234	0.0334	0.0272	0.0234	0.0240	0.0145	0.0203	0.0155
1996	1	5	2	0.000	0	0	0	0.0260	0.0219	0.0436	0.0794	0.0796
		0.0436	0.0226	0.0218	0.0245	0.0202	0.0161	0.0285	0.0244	0.0156	0.0087	0.0236

1997	1	5	2	0.000	0	0	0	0.0004	0.0037	0.0016	0.0020	0.0146
		0.0791	0.0969	0.0616	0.0212	0.0137	0.0095	0.0146	0.0143	0.0109	0.0084	0.0208
1998	1	5	2	0.000	0	0	0	0.0145	0.0196	0.0101	0.0088	0.0111
		0.0116	0.0303	0.1040	0.1153	0.0594	0.0303	0.0252	0.0225	0.0235	0.0232	0.0336
1999	1	5	2	0.000	0	0	0	0.0243	0.0169	0.0125	0.0115	0.0044
		0.0055	0.0093	0.0164	0.0512	0.0800	0.0583	0.0358	0.0340	0.0199	0.0123	0.0268
2000	1	5	2	0.000	0	0	0	0.0018	0.0067	0.0269	0.0403	0.0357
		0.0272	0.0255	0.0226	0.0358	0.0524	0.0676	0.0603	0.0419	0.0208	0.0167	0.0433
2001	1	5	2	0.000	0	0	0	0.0056	0.0168	0.0195	0.0136	0.0259
		0.0598	0.0779	0.0579	0.0395	0.0398	0.0291	0.0691	0.0560	0.0262	0.0103	0.0205
2002	1	5	2	0.000	0	0	0	0.0506	0.0769	0.0485	0.0247	0.0222
		0.0176	0.0225	0.0520	0.0399	0.0296	0.0163	0.0206	0.0205	0.0221	0.0071	0.0136
2003	1	5	2	0.000	0	0	0	0.0163	0.0059	0.0143	0.0314	0.0414
		0.0464	0.0239	0.0292	0.0351	0.0533	0.0526	0.0356	0.0219	0.0265	0.0220	0.0349
2004	1	5	2	0.000	0	0	0	0.0279	0.0327	0.0194	0.0132	0.0199
		0.0369	0.0577	0.0514	0.0334	0.0204	0.0196	0.0232	0.0184	0.0166	0.0127	0.0225
2005	1	5	2	0.000	0	0	0	0.0405	0.0561	0.0457	0.0116	0.0099
		0.0336	0.0386	0.0521	0.0567	0.0468	0.0336	0.0383	0.0347	0.0227	0.0165	0.0246
2006	1	5	2	0.000	0	0	0	0.0143	0.0139	0.0198	0.0425	0.0615
		0.0462	0.0254	0.0259	0.0481	0.0656	0.0619	0.0415	0.0301	0.0352	0.0167	0.0186
2007	1	5	2	0.000	0	0	0	0.0015	0.0023	0.0064	0.0078	0.0155
		0.0356	0.0574	0.0560	0.0325	0.0570	0.0614	0.0641	0.0459	0.0343	0.0210	0.0323
2008	1	5	2	0.000	0	0	0	0.0000	0.0027	0.0054	0.0136	0.0116
		0.0167	0.0303	0.0570	0.0724	0.0560	0.0555	0.0562	0.0575	0.0355	0.0234	0.0216
2009	1	5	2	0.000	0	0	0	0.0005	0.0019	0.0050	0.0055	0.0081
		0.0122	0.0206	0.0466	0.0656	0.0866	0.0645	0.0603	0.0523	0.0705	0.0514	0.0470
2010	1	5	2	0.000	0	0	0	0.0018	0.0006	0.0037	0.0048	0.0069
		0.0116	0.0213	0.0365	0.0565	0.0927	0.0955	0.0700	0.0509	0.0497	0.0508	0.0545
2011	1	5	2	0.000	0	0	0	0.0058	0.0085	0.0092	0.0141	0.0284
		0.0310	0.0384	0.0484	0.0299	0.0530	0.0637	0.0905	0.0635	0.0571	0.0430	0.0710
2012	1	5	2	0.000	0	0	0	0.0293	0.0180	0.0191	0.0250	0.0281
		0.0461	0.0351	0.0220	0.0331	0.0355	0.0365	0.0461	0.0663	0.0521	0.0462	0.0633
2013	1	5	2	0.000	0	0	0	0.0008	0.0027	0.0093	0.0112	0.0067
		0.0125	0.0202	0.0384	0.0429	0.0450	0.0304	0.0302	0.0455	0.0491	0.0405	0.0786
2014	1	5	2	0.000	0	0	0	0.0000	0.0000	0.0012	0.0040	0.0091
		0.0258	0.0219	0.0320	0.0499	0.0770	0.0569	0.0456	0.0307	0.0399	0.0516	0.0859
2015	1	5	2	0.000	0	0	0	0.0074	0.0129	0.0110	0.0055	0.0120
		0.0114	0.0107	0.0234	0.0408	0.0461	0.0616	0.0668	0.0531	0.0503	0.0362	0.0819
2016	1	5	2	0.000	0	0	0	0.0120	0.0019	0.0036	0.0043	0.0026
		0.0051	0.0143	0.0141	0.0390	0.0714	0.0782	0.1023	0.0737	0.0823	0.0617	0.1158
2017	1	5	2	0.000	0	0	0	0.0010	0.0028	0.0030	0.0126	0.0258
		0.0248	0.0167	0.0188	0.0214	0.0511	0.0665	0.0804	0.0885	0.0769	0.0569	0.0973
2018	1	5	2	0.000	0	0	0	0.0031	0.0109	0.0172	0.0186	0.0094
		0.0198	0.0516	0.0362	0.0421	0.0296	0.0254	0.0652	0.0462	0.0495	0.0509	0.0773
2019	1	5	2	0.000	0	0	0	0.0017	0.0105	0.0018	0.0070	0.0070
		0.0140	0.0143	0.0174	0.0312	0.0355	0.0335	0.0279	0.0515	0.0766	0.0656	0.1276

#BSFRF		males										
#Year	Season	Fleet	Sex	Type	Shell	Maturity		Nsamp	DataVec			
2007	1	6	1	0	0	0	200	0.0045	0.0074	0.0103	0.0155	0.0198
		0.0321	0.0532	0.0491	0.0443	0.0354	0.0268	0.0231	0.0236	0.0256	0.0223	0.032
		0.0246	0.0218	0.017	0.0278							
2008	1	6	1	0	0	0	200	0.0017	0.001	0.0093	0.0119	0.0175
		0.0279	0.0267	0.0348	0.0428	0.0596	0.0581	0.0455	0.0371	0.0284	0.0218	0.0211
		0.0156	0.0157	0.0202	0.0294							
2013	1	6	1	0	0	0	75.75	0	0.0073	0.0145	0.0291	0.0102
		0.0136	0.0205	0.0341	0.0357	0.0458	0.0448	0.0383	0.042	0.0348	0.0206	0.0149
		0.0337	0.0426	0.0358	0.0986							
2014	1	6	1	0	0	0	105.75	0	0	0.003	0.0101	0.0118
		0.0448	0.0546	0.0423	0.047	0.0164	0.0221	0.0321	0.0226	0.0369	0.022	0.0282
		0.0257	0.026	0.0116	0.039							
2015	1	6	1	0	0	0	98.75	0.0208	0.0463	0.037	0.0162	0.0069
		0.0162	0.0119	0.0174	0.0355	0.0206	0.0274	0.0357	0.0228	0.0262	0.0131	0.0428
		0.0215	0.0327	0.0396	0.0627							
2016	1	6	1	0	0	0	73.5	0.0138	0.0039	0.02	0.0193	0.0104
		0.0122	0.0064	0.0126	0.0062	0.0034	0.0068	0.0134	0.0204	0.01	0.011	0.0254
		0.023	0.0215	0.0249	0.0774							

#BSFRF		females										
#Year	Season	Fleet	Sex	Type	Shell	Maturity		Nsamp	DataVec			
2007	1	6	2	0	0	0	000	0.0007	0.0016	0.0044	0.0198	0.0302
		0.0705	0.0563	0.0345	0.0364	0.0493	0.0501	0.0448	0.0272	0.0183	0.0152	0.0243
2008	1	6	2	0	0	0	000	0.0004	0.0013	0.0088	0.0142	0.0286
		0.0483	0.0754	0.0687	0.0463	0.0386	0.0411	0.0357	0.021	0.0179	0.0126	0.015
2013	1	6	2	0	0	0	000	0.0035	0	0.0191	0.0258	0.0176
		0.0105	0.0094	0.0407	0.024	0.0291	0.0308	0.0216	0.0232	0.0403	0.0392	0.0483
2014	1	6	2	0	0	0	000	0	0.0037	0.0071	0.0037	0.014
		0.031	0.0238	0.0415	0.0457	0.0708	0.0481	0.0279	0.0385	0.0448	0.0324	0.0707
2015	1	6	2	0	0	0	000	0.0116	0.0324	0.0231	0.0069	0.0153
		0.0112	0.0042	0.0231	0.0361	0.0358	0.0427	0.0364	0.0528	0.0366	0.0208	0.0575
2016	1	6	2	0	0	0	000	0.0039	0.0178	0.0039	0.0263	0.003
		0.0124	0.0096	0.0168	0.0422	0.0514	0.0826	0.1077	0.072	0.078	0.0429	0.1016

Growth data
Type of growth increment (1=growth increment with a CV;2=size-at-release; size-at)
0
nobs_growth
0
Note SM used loewss regression for males BBRKC data
and cubic spine to interpolate 3 sets of female BBRK data
MidPoint Sex Increment CV
#67.5 2 14.766667 1000000000000000000000
MidPoint Sex MidPoint Time-at-liberty Size-trans matrix Number of points
Release Recapture
eof
9999

Appendix C. Control File for Model 19.3

```
## ——————————————————————————————————————————————————— ##
## LEADING PARAMETER CONTROLS                                          ##
##     Controls for leading parameter vector (theta)                   ##
## LEGEND                                                  ##
##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma          ##
## ——————————————————————————————————————————————————— ##
## ntheta
  91
## ——————————————————————————————————————————————————— ##
## ival       lb       ub       phz   prior    p1      p2        # parameter       ##
## ——————————————————————————————————————————————————— ##
   0.18       0.15    0.2       -4      2    0.18    0.04       # M
  # 0.18       0.15    0.4        4      2    0.18    0.03       # M
   0.0       -0.4     0.4        4      1    0.0     0.03       # M
  16.5      -10       18        -2      0  -10.0    20.0       # logR0
  19.5      -10       25         3      0   10.0    25.0       # logRini, to estimate if NOT initialized at unfished (n68)
  16.5      -10       25         1      0   10.0    20.0   #1     # logRbar, to estimate if NOT initialized at unfished      #1
  72.5       55      100        -4      1   72.5    7.25       # recruitment expected value (males or combined)
   0.726149   0.32    1.64       3      0    0.1     5.0       # recruitment scale (variance component) (males or combined)
   0.00      -5        5        -4      0    0.0    20.00      # recruitment expected value (females)
   0.00      -1.69     0.40      3      0    0.0    20.0       # recruitment scale (variance component) (females)
  -0.10536    -10       0.75     -4      0  -10.0     0.75       # ln(sigma_R)
  #-0.10       -5        5.0      4      0  -10.0    10.0       # ln(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
#   0.00      -10        4        2      0   10.0    20.00       # Deviation for size-class 1 (normalization class)
   1.107962885630     -10      4      9     0   10.0    20.00      # Deviation for size-class 2
   0.563229168219     -10      4      9     0   10.0    20.00      # Deviation for size-class 3
   0.681928313426     -10      4      9     0   10.0    20.00      # Deviation for size-class 4
   0.491057364532     -10      4      9     0   10.0    20.00      # Deviation for size-class 5
   0.407911777560     -10      4      9     0   10.0    20.00      # Deviation for size-class 6
   0.436516142684     -10      4      9     0   10.0    20.00      # Deviation for size-class 7
   0.40612675395550    -10      4      9     0   10.0    20.00      # Deviation for size-class 8
   0.436145974880     -10      4      9     0   10.0    20.00      # Deviation for size-class 9
   0.40494522852708    -10      4      9     0   10.0    20.00      # Deviation for size-class 10
   0.30401970466854    -10      4      9     0   10.0    20.00      # Deviation for size-class 11
   0.2973752673022    -10      4      9     0   10.0    20.00      # Deviation for size-class 12
   0.1746800712364  -10      4      9     0   10.0    20.00      # Deviation for size-class 13
   0.0845298456942    -10      4      9     0   10.0    20.00      # Deviation for size-class 14
   0.0107462399193    -10      4      9     0   10.0    20.00      # Deviation for size-class 15
   -0.190468322904    -10      4      9     0   10.0    20.00      # Deviation for size-class 16
   -0.376312503735    -10      4      9     0   10.0    20.00      # Deviation for size-class 17
   -0.699162895473    -10      4      9     0   10.0    20.00      # Deviation for size-class 18
   -1.15881771530     -10      4      9     0   10.0    20.00      # Deviation for size-class 19
   -1.17311583316     -10      4      9     0   10.0    20.00      # Deviation for size-class 20
 -100.00     -101      5      -2     0   10.0    20.00      # Deviation for size-class 1
 -100.00     -101      5      -2     0   10.0    20.00      # Deviation for size-class 2
 -100.00     -101      5      -2     0   10.0    20.00      # Deviation for size-class 3
 -100.00     -101      5      -2     0   10.0    20.00      # Deviation for size-class 4
 -100.00     -101      5      -2     0   10.0    20.00      # Deviation for size-class 5
 -100.00     -101      5      -2     0   10.0    20.00      # Deviation for size-class 6
 -100.00     -101      5      -2     0   10.0    20.00      # Deviation for size-class 7
 -100.00     -101      5      -2     0   10.0    20.00      # Deviation for size-class 8
```

```
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 9
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 10
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 11
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 12
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 13
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 14
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 15
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 16
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 17
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 18
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 19
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 20
   0.425704202053    -10   4   9   0  10.0   20.00   # Deviation for size-class 1
   2.268408592660    -10   4   9   0  10.0   20.00   # Deviation for size-class 2
   1.810451373080    -10   4   9   0  10.0   20.00   # Deviation for size-class 3
   1.37035725111     -10   4   9   0  10.0   20.00   # Deviation for size-class 4
   1.158258087990    -10   4   9   0  10.0   20.00   # Deviation for size-class 5
   0.596196784439    -10   4   9   0  10.0   20.00   # Deviation for size-class 6
   0.225756761257    -10   4   9   0  10.0   20.00   # Deviation for size-class 7
   -0.0247857565368  -10   4   9   0  10.0   20.00   # Deviation for size-class 8
   -0.214045895269   -10   4   9   0  10.0   20.00   # Deviation for size-class 9
   -0.560539577780   -10   4   9   0  10.0   20.00   # Deviation for size-class 10
   -0.974218300021   -10   4   9   0  10.0   20.00   # Deviation for size-class 11
   -1.24580072031    -10   4   9   0  10.0   20.00   # Deviation for size-class 12
   -1.49292897450    -10   4   9   0  10.0   20.00   # Deviation for size-class 13
   -1.94135821253    -10   4   9   0  10.0   20.00   # Deviation for size-class 14
   -2.05101560679    -10   4   9   0  10.0   20.00   # Deviation for size-class 15
   -1.94956606430    -10   4   9   0  10.0   20.00   # Deviation for size-class 16
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 17
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 18
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 19
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 20
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 1
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 2
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 3
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 4
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 5
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 6
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 7
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 8
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 9
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 10
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 11
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 12
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 13
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 14
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 15
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 16
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 17
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 18
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 19
-100.00   -101   5   -2   0  10.0   20.00   # Deviation for size-class 20

#     weight-at-length input   method  (1 = allometry   [w_l = a*l^b],   2 = vector by sex)
2
##    Males
```

0.000224781 0.000281351 0.000346923 0.000422209 0.000507927 0.000604802
0.000713564 0.00083495 0.0009697 0.00111856 0.00128229 0.00146163
0.00165736 0.00187023 0.00210101 0.00235048 0.00261942 0.00290861
0.00321882 0.0039059
Females

0.0002151 0.00026898 0.00033137 0.00040294 0.00048437 0.00062711 0.0007216
0.00082452 0.00093615 0.00105678 0.00118669 0.00132613 0.00147539
0.00163473 0.00180441 0.00218315 0.00218315 0.00218315 0.00218315
0.0021831
Proportion mature by sex
0 0 0 0 0 0 0 0 0 0 0 1 1
1 1 1 1 1 1 1
0 0 0 0 0 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1
Proportion legal by sex
0 0 0 0 0 0 0 0 0 0 0 1 1
1 1 1 1 1 1 1
0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0
————————————————————————————————

————————————————————————————————
GROWTH PARAMETER CONTROLS
Two lines for each parameter if split sex, one line if not
————————————————————————————————
Use growth transition matrix option (1=read in growth-increment matrix; 2=read in size-transition; 3=gamma distribution for size-increment; 4=gamma distribution for size after increment)
3
growth increment model (1=alpha/beta; 2=estimated by size-class;3=pre-specified/emprical)
3
molt probability function (0=pre-specified; 1=flat;2=declining logistic)
2
Maximum size-class for recruitment(males then females)
7 5
number of size-increment periods
1 3
Year(s) size-incremnt period changes (blank if no changes)
1983 1994
number of molt periods
2 2
Year(s) molt period changes (blank if no changes)
1980 1980
Beta parameters are relative (1=Yes;0=no)
1
————————————————————————————————
ival lb ub phz prior p1 p2 # parameter
————————————————————————————————
16.5 0 20 -33 0 0 999 # Males
16.5 0 20 -33 0 0 999 # Males
16.4 0 20 -33 0 0 999 # Males
16.3 0 20 -33 0 0 999 # Males
16.3 0 20 -33 0 0 999 # Males
16.2 0 20 -33 0 0 999 # Males

16.2	0	20	-33	0	0	999	# Males
16.1	0	20	-33	0	0	999	# Males
16.1	0	20	-33	0	0	999	# Males
16	0	20	-33	0	0	999	# Males
16	0	20	-33	0	0	999	# Males
15.9	0	20	-33	0	0	999	# Males
15.8	0	20	-33	0	0	999	# Males
15.8	0	20	-33	0	0	999	# Males
15.7	0	20	-33	0	0	999	# Males
15.7	0	20	-33	0	0	999	# Males
15.6	0	20	-33	0	0	999	# Males
15.6	0	20	-33	0	0	999	# Males
15.5	0	20	-33	0	0	999	# Males
15.5	0	20	-33	0	0	999	# Males
#1.38403	0.5	3.7	7	0	0	999	# Males (beta)
1.0	0.5	3.0	6	0	0	999	# Males (beta)
13.8	0	20	-33	0	0	999	# Females
12.2	0	20	-33	0	0	999	# Females
10.5	0	20	-33	0	0	999	# Females
8.4	0	20	-33	0	0	999	# Females
7.5	0	20	-33	0	0	999	# Females
7	0	20	-33	0	0	999	# Females
6.6	0	20	-33	0	0	999	# Females
6.1	0	20	-33	0	0	999	# Females
5.6	0	20	-33	0	0	999	# Females
5.1	0	20	-33	0	0	999	# Females
4.6	0	20	-33	0	0	999	# Females
4.1	0	20	-33	0	0	999	# Females
3.6	0	20	-33	0	0	999	# Females
3.2	0	20	-33	0	0	999	# Females
2.7	0	20	-33	0	0	999	# Females
2.2	0	20	-33	0	0	999	# Females
1.7	0	20	-33	0	0	999	# Females
1.2	0	20	-33	0	0	999	# Females
0.7	0	20	-33	0	0	999	# Females
0.4	0	20	-33	0	0	999	# Females
#1.38403	0.5	3.0	7	0	0	999	# Females (beta)
1.5	0.5	3.0	6	0	0	999	# Females (beta)
15.4	0	20	-33	0	0	999	# Females
13.8	0	20	-33	0	0	999	# Females
12.2	0	20	-33	0	0	999	# Females
10.5	0	20	-33	0	0	999	# Females
8.9	0	20	-33	0	0	999	# Females
7.9	0	20	-33	0	0	999	# Females
7.2	0	20	-33	0	0	999	# Females
6.6	0	20	-33	0	0	999	# Females
6.1	0	20	-33	0	0	999	# Females
5.6	0	20	-33	0	0	999	# Females
5.1	0	20	-33	0	0	999	# Females
4.6	0	20	-33	0	0	999	# Females
4.1	0	20	-33	0	0	999	# Females
3.6	0	20	-33	0	0	999	# Females
3.2	0	20	-33	0	0	999	# Females
2.7	0	20	-33	0	0	999	# Females
2.2	0	20	-33	0	0	999	# Females
1.7	0	20	-33	0	0	999	# Females

```
1.2        0    20    -33    0    0    999          # Females
0.7        0    20    -33    0    0    999          # Females
0.0   -1.0 1.0    -7    0    0    999          # Females (beta)
#1.38403   0.5  3.7    -7    0    0    999          # Females (beta)
15.1       0    20    -33    0    0    999          # Females
14         0    20    -33    0    0    999          # Females
12.9       0    20    -33    0    0    999          # Females
11.8       0    20    -33    0    0    999          # Females
10.6       0    20    -33    0    0    999          # Females
8.7        0    20    -33    0    0    999          # Females
7.4        0    20    -33    0    0    999          # Females
6.6        0    20    -33    0    0    999          # Females
6.1        0    20    -33    0    0    999          # Females
5.6        0    20    -33    0    0    999          # Females
5.1        0    20    -33    0    0    999          # Females
4.6        0    20    -33    0    0    999          # Females
4.1        0    20    -33    0    0    999          # Females
3.6        0    20    -33    0    0    999          # Females
3.2        0    20    -33    0    0    999          # Females
2.7        0    20    -33    0    0    999          # Females
2.2        0    20    -33    0    0    999          # Females
1.7        0    20    -33    0    0    999          # Females
1.2        0    20    -33    0    0    999          # Females
0.7        0    20    -33    0    0    999          # Females
0.0   -1.0 1.0    -7    0    0    999          # Females (beta)
#1.38403   0.5  3.7    -7    0    0    999          # Females (beta)
## ——————————————————————————————————————————— ##

## ——————————————————————————————————————————— ##
## MOLTING PROBABILITY CONTROLS                              ##
##    Two lines for each parameter if split sex, one line if not       ##
## ——————————————————————————————————————————— ##
## ival     lb      ub     phz   prior    p1     p2       # parameter              ##
## ——————————————————————————————————————————— ##
## males and combined
  145.0386    100.    500.0     3     0   0.0    999.0       # molt_mu males
    0.053036    0.02    2.0     3     0   0.0    999.0     # molt_cv males
  145.0386    100.    500.0     3     0   0.0    999.0       # molt_mu males
    0.053036    0.02    2.0     3     0   0.0    999.0     # molt_cv males
## females
  300.0000     5.    500.0    -4     0   0.0    999.0      # molt_mu females (molt every year)
    0.01       0.001   9.0    -4     0   0.0    999.0     # molt_cv females (molt every year)
  300.0000     5.    500.0    -4     0   0.0    999.0      # molt_mu females (molt every year)
    0.01       0.001   9.0    -4     0   0.0    999.0     # molt_cv females (molt every year)
## ——————————————————————————————————————————— ##
# The custom growth-increment matrix
# custom molt probability matrix

## ——————————————————————————————————————————— ##
## SELECTIVITY CONTROLS                                        ##
##    Selectivity P(capture of all sizes). 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 (NIY), 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                       ##
## ———————————————————————————————————————————————————————————————————— ##
## Gear-1   Gear-2   Gear-3   Gear-4   Gear-5   Gear-6
## PotFshry TrawlByc TCFshry  FixedGr  NMFS     BSFRF
   1     1     1     1     2     1       # selectivity periods
   1     0     1     0     1     1       # sex specific selectivity
  # 9     2     2     2     2     2       # male selectivity type
   2     2     2     2     2     2       # male selectivity type
   2     2     2     2     2     2       # female selectivity type
   0     0     0     0     6     0  #6     # within another gear
  # 5     0     0     0     0     0       #-NEW: extra parameters for each pattern by fleet, males
   0     0     0     0     0     0       #-NEW: extra parameters for each pattern by fleet, males
   0     0     0     0     0     0       #-NEW: extra parameters for each pattern by fleet, females
## Gear-1   Gear-2   Gear-3   Gear-4   Gear-5   Gear-6
   2     1     1     1     1     1       # retention periods
   1     0     0     0     0     0       # sex specific retention
   2     6     6     6     6     6       # male   retention type
   6     6     6     6     6     6       # female retention type
   1     0     0     0     0     0       # male   retention flag (0 = no, 1 = yes)
   0     0     0     0     0     0       # female retention flag (0 = no, 1 = yes)
   0     0     0     0     0     0       #-NEW: extra parameters for each pattern by fleet, males
   0     0     0     0     0     0       #-NEW: extra parameters for each pattern by fleet, females

## ———————————————————————————————————————————————————————————————————— ##
## gear  par   sel                                   start  end        ##
## index index par sex  ival  lb    ub    prior  p1   p2    phz   period period      ##
## ———————————————————————————————————————————————————————————————————— ##
  # Gear-1
  1    1   1   1    125.0000    5   190    0     1    999    4     1975   2019  #4
  1    2   2   1     8.0     0.1   20    0     1    999    4     1975   2019  #4
 # Gear-1
#  1    1   1   1     67.5     0   200    0     1    999   -999    1975   2018  #4        #parameters for cubic spine
#  1    2   2   1     87.5     0   200    0     1    999   -999    1975   2018  #4
#  1    3   3   1     97.5     0   200    0     1    999   -999    1975   2018  #4
#  1    4   4   1     112.5     0   200    0     1    999   -999    1975   2018  #4
#  1    5   5   1     162.5     0   200    0     1    999   -999    1975   2018  #4
#  1    6   6   1     0.001      0.00001  0.99999    0     1    999    4     1975   2018  #4
#  1    6   7   1     0.1       0.00001  0.99999    0     1    999    4     1975   2018  #4
#  1    6   8   1     0.3       0.00001  0.99999    0     1    999    4     1975   2018  #4
#  1    6   9   1     0.7       0.00001  0.99999    0     1    999    4     1975   2018  #4
#  1    6   10   1     0.99999     0.00001  1.01      0     1    999   -4     1975   2018  #4
  1    3   1   2     84.00     5   150    0     1    999    4     1975   2019
  1    4   2   2     4.0000    0.1   20    0     1    999    4     1975   2019
# Gear-2
  2    5   1   0    165.0      5   190    0     1    999    4     1975   2019
  2    6   2   0    15.0000    0.1   25    0     1    999    4     1975   2019
# Gear-3-9
  3    7   1   1    115.0      5   190    0     1    999    4     1975   2019
  3    8   2   1     15.0     0.1   25    0     1    999    4     1975   2019
  3    9   1   2     95.0      5   190    0     1    999    4     1975   2019  # dummy
  3    10   2   2     2.5     0.1   25    0     1    999    4     1975   2019
# Gear-4
  4    11   1   0    115.0      5   190    0     1    999    4     1975   2019  # dummy
  4    12   2   0     9.0     0.1   25    0     1    999    4     1975   2019
# Gear-5
```

```
  5    13    1   1    75.0     30   190    0      1    999    5     1975   1981  #5
  5    14    2   1     5.0     1     50    0      1    999    5    1975   1981  #5
  5    15    1   1    80.0     30   190    0      1    999    5     1982   2020  #5
  5    16    2   1     10.0    1     50    0      1    999    5    1982   2020  #5
  5    17    1   2    70.0     30   180    0      1    999    5     1975   1981  #5
  5    18    2   2     9.0     1     50    0      1    999    5    1975   1981  #5
  5    19    1   2    70.0     30   180    0      1    999    5     1982   2020  #5
  5    20    2   2     4.00    1.0   50    0      1    999    5    1982   2020  #5
# Gear-6
  6    21    1   1    75.0     1    180    0      1    999    5     1975   2020  # 5
  6    22    2   1     8.5     1     50    0      1    999    5    1975   2020  # 5
  6    23    1   2    85.0     1    180    0      1    999    5     1975   2020  # 5
  6    24    2   2    10.0     1     50    0      1    999    5    1975   2020  # 5

## ———————————————————————————————————————————————————————————————— ##
## Retained                                                        ##
## gear  par   sel                          start  end             ##
## index index par sex  ival  lb    ub     prior   p1   p2     phz   period period     ##
## ———————————————————————————————————————————————————————————————— ##
# Gear-1
 -1    25    1   1    135    1    999    0     1    999    4     1975   2004
 -1    26    2   1    2.0    1     20    0     1    999    4    1975   2004
 -1    27    1   1    140    1    999    0     1    999    4     2005   2019
 -1    28    2   1    2.5    1     20    0     1    999    4    2005   2019
 -1    29    1   2    591    1    999    0     1    999   -3     1975   2004
 -1    30    1   2    591    1    999    0     1    999   -3     2005   2019
# Gear-2
 -2    31    1   0    595    1    999    0     1    999   -3     1975   2019
# Gear-3
 -3    32    1   0    595    1    999    0     1    999   -3     1975   2019    #Dummy
# Gear-4
 -4    33    1   0    595    1    999    0     1    999   -3     1975   2019
# Gear-5
 -5    34    1   0    590    1    999    0     1    999   -3     1975   2020
# Gear-6
 -6    35    1   0    580    1    999    0     1    999   -3     1975   2020
## ———————————————————————————————————————————————————————————————— ##

# Number of asyptotic parameters
1
# Fleet   Sex    Year      ival  lb   ub    phz
     1    1    1975   0.000001   0   1    -3
#    1    1    2006   0.044000   0   1    -3
#    1    1    2007   0.019700   0   1    -3
#    1    1    2008   0.019875   0   1    -3
#    1    1    2009   0.032750   0   1    -3
#    1    1    2010   0.015320   0   1    -3
#    1    1    2011   0.011250   0   1    -3
#    1    1    2012   0.024045   0   1    -3
#    1    1    2013   0.063200   0   1    -3
#    1    1    2014   0.160500   0   1    -3
#    1    1    2015   0.070950   0   1    -3
#    1    1    2016   0.082600   0   1    -3
## ———————————————————————————————————————————————————————————————— ##
## 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       ##
## ——————————————————————————————————————————————————————————————————————————— ##
## ival     lb      ub    phz   prior  p1       p2     Analytic?   LAMBDA Emphasis
  0.896    0       2     6    1      0.896    0.03   0          1           1
  1.0      0       5    -6    0      0.001    5.00   0          1           1   # BSFRF
## ——————————————————————————————————————————————————————————————————————————— ##

## ——————————————————————————————————————————————————————————————————————————— ##
## 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 type: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma         ##
## ——————————————————————————————————————————————————————————————————————————— ##
## ival       lb        ub       phz   prior    p1      p2
  0.0001      0.00001   10.0      -4    4        1.0     100   # NMFS
 0.25      0.00001   10.0       9    0        0.001   1.00   # BSFRF
## ——————————————————————————————————————————————————————————————————————————— ##

## ——————————————————————————————————————————————————————————————————————————— ##
## PENALTIES FOR AVERAGE FISHING MORTALITY RATE FOR EACH GEAR
## ——————————————————————————————————————————————————————————————————————————— ##
## Mean_F   Female Offset STD_PHZ1   STD_PHZ2   PHZ_M   PHZ_F
                                                # Upper bound value for male directed fishig mortality deviations
  0.22313        0.0505      0.5      45.50     1      1     -12      4    -10   2.95     -10    10  # Pot
  0.0183156        1.0      0.5      45.50     1     -1     -12      4    -10     10      -10    10   # Trawl
  0.011109         1.0      0.5      45.50     1      1     -12      4    -10     10      -10    10   # Tanner (-1 -5)
  0.011109         1.0      0.5      45.50     1     -1     -12      4    -10     10      -10    10   # Fixed
  0.00             0.0     2.00      20.00    -1     -1     -12      4    -10     10      -10    10   # NMFS trawl survey (0 catch)
  0.00             0.0     2.00      20.00    -1     -1     -12      4    -10     10      -10    10   # BSFRF (0)
## ——————————————————————————————————————————————————————————————————————————— ##

## ——————————————————————————————————————————————————————————————————————————— ##
## OPTIONS FOR SIZE COMPOSTION DATA                                            ##
##     One column for each data matrix                                         ##
## LEGEND                                                                      ##
##     Likelihood: 1 = Multinomial with estimated/fixed sample size            ##
##                 2 = Robust approximation to multinomial                     ##
##                 3 = logistic normal (NIY)                                   ##
##                 4 = multivariate-t (NIY)                                    ##
##                 5 = Dirichlet                                               ##
## AUTO TAIL COMPRESSION                                                       ##
##     pmin is the cumulative proportion used in tail compression              ##
## ——————————————————————————————————————————————————————————————————————————— ##
#  Pot        Trawl   Tanner  Fixed   NMFS    BSFRF
  2  2  2  2  2  2  2  2  2  2  2  2  2  # Type of likelihood
  0  0  0  0  0  0  0  0  0  0  0  0  0  # Auto tail compression (pmin)
  1  1  1  1  1  1  1  1  1  1  1  1  1  # Initial value for effective sample size multiplier
 -4  -4  -4  -4  -4  -4  -4  -4  -4  -4  -4  -4 -4   # Phz for estimating effective sample size (if appl.)
  1  2  3  4  4  5  5  6  6  7  7  8  8  # Composition aggregator
  1  1  1  1  1  1  1  1  1  1  1  1  1  # LAMBDA
  1  1  1  1  1  1  1  1  1  1  1  1  1  # Emphasis AEP
## ——————————————————————————————————————————————————————————————————————————— ##
```

```
## ——————————————————————————————————————— ##
## TIME VARYING NATURAL MORTALIIY RATES                                   ##
## LEGEND                                                                  ##
## 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
6
## M is relative (YES=1; NO=0)
1
## Phase of estimation
3
## STDEV in m_dev for Random walk
0.25
## Number of nodes for cubic spline or number of step-changes for option 3
2
2
## Year position of the knots (vector must be equal to the number of nodes)
1980 1985
1980 1985
# number of breakpoints in M by size
0
## Specific initial values for the natural mortality devs (0-no, 1=yes)
1
## ——————————————————————————————————————————— ##
## ival       lb       ub       phz   extra    prior    p1      p2        # parameter     ##
## ——————————————————————————————————————————— ##
 1.7342575      0        2         8     0
 0.000000     -2         2       -99     0
1.780586      0         2         -8     -1
0.000000     -2         2       -99     0
## ——————————————————————————————————————— ##

## ——————————————————————————————————————— ##
## OTHER CONTROLS
## ——————————————————————————————————————— ##
1975       # First rec_dev
2019       # last rec_dev
   2       # Estimated rec_dev phase
   2       # Estimated sex_ratio
 0.5       # initial sex-ratio
  -3       # Estimated rec_ini phase
   1       # VERBOSE FLAG (0 = off, 1 = on, 2 = objective func; 3 diagnostics)
   3       # Initial conditions (0 = Unfished, 1 = Steady-state fished, 2 = Free parameters, 3 = Free parameters (revised))
   1       # Lambda (proportion of mature male biomass for SPR reference points).
   0       # Stock-Recruit-Relationship (0 = none, 1 = Beverton-Holt)
  10       # Maximum phase (stop the estimation after this phase).
  -1       # Maximum number of function calls.
## ——————————————————————————————————————— ##
## EMPHASIS FACTORS (CATCH)
## ——————————————————————————————————————— ##
#Ret_male Disc_male Disc_female Disc_trawl Disc_Tanner_male Disc_Tanner_female Disc_fixed
       1         1           1          1               1                 1         1
```

```
## ——————————————————————————————————————————————— ##
## EMPHASIS FACTORS (Priors)
## ——————————————————————————————————————————————— ##
# Log_fdevs   meanF    Mdevs  Rec_devs Initial_devs Fst_dif_dev Mean_sex-Ratio
   10000        0        1.0        2         0        0           10        #(10000)
## EOF
9999
```

Appendix D. Assessing Uncertainty of Management Qualities without Trawl Survey in the Terminal Year (2020)

Approaches

Based on the suggestion by a CPT subgroup, three approaches are used to evaluate the loss of the 2020 EBS NMFS survey on crab assessments:

Approach 1: Retrospective analysis with two sets of runs.

"This approach entails doing two sets of retrospective runs. The first set would be simply the standard retrospective analysis in which data are removed from the assessment sequentially one year at a time beginning with the most recent year. The second set of retrospective runs is like the first except that the survey data in the final year are also removed. One set of comparisons would look at the CVs of estimated management quantities such as OFL and MMB based on the usual Hessian approximations provided by ADMB (Fournier et al. 2012). The expectation is that the average CV for the runs with last year of survey data omitted would be higher than the average CV when these data are available. A second kind of analysis would be considered the most recent assessment as the "truth," and look at the mean squared error (MSE) between management quantities estimated in the retrospective runs and the most recent assessment. Again the expectation would be that MSE would be larger for the runs with the missing ending year survey."

Approach 2: Drop the most recent survey.

"This approach would entail dropping the 2019 survey from the 2019 accepted assessment model. Changes in OFL and MMB and their CVs are the main interest."

Approach 3: Sensitivity analysis with high and low proxy surveys.

"This method evaluates the impact of different hypothetical 2020 survey outcomes, and is based on a SSC recommendation in its June minutes. For the survey time series fit in proposed base model for this year, calculate the multiplicative residuals, y^_i/y_i , where y_i is observed survey observation, and y^_i is the predicated survey observation after fitting the model. Obtain the 25th and the 75th percentiles of the multiplicative residuals (in R: quantile(mresids,prob=c(0.25,.75)). The rationale for the 25th and 75th percentiles is that they are a typical high and low value for the survey. Obtain the predicated survey value for the 2020 by putting in a trial survey value for 2020 with a very high CV, say 100, so that the model does not attempt to fit that observation. Multiply the predicted survey value by the 25th and 75th percentile of the multiplicative residual for a high and a low survey observation for 2020. Assume a CV equal to the median survey CV and fit these values in two model runs to evaluate sensitivity of ending year survey sensitivity. Large changes in management quantities such as OFL and MMB indicate high sensitivity."

Results

The results are summarized below. The second approach is a subset of the first approach.

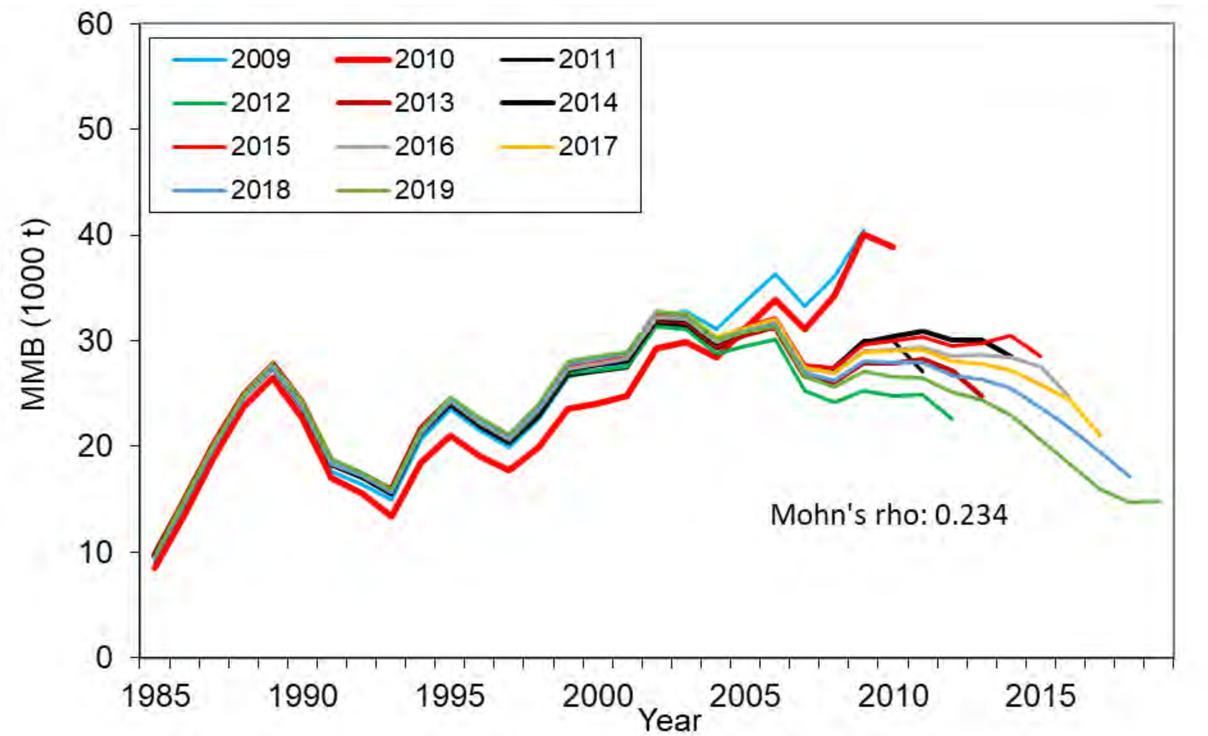
Table D1. Summary of results of two sets of retrospective analyses for mature male biomass in terminal years, OFL and ratio of mature male biomass in terminal years to $B_{35\%}$.

With survey:												
Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Mean	Abs mean
MMB	40.46	38.90	27.03	22.62	24.68	28.45	28.48	24.70	21.03	17.09	14.85	27.34	
CV	0.07	0.08	0.08	0.08	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.07	
Relative error	49.68 %	46.12 %	2.15%	-9.84 %	1.29 %	24.00 %	37.69 %	34.98 %	31.87 %	16.13 %		23.41 %	27.10 %
SE	180.33	150.7	0.32	6.09	0.10	30.32	60.77	40.98	25.84	5.63		50.11	
OFL	9.45	10.33	6.95	5.03	5.97	7.37	7.56	6.09	4.64	3.13	2.18	6.65	
CV	0.07	0.08	0.14	0.15	0.14	0.13	0.12	0.12	0.14	0.14	0.15	0.12	
MMB/ B35%	1.26	1.22	0.93	0.80	0.87	0.96	0.99	0.89	0.77	0.65	0.58	0.93	
CV	0.05	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.06	0.06	0.06	0.06	
Without survey:													
MMB	42.49	40.17	30.92	22.94	23.49	26.54	28.91	26.02	21.79	16.73	16.54	26.96	
CV	0.07	0.08	0.09	0.09	0.08	0.07	0.07	0.07	0.08	0.09	0.08	0.08	
Relative error	52.44 %	45.39 %	12.13 %	-12.68 %	-8.62 %	8.35 %	28.90 %	28.71 %	21.28 %	-0.53 %		17.54 %	21.90 %
SE	213.64	157.3	11.19	11.09	4.91	4.18	42.00	33.70	14.62	0.01		49.26	
OFL	9.98	10.45	8.72	5.19	5.45	6.52	7.73	6.56	4.92	3.02	2.70	6.47	
CV	0.07	0.08	0.09	0.17	0.15	0.14	0.13	0.13	0.15	0.17	0.15	0.13	
MMB/ B35%	1.30	1.27	1.03	0.81	0.83	0.92	1.00	0.92	0.79	0.63	0.63	0.92	
CV	0.06	0.06	0.07	0.07	0.06	0.06	0.05	0.05	0.06	0.07	0.07	0.06	
(No survey – survey)/survey													
MMB	5.02 %	3.28 %	14.40 %	1.44 %	-4.85 %	-6.73 %	1.51 %	5.35 %	3.60 %	-2.12 %	11.41 %	2.94 %	5.04 %
OFL	5.62 %	1.17 %	25.51 %	3.19 %	-8.72 %	-11.64 %	2.24 %	7.76 %	6.00 %	-3.36 %	23.56 %	4.67 %	8.37 %
MMB/ B35%	3.48 %	4.53 %	10.16 %	1.11 %	-3.94 %	-4.53 %	1.13 %	3.26 %	2.45 %	-2.26 %	8.38 %	-1.35 %	4.11 %

Table D2. Summary of results for approach 3.

	Model			
	19.3l	19.3	19.3h	(19.3h-19.3l)/19.3
B35%	25.324	25.445	25.523	0.78%
MMB-terminal	14.422	14.928	15.220	5.34%
F35%	0.290	0.291	0.291	0.17%
Fofl	0.152	0.157	0.160	5.66%

OFL	1.997	2.141	2.224	10.58%
MMB/B35%	0.570	0.587	0.596	4.57%



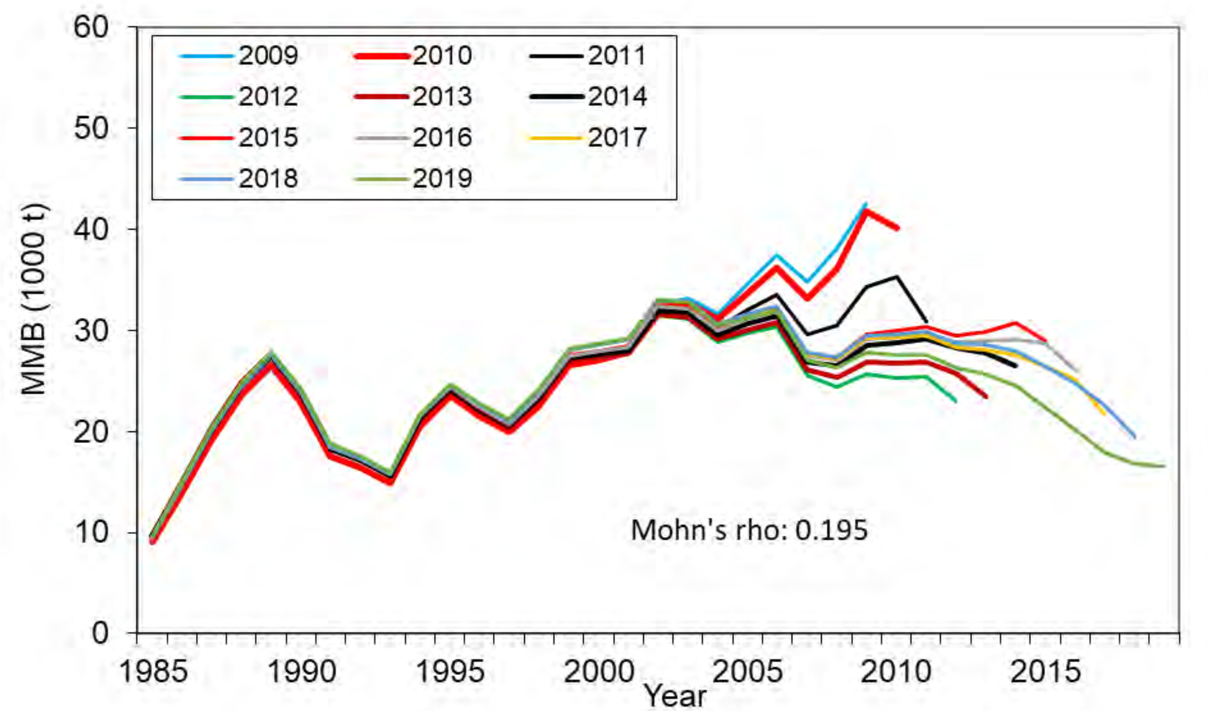


Figure D1. Comparison of hindcast (retrospective) estimates of mature male biomass on Feb. 15 of Bristol Bay red king crab from 1975 to 2019 made with terminal years 2009-2019 with terminal year trawl survey (upper panel) and without terminal year trawl survey (lower panel) with model 19.3. Legend shows the terminal year.

Figure D2. Comparison of estimated mature male biomasses in the terminal years with two sets of retrospective analyses.

Figure D3. Comparison of estimated OFLs in the terminal years with two sets of retrospective analyses.

Figure D4. Comparison of estimated ratios of MMB/$B_{35\%}$ in the terminal years with two sets of retrospective analyses.

As expected, CVs for MMB, OFL and ratio of MMB/$B_{35\%}$ in terminal years are generally slightly less with trawl survey in terminal years than those without trawl survey (Table D1). However, retrospective patterns, Mohn's rho, mean relative error, mean absolute relative error, and MSE for MMB are unexpectedly better without trawl survey in the terminal years than with trawl survey (Table D1, Figure D1). It seems that the expectation is reasonable as long as the trawl survey results are as expected. The trawl survey in 2014 results in a much higher than expected crab abundance, and surveys in 2018 and 2019 produce unexpected lower crab abundances. These unexpected trawl survey results are likely the cause for better retrospective patterns for MMB without trawl survey in the terminal years.

Overall, the differences of MMB, OFL and ratio of MMB/ $B_{35\%}$ are small between with and without trawl survey in the terminal years (Table D1, Figures D2, D3 and D4). Mean absolute relative errors are 5.04%, 8.37%, and 4.11%, respectively, for MMB, OFL and ratio of MMB/ $B_{35\%}$ for without survey relative to with survey in the terminal years. The differences of MMB, OFL and ratio of MMB/ $B_{35\%}$ between models 19.3l and 19.3h are 5.34%, 10.58% and 4.57%, respectively (Table D2, Figure D5).

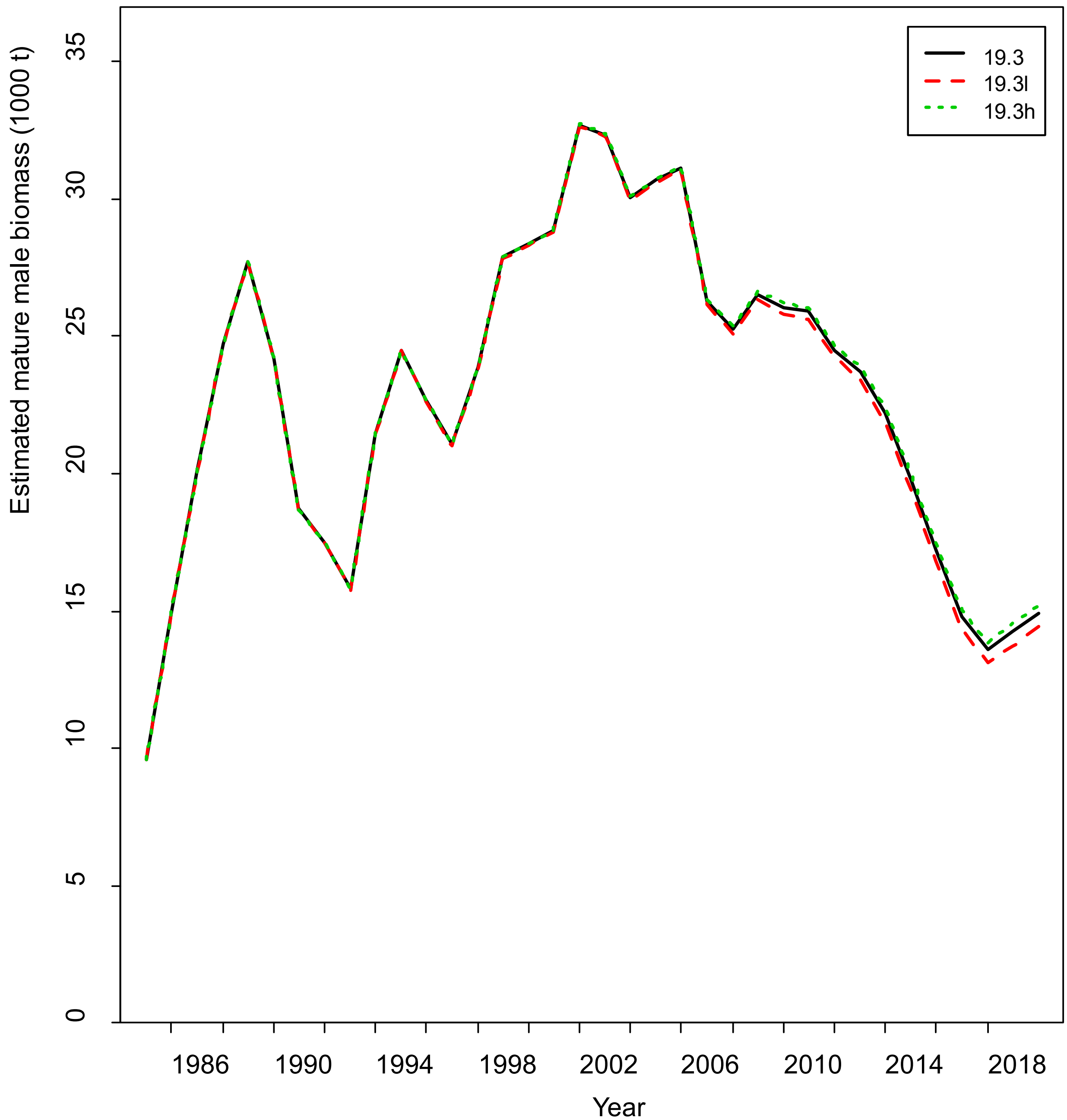


Figure D5. Comparison of estimated mature male biomass under three models (19.3, 19.3l and 19.3h). The results before 1985 are not shown for a better scale.

Appendix E. Ecosystem and Socioeconomic Profile of the Bristol Bay Red King Crab Stock

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September 2020

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Executive Summary

National initiative and NPFMC recommendations suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for the Bristol Bay red king crab (BBRKC) stock due to recent declines in abundance and poor recruitment. In addition, scores for stock prioritization, habitat prioritization, and data classification analysis were moderate to high. The BBRKC ESP follows the new standardized framework for evaluating ecosystem and socioeconomic considerations, and may be considered a proving ground for potential operational use in the main stock assessment.

We use information from a variety of data streams available for the BBRKC stock and present results of applying the ESP process through a metric and subsequent indicator assessment. Analysis of the ecosystem and socioeconomic metrics for BBRKC by life history stage along with information from the literature identified a suite of indicators for testing and continued monitoring within the ESP. Results of the metric and indicator assessment are summarized below as ecosystem and socioeconomic considerations that can be used for evaluating concerns in the main stock assessment.

Ecosystem Considerations

- Available physical indicators for 2020 show a return to near-average conditions in Bristol Bay. A relatively high positive Arctic Oscillation index in winter 2020 may suggest favorable conditions for BBRKC productivity.
- Persistently low levels of chlorophyll *a* and above-average wind stress in Bristol Bay in combination with substantial increases in juvenile sockeye salmon abundance in the past 5 years could be indicative of poor larval conditions.
- The degree of match or mismatch of first-feeding larval red king crab with preferred diatom prey may be critical for larval survival, and recent fluctuations in spring temperatures during embryo development could impact the synchrony between hatch timing and the spring bloom.
- BBRKC recruitment remains well below the long-term average. Concurrent declines in Pacific cod and benthic invertebrate biomass in the past 5 years coinciding with above-average bottom temperatures and a reduced cold pool may suggest bottom-up climate forcing on Bristol Bay benthic communities.
- Current-year increases in corrosive bottom waters in Bristol Bay have the potential to impact shell formation, growth and survival of BBRKC.

Socioeconomic Considerations

- The numbers of vessels and processors active in the 2018/19 and 2019/20 BBRKC seasons dropped below the lower bounds of their long-term historical range during 2018 and 2019. Both metrics have been in a generally declining trend since the BBRKC fishery was substantially restructured and consolidated following rationalization.
- Ex-vessel price has remained above the long-term average since 2010, partially mitigating some income effects of declining BBRKC production, but the reduced level of participation and employment suggest that reduced economic performance of the BBRKC fishery may have negative distributional effects.
- While aggregate BBRKC ex-vessel value was at a historical low in 2019, BBRKC ex-vessel revenue share on average for active vessels was only moderately below average during 2019. The local quotient for BBRKC catch value of landings to Dutch Harbor also declined to a historical low in 2019.

Introduction

Ecosystem-based science is becoming a component of effective marine conservation and resource management; however, the gap remains between conducting ecosystem research and integrating with the stock assessment. A consistent approach has been lacking for deciding when and how to incorporate ecosystem and socioeconomic information into a stock assessment and how to test the reliability of this information for identifying future change. A new standardized framework termed the ecosystem and socioeconomic profile (ESP) has recently been developed to serve as a proving ground for testing ecosystem and socioeconomic linkages within the stock assessment process (Shotwell et al., *In Review*). The ESP uses data collected from a large variety of national initiatives, literature, process studies, and laboratory analyses in a four-step process to generate a set of standardized products that culminate in a focused, succinct, and meaningful communication of potential drivers on a given stock. The ESP process and products are supported in several strategic documents (Dorn et al., 2018; Lynch et al., 2018) and recommended by the North Pacific Fishery Management Council's (NPFMC) groundfish and crab Plan Teams and the Scientific and Statistical Committee (SSC).

This ESP for Bristol Bay red king crab (hereafter referred to as BBRKC) follows a template for ESPs (Shotwell et al., *In Review*) and replaces the previous ecosystem considerations chapter in the 2011 Bering Sea and Aleutian Islands Crab SAFE document and the stock-specific report cards produced in recent years.

The ESP process consists of the following four steps:

1.) Evaluate national initiative and stock assessment classification scores (Lynch et al., 2018) along with regional research priorities to assess the priority and goals for conducting an ESP.

2.) Perform a metric assessment to identify potential vulnerabilities and bottlenecks throughout the life history of the stock and provide mechanisms to refine indicator selection.

3.) Select a suite of indicators that represent the critical processes identified in the metric assessment and monitor the indicators using statistical tests appropriate for the data availability of the stock.

4.) Generate the standardized ESP report following the guideline template and report ecosystem and socioeconomic considerations, data gaps, caveats, and future research priorities.

Justification

The national initiative stock and habitat prioritization scores for BBRKC are overall high primarily because the distribution of this stock depends greatly on habitat. There is also increasing model development for BBRKC, and the stock is highly vulnerability to the impacts of future ocean acidification. Furthermore, the BBRKC stock has been on a declining trend with subsequent lower total allowable catch in recent years, warranting the Crab Plan Team to request an evaluation of ecosystem factors. Current data availability as well as target data availability for five attributes of stock assessment model input data (i.e. catch, size composition, abundance, life history and ecosystem linkage) were classified for the BBRKC stock in order to identify data gaps and assess the priority for conducting an ESP. BBRKC is currently managed as a Tier 3 crab stock and as such, the new data classification scores characterize the stock as data-moderate with estimates of spawner/recruit relationships currently unavailable. Both current and target data availability attribute levels for the BBRKC stock size composition attribute were classified as a 3, which adequately supports a size-structured stock assessment. However, abundance, life history and ecosystem linkage attributes were highlighted as having gaps between current and target data availability. Research priorities for data classification include improvements in stock specific growth estimates and associated life history information, as well as understanding mechanisms for detecting productivity regimes in the population. These initiative scores and data classification levels suggest a high priority for conducting an ESP for BBRKC.

Data

Initially, information on BBRKC was gathered through a variety of national initiatives that were conducted by AFSC personnel. These include (but are not limited to) stock assessment prioritization, habitat assessment prioritization, climate vulnerability analysis, and stock assessment categorization. A form was submitted to stock assessment authors to gather results from all the initiatives in one location, thus serving as the initial starting point for developing the ESP metrics for groundfish and crab stocks in the BSAI and GOA fishery management plans (FMP).

Data used to generate ecosystem metrics and indicators for the BBRKC ESP were collected from a variety of laboratory studies, remote sensing databases, fisheries surveys, regional reports and fishery observer data collections (Table 1). Results from laboratory studies were specifically used to inform metrics and indicators relating to thermal tolerances, phenology and energetics across RKC life history stages. Larval indicator development utilized datasets from the NOAA Bering Arctic Subarctic Integrated Survey (BASIS) and blended satellite data products from NOAA, NASA and ESA. Data for late-juvenile through adult RKC stages were derived from the annual NOAA eastern Bering Sea bottom trawl survey and fishery observer data collected during the BBRKC fishery. Information on RKC habitat use was derived from essential fish habitat (EFH) model output and maps (Figure 3; Laman et al., 2017) as well as laboratory studies and collaborative RKC tagging efforts. Data from the NOAA Resource Ecology and Ecosystem Modeling (REEM) food habits database were used to determine species compositions of benthic predators on commercial crab species.

Data used to generate socioeconomic metrics and indicators were derived from fishery-dependent sources, including commercial landings data for BBRKC collected in ADFG fish tickets and the BSAI Crab Economic Data Report (EDR) database (both sourced from AKFIN), and effort statistics reported in the most recent ADFG Annual Management Report for BSAI shellfish fisheries estimated from ADF&G Crab Observer program data (Leon et al. 2017).

Metrics Assessment

National Metrics

The national initiative form data were summarized into a metric panel (Figure 1) that acts as a first pass ecosystem and socioeconomic synthesis. Metrics range from estimated values to qualitative scores of population dynamics, life history, or economic data for a given stock (see Shotwell et al., *In Review* for more details). To simplify interpretation, the metrics are rescaled by using a percentile rank for BBRKC relative to all other stocks in the groundfish and crab FMP's. Additionally, some metrics are reversed so that all metrics can be compared on a low to high scale between all stocks in the FMP. These adjustments allow for initial identification of vulnerable (percentile rank value is high) and resilient (percentile rank value is low) traits for BBRKC. Data quality estimates are also provided from the lead stock assessment author (0 or green shaded means no data to support answer, 4 or purple shaded means complete data), and if there are no data available for a particular metric then an "NA" will appear in the panel. The metric panel gives context for how BBRKC relate to other groundfish and crab stocks and highlights the potential vulnerabilities and data gaps for the stock. Threshold values identified from national initiatives (Methot, 2015, Morrison et al., 2015, NMFS, 2011) for select metrics are provided to highlight high levels of vulnerability for a given stock (Figure 1, red dots).

For BBRKC ecosystem metrics, latitude range, reproductive strategy, early life history survival, ocean acidification sensitivity, and habitat specificity indicate high vulnerability via the percentile method when compared to other Alaska groundfish and crab stocks. Additionally, maximum length, recruitment variability, population growth rate, depth range, bottom-up ecosystem value, fecundity, and maximum age were over the thresholds defined by national initiatives. Scores suggest that RKC are habitat specialists and reproductive success may be highly sensitive to specific environmental conditions due to aggregate mating behavior. Additionally, a relatively long larval duration, pelagic predation pressure, and specific habitat requirements following settlement indicate that early life history stages are a criticality in RKC life stages. Initial metric panel results indicate that stage-based information incorporating predation pressures, habitat dependence, ocean acidification and climatic conditions would be valuable for the stock and would assist with subsequent indicator development. For the three applicable socioeconomic metrics, values indicated fairly high commercial importance, indicating that RKC may be increasingly sensitive to targeted fishing.

BBRKC had numerous data gaps for ecosystem metrics including length- and age-based metrics, recruitment variability and natural mortality. Data quality was rated as medium to complete for all metrics with data available, although the prevalence of data gaps for important life history metrics highlight the need for additional research to better understand RKC life history processes.

Ecosystem Processes

Data evaluated over ontogenetic shifts (e.g., egg, larvae, juvenile, adult) may be helpful for identifying specific bottlenecks in productivity and relevant indicators for monitoring. As a first attempt to summarize important processes or potential bottlenecks across RKC life history stages, we include a detailed life history synthesis (Table 2a), an associated summary of relevant ecosystem processes (Table 2b), and a baseline life history conceptual model (Figure 2a). In the life history tables and conceptual model, abiotic and biotic processes were identified by each life stage from the literature, process studies and laboratory rearing experiments. Details on why these processes were highlighted, as well as the potential relationship between ecosystem processes and stock productivity are described below.

Red king crab molt, mate and extrude new egg clutches each spring, after which females brood fertilized eggs externally for up to a year (Stevens and Swiney, 2007). Embryo development is delayed in cold years (Chilton et al., 2010) and laboratory studies suggest that acidified conditions have significant effects on embryogenesis (Long et al., 2013). Following hatch, RKC larval development consists of four zoeal stages and one glaucothoe stage, after which larvae metamorphose and settle as stage C1 benthic juveniles. Zoea larvae feed primarily on diatoms; the chain-forming diatom *Thallasiosira nordenskioldii* is a particularly important larval food source due to its large size and high densities in natural populations (Paul et al., 1989). First-feeding larvae represent a critical bottleneck during development as previous research indicates that chances of survival are greatly reduced if larvae do not feed within 60 hours of hatching (Paul and Paul, 1980). Likewise, because the glaucothoe stage is a non-feeding stage, survival likely depends on nutrition acquired during zoeal stages. Laboratory rearing experiments reported optimal larval survival at 8°C (Nakanishi, 1987), although RKC zoeal stages appear to exhibit an ontogenetic change in thermal tolerance, and ZII larval survival is greatly reduced above 6°C (Shirley and Shirley, 1989). Although first-feeding success of RKC larvae is likely higher for earlier hatch dates coinciding with high densities of *Thallasiosira*, cooler water temperatures slow larval development rates and increase mortality due to both increased offshore transport and larval stage duration (Loher and Armstrong, 2000). Shirley and Shirley (1990) found that the length of the RKC larval period was inversely related to chlorophyll *a* concentrations, and that larval survival was inversely related to larval period length. Likewise, larval advection and dispersal relative to oceanographic conditions and the availability of suitable settlement habitat may be significant drivers of recruitment success in a given year (Daly et al., 2018).

During the early juvenile stages, successful settlement requires shallow, nearshore waters (<50m) and structurally complex habitats due to the reliance on crypsis to evade predation (Loher and Armstrong, 2000; Stevens, 2003). Survival in small juvenile RKC increases with the amount of physical structure in settlement habitats (Stoner, 2009; Pirtle et al., 2012), whereas larger juveniles are often associated with habitats composed of structural invertebrates that likely provide increased foraging opportunities (Pirtle and Stoner, 2010). These results suggest an ontogenetic shift in habitat requirements following the first year of benthic life as RKC juveniles rely less on high-relief habitat, and instead form large pods to evade predators. Juvenile RKC molt several times a year during early benthic instar stages and are especially vulnerable to groundfish predators such as Pacific cod while soft (Livingston, 1989). Overall, juvenile RKC appear to have a broad range of temperature tolerance, indicated by relatively high survival over the range of temperatures tested (2 to 12 °C) in a laboratory experiment (Stoner et al., 2010). This is likely advantageous during the juvenile stage when RKC utilize relatively shallow habitats more prone to temperature fluctuations.

Late juvenile and adult RKC are less reliant on complex substrate and, instead, temperatures appear to drive patterns in spatial distributions and migration timing. Northerly shifts in stock distribution are generally associated with both warmer temperatures and high Pacific Decadal Oscillation values during the summer (Loher and Armstrong, 2005; Zheng and Kruse, 2006), whereas fall distributions during the fishery tend to contract to the center of Bristol Bay during warm years (Zacher et al., 2018). Mature female RKC appear to avoid waters <2 °C (Chilton et al., 2010) and recent tagging efforts suggest that mature males tend to avoid warm waters >4 °C. Historic spawning grounds for RKC have been identified off the western end of the Alaska Peninsula in an area commonly referred to as "Cod Alley", although in recent years the area has been subject to intense fishing pressure (Dew, 2010). Essential fish habitat for red king crab remains poorly defined and very little is known about the potential effects of bottom trawling on RKC spatial distributions, spawning aggregations and habitat use.

Socioeconomic Processes

As described below, the set of socioeconomic indicators reported in this ESP are categorized as *Fishery Performance, Economic Performance* and *Community Effects* indicators. Fishery Performance indicators are intended to represent processes most directly involved in prosecution of the BBRKC fishery, and thus have the potential to differentially affect the condition of the stock depending on how they influence the timing, spatial distribution, selectivity, and other aspects of fishing pressure. *Economic Performance* and *Community Effects* indicators are intended to capture key dimensions of the economic and social processes through which outputs, benefits and other effects flowing from commercial exploitation of the fishery are generated and distributed. Notwithstanding these categorical distinctions, the social and economic processes that affect, and are affected by, the condition of the stock are complex and interrelated at different time scales. Moreover, these processes are strongly influenced by the institutional structures of fishery management, which develop over time and include both small adjustments in in-season management as well as comprehensive structural changes that induce complex, multidimensional change affecting numerous social and economic processes. Implementation of the Crab Rationalization (CR) Program in 2005 is an example of the latter (a full summary of the management history of the BBRKC fishery is beyond the scope of the ESP; see Nichols, et al., 2019).

Among other changes, rationalization resulted in rapid consolidation of the BBRKC fleet, from a high of 274 vessels in 1998 to 89 during the first year of the CR program, which has subsequently further consolidated to 56 vessels operating in the 2019/20 season. Allocation of tradable crab harvest quota shares, with leasing of annual harvest quota, facilitated fleet consolidation and improved operational and economic efficiency of the fleet, changing the timing of the fishery from short derby seasons to more extended seasons, and inducing extensive and ongoing changes in harvest sector ownership, employment, and income. Crab processing sector provisions of the CR program, including allocation of transferable processing quota shares (PQS) and leasing of annual quota, facilitated similar operational and economic efficiencies in the sector, with more limited consolidation of processing capacity to fewer locations, and fewer plants in those ports (with Unalaska/Dutch Harbor receiving the largest share of BBRKC landings before and after 2005, and Akutan, King Cove, Kodiak, and St. Paul continuing to receive landings to date).

These and other institutional changes continue to influence the geographic and inter-sectoral distribution of benefits produced by the BBRKC fleet, both through direct ownership and labor income in the BBRKC harvest and processing sectors, and indirect social and economic effects on fishery-dependent communities throughout Alaska and greater Pacific Northwest region. The full range of fishery, economic, and social processes cannot be captured within the scope of the ESP framework, and more comprehensive set of metrics and indicators intended to inform BBRKC fishery management and annual harvest specifications are provided in the annual Crab Economic SAFE.

Indicators Assessment

We first provide information on how we selected the indicators for the third step of the ESP process and then provide results on the indicators analysis. Developing and selecting a suite of meaningful indicators necessitates compiling time series data that represent stock vulnerabilities or critical processes, as identified by the metric assessment. These indicators must be useful for stock assessments in that they are regularly updated, reliable, consistent, and long-term. The indicator suite is then monitored in a series of statistical tests that gradually increase in complexity depending on the data availability of the stock (Shotwell et al., *In Review*).

Indicator Suite

Very few studies have effectively linked environmental variables or ecosystem conditions to recruitment of Bering Sea crab stocks, owing primarily to the highly variable nature of crab recruitment. Zheng and Kruse (2000) noted that strong year classes of RKC in the early 1970's corresponded with low temperatures. However, recruitment trends are not consistently explained by temperatures or decadal-scale environmental variability and weak relationships suggest that climatic conditions alone do not account for all the variability in year class strength. Groundfish predation has been hypothesized as a mechanism driving recruitment variability and previous studies indicate a strong negative relationship between Pacific cod biomass and red king crab recruitment (Zheng and Kruse, 2006; Betchol and Kruse, 2010). Large-scale indices of environmental variation including the Aleutian Low, Pacific Decadal Oscillation and Arctic Oscillation have also been linked to red king crab productivity (Loher and Armstrong, 2005; Zheng and Kruse, 2006; Szuwalski et al., *in review*) , although associated mechanisms remain unclear. In acknowledging the paucity of these mechanistic linkages, we generated a suite of ecosystem and socioeconomic indicators using stock vulnerabilities identified in the metric assessment (Figure 1) in addition to tested driver-response relationships from previously published studies (Table 2b). When selecting a suite of indicators for the BBRKC ESP, efforts were focused on developing spatially explicit indicators bounded by the BBRKC management area, which 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.; ADF&G 2012). The following list of indicators is organized by process, and ecosystem indicators are grouped by RKC life history stage when applicable. Indicator title and a brief description are provided in Table 3a for ecosystem indicators and Table 3b for socioeconomic indicators with references, where possible, for more information.

Ecosystem Indicators:

1. Physical Indicators

- The EBS **cold pool index** (<2°C) is not only important in driving RKC distributions, but also in driving distributions of major predators of RKC. Pacific cod and several flatfish species typically avoid temperatures less than 1° C (Kotwicki and Lauth, 2013), suggesting that cold years when the cold pool extends into Bristol Bay may offer RKC a refuge from predation. The cold pool index was calculated as the fraction of the EBS BT survey area with bottom water less than 2°C on 1 July of each year from Bering10K ROMS model output hindcasts (Kearney et al., 2020).
- **Summer bottom temperatures** in Bristol Bay represent environmental conditions during the summer survey period and drive juvenile and adult RKC distributions (Loher and Armstrong, 2005), timing of the reproductive cycle (Chilton et al., 2010) and larval transport (Daly et al., 2018). Laboratory studies have also shown that temperature is a direct driver of growth, molt duration and feeding ration (Long et al., 2017: Stoner et al., 2013). Summer bottom temperatures were calculated as the average of June-July bottom temperatures within the BBRKC management boundary from ROMS model output (Kearney et al., 2020).
- The **Arctic Oscillation** is a large-scale mode of climate variability; increased red king crab recruitment has been associated with increases in the Arctic Oscillation (Szuwalski et al., *in review*). When the Arctic Oscillation is in its positive phase, strong winds circling the North Pole confine colder air across polar regions. The Arctic Oscillation indicator was determined as the average of Jan-March Arctic Oscillation deviations, developed by NOAA's Climate Prediction Center.
- A **Corrosivity Index** developed from Bering10K ROMS output was calculated as the percent of the BBRKC management area containing an average bottom aragonite saturation state of < 1 from Feb-April (D. Pilcher, *pers. commun.*, 2020; Pilcher et al., 2019). The corrosivity index represents potential acidified bottom water conditions in Bristol Bay, which would negatively affect RKC physiology. Reductions in RKC larval condition (Long et al., 2013), juvenile growth and survival (Long et al., 2013), and shell hardness (Coffey et al., 2017) have been documented in low pH conditions.
- **Spring bottom temperatures, wind stress** and **chlorophyll *a* biomass** indicators represent environmental conditions and food sources for RKC early life history stages. Temperature-mediated shifts in embryo development, hatch timing and larval duration could subsequently result in RKC larvae mismatches with prey resources, or increase the probability of advection away from favorable nursery grounds. First-feeding success of RKC larvae has also been linked to high diatom abundances, light winds and water column stability (Paul et al., 1989). Spring bottom temperatures were calculated as the average of Feb-March bottom temperatures within the BBRKC management boundary from ROMS model output (Kearney et al., 2020). Wind stress was determined by averaging June ocean surface wind speeds from remote sensing data within the BBRKC management boundary (Zhang et al., 2006, NOAA/NESDIS, CoastWatch). Chlorophyll *a* biomass was calculated as the April-June average chlorophyll-a estimates from MODIS satellites within the Southern Inner Shelf of the Bering Sea (J. Nielsen, *pers. commun.*, 2020).

2. Biological Indicators

- Estimates of **juvenile sockeye salmon abundance** in the EBS and **Pacific cod biomass** in Bristol Bay represent major predators during the larval and juvenile to adult stages, respectively. Sockeye salmon abundance was estimated from NOAA Bering Arctic Subarctic Integrated

Surveys in the EBS (E. Yasumiishi, *pers. commun*., 2020). Estimates of Pacific cod biomass were derived from the EBS bottom trawl survey catch data.

- Species included in the **benthic invertebrate biomass** indicator (i.e. brittle stars, sea stars, sea cucumber, bivalves, non-commercial crab species, shrimp and polychaetes) are important prey sources for BBRKC (Feder et al. 1980; Jewett and Feder, 1982).. Increases in invert biomass may suggest optimal foraging conditions for RKC, although increases in highly mobile benthic foragers such as hermit crabs and sea stars may, instead, may point towards increased competition for benthic resources. Biomass estimates were determined from the EBS bottom trawl survey catch data.
- A **BBRKC recruit biomass** index effectively tracks the number of males that will likely enter the fishery the following year. Small catches of these sub-legal RKC are often a reliable indicator of impending declines in mature male biomass. BBRKC recruit biomass (110-134 mm CL) was estimated from the EBS bottom trawl survey catch data (J. Richar, *pers. commun*., 2020).
- Spatial distribution indicators include summer **area occupied by mature male and female RKC**, as well as male **catch distance from shore** during the fishery. Areas occupied were determined as the minimum area containing 95% of the cumulative BBRKC CPUE from the EBS bottom trawl survey. Catch distance from shore was calculated using fishery observer data as the mean distance legal male RKC were caught from shore during the fishery (L. Zacher, *pers. commun*., 2020). In warm years, RKC tend to aggregate in the center of Bristol Bay (Zacher et al., 2018), which may have implications for the effectiveness of fixed closure areas and RKC bycatch during winter groundfish fisheries.

Socioeconomic Indicators:

1. Fishery Performance Indicators

- CPUE (mean no. of crabs per potlift): Fishing effort efficiency, as measured by estimated mean number of retained BBRKC per potlift.
- Total Potlifts: Fishing effort, as measured by estimated number of crab pots lifted by vessels during the BBRKC fishery.
- Vessels active in fishery: Annual count of crab vessels that delivered commercial landings of BBRKC to processors.
- BBRKC male bycatch biomass: Incidental bycatch biomass estimates of male BBRKC (tons) in trawl and fixed gear fisheries

2. Economic Indicators

- TAC Utilization (%): Percentage of the annual BBRKC TAC (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing.
- Ex-vessel value of BBRKC landings: Aggregate ex-vessel value of BBRKC landings (as adjusted by CFEC to account for post-season adjustments to ex-vessel settlements), summed over all ex-vessel sales reported.
- Ex-vessel price per pound: commercial value per unit (pound) of BBRKC landings (as adjusted by CFEC to account for post-season adjustments to ex-vessel settlements), measured as weighted average value over all ex-vessel sales reported. Ex-vessel prices, combined with vessel operating costs and other factors, determine the economic return to vessels per unit of catch and, considering the availability and expected returns from alternative fishing targets, are a direct driver of the level and intensity of fishing effort.
- BBRKC ex-vessel revenue share (% of total exvessel revenue): BBRKC ex-vessel revenue share as percentage of total calendar year ex-vessel revenue from all commercial landings in Alaska fisheries, mean value over all vessels active in BBRKC during the respective year. Revenue share provides an indicator of the relative income dependence of participating vessels on the BBRKC

fishery, where changes in the fishery that reduce the returns from fishing (e.g., reductions in TAC and/or ex-vessel price) are offset by income produced from alternative fishing targets.

3. Community Indicators

- Processors active in fishery: Total number of crab processors that purchased landings of BBRKC from delivering vessels during the calendar year. This provides an indicator of the level of participation of buyers in the market for BBRKC landings.
- Processing Employment in BBRKC: Crab processing employment generated in BBRKC fishery as measured by total paid hours of labor input by processing employees, summed over all shore-based plants that processed BBRKC landings.
- Local Quotient of BBRKC landed catch in Dutch Harbor: Ex-vessel value share of BBRKC landings to Unalaska/Dutch Harbor, as percentage of total value of commercial landings to processors in the community from all commercial Alaska fisheries, as aggregate percentage over all landings during the respective year. Dutch Harbor is the principal port of landing for the BBRKC fishery, historically, representing between 43% and 58% of annual landings since 2005.

Indicator Analysis

We provide the list and time-series of indicators (Table 3, Figures 4-5) and then monitor the indicators using three stages of statistical tests that gradually increase in complexity depending on the stability of the indicator for monitoring the ecosystem or socioeconomic process and the data availability for the stock (Shotwell et al., *In Review*). At this time, we report the results of the first and second stage statistical tests of the indicator analysis for BBRKC. The third stage will require more indicator development and review of the ESP modeling applications.

Stage 1, Traffic Light Test:

The first stage of the indicator analysis is a simple assessment of the most recent year relative value and a traffic-light evaluation of the most current year where available (Table 3). Both measures are based on one standard deviation from the long-term mean of the time series. A symbol is provided if the most recent year of the time series is greater than (+), less than (-), or within (•) one standard deviation of the long-term mean for the time series. If the most recent year is also the current year then a color fill is provided for the traffic-light ranking based on whether the relative value creates conditions that are good (blue), average (white), or poor (red) for BBRKC (Caddy et al., 2015). The blue or red coloring does not always correspond to a greater than (+) or less than (-) relative value. In many cases the most current year was not available and this demonstrates significant data gaps for evaluating ecosystem and socioeconomic data for BBRKC.

Overall, BBRKC recruitment still remains well below average. EBS bottom trawl survey biomass estimates were not available for 2020, however the 2018 recruitment estimate was the lowest in the 40-year time series, following the lowest previously observed in 2017. Trends in physical ecosystem indicators suggest poor to fair environmental conditions during the past 5 years for the BBRKC stock. The cold pool extent in Bristol Bay was at an all-time low from 2018-2019 while average summer bottom temperatures have exceeded 4°C in three of the past five years. Environmental conditions in 2020 appear to have returned to near-average compared to the long-term mean, with a positive phase Arctic Oscillation coinciding with an increase in the cold pool extent and a nearly 2°C decline in summer bottom temperatures from 2019 to 2020. On the contrary, a nearly 3-fold increase in bottom water corrosivity in Bristol Bay from 2019 to 2020 suggests that over 50% of Bristol Bay bottom waters were below the aragonite saturation threshold ($\Omega arag < 1$) from February to April.

Spring bottom temperatures in 2020 averaged 0.37°C, which suggests that embryo development and hatching may have been delayed due to colder than average bottom temperatures. 2020 spring bottom temperatures were below 2006 and 2007 bottom temperatures when Chilton et al. (2010) noted that stations sampled in May had high numbers of mature female RKC still brooding embryos fertilized the previous season. These results suggest that in 2020, peak hatch timing may have been delayed until June, which could have implications for temporal synchrony between larval RKC and the spring bloom. Furthermore, chlorophyll *a* biomass estimates have remained below-average for the past five years and wind stress in Bristol Bay has been above-average during this time period. Together these conditions may be indicative of declines in diatom abundances and low larval encounter rates due to increased surface mixing. Record high juvenile sockeye salmon abundances since 2014 may be further indicative of increased predation and subsequent poor survival of RKC larval stages in the past 5 years.

Due to the 2020 cancellation of the EBS bottom trawl survey, current-year data are not available for Pacific cod and benthic invert biomass indicators. However, both indicators are on a downward trend and Pacific cod biomass has been below average since 2016 in Bristol Bay. Current year data was also unobtainable for spatial distribution indicators, though recent trends are consistent with documented shifts in spatial distributions during previous warm periods in Bristol Bay (Loher and Armstrong, 2005; Zacher et al., 2018). During warm years in 2018-2019, male RKC were located further from shore during the fishery, and both males and females occupied a larger area during the summer trawl survey in recent years.

Indicators reported for applicable socioeconomic metrics are derived from fishery-dependent sources that are typically available for the prior year or lagged by up to three years (as of the September-November assessment cycle for most Alaska-region FMP crab and groundfish stocks), and as such are limited to providing retrospective information. The metrics reported in Table 3b, therefore, are based on the most current available value of the respective data series, representing conditions in the BBRKC fishery during 2018 or 2019.

Fishery performance metrics related to aggregate fishing effort, including number of active vessels and total number of potlifts, were low relative to the long term averages, but were within the range of recent variation and exhibiting declining trends commensurate with lower TACs following the 2016/17 season. CPUE has declined since 2016, but was slightly below average during 2019.

Metrics for economic and community indicators were more generally negative for 2018-2019. Ex-vessel price remained relatively high over the most recent years, which may have partially mitigated some effects of decreased production, however, aggregate ex-vessel value reached a historical low during 2019, falling below 1 standard deviation of the long-term mean. BBR ex-vessel revenue share declined more modestly during 2019, possibly reflecting distribution of aggregate landings over fewer vessels, as well as a relatively brief BBRKC season allowing more time devoted to other fisheries. Processing employment generated by BBRKC, as measured in aggregate paid processing labor hours, also fell to a historical low. The local quotient of BBRKC catch value in Dutch Harbor fell to 7%, indicating that the decline in BBRKC landing value was somewhat isolated to the fishery, with local landings from other fisheries maintaining value in 2019.

Stage 2, Importance Test:

Bayesian adaptive sampling (BAS) was used for the second stage statistical test to quantify the association between hypothesized predictors and BBRKC mature male biomass (MMB), and to assess the strength of support for each hypothesis. BAS explores model space, or the full range of candidate combinations of predictor variables, to calculate marginal inclusion probabilities for each predictor, model weights for each combination of predictors, and generate Bayesian model averaged predictions for outcomes (Clyde et al., 2011). In this second test, the full set of indicators is first winnowed to the predictors that could directly relate to MMB, and have consistent temporal scales. We then provide the mean relationship between each predictor variable and log MMB over time (Figure 6a), with error bars describing the uncertainty (1 standard deviation) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure 6b). A higher probability indicates that the variable is a better candidate predictor of BBRKC MMB. The highest ranked predictor variables (> 0.50 inclusion probability) were: BBRKC recruit biomass, Pacific cod biomass, and the Arctic Oscillation. Unfortunately, due to the nature of the BAS model only being able to fit years with complete observations for each covariate, the final subset of covariates was quite small and creates a significant data gap. Despite this shortcoming, predictive performance of the BAS model appears to generally capture BBRKC MMB trends across the time series (Figure 6d).

Recommendations

The BBRKC ESP follows the standardized framework for evaluating the various ecosystem and socioeconomic considerations for this stock (Shotwell et al., *In Review*). Given the metric and indicator assessment we provide the following set of considerations:

Ecosystem Considerations

- Available physical indicators for 2020 show a return to near-average conditions in Bristol Bay. A relatively high positive Arctic Oscillation index in winter 2020 may suggest favorable conditions for BBRKC productivity.
- Persistently low levels of chlorophyll *a* and above-average wind stress in Bristol Bay in combination with substantial increases in juvenile sockeye salmon abundance in the past 5 years could be indicative of poor larval conditions.
- The degree of match or mismatch of first-feeding larval red king crab with preferred diatom prey may be critical for larval survival, and recent fluctuations in spring temperatures during embryo development could impact the synchrony between hatch timing and the spring bloom.
- BBRKC recruitment remains well below the long-term average. Concurrent declines in Pacific cod and benthic invertebrate biomass in the past 5 years coinciding with above-average bottom temperatures and a reduced cold pool may suggest bottom-up climate forcing on Bristol Bay benthic communities.
- Current-year increases in corrosive bottom waters in Bristol Bay have the potential to impact shell formation, growth and survival of BBRKC.

Economic Considerations

- The numbers of vessels and processors active in the 2018/19 and 2019/20 BBRKC seasons dropped below the lower bounds of their long-term historical range during 2018 and 2019. Both metrics have been in a generally declining trend since the BBRKC fishery was substantially restructured and consolidated following rationalization.
- Ex-vessel price has remained above the long-term average since 2010, partially mitigating some income effects of declining BBRKC production, but the reduced level of participation and employment suggest that reduced economic performance of the BBRKC fishery may have negative distributional effects.
- While aggregate BBRKC ex-vessel value was at a historical low in 2019, BBRKC ex-vessel revenue share on average for active vessels was only moderately below average during 2019. The local quotient for BBRKC catch value of landings to Dutch Harbor also declined to a historical low in 2019.

Data Gaps and Future Research Priorities

Current year data gaps for ecosystem indicators due to the cancellation of the 2020 EBS bottom trawl survey emphasize the necessity of annual surveys for tracking impending ecosystem shifts and potential impacts to BBRKC. Low stock recruitment in the past decade also warrants a better understanding of early life history processes and bottlenecks to aid in developing meaningful larval indicators as early warning signs. Evaluating RKC phenology relative to spring bloom timing may be useful for predicting larval condition and subsequent survival to settlement. Additionally, evaluating larval drift patterns and identifying essential fish habitat for benthic juvenile RKC may support the development of a larval retention or settlement success indicator.

Given the dramatic increase in Bristol Bay sockeye salmon in recent years, we emphasize the importance of understanding predator-prey interactions and spatial overlap. Furthermore, additional groundfish stomach data outside of the summer survey time series would inform predation mortality during the molt when RKC are highly vulnerable. The prevalence of corrosive bottom waters in Bristol Bay also highlights the need for continued research to identify the potential impacts of ocean acidification on RKC physiology. Ongoing efforts to understand the relationship between aragonite saturation states and BBRCK distributions (E. Kennedy, *pers. commun*., 2020) will be particularly important if Bristol Bay continues to experience corrosive water conditions. Overall, we highlight the continued importance of developing a mechanistic understanding of driver-response relationships to facilitate the inclusion of ecosystem indicators in future management strategies for Bering Sea commercial crab stocks.

Socioeconomic indicators of community participation in the BBRKC fishery included in this report are limited to general metrics related to the processing sector (number of active processors, aggregate processing labor hours), and local quotient of landed value in Dutch Harbor. Extensive data resources are available to support development of a wide variety of useful community-related indicators, however, more comprehensive depiction of indicators at the level of individual communities within the ESP is currently constrained by the limited scope and intent of the document. AFSC is currently developing a dedicated annual report to accompany the Crab and Groundfish Economic SAFE reports, focused on providing comprehensive analysis and monitoring of community participation and engagement in groundfish and crab fisheries. The Annual Community Engagement and Participation Overview (ACEPO) will provide detailed, community-level metrics of fishery participation, including income and employment, and ownership of vessel, plant, permit and quota share assets. Development of methods and indices for effectively capturing these and other dimensions of management effects on communities is currently concentrated on producing the ACEPO report. It is expected that this will provide the basis for identifying reduced-form indicators of community effects that will be suitable for incorporation in future ESPs.

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[*]Superscript numbers refer to references in Tables 2a and 2b

Table 1. List of data sources used in the Bristol Bay red king crab (BBRKC) ESP evaluation. Please see the BBRKC SAFE document (Zheng et al., 2019), the NOAA EBS Trawl Survey: Results for Commercial Crab Species Technical Memo (Zacher et al., 2020) and the SAFE Economic Status Report (Garber-Yonts and Lee, 2019) for more details.

	Title	Description	Years	Extent
Ecosystem	RACE EBS Bottom Trawl Survey	Bottom trawl survey of groundfish and crab on standardized 376-station grid using an 83-112 Eastern otter trawl	1975-2019	EBS annual
	REEM Food Habits Database	Diet data for key groundfish species collected by the Resource Ecology and Ecosystem Modeling (REEM) Program on the EBS bottom trawl survey	1987-2019	EBS annual
	ADF&G Crab Observer program data	BBRKC catch and effort data reported by ADF&G statistical areas during the fall fishery	2000-2019	EBS annual
	Essential Fish Habitat Models	Habitat suitability MaxEnt models for describing essential fish habitat of groundfish and crab in Alaska, EFH 2017 Update	1970-2017	Alaska
	BASIS survey	Surface/midwater column community survey of forage fish and salmon stocks	2002-2018	EBS, biennial
	ROMS Model Output	High-resolution regional oceanographic model hindcasts from the Bering Sea Regional Ocean Modeling System (ROMS)	1970-2020	EBS variable
	NOAA Climate Model Output	Monthly large-scale climate indices constructed by the National Weather Service's Climate Prediction Center	1854-2020	North Pacific annual
	Satellite Data	Monthly wind stress and 8-day composite ocean color products from MODIS Aqua and MetOp ASCAP sensors (NOAA NCEI/NOAA NESDIS)	1988-2020	Global annual
Socioeconomic	ADF&G fish ticket database	Volume, value, and port of landing for Alaska crab and groundfish commercial landings; data processed and provided by Alaska Fisheries Information Network	1992-2019	Alaska
	ADF&G Crab Observer program data	BBRKC catch and effort data (number of active vessels, total pots lifted, and CPUE), sourced from ADF&G Annual Fishery Management Report	1980-2019	Alaska
	BSAI Crab Economic Data Report database	Crab processing employment; data processed and provided by Alaska Fisheries Information Network	1998-2018	Alaska

Table 2a: Ecological information by life history stage for Bristol Bay red king crab

Stage	Habitat & Distribution	Phenology	Age, Length, Growth	Energetics	Diet	Predators
Egg	Clutch of embryos brooded under the female's abdomen until hatching[7]	328-365 day embryo incubation, peak hatch in Feb[5]	Egg length 1.16mm[3]	Optimal: 3°C – 8°C[3]	Yolk	Nemertean worms and amphipods feed on egg clutches[6]
Larvae	Pelagic; nearshore along the Alaska Peninsula (40-70m depth)[9]	March-June, Hatch to C1 benthic stage: 130 d at 8°C[3]	1.1 – 2mm CL[2]	Optimal: 5°C – 10°C[2,3]	Phytoplankton-diatoms[4] (glaucothoe: non-feeding)	Planktivorous fish, salmon smolt[11]
Juvenile	Benthic; nearshore complex habitat- boulders, cobble, shell hash, structural invertebrates (<50m depth)[8, 14]	Peak settlement in July[8], 1 to 5-6 years duration for benthic instar stages	Mean size at settlement: 1.91 - 2.18mm CL[16,17]	No effect on survival of C1-C4 juveniles from 1.5°C to 12°C[18]	Sponges, diatoms, foraminifera, crustaceans, polychaetes, bryozoans[15]	Pacific cod[13], flatfish, crab[22]
Adult	Benthic: sand and mud bottoms (50-200m depth)[20, 21]	5-6+ years, Annual molt and mate Jan-June	For management, females >89 mm CL and males >119 mm CL are assumed to be mature[12]	Optimal: 2°C – 4°C[20]	Mollusks, echinoderms, polychaetes, crustaceans, hydroids, sea stars[19]	Pacific cod, halibut, skates[13,23] (primarily during the molt)

Table 2b. Key processes affecting survival by life history stage for Bristol Bay red king crab (BBRKC)

Stage	Processes Affecting Survival	Relationship to BBRKC
Egg	1. Temperature 2. CO_2 concentrations	Cold temperatures extend embryo development[25] while embryo mortality increases at temperatures above 8°C[3]. Exposure to increased $C0_2$ levels delays hatch time and reduces embryo condition[24]
Larvae	1. Spatial and temporal synchrony with spring bloom 2. Diatom abundance in spring/summer 3. Larval transport/retention onshore	RKC peak hatch coinciding with high abundances of *Thallasiosira* ssp. may increase larval survival[4]. Settlement success and benthic survival is likely related to oceanographic conditions that facilitate transport to suitable nearshore nurseries[27].
Juvenile	1. Availability of highly structured habitat 2. Predation	Complex nursery habitats promote the survival of benthic juvenile stages by providing refuge from predators[14]
Adult	1. Bottom temperature 2. Predation	Bottom temperatures are likely responsible for shifts in spatial distribution and migration timing[28]. After molting, adult RKC are highly vulnerable to groundfish predation.

Table 3a. First stage ecosystem indicator analysis for Bristol Bay red king crab (BBRKC), including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for BBRKC of the current year conditions relative to 1 standard deviation of the longterm mean (white = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
Cold Pool Index	Fraction of the EBS BT survey area with bottom water less than 2°C on 1 July of each year from Bering10K ROMS model output hindcasts	●
Summer Bottom Temperature	Average of June-July bottom temperatures (° C) within the BBRKC management boundary from the Bering 10K ROMS model output hindcasts	●
Arctic Oscillation	Average of Jan-March Arctic Oscillation Index estimates; constructed by projecting daily 1000mb height anomalies poleward of 20°N onto the loading pattern of the Arctic Oscillation	+
Corrosivity Index	Percent of the BBRKC management area containing an average bottom aragonite saturation state of < 1 from Feb-April	+
Spring Bottom Temperature	Average of Feb-March bottom temperatures (° C) within the BBRKC management boundary from the Bering 10K ROMS model output hindcasts	●
Wind Stress	June ocean surface wind stress within the BBRKC management boundary. Product of NOAA blended winds and MetOp ASCAP sensors from multiple satellites	●
Chlorophyll-a Biomass	April-June average chlorophyll-a biomass within the Southern Inner Shelf of the Bering Sea; calculated with 8-day composite data from MODIS satellites	●
Juvenile sockeye salmon abundance	Estimated September juvenile sockeye salmon biomass from the Bering Arctic Subarctic Integrated Surveys in the EBS	+
Pacific cod biomass	Biomass (1,000t) of Pacific cod within the BBRKC management boundary on the EBS bottom trawl survey	-

Table 3a (cont.). First stage ecosystem indicator analysis for Bristol Bay red king crab (BBRKC), including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for BBRKC of the current year conditions relative to 1 standard deviation of the longterm mean (white = average, blue = good, red = poor, no fill = no current year data).

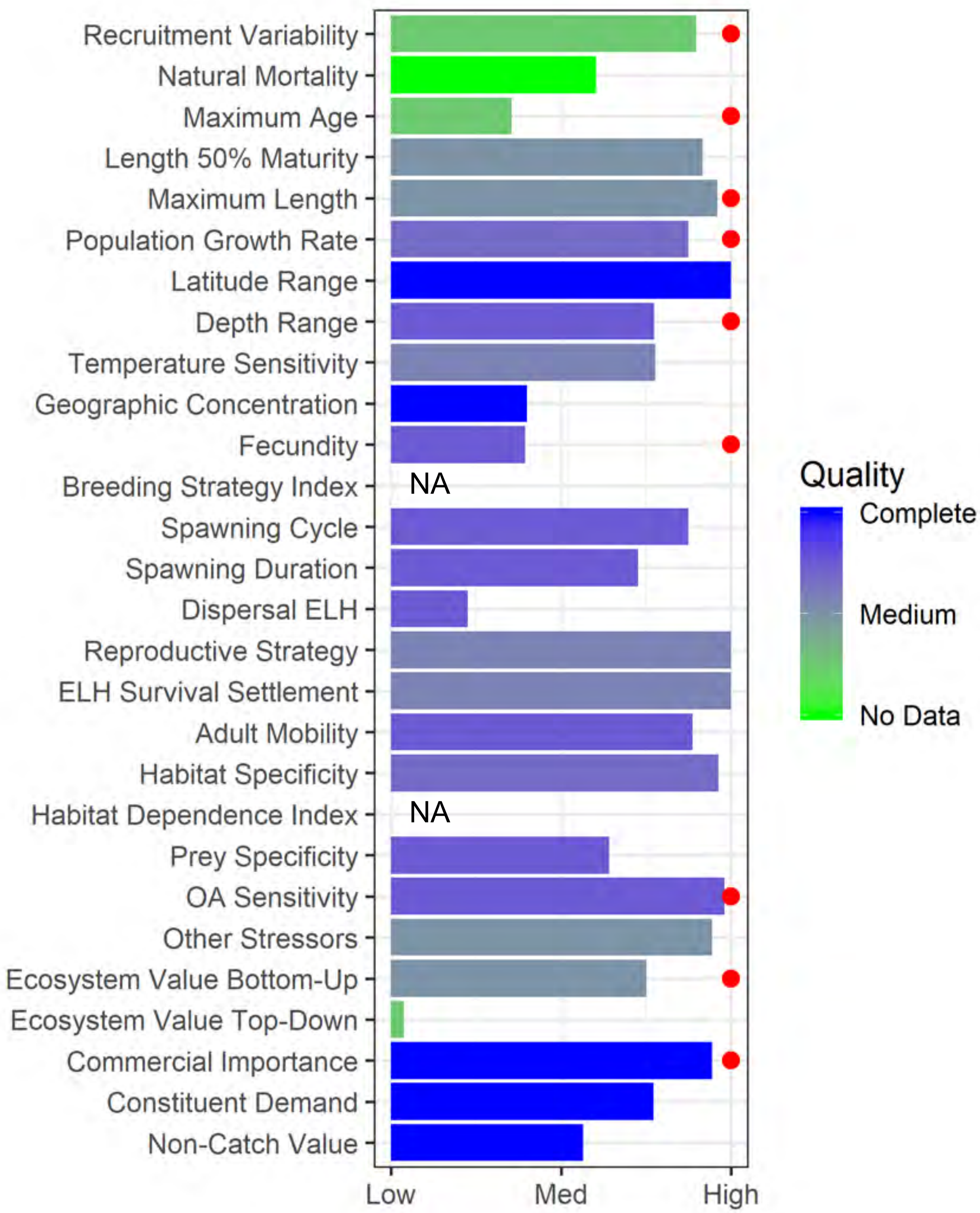
Title	Description	Recent
Benthic invertebrate biomass	Combined biomass (1,000t) of benthic invertebrates within the BBRKC management boundary on the EBS bottom trawl survey	●
BBRKC recruit biomass	Biomass of male red king crab (110-134 mm CL) from the EBS bottom trawl survey that will likely enter the fishery the following year.	-
BBRKC Catch Distance from Shore	Mean distance (km) legal male Bristol Bay red king crab were caught from shore in the autumn fishery (starting Oct. 15th) using observer data.	+
BBRKC mature male area occupied	The minimum area containing 95% of the cumulative CPUE for BBRKC mature males from the EBS bottom trawl survey	+
BBRKC mature female area occupied	The minimum area containing 95% of the cumulative CPUE for BBRKC mature females from the EBS bottom trawl survey	+

Table 3b. First stage socioeconomic indicator analysis for Bristol Bay red king crab (BBRKC), including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for BBRKC of the current year conditions relative to 1 standard deviation of the longterm mean (white = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
CPUE	Fishing effort efficiency, as measured by estimated mean number of retained BBRKC per potlift	●
Vessels active in fishery	Annual count of crab vessels that delivered commercial landings of BBRKC to processors[2]	-
Total Potlifts	Fishing effort, as measured by estimated number of crab pots lifted by vessels during the BBRKC fishery	●
BBRKC Male Bycatch in Groundfish Fishery	Incidental bycatch biomass estimates of male BBRKC (tons) in trawl and fixed gear fisheries	●
TAC Utilization	Percentage of the annual BBRKC TAC (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing.	●
Ex-vessel value of BBRKC landings	Aggregate ex-vessel value of BBRKC landings (as adjusted by CFEC to account for post-season adjustments to ex-vessel settlements), summed over all ex-vessel sales reported.	-
Ex-vessel price per pound	Commercial value per unit (pound) of BBRKC landings (as adjusted by CFEC to account for post-season adjustments to ex-vessel settlements), measured as weighted average value over all ex-vessel sales reported.	●
BBRKC ex-vessel revenue share	BBRKC ex-vessel revenue share as percentage of total calendar year ex-vessel revenue from all commercial landings in Alaska fisheries, mean value over all vessels active in BBRKC during the respective year.	-
Processors active in fishery	Total number of crab processors that purchased landings of BBRKC from delivering vessels during the calendar year.	-
Processing Employment in BBRKC	Crab processing employment generated in BBRKC fishery as measured by total paid hours of labor input by processing employees, summed over all shore-based plants that processed BBRKC landings.	-

Local Quotient of BBRKC landed catch in Dutch Harbor	Ex-vessel value share of BBRKC landings to Unalaska/Dutch Harbor, as percentage of total value of commercial landings to processors in the community from all commercial Alaska fisheries, as aggregate percentage over all landings during the respective year.	-

Figure 1. Baseline metrics for Bristol Bay red king crab graded as a percentile rank over all groundfish and crab stocks in the FMP. Higher rank values indicate a vulnerability and color of the horizontal bar describes data quality of the metric (see Shotwell et al., *In Review*, for more details on the metric definitions). The red dot is a threshold value based on information collected from national initiatives.



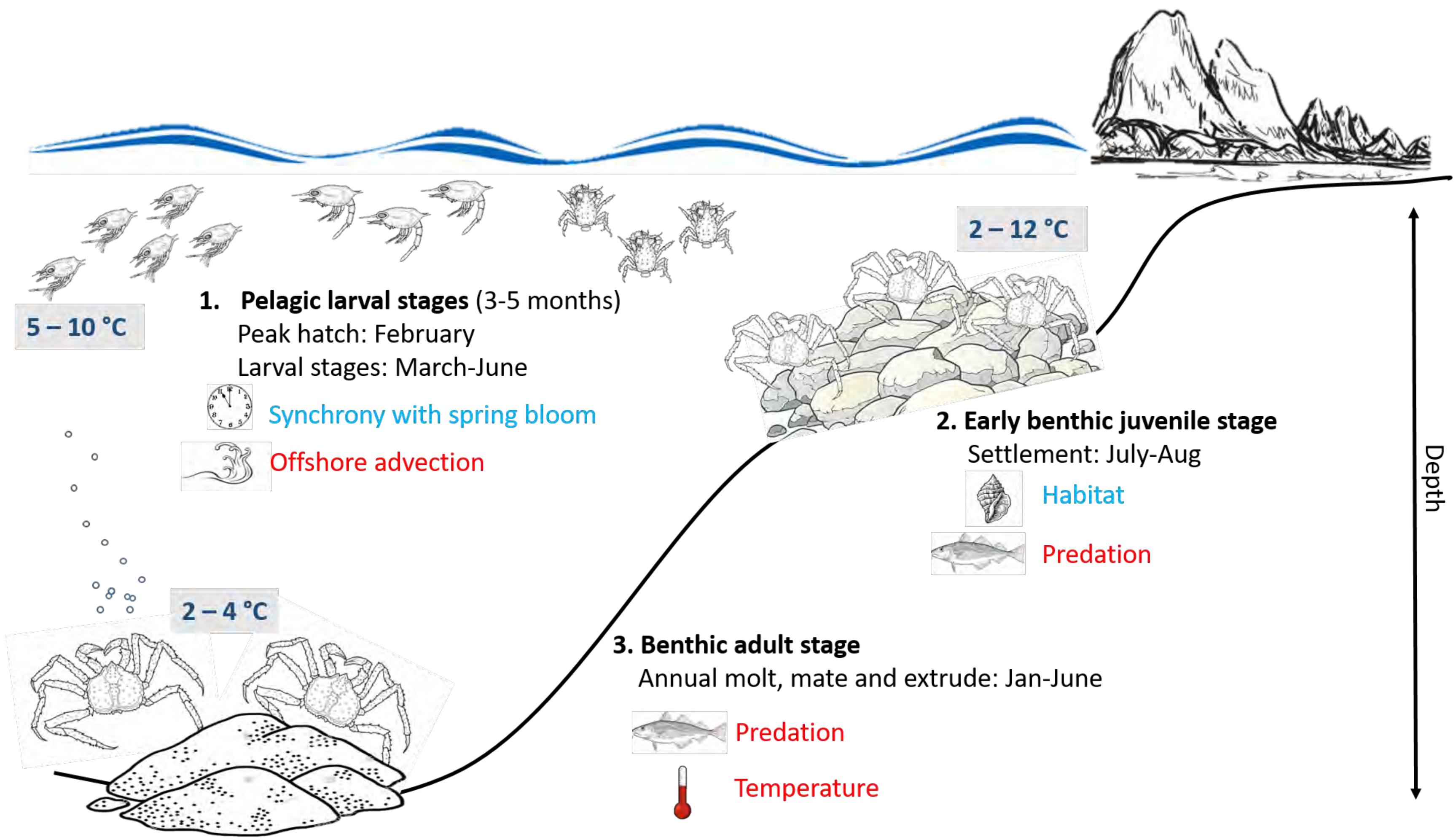


Figure 2a. Conceptual diagram of phenological information by life history stage for Bristol Bay red king crab and processes likely affecting survival in each stage. Thermal requirements by life history stage were determined from RKC laboratory studies.

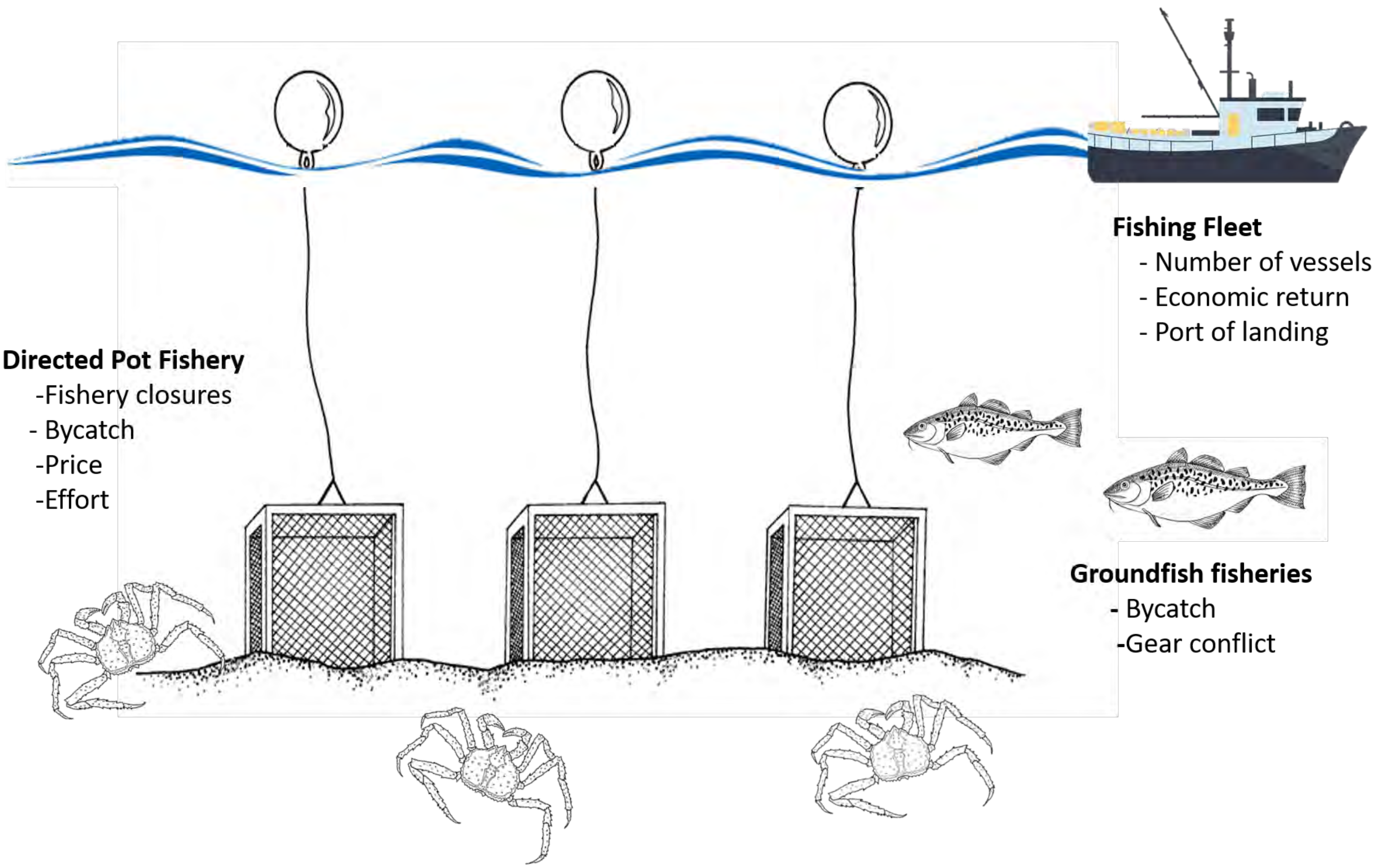


Figure 2b. Conceptual diagram of socioeconomic performance metrics that may identify dominant pressures on the Bristol Bay red king crab stock.

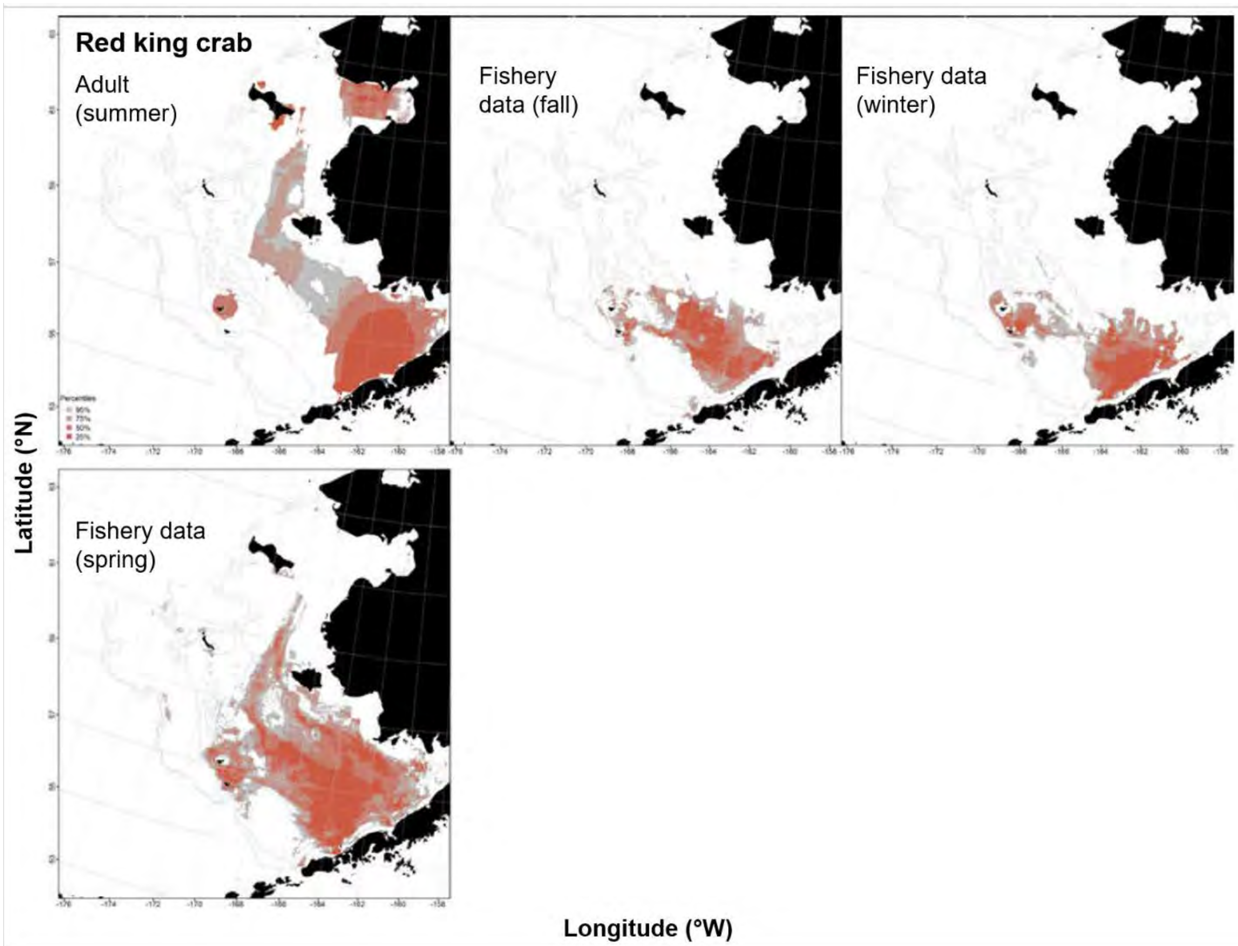


Figure 3. Essential fish habitat (EFH) predicted for red king crab (upper left panel) from RACE-GAP summertime bottom trawl surveys (1982-2014) and predicted from presence in commercial fishery catches (2003-2013) from fall, winter, and spring (remaining three panels) in the eastern Bering Sea. Figure modified from Laman et al., (2017).

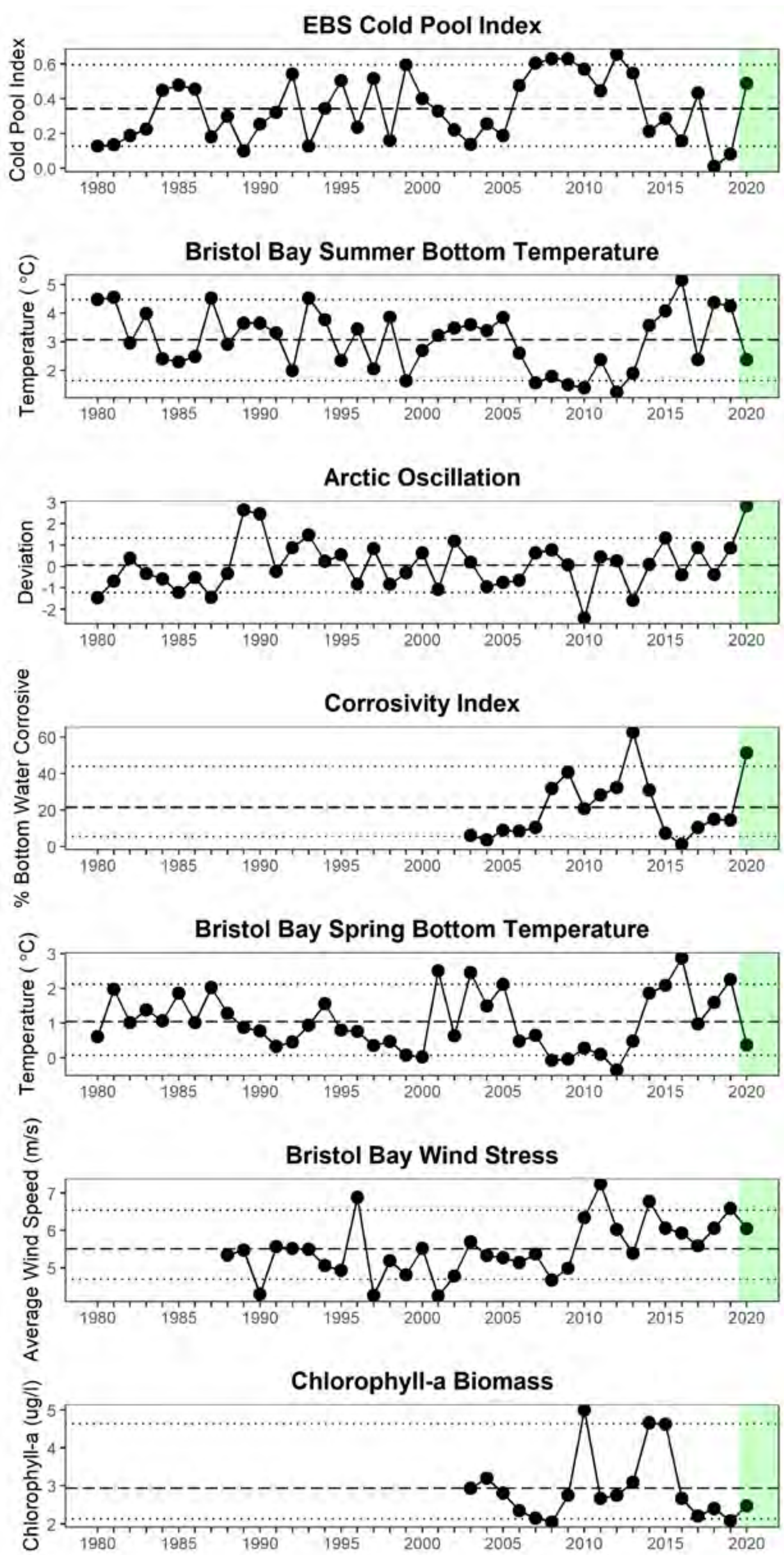


Figure 4. Selected ecosystem indicators for Bristol Bay red king crab with time series ranging from 1980 – 2020. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is the mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

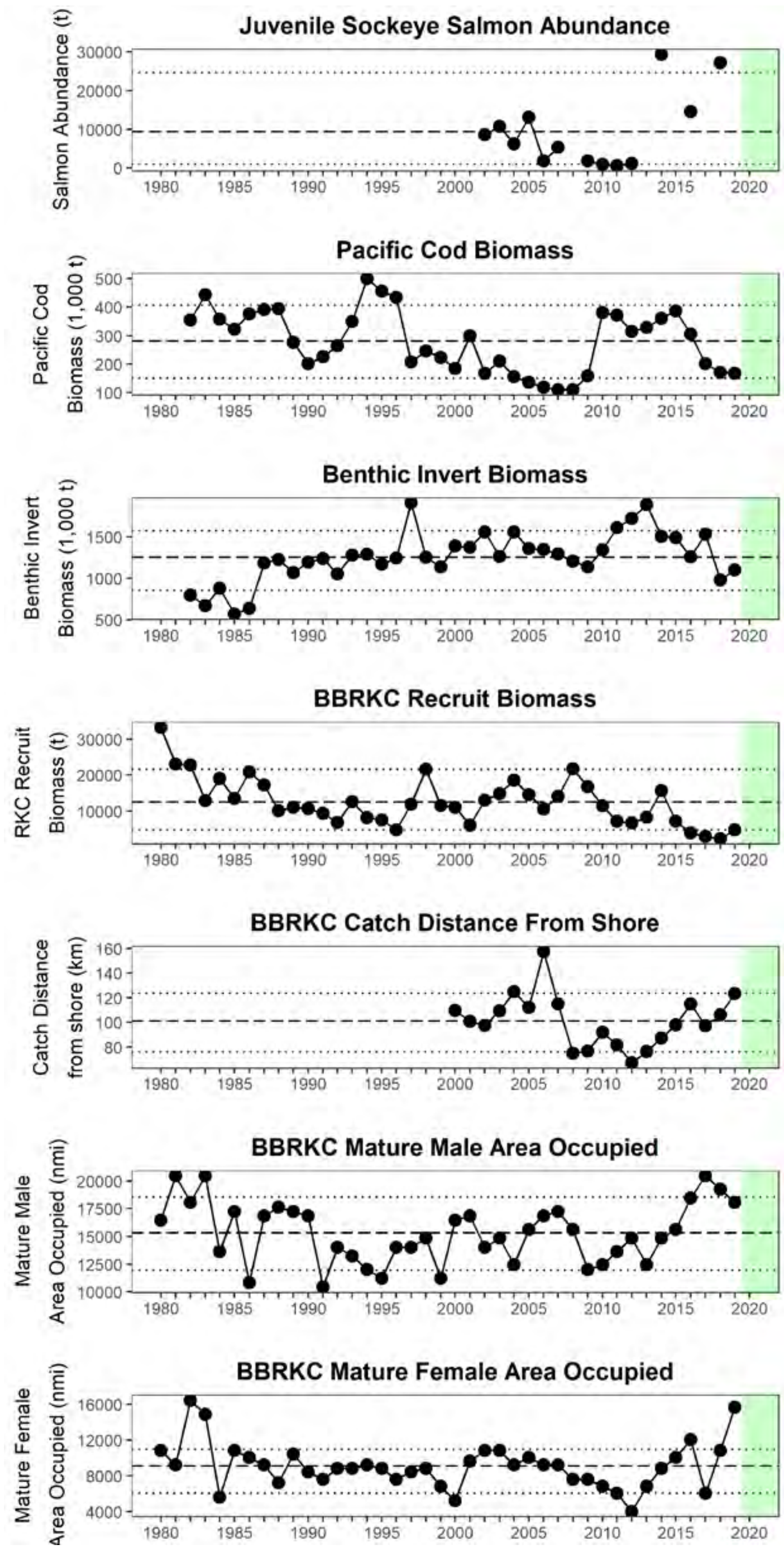


Figure 4 (cont.). Selected ecosystem indicators for Bristol Bay red king crab with time series ranging from 1980 – 2020. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is the mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

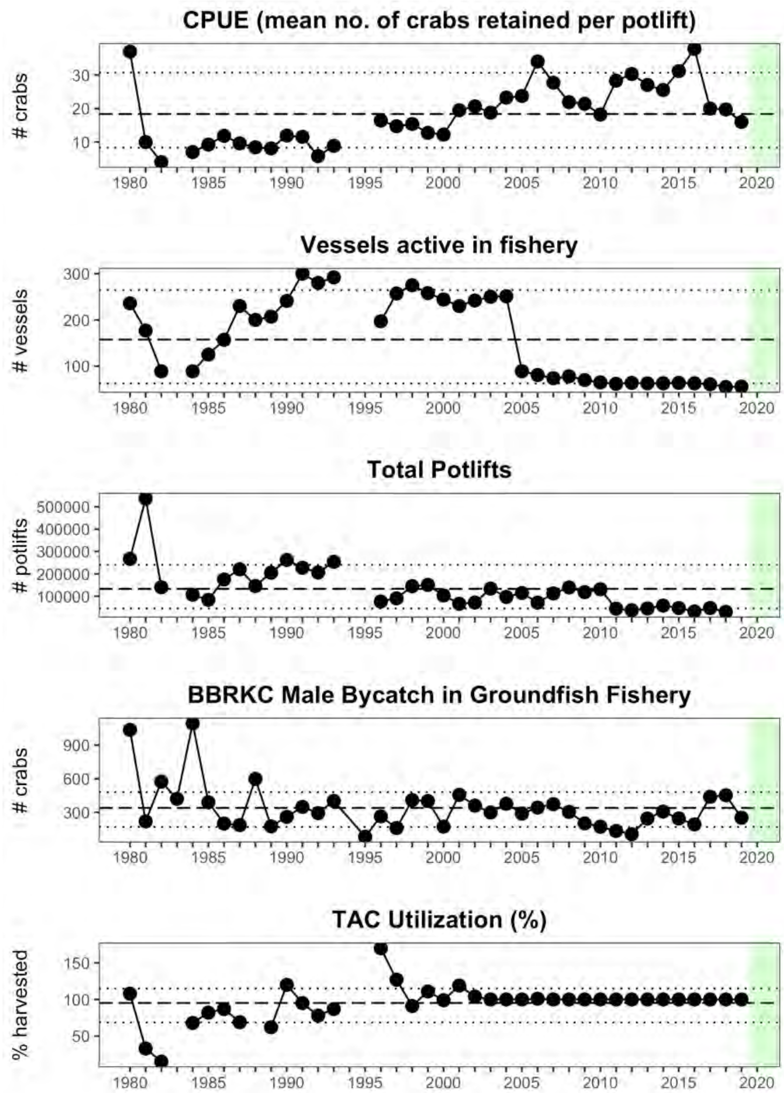


Figure 5. Selected socioeconomic indicators for Bristol Bay red king crab with time series ranging from 1980 – 2019. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is the mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

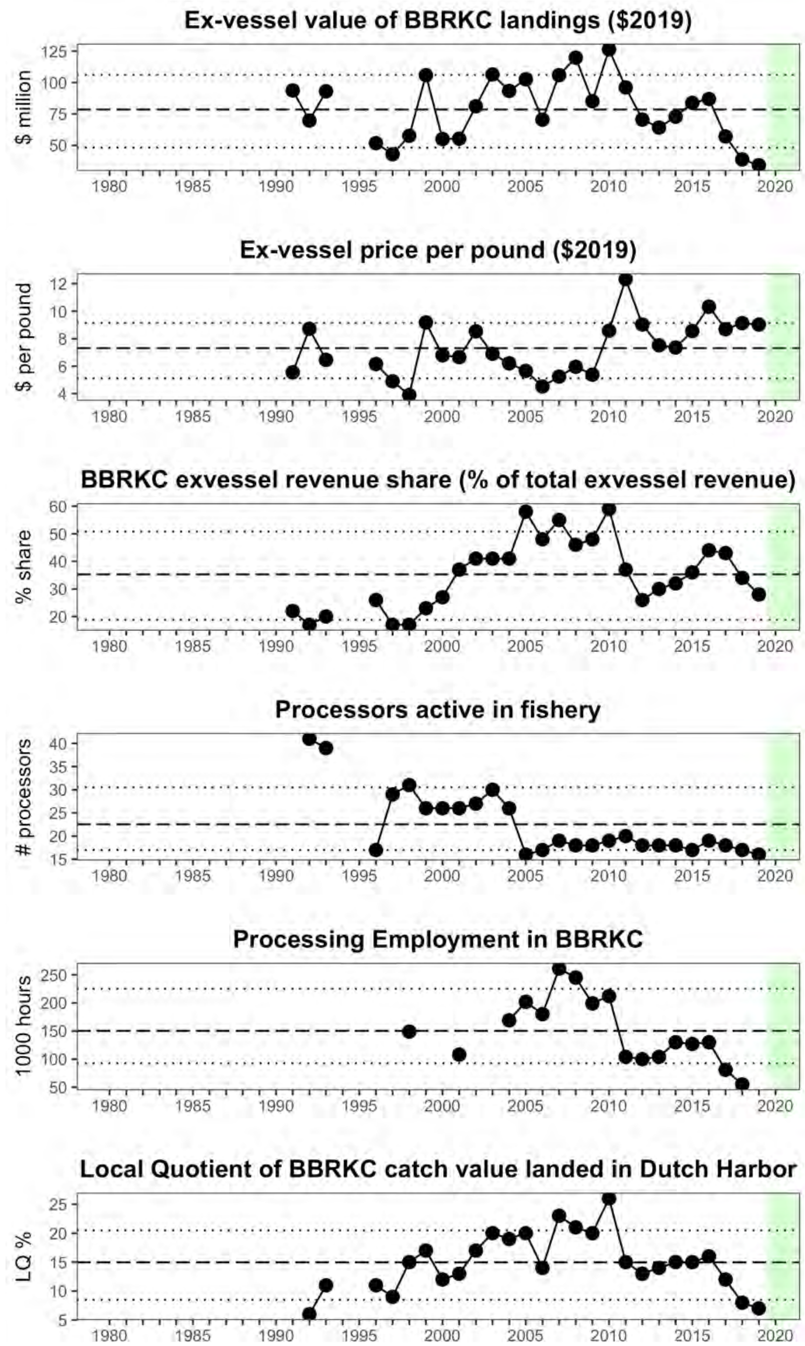


Figure 5. (cont.) Selected socioeconomic indicators for Bristol Bay red king crab with time series ranging from 1980 – 2019. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is the mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

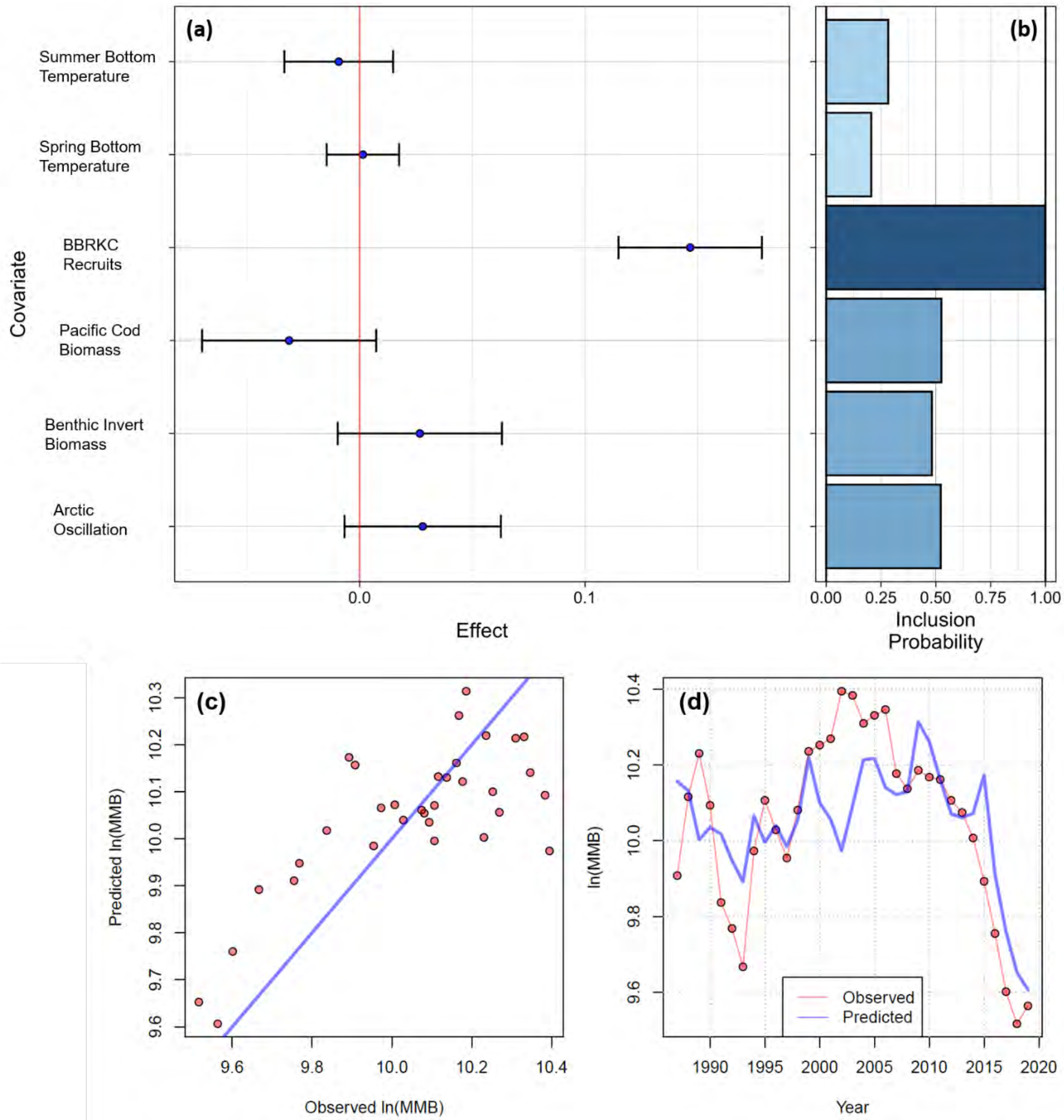


Figure 6. Bayesian adaptive sampling output showing the mean relationship and uncertainty (± 1 SD) with log-transformed Bristol Bay red king crab mature male biomass: a) the estimated effect and b) marginal inclusion probabilities for each predictor variable of the subsetted covariate ecosystem indicator dataset. Output also includes model c) predicted fit (1:1 line) and d) average fit across the MMB time series.

2020 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
September 2020

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 NPFMC annually determines the overfishing limit (OFL) and acceptable biological catch (ABC) levels for Tanner crab in the EBS, while the Alaska Department of Fish and Game (ADFG) determines the total allowable catch (TAC) separately for areas east and west of 166ºW longitude in the Eastern Subdistrict of the Bering Sea District Tanner crab Registration Area J. Following rationalization of the Bering Sea and Aleutian Islands (BSAI) crab fisheries in 2005/06, the directed fishery for Tanner crab was open through 2009/10, after which time it was determined that the stock was overfished in the EBS and directed fishing was closed. Prior to the closure, the retained catch averaged 770 t per year between 2005/06-2009/10. The directed fishery was re-opened in 2013/14 following determinations by NMFS in 2012 that the stock was rebuilt and no longer overfished and by ADFG that the stock met state harvest guidelines for opening the fishery. ADFG set the TAC 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. 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.

TACs were steadily increased for the next two years, with concomitant increasing harvests. In 2014/15, TAC was set at 6,625,000 lbs (2,329 t) for the area west of 166º W and at 8,480,000 lbs (3,829 t) for the area east of 166º W. On closing, 77.5% (2,329 t) of the TAC was taken in the western area while 99.6% (3,829 t) were taken in the eastern area. In 2015/16, TAC was set at 8,396,000 lbs (3,808 t) for the western area and 11,272,000 lbs (5,113 t) for the eastern area. On closing, essentially 100% of the TAC was taken in both areas (8,373,493 lbs [3,798 t] in the western area, 11,268,885 lbs [5,111 t] in the eastern area based on the 5/20/2016 in-season catch report).

Although the NPFMC determined an OFL of almost 60,000,000 lbs (~25,000 t) based on the 2016 assessment (Stockhausen, 2016), mature female Tanner crab biomass fell below the threshold set in the State of Alaska's harvest strategy for opening the fishery; consequently, the fishery was closed and the TAC was set to 0. Thus, no directed harvest occurred in 2016/17. In 2017/18, ADFG determined that a directed fishery could occur in the area west of 166ºW longitude. The TAC was set at 2,500,200 lbs (1,130 t), of which 100% was taken. A similar situation occurred in 2018/19, with only the area west of 166ºW open to directed fishing. The TAC for 2018/19 was 2,439,000 lbs (1,106 t), with slightly more actually harvested (2,441,201 lbs [1,107 t]). Mature female biomass again fell below State of Alaska's threshold for opening the 2019/20 Tanner crab fishery (The 2019/20 OFL was 63,620,000 lbs [28,860 t]) and no directed occurred in 2019/20.

In addition to legal-sized males, females and sub-legal males are taken in the directed fishery as bycatch and must be discarded. Discarding of legal-sized males also occurs, primarily because the minimum size preferred by processors is larger than the minimum legal size but also because "old shell" crab can be less desirable than "new shell" males. No bycatch occurred in the directed fishery in 2019/20, of course, because it was closed. The average bycatch over the last five years the fishery was open (i.e., since 2013/14) in the directed fishery was 1,396 t. Tanner crab are also taken as bycatch in the snow crab and Bristol Bay red king crab fisheries, in the groundfish fisheries and, to a very 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 ~1,900 t for the 5-year period 2015/16-2019/20. Bycatch in the snow crab fishery in 2019/20 was 1,018 t. The groundfish fisheries have been the next major source of Tanner crab bycatch over the same five year time period, averaging 229 t. Bycatch in the groundfish fisheries in 2019/20 was 148 t. Excluding the scallop fishery, the Bristol Bay red king crab fishery has typically been the smallest source of Tanner crab bycatch among these fisheries, averaging 134 t over the 5-year time period. In 2019/20, this fishery accounted for only 18 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, 50% for Tanner crab in the groundfish fisheries using fixed gear, 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 (20.07), estimated MMB for 2019/20 was 56.1 thousand t (Table 30). MMB has been on a declining trend since 2014/15 when it peaked at 131.7 thousand t, and it is approaching the very low levels seen in the mid-1990s to early 2000s (1993 to 2003 average: 55.1 thousand t).

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

From the author's preferred model (20.07), the estimated total recruitment for 2020 (the number of crab entering the population on July 1) is 274.5 million crab (Table 33). However, this estimate is uninformed by data because the 2020 NMFS EBS shelf bottom trawl survey was canceled due to safety concerns associated with the COVID-19 pandemic. As such, it is highly uncertain. More believable, but still fairly uncertain, last year's estimated recruitment of 1193.6 million crab was the highest since 2008. Average recruitment over the previous 10 years is 398 million crab, which is slightly above the longterm (1982+) mean of 370 million crab.

5. Management performance

Historical status and catch specifications for eastern Bering Sea Tanner crab, with 2020/21 values based on the author's recommended model, 20.07, and MCMC results.

(a) in 1000's t.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2016/17	14.58	77.96	0.00	0.00	1.14	25.61	20.49
2017/18	15.15	64.09	1.13	1.13	2.37	25.42	20.33
2018/19	20.54	82.61	1.11	1.11	1.90	20.87	16.70
2019/20	18.31	56.15	0.00	0.00	0.54	28.86	23.09
2020/21		35.31				20.88	16.70

(b) in millions lbs.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2016/17	32.15	171.87	0.00	0.00	2.52	56.46	45.17
2017/18	33.40	95.49	2.50	2.50	5.22	56.03	44.83
2018/19	45.27	182.09	2.44	2.44	4.18	46.01	36.82
2019/20	40.36	123.77	0.00	0.00	1.20	63.62	50.89
2020/21		77.84				46.02	36.82

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 retained catch and total catch mortality.

6. Basis for the OFL

a) in 1000's t.

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY}	F_{OFL} (yr^{-1})	Years to define B_{MSY}	Natural Mortality (yr^{-1})
2016/17	3a	25.65	45.34	1.77	0.79	1982-2016	0.23
2017/18	3a	29.17	47.04	1.49	0.75	1982-2017	0.23
2018/19	3a	21.87	23.53	1.08	0.93	1982-2018	0.23
2019/20	3b	41.07	39.55	0.96	1.08	1982-2019	0.23
2020/21	3b	36.62	35.31	0.96	0.93	1982-2019	0.23

b) in millions lbs.

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY}	F_{OFL} (yr^{-1})	Years to define B_{MSY}	Natural Mortality (yr^{-1})
2016/17	3a	56.54	99.95	1.77	0.79	1982-2016	0.23
2017/18	3a	64.30	103.70	1.49	0.75	1982-2017	0.23
2018/19	3a	48.21	51.87	1.08	0.93	1982-2018	0.23
2019/20	3b	90.53	87.18	0.96	1.08	1982-2019	0.23
2020/21	3b	80.72	77.84	0.96	0.93	1982-2019	0.23

Notes: Values are 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 2020/21. Values for natural mortality are nominal. Actual rates used in the assessment are estimated and may be different.

Current male spawning stock biomass (MMB), as projected for 2020/21, is estimated at 35.31 thousand t. B_{MSY} for this stock is calculated to be 36.62 thousand t, so MSST is 18.31 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 2019/20 was 0.54

thousand t, which was less than the OFL for 2019/20 (28.86 thousand t); consequently, **overfishing did not occur**. The OFL for 2020/21, based on the author's preferred model (20.07), is 20.88 thousand t. The ABC_{max} for 2020/21, based on the p^* ABC, is 20.87 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 16.70 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.
The SOA's harvest control rule (HCR) for setting TAC in the directed Tanner crab fisheries has undergone three revisions in the past 6 years (Daly et al., 2020). In 2015, the minimum preferred harvest size used to compute TAC for the area east of 166ºW longitude was changed from 140 mm CW (5.5 inches; including the lateral spines) to 127 mm CW (5.0 inches), the preferred size used to compute TAC for the area west of 166ºW longitude. In 2017, the criteria used to determine mature female biomass (MFB) was changed from an area-specific one based on carapace width to one based on morphology (the same as that used by the NMFS EBS shelf bottom trawl survey), the definition of 'long-term average' for calculating average mature biomass was changed from 1975-2010 to 1982-2016, the spatial range for calculating average MFB was expanded to include the entire NMFS EBS shelf bottom trawl survey area, and a so-called 'error band system' was introduced to account for survey uncertainty such that the exploitation rate on industry-preferred males used to calculate was gradually reduced when the lower 95% confidence interval of the point estimate of MFB fell below 40% of the long-term average (replacing a requirement to close the fisheries when MFB fell below the 40% threshold; ADF&G, 2017; Daly et al., 2020). In March 2020, the harvest control rule was again changed based on results from an extensive management strategy evaluation (MSE) conducted with input from industry stakeholders, NMFS and academic scientists, and ADF&G managers (Daly et al., 2020). The current HCR (HCR 4_1 in Daly et al., 2020) defines the period for calculating average mature biomass as 1982-2018 and implements sliding scales for exploitation rates on mature males which are functions of the ratios of MMB and MFB to their longterm averages.

The directed Tanner crab fishery east of 166ºW longitude has been closed since 2016/17 because mature female Tanner crab biomass in the area has failed to meet the criteria defined in the SOA's harvest strategy to open the fishery. The directed fishery west of 166ºW longitude was also closed in 2016/17, but was prosecuted in 2017/18 and 2018/19. It was closed, as well, in 2019/20.

2. Changes to the input data
Due to safety concerns associated with the COVID-19 pandemic, the 2020 NMFS EBS shelf bottom trawl survey was cancelled. In addition, the directed fisheries for Tanner crab were closed by SOA regulation (estimated mature female biomass failed to meet the criteria for opening the fisheries). Thus, the changes to the input data to the assessment consisted mainly of finalized catch data for 2018/19 and new bycatch data for 2019/20. However, estimated bycatch abundance and biomass in the groundfish fisheries for 2016/17-2018/19 also changed because AKFIN updated the algorithms it uses to calculate the estimate to match those the NMFS Alaska Regional Office uses to calculate Prohibited Species Catch (PSC) estimates. The following table summarizes data sources that have been updated for this assessment:

Updated data sources.

Description	Data types	Time frame	Notes	Source
NMFS EBS Bottom Trawl Survey	area-swept abundance, biomass	1975-2019	no 2020 survey	NMFS
	size compositions	1975-2019	no 2020 survey	
	male maturity data	2006+	no new data	
NMFS/BSFRF	molt-increment data	2015-17, 2019	no new data	NMFS, BSFRF
BSFRF SBS Bottom Trawl Survey	area-swept abundance, biomass	2013-17	no new data	BSFRF
	size compositions	2013-17	no new data	
Directed fishery	historical retained catch (numbers, biomass)	1965/66-1996/97	not updated	2018 assessment
	historical retained catch size compositions	1980/81-2009/10	not updated	2018 assessment
	retained catch (numbers, biomass)	2005/06-2018/19	fisheries closed 2019/20	ADFG
	retained catch size compositions	2013/14-2018/19	fisheries closed 2019/20	ADFG
	total catch (abundance, biomass)	1991/92-2018/19	fisheries closed 2019/20	ADFG
	total catch size compositions	1991/92-2018/19	fisheries closed 2019/20	ADFG
Snow Crab Fishery	historical effort	1978/79/1989/90	not updated	2018 assessment
	effort	1990/91-2019/20		ADFG
	total bycatch (abundance, biomass)	1990/91-2019/20		ADFG
	total bycatch size compositions	1990/91-2019/20		ADFG
Bristol Bay Red King Crab Fishery	historical effort	1953/54-1989/90	not updated	2018 assessment
	effort	1990/91-2019/20		ADFG
	total bycatch (abundance, biomass)	1990/91-2019/20		ADFG
	total bycatch size compositions	1990/91-2019/20		ADFG
Groundfish Fisheries (all gear types)	historical total bycatch (abundance, biomass`	1973/74-1990/91	not updated	2018 assessment
	hostorical total bycatch size compositions	1973/74-1990/91	not updated	
	total bycatch (abundance, biomass)	1991/92-2019/20	now using AKRO algorithm for 2016/17+	NMFS/AKFIN
	total bycatch size compositions	1991/92-2019/20		

3. Changes to the assessment methodology.

The assessment model framework, TCSAM02, is described in detail in Appendix 1. The model accepted for the 2019 assessment, "19.03" (referred to as M19F03 in the 2019 SAFE chapter), differed rather substantially from the 2017 and 2018 assessment models by: 1) adding a likelihood component to fit annual male maturity ogives determined from chela height-to-carapace width ratios in the NMFS survey; 2) eliminating fits to survey biomass and size composition data for male crab classified as mature/immature based on a maturity ogive determined outside the model; and 3) instead fitting to time series of undifferentiated male survey biomass, abundance, and size compositions. In addition, this scenario fit revised time series data for retained and total catch biomass since 1990/91 provided by ADFG for the directed Tanner crab, snow crab and Bristol Bay red king crab fisheries. The model scenario 19.03(2020) is the base model for this assessment, and represents last year's assessment model, 19.03, with the addition of fishery data for 2019/20.

The additional uncertainty introduced into the assessment due to the lack of a 2020 NMFS EBS shelf bottom trawl survey was evaluated (Appendix 2) for 19.03 and 19.03(2020) using: 1) retrospective analyses in which the terminal year was sequentially dropped from the 19.03 dataset, re-run, and compared with results from the same model run without NMFS survey data in the terminal year and 2) model runs with simulated 2020 survey biomass data that bracketed the range of the value expected if the survey had been conducted.

The author-preferred scenario for this assessment is Scenario 20.07, which builds on 19.03 by incorporating BSFRF trawl survey data from its cooperative "side-by-side" (SBS) catch comparison studies with the NMFS EBS shelf bottom trawl survey in order to better fix the scale of the NMFS survey data. Empirical availability curves for the BSFRF were determined outside the assessment model (Appendix 3). These were used in the model to relate the BSFRF estimates of absolute abundance (at spatial scales smaller than the stock distribution) and the stock abundance estimated by the assessment model.

4. Changes to the assessment results
Changes in the assessment results are relatively minor, but this may reflect the absence of data from the cancelled NMFS EBS shelf bottom trawl survey. Average recruitment (1982-2019) was estimated at 394 million in last year's assessment, but it is slightly lower at 370 million from the author's preferred model this year. F_{MSY} is smaller this year (0.96 yr^{-1} this year vs. 1.18 yr^{-1} last year), as is B_{MSY} (36.62 thousand t vs. 40.75 thousand t). The stock remains in Tier 3b because the ratio of projected MMB to B_{MSY} is below 1 (as it was last year). Because both average recruitment and F_{MSY} were estimated somewhat smaller than last year, this year's OFL ended up being smaller than that for 2019/20 by 28%.

B. Responses to SSC and CPT Comments

1. Responses to the most recent two sets (May/June 2020, September/October 2019) of SSC and CPT comments on assessments in general. [Note: for continuity with the previous assessment, the following may include comments prior to the most recent two sets.]

June 2020 SSC Meeting
SSC Comment: The SSC reminds all stock assessment authors to implement the guidelines for model numbering for consistency and easier version tracking over time, and emphasizes how important this is for SSC review.
Response (9/20): The SSC numbering convention is followed in this chapter (having finally been implemented for Tanner crab in May 2020).

May 2020 CPT Meeting
CPT Comment: Should no survey occur, the CPT recommends that stock assessment authors roll over last year's accepted model, incorporating updated fishery data when possible, and projecting OFL/ABCs based on our understanding of stock trends from surveys to 2019.
Response (9/20): The 2020 NMFS EBS Shelf bottom trawl survey was indeed cancelled. Model runs were conducted with last year's accepted model, updated with fishery data for 2019/20 (Scenario 19.03(2020)). Additional runs were made that included simulated 2020 survey data which bracketed the survey biomass for 2020 predicted by 19.03(2020) by 25% of expected variation. The results of these runs are discussed in Appendix 2 but the variability had little effect on the resulting OFL because other quantities exhibited offsetting changes.

Oct 2019 SSC Meeting
SSC Comment: The SSC reminds authors to use the model numbering protocols that allows the SSC to understand the year in which a particular version of the model was first introduced.
Response (5/20): The requested numbering protocols have been implemented, with the 2019 assessment model "backdated" and referred here as 19.03 (where it was referred to 19F03 during the 2019 assessment).

SSC Comment: the SSC requests that the CPT consider developing a standard approach for projecting the upcoming year's biomass that does not include removing the entire OFL for stocks where recent mortality has been substantially below the OFL. This may appreciably change the projected biomass levels for stocks such as Tanner crab, where actual catch mortality has been less than 10% of the OFL .
Response (updated 9/20): The CPT has not yet developed a standard approach for doing so, but will discuss ideas at the September 2020 meeting for implementation prior to the May 2021 CPT meeting.

SSC Comment: the SSC encouraged authors to work together to create a standard approach for creating priors on selectivity and catchability from these (BSFRF/NMFS side-by-side trawl) data for use in the respective assessments. A hierarchical comparison of all species pooled, separated species, and separated sexes may be helpful for understanding where statistically supported differences exist. Where sample sizes are modest (e.g., snow crab), bootstrapping, or a sample size-weighted estimate rather than a raw average may be useful for aggregating across years.
Response (updated 9/20): An option to use such priors has also been added to the Tanner crab assessment model code, but has not yet been utilized. Results from a preliminary attempt to develop priors on sex/size-specific catchability (q *x* selectivity) and availability were presented for Tanner crab in the May 2020 CPT Report. Further work estimating catchability outside the assessment model using catch ratio analysis of the BSFRF/NMFS side-by-side trawl data using GAMMs is underway but incomplete (see Appendix 4 for an interim report). A model scenario (20.10) using the "best" estimates (from a limited, preliminary set of candidate models) of sex-specific catchability from this analysis is presented in this chapter, however, the estimated catchability curves are used as "known" in the assessment model rather than as priors partly because the uncertainty associated with the curves has not yet been adequately characterized and partly because assuming the curves are known reduces the complexity of the model. The suggested hierarchical comparison is an intriguing suggestion, and can be addressed in future research.

September 2019 Crab Plan Team Meeting
No new general comments.

October 2018 SSC Meeting
SSC Comment: The SSC encourages authors (using VAST estimates of survey biomass) to consider whether or not the apparent reduction in uncertainty in survey biomass is appropriately accounted for with their models.
Updated response (09/20): At its May 2020 meeting, the CPT suggested authors not use VAST estimates in assessment models until the estimates could be better validated.

Updated response (05/20): Two model scenarios fitting VAST estimates of survey biomass were included in this report: one which fit the estimates without adjusting the variance estimates and one which estimated parameters describing "extra" uncertainty (i.e., re-inflating the uncertainty of the VAST estimates). While the model fit without estimating "extra" uncertainty was "worse" from a strictly likelihood perspective (larger z-scores) compared to that from the same model fit to the standard design-based estimates, the predicted values "fit" the VAST estimates better from a visual standpoint (i.e., on a scale unweighted by the uncertainty). Unfortunately, the attempt to compensate for the possible over-shrinkage of uncertainty in the VAST estimates by estimating parameters related to "extra" uncertainty failed because the model converged to with the parameters at their upper bounds (equivalent to "extra" CVs of 270%).

2. Responses to the most recent two sets (May/June 2020, September/October 2019) 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 2020 SSC Meeting
SSC Comment: The SSC requested that, for the next assessment, models be reparametrized, simplified, or have parameter bounds adjusted such that no parameters remain at the bounds after estimation.
Response (9/20): Several attempts so far to do so have not been successful. Model scenario 20.10 considered here reduced the number of parameters at bounds from 12 to 5, but was unsatisfactory for other reasons. It appears that reparameterizing selectivity functions from using logistic functions to using half-normal functions may eliminate several such parameters. It is also apparent that three parameters related to estimates of fully-selected retention can be eliminated. A simplified male-only model including

only the directed and snow crab fisheries as source of fishing mortality is being investigated, as well as whether bycatch in the BBRKC fishery is small enough to be dropped post-2004 (at least for females). As such, a number of avenues are being explored but work continues on this topic.

SSC Comment: Provide additional information on data weighting. Specifically, identify standardized residuals appreciably greater than would be expected by chance (e.g., values of four and larger), report mean input and harmonic mean effective sample sizes by source for evaluation of model fit, and consider basing input sample sizes on the number of trips/hauls sampled rather than the number of individual crab measured.
Response (9/20): Information is not currently provided to base input sample sizes on the number of trips/hauls sampled for fishery-related size compositions, and the sample sizes in the survey are limited to 200 in order to avoid numerical issues (the number of hauls would typically be 375 in any survey year post-1987, and would never be as low as 200 in any case). Geometric mean, not harmonic mean, effective sample sizes based on the McAllister-Ianelli method are provided for all size composition data. Large standardized residuals are not specifically flagged as part of the assessment model output. This capability will be added in the future.

SSC Comment: The SSC reiterated its previous recommendation on analysis of the BSFRF data. The SSC encouraged authors to work together to create a standard approach for creating priors on selectivity and catchability from these data for use in the respective assessments. A hierarchical comparison of all species pooled, separated species, and separated sexes may be helpful for understanding where statistically supported differences exist. Where sample sizes are modest (e.g., snow crab), bootstrapping, or a sample size-weighted estimate rather than a raw average may be useful for aggregating across years.
Response: This needs to be highlighted as a request to the CPT to add this topic as an agenda item to its January 2021 meeting, if possible. It seems like the best avenue forward at the moment is for individual authors to continue to develop the best analysis for their own stock. These can be compared in January and perhaps the best of these can be used as the basis for an hierarchical model, as the SSC recommends. Off hand, it seems likely that the differing morphological characteristics of *Chionoecetes* and *Paralithodes* crab, as well as the different environmental conditions they experience across the EBS shelf, will affect catchability differently and produce statistically-supported differences among the stocks.

May 2020 CPT Meeting

CPT Comment: Therefore, the CPT recommends that model 20.07 be identified as a preliminary base model for September. The CPT discussed a refinement to model 20.07 (here denoted model 20.07b), in which the empirical availability curves are input as data vectors with specified uncertainty, rather than assumed known. If Model 20.07b turns out to be straightforward to implement, as we expect, then Model 20.07b could be regarded as the preliminary base model rather than Model 20.07.
Response: Given the current model code, Model 20.07b would be possible to implement, once the empirical curves and associated uncertainty were developed. Empirical curves (smooth functions of size) were developed by fitting the ratio of observed survey abundance in the side-by-side study area to that from the entire survey area on an annual basis for 2013-2017 using the same size bins as in the assessment model (Appendix 3). However, it is unclear what the appropriate measure of uncertainty should be. Estimates of uncertainty from fitting the empirical curves seem to be too small, while ones developed previously from bootstrapping (May 2020 CPT Tanner Crab Report) seem to be too large. With more pressing issues (characterizing the uncertainty associated with the missing 2020 NMFS EBS shelf bottom trawl survey), it was not possible to further resolve this one. The author looks forward to recommendations to move forward.

CPT Comment: Consider ways to remove any additional complexity in the Tanner crab assessment that does not add to our understanding of stock dynamics.
Response (9/20): A male-only model including only the directed and snow crab fisheries is in development as a simplified baseline for adding further complexity (e.g., bycatch in the groundfish and BBRKC fisheries). A model that starts in 1982, after the survey gear change, is under consideration for development. Its implementation would require new code to parameterize the initial size compositions; this approach would be substantially different from the way the model is initialized at present.

CPT Comment: Evaluate potential conflicts between data sets in the assessment using likelihood profiles and other approaches.
Response (9/20): This is a good suggestion, but ADMB's likelihood profiling does not appear to be adequate to address this request because it does not report individual components to the likelihood. Thus, some specialized software needs to be developed in order to proceed.

CPT Comment: Further work is needed to incorporate empirical estimates of catchability in the assessment. Quantifying uncertainty in catchability is critical. Uncertainty estimates should consider year-to-year variation catchability either as a random effect or as a level of a hierarchical model.
Response: Survey catchability for the NMFS EBS shelf bottom trawl survey was estimated outside the assessment model using BSFRF-NMFS side-by-side (paired tows) data in a catch-comparison analysis (Appendix 4). The catchability curves were estimated using GAMs with haul as a random effect. The analysis of models with year as a random effect, as well as the addition of potential environmental covariates, is pending. The curves were used in Scenario 20.10 as "known" values without any uncertainty. The author welcomes more-specific recommendations on how best to quantify the uncertainty, as well as how to include it in the assessment model.

October 2019 SSC Meeting
SSC comment: The SSC requested that for the next assessment, models be reparameterized, simplified, or have parameter bounds adjusted such that no parameters remain at the bounds after estimation.
Response: See response above.

SSC comment: Use the standard model numbering approach.
Response: Done.

SSC comment: In next year's assessment, project biomass using a mortality level consistent with recent years, rather than the full OFL (see general CPT comments).
Response: See response above.

SSC comment: Provide a retrospective analysis for future assessments.
Response (9/20): Retrospective analyses are now provided.

SSC comment: Add the 2018 BSFRF/NMFS side-by-side data for all future analyses of that time-series.
Response (9/20): BSFRF has not provided this data, although it has been promised.

SSC comment: Report the values for natural mortality actually used for calculation of reference points in the appropriate table(s).
Response (9/20): The values for natural mortality actually used for calculation of reference points are now reported in tables in the Introduction to the SAFE and are updated by the CPT.

SSC comment: Provide additional information on data weighting. Specifically, identify standardized residuals appreciably greater than would be expected by chance (e.g., values of 4 and larger), report mean input and harmonic mean effective sample sizes by source for evaluation of model fit, and consider basing input sample sizes on the number of trips/hauls sampled rather than number of individual crab measured..
Response: See response above.

September 2019 CPT Meeting
The CPT suggested exploring appropriate values for catchability. For example, runs that fit to the BSFRF data and fix availability to empirical estimates to contrast the outcomes with runs in which availability is estimated could be informative for what is driving the small estimates of catchability in the author-preferred model.
Response (9/20): Empirical estimates of availability and selectivity were developed from BSFRF and NMFS side-by-side (SBS) selectivity study data for Tanner crab and presented in the May 2020 CPT Report. These were used in several model scenarios.

The CPT suggested exploring the relationship between natural mortality, growth, and overestimates of large crab. For example, estimate growth outside the model to attempt to address the overestimates of large crab.
Response (9/20): Model scenarios have been run where growth is estimated outside the model. This does not seem to solve this issue. Software to perform a likelihood profile on male growth parameters is under development and the results of the profile will hopefully shed some light on this issue.

The CPT suggested exploring maturity states for growth increment data and make recommendations for directions for growth model development.
Response (9/20): Except for the 2019 data, there seems to be little information on whether or not a molt was considered terminal.

Response (5/20): Work is in progress to address this issue.

The CPT requested include the data to which the models are fit for the survey biomasses figures in the presentation.
Response (5/20): The data was dropped for clarity of comparison among model predictions of survey biomass. The data will be included in future plots of this sort.

The CPT requested that if 'catchability' is to be used for something similar to 'fully-selected fishing mortality', perhaps translate it to a 0-1 scale and distinguish it from survey catchability so that it is clear that there is mortality associated with it.
Response (5/20): The term "catchability" was used to describe the rate at which "fully-selected" crab are captured in a fishery. Because some discards are assumed to survive, this is not equivalent to "fully-selected fishing mortality" (if discard mortality were 0, there would be *no* mortality associated with capture in a bycatch fishery). Perhaps "capturability" would cause less confusion?

The CPT requested that the author explore ways to provide a retrospective analysis of the assessment model.
Updated Response (9/20): A substantial effort was made to add the capability to perform a retrospective analysis to the assessment model. Retrospective analyses are provided here for several model scenarios.

June 2019 SSC Meeting
The SSC endorsed the CPT suggestions from its May meeting.
Response: none.

The SSC requested an evaluation of all parameters estimated to be at or very near bounds, or substantially limited by priors (unless those priors can be logically defended).
Original response (9/19): Two tables of parameters estimated at or near their bounds are provided (Tables 18 and 19). These parameters are estimated at their bounds in all (or nearly all) of the scenarios examined here. The parameters include one related to peak retention in the directed fishery prior to 1997 (at its upper bound on the logit scale, implying full retention of large legal males) and two related to the probability of undergoing terminal molt (effectively 1 for males in the largest model size bin and 0 for females in the smallest model size bin). These could be fixed in future models (the latter two are in several scenarios here). Survey catchability parameters for the 1975-1981 time period were also estimated at their lower bound (0.5). This might not be unreasonable given the reduced areal coverage of these surveys relative to later surveys and the spatial limits of the Tanner crab stock. However, it would be worthwhile to explore the effect of reducing these bounds. The remaining parameters are related to selectivity functions describing the size-specific capture efficiency of the fisheries and surveys. Two at their lower bounds are probably inconsequential (pS2[10] and pS4[1]) and are related to the ascending and descending slopes of the dome-shaped selectivity describing male bycatch in the snow crab fishery prior to 1997. A double-normal is used to describe the dome shape, but an alternative function (e.g., a single normal) might have better estimation properties. The size at 50% selected was estimated at its upper bound (90 mm CW) for NMFS survey selectivity in the 1975-1981 time period pS1[1]). This results in an almost linear function, rather than asymptotic, across the size range. This result may reflect the changing interaction between the areas surveyed (availability) and the gear selectivity in this time period as the survey gradually extended from the southeast shelf and Bristol Bay where adult males were prevalent to the north and west where more immature males would be encountered, effectively "seeing" relatively more large males than small males. Two other survey-related selectivity parameters, describing the size difference between crab at 50% and 95% selected) were estimated at their upper bounds for the both males and females in the NMFS EBS trawl survey in the 1982-present time period (pS2[2] and pS2[4]). The selectivity functions are assumed to be logistic, with the other estimated parameter being the size at 95% selected. The practical consequence of this is that small crab (females in particular) are described as fairly well-selected (> 50% for females) relative to fully-selected (sex-specific) large crab. This result may reflect conflicts from between the model assumption of equal sex ratios for recruitment in the 25-40 mm CW range, apparent equal abundances and spatial patterns for males and females at small sizes in the NMFS EBS survey, and assumed logistic selectivity. The selectivity parameter describing the size at 50% selected for males in the groundfish fisheries during 1987-1996 was estimated in all scenarios at its lower bound (40 mm CW), probably a consequence of fairly substantial catches of small crab in some years (e.g., 1993, Figure 12). Finally, three parameters at their upper bounds (pS1[23], pS1[24], and pS1[27]) are related to the size at 95% selected in the BBRKC fishery in the 1997-2004 (males) and 2005+ (males and females) time periods. The upper bounds (180 for males, 140 for females) were selected to reflect the largest possible sizes reasonably expected in the model, so the resulting selectivity functions are essentially positively-sloped linear functions with values fixed at 0.95 at the parameter bound because the other estimated logistic parameter estimates a large size at 50% selected (see selectivity curves in Figure 46).

May2019 Crab Plan Team Meeting
CPT comment: Compare trends in largest crab to fishing pressure and area occupied by stock.
Original response (9/19): This is a good suggestion that, time permitting, will be addressed before the January 2021 CPT meeting.

CPT comment: Compare the maximum sizes seen in the fishery to the survey.
Original response (9/19): Another good suggestion that, time permitting, will be addressed before the January 2021 CPT meeting.

CPT comment: Consider blocking for estimation of growth and probability of maturing.
Original response (9/19): This has been on the “to do” list for a while now, but with relatively low priority. The problem is that the principal data which the model relies on for estimating both processes is, except for size compositions, only available (from a practical standpoint) since 2006 for male maturity ogives and since 2015 for (both sexes) molt increment data. The ability of the model to reliably estimate changes in these processes is thus somewhat doubtful.

CPT comment: Provide retrospective analysis and calculate Mohn’s rho for MMB
Updated response (9/20): This has been done and results are presented in this chapter.

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). Clinal differences across the EBS shelf in some biological characteristics such as mean mature size exist across the range of the unit stock, leading some authors to argue for a division into eastern and western stocks in the EBS (Somerton 1981b, Zheng 2008, Zheng and Pengilly 2011). However, it was not generally recognized at the time of these analyses that this species undergoes a terminal molt at maturity (Tamone et al. 2007), nor were the implications of ontogenetic movement considered. Thus, biological characteristics estimated using comparisons of length frequency distributions across the range of the stock, or on modal length analysis over time, may be confounded as a result and do not provide definitive evidence of stock structure.

Simulated patterns of larval dispersal suggest that Tanner crab in Bristol Bay may be somewhat isolated from other areas on the shelf, and that this component of the stock relies heavily on local retention of larvae for recruitment, suggesting that Tanner crab on the shelf may exist as a metapopulation of weakly-connected sub-stocks (Richar et al. 2015). However, recent genetic analysis has failed to distinguish multiple non-intermixing, non-interbreeding sub-stocks on the EBS shelf (Johnson 2019), suggesting that Tanner crab in the EBS form a single unit stock.

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 approximately 25 mm CW proceeds by a series of annual molts, up to a final (terminal) molt to maturity (Tamone et al., 2007). 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). 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.

Molt increment data was collected for Tanner crab in the EBS during 2015, 2016, 2017 and 2019 in cooperative research between NMFS and the Bering Sea Research Foundation (R. Foy and E. Fedewa, NMFS, pers. comm.s). Previous analysis of the data suggests it is not substantially different from that obtained near Kodiak Island (Stockhausen, 2017). The EBS molt increment data is incorporated in the assessment model to inform inferred growth trajectories in all of the alternative models evaluated in this assessment.

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. Maturity in females can be determined visually rather unambiguously from the relative size of the abdomen. 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, but is not as easily determined as with females. 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). The ratio of chela height (CH) to carapace width (CW) has been used to classify male Tanner crab as to morphometric maturity. 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). In this assessment, several model scenarios are considered in which size-specific annual proportions of mature, new shell male crab to all new shell male crab in the NMFS EBS bottom trawl survey, based on classification using CH:CW ratios, are fit to inform size-specific probabilities of terminal molt.

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. Alternatively, if 20 years was assumed to represent the 95% percentile of the distribution of ages in the unexploited stock, the estimate for M would be 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 the 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 ADFG 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 (SOA), with federal oversight (Bowers et al. 2008). The SOA 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 (Figure 1) includes all waters of the Bering Sea north of Cape Sarichef at 54° 36'N and east of the U.S.-Russia Maritime Boundary Line of 1991. This district is divided into the Eastern and Western Subdistricts at 173°W. The Eastern Subdistrict is further divided at the Norton Sound Section north of the latitude of Cape Romanzof and east of 168°W and the General Section to the south and west of the Norton Sound Section (Bowers et al. 2008). In this report, the terms "east region" and "west region" are used in shorthand fashion to refer to the regions demarcated by 166°W longitude.

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" (140 mm CW, including lateral spines) throughout the Bering Sea District. The new regulations established different minimum size limits east and west of 166° W. The minimum size limit for the fishery to the east of 166° W is now 4.8" (122 mm CW) and that to the west is 4.4" (112 mm CW), 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 control rules (HCRs) used to determine total allowable catch (TAC) generally incorporate minimum industry-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 (ADFG 2014). The harvest strategy also employed a minimum threshold that the mature female biomass (MFB) in the Eastern subdistrict be larger than 40% of its longterm (1975-2010) average in two subsequent years before the fisheries in either subdistrict could be opened. Minimum thresholds for opening the fishery in a subdistrict were also defined using the ratio subdistrict-specific MMB to its associated longterm average. Finally, the harvest strategy defined subdistrict-specific sloping harvest control rules to determine the maximum allowable exploitation rate on mature males in each subdistrict based on the ratio of MFB to average MFB, together with limits on the maximum exploitation rate (Figure 2).

Subsequently, the SOA's harvest strategy has undergone three revisions in the past 6 years (Daly et al., 2020). In 2015, the minimum preferred harvest size used to compute TAC for the area east of 166°W longitude was changed from 140 mm CW (5.5 inches; including the lateral spines) to 127 mm CW (5.0 inches), the preferred size used to compute TAC for the area west of 166°W longitude. In 2017, the criteria used to determine MFB was changed from an area-specific one based on carapace width to one based on morphology (the same as that used by the NMFS EBS shelf bottom trawl survey), the definition of 'long-term average' for calculating average mature biomass was changed from 1975-2010 to 1982-2016, the spatial range for calculating average MFB was expanded to include the entire NMFS EBS shelf bottom trawl survey area, and a so-called 'error band system' was introduced in the HCR to account for survey uncertainty such that the exploitation rate on industry-preferred males used to calculate was gradually reduced when the lower 95% confidence interval of the point estimate of MFB fell below 40% of the long-term average (replacing the requirement to close the fisheries when MFB fell below the 40% threshold; ADF&G, 2017; Daly et al., 2020).

Most recently, the harvest strategy was changed in March 2020 based on results from an extensive management strategy evaluation (MSE) conducted with input from industry stakeholders, NMFS and academic scientists, and ADF&G managers (Daly et al., 2020). The current HCR (Figure 3; HCR 4_1 in Daly et al., 2020) defines the period for calculating average mature biomass as 1982-2018 and implements sliding scales for exploitation rates on mature males which are functions of the ratios of MMB and MFB to their longterm averages. One particularly notable change is that there is no longer a threshold for opening the fisheries based on MFB.

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; Figure 4). Foreign fishing for Tanner crab ended in 1980.

The domestic Tanner crab pot fishery developed rapidly in the mid-1970s (Tables 1 and 2; Figure 5). 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 re-opened and landings rose again in the late-1980s to a second peak in 1990/91 at 16.61 thousand t, and then fell sharply through the mid-1990s. The domestic Tanner crab fishery was closed between 1997/98 and 2004/05 as a result of conservation concerns regarding the depressed status of the stock. It re-opened in 2005/06 and averaged 0.77 thousand t retained catch between 2005/06-2009/10 (Tables 1 and 2). The SOA closed directed commercial fishing for Tanner crab during the 2010/11-2012/13 seasons because estimated female stock metrics fell 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 166° W and at 1,463,000 lbs (664 t) for the area east of 166° W in the 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 166° W and at 8,480,000 lbs (3,846 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. 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; Figures **4** and 5). The directed fisheries in both areas were closed in 2016/17 because mature female biomass in the NMFS EBS Bottom Trawl Survey did not exceed the threshold set in the SOA's harvest strategy to allow them to open. Total retained catch was thus 0 in 2016/17. In 2017/18, the SOA allowed a limited directed fishery west of 166°W longitude but closed the fishery east of 166°W. Essentially, the entire TAC (1,130 t) was taken in 2017/18. The 2018/19 season followed a similar pattern, with the directed fishery closed in the eastern area and open in the western area (with a TAC of 1.106 thousand t). The entire TAC was again harvested in 2018/19. The directed fisheries in both subdistricts were again closed in 2018/19 because the threshold mature female biomass was not met.

Bycatch and discard losses of Tanner crab originate from the directed pot fishery, non-directed snow crab and Bristol Bay red king crab pot fisheries, and the groundfish fisheries (Table 3; Figure 6). Within the assessment model, 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 occurred in the early-1990s. In the early-

1970s, the groundfish fisheries contributed substantially 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 considered to be 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

Data incorporated into the Tanner crab assessment this year include: 1) annual abundance, biomass and size composition data collected by crab fishery observers for Tanner crab retained in the directed fisheries and taken as bycatch in the directed and other (snow crab, Bristol Bay red king crab) fisheries provided by ADFG; 2) annual abundance, biomass, and size composition data collected by groundfish fishery observers for bycatch in the groundfish fisheries provided by AFSC's Fisheries Monitoring and Analysis Division and the NMFS Alaska Regional Office (and hosted by AKFIN); 3) limited historical (pre-1990) data on annual abundance, biomass, and size compositions for Tanner crab retained in the foreign (1965-1980) and domestic (1968-1989) crab fisheries or taken as bycatch in the groundfish fisheries (1973-1990); 4) annual abundance, biomass and size composition data, as well as limited year-specific male maturity ogives, from the NMFS EBS shelf bottom trawl survey; 5) abundance, biomass, and size composition data from BSFRF/NMFS cooperative side-by-side trawl studies; and 6) molt increment data from NMFS/ADFG/ BSFRF cooperative studies.

1. Summary of new information

In general, incidental retained catch of Tanner crab in the snow crab and BBRKC fisheries has been very small compared with that from the directed fishery and continues to be "lumped" with that for the directed fishery. However, in 2019/20 the directed Tanner crab fisheries were closed by ADFG and incidentally-retained catch in the snow crab and BBRKC fisheries amounted to less than 50 kg—this small amount was not included in the assessment. ADFG also provided updated values for total catch of Tanner crab in the crab fisheries for 2018/19 and new values for 2019/20.

Tanner crab bycatch data in the groundfish fisheries (abundance, biomass, size compositions) were extracted for 1991/92-2018/19 from the groundfish observer and AKRO databases on AKFIN. Although the bycatch data in the groundfish fisheries is available by gear type, all model scenarios examined here fit the data aggregated over gear types. There were relatively small differences for estimates of total bycatch abundance and biomass between results provided by AKFIN last year and those provided this year for 2016/17, 2017/18, and 2018/19 due to a change in the algorithms AKFIN used to expand observed catch to total catch to align them with those used by the NMFS Alaska Regional Office to estimate Prohibited Species Catch (Figure 7). The effects of the changes were relatively minor, as shown in the following table:

Table. Comparison of management-related quantities to show the effects of the revised estimates for Tanner crab bycatch in the groundfish fisheries for 2016/17-2018/19.

case	average recruitment	Bmsy	current MMB	Fmsy	MSY	Fofl	OFL	projected MMB
	millions	(1000's t)	(1000's t)	per year	(1000's t)	per year	(1000's t)	(1000's t)
19.03	393.84	41.64	82.61	1.18	19.49	1.12	29.51	39.73
19.03R	393.44	41.29	81.66	1.19	19.33	1.13	29.20	39.25

The scheduled 2020 NMFS EBS shelf bottom trawl survey was cancelled this year due to safety concerns associated with the COVID-19 pandemic. Thus, no new survey data was available. In addition, no new molt increment or maturity ogive data was available to incorporate into the assessment.

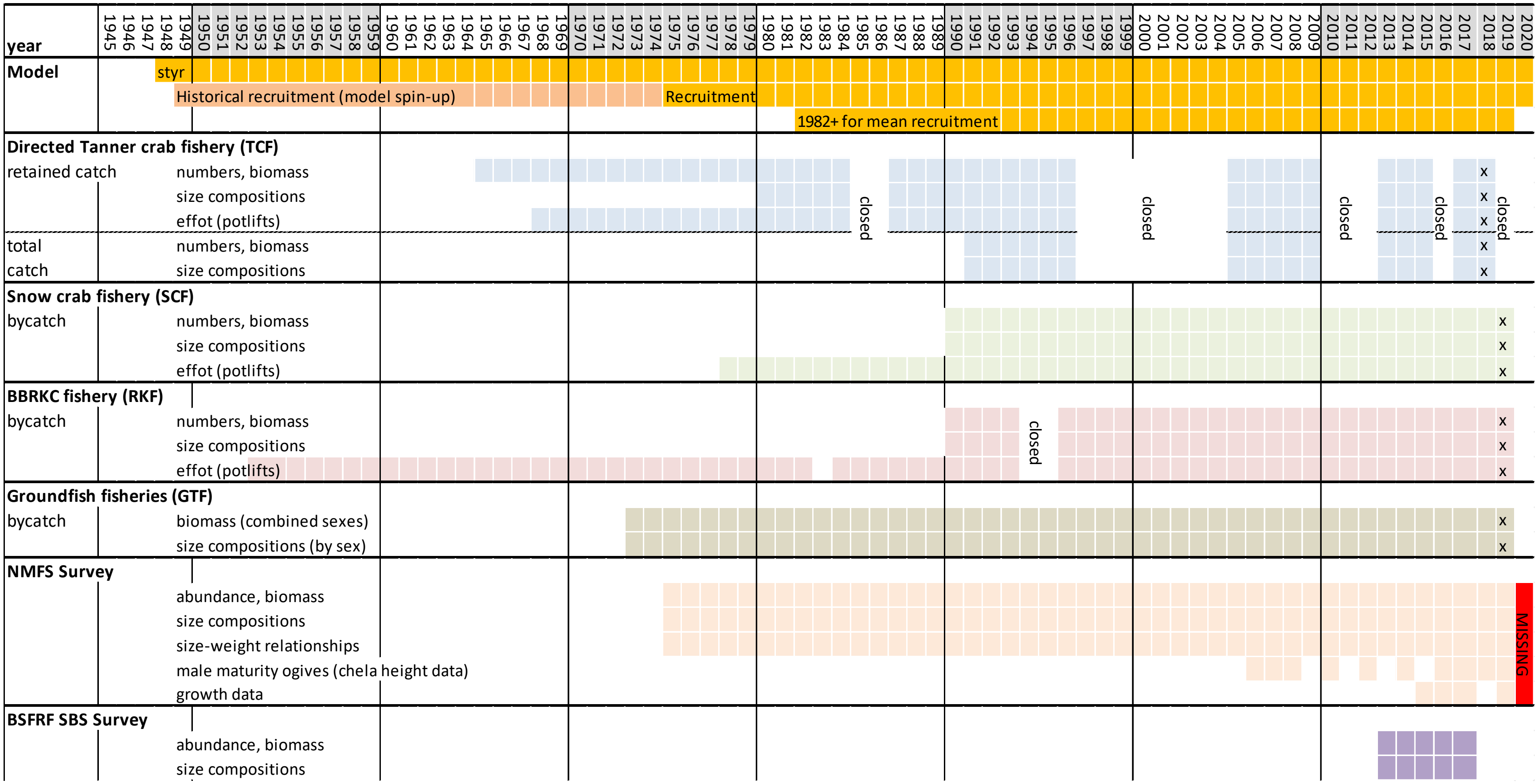
The following table summarizes data sources that have been updated for this assessment:

Table. Data sources updated for 2019/20.

Description	Data types	Time frame	Notes	Source
NMFS EBS Bottom Trawl Survey	area-swept abundance, biomass	1975-2019	no 2020 survey	NMFS
	size compositions	1975-2019	no 2020 survey	
	male maturity data	2006+	no new data	
NMFS/BSFRF	molt-increment data	2015-17, 2019	no new data	NMFS, BSFRF
BSFRF SBS Bottom Trawl Survey	area-swept abundance, biomass	2013-17	no new data	BSFRF
	size compositions	2013-17	no new data	
Directed fishery	historical retained catch (numbers, biomass)	1965/66-1996/97	not updated	2018 assessment
	historical retained catch size compositions	1980/81-2009/10	not updated	2018 assessment
	retained catch (numbers, biomass)	2005/06-2018/19	fisheries closed 2019/20	ADFG
	retained catch size compositions	2013/14-2018/19	fisheries closed 2019/20	ADFG
	total catch (abundance, biomass)	1991/92-2018/19	fisheries closed 2019/20	ADFG
	total catch size compositions	1991/92-2018/19	fisheries closed 2019/20	ADFG
Snow Crab Fishery	historical effort	1978/79/1989/90	not updated	2018 assessment
	effort	1990/91-2019/20		ADFG
	total bycatch (abundance, biomass)	1990/91-2019/20		ADFG
	total bycatch size compositions	1990/91-2019/20		ADFG
Bristol Bay Red King Crab Fishery	historical effort	1953/54-1989/90	not updated	2018 assessment
	effort	1990/91-2019/20		ADFG
	total bycatch (abundance, biomass)	1990/91-2019/20		ADFG
	total bycatch size compositions	1990/91-2019/20		ADFG
Groundfish Fisheries (all gear types)	historical total bycatch (abundance, biomass)	1973/74-1990/91	not updated	2018 assessment
	hostorical total bycatch size compositions	1973/74-1990/91	not updated	
	total bycatch (abundance, biomass)	1991/92-2019/20	now using AKRO algorithm for 2016/17+	NMFS/AKFIN
	total bycatch size compositions	1991/92-2019/20		

The following table summarizes the data coverage in the assessment:

Table. Data coverage in the assessment model (color shading highlights different model time periods and data components, x's denote new data).



2. Data presented as time series

For the 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. Retained catch

Retained catch 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 Figures 4 and 5 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 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 increased each subsequent year until 2016/17 as TACs increased (Figures 2 and 3). The retained catch for 2015/16 (8,910 t) was the largest since 1992/1993 (15,920 t; Table 1). However, ADFG closed the directed fishery in both areas for the 2016/17 fishing season because mature female biomass in the 2016 NMFS EBS bottom trawl survey did not meet the SOA's criteria for opening the fisheries. In 2017/18, ADFG allowed the fishery to commence in the western area (TAC was set at 1,130 t) but was closed in the eastern area. The directed fishery essentially caught the entire TAC. The 2018/19 fishery was similar to that in 2017/18 in that the eastern area was closed and the entire TAC (1,100 t) was taken west of 166°W longitude. In 2019/20, the directed fisheries in both areas were closed because mature female biomass failed to exceed the threshold to open the fisheries.

b. Information on bycatch and discards

Total catch estimates for Tanner crab in the directed Tanner crab, the snow crab, and the BBRKC fisheries are provided in Table 4 and Figure 6 based on ADFG "at-sea" crab observer sampling starting in 1990/91. Annual bycatch in the groundfish fisheries, based on NMFS groundfish observer programs, is also available starting in 1973/74, but sex is undifferentiated. A value of 0.321 is used in the assessment model 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 is used for handling mortality aggregated across gear types to reflect differences in groundfish gear effects and on-deck operations compared with the crab fleets. Mortality associated with the handling process can be estimated outside the assessment model for bycatch in the groundfish and non-directed crab fisheries (most or all Tanner crab bycatch is discarded), but estimates of "discard mortality" for males in the directed fishery obtained outside the assessment model are problematic if (due to sampling error) estimated total catch is less than reported retained catch.

Estimated bycatch mortality in the groundfish fisheries (without distinguishing gear type) was highest (~15,000 t) in the early 1970s, but it declined substantially by1977 to ~2,000 t with the curtailment of foreign fishing fleets (Stockhausen, 2017). It declined further in the 1980s (to ~500 t) but increased somewhat in the late 1980s to a peak of ~2,000 t in the early 1990s before undergoing another (gradual) decline until 2008, after which it has fluctuated annually below ~300 t to the present (~150 t in 2019/20).

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 2013/14, 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 dockside observer sampling is shown in Figure 8 by fishery region and shell condition since rationalization of the crab fisheries in 20105/06. These indicate a shift to retaining somewhat smaller minimum sizes since 2013/14, compared with 2005/06-2009/10. As noted previously, the SOA changed its harvest strategy for calculating TACs to reflect a smaller minimum industry-preferred size of 125 mm CW east of 166°W longitude. In addition, the proportion of old shell crab retained appears to have increased over the past few years and substantially exceeded that of new shell crab across the retained size range in 2018/19.

Normalized total catch (retained + discards) size compositions from at-sea crab fishery observer sampling are presented by fishery for males in Figure 9 and for females in Figure 10. The snow crab fishery, conducted primarily in the northern and western parts of the EBS shelf, catches predominantly small males while the BBRKC fishery, conducted to the south and east in Bristol Bay, predominantly catches large males. The 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, selectivity in the BBRKC fishery appears more consistent with asymptotic selection. The directed fishery, which extends across the shelf from west of the Pribilof Islands into Bristol Bay in the east catches primarily intermediate-sized males, with about half the new shell males caught larger than the industry-preferred size of 125 mm CW. Similar patterns are apparent for females, as well.

Sex-specific size compositions from observer sampling for bycatch in the groundfish fisheries, expanded to total bycatch, are shown in Figure 11 for 1991/92 to 2019/20. These fisheries, targeting a variety of groundfish stocks and using a variety of gear types, take a much larger size range of Tanner crab as bycatch than does the pot gear used in the crab fisheries—perhaps even providing support for recruitment events (see, e.g., the peaks in relative abundance at small sizes in the size compositions for 2003/04 and 2004/05; Figure 11).

Raw (number of individuals measured) and scaled sample sizes for size composition data from the various fisheries are presented in Tables 5-7.

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 (Tables 8-9, Figures12-13). Estimated biomass of male crab in the survey time series started at its maximum (295,000 t) in 1975, decreased rapidly to a low (15,000 t) in 1985, and rebounded quickly to a smaller peak (146,000 t) in 1991 (Table 8). After 1991, male survey biomass decreased again, reaching a minimum of 14,600 t in 1997. Recovery following this decline was slow and male survey biomass did not peak again until 2007 (104,000 t), after which it has fluctuated more rapidly—decreasing within two years by over 50% to a minimum in 2009 (47,000 t), followed by a doubling to a peak in 2014 (109,000 t). Since 2014 the trend has been a steady decline, with male biomass in 2019 at its lowest point (28,000 t) since 2000 (Table 8). Trends in the male and female components of survey biomass have primarily been in synchrony with one another, as have changes in the eastern and western management regions (east and west of 166ºW longitude), although the magnitudes differ (Figure 12). Preferred-size male survey biomass has been declining east of 166ºW (and in the EBS as a whole) since 2014, but was increasing up to 2016 in the west. In the west, it declined in 2017, remained essentially unchanged in 2018, and dropped by over 50% from 2018 to 2019 (Table 9, Figure 13). The ratio of new shell to old shell preferred-size males crab across the EBS has dropped dramatically since 2015, when the ratio was almost 1:1. In 2019, the ratio was almost 1:20 new shell to old shell crab biomass.

Data from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies are incorporated into several model scenarios in this assessment for the first time. During the SBS catchability studies, NMFS performed standard survey tows (e.g., 83-122 trawl gear, 30 minute tow duration) as part of its annual EBS bottom trawl survey while BSFRF performed parallel tows within 0.5 nm using a nephrops trawl and 5 minute tow duration. Because the nephrops trawl has better bottom-tending performance than the 83-112 gear, the BSFRF tows are hypothesized to catch all crab within the net path (i.e., to have selectivity equal to 1 at all crab sizes) and thus provide a measure of absolute abundance/biomass. The spatial footprints of the SBS studies for 2013-2017 are illustrated in Figure 14, while estimates of area-swept biomass for the study areas are compared in Figure 15 for the BSFRF and NMFS tows. Although the BSFRF gear is assumed to provide estimates of absolute abundance with the area surveyed, the relationship between these estimates and Tanner crab stock biomass is confounded by changes in the availability of Tanner crab to the BSFRF gear because the studies did not sample across the entire spatial extent of the population (in contrast to the full NMFS EBS bottom trawl survey).

e. Survey catch-at-length

Bubble plots of NMFS EBS bottom survey size compositions for Tanner crab by sex and fishery region are shown in Figure 16. Distinct recruitment events (late 1970s, early 1990s, mid-2000s, early 2010s and possibly late 2010s) and subsequent cohort progression are evident in the plots, particularly in the western area. The absence of small male crab in the 2010-2016 period is notable, although there is evidence for new recruitment in the western area in 2016-2109, with perhaps some spillover to the eastern area lagged by a year at slightly larger sizes.

Based on the total abundance size compositions from the BSFRF-NMFS SBS studies (Figure 17), the BSFRF nephrops gear is in general (as expected) more selective for Tanner crab, particularly at smaller sizes (< 60 mm CW), than is the NMFS 83-112 gear. However, the size-specific catch ratio of the BSFRF survey to the NMFS survey appears to vary substantially across years, which one would not expect if gear-specific selectivity were, in general, constant. It is worth noting that the nephrops gear appear to give a much better indication of recruitment than the 83-112 gear does (e.g., Figure 17, survey year 2017).

Observed sample sizes for the NMFS survey size compositions, aggregated to the EBS regional level used in the assessment, are presented in Table 10. Given the large number of individuals sampled, a sample size of 200 is used to fit survey size compositions in the assessment model to prevent convergence issues associated with using the actual sample sizes.

f. Other time series data.

Spatial patterns of abundance in the 2014-2019 NMFS bottom trawl surveys are shown in Figure 18 for males and females classified by maturity state. There has been some suggestions that an extensive cold pool in the middle region of the EBS shelf may act to diminish relative crab densities in this region, particularly for mature males. The cold pool on the EBS shelf was extensive during the 2017 survey and absent during the 2018 and 2019 surveys, but the distribution of mature males did not change remarkably.

Annual maturity ogives for new shell males, based on chela height collections from the NMFS EBS bottom trawl survey, are shown in Figure 19 for years in which chela heights were measured to 0.1 mm precision (i.e., since 2006). For each year, chela height:carapace width ratios for individual new shell crab were binned into 10 mm size bins, with the data split based on which management area (east or west of 166°W longitude) it was collected in. The resulting histograms were analyzed to determine threshold sizes to discriminate mature from immature crab, and the fraction of mature crab was taken as the value of the resulting maturity ogive in the associated size bin (J. Richar, NMFS, pers. comm.). The area-specific ogives were combined to obtain one for the entire EBS by weighting each by the estimated abundance of new shell males in each area by size bin.

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 11).

3. Data which may be aggregated over time:

a. Growth-per-molt
Molt increment data collected for Tanner crab in the EBS in 2015-2017 and 2019 (Figure 20) is included in the parameter optimization for every model scenario considered in this assessment and is assumed to reflect growth rates over the entire model period.

b. Weight-at size
Weight-at-size relationships used in the assessment model for males, immature females, and mature females is depicted in Figure 21.

c. Size distribution at recruitment
The assumed size distribution for recruits to the population in the assessment model is presented in Figure 22.

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. Molt increment data from the Kodiak area in the Gulf of Alaska were not included in the assessment given the current use of molt increment data from the EBS to inform growth estimates. BSFRF survey data focused on Tanner crab recruitment (size compositions) have not yet been incorporated into the assessment.

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 the authors' 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.

Modifications were 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[1].

The current model "framework", TCSAM02, was reviewed by the CPT and SSC in May/June 2017 and adopted for use in subsequent assessments as a transition to Gmacs. This framework is a completely-rewritten basis for the Tanner crab model: substantially different model scenarios can be created and run by editing model configuration files rather than modifying the underlying code itself. Most importantly, no time blocks are "hard-wired" into the code—any time blocks are defined in the configuration files. In addition, the framework has been used to incorporate new data types (molt increment data, male maturity ogives), new survey data (the BSFRF surveys), and new fishery data (bycatch in the groundfish fisheries by gear type). The framework also incorporates status determination and OFL calculations directly within a model run, so a follow-on, stand-alone projection model does not need to be run (as was the case with TCSAM2013). This approach has the added benefit of allowing a more complete characterization of model uncertainty in the OFL calculation, because the OFL calculations are now included in the Markov Chain Monte Carlo (MCMC) evaluation of a model's posterior probability distribution.

Most recently, the model code has been restructured to function in a management strategy evaluation (MSE) mode and allow retrospective analyses. The code for the TCSAM02 model framework is publicly available on GitHub[2].

2. Model Description

a. Overall modeling approach

TCSAM02 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 1.

In brief, crab enter the modeled population as recruits following the size distribution in Figure 22. An equal (50:50) sex ratio is generally assumed at recruitment (although can be set otherwise or estimated), 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

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

[2] https://github.com/wStockhausen/wtsTCSAM02.git

them as bycatch are prosecuted as pulse fisheries (i.e., instantaneously). Catch by sex/shell condition/maturity state/size in the directed Tanner crab, snow crab, BBRKC, and groundfish fisheries is calculated based on fishery-specific stage/size-based selectivity curves and fully-selected fishing mortalities and removed from the population. The numbers of surviving immature, new shell crab that will molt to maturity are then calculated based on sex/size-specific probabilities of maturing, and growth (via molt) is calculated for all surviving new shell crab. Crab that were new shell, mature crab become old shell, mature crab (i.e., they don't molt) and old shell crab remain old shell. Population numbers are then adjusted for the effects of maturation, growth, and change in shell condition. Finally, population numbers are reduced for the effects of natural mortality operating from Feb. 15 to July 1 ($\delta t = 0.375$ yr) to calculate the population numbers (prior to recruitment) on July 1.

Model parameters are estimated using a maximum likelihood approach, with Bayesian-like priors on some parameters and penalties for smoothness and regularity on others. Data components in the base model 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.

b. Changes since the previous assessment.

The model code has been revised to facilitate retrospective analyses and to allow the user to specify the time period for calculating average recruitment. In addition, selectivity curves based on the normal or "double normal" have been implemented, as has the option to use fit selectivity curves using splines.

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

The TCSAM02 model framework was demonstrated to produce results that were exactly equivalent to those from the 2016 assessment model incorporating the changes listed in the previous table. TCSAM02 also underwent a review in July 2017 conducted by the Center for Independent Experts and has been further reviewed by the CPT in May 2017 and September 2017. Changes to model code are validated against results from the previous assessment model to ensure that modifications do not change the results of the previous assessment.

3. Model Selection and Evaluation

a. Description of alternative model configurations

The model selected for the 2019 assessment (Model 19F03 from Stockhausen 2019) provides the baseline model configuration for subsequent alternative model scenarios evaluated in this assessment. Here, the 2019 assessment model is referred to as "19.03" in accordance with SSC guidelines on model numbering. The following tables provide a summary of the baseline model configuration, 19.03, for this assessment.

Model 19.03: Description of model population processes and survey characteristics.

process	time blocks	description
Population rates and quantities		
Population built from annual recruitment		
Recruitment	1949-1974	ln-scale mean + annual devs constrained as AR1 process
	1975+	ln-scale mean + annual devs
Growth	1949+	sex-specific
		mean post-molt size: power function of pre-molt size
		post-molt size: gamma distribution conditioned on pre-molt size
Maturity	1949+	sex-specific
		size-specific probability of terminal molt
		logit-scale parameterization
Natural mortalty	1949-1979,	estimated sex/maturity state-specific multipliers on base rate
	1985+	priors on multipliers based on uncertainty in max age
	1980-1984	estimated "enhanced mortality" period multipliers
Surveys		
NMFS EBS trawl survey		
male survey q	1975-1981	ln-scale
	1982+	ln-scale w/ prior based on Somerton's underbag experiment
female survey q	1975-1981	ln-scale
	1982+	ln-scale w/ prior based on Somerton's underbag experiment
male selectivity	1975-1981	ascending logistic
	1982+	ascending logistic
female selectivity	1975-1981	ascending logistic
	1982+	ascending logistic

Model 19.03: Description of model fishery characteristics.

Fishery/process	time blocks	description
TCF	directed Tanner crab fishery	
capture rates	pre-1965	male nominal rate
	1965+	male ln-scale mean + annual devs
	1949+	ln-scale female offset
male selectivity	1949-1990	ascending logistic
	1991-1996	annually-varying ascending logistic
	2005+	annually-varying ascending logistic
female selectivity	1949+	ascending logistic
male retention	1949-1990, 1991-1996, 2005-2009, 2013-2015, 2017	ascending logistic
SCF	bycatch in snow crab fishery	
capture rates	pre-1978	nominal rate on males
	1979-1991	extrapolated from effort
	1992+	male ln-scale mean + annual devs
	1949+	ln-scale female offset
male selectivity	1949-1996	dome-shaped
	1997-2004	dome-shaped
	2005+	dome-shaped
female selectivity	1949-1996	ascending logistic
	1997-2004	ascending logistic
	2005+	ascending logistic
RKF	bycatch in BBRKC fishery	
capture rates	pre-1952	nominal rate on males
	1953-1991	extrapolated from effort
	1992+	male ln-scale mean + annual devs
	1949+	ln-scale female offset
male selectivity	1949-1996	ascending logistic
	1997-2004	ascending logistic
	2005+	ascending logistic
female selectivity	1949-1996	ascending logistic
	1997-2004	ascending logistic
	2005+	ascending logistic
GTF	bycatch in groundfish fisheries	
capture rates	pre-1973	male ln-scale mean from 1973+
	1973+	male ln-scale mean + annual devs
	1973+	ln-scale female offset
male selectivity	1949-1986	ascending logistic
	1987-1996	ascending logistic
	1997+	ascending logistic
female selectivity	1949-1986	ascending logistic
	1987-1996	ascending logistic
	1997+	ascending logistic

Model 19.03: Description of model likelihood components.

Name	Component	Type	included in optimization	Distribution	Likelihood
19.03	TCF: retained catch	abundance	no	lognormal	males only
		biomass	yes	norm2	males only
		size comp.s	yes	multinomial	males only
	TCF: total catch	abundance	no	lognormal	by sex
		biomass	yes	norm2	by sex
		size comp.s	yes	multinomial	by sex
	SCF: total catch	abundance	no	lognormal	by sex
		biomass	yes	norm2	by sex
		size comp.s	yes	multinomial	by sex
	RKF: total catch	abundance	no	lognormal	by sex
		biomass	yes	norm2	by sex
		size comp.s	yes	multinomial	by sex
	GTF: total catch	abundance	no	lognormal	by sex
		biomass	yes	norm2	by sex
		size comp.s	yes	multinomial	by sex
	NMFS "M" survey (males only, no maturity)	abundance	no	lognormal	all males
		biomass	yes	lognormal	all males
		size comp.s	yes	multinomial	all males
	NMFS "F" survey (females only, w/ maturity)	abundance	no	lognormal	by maturity classification
		biomass	yes	lognormal	by maturity classification
		size comp.s	yes	multinomial	by maturity classification
	growth data	EBS only	yes	gamma	by sex
	male maturity ogive data	EBS only	yes	binomial	males only

The NMFS "M" survey refers to a male-only "flavor" of the NMFS survey data in which maturity is not determined outside the model (males in the M survey have "undetermined" maturity). The NMFS "F" survey is simply the female portion of the NMFS survey data configured as a separate data file to accompany the NMFS "M" survey data file.

The following model scenarios are described as part of this assessment:

model scenario	number of parameters	objective function value	max gradient	Jitter runs	# runs converged to MLE	scenario description
19.03 (2019)	343	3,228.46	0.0001	--	--	2019 assessment model (M19F03)
19.03R	343	3,169.69	0.0004	--	--	19.03 with updated 2016/17-2018/19 groundfish bycatch data
19.03 (2020)	347	3,155.40	0.0003	400	24	19.03R with 2019/20 data
20.07	349	3,429.39	0.0003	400	47	19.03 + empirical SBS availability curves
20.10	341	3,747.27	0.0007	--	--	19.03 + empirical NMFS survey selectivity curves from SBS studies

Scenario 19.03R represents a check on the revised estimates for Tanner crab bycatch in the groundfish fisheries from 2016/17 to 2018/19. It does not include 2019/20 data and simply allows the incremental step associated with this change to be accounted for. Scenario 19.03(2020) updates the available data (bycatch in the snow crab, BBRKC, and groundfish fisheries) for the 2019/20 crab fishery year. Scenario 20.07 was recommended by the CPT as a scenario to consider basing the assessment upon after they reviewed results with 2019/20 data during the May 2020 CPT meeting. This scenario fits biomass and size composition estimates from the 2013-2017 BSFRF SBS catch ratio comparison studies along with

the standard NMFS EBS shelf bottom trawl survey data to try to better estimate NMFS survey catchability. Year-specific availability curves for the BSFRF data were determined outside the model using the ratio of expanded (area-swept) estimates of abundance-by-5 mm CW size classes derived from NMFS survey data at stations at which SBS tows were conducted to those derived from NMFS survey data for the entire survey grid (Figures 23 and 24; Appendix 3). Estimating the availability curves outside the model was reasonably straightforward and vastly reduced the number of model parameters that would otherwise be necessary.

Scenario 20.10 represents another approach suggested by the CPT to using the BSFRF SBS data (Appendix 4). In this case, size-specific catch ratio analysis is performed outside the model using the BSFRF and NMFS data from SBS tows to directly estimate the size-specific selectivity of the NMFS survey. The estimated curve(s) are then used directly in the assessment, rather than having to estimate survey selectivity (and fully-selected catchability) inside the model. For this scenario, sex-specific selectivity curves were estimated by evaluating the fits of a logistic curve and cubic splines of different degrees of freedom to the size-specific catch ratios from all SBS hauls and the selecting the “best” overall model, similar to that done by Somerton et al (2013, 2017) for snow crab. For females, the “best” model selected on the basis of BIC was a spline with 5 degrees of freedom (Figure 25). For males, the “best” model selected on the basis of BIC was a spline with 8 degrees of freedom (Figure 26). However, this analysis is incomplete (environmental factors such as depth and sediment type need to be incorporated into the analysis) and the selectivity curves used for this scenario are provisional, at best. As such, Scenario 20.10 should not be regarded as a viable candidate for status determination and OFL calculation.

The number of estimated parameters, the final value of the objective function for each converged scenario and the maximum gradient of the objective function at the converged solution are listed table above. However, the total objective function values can only be directly compared between scenarios 19.03(2020) and 10.07, because the other scenarios do not fit identical datasets. Convergence for the two scenarios under consideration for status determination and OFL-setting (19.03 and 20.07) was evaluated using parameter jittering, with a total of 400 runs initiated for each scenario. Of these runs, generally a large number failed to converge because initial starting values led to negative growth increments at some point in the search for the MLE solution, while a smaller number converged to local minima larger than the maximum likelihood (ML) solution (i.e., the global *minimum* of the objective function). About 5% of the runs found the (presumed) ML solution in 19.03(2020) and about 10% did so for 20.07. In the interest of time and computing resources, the other scenarios were not subjected to jittering.

Scenario 20.07 is the author’s preferred scenario, as justified below.

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

The following table summarizes basic model results based on the MLE from the 2019 assessment model (19.03) and the 3 scenarios considered here in detail. The author’s preferred scenario is 20.07.

case	average recruitment millions	Bmsy (1000's t)	current MMB (1000's t)	Fmsy per year	MSY (1000's t)	Fofl per year	OFL (1000's t)	projected MMB (1000's t)	status ratio
19.03	393.84	41.64	82.61	1.18	19.49	1.12	29.51	39.73	0.95
19.03(2020)	383.96	40.39	77.76	1.14	18.90	1.11	26.15	39.38	0.98
20.07	374.43	36.77	66.87	0.98	16.94	0.94	21.13	35.33	0.96
20.10	1,047.74	39.94	72.37	1.68	21.55	1.44	24.18	34.98	0.88

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

Scenarios 20.07 and 20.10 represent simplifications to a “full” model (e.g., M19F05 from the 2019 assessment) that incorporated the BSFRF and NMFS SBS data simultaneously into the assessment to estimate NMFS survey selectivity but also required estimating size-specific annual availability in the SBS study areas at the cost of hundreds of additional parameters (~50 parameters for each year the SBS studies were conducted). In particular, 20.10 eliminated 6 parameters (4 selectivity parameters and 2 catchability parameters) used in 19.03(2020), but at a cost of ~600 likelihood units of worse overall fit.

In addition to these scenarios, a number of other models were evaluated in the interim between the May and September 2020 CPT meetings in an effort to identify a working model with reduced complexity but realistic dynamics. The simplest of these was a single-sex model which incorporated fits to catch data from only the directed and snow crab fisheries and re-parameterized logistic and double-logistic selectivity functions to normal and double-normal ones. Results from this (and several other) models indicated a strong confounding between estimated natural mortality rates and survey catchability, both of which affect (or are affected by) estimates of mean recruitment. The extent of this confounding needs to be characterized more fully in the future in order to better understand tradeoffs in the actual assessment model.

d. Convergence status and convergence criteria

As noted above, convergence in the two candidate scenarios (19.03[2020] and 20.07) for possible use to determine status and OFL was assessed by running each model 400 times with randomly-selected ("jittered") initial parameter values for each run. For both models, most of these jitter runs failed—primarily because the initial values eventually led to estimated growth parameters that resulted in negative mean molt increments. Of those that converged, 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 should be zero. However, because numerical methods have finite precision, the numerical search for the minimum is terminated after either achieving a minimum threshold for the maximum gradient or exceeding the maximum number of iterations. As noted previously, about 5% of jittered runs converged to the presumed MLE for scenario 19.03(2020) while 10% did so for 20.07.

e. Sample sizes assumed for the compositional data

Actual and input sample sizes used for compositional data are listed in Tables 5-7 for fishery-related size compositions. Actual samples sizes for survey size compositions are listed in Table 10. Input sample sizes for all survey size compositions were set to 200, which was also the maximum allowed for fishery-related input sample sizes. Otherwise, input sample sizes were scaled as described in Stockhausen (2014, Appendix 5) using the formula:

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

where $\overline{SS}$ is the mean sample size for all males from dockside sampling in the directed fishery.

f. Parameter sensibility

Limits were placed on all estimated parameters in all model scenarios primarily to provide ranges for jittering initial parameter values. Although these limits, for the most part, did not constrain parameter estimates in the converged models, some parameters were found to be at, or very close, to one of the bounds placed on them. These parameters are listed for the scenarios in Table 12. The CPT and SSC have both expressed concerns regarding parameters estimated at their bounds, as such results frequently violate assumptions regarding model convergence, parameter uncertainty estimates, and suggest that model suitability may be improved by widening the bounds or re-parameterizing the model. Estimates of parameter uncertainty based on inverting the model hessian and using the "delta" method were also obtained from each converged model's ADMB "std" file (Tables 13-23).

Of the scenarios considered in detail here, 19.03 and 19.03(2020) had the same 12 parameters estimated at a bound, 20.07 had 8 of these parameters estimated at a bound, as well as 3 others for 11 total, but 20.10 had only 5 parameters at bounds—and these were all at a bound in the other scenarios. The 5 parameters at a bound common among all these scenarios were: 1) a logit-scale parameter (pLgtRet[1]) at its upper bound (15) used to estimate maximum retention in the directed fishery prior to 1997; 2) two parameters (pS1[23], pS1[24]) at their upper bounds (180) describing the size at 95% selection for male bycatch in the BBRKC fishery during the periods 1997-2004 and 2005-2019, respectively; and 3) parameters (pS2[10] and pS4[1]) at their lower bounds (0.1) describing the ascending and descending slopes, respectively, of the double-logistic functions used to describe male bycatch selectivity in the snow crab fishery before 1997. Given the nature of these parameters, the first two of these may reflect reasonable structural limits in the fisheries: 1) large males in the directed fishery are highly prized and essentially always retained and 2) the larger mesh used in pots targeting BBRKC is such that selectivity for large male Tanner crab never reached an asymptote within the size range used in the model (25-185 mm CW) during the periods in question. The lower bound (0.1) for the two parameters characterizing the ascending and descending slopes of the double logistic selectivity function for males in the pre-1997 snow crab fishery should be decreased to allow greater "spread" in this function.

In scenarios 19.03(2020) and 20.07, the sex-specific parameters (pQ[1] and pQ[3]) were estimated at their lower bounds (ln(0.5)), as has been the case in almost all Tanner crab assessments to date. These parameters reflect ln-scale survey catchability during the 1975-1981 time period prior to the survey gear change to the 83-112 bottom trawl net. Previously, the chosen bounds seemed reasonable given the spatial limits of the Tanner crab stock and the reduced areal coverage of these pre-1982 surveys relative to those conducted after 1981 because an early estimate of fully-selected catchability using the 83-112 net was ~0.9 (Somerton et al. 1999). However, preliminary results from the BSFRF-NMFS SBS catch ratio studies suggest that fully-selected Q for Tanner crab in the current NMFS survey may be < 0.5 so the lower bounds on catchability during the pre-gear change time period should definitely be reduced. This is supported by results from Scenario 20.10, in which the lower bounds on these parameters were decreased and estimates were obtained that did not hit them (Table 13).

Another survey-related parameter, pS2[4] describing the size difference between female crab at 50% and 95% selected, was estimated at its upper bound in the post-gear change time period (1982-present) in both 19.03(2020) and 20.07. The resulting selectivity curve (see Figure 48) from 20.07 seems reasonable in that small crab are much less well-selected than larger females, but the curve from 19.03(2020) seems less so because it is relatively flat across all size ranges.

Scenarios 19.03(2020) and 20.07 also had a parameter describing the size-at-95% selectivity for females in the BBRKC fishery since 2005 at its upper bound (140 mm CW, which is larger than any seen in the NMFS survey). This may be the result of a simplifying assumption (that eliminates a number of extra parameters) that fully-selected fishing mortality on females in the BBRKC fishery is a scaled version of that on males. However, similar selectivity parameters applying to both males and females taken in the BBRKC fishery during different time periods were very poorly estimated, if not at a bound (pS1[23-27], Table 13).

Scenario 19.03(2020) estimated three additional parameters at bounds that 20.07 did not. These were the male size-at-50% selected in the NMFS survey prior to 1982 (pS1[1]) at its upper bound, the male size-at-50% selected in the groundfish fisheries during the 1987-1996 time period (pS1[20]) at its lower bound, and the difference between the sizes at 50%- and 95%-selected for males in the NMFS survey after 1981 (pS2[2]) at its upper bound. Scenario 20.07 was able to estimate all of these parameters reasonably well (Table 13). Conversely, the molt increment uncertainty parameter pGrBeta[1] (the scale factor for a gamma distribution) and the selectivity parameter pS1[4] (the size at 50% selected for females in the

NMFS survey in the 1982+ time period) were estimated at bounds in Scenario 20.07 but not in 19.03(2020), although the estimates of pS1[4] in 19.03(2020) were highly uncertain.

A few other parameters exhibited rather large uncertainties, as well. Among these, the logit-scale parameters that characterized fully-selected retention in the directed fishery (pLgtRet) exhibited large standard errors for all model scenarios (Table 13). The associated estimated values (~15) imply that fully-selected retention was essentially 1 in all time periods. In the future, these parameters will be fixed such that maximum retention is 1. Another notable parameter with large uncertainty across all scenarios was the estimated ln-scale recruitment deviation for recruits entering the population on July 1, 2020 (Table 15, last row). Clearly this is a result of the missing 2020 NMFS EBS survey, which is generally the only source of information on recruitment.

Although the overall likelihood cannot be compared across models here, individual components to the likelihood can be, if the underlying data is the same among the models. Data-related components to the likelihood are documented in Table 24; non-data components (penalties and priors) are documented in Table 25. Scenario 19.03(2020) fits the data better than Scenario 20.07 in six categories, while the reverse is true for two categories, and both fit similarly in 17 categories. Both scenarios exhibit similar likelihood penalties and prior likelihoods (Table 25), except the prior on the natural mortality multiplier for mature females (pDM1[3]) is much larger (~14 likelihood units) for Scenario 20.07 while the prior on fully-selected female catchability in the NMFS survey after 1981 (pQ[4]) is much larger ($55 likelihood units) for Scenario 19.03(2020).

Root mean square errors (RMSEs) for fits to biomass time series data are given in Table 26. Scenario 19.03(2020) generally had smaller RMSEs (better fits) across the data sources than 20.07 (17 out of 23 categories), but the differences were small. For size composition data, geometric means of effective sample sizes based on the McAllister-Ianelli method are presented in Table 27. For the most part, the effective N's for different data sources were very similar between 19.03(2020) and 20.07, although 20.07 had noticeably higher effective N's for male size compositions from the NMFS survey and retained catch size compositions, while 19.03(2020) had the higher N for male total catch size compositions in the directed fishery.

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

Scenarios 19.03(2020) and 20.07 are the two candidates on which to base status determination and OFL calculation—as noted previously, 20.01 should be considered a research scenario pending further development. These two models are not directly comparable on the basis of total likelihood because 20.07 includes the BSFRF SBS data in the model fitting whereas 19.03(2020) does not. However, one can look at individual components in the likelihood and summary statistics such as RMSEs and effective N's (discussed above). In this regard, 19.03(2020) appears to fit the data shared by both scenarios slightly better than 20.07, but this is understandable given that 20.07 is also constrained to fit the BSFRF data. More importantly, 20.07 does incorporate the BSFRF SBS data into the fitting procedure. These data are an important addition to the NMFS EBS bottom trawl data because it is assumed they provide estimates of absolute abundance within the SBS study areas and thus provide a measure of absolute scale lacking in the NMFS data. And this addresses one of the more fundamental problems with the assessment model, and that has been the sensitivity of estimates of fully-selected survey catchability to new data, leading to an annually changing baseline for status determination. Finally, neither scenario stands out from the other in regards to lack of sensible parameter values or biological realism.

h. Residual analysis

Standardized residuals to model fits were plotted and examined for all data components, including datasets that were not included (weighted 0) in the model objective function. Due to the large number of plots involved, these were created programmatically using the R package “rmarkdown” (R Core Team, 2020; Xie et al., 2020) and converted to pdf format. They are provided as appendices to the chapter. Standardized residuals for model fits to fishery data are given in Appendix 5, while standardized residuals for model fits to NMFS and BSFRF SBS data are given in Appendix 6. Standardized residuals for model fits to molt increment and male maturity ogive data are given in Appendix 7.

i. Evaluation of the model(s)

All scenarios fit the retained and total fishery catch biomass time series quite well (Figures 27-31). Z-scores for standardized residuals (Appendix 5) are all between -1 and 1, perhaps indicating a small tendency to overfit these data. The only concern is that the similar lack-of-fit to bycatch biomass in the groundfish fisheries during the early 1990s across all models indicates the possibility of an issue with the transition between historical datasets for bycatch in the groundfish fisheries and implementation of the Catch Accounting System in 1990 or a conflict with the bycatch data in the crab fisheries which starts in 1990 (Figure 32).

Normal distributions were assumed for all fishery catch biomass likelihoods in all model scenarios, with a standard deviation of 0.22 thousand t in order to fit the time series well. Consequently, the assumed sampling error is independent of catch size, which seems unlikely given the range of observed values across the fisheries, ranging from almost 0 to over 35 thousand t. Given the small levels of female bycatch observed in most of the fisheries, these data consequently have little effect on model convergence (which may be a worthwhile simplification considering that capture rates on fully-selected females are assumed to have the same temporal pattern as those for males). Using a lognormal assumption with fixed cv's as an alternative would align the error assumptions for fishery data with those made for survey data, but it would also reduce the relative influence of large catches over small ones—which may be undesirable in that it increases the arithmetic uncertainty associated with large removals from the population.

Except for the groundfish fisheries, catch abundance data is not fit in the model, but it does provide a diagnostic contrast to the fits to the biomass data. Comparison of model predictions with retained and total catch abundance in the fisheries are given in Appendix 5. All model scenarios over-predict the number of retained crab in the foreign fleets period prior to 1980. However, these data were based on IPHC reports and subject to considerable uncertainty. It seems likely that some sort of average retained male weight was used to convert biomass to abundance, in which case the average male retained prior to 1980 was heavier than those retained subsequently. Fits to total catch abundance from the fisheries seem remarkably good, considering that the data from the crab fisheries are not actually fit. However, the estimates of total catch biomass in the crab fisheries are converted from estimates of total catch abundance by applying annual mean weights based on size compositions. Therefore, the abundance and biomass data are redundant to one another.

Scenarios 19.03(2020) and 20.07 essentially fit the NMFS survey biomass time series data equally well (Figure 32), except for males in the 1975-1980 period. In this period, 19.03(2020) follows lower observations in 1976-78 while 20.07 follows higher observations in 1975 and 1980. A pattern both scenarios follow after 1990 is to underestimate the periods of high observed biomass and overestimate the periods of lower abundance. Z-scores (Appendix 6, Figures 19 and 20) reflect these observations, as well. While the biomass trajectories both scenarios follow are very similar in nature, the associated predicted survey abundance trajectories show a few more differences, with 20.07 exhibiting slightly less in the way of variability with respect to 19.03(2020). Scenario 20.07 also fits the BSFRF SBS survey biomass data well (Figure 33).

Both scenarios also fit the molt increment and maturity ogive data similarly (Figures 34 and 35, respectively). Both scenarios overpredict growth for females at small and large crab sizes, but underpredict growth at intermediate sizes (Figure 3 in Appendix 7,), which may be related to differences in growth of terminal molting crab. Also, both scenarios overpredict growth of male crab, with residuals increasing with pre-molt crab size (Figure 3 in Appendix 7). Results from fitting the molt increment data outside the model are similar for females to those from fitting the data inside the model, but not for males. There is no increasing bias with crab size when fitting the male data outside the model. Model runs have been conducted with growth fixed outside the model, but this gives rise to much poorer fits to size composition data. Fits to the maturity ogive data are similar for both scenarios (Figure 35 and Appendix 7).

Fits to retained catch size compositions are essentially identical and quite good for Scenarios 19.03(2020). and 20.07 (Figures 22-25 in Appendix 8). There are some slight (but identical) misfits in some years (e.g., 2005) when only one, but not both, of the directed fisheries was open. Fits could no doubt be slightly improved by allowing the retention curves to be estimated annually, rather than constant within a time block. Fits to total catch size compositions from the directed fishery (Figures 26-31 in Appendix 8) are also essentially identical among the scenarios, but more variable with respect to the data, with the fit in 1996 looking particularly poor (it was a year with very low sample sizes). Also, the predicted size compositions consistently overpredict larger size classes for males after 2013. This coincides with a relative increase in catch in the directed fishery west of 166°W longitude, in which case the underlying selectivity pattern may have changed from an (assumed) asymptotic one (estimated as a logistic curve) to a dome-shaped one because larger males tend to be east of 166°W longitude. Predicted bycatch size compositions for females in the directed fishery are also identical across scenarios and exhibit good fits to the data (Figures 29-31 in Appendix 8).

Predicted bycatch size compositions for the snow crab and BBRKC fisheries are likewise identical across scenarios (Figures 32-37 and 48-53, respectively, in Appendix 8). Fits to the male size composition data from the snow crab fishery are fairly poor in the early 1990s, with predictions overestimating the proportions small crab in the catch in 1992-1996, but the fits improve after 1997 for the most part (2002 and 2004 being notable exceptions with underpredicted proportions of small crab). Fits to female size composition data in the snow crab fishery are moderately good, with small variations in patterns of over- or under-prediction, but nothing dramatic. Fits to the male size composition data from the BBRKC fishery are also poor in the early 1990s, with predictions consistently overestimating the proportions small crab in the catch in 1990-1997. Then from 1999-2007, and from 2016-2019, the models overestimate the proportions of large crab taken. Somewhat unexpectedly, the fits to female size compositions from the BBRKC fishery seem to be more consistent than for males. However, sample sizes are generally very small (3 in 2019; Table 6) and trying to estimate a selectivity curve from this data may be futile (as evidenced by the associated parameters ending at bounds or exhibiting large uncertainty estimates).

Predicted bycatch size compositions for the groundfish fisheries are the most variable across the scenarios, although this is because Scenario 20.10 tends to be a bit different from the others (Figures 38-47 in Appendix 8). The fits to the data also tend to be the most variable among the fisheries, which may reflect the selectivity characteristics and relative importance to the total bycatch of different gear types that are currently lumped as "groundfish fisheries".

Estimated capture rates in the directed fishery (Figure 36) follow the same temporal patterns in all scenarios, with the largest peak in 1979 or 1980 and a lesser peak in 1992. However, the relative levels vary among the scenarios, reflecting differences in recruitment (see below) rather than differences in estimated size-specific capture functions (Figures 37) or retention functions (Figure 38), which are essentially identical.

Estimated capture rates in the snow crab (Figure 39), BBRKC (Figure 41), and groundfish fisheries (Figure 43) also exhibited similar temporal patterns but with different scales across the scenarios. Estimated sex-specific bycatch selectivity functions in the snow crab and BRKC fisheries were essentially identical across the scenarios in the time periods for which they were defined (Figures 40 and 42). The selectivity curves for bycatch in the groundfish fisheries differed the most among the scenarios, but this amounted to a consistent shift of the male selectivity curves from 2019.03(2020) by ~10 mm CW to smaller sizes in 20.07 in each of the three time periods selectivity was estimated. Selectivity curves for females were similarly shifted, but by a lesser amount.

Overall, the most dramatic differences among the scenarios were exhibited for NMFS survey selectivity and fully-selected catchability estimates (Figures 45-48). The selectivity curves for males in the period before 1982 for Scenarios 19.03(2020) and 20.10 both had the small values in the smallest model size class (25 mm CW), but the curve for 19.03(2020) was essentially a linearly increasing function to 1 at 185 mm CW, whereas it approached it's asymptote of 1 at much smaller sizes (near 75 mm CW) for 20.10. The curve for 20.10 seems better estimated, given that the size at 95% selected parameter for this curve in 19.03(2020) was estimated at it upper bound. The selectivity curves for males in the 1982+ time period from the two scenarios are far more similar to each other. For females, the selectivity curves from the two scenarios are similar in the 1975-1981 period, but differ substantially in the 1982+ time period. For the latter time period, the selectivity curve from 19.03(2020) is almost flat across the model size range, suggesting that the survey is not size-selective for females, whereas it is more S-shaped for 20.01. When fully-selected catchability is applied (Figure 48), the catchability at small sizes is similar—but as crab size increases it essentially remains the same in Scenario 19.03(2020) while it increases across the size range in Scenario 20.07.

Parameter estimates for biological processes in the model (natural mortality, growth, and terminal molt) are generally similar for Scenarios 19.03(2020) and 20.07 (Figures 51-53), except in the case of natural mature male natural mortality in the "enhanced" mortality time block (1980-1984). In this case, "M" is estimated as 15% smaller in 20.07 compared with that in 19.03(2020).

The estimated recruitment time series exhibit the same basic fluctuations across the model time period, but the scale, and some of the fine details, differ among the scenarios (Figures 54 and 55). The time series estimated in Scenarios 19.03(2020) and 20.07 are very similar in the time period from 1980 to 2002, but differences are apparent before 1980 and after 2002 (Figure 54). However, estimated peaks in recruitment in 2008 and 2018 are almost identical, although estimates in the interim are somewhat different. One effect of the missing 2020 NMFS EBS shelf bottom trawl survey is not evident in the recruitment estimates shown in Figure 54 for 2019 (i.e., those that enter the population at the start of 2020): the estimated ln-scale rec dev for 2019 is 0 for all three 2020 model scenarios, but the estimate is also highly uncertain (~22 on the ln-scale!) because, without the survey data, there is nothing in the remaining data for 2019/20 to constrain the estimate.

Not surprisingly, then, estimates of the time series of mature biomass differ across the scenarios—again, the temporal variations are similar but the scales are different (Figure 56 and 57). "Current" MMB is about 15% smaller in Scenario 20.07 than in 19.03(2020).

The author's preferred model is 20.07 because it fits all of the datasets reasonably well and includes the BSFRF SBS data , which provides a measure of absolute scale for the NMFS EBS shelf bottom trawl survey data that the base model, 19.03(2020), does not.

4. Results (best model(s))

Scenario 20.10 was selected as the author's preferred model for the 2020 assessment.

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

Effective sample sizes for size composition data fit in the model are listed in Table 27. A weighting factor of 20 (corresponding to a standard deviation of 0.158) was applied to all fishery catch biomass likelihood components to achieve close fits to the catch biomass time series.

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 13-23.

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

Estimates for mature survey biomass are listed in Tables 28 and 29 for males and females, respectively. Estimates for mature biomass at mating are listed in Tables 30 and 31. Due to the size of the tables, the numbers at size for females and males by year in 5 mm CW size bins for scenario M19F03 are available online as zipped csv files (as noted in the caption for Table 32).

iii. Recruitment time series

The estimated recruitment time series from the scenarios are listed in Table 33.

iv. Time series of catch divided by biomass.

Time series of catch divided by biomass (i.e., exploitation rate) are listed in Table 34.

c. Graphs of estimates

Graphs of estimated quantities are shown in Figures 36-59 and have been discussed above in the "Model Selection" section.

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

Graphs of estimated selectivity for the directed fishery are shown in Figure 37, for the snow crab fishery in Figure 40, for the BBRKC fishery in Figure 42, and for the groundfish fisheries in Figure 44. Estimated retention curves are shown in Figure 38. Graphs of selectivity and catchability curves for the NMFS survey are shown Figures 45-48 and graphs of the annual availability curves from the BSFRF-NMFS SBS studies (estimated outside the model) used in Scenario 20.07 are shown in Figures 49 and 50. Natural mortality estimates are shown in Figure 51, terminal molt probabilities are shown in Figure 52, and mean growth rates (molt increments) are shown in Figure 53.

iii. Estimated full selection F over time

Graphs of time series of estimated fully-selected F (total catch *capture rates*, not mortality) on males in the directed fishery and bycatch in the snow crab, BBRKC and groundfish fisheries are shown in Figures 36, 39, 41, and 43.

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

Estimates of the time trends in population biomass for mature and immature components of the stock are shown by sex in Figure 58. Mature male and female biomass trends (MMB and MFB) are shown in Figures 56 and 57.

iv. Estimated fishing mortality versus estimated spawning stock biomass

Estimated fishing mortality is plotted against spawning stock biomass (MMB) for the author's preferred model, 20.07, in Figure 68.

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

Fits to a stock-recruit relationship were not evaluated.

e. Evaluation of the fit to the data:

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

Graphs of fits to observed catches are provided in Figures 27 and 28 for retained and total catch, respectively, in the directed fishery, as well as in Figures 29-31 for total catch in the snow crab, BBRKC, and groundfish fisheries. Fits to NMFS survey biomass are shown in Figure 32, while fits to the BSFRF SBS survey biomass are shown in Figure 33.

ii. Graphs of model fits to survey numbers

See Appendix 6 for graphs of observed and predicted survey abundance time series, including graphs of standardized residuals.

iii. Graphs of model fits to catch proportions by size class

Due to the large number of plots involved, these were created programmatically using the R package "rmarkdown" (RCore Team, 2020; Xie e tal., 2018) and converted to pdf format. They are provided as an appendix to the chapter. See Appendix 8 for model fits to annual catch proportions by size class for both fishery and survey data.

iv. Graphs of model fits to survey proportions by size class

Due to the large number of plots involved, these were created programmatically using the R package "rmarkdown" (RCore Team, 2020; Xie e tal., 2018) and converted to pdf format. They are provided as an appendix to the chapter. See Appendix 8 for model fits to annual survey proportions by size class.

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

Due to the large number of plots involved, these were created programmatically using the R package "rmarkdown" (RCore Team, 2020; Xie e tal., 2018) and converted to pdf format. They are provided as appendices to the chapter. See Appendix 9 for marginal distributions of fits to the fishery compositional data. See Appendix 10 for marginal distributions of fits to the survey compositional data.

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

See Appendix 9 for time-series of implied effective sample sizes for the fishery compositional data. See Appendix 10 for time-series of implied effective sample sizes for the survey compositional data.

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

Root mean square error (RMSEs) for fits to various datasets are provided in Table 26, but no comparison is available with the cv's assumed for the indices. The author requests guidance on how the cv's for time series indices should be combined to compare with the RMSEs.

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.

Quantile-quantile (q-q) plots and histograms of residuals were not completed for this assessment.

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).

Retrospective analyses were conducted for both 19.03(2020) and 20.10. The analysis for 19.03 used 9 "peels' of annual data (2020-2011), with the model re-fit after each removal of the terminal year's data. The analysis for 20.10 was limited to 2013-2020 because no BSFRF SBS surveys were available before 2013. For each scenario, time series plots of recruitment and MMB were made to identify potential patterns in how the terminal year's estimate for each peel differed from the model result using the complete dataset. Relative bias in the terminal year estimates was quantified using Mohn's rho (Mohn, 1999). The retrospective patterns don't indicate any apparent problems (Figures 60-63). Mohn's rho was 0.986 and 0.737 for the recruitment patterns and -0.0471 and 0.0187 for the MMB patterns for 19.03(2020) and 20.10, respectively.

ii. Historical analysis (plot of actual estimates from current and previous assessments).
Estimated recruitment and mature biomass time series from previous assessments (2017-2019) are compared with those from Scenario 20.20 in Figure 64. The temporal patterns are quite similar across the assessments, but the scale varies among them—with 20.20 exhibiting an overall scale intermediate between 2017 and 2018 (low) and 2019 (high).

g. Uncertainty and sensitivity analyses
MCMC runs were completed for scenario 19.03(2020) and 20.07 to explore model uncertainty. Prior MCMC runs with 10 million iterations per chain took over 3 days to complete each chain. Consequently, the models were run to create four chains, each with 1 million iterations and a thinning factor of 2,000 to reduce serial autocorrelation, yielding 400 samples per chain. Each chain took ~10 hours to complete. Unfortunately, trace plots (Figure 65, 67) and histograms (Figures 66, 68) of OFL-related quantities indicated mixing was insufficient for both models, although the situation seemed much worse for 19.03(2020).

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 2019/20 was 28.86 thousand t while the total catch mortality was 0.54 thousand t, based on applying 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 model-estimated catch by fleet for 2019/20. 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 (Figure 69):

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

and is based on an estimate of "current" spawning biomass at mating (B above, taken as the projected 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 2020/21 require estimates of B = $MMB_{2020/21}$ (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 $F_{OFL} = F_{MSY} = F_{35\%}$. 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 (Figure 69). If the ratio is less than β, then the stock falls into Tier 3c and directed fishing must cease. In addition, if B is less than ½ $B_{35\%}$ (the minimum stock size threshold, MSST), the stock must be declared overfished and a rebuilding plan subsequently developed.

The OFL is calculated within the assessment model based on equilibrium calculations for F_{MSY} and projecting the state of the population at the end of the modeled time period one year forward assuming fishing mortality at F_{OFL}. Using MCMC, one can thus estimate the pdf of OFL (and related quantities of interest) and better characterize full model uncertainty.

To calculate F_{MSY}, 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 (i.e., $B = 0.35 \cdot B_0 = B_{35\%} = B_{MSY}$). This calculation depends on the assumed bycatch F's on Tanner crab in the snow crab, BBRKC and groundfish fisheries. As with recent assessments, the average F over the last 5 years for each of the bycatch fisheries is used in these calculations (in previous years, a different approach was used to determine the F to use for the snow crab fishery—see e.g., Stockhausen, 2016). Fishery selectivity curves were set using the average curve over the last 5 years for each fishery, as in previous assessments (e.g., Stockhausen 2019).

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 ($\bar{R}$). Following 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. This issue was revisited at the May 2018 CPT meeting with regard to whether or not the final year should be included in the calculation, but no definitive recommendations were made.

In previous assessments, average recruitment has been calculated by including the estimate for the terminal year. However, this was found to be problematic this year due to the absence of the 2020 NMFS EBS shelf bottom trawl survey, because the terminal year survey size composition is the only data providing information on the size of terminal year recruitment. In the absence of a terminal year survey, terminal year estimates of recruitment in a retrospective analysis were highly variable (and highly uncertain), leading to potentially large differences in estimated average recruitment depending on whether the model was fit with or without a terminal year survey. Consequently, average recruitment is calculated here by dropping the terminal year estimate and using the period 1982-2019 to compute the average.

The value of $\bar{R}$ for this period from MCMC runs of the author's preferred model is 369.64 million. This estimate of average recruitment is quite similar to that from the 2019 assessment model (373.96 million). The value of $B_{MSY}=B_{35\%}$ for $\bar{R}$ is 36.62 thousand t, which is somewhat smaller than that obtained in the 2019 assessment (41.07 thousand t).

Once F_{MSY} and B_{MSY} are determined, the (total catch) OFL can be calculated iteratively based on projecting the population forward one year assuming an F, calculating the catch and projected biomass B, comparing the stock's position on the harvest control rule's phase plane and adjusting F and recalculating the projected *B* until the point (*F*, *B*) lies on the control rule. 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 mortality when fishing at $F = F_{OFL}$.

The total catch mortality (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, 2020 as estimated by the assessment model.

Assessment model uncertainty was included in the calculation of OFL using MCMC. Conceptually, a random draw from the assessment model's joint posterior distribution for the estimated parameters was taken, and the $\bar{R}$, B_0, F_{MSY}, B_{MSY}, F_{OFL}, OFL, and "current" MMB for 2020/21 were calculated based on the resulting parameter values. This should be repeated a large number of times to approximate the distribution of OFL given the full model uncertainty. For this assessment, four chains of 1 million MCMC steps each were generated from the author's preferred model (20.07), with the OFL and associated quantities calculated at each step. The chains were initialized from the converged model state using a "burn in" of 200,000 steps and subsequently thinned by a factor of 2,000 to reduce serial autocorrelation in the MCMC sampling. This resulted in about 1,600 MCMC samples with which to characterize the distribution of the OFL.

However, trace plots for the OFL and related quantities (Figures 63 and 64) indicate that the chains failed to achieve sufficient mixing, with subsequent samples in each chain highly autocorrelated when they should be independent. This may reflect the absence of a NMFS survey this year on model stability. Certainly, the mixing characteristics were as bad—actually much worse—or Scenario 19.03(2020) (Figures 61 and 62). **Despite the poor mixing characteristics of the MCMC sampling, the median value of across all chains was taken as the OFL for 2020/21. The median tends to be insensitive to outliers, and thus may perform better than, for example, a mean, under these circumstances. As such, the OFL for 2020/21 from the author's preferred scenario (20.07) is 20.88 thousand t** (Figure 66)**.**

The B_{MSY} proxy, $B_{35\%}$, from the author's preferred model is 36.62 thousand t, so MSST = 0.5 B_{MSY} = 18.31 thousand t. Because current projected *B* = 35.31 thousand t > MSST, **the stock is not overfished**. However, because current projected *B* < B_{MSY}, the **stock falls into Tier 3b**. The population state (directed F vs. MMB) is plotted for each year from 1965/66-2019/20 in Figure 67 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. However, because determining the P* ABC relies on an uncertainty distribution for the OFL derived from the MCMC results, its validity seems highly dubious this year.

For the author's preferred scenario, 20.07, the P* ABC (ABC_{max}) is 20.87 thousand t while the 20% Buffer ABC is 16.70 thousand t. As noted, the value for the P* ABC is questionable given the poor MCMC performance. In addition, the author remains concerned that the OFL calculation, 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 the P* ABC level 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. In addition, the estimates of survey catchability for this stock remain problematic and contribute to this year's inflated OFL recommendation (relative to last year's) despite a continued decline in survey biomass across the last few years. Given this uncertainty concerning the stock, **the author recommends using the 20% buffer previously adopted by the SSC for this stock to calculate ABC. Consequently, the author's recommended ABC is 16.70 thousand t**.

Given the poor MCMC results, the following tables summarize the OFL/ABC results for scenario 20.07 based on MLE results as well as the MCMC results:

Table: OFL/ABC results for scenario 20.07 based on MLE results.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2016/17	14.58	77.96	0.00	0.00	1.14	25.61	20.49
2017/18	15.15	64.09	1.13	1.13	2.37	25.42	20.33
2018/19	20.54	82.61	1.11	1.11	1.90	20.87	16.70
2019/20	18.38	56.15	0.00	0.00	0.54	28.86	23.09
2020/21		35.33				21.13	16.90

Table: OFL/ABC results for scenario 20.07 based on MCMC results.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2016/17	14.58	77.96	0.00	0.00	1.14	25.61	20.49
2017/18	15.15	64.09	1.13	1.13	2.37	25.42	20.33
2018/19	20.54	82.61	1.11	1.11	1.90	20.87	16.70
2019/20	18.31	56.15	0.00	0.00	0.54	28.86	23.09
2020/21		35.31				20.88	16.70

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 been collected in the EBS on Tanner crab and incorporated into the assessment. It would be helpful to have more information on growth associated with the terminal molt, because it seems likely this has different characteristics than previous molts. Additionally, more data regarding temperature-dependent effects on molting frequency would be helpful to assess potential impacts of the EBS cold pool on the stock and potentially improve recruitment estimates. Information on temperature-dependent changes in crab movement and survey catchability would also be of value. In addition, it would be worthwhile to develop a "better" index of reproductive potential than MMB that can be calculated in the assessment model, as well as 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 differences in the directed fishery in areas east and west 166ºW longitude should be explicitly represented in the assessment model need to be addressed. The question of whether or not bycatch in the groundfish fisheries should be split into pot- and trawl-related components should be revisited. Also, the appropriate weight for male maturity ogives based on NMFS survey data in the model likelihood needs to be further explored.

Incorporating the BSFRF side-by-side (SBS) surveys into the assessment in the best way possible is also a matter for further exploration. Further catch ratio analysis using the SBS survey data outside the model (similar to what Somerton et al, 2013, did for snow crab) may eventually provide year-specific estimates of (or priors on) NMFS survey selectivity that account for variations in stock abundance across different depths and benthic substrates.

Development of a GMACS version of the Tanner crab model is also a priority and can proceed now that a GMACS model for snow crab has been developed. Further model development needs to continue the effort to eliminate parameters at bounds.

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, a better 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 at decadal time scales (Rugolo and Turnock, 2012), suggesting a 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 fishery	possible concern
Fishery effects on age-at-maturity and fecundity	none	unknown	possible concern

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Table captions

Figure captions

Tables

Table 1. Retained catch (males) in directed Tanner crab fisheries (1965/66-2000/01). Catch units are metric tons. 'c' appended to the year denotes a closure of the directed domestic fishery.

year	US	Japan	Russia	Total
1965	0	1,170	750	1,920
1966	0	1,690	750	2,440
1967	0	9,750	3,840	13,590
1968	460	13,590	3,960	18,010
1969	460	19,950	7,080	27,490
1970	80	18,930	6,490	25,500
1971	50	15,900	4,770	20,720
1972	100	16,800	0	16,900
1973	2,290	10,740	0	13,030
1974	3,300	12,060	0	15,360
1975	10,120	7,540	0	17,660
1976	23,360	6,660	0	30,020
1977	30,210	5,320	0	35,530
1978	19,280	1,810	0	21,090
1979	16,600	2,400	0	19,000
1980	13,426	0	0	13,426
1981	4,990	0	0	4,990
1982	2,390	0	0	2,390
1983	549	0	0	549
1984	1,429	0	0	1,429
1985c	0	0	0	0
1986c	0	0	0	0
1987	998	0	0	998
1988	3,180	0	0	3,180
1989	11,113	0	0	11,113
1990	18,189	0	0	18,189
1991	14,424	0	0	14,424
1992	15,921	0	0	15,921
1993	7,666	0	0	7,666
1994	3,538	0	0	3,538
1995	1,919	0	0	1,919
1996	821	0	0	821
1997c	0	0	0	0
1998c	0	0	0	0
1999c	0	0	0	0
2000c	0	0	0	0

Table 1 (cont.). Retained catch (males) in directed Tanner crab fisheries (2001/02-2018/19). Catch units are metric tons. Asterisks denote a closure of the directed domestic fishery; retained catch in these years represent incidentally retained Tanner crab in the snow crab and Bristol Bay red king crab fisheries.

year	US	Japan	Russia	Total
2001c	0	0	0	0
2002c	0	0	0	0
2003c	0	0	0	0
2004c	0	0	0	0
2005	432	0	0	432
2006	963	0	0	963
2007	956	0	0	956
2008	880	0	0	880
2009	603	0	0	603
2010c	1	0	0	1
2011c	2	0	0	2
2012c	1	0	0	1
2013	1,264	0	0	1,264
2014	6,216	0	0	6,216
2015	8,910	0	0	8,910
2016c	1	0	0	1
2017	1,133	0	0	1,133
2018	1,107	0	0	1,107
2019c	0	0	0	0

Table 2. Retained catch (males) in the US domestic pot fishery. Information from the Community Development Quota (CDQ) fisheries is included in the table for fishery years 2005/06 to the present. Total crab caught and total harvest include deadloss. The "Fishery Year" YYYY/YY+1 runs from July 1, YYYY to June 30, YYYY+1. The ADFG year (in parentheses, if different from the "Fishery Year") indicates the year ADFG assigned to the fishery season in compiled reports.

year (ADFG 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---				
1986/87 (1987)	---closed---				
1987/88 (1988)	957,318	2,294,997	5.6	98	01/15-04/20
1988/89 (1989)	2,894,480	6,982,865	13.5	109	01/15-05/07
1989/90 (1990)	9,800,763	22,417,047	29.5	179	01/15-04/24
1990/91	16,608,625	40,081,555	42.8	255	11/20-03/25
1991/92	12,924,102	31,794,382	32.8	285	11/15-03/31
1992/93	15,265,865	35,130,831	39.2	294	11/15-03/31
1993/94	7,235,898	16,892,320	9.1	296	11/01-11/10, 11/20-01/01
1994/95 (1994)	3,351,639	7,766,886	7.5	183	11/01-11/21
1995/96 (1995)	1,877,303	4,233,061	5.5	196	11/01-11/16
1996/97 (1996)	734,296	1,806,077	6.2	196	11/01-11/05, 11/15-11/27
1997/98-2004/05	---closed---				
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---				
2011/12	---closed---				
2012/13	---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
2016/17	---closed---				
2017/18	1,340,394	2,497,033	2.500	34	10/15-03/31
2018/19	1,381,008	2,441,201	2.439	36	10/15-03/31
2019/20	---closed---				

Table 3. Total catch (retained + discarded) of Tanner crab in various fisheries, as estimated from observer data. Units are 1000's t. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery; GTF: groundfish fisheries.

	TCF				SCF		RKF		GTF	Total
	West 166W		East 166W		all EBS		all EBS		all EBS	all EBS
year	male	female	male	female	male	female	male	female	all	all
1973	–	–	–	–	–	–	–	–	17.7355	17.7355
1974	–	–	–	–	–	–	–	–	24.4486	24.4486
1975	–	–	–	–	–	–	–	–	9.4075	9.4075
1976	–	–	–	–	–	–	–	–	4.6992	4.6992
1977	–	–	–	–	–	–	–	–	2.7760	2.7760
1978	–	–	–	–	–	–	–	–	1.8688	1.8688
1979	–	–	–	–	–	–	–	–	3.3974	3.3974
1980	–	–	–	–	–	–	–	–	2.1137	2.1137
1981	–	–	–	–	–	–	–	–	1.4742	1.4742
1982	–	–	–	–	–	–	–	–	0.4491	0.4491
1983	–	–	–	–	–	–	–	–	0.6713	0.6713
1984	–	–	–	–	–	–	–	–	0.6441	0.6441
1985c	–	–	–	–	–	–	–	–	0.3992	0.3992
1986c	–	–	–	–	–	–	–	–	0.6486	0.6486
1987	–	–	–	–	–	–	–	–	0.6396	0.6396
1988	–	–	–	–	–	–	–	–	0.4627	0.4627
1989	–	–	–	–	–	–	–	–	0.6713	0.6713
1990	–	–	–	–	7.0812	0.1057	3.7224	0.0356	0.9435	11.8885
1991	6.2206	0.4408	19.5967	1.4452	8.3602	0.1440	1.9703	0.0272	2.5432	40.7482
1992	7.3470	0.5996	29.6604	1.1040	2.4872	0.1625	1.3167	0.0190	2.7596	45.4561
1993	1.6439	0.1361	10.2100	0.8601	2.8744	0.4004	3.1308	0.1493	1.7580	21.1630
1994	0.3573	0.1124	6.9581	0.7293	1.3451	0.1942	–	–	2.0960	11.7924
1995	0.6503	0.1407	4.4152	0.9242	1.0210	0.1209	–	–	1.5249	8.7973
1996	0.0718	–	0.2286	0.0567	1.9607	0.1196	0.2700	0.0024	1.5945	4.3044
1997c	–	–	–	–	1.9637	0.0927	0.1601	0.0017	1.1800	3.3981
1998c	–	–	–	–	0.6559	0.0804	0.1152	0.0017	0.9350	1.7882
1999c	–	–	–	–	0.1318	0.0112	0.0751	0.0022	0.6306	0.8509
2000c	–	–	–	–	0.3128	0.0061	0.0664	0.0014	0.7415	1.1282

Table 3 (cont.). Total catch (retained + discarded) of Tanner crab in various fisheries, as estimated from observer data. Units are 1000's t. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery; GTF: groundfish fisheries.

	TCF				SCF		RKF		GTF	Total
	West 166W		East 166W		all EBS		all EBS		all EBS	all EBS
year	male	female	male	female	male	female	male	female	all	all
2001c	–	–	–	–	0.545308	0.020530	0.042200	0.000963	1.185191	1.794192
2002c					0.167178	0.013815	0.061253	0.001580	0.719068	0.962894
2003c	–	–	–	–	0.064743	0.007011	0.054937	0.001847	0.423801	0.552339
2004c					0.134619	0.039899	0.049761	0.001650	0.675058	0.900987
2005	0.684588	0.023750			1.162843	0.016258	0.041416	0.000991	0.621172	2.551018
2006	0.579229	0.072287	1.132145	0.048832	1.527248	0.085518	0.029515	0.001481	0.717134	4.193389
2007	0.679879	0.014809	1.779104	0.029297	1.861591	0.052063	0.060557	0.001422	0.694930	5.173652
2008	0.119145	0.001495	1.177782	0.006659	1.100270	0.024925	0.279901	0.002541	0.532864	3.245582
2009			0.664586	0.002270	1.559556	0.015674	0.186506	0.001139	0.374187	2.803918
2010c	–	–	–	–	1.453261	0.009179	0.031920	0.000553	0.231367	1.726280
2011c					2.141349	0.013272	0.017470	0.000072	0.203984	2.376147
2012c	–	–	–	–	1.564344	0.010297	0.042113	0.001314	0.153263	1.771331
2013	0.933101	0.011362	0.746213	0.012106	1.841754	0.015630	0.128942	0.001265	0.348367	4.038740
2014	3.057006	0.030467	5.306589	0.008767	5.330041	0.050675	0.305409	0.000997	0.435732	14.525683
2015	5.467550	0.029386	6.761436	0.028221	3.919177	0.016818	0.204958	0.005581	0.361220	16.794347
2016c	–	–	–	–	2.575704	0.016695	0.175692	0.004222	0.299052	3.071365
2017	1.362519	0.038489			1.081659	0.006841	0.183555	0.001433	0.160506	2.835002
2018	1.598424	0.034668			0.879726	0.008857	0.074017	0.000131	0.176189	2.772012
2019c	–	–	–	–	1.003315	0.015094	0.017965	0.000028	0.147583	1.183985

Table 4. Retained catch biomass in the directed Tanner crab (TCF), snow crab (SCF), and BBRKC (RKF) fisheries since 2005. The directed fishery was completely closed from 2010/11 to 2012/13, as well as in 2016/17 and 2019/20. Legal-sized Tanner crab can be incidentally-retained in the snow crab and BBRKC fisheries up to a cap of 5% the target catch.

	TCF						SCF		RKF	
	West 166W		East 166W		all EBS		all EBS		all EBS	
year	Abundance	Biomass (kg)	Abundance	Biomass (kg)	Abundance	Biomass (kg)	Abundance	Biomass (kg)	Abundance	Biomass (kg)
2005	255,859	244,534	0	0	255,859	244,534	188,118	187,689	0	0
2006	164,719	155,532	583,650	633,937	748,369	789,469	175,904	171,439	1,830	1,883
2007	151,525	151,112	679,137	711,640	830,662	862,752	90,148	86,478	6,354	6,334
2008	48,171	47,157	760,166	809,022	808,337	856,179	3,300	2,535	18,732	21,068
2009	0	0	476,668	592,417	476,668	592,417	2,544	1,714	6,751	8,402
2010	0	0	0	0	0	0	1,689	1,154	6	3
2011	0	0	0	0	0	0	3,095	2,092	0	0
2012	0	0	0	0	0	0	1,643	1,111	4	3
2013	722,469	593,617	704,201	654,271	1,426,670	1,247,888	13,256	9,882	5,842	6,322
2014	3,121,442	2,368,693	4,378,199	3,829,288	7,499,641	6,197,981	19,512	14,458	3,691	3,792
2015	4,817,145	3,770,319	5,998,876	5,107,722	10,816,021	8,878,041	39,011	30,252	1,386	1,350
2016	0	0	0	0	0	0	1,733	1,177	33	21
2017	1,322,542	1,117,483	139	119	1,322,681	1,117,602	17,688	15,018	25	17
2018	1,376,977	1,103,903	0	0	1,376,977	1,103,903	4,013	3,409	18	12
2019	0	0	0	0	0	0	125	84	0	0

Table 5. Sample sizes for retained and total catch-at-size in the directed fishery. N = number of individuals. N' = scaled sample size used in assessment.

year	Retained catch		Total catch			
	Males		Males		Females	
	N	N'	N	N'	N	N'
1980/81	13,310	104.6	–	–	–	–
1981/82	11,311	88.9	–	–	–	–
1982/83	13,519	106.2	–	–	–	–
1983/84	1,675	13.2	–	–	–	–
1984/85	2,542	20.0	–	–	–	–
1988/89	12,380	97.3	–	–	–	–
1989/90	4,123	32.4	–	–	–	–
1990/91	120,676	200.0	–	–	–	–
1991/92	126,299	200.0	31,252	169.6	5,605	30.4
1992/93	125,193	200.0	54,836	172.5	8,755	27.5
1993/94	71,622	200.0	40,388	158.8	10,471	41.2
1994/95	27,658	198.8	5,792	41.6	2,132	15.3
1995/96	19,276	138.6	5,589	40.2	3,119	22.4
1996/97	4,430	31.8	352	2.5	168	1.2
2005/06	705	5.1	19,715	141.7	1,107	8.0
2006/07	2,940	21.1	24,226	169.1	4,432	30.9
2007/08	5,827	41.9	61,546	189.8	3,318	10.2
2008/09	3,490	25.1	29,166	195.7	646	4.3
2009/10	2,417	17.4	17,289	124.3	147	1.1
2013/14	4,553	32.7	17,291	124.3	710	5.1
2014/15	14,371	103.3	85,120	197.2	1,191	2.8
2015/16	24,320	174.8	119,843	197.3	1,624	2.7
2016/17	–	–	–	–	–	–
2017/18	3,470	24.9	18,785	135.1	1,721	12.4
2018/19	3,306	23.8	28,338	186.6	2,036	13.4
2019/20	–	–	–	–	–	–

Table 6. Sample sizes for total bycatch-at-size in the snow crab and Bristol Bay red king crab (BBRKC) fisheries, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.

year	Snow crab fishery				Bristol Bay red king crab			
	Males		Females		Males		Females	
	N	N'	N	N'	N	N'	N	N'
1990/91	14,032	100.9	478	3.4	1,580	11.4	43	0.3
1991/92	11,708	84.2	686	4.9	2,273	16.3	89	0.6
1992/93	6,280	45.1	859	6.2	2,056	14.8	105	0.8
1993/94	6,969	50.1	1542	11.1	7,359	52.9	1,196	8.6
1994/95	2,982	21.4	1523	10.9	–	–	–	–
1995/96	1,898	13.6	428	3.1	–	–	–	–
1996/97	3,265	23.5	662	4.8	114	0.8	5	0.0
1997/98	3,970	28.5	657	4.7	1,030	7.4	41	0.3
1998/99	1,911	13.7	324	2.3	457	3.3	20	0.1
1999/00	976	7.0	82	0.6	207	1.5	14	0.1
2000/01	1,237	8.9	74	0.5	845	6.1	44	0.3
2001/02	3,113	22.4	160	1.2	456	3.3	39	0.3
2002/03	982	7.1	118	0.8	750	5.4	50	0.4
2003/04	688	4.9	152	1.1	555	4.0	46	0.3
2004/05	833	6.0	707	5.1	487	3.5	44	0.3
2005/06	9,807	70.5	368	2.6	983	7.1	70	0.5
2006/07	10,391	74.7	1256	9.0	746	5.4	68	0.5
2007/08	13,797	99.2	728	5.2	1,360	9.8	89	0.6
2008/09	8,455	60.8	722	5.2	3,797	27.3	121	0.9
2009/10	11,057	79.5	474	3.4	2,871	20.6	70	0.5
2010/11	12,073	86.8	250	1.8	582	4.2	28	0.2
2011/12	9,453	68.0	189	1.4	323	2.3	4	0.0
2012/13	11,004	79.1	270	1.9	618	4.4	48	0.3
2013/14	12,935	93.0	356	2.6	2,110	15.2	60	0.4
2014/15	24,878	178.9	804	5.8	3,110	22.4	32	0.2
2015/16	19,839	142.6	230	1.7	2,175	15.6	186	1.3
2016/17	16,369	117.7	262	1.9	3,220	23.1	246	1.8
2017/18	5,598	40.2	109	0.8	3,782	27.2	86	0.6
2018/19	6,145	44.2	233	1.7	1,283	9.2	6	0.0
2019/20	8,881	63.8	423	3.0	357	2.6	3	0.0

Table 7. 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	Males		Females	
	N	N'	N	N'
1973/74	3,155	22.7	2,277	16.4
1974/75	2,492	17.9	1,600	11.5
1975/76	1,251	9.0	839	6.0
1976/77	6,950	50.0	6,683	48.0
1977/78	10,685	76.8	8,386	60.3
1978/79	18,596	115.3	13,665	84.7
1979/80	19,060	125.4	11,349	74.6
1980/81	12,806	92.1	5,917	42.5
1981/82	6,098	43.8	4,065	29.2
1982/83	13,439	96.6	8,006	57.6
1983/84	18,363	132.0	8,305	59.7
1984/85	27,403	133.1	13,771	66.9
1985/86	23,128	129.0	12,728	71.0
1986/87	14,860	106.8	7,626	54.8
1987/88	23,508	119.4	15,857	80.6
1988/89	10,586	76.1	7,126	51.2
1989/90	59,943	118.5	41,234	81.5
1990/91	23,545	135.5	11,212	64.5
1991/92	6,817	49.0	3,479	25.0
1992/93	3,128	22.5	1,175	8.4
1993/94	1,217	8.7	358	2.6
1994/95	3,628	26.1	1,820	13.1
1995/96	3,904	28.1	2,669	19.2
1996/97	8,306	59.7	3,400	24.4
1997/98	9,949	71.5	3,900	28.0
1998/99	12,105	87.0	4,440	31.9
1999/00	11,053	79.5	4,522	32.5
2000/01	12,895	92.7	3,087	22.2
2001/02	15,788	113.5	3,083	22.2
2002/03	15,401	110.7	3,249	23.4
2003/04	9,572	68.8	2,733	19.6
2004/05	13,844	99.5	4,460	32.1
2005/06	17,785	127.9	3,709	26.7
2006/07	15,903	114.3	3,047	21.9
2007/08	16,148	116.1	3,819	27.5
2008/09	26,171	172.1	4,235	27.9
2009/10	19,043	136.9	2,701	19.4
2010/11	15,666	112.6	2,604	18.7
2011/12	16,359	117.6	4,263	30.6
2012/13	13,186	94.8	3,103	22.3
2013/14	28,908	165.2	6,081	34.8
2014/15	39,276	180.4	4,262	19.6
2015/16	27,703	165.5	5,781	34.5
2016/17	18,731	134.7	4,430	31.8
2017/18	13,591	97.7	1,743	12.5
2018/19	7,701	55.4	1,485	10.7
2019/20	7,188	51.7	2,113	15.2

Table 8. Trends in Tanner crab biomass (metric tons) in the NMFS EBS summer bottom trawl survey, by sex and area.

	male			female		
year	W166	E166	all EBS	W166	E166	all EBS
1975	80,689	214,202	294,891	13,374	27,594	40,968
1976	55,092	101,958	157,050	12,140	25,420	37,560
1977	51,038	87,463	138,501	21,613	31,435	53,048
1978	25,394	72,913	98,308	14,167	18,406	32,574
1979	32,058	17,978	50,036	19,701	3,448	23,149
1980	103,505	48,979	152,484	64,420	12,883	77,303
1981	56,540	23,390	79,930	35,525	8,577	44,102
1982	49,255	16,602	65,856	57,757	8,107	65,864
1983	24,708	13,337	38,045	17,418	5,350	22,769
1984	18,490	12,020	30,510	12,358	4,800	17,158
1985	6,676	8,231	14,907	3,393	3,160	6,554
1986	11,986	9,625	21,612	2,570	3,504	6,074
1987	16,648	28,863	45,511	5,137	15,009	20,146
1988	41,093	58,130	99,223	12,668	22,885	35,553
1989	45,106	87,718	132,824	12,254	18,975	31,230
1990	55,539	76,879	132,418	22,532	25,022	47,554
1991	55,986	89,825	145,811	20,445	31,341	51,787
1992	37,674	89,918	127,592	16,857	11,358	28,215
1993	19,877	53,394	73,271	7,382	5,325	12,707
1994	16,032	32,303	48,335	5,716	5,332	11,048
1995	15,310	19,672	34,982	7,474	5,982	13,456
1996	10,790	19,979	30,770	4,470	6,548	11,019
1997	5,561	9,088	14,649	1,893	2,914	4,806
1998	6,604	8,404	15,008	2,489	1,752	4,241
1999	6,719	14,835	21,554	3,347	3,360	6,708
2000	6,903	16,429	23,332	2,999	3,613	6,613

Table 8 (cont). Trends in Tanner crab biomass (metric tons) in the NMFS EBS summer bottom trawl survey, by sex and area.

		male			female	
year	W166	E166	all EBS	W166	E166	all EBS
2001	13,089	16,231	29,320	6,989	3,931	10,920
2002	13,010	14,402	27,411	6,499	3,469	9,968
2003	20,661	17,164	37,825	10,297	2,795	13,092
2004	26,468	12,455	38,923	7,731	1,131	8,862
2005	46,313	17,443	63,756	17,469	4,493	21,962
2006	72,907	28,636	101,543	21,723	6,476	28,198
2007	76,285	27,938	104,223	12,465	6,612	19,076
2008	47,736	37,177	84,913	9,444	5,079	14,523
2009	32,653	14,786	47,439	6,495	4,553	11,048
2010	34,601	14,426	49,027	6,366	2,910	9,276
2011	39,321	23,390	62,712	9,190	6,615	15,805
2012	34,764	45,367	80,131	9,787	14,245	24,032
2013	38,839	64,580	103,420	10,866	13,398	24,264
2014	50,739	58,196	108,936	8,728	8,648	17,377
2015	39,158	35,093	74,251	7,574	5,304	12,878
2016	43,315	25,520	68,835	7,133	1,479	8,612
2017	29,685	23,952	53,637	6,274	2,144	8,418
2018	32,734	13,769	46,503	8,213	1,588	9,801
2019	17,503	10,790	28,293	7,452	2,133	9,585

Table 9. Trends in biomass for preferred-size (> 125 mm CW) male Tanner crab in the NMFS EBS summer bottom trawl survey (in metric tons).

	W166			E166			all EBS		
year	new shell	old shell	all	new shell	old shell	all	new shell	old shell	all
1975	56,181	2,509	58,691	152,683	6,522	159,205	208,864	9,032	217,896
1976	38,107	1,534	39,640	57,034	9,674	66,709	95,141	11,208	106,349
1977	26,511	6,808	33,319	50,855	7,543	58,399	77,366	14,351	91,717
1978	3,221	6,626	9,847	40,633	9,780	50,413	43,853	16,406	60,259
1979	4,115	3,745	7,860	9,767	3,426	13,192	13,882	7,171	21,052
1980	11,210	1,677	12,887	23,184	10,857	34,041	34,394	12,534	46,927
1981	5,884	2,167	8,050	3,445	11,286	14,731	9,329	13,452	22,781
1982	5,763	5,859	11,622	3,009	4,851	7,860	8,772	10,710	19,481
1983	2,416	3,240	5,655	5,151	2,082	7,233	7,566	5,322	12,889
1984	571	3,159	3,730	4,348	3,077	7,424	4,919	6,236	11,154
1985	588	870	1,458	4,055	1,046	5,101	4,642	1,917	6,559
1986	142	674	816	734	2,546	3,280	876	3,219	4,096
1987	3,505	658	4,163	4,911	3,473	8,385	8,416	4,132	12,548
1988	9,690	929	10,618	15,698	2,715	18,413	25,387	3,644	29,031
1989	13,758	2,741	16,499	37,364	3,740	41,104	51,122	6,481	57,603
1990	21,082	3,274	24,356	35,903	7,084	42,987	56,985	10,358	67,343
1991	13,386	8,430	21,816	32,973	14,476	47,449	46,359	22,906	69,265
1992	9,851	6,461	16,311	41,423	16,242	57,665	51,274	22,703	73,977
1993	3,716	2,596	6,312	22,942	11,990	34,932	26,658	14,586	41,244
1994	1,248	4,143	5,391	10,000	13,912	23,912	11,248	18,054	29,303
1995	370	5,392	5,761	1,241	13,516	14,757	1,611	18,907	20,518
1996	100	3,580	3,680	330	13,912	14,242	430	17,492	17,922
1997	163	958	1,121	316	4,245	4,561	478	5,203	5,681
1998	441	644	1,085	1,001	2,604	3,605	1,442	3,247	4,689
1999	256	356	612	1,645	1,838	3,483	1,902	2,194	4,095
2000	250	377	627	4,484	3,045	7,529	4,734	3,422	8,156

Table 9 (cont.). Trends in biomass for preferred-size (> 125 mm CW) male Tanner crab in the NMFS EBS summer bottom trawl survey (in metric tons).

	W166			E166			all EBS		
year	new shell	old shell	all	new shell	old shell	all	new shell	old shell	all
2001	418	1,361	1,780	4,473	3,600	8,073	4,892	4,961	9,853
2002	384	838	1,222	944	7,102	8,046	1,328	7,940	9,268
2003	434	2,227	2,661	1,558	6,433	7,991	1,992	8,660	10,652
2004	980	1,825	2,805	1,597	4,916	6,513	2,577	6,741	9,318
2005	8,776	5,062	13,839	2,368	5,822	8,190	11,145	10,884	22,029
2006	3,755	15,328	19,083	2,134	6,794	8,927	5,889	22,122	28,011
2007	8,523	7,757	16,281	4,143	5,314	9,457	12,666	13,071	25,737
2008	8,688	4,457	13,145	15,476	3,288	18,764	24,163	7,745	31,909
2009	6,657	4,156	10,812	2,644	5,139	7,783	9,300	9,295	18,595
2010	9,593	4,867	14,460	3,006	4,576	7,582	12,599	9,443	22,042
2011	9,023	6,637	15,660	1,513	6,987	8,500	10,536	13,624	24,160
2012	2,368	3,997	6,365	3,352	5,026	8,378	5,720	9,023	14,743
2013	5,383	2,837	8,220	10,871	3,527	14,397	16,254	6,364	22,618
2014	7,163	4,604	11,766	14,899	9,310	24,210	22,062	13,914	35,976
2015	8,380	5,925	14,306	9,084	10,217	19,301	17,464	16,143	33,607
2016	5,799	12,527	18,326	2,640	8,055	10,695	8,439	20,582	29,021
2017	894	11,659	12,553	1,629	10,841	12,470	2,523	22,500	25,024
2018	996	11,875	12,871	102	7,253	7,355	1,097	19,128	20,225
2019	202	4,799	5,001	315	4,455	4,769	517	9,254	9,771

Table 10. Sample sizes for NMFS survey size composition data. In the assessment model, an input 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	1,047	91	1,861	39	706	127	2,895	127	3,993	80	399
1976	214	88	1,097	91	1,304	39	311	130	2,023	130	2,469	47	242
1977	155	69	776	76	1,183	60	738	114	1,778	114	1,971	79	485
1978	230	88	1,949	82	638	65	1,307	147	2,957	147	1,570	104	700
1979	307	74	733	62	735	42	341	138	1,805	138	808	68	306
1980	320	103	1,491	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	87	823	72	457	103	2,384	181	1,751	181	1,371	147	2,082
1983	353	102	2,113	56	201	102	2,154	166	2,484	166	983	132	1,181
1984	355	135	1,879	53	284	94	1,531	171	1,965	171	490	126	1,399
1985	353	141	847	52	228	65	601	179	1,060	179	381	86	459
1986	353	162	1,588	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	3,735	149	1,753	100	530	252	5,627	252	2,210	101	475
1989	373	204	3,271	144	1,241	108	882	237	4,977	237	3,201	135	1,067
1990	370	198	3,114	155	1,502	126	1,511	247	5,107	247	3,149	151	1,342
1991	371	163	2,259	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	869	96	545	122	1,337	207	2,051	207	1,677	180	1,865
1994	374	97	921	52	148	104	1,293	175	1,281	175	724	174	1,827
1995	375	115	834	35	140	107	1,057	153	958	153	220	137	1,611
1996	374	115	883	57	109	98	963	148	1,069	148	222	134	1,414
1997	375	116	1,329	62	168	83	504	161	1,336	161	289	125	582
1998	374	146	1,710	53	160	73	344	176	2,032	176	396	128	624
1999	372	138	2,628	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

Table10 (cont.). Sample sizes for NMFS survey size composition data. In the assessment model, an input 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
2001	374	164	3,678	83	364	72	644	211	4,036	211	629	145	817
2002	374	155	3,585	81	350	70	500	186	3,912	186	458	154	1,089
2003	375	153	2,834	111	923	83	752	203	4,754	203	900	153	1,349
2004	374	175	3,922	90	427	80	656	236	4,568	236	1,027	179	1,873
2005	372	201	3,352	103	634	74	928	254	4,496	254	1,280	185	1,753
2006	375	211	4,364	143	1,332	125	1,327	254	6,224	254	1,757	211	4,054
2007	375	186	2,430	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	3,180	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	3,611	100	942	97	720	215	5,526	215	1,564	139	1,296
2013	375	163	2,917	116	1,417	101	1,002	207	5,592	207	2,675	137	1,344
2014	375	165	2,211	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	1,373	56	370	82	1,248	222	2,235	222	1,170	218	3,668
2017	375	131	2,033	50	213	99	1,125	186	2,241	186	424	205	3,541
2018	375	196	4,666	68	525	93	703	222	4,990	222	513	190	2,748
2019	375	181	3,810	85	649	55	541	208	4,216	208	522	169	1,175

Table 11. Effort data (potlifts) in the crab fisheries, by area. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery. Hyphens indicate years with no effort.

	SCF	RKF
year	all EBS	all EBS
1953	–	30,083
1954	–	17,122
1955	–	28,045
1956		41,629
1957	–	23,659
1958	–	27,932
1959		22,187
1960	–	26,347
1961	–	72,646
1962	–	123,643
1963	–	181,799
1964	–	180,809
1965	–	127,973
1966	–	129,306
1967	–	135,283
1968	–	184,666
1969	–	175,374
1970	–	168,059
1971	–	126,305
1972	–	208,469
1973	–	194,095
1974	–	212,915
1975	–	205,096
1976	–	321,010
1977	–	451,273
1978	190,746	406,165
1979	255,102	315,226
1980	435,742	567,292
1981	469,091	536,646
1982	287,127	140,492
1983	173,591	–
1984	370,082	107,406
1985	542,346	84,443
1986	616,113	175,753
1987	747,395	220,971
1988	665,242	146,179
1989	912,718	205,528

Table 11 (cont.). Effort data (potlifts) in the crab fisheries, by area. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: Bristol Bay red king crab fishery. Hyphens indicate years with no effort.

	TCF			SCF	RKF
year	West 166W	East 166W	all EBS	all EBS	all EBS
1990	479	493,820	494,299	1,382,908	262,761
1991	140,050	360,864	500,914	1,278,502	227,555
1992	166,670	508,922	675,592	969,209	206,815
1993	40,100	286,620	326,720	716,524	254,389
1994	21,282	228,254	249,536	507,603	697
1995	46,454	201,988	248,442	520,685	547
1996	8,533	64,989	73,522	754,140	77,081
1997	–	–	–	930,794	91,085
1998	–	–	–	945,533	145,689
1999	–	–	–	182,634	151,212
2000	–	–	–	191,200	104,056
2001	–	–	–	326,977	66,947
2002	–	–	–	153,862	72,514
2003	–	–	–	123,709	134,515
2004				75,095	97,621
2005	6,346	–	6,346	117,375	116,320
2006	4,517	15,273	19,790	86,328	72,404
2007	7,268	26,441	33,709	140,857	113,948
2008	2,336	19,401	21,737	163,537	139,937
2009	–	6,635	6,635	137,292	119,261
2010	–	–	–	147,478	132,183
2011	–	–	–	270,602	45,784
2012				225,627	38,842
2013	23,062	16,613	39,675	225,245	46,589
2014	68,695	72,768	141,463	279,183	57,725
2015	84,933	130,302	215,235	202,526	48,763
2016	–	–	–	118,548	33,608
2017	19,284	11	19,295	114,673	49,169
2018	29,833	–	29,833	119,484	31,975
2019	–	–	–	188,958	35,033

Table 12.Parameters from all model scenarios that were estimated within 1% of bounds. TCF: Tanner crab fishery, SCF: snow crab fishery; RKF: BBRCK fishery; GF: groundfish fisheries. z50: size at 50% selected; z95: size at 95% selected.

case	category	name	parameter scale	min	max	which bound?	description
19.03_2020	selectivity	pS1[1]	ARITHMETIC	0	90	at upper bound	z50 for NMFS survey selectivity (males, pre-1982)
19.03_2020	selectivity	pS1[20]	ARITHMETIC	40	250	at lower bound	z50 for GF.AllGear selectivity (males, 1987-1996)
19.03_2020	selectivity	pS1[23]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 1997-2004)
19.03_2020	selectivity	pS1[24]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 2005+)
19.03_2020	selectivity	pS1[27]	ARITHMETIC	100	140	at upper bound	z95 for RKF selectivity (females, 2005+)
19.03_2020	selectivity	pS2[2]	ARITHMETIC	0	100	at upper bound	z95-z50 for NMFS survey selectivity (males, 1982+)
19.03_2020	selectivity	pS2[4]	ARITHMETIC	0	100	at upper bound	z95-z50 for NMFS survey selectivity (females, 1982+)
19.03_2020	selectivity	pS2[10]	ARITHMETIC	0.1	0.5	at lower bound	ascending slope for SCF selectivity (males, pre-1997)
19.03_2020	selectivity	pS4[1]	ARITHMETIC	0.1	0.5	at lower bound	descending slope for SCF selectivity (males, pre-1997)
19.03_2020	fisheries	pLgtRet[1]	ARITHMETIC	0	15	at upper bound	TCF: logit-scale max retention (pre-1997)
19.03_2020	surveys	pQ[1]	LOG	0.5	1.001	at lower bound	NMFS trawl survey: males, 1975-1981
19.03_2020	surveys	pQ[3]	LOG	0.5	1.001	at lower bound	NMFS trawl survey: females, 1975-1981
19.03	selectivity	pS1[1]	ARITHMETIC	0	90	at upper bound	z50 for NMFS survey selectivity (males, pre-1982)
19.03	selectivity	pS1[20]	ARITHMETIC	40	250	at lower bound	z50 for GF.AllGear selectivity (males, 1987-1996)
19.03	selectivity	pS1[23]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 1997-2004)
19.03	selectivity	pS1[24]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 2005+)
19.03	selectivity	pS1[27]	ARITHMETIC	100	140	at upper bound	z95 for RKF selectivity (females, 2005+)
19.03	selectivity	pS2[2]	ARITHMETIC	0	100	at upper bound	z95-z50 for NMFS survey selectivity (males, 1982+)
19.03	selectivity	pS2[4]	ARITHMETIC	0	100	at upper bound	z95-z50 for NMFS survey selectivity (females, 1982+)
19.03	selectivity	pS2[10]	ARITHMETIC	0.1	0.5	at lower bound	ascending slope for SCF selectivity (males, pre-1997)
19.03	selectivity	pS4[1]	ARITHMETIC	0.1	0.5	at lower bound	descending slope for SCF selectivity (males, pre-1997)
19.03	fisheries	pLgtRet[1]	ARITHMETIC	0	15	at upper bound	TCF: logit-scale max retention (pre-1997)
19.03	surveys	pQ[1]	LOG	0.5	1.001	at lower bound	NMFS trawl survey: males, 1975-1981
19.03	surveys	pQ[3]	LOG	0.5	1.001	at lower bound	NMFS trawl survey: females, 1975-1981
20.07	population	pGrBeta[1]	ARITHMETIC	0.5	1	at upper bound	growth distribution scale (both sexes)
20.07	selectivity	pS1[4]	ARITHMETIC	-50	69	at upper bound	z50 for NMFS survey selectivity (females, 1982+)
20.07	selectivity	pS1[23]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 1997-2004)
20.07	selectivity	pS1[24]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 2005+)
20.07	selectivity	pS1[27]	ARITHMETIC	100	140	at upper bound	z95 for RKF selectivity (females, 2005+)
20.07	selectivity	pS2[4]	ARITHMETIC	0	100	at upper bound	z95-z50 for NMFS survey selectivity (females, 1982+)
20.07	selectivity	pS2[10]	ARITHMETIC	0.1	0.5	at lower bound	ascending slope for SCF selectivity (males, pre-1997)
20.07	selectivity	pS4[1]	ARITHMETIC	0.1	0.5	at lower bound	descending slope for SCF selectivity (males, pre-1997)
20.07	fisheries	pLgtRet[1]	ARITHMETIC	0	15	at upper bound	TCF: logit-scale max retention (pre-1997)
20.07	surveys	pQ[1]	LOG	0.5	1.001	at lower bound	NMFS trawl survey: males, 1975-1981
20.07	surveys	pQ[3]	LOG	0.5	1.001	at lower bound	NMFS trawl survey: females, 1975-1981
20.1	selectivity	pS1[23]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 1997-2004)
20.1	selectivity	pS1[24]	ARITHMETIC	95	180	at upper bound	z95 for RKF selectivity (males, 2005+)
20.1	selectivity	pS2[10]	ARITHMETIC	0.1	0.5	at lower bound	ascending slope for SCF selectivity (males, pre-1997)
20.1	selectivity	pS4[1]	ARITHMETIC	0.1	0.5	at lower bound	descending slope for SCF selectivity (males, pre-1997)
20.1	fisheries	pLgtRet[1]	ARITHMETIC	0	15	at upper bound	TCF: logit-scale max retention (pre-1997)

Table 13. All non-vector parameters. Parameters with phase > 0 are MLEs; otherwise, the values were fixed outside the model. Highlights indicate poorly-estimated parameters (large standard errors or estimates at bounds).

			19.03		19.03(2020)		20.07		20.10		
process	name	phase	est	stdv	est	stdv	est	stdv	est	stdv	label
fisheries	pDC2[1]	1	-2.202	0.225	-2.252	0.247	-1.999	0.240	-2.561	0.230	TCF: female offset
fisheries	pDC2[2]	2	-3.393	0.616	-3.451	0.617	-3.212	0.592	-3.672	0.610	SCF: female offset
fisheries	pDC2[3]	2	-1.002	0.083	-1.017	0.086	-0.850	0.076	-1.212	0.091	GTF: female offset
fisheries	pDC2[4]	2	-1.832	2.062	-1.757	2.156	-1.409	2.286	-2.133	1.844	RKF: female offset
fisheries	pHM[1]	-1	0.321	0.000	0.321	0.000	0.321	0.000	0.321	0.000	handling mortality for pot fisheries
fisheries	pHM[2]	-1	0.800	0.000	0.800	0.000	0.800	0.000	0.800	0.000	handling mortality for groundfish trawl fisheries
fisheries	pLgtRet[1]	3	14.999	4.757	14.999	4.872	14.999	4.089	14.999	4.945	TCF: logit-scale max retention (pre-1997)
fisheries	pLgtRet[2]	3	14.808	640.170	14.888	470.840	14.811	670.000	14.815	583.740	TCF: logit-scale max retention (2005-2009)
fisheries	pLgtRet[3]	3	14.984	66.684	14.978	85.510	14.972	112.400	14.988	47.896	TCF: logit-scale max retention (2013+)
fisheries	pLnC[1]	-1	-2.996	0.000	-2.996	0.000	-2.996	0.000	-2.996	0.000	TCF: base capture rate, pre-1965 (=0.05)
fisheries	pLnC[2]	1	-1.819	0.087	-1.803	0.087	-1.685	0.079	-1.788	0.078	TCF: base capture rate, 1965+
fisheries	pLnC[3]	-2	-4.605	0.000	-4.605	0.000	-4.605	0.000	-4.605	0.000	SCF: base capture rate, pre-1978 (=0.01)
fisheries	pLnC[4]	2	-3.732	0.116	-3.670	0.119	-3.512	0.106	-3.469	0.095	SCF: base capture rate, 1992+
fisheries	pLnC[5]	-2	-4.181	0.000	-4.181	0.000	-4.181	0.000	-4.181	0.000	DUMMY CAPTURE RATE
fisheries	pLnC[6]	2	-4.992	0.069	-4.999	0.070	-4.909	0.056	-4.827	0.057	GTF: base capture rate, ALL YEARS
fisheries	pLnC[7]	-2	-3.912	0.000	-3.912	0.000	-3.912	0.000	-3.912	0.000	RKF: base capture rate, pre-1953 (=0.02)
fisheries	pLnC[8]	2	-3.758	0.120	-3.793	0.121	-3.722	0.114	-3.549	0.111	RKF: base capture rate, 1992+
growth	pGrA[1]	4	32.741	0.292	32.697	0.292	32.553	0.251	30.496	0.253	males
growth	pGrA[2]	4	33.995	0.336	33.951	0.336	33.741	0.267	31.989	0.257	females
growth	pGrB[1]	4	166.566	0.921	166.561	0.930	168.825	0.917	169.604	1.075	males
growth	pGrB[2]	4	114.869	0.648	114.794	0.649	114.791	0.591	116.109	0.610	females
growth	pGrBeta[1]	5	0.904	0.114	0.889	0.113	1.000	0.000	0.944	0.125	gamma distribution scale parameter
natural mortality	pDM1[1]	4	0.984	0.051	0.984	0.052	1.041	0.044	1.710	0.039	multiplier for immature crab
natural mortality	pDM1[2]	4	1.292	0.040	1.295	0.040	1.272	0.038	1.527	0.035	multiplier for mature males
natural mortality	pDM1[3]	4	1.316	0.039	1.315	0.039	1.412	0.036	1.325	0.035	multiplier for mature females
natural mortality	pDM2[1]	4	2.230	0.215	2.294	0.225	1.986	0.181	2.362	0.224	1980-1984 multiplier for mature males
natural mortality	pDM2[2]	4	1.873	0.155	1.864	0.157	1.716	0.138	1.924	0.161	1980-1984 multiplier for mature females
natural mortality	pM[1]	-1	-1.470	0.000	-1.470	0.000	-1.470	0.000	-1.470	0.000	base ln-scale M
recruitment	pLnR[1]	1	6.301	0.476	6.300	0.476	6.229	0.451	7.410	0.482	historical recruitment period
recruitment	pLnR[2]	1	5.691	0.083	5.671	0.498	5.615	0.495	6.515	0.494	current recruitment period
recruitment	pRa[1]	-1	2.442	0.000	2.442	0.000	--	--	2.442	0.000	fixed value
recruitment	pRa[1]	5	--	--	--	--	2.105	0.043	--	--	fixed value
recruitment	pRb[1]	-1	1.386	0.000	1.386	0.000	--	--	1.386	0.000	fixed value
recruitment	pRb[1]	5	--	--	--	--	1.117	0.117	--	--	fixed value
recruitment	pRCV[1]	-1	-0.693	0.000	-0.693	0.000	-0.693	0.000	-0.693	0.000	full model period
recruitment	pRX[1]	-1	--	--	--	--	--	--	--	--	full model period
surveys	pQ[1]	5	-0.693	0.000	-0.693	0.000	-0.693	0.000	-1.477	0.091	NMFS trawl survey: males, 1975-1981
surveys	pQ[2]	5	-0.848	0.069	-0.817	0.069	-0.715	0.051	--	--	NMFS trawl survey: males, 1982+
surveys	pQ[3]	5	-0.693	0.001	-0.693	0.001	-0.693	0.002	-1.401	0.265	NMFS trawl survey: females, 1975-1981
surveys	pQ[4]	5	-1.437	0.105	-1.415	0.107	-0.669	0.050	--	--	NMFS trawl survey: females, 1982+

Table 14 (cont.). All non-vector parameters. Parameters with phase > 0 are MLEs; otherwise, the values were fixed outside the model. Highlights indicate poorly-estimated parameters (large standard errors or estimates at bounds).

				19.03		19.03(2020)		20.07		20.10		
category	process	name	phase	est	stdv	est	stdv	est	stdv	est	stdv	label
selectivity	selectivity	pS1[1]	1	90.000	0.000	90.000	0.000	51.378	1.816	58.921	2.330	z50 for NMFS survey selectivity (males, pre-1982)
selectivity	selectivity	pS1[10]	2	113.499	1.864	114.573	1.903	114.588	1.883	118.699	1.709	ascending z50 for SCF selectivity (males, pre-1997)
selectivity	selectivity	pS1[11]	2	95.758	3.008	96.163	3.268	95.324	3.234	97.893	3.137	ascending z50 for SCF selectivity (males, 1997-2004)
selectivity	selectivity	pS1[12]	2	106.295	1.103	106.252	1.129	105.521	1.126	107.345	1.096	ascending z50 for SCF selectivity (males, 2005+)
selectivity	selectivity	pS1[13]	2	73.422	4.650	73.524	4.885	75.412	4.729	76.471	4.416	ascending z50 for SCF selectivity (females, pre-1997)
selectivity	selectivity	pS1[14]	2	76.348	4.447	76.416	4.651	77.232	4.551	77.678	4.392	ascending z50 for SCF selectivity (females, 1997-2004)
selectivity	selectivity	pS1[15]	2	79.972	3.937	79.247	3.879	80.286	3.790	80.886	3.616	ascending z50 for SCF selectivity (females, 2005+)
selectivity	selectivity	pS1[16]	2	57.537	2.499	57.530	2.620	54.155	1.796	65.138	2.300	z50 for GF.AllGear selectivity (males, pre-1987)
selectivity	selectivity	pS1[17]	2	68.392	5.326	67.344	5.648	58.585	4.946	103.954	10.079	z50 for GF.AllGear selectivity (males, 1987-1996)
selectivity	selectivity	pS1[18]	2	92.845	2.489	92.390	2.509	86.630	2.210	98.833	1.888	z50 for GF.AllGear selectivity (males, 1997+)
selectivity	selectivity	pS1[19]	2	41.452	1.663	41.086	1.727	43.691	1.510	47.952	1.741	z50 for GF.AllGear selectivity (males, pre-1987)
selectivity	selectivity	pS1[2]	1	46.968	5.617	48.015	5.608	49.498	2.982	--	--	z50 for NMFS survey selectivity (males, 1982+)
selectivity	selectivity	pS1[20]	2	40.000	0.000	40.000	0.000	41.517	1.924	74.902	11.957	z50 for GF.AllGear selectivity (males, 1987-1996)
selectivity	selectivity	pS1[21]	2	85.087	3.036	84.308	3.144	81.866	2.450	87.222	2.790	z50 for GF.AllGear selectivity (males, 1997+)
selectivity	selectivity	pS1[22]	3	151.025	4.078	149.898	4.259	149.585	4.425	149.829	4.020	z95 for RKF selectivity (males, pre-1997)
selectivity	selectivity	pS1[23]	3	180.000	0.001	180.000	0.001	180.000	0.001	180.000	0.001	z95 for RKF selectivity (males, 1997-2004)
selectivity	selectivity	pS1[24]	3	180.000	0.000	180.000	0.000	180.000	0.000	180.000	0.000	z95 for RKF selectivity (males, 2005+)
selectivity	selectivity	pS1[25]	3	118.659	23.644	119.018	25.218	119.216	26.567	116.001	19.491	z95 for RKF selectivity (females, pre-1997)
selectivity	selectivity	pS1[26]	3	121.229	48.065	121.583	50.723	118.987	44.217	118.342	41.514	z95 for RKF selectivity (females, 1997-2004)
selectivity	selectivity	pS1[27]	3	140.000	0.103	140.000	0.097	140.000	0.166	135.743	45.470	z95 for RKF selectivity (females, 2005+)
selectivity	selectivity	pS1[28]	1	137.711	0.330	137.709	0.334	137.695	0.304	137.702	0.307	z50 for TCF retention (2005-2009)
selectivity	selectivity	pS1[29]	1	125.254	0.538	125.261	0.555	125.306	0.556	125.300	0.551	z50 for TCF retention (2013+)
selectivity	selectivity	pS1[3]	1	92.146	4.945	92.257	5.011	77.604	2.995	78.951	8.912	z50 for NMFS survey selectivity (females, pre-1982)
selectivity	selectivity	pS1[4]	1	-0.044	18.679	1.429	18.716	69.000	0.000	--	--	z50 for NMFS survey selectivity (females, 1982+)
selectivity	selectivity	pS1[5]	1	138.638	0.446	138.719	0.402	138.344	0.354	138.763	0.404	z50 for TCF retention (pre-1991)
selectivity	selectivity	pS1[6]	1	138.475	0.357	138.530	0.364	138.451	0.359	138.456	0.356	z50 for TCF retention (1991-1996)
selectivity	selectivity	pS1[8]	1	4.859	0.007	4.858	0.007	4.856	0.007	4.863	0.007	ln(z50) for TCF selectivity (males)
selectivity	selectivity	pS1[9]	1	95.205	2.202	94.500	2.606	94.726	2.469	94.411	2.281	z50 for TCF selectivity (females)

Table 15 (cont.). All non-vector parameters. Parameters with phase > 0 are MLEs; otherwise, the values were fixed outside the model. Highlights indicate poorly-estimated parameters (large standard errors or estimates at bounds).

				19.03		19.03(2020)		20.07		20.10		
category	process	name	phase	est	stdv	est	stdv	est	stdv	est	stdv	label
selectivity	selectivity	pS2[1]	1	92.629	7.617	93.604	7.842	21.515	2.678	25.996	3.125	z95-z50 for NMFS survey selectivity (males, pre-1982)
selectivity	selectivity	pS2[10]	2	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000	ascending slope for SCF selectivity (males, pre-1997)
selectivity	selectivity	pS2[11]	2	0.211	0.056	0.206	0.057	0.212	0.061	0.203	0.049	ascending slope for SCF selectivity (males, 1997-2004)
selectivity	selectivity	pS2[12]	2	0.182	0.013	0.183	0.013	0.185	0.014	0.186	0.012	ascending slope for SCF selectivity (males, 2005+)
selectivity	selectivity	pS2[13]	2	0.170	0.068	0.169	0.071	0.167	0.064	0.172	0.061	slope for SCF selectivity (females, pre-1997)
selectivity	selectivity	pS2[14]	2	0.264	0.126	0.263	0.131	0.261	0.122	0.265	0.117	slope for SCF selectivity (females, 1997-2004)
selectivity	selectivity	pS2[15]	2	0.193	0.058	0.199	0.060	0.199	0.056	0.205	0.053	slope for SCF selectivity (females, 2005+)
selectivity	selectivity	pS2[16]	2	0.093	0.010	0.093	0.011	0.121	0.012	0.098	0.008	slope for GF.AllGear selectivity (males, pre-1987)
selectivity	selectivity	pS2[17]	2	0.046	0.007	0.048	0.008	0.075	0.017	0.043	0.005	slope for GF.AllGear selectivity (males, 1987-1996)
selectivity	selectivity	pS2[18]	2	0.061	0.003	0.062	0.003	0.072	0.003	0.072	0.002	slope for GF.AllGear selectivity (males, 1997+)
selectivity	selectivity	pS2[19]	2	0.138	0.020	0.141	0.022	0.155	0.020	0.135	0.016	slope for GF.AllGear selectivity (females, pre-1987)
selectivity	selectivity	pS2[2]	1	100.000	0.000	100.000	0.000	59.152	6.865	--	--	z95-z50 for NMFS survey selectivity (males, 1982+)
selectivity	selectivity	pS2[20]	2	0.168	0.038	0.169	0.046	0.184	0.045	0.043	0.010	slope for GF.AllGear selectivity (females, 1987-1996)
selectivity	selectivity	pS2[21]	2	0.063	0.005	0.064	0.005	0.075	0.005	0.078	0.004	slope for GF.AllGear selectivity (females, 1997+)
selectivity	selectivity	pS2[22]	3	2.914	0.133	2.902	0.143	2.909	0.147	2.867	0.137	ln(z95-z50) for RKF selectivity (males, pre-1997)
selectivity	selectivity	pS2[23]	3	3.433	0.072	3.439	0.075	3.456	0.077	3.424	0.071	ln(z95-z50) for RKF selectivity (males, 1997-2004)
selectivity	selectivity	pS2[24]	3	3.408	0.035	3.408	0.036	3.429	0.037	3.390	0.034	ln(z95-z50) for RKF selectivity (males, 2005+)
selectivity	selectivity	pS2[25]	3	2.743	0.529	2.747	0.552	2.731	0.561	2.658	0.500	ln(z95-z50) for RKF selectivity (males, pre-1997)
selectivity	selectivity	pS2[26]	3	2.865	0.860	2.866	0.890	2.803	0.862	2.785	0.842	ln(z95-z50) for RKF selectivity (males, 1997-2004)
selectivity	selectivity	pS2[27]	3	3.026	0.201	3.022	0.210	2.995	0.206	2.967	0.386	ln(z95-z50) for RKF selectivity (males, 2005+)
selectivity	selectivity	pS2[28]	1	2.000	0.624	2.000	0.611	2.000	0.471	2.000	0.484	slope for TCF retention (2005-2009)
selectivity	selectivity	pS2[29]	1	0.565	0.100	0.566	0.104	0.565	0.104	0.564	0.103	slope for TCF retention (2013+)
selectivity	selectivity	pS2[3]	1	68.011	8.993	68.444	9.157	50.041	5.317	46.605	7.481	z95-z50 for NMFS survey selectivity (females, pre-1982)
selectivity	selectivity	pS2[4]	1	100.000	0.001	100.000	0.001	100.000	0.000	--	--	z95-z50 for NMFS survey selectivity (females, 1982+)
selectivity	selectivity	pS2[5]	1	0.689	0.116	0.725	0.117	0.750	0.122	0.734	0.120	slope for TCF retention (pre-1991)
selectivity	selectivity	pS2[6]	1	0.908	0.212	0.914	0.208	0.943	0.226	0.936	0.221	slope for TCF retention (1997+)
selectivity	selectivity	pS2[7]	1	0.116	0.006	0.117	0.007	0.117	0.007	0.126	0.007	slope for TCF selectivity (males, pre-1997)
selectivity	selectivity	pS2[8]	1	0.159	0.007	0.160	0.007	0.160	0.008	0.163	0.007	slope for TCF selectivity (males, 1997+)
selectivity	selectivity	pS2[9]	1	0.184	0.017	0.186	0.022	0.192	0.022	0.199	0.021	slope for TCF selectivity (females)
selectivity	selectivity	pS3[1]	2	3.515	0.135	3.432	0.144	3.361	0.140	3.392	0.157	ln(dz50-az50) for SCF selectivity (males, pre-1997)
selectivity	selectivity	pS3[2]	2	3.836	0.148	3.815	0.163	3.825	0.159	3.799	0.163	ln(dz50-az50) for SCF selectivity (males, 1997-2004)
selectivity	selectivity	pS3[3]	2	3.509	0.060	3.502	0.063	3.522	0.061	3.490	0.063	ln(dz50-az50) for SCF selectivity (males, 2005+)
selectivity	selectivity	pS4[1]	2	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000	descending slope for SCF selectivity (males, pre-1997)
selectivity	selectivity	pS4[2]	2	0.168	0.103	0.162	0.104	0.162	0.103	0.174	0.122	descending slope for SCF selectivity (males, 1997-2004)
selectivity	selectivity	pS4[3]	2	0.196	0.025	0.193	0.025	0.195	0.025	0.197	0.027	descending slope for SCF selectivity (males, 2005+)

Table 16. Historical recruitment devs estimates (1949-1974) for all model scenarios.

	19.03		19.03(2020)		20.07		20.10	
index	est	stdv	est	stdv	est	stdv	est	stdv
1	-1.341	1.620	-1.352	1.620	-1.404	1.598	-1.364	1.643
2	-1.338	1.476	-1.349	1.476	-1.400	1.453	-1.362	1.500
3	-1.332	1.338	-1.343	1.338	-1.393	1.314	-1.358	1.360
4	-1.320	1.207	-1.331	1.207	-1.379	1.182	-1.349	1.226
5	-1.301	1.085	-1.312	1.085	-1.357	1.061	-1.334	1.100
6	-1.271	0.976	-1.282	0.975	-1.322	0.952	-1.311	0.986
7	-1.225	0.882	-1.237	0.881	-1.270	0.860	-1.273	0.886
8	-1.158	0.806	-1.169	0.805	-1.193	0.786	-1.213	0.804
9	-1.057	0.750	-1.068	0.749	-1.077	0.732	-1.120	0.745
10	-0.904	0.714	-0.915	0.713	-0.901	0.698	-0.970	0.709
11	-0.667	0.697	-0.676	0.697	-0.626	0.682	-0.726	0.696
12	-0.285	0.698	-0.292	0.698	-0.180	0.685	-0.324	0.702
13	0.311	0.708	0.308	0.708	0.496	0.690	0.282	0.712
14	1.069	0.706	1.068	0.705	1.269	0.680	1.017	0.709
15	1.649	0.688	1.648	0.687	1.704	0.656	1.569	0.692
16	1.771	0.671	1.769	0.670	1.697	0.647	1.691	0.680
17	1.591	0.673	1.592	0.673	1.490	0.654	1.575	0.683
18	1.357	0.672	1.366	0.672	1.311	0.653	1.483	0.680
19	1.204	0.660	1.222	0.659	1.261	0.636	1.532	0.658
20	1.151	0.645	1.178	0.643	1.332	0.613	1.674	0.628
21	1.119	0.637	1.146	0.636	1.365	0.600	1.666	0.623
22	0.972	0.613	0.990	0.612	1.112	0.567	1.265	0.604
23	0.759	0.562	0.765	0.562	0.625	0.536	0.583	0.588
24	0.358	0.558	0.362	0.558	0.084	0.537	-0.043	0.594
25	-0.035	0.556	-0.022	0.555	-0.209	0.534	-0.324	0.586
26	-0.079	0.596	-0.065	0.595	-0.032	0.556	-0.265	0.659

Table 17. Current recruitment devs estimates (1975-2020) for all model scenarios. Note the large uncertainties in the last row (devs for recruits entering the population on July 1, 2020).

	19.03		19.03(2020)		20.07		20.10	
index	est	stdv	est	stdv	est	stdv	est	stdv
1	0.875	0.334	0.864	0.601	1.373	0.526	0.345	1.025
2	1.924	0.153	1.934	0.516	1.685	0.516	2.442	0.523
3	1.643	0.171	1.658	0.521	1.389	0.522	1.433	0.581
4	0.944	0.261	0.947	0.560	0.287	0.609	0.487	0.711
5	-0.067	0.430	-0.124	0.672	-0.373	0.684	-0.292	0.857
6	-0.578	0.517	-0.563	0.710	-0.578	0.675	-0.604	0.867
7	-0.109	0.264	-0.146	0.563	-0.050	0.552	-0.363	0.655
8	-0.253	0.243	-0.290	0.552	-0.107	0.549	-0.251	0.574
9	0.846	0.110	0.880	0.504	1.010	0.505	0.978	0.507
10	0.751	0.143	0.782	0.514	0.894	0.512	0.776	0.522
11	0.952	0.137	0.945	0.513	0.906	0.515	0.995	0.519
12	0.948	0.141	1.002	0.512	1.076	0.510	1.375	0.512
13	0.989	0.133	1.031	0.511	1.044	0.509	0.887	0.535
14	0.699	0.154	0.639	0.520	0.229	0.534	0.616	0.537
15	-0.172	0.211	-0.154	0.538	-0.278	0.538	-0.277	0.587
16	-1.323	0.410	-1.353	0.657	-1.747	0.772	-1.781	0.957
17	-1.424	0.321	-1.418	0.589	-1.302	0.574	-1.474	0.652
18	-1.391	0.258	-1.387	0.556	-1.421	0.565	-1.219	0.571
19	-1.482	0.274	-1.475	0.563	-1.283	0.551	-1.601	0.626
20	-1.256	0.246	-1.275	0.551	-1.271	0.554	-1.153	0.562
21	-0.723	0.174	-0.741	0.522	-0.628	0.521	-0.674	0.528
22	-1.012	0.233	-1.012	0.544	-0.786	0.537	-1.241	0.577
23	0.027	0.112	0.018	0.504	-0.006	0.506	0.092	0.506
24	-0.845	0.209	-0.851	0.535	-0.858	0.544	-0.787	0.547
25	0.419	0.104	0.425	0.503	0.583	0.502	0.449	0.505
26	-0.292	0.213	-0.292	0.536	-0.366	0.553	-0.208	0.545
27	0.935	0.098	0.940	0.501	0.934	0.503	0.968	0.505
28	-0.247	0.257	-0.249	0.555	-0.254	0.566	-0.049	0.567
29	1.030	0.108	1.011	0.504	1.109	0.502	0.981	0.509
30	0.842	0.117	0.864	0.505	0.467	0.514	0.987	0.509
31	-0.465	0.260	-0.463	0.557	-0.540	0.558	-0.933	0.699
32	-0.844	0.303	-0.842	0.579	-0.898	0.586	-1.194	0.704
33	-0.979	0.317	-0.955	0.585	-0.821	0.588	-0.784	0.604
34	-0.503	0.264	-0.487	0.558	0.246	0.541	-0.308	0.563
35	1.346	0.100	1.346	0.502	1.429	0.502	1.474	0.504
36	1.078	0.120	1.060	0.507	0.563	0.518	0.953	0.516
37	0.017	0.195	0.014	0.529	-0.281	0.533	-0.109	0.562
38	-1.552	0.460	-1.557	0.675	-1.610	0.662	-2.223	1.236
39	-0.535	0.175	-0.551	0.523	-0.498	0.512	-0.489	0.539
40	-1.018	0.221	-1.016	0.539	-1.237	0.547	-0.844	0.557
41	-1.309	0.257	-1.281	0.554	-0.738	0.525	-1.236	0.590
42	-0.926	0.231	-0.886	0.543	-0.713	0.549	-0.642	0.547
43	0.782	0.121	0.814	0.506	1.304	0.500	0.985	0.508
44	0.828	0.179	0.829	0.522	0.646	0.535	1.386	0.519
45	1.428	0.185	1.363	0.522	1.470	0.525	2.129	0.520
46	--	--	0.000	22.116	0.000	22.116	0.000	22.116

Table 18. Logit-scale parameters for the probability of terminal molt for all model scenarios. The probability of terminal molt is 0 at sizes less than, and 1 at sizes greater than, the indicated range.

	19.03		19.03(2020)		20.07		20.10		
index	est	stdv	est	stdv	est	stdv	est	stdv	label
1	-6.825	0.991	-6.845	0.997	-6.620	0.982	-6.426	0.942	females 50-105 mmCW (entire model period)
2	-5.053	0.452	-5.070	0.454	-4.891	0.444	-4.804	0.426	females 50-105 mmCW (entire model period)
3	-3.339	0.206	-3.350	0.207	-3.210	0.201	-3.221	0.199	females 50-105 mmCW (entire model period)
4	-1.794	0.115	-1.796	0.116	-1.689	0.112	-1.769	0.111	females 50-105 mmCW (entire model period)
5	-0.514	0.090	-0.514	0.091	-0.412	0.087	-0.534	0.087	females 50-105 mmCW (entire model period)
6	0.221	0.091	0.217	0.092	0.332	0.089	0.188	0.088	females 50-105 mmCW (entire model period)
7	0.545	0.101	0.542	0.102	0.621	0.098	0.509	0.099	females 50-105 mmCW (entire model period)
8	1.179	0.142	1.182	0.144	1.189	0.135	1.148	0.140	females 50-105 mmCW (entire model period)
9	2.263	0.251	2.259	0.253	2.344	0.247	2.272	0.255	females 50-105 mmCW (entire model period)
10	3.483	0.475	3.474	0.488	3.815	0.508	3.594	0.528	females 50-105 mmCW (entire model period)
11	4.776	0.989	4.763	1.015	5.371	1.071	4.996	1.092	females 50-105 mmCW (entire model period)
1	-2.909	0.281	-2.919	0.285	-3.237	0.313	-3.023	0.311	males 60-150 mmCW (entire model period)
2	-3.293	0.294	-3.298	0.296	-3.591	0.311	-3.337	0.307	males 60-150 mmCW (entire model period)
3	-2.861	0.248	-2.869	0.252	-3.106	0.268	-2.936	0.264	males 60-150 mmCW (entire model period)
4	-2.174	0.161	-2.178	0.163	-2.429	0.171	-2.239	0.171	males 60-150 mmCW (entire model period)
5	-1.659	0.138	-1.659	0.140	-1.908	0.145	-1.695	0.145	males 60-150 mmCW (entire model period)
6	-1.411	0.121	-1.413	0.123	-1.534	0.120	-1.378	0.126	males 60-150 mmCW (entire model period)
7	-0.855	0.107	-0.849	0.109	-0.934	0.104	-0.809	0.110	males 60-150 mmCW (entire model period)
8	-0.466	0.095	-0.452	0.097	-0.550	0.094	-0.466	0.099	males 60-150 mmCW (entire model period)
9	-0.320	0.096	-0.310	0.097	-0.433	0.094	-0.348	0.099	males 60-150 mmCW (entire model period)
10	-0.154	0.096	-0.154	0.097	-0.213	0.093	-0.176	0.099	males 60-150 mmCW (entire model period)
11	0.302	0.105	0.287	0.106	0.258	0.105	0.295	0.111	males 60-150 mmCW (entire model period)
12	0.904	0.134	0.882	0.134	1.024	0.142	1.013	0.159	males 60-150 mmCW (entire model period)
13	1.757	0.185	1.732	0.187	1.947	0.176	1.978	0.191	males 60-150 mmCW (entire model period)
14	3.110	0.305	3.071	0.301	3.328	0.282	3.370	0.282	males 60-150 mmCW (entire model period)
15	4.353	0.345	4.296	0.340	4.483	0.336	4.502	0.338	males 60-150 mmCW (entire model period)
16	6.116	0.733	6.043	0.721	6.067	0.727	5.955	0.727	males 60-150 mmCW (entire model period)
17	8.033	1.544	7.946	1.527	7.824	1.522	7.587	1.519	males 60-150 mmCW (entire model period)

Table 19. Availability parameters used in Scenario 20.07 (all fixed).

size bin	males					females				
(mm CW)	2013	2014	2015	2016	2017	2013	2014	2015	2016	2017
27	0.0553	0.0217	0.0204	0.0003	0.3022	0.0163	0.0151	0.0102	0.0000	0.4480
32	0.0579	0.0248	0.0252	0.0008	0.3438	0.0166	0.0185	0.0147	0.0000	0.4225
37	0.0606	0.0283	0.0311	0.0022	0.3929	0.0169	0.0225	0.0208	0.0117	0.4358
42	0.0635	0.0324	0.0383	0.0059	0.4536	0.0170	0.0269	0.0282	0.1017	0.5208
47	0.0667	0.0370	0.0470	0.0149	0.5308	0.0171	0.0315	0.0356	0.1102	0.6392
52	0.0703	0.0424	0.0576	0.0354	0.6163	0.0176	0.0361	0.0402	0.1390	0.6865
57	0.0744	0.0485	0.0704	0.0755	0.6806	0.0186	0.0393	0.0408	0.2271	0.6556
62	0.0791	0.0558	0.0864	0.1399	0.6844	0.0206	0.0395	0.0380	0.2123	0.6137
67	0.0848	0.0642	0.1061	0.2200	0.6168	0.0251	0.0376	0.0344	0.1391	0.6057
72	0.0915	0.0740	0.1281	0.2982	0.5299	0.0355	0.0357	0.0326	0.1454	0.6628
77	0.0994	0.0856	0.1495	0.3565	0.4680	0.0557	0.0355	0.0337	0.2528	0.7555
82	0.1087	0.0993	0.1659	0.3851	0.4554	0.0864	0.0383	0.0380	0.3893	0.7682
87	0.1199	0.1152	0.1751	0.3895	0.4842	0.1304	0.0486	0.0493	0.4249	0.6891
92	0.1333	0.1338	0.1777	0.3851	0.5309	0.2141	0.0826	0.0816	0.4314	0.6363
97	0.1497	0.1553	0.1757	0.3886	0.5659	0.3845	0.1815	0.1702	0.4860	0.5586
102	0.1696	0.1797	0.1715	0.4087	0.5696	0.6400	0.3785	0.3622	0.5985	0.2931
107	0.1936	0.2074	0.1679	0.4363	0.5588	0.8178	0.5978	0.6583	0.7664	0.0205
112	0.2218	0.2382	0.1677	0.4579	0.5560	0.6568	0.7107	0.9415	0.9329	0.0000
117	0.2543	0.2723	0.1736	0.4593	0.5797	0.0000	0.0000	1.0000	1.0000	0.0000
122	0.2902	0.3097	0.1873	0.4420	0.6195	0.0000	0.0000	0.9901	0.0000	0.0000
127	0.3276	0.3508	0.2109	0.4158	0.6464	0.0000	0.0000	0.0000	0.0000	0.0000
132	0.3634	0.3959	0.2479	0.3895	0.6277	0.0000	0.0000	0.0000	0.0000	0.0000
137	0.3927	0.4441	0.3015	0.3702	0.5651	0.0000	0.0000	0.0000	0.0000	0.0000
142	0.4076	0.4909	0.3688	0.3634	0.5026	0.0000	0.0000	0.0000	0.0000	0.0000
147	0.4007	0.5300	0.4411	0.3751	0.4737	0.0000	0.0000	0.0000	0.0000	0.0000
152	0.3692	0.5550	0.5020	0.4127	0.4601	0.0000	0.0000	0.0000	0.0000	0.0000
157	0.3213	0.5660	0.5353	0.4785	0.2592	0.0000	0.0000	0.0000	0.0000	0.0000
162	0.2681	0.5665	0.5288	0.5731	0.0394	0.0000	0.0000	0.0000	0.0000	0.0000
167	0.2174	0.5608	0.4785	0.6952	0.0008	0.0000	0.0000	0.0000	0.0000	0.0000
172	0.1733	0.5518	0.3993	0.8448	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
177	0.1366	0.5410	0.3154	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
182	0.1070	0.0000	0.2423	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 20. NMFS survey selectivity values used in Scenario 20.10. These were estimated outside the model.

size bin (mm CW)	males	females
27	0.0166	0.0073
32	0.0341	0.0152
37	0.0597	0.0283
42	0.0910	0.0458
47	0.1238	0.0657
52	0.1549	0.0854
57	0.1827	0.1034
62	0.2076	0.1191
67	0.2302	0.1335
72	0.2514	0.1487
77	0.2727	0.1658
82	0.2959	0.1841
87	0.3229	0.2026
92	0.3529	0.2200
97	0.3843	0.2348
102	0.4154	0.2455
107	0.4440	0.2511
112	0.4688	0.2521
117	0.4904	0.2494
122	0.5107	0.2441
127	0.5312	0.2371
132	0.5535	0.2293
137	0.5780	0.2293
142	0.6007	0.2293
147	0.6165	0.2293
152	0.6209	0.2293
157	0.6088	0.2293
162	0.5764	0.2293
167	0.5254	0.2293
172	0.4604	0.2293
177	0.3882	0.2293
182	0.3166	0.2293

Table 21. Ln-scale devs for annual deviations, starting in 1991/92, in the ln-scale size at 50% selected in the directed fishery.

	19.03		19.03(2020)		20.07		20.10		
index	est	stdv	est	stdv	est	stdv	est	stdv	label
1	0.090	0.010	0.090	0.011	0.090	0.011	0.087	0.010	ln(z50 devs) for TCF selectivity (males, 1991+)
2	0.038	0.010	0.037	0.010	0.037	0.010	0.039	0.009	ln(z50 devs) for TCF selectivity (males, 1991+)
3	0.112	0.012	0.113	0.013	0.115	0.012	0.106	0.011	ln(z50 devs) for TCF selectivity (males, 1991+)
4	0.066	0.017	0.065	0.017	0.072	0.017	0.061	0.015	ln(z50 devs) for TCF selectivity (males, 1991+)
5	0.005	0.024	0.012	0.024	0.022	0.023	0.011	0.021	ln(z50 devs) for TCF selectivity (males, 1991+)
6	0.161	0.036	0.161	0.037	0.164	0.036	0.146	0.033	ln(z50 devs) for TCF selectivity (males, 1991+)
7	-0.061	0.015	-0.061	0.016	-0.064	0.016	-0.060	0.015	ln(z50 devs) for TCF selectivity (males, 1991+)
8	-0.062	0.015	-0.063	0.016	-0.066	0.016	-0.057	0.015	ln(z50 devs) for TCF selectivity (males, 1991+)
9	-0.103	0.014	-0.103	0.015	-0.107	0.015	-0.101	0.014	ln(z50 devs) for TCF selectivity (males, 1991+)
10	0.030	0.013	0.029	0.013	0.028	0.013	0.027	0.012	ln(z50 devs) for TCF selectivity (males, 1991+)
11	0.195	0.014	0.193	0.015	0.193	0.015	0.184	0.014	ln(z50 devs) for TCF selectivity (males, 1991+)
12	-0.020	0.015	-0.021	0.015	-0.023	0.016	-0.023	0.015	ln(z50 devs) for TCF selectivity (males, 1991+)
13	-0.085	0.012	-0.085	0.012	-0.088	0.012	-0.080	0.011	ln(z50 devs) for TCF selectivity (males, 1991+)
14	-0.124	0.013	-0.123	0.013	-0.127	0.013	-0.111	0.011	ln(z50 devs) for TCF selectivity (males, 1991+)
15	-0.098	0.017	-0.099	0.018	-0.099	0.018	-0.093	0.017	ln(z50 devs) for TCF selectivity (males, 1991+)
16	-0.145	0.016	-0.144	0.016	-0.144	0.016	-0.135	0.015	ln(z50 devs) for TCF selectivity (males, 1991+)

Table 22. Annual (1965+) ln-scale capture rate devs estimated for males taken in the directed fishery, for all model scenarios. Devs indexing skips years where the fishery was closed.

	19.03		19.03(2020)		20.07		20.10	
index	est	stdv	est	stdv	est	stdv	est	stdv
1	-0.508	0.487	-0.509	0.488	-0.495	0.491	-0.532	0.483
2	-0.731	0.374	-0.732	0.374	-0.722	0.378	-0.751	0.368
3	0.491	0.328	0.490	0.329	0.490	0.337	0.497	0.321
4	0.352	0.307	0.348	0.308	0.344	0.312	0.370	0.300
5	0.532	0.296	0.525	0.297	0.532	0.301	0.527	0.297
6	0.375	0.291	0.365	0.293	0.385	0.300	0.307	0.298
7	0.169	0.276	0.155	0.278	0.174	0.291	0.007	0.284
8	0.001	0.242	-0.019	0.244	-0.023	0.259	-0.281	0.244
9	-0.220	0.185	-0.247	0.186	-0.304	0.195	-0.631	0.179
10	0.008	0.130	-0.024	0.130	-0.146	0.128	-0.507	0.121
11	0.281	0.104	0.246	0.104	0.083	0.097	-0.281	0.098
12	1.086	0.101	1.049	0.102	0.889	0.091	0.504	0.098
13	1.827	0.117	1.784	0.117	1.678	0.101	1.162	0.114
14	1.996	0.152	1.944	0.149	1.983	0.130	1.219	0.145
15	2.490	0.222	2.445	0.219	2.789	0.219	1.646	0.191
16	2.074	0.162	2.105	0.166	2.260	0.168	1.696	0.169
17	0.391	0.109	0.425	0.111	0.472	0.108	0.384	0.109
18	-0.640	0.122	-0.614	0.123	-0.607	0.122	-0.534	0.124
19	-1.707	0.248	-1.679	0.250	-1.696	0.248	-1.510	0.256
20	-0.714	0.176	-0.669	0.178	-0.725	0.174	-0.385	0.186
21	-1.119	0.213	-1.087	0.214	-1.144	0.215	-0.832	0.222
22	-0.223	0.104	-0.210	0.105	-0.282	0.105	0.050	0.108
23	0.998	0.078	1.003	0.079	0.909	0.079	1.274	0.084
24	1.669	0.082	1.679	0.084	1.619	0.084	1.981	0.092
25	1.827	0.116	1.817	0.118	1.795	0.117	2.047	0.124
26	1.875	0.109	1.853	0.109	1.848	0.106	2.104	0.113
27	1.428	0.136	1.439	0.137	1.480	0.134	1.675	0.136
28	0.697	0.151	0.698	0.150	0.800	0.151	0.926	0.146
29	0.205	0.161	0.253	0.165	0.361	0.168	0.497	0.158
30	-0.381	0.402	-0.369	0.408	-0.288	0.410	-0.156	0.393
31	-2.158	0.207	-2.151	0.207	-2.162	0.205	-1.974	0.210
32	-1.649	0.137	-1.644	0.138	-1.659	0.136	-1.449	0.140
33	-1.617	0.117	-1.608	0.118	-1.609	0.116	-1.447	0.119
34	-1.785	0.154	-1.781	0.154	-1.794	0.152	-1.596	0.156
35	-1.090	0.260	-1.109	0.262	-1.146	0.258	-0.983	0.261
36	-1.646	0.137	-1.644	0.137	-1.656	0.135	-1.439	0.138
37	-0.545	0.088	-0.534	0.088	-0.542	0.084	-0.295	0.090
38	-0.277	0.085	-0.262	0.085	-0.237	0.081	-0.023	0.086
39	-1.982	0.141	-1.966	0.141	-1.927	0.139	-1.746	0.142
40	-1.783	0.134	-1.764	0.135	-1.729	0.132	-1.522	0.135

Table 23. Annual (1992+) ln-scale capture rate devs for males caught in the snow crab fishery, for all model scenarios.

	19.03		19.03(2020)		20.07		20.10	
index	est	stdv	est	stdv	est	stdv	est	stdv
1	0.512	0.104	0.525	0.104	0.540	0.104	0.544	0.104
2	0.807	0.097	0.828	0.097	0.866	0.097	0.856	0.097
3	0.242	0.179	0.268	0.179	0.310	0.179	0.308	0.179
4	0.199	0.234	0.231	0.233	0.276	0.234	0.305	0.233
5	1.099	0.140	1.131	0.140	1.175	0.140	1.242	0.141
6	0.901	0.161	0.892	0.168	0.886	0.165	0.921	0.164
7	-0.134	0.351	-0.125	0.349	-0.127	0.346	-0.074	0.344
8	-0.982	0.548	-0.968	0.546	-0.972	0.543	-0.922	0.548
9	-0.718	0.492	-0.701	0.488	-0.707	0.485	-0.654	0.486
10	-0.419	0.384	-0.407	0.382	-0.411	0.380	-0.372	0.377
11	-1.115	0.500	-1.106	0.499	-1.103	0.499	-1.099	0.492
12	-1.390	0.501	-1.387	0.500	-1.396	0.498	-1.394	0.494
13	-1.435	0.470	-1.435	0.469	-1.440	0.469	-1.461	0.462
14	-0.079	0.204	-0.098	0.203	-0.110	0.203	-0.125	0.201
15	0.069	0.163	0.048	0.163	0.028	0.163	-0.008	0.162
16	0.124	0.141	0.104	0.141	0.098	0.141	0.055	0.140
17	-0.494	0.206	-0.514	0.206	-0.524	0.205	-0.555	0.204
18	-0.085	0.159	-0.110	0.159	-0.124	0.159	-0.178	0.158
19	0.014	0.169	-0.010	0.168	-0.033	0.168	-0.070	0.167
20	0.568	0.128	0.543	0.129	0.514	0.129	0.504	0.128
21	0.215	0.161	0.192	0.161	0.168	0.161	0.166	0.160
22	0.101	0.142	0.079	0.142	0.059	0.142	0.077	0.141
23	1.005	0.089	0.982	0.089	0.970	0.089	0.971	0.089
24	0.773	0.096	0.754	0.096	0.766	0.096	0.720	0.096
25	0.548	0.115	0.531	0.115	0.547	0.115	0.490	0.115
26	-0.148	0.217	-0.157	0.215	-0.147	0.216	-0.171	0.214
27	-0.177	0.260	-0.183	0.257	-0.183	0.258	-0.174	0.256
28	0.000	0.000	0.095	0.236	0.076	0.235	0.098	0.235

Table 24. Annual (1992+) ln-scale capture rate devs for males caught in the BBRKC fishery, for all model scenarios. Devs indexing skips years where the fishery was closed.

	19.03		19.03(2020)		20.07		20.10	
index	est	stdv	est	stdv	est	stdv	est	stdv
1	0.466	0.185	0.451	0.184	0.471	0.186	0.447	0.185
2	1.433	0.121	1.436	0.120	1.500	0.123	1.446	0.121
3	0.088	0.330	0.079	0.333	0.115	0.343	0.112	0.340
4	0.282	0.421	0.251	0.420	0.245	0.423	0.255	0.426
5	0.255	0.424	0.224	0.422	0.212	0.421	0.223	0.426
6	0.222	0.419	0.194	0.418	0.181	0.416	0.192	0.420
7	0.196	0.412	0.172	0.411	0.157	0.409	0.170	0.413
8	0.145	0.397	0.127	0.398	0.112	0.396	0.127	0.400
9	0.106	0.381	0.094	0.384	0.081	0.382	0.093	0.385
10	0.041	0.364	0.035	0.368	0.026	0.367	0.026	0.366
11	-0.053	0.344	-0.053	0.348	-0.070	0.346	-0.064	0.346
12	-0.128	0.326	-0.118	0.331	-0.131	0.329	-0.130	0.329
13	-0.233	0.309	-0.218	0.314	-0.228	0.313	-0.229	0.313
14	-0.278	0.299	-0.258	0.304	-0.265	0.303	-0.280	0.301
15	-0.195	0.282	-0.170	0.288	-0.173	0.287	-0.183	0.286
16	-0.306	0.280	-0.283	0.285	-0.283	0.285	-0.296	0.283
17	-0.361	0.290	-0.342	0.294	-0.343	0.294	-0.362	0.292
18	-0.274	0.304	-0.260	0.308	-0.264	0.307	-0.269	0.307
19	-0.189	0.314	-0.178	0.319	-0.184	0.317	-0.181	0.319
20	-0.174	0.306	-0.159	0.311	-0.165	0.309	-0.159	0.311
21	-0.175	0.280	-0.150	0.285	-0.158	0.284	-0.131	0.288
22	-0.302	0.277	-0.274	0.283	-0.268	0.284	-0.253	0.285
23	-0.266	0.286	-0.239	0.291	-0.225	0.294	-0.231	0.292
24	-0.156	0.301	-0.135	0.307	-0.122	0.310	-0.128	0.308
25	-0.145	0.319	-0.127	0.325	-0.120	0.327	-0.110	0.328
26	0.000	0.000	-0.100	0.339	-0.104	0.339	-0.085	0.343

Table 25. Annual (1973+) ln-scale capture rate devs for males caught in the groundfish fisheries, for all model scenarios.

	19.03		19.03(2020)		20.07		20.10	
index	est	stdv	est	stdv	est	stdv	est	stdv
1	1.428	0.097	1.427	0.098	1.406	0.095	0.820	0.112
2	1.853	0.077	1.850	0.078	1.814	0.072	1.236	0.094
3	1.036	0.072	1.034	0.073	1.003	0.067	0.449	0.090
4	0.519	0.080	0.518	0.081	0.511	0.074	-0.020	0.097
5	0.203	0.100	0.203	0.101	0.233	0.096	-0.288	0.116
6	-0.070	0.131	-0.066	0.132	0.006	0.128	-0.499	0.144
7	0.520	0.095	0.531	0.096	0.667	0.089	0.139	0.112
8	0.132	0.121	0.156	0.121	0.305	0.120	-0.149	0.132
9	-0.058	0.156	-0.022	0.156	0.097	0.156	-0.219	0.162
10	-0.836	0.361	-0.797	0.364	-0.721	0.368	-0.888	0.360
11	-0.260	0.306	-0.209	0.309	-0.169	0.309	-0.236	0.311
12	-0.030	0.334	0.028	0.337	0.026	0.335	0.046	0.342
13	-0.452	0.446	-0.407	0.453	-0.417	0.453	-0.394	0.454
14	-0.254	0.331	-0.215	0.333	-0.219	0.336	-0.238	0.331
15	-0.363	0.329	-0.343	0.331	-0.404	0.331	-0.001	0.360
16	-0.769	0.379	-0.757	0.381	-0.818	0.379	-0.471	0.413
17	-0.560	0.301	-0.552	0.302	-0.611	0.301	-0.279	0.327
18	-0.252	0.233	-0.245	0.234	-0.296	0.232	0.027	0.259
19	0.405	0.069	0.418	0.072	0.358	0.066	0.764	0.144
20	0.666	0.066	0.682	0.069	0.644	0.062	1.003	0.140
21	0.291	0.082	0.310	0.084	0.286	0.078	0.628	0.145
22	0.821	0.071	0.842	0.073	0.825	0.067	1.166	0.137
23	0.758	0.080	0.782	0.081	0.770	0.076	1.123	0.141
24	0.877	0.083	0.904	0.084	0.874	0.080	1.295	0.145
25	1.445	0.080	1.471	0.080	1.466	0.079	1.555	0.084
26	1.348	0.089	1.377	0.090	1.367	0.088	1.477	0.093
27	0.729	0.136	0.760	0.137	0.749	0.136	0.862	0.139
28	0.729	0.127	0.759	0.128	0.744	0.126	0.861	0.130
29	0.863	0.100	0.893	0.101	0.893	0.099	0.979	0.104
30	0.140	0.160	0.167	0.160	0.158	0.159	0.242	0.162
31	-0.266	0.190	-0.240	0.191	-0.250	0.189	-0.172	0.192
32	0.025	0.127	0.051	0.128	0.055	0.126	0.104	0.130
33	-0.343	0.156	-0.318	0.156	-0.319	0.155	-0.268	0.158
34	-0.378	0.149	-0.353	0.149	-0.359	0.148	-0.310	0.151
35	-0.116	0.116	-0.092	0.117	-0.103	0.115	-0.061	0.119
36	-0.439	0.155	-0.418	0.155	-0.434	0.154	-0.407	0.157
37	-0.812	0.223	-0.791	0.224	-0.796	0.222	-0.795	0.225
38	-1.100	0.294	-1.078	0.295	-1.063	0.295	-1.055	0.296
39	-0.662	0.204	-0.639	0.205	-0.627	0.204	-0.577	0.207
40	-1.219	0.295	-1.196	0.296	-1.201	0.295	-1.117	0.299
41	-0.858	0.201	-0.833	0.201	-0.844	0.200	-0.764	0.203
42	-0.809	0.193	-0.782	0.194	-0.783	0.193	-0.741	0.196
43	-0.938	0.244	-0.911	0.245	-0.900	0.245	-0.886	0.247
44	-0.782	0.253	-0.787	0.261	-0.774	0.261	-0.762	0.262
45	-1.186	0.377	-1.186	0.385	-1.190	0.384	-1.159	0.387
46	-0.976	0.349	-1.008	0.364	-1.017	0.363	-1.009	0.365
47	0.000	0.000	-0.917	0.324	-0.943	0.322	-1.012	0.322

Table 26. Objective function values for all data components from the model scenarios. TCF: directed Tanner crab fishery (RC: retained catch; TC: total catch); SCF: snow crab fishery; RKF: BBRKC fishery; GF All: groundfish fisheries. n.at.z: size compositions. Highlighted cells indicate best fits by > 5 likelihood units between Scenarios 19.03(2020) and 20.07.

				Model Scenarios			
category	fleet	data type	sex	19.03	19.03(2020)	20.07	20.1
surveys data	NMFS	biomass	male	54.22	49.34	65.33	56.88
		n.at.z	male	448.98	450.26	411.35	634.03
		biomass	female	137.41	136.39	139.92	147.29
		n.at.z	female	343.69	343.34	330.88	674.82
	SBS BSFRF	biomass	male	--	--	-1.02	--
		n.at.z	male	--	--	153.24	--
		biomass	female	--	--	-6.64	--
		n.at.z	female	--	--	146.29	--
fisheries data	TCF (RC)	biomass	male	7.35	7.06	8.13	7.64
		n.at.z	male	51.99	50.51	55.13	49.71
	TCF (TC)	biomass	female	9.96	9.72	9.28	9.69
			male	3.77	3.61	3.69	3.51
		n.at.z	female	18.16	13.65	13.74	13.41
			male	88.14	83.30	89.33	84.79
	SCF	biomass	female	1.92	1.91	1.91	1.86
			male	17.75	16.75	16.44	14.30
		n.at.z	female	15.69	14.71	14.57	14.36
			male	124.76	117.64	119.65	119.38
	RKF	biomass	female	0.07	0.07	0.06	0.07
			male	27.22	26.09	25.79	27.91
		n.at.z	female	3.06	2.85	2.91	2.80
			male	74.42	70.18	70.64	71.72
	GF All	abundance	all sexes	3.19	3.23	3.45	2.93
		biomass	all sexes	29.69	29.43	32.03	23.20
		n.at.z	female	274.47	254.72	262.14	270.42
			male	285.08	262.32	276.68	302.55
growth data	--	molt increment	female	252.27	251.13	252.78	251.06
			male	287.61	287.34	296.49	284.59
maturity ogive data	--	male maturity ogives	male	95.41	94.90	107.27	89.50

Table 27. Objective function values for all non-data components from the model scenarios.

category	type	element	level	19.03	19.03(2020)	20.07	20.10	description
penalties	maturity	smoothness	1	0.9	0.9	0.8	0.7	male probability of terminal molt bby size
			2	0.9	0.9	1.1	0.9	male probability of terminal molt bby size
priors	fisheries	pDevsLnC	1	137.4	136.4	138.5	125.4	annual devs for directed fishery
			2	31.1	32.0	32.1	32.1	annual devs for snow crab fishery
			3	55.9	57.3	57.2	56.8	annual devs for groundfish fisheries
			4	147.8	152.8	153.4	153.0	annual devs for BBRKC fishery
	natural mortality	pDM1	1	0.0	0.0	0.0	98.8	multiplier for immature crab
			2	15.0	15.4	12.7	53.4	multiplier for mature males
			3	17.9	17.8	31.9	19.0	multiplier for mature females
	recruitment	pDevsLnR	1	48.0	48.0	48.3	48.6	prior to 1975 (devs are AR1 process)
			2	0.1	0.1	0.1	0.1	after 1975
	surveys	pQ	2	38.7	36.3	28.5	0.0	male fully-selected NMFS survey catchability, after 1982
			4	80.4	79.1	25.0	0.0	female fully-selected NMFS survey catchability, after 1982

Table 28. Root mean square errors (RMSE) for data components from the model scenarios. TCF: directed Tanner crab fishery (RC: retained catch; TC: total catch); SCF: snow crab fishery; RKF: BBRKC fishery; GF All: groundfish fisheries. Abundance values were not included the model fits. Highlighted values indicate smallest RMSE between Scenarios 19.03(2020) and 20.07.

				Model Scenarios			
category	fleet	sex	data type	19.03	19.03(2020)	20.07	20.1
surveys data	NMFS	male	abundance	3.27	3.25	3.40	3.13
			biomass	2.50	2.46	2.60	2.53
		female	abundance	5.38	5.38	5.49	5.99
			biomass	4.97	4.96	4.99	5.05
	SBS BSFRF	male	abundance	--	--	1.73	--
			biomass	--	--	1.58	--
		female	abundance	--	--	2.98	--
			biomass	--	--	1.90	--
fisheries data	TCF (RC)	male	abundance	0.00	3.27	3.34	3.13
			biomass	2.05	2.06	2.12	1.99
	TCF (TC)	female	abundance	0.00	39.17	37.01	33.52
		male	abundance	0.00	1.07	1.08	1.04
		female	biomass	41.20	10.99	10.43	9.51
		male	biomass	1.69	1.68	1.69	1.67
	SCF	female	abundance	0.00	4.95	4.97	4.68
		male	abundance	0.00	2.60	2.63	2.71
		female	biomass	5.13	4.85	4.85	4.57
		male	biomass	3.35	3.37	3.40	3.52
	RKF	female	abundance	0.00	10.91	12.04	11.57
		male	abundance	0.00	27.58	27.65	27.38
		female	biomass	42.13	3.38	3.62	3.63
		male	biomass	30.08	31.95	31.95	31.79
	GF All	all sexes	abundance	0.53	0.57	0.58	0.58
		all sexes	biomass	1.02	1.03	1.04	1.00
growth data	--	female	molt	0.31	0.31	0.28	0.24
		male	increment	0.55	0.55	0.56	0.50
maturity ogive data	--	male	male maturity ogives	17.75	17.52	19.35	17.97

Table 29. Geometric means of effective sample sizes used for size composition data. Effective sample sizes were estimated using the McAllister-Ianelli approach. TCF: directed Tanner crab fishery (RC: retained catch; TC: total catch); SCF: snow crab fishery; RKF: BBRKC fishery; GF All: groundfish fisheries. Highlighted cells indicate "best" value between Scenarios 19.03(2020) and 20.07.

			Model Scenarios			
category	**fleet**	**sex**	**19.03**	**19.03(2020)**	**20.07**	**20.1**
surveys data	**NMFS**	**male**	**161.83**	**161.20**	**172.72**	**124.59**
		female	**79.49**	**79.48**	**82.05**	**55.35**
	SBS BSFRF	**male**	--	--	**60.82**	--
		female	--	--	**28.86**	--
fisheries data	TCF (RC)	male	232.58	234.09	244.83	232.71
	TCF (TC)	female	104.91	98.98	98.59	99.90
		male	299.03	292.50	281.16	**292.21**
	SCF	female	45.47	44.83	44.82	46.45
		male	146.18	148.35	149.62	151.59
	RKF	female	33.81	30.73	30.26	31.10
		male	44.98	46.51	46.50	45.90
	GF All	female	258.04	256.67	253.58	235.98
		male	278.61	273.60	267.68	241.33

Table 30. Comparison of observed and predicted (total) male survey biomass (in 1000's t) from the model scenarios.

	Observed	Scenario			
year	(1000's t)	19.03	19.03(2020)	20.07	20.10
1975	294.9	200.4	202.6	252.6	194.7
1976	157.0	171.9	173.6	211.4	157.3
1977	138.5	138.6	139.9	168.8	123.3
1978	98.3	111.0	111.7	137.2	101.2
1979	50.0	107.1	107.1	131.0	96.9
1980	152.5	114.5	113.7	127.4	97.9
1981	79.9	100.4	98.0	106.8	72.2
1982	65.9	87.9	87.5	82.2	109.9
1983	38.0	64.7	63.7	61.9	73.4
1984	30.5	47.1	45.9	46.8	49.0
1985	14.9	38.6	37.5	39.7	38.1
1986	21.6	47.0	46.4	48.2	49.3
1987	45.5	59.1	59.2	61.4	65.5
1988	99.2	72.1	72.9	76.1	83.8
1989	132.8	82.5	83.9	87.8	99.9
1990	132.4	85.4	87.1	90.8	106.1
1991	145.8	79.6	81.2	84.3	99.0
1992	127.6	71.8	72.9	74.9	88.0
1993	73.3	56.8	57.4	57.6	67.7
1994	48.3	44.7	45.0	44.8	51.9
1995	35.0	34.9	35.0	34.7	39.1
1996	30.8	27.9	27.9	27.7	30.0
1997	14.6	24.0	24.0	23.9	25.2
1998	15.0	22.0	21.9	21.9	22.9
1999	21.5	22.4	22.2	22.2	23.3
2000	23.3	24.3	24.2	24.3	25.8
2001	29.2	28.4	28.3	28.1	30.6
2002	27.4	33.2	33.1	33.1	36.8
2003	37.8	40.1	40.1	40.0	45.2
2004	38.9	48.7	48.7	48.5	55.6
2005	63.7	57.5	57.6	57.1	66.4
2006	101.5	65.3	65.4	65.1	76.0
2007	104.2	71.0	71.2	70.8	82.9
2008	84.9	72.7	73.0	72.9	85.2
2009	47.4	68.8	69.3	69.1	81.5
2010	49.0	62.1	62.5	62.0	72.8
2011	62.7	59.1	59.4	58.9	67.6
2012	80.1	63.3	63.5	63.3	71.1
2013	103.4	74.0	74.1	131.9	82.8
2014	108.9	81.0	81.0	163.4	91.7
2015	74.2	74.4	74.3	135.4	85.1
2016	69.6	60.1	60.0	133.4	68.1
2017	54.2	50.9	50.8	131.5	57.0
2018	47.1	44.3	44.3	43.9	49.7
2019	28.7	42.6	42.6	42.9	50.8
2020	--	--	47.0	49.2	61.2

Table 31. Comparison of observed and estimated mature female survey biomass (in 1000's t) from the model scenarios.

	Observed	Scenario			
year	(1000's t)	19.03	19.03(2020)	20.07	20.10
1975	31.4	43.5	43.8	48.3	52.6
1976	31.2	38.1	38.3	41.1	44.2
1977	38.6	32.7	32.9	34.1	36.4
1978	25.8	29.0	29.1	29.4	30.7
1979	19.3	28.8	28.7	28.3	28.6
1980	63.8	31.0	30.7	29.2	29.1
1981	42.6	26.1	25.9	24.5	22.9
1982	64.1	20.0	20.3	20.7	22.6
1983	20.4	14.2	14.3	14.8	15.3
1984	14.9	9.8	9.9	10.4	10.2
1985	5.6	7.5	7.5	7.9	7.3
1986	3.4	8.5	8.5	9.0	8.1
1987	5.1	10.5	10.5	11.4	9.9
1988	25.4	12.7	12.8	14.2	12.3
1989	19.4	14.9	15.0	16.8	14.9
1990	37.7	16.5	16.7	18.8	17.0
1991	44.8	17.1	17.3	19.7	17.7
1992	26.2	16.2	16.4	18.5	16.7
1993	11.6	13.9	14.0	15.7	14.5
1994	9.8	11.2	11.3	12.5	11.7
1995	12.4	8.9	8.9	9.7	9.2
1996	9.6	7.1	7.1	7.6	7.3
1997	3.4	5.8	5.8	6.1	6.0
1998	2.3	5.0	5.0	5.2	5.1
1999	3.8	4.7	4.6	4.8	4.6
2000	4.1	4.7	4.7	4.9	4.6
2001	4.6	5.1	5.1	5.3	4.9
2002	4.5	5.8	5.7	6.0	5.5
2003	8.4	6.8	6.7	7.2	6.4
2004	4.7	8.1	8.1	8.6	7.7
2005	11.6	9.7	9.6	10.3	9.2
2006	14.9	11.2	11.1	11.9	10.7
2007	13.4	12.7	12.6	13.5	12.1
2008	11.7	13.1	13.1	14.2	12.7
2009	8.5	12.0	11.9	13.0	11.8
2010	5.5	10.2	10.2	11.1	10.3
2011	5.4	9.4	9.3	9.9	9.4
2012	12.4	10.6	10.5	11.0	10.2
2013	17.8	13.2	13.1	23.2	12.3
2014	14.9	14.6	14.5	21.7	13.7
2015	11.2	13.7	13.6	21.1	13.2
2016	7.6	11.5	11.4	31.6	11.3
2017	7.1	9.5	9.4	34.8	9.4
2018	5.0	7.9	7.9	8.3	7.9
2019	4.8	7.0	7.0	7.4	7.2
2020	--	--	7.6	8.2	8.1

Table 32. Comparison of estimates of mature male biomass-at-mating by sex (in 1000's t) from the model scenarios.

	Scenario			
year	19.03	19.03(2020)	20.07	20.10
1948	0.0	0.0	0.0	0.0
1949	0.0	0.0	0.0	0.0
1950	0.0	0.0	0.0	0.1
1951	0.4	0.4	0.1	0.6
1952	2.2	2.2	0.8	2.7
1953	7.3	7.1	3.8	8.0
1954	14.7	14.4	9.6	16.0
1955	21.4	20.9	15.4	23.6
1956	26.4	25.9	19.9	29.5
1957	30.2	29.7	23.3	33.8
1958	33.3	32.7	26.0	37.0
1959	36.1	35.4	28.3	39.7
1960	38.9	38.2	30.7	42.4
1961	42.2	41.4	33.3	45.6
1962	46.9	46.1	37.0	50.4
1963	55.2	54.2	43.2	59.5
1964	72.3	71.0	55.9	78.7
1965	108.4	106.7	82.9	118.7
1966	181.0	178.4	140.7	195.2
1967	280.3	276.6	221.2	297.6
1968	389.2	384.8	311.7	414.5
1969	457.3	453.2	367.3	503.3
1970	482.0	479.3	389.6	564.1
1971	479.4	478.7	394.8	611.0
1972	464.6	466.1	397.1	652.7
1973	441.2	444.6	397.2	678.2
1974	402.4	406.6	378.9	652.0
1975	358.6	362.6	342.8	576.9
1976	289.5	292.9	271.1	451.9
1977	209.9	212.6	187.3	321.7
1978	163.7	165.7	137.0	240.8
1979	142.6	143.3	105.9	202.0
1980	131.1	127.8	97.1	155.5
1981	131.6	126.0	103.2	129.2
1982	120.1	114.3	98.6	104.1
1983	91.7	86.3	77.5	70.9
1984	60.9	56.4	53.2	42.1
1985	55.2	51.2	48.1	38.4
1986	64.1	60.4	54.2	48.0
1987	80.7	77.5	67.8	64.9
1988	102.2	99.7	88.4	86.6
1989	112.9	110.8	97.6	99.7
1990	111.8	110.2	94.4	102.3
1991	116.6	115.6	99.0	109.7
1992	108.8	107.5	91.0	99.7
1993	100.1	98.1	82.0	89.1
1994	83.6	81.6	68.0	72.7
1995	65.7	64.0	53.2	55.2
1996	52.6	51.2	42.7	42.6
1997	43.3	42.0	35.4	34.2
1998	37.8	36.7	31.0	29.5
1999	36.2	35.0	29.7	28.3
2000	37.6	36.3	31.1	29.8
2001	42.1	40.7	34.7	33.9
2002	49.1	47.5	40.4	40.8
2003	58.7	56.9	48.5	50.0
2004	71.7	69.7	59.9	62.0
2005	87.0	84.7	71.6	75.9
2006	102.3	99.6	84.4	89.8
2007	116.9	113.6	95.5	102.7
2008	130.7	127.1	107.6	113.1
2009	128.2	125.2	106.7	111.3
2010	111.6	109.3	93.9	96.8
2011	95.5	93.5	80.4	81.8
2012	94.2	92.1	78.3	81.1
2013	114.8	111.7	94.5	97.7
2014	135.8	131.7	111.3	112.8
2015	131.9	127.6	105.6	108.8
2016	117.1	113.5	93.7	97.6
2017	96.4	93.3	77.2	78.9
2018	79.5	76.9	64.2	63.7
2019	–	66.1	56.1	55.5

Table 33. Comparison of estimates of mature female biomass-at-mating by sex (in 1000's t) from the model scenarios.

	Scenario					Scenario			
year	19.03	19.03(2020)	20.07	20.10	year	19.03	19.03(2020)	20.07	20.10
1948	0.0	0.0	0.0	0.0	1986	31.9	31.4	22.6	35.2
1949	0.0	0.0	0.0	0.0	1987	39.3	38.7	28.9	43.6
1950	0.1	0.1	0.0	0.1	1988	47.8	47.3	36.1	54.2
1951	0.5	0.4	0.1	0.7	1989	55.5	55.1	42.3	65.2
1952	1.9	1.8	0.8	2.5	1990	61.3	61.1	47.0	73.6
1953	4.3	4.2	2.4	5.7	1991	63.3	63.0	48.6	75.8
1954	7.0	6.8	4.3	9.3	1992	59.8	59.3	45.2	70.7
1955	9.2	9.0	6.0	12.5	1993	51.6	51.0	38.3	60.8
1956	10.9	10.7	7.3	15.0	1994	41.7	41.2	30.5	49.1
1957	12.2	12.0	8.3	16.9	1995	32.9	32.5	23.7	38.8
1958	13.4	13.1	9.1	18.5	1996	26.2	25.9	18.6	30.8
1959	14.5	14.2	9.9	20.0	1997	21.5	21.2	15.1	25.2
1960	15.7	15.4	10.7	21.6	1998	18.7	18.3	13.0	21.6
1961	17.3	16.9	11.8	23.7	1999	17.4	17.0	12.1	19.9
1962	19.8	19.4	13.5	27.1	2000	17.7	17.3	12.4	19.8
1963	24.6	24.2	16.7	33.8	2001	19.2	18.6	13.4	21.3
1964	35.1	34.5	23.6	48.2	2002	21.7	21.1	15.3	24.1
1965	56.8	55.9	38.8	76.5	2003	25.5	24.8	18.3	28.3
1966	93.8	92.4	65.7	122.9	2004	30.6	29.9	21.9	34.0
1967	140.1	138.2	100.1	181.7	2005	36.3	35.4	26.0	40.6
1968	180.5	178.7	130.3	238.7	2006	42.2	41.0	30.1	47.1
1969	203.7	202.3	147.8	282.3	2007	47.8	46.5	34.1	52.8
1970	210.3	209.6	153.9	312.9	2008	49.3	48.1	35.4	54.6
1971	207.4	207.6	154.7	337.0	2009	44.7	43.8	32.3	50.4
1972	200.6	201.7	154.9	355.3	2010	38.3	37.6	27.5	43.8
1973	190.4	192.0	152.4	358.3	2011	35.1	34.4	24.8	40.7
1974	175.8	177.6	143.2	337.3	2012	39.8	38.8	28.0	45.2
1975	158.3	159.9	127.8	296.9	2013	49.7	48.3	35.3	54.4
1976	137.8	139.2	108.1	248.0	2014	54.8	53.3	38.9	59.5
1977	118.2	119.3	89.5	204.0	2015	51.1	49.7	35.9	56.1
1978	106.3	106.9	78.0	174.6	2016	43.1	42.0	30.0	47.9
1979	107.1	106.9	75.3	165.8	2017	35.6	34.7	24.6	39.8
1980	98.8	98.2	68.4	142.3	2018	29.7	28.9	20.5	33.7
1981	82.3	81.8	57.3	110.2	2019	–	25.8	18.4	31.2
1982	63.4	63.2	44.3	79.8					
1983	44.8	44.6	31.4	53.7					
1984	31.1	30.8	22.0	35.7					
1985	27.9	27.5	19.7	31.1					

Table 34. Estimated population size (millions) on July 1 of year. from the model scenarios 19.03(2020) and 20.07.
<<Table too large: available online in the zip file "TannerCrab.PopSizeStructure.csv.zip".>>

Table 35. Comparison of estimates of recruitment (in millions) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03).

	Scenario					Scenario			
year	19.03	19.03(2020)	20.07	20.10	year	19.03	19.03(2020)	20.07	20.10
1948	142.7	140.8	124.7	422.6	1986	796.3	814.3	779.4	1639.1
1949	143.1	141.2	125.1	423.3	1987	595.9	550.3	345.0	1250.0
1950	144.0	142.1	126.0	425.3	1988	249.4	248.9	207.9	511.7
1951	145.7	143.8	127.8	429.0	1989	78.8	75.0	47.8	113.8
1952	148.5	146.6	130.7	435.3	1990	71.3	70.3	74.7	154.6
1953	153.0	151.0	135.2	445.8	1991	73.7	72.5	66.3	199.5
1954	160.1	158.0	142.5	463.0	1992	67.3	66.4	76.0	136.2
1955	171.3	169.0	153.9	491.3	1993	84.3	81.1	77.0	213.0
1956	189.5	187.0	172.8	539.5	1994	143.7	138.3	146.5	344.0
1957	220.8	218.0	206.1	626.5	1995	107.6	105.5	125.1	195.1
1958	279.9	276.8	271.4	800.2	1996	304.3	295.6	273.0	740.4
1959	410.0	406.5	423.9	1195.2	1997	127.2	124.0	116.3	307.3
1960	744.0	740.4	833.5	2191.4	1998	450.4	443.8	491.7	1057.9
1961	1587.8	1584.2	1804.6	4571.5	1999	221.1	216.7	190.4	548.1
1962	2837.5	2827.9	2787.9	7940.9	2000	754.2	743.5	698.7	1777.4
1963	3206.0	3193.7	2768.4	8966.4	2001	231.3	226.3	212.9	643.0
1964	2676.0	2675.2	2250.7	7983.0	2002	829.7	797.8	831.8	1799.7
1965	2119.0	2134.2	1882.1	7284.3	2003	687.4	688.9	438.0	1811.0
1966	1817.4	1848.0	1791.3	7647.8	2004	185.9	182.8	159.9	265.6
1967	1724.2	1767.7	1922.6	8821.1	2005	127.3	125.1	111.8	204.6
1968	1669.1	1712.1	1987.3	8745.8	2006	111.2	111.7	120.8	308.1
1969	1442.0	1465.2	1543.6	5858.4	2007	179.0	178.4	350.9	496.3
1970	1165.2	1170.2	948.0	2961.3	2008	1138.1	1115.6	1146.1	2947.0
1971	779.7	781.6	551.7	1583.3	2009	870.5	838.3	482.0	1750.1
1972	526.3	532.2	411.9	1196.1	2010	301.2	294.5	207.2	605.1
1973	504.0	509.9	491.5	1268.7	2011	62.7	61.2	54.9	73.1
1974	710.5	688.8	1083.3	953.4	2012	173.4	167.4	166.8	414.0
1975	2028.5	2008.1	1479.7	7757.5	2013	107.0	105.1	79.6	290.4
1976	1530.9	1524.2	1101.1	2828.1	2014	79.9	80.6	131.2	196.2
1977	761.0	748.2	365.6	1098.4	2015	117.3	119.7	134.6	355.2
1978	277.0	256.4	189.1	503.9	2016	647.0	655.1	1011.1	1807.3
1979	166.2	165.3	154.0	368.9	2017	677.6	665.0	523.8	2700.7
1980	265.6	250.9	261.1	469.5	2018	1234.9	1135.0	1193.6	5676.0
1981	229.9	217.2	246.6	525.4	2019	–	290.4	274.5	675.1
1982	690.0	700.1	753.2	1794.6					
1983	627.3	634.3	671.4	1467.3					
1984	767.4	746.6	679.3	1825.9					
1985	764.4	791.1	804.9	2669.6					

Table 36. Comparison of exploitation rates (i.e., catch divided by biomass) from the 2018 assessment model (M19F00) and the author’s preferred model (M19F03).

	Scenario			
year	19.03	19.03(2020)	20.07	20.10
1948	–	–	--	--
1949	0.001	0.001	0.001	0.000
1950	0.001	0.001	0.001	0.001
1951	0.002	0.002	0.002	0.001
1952	0.003	0.003	0.003	0.002
1953	0.005	0.005	0.005	0.004
1954	0.008	0.008	0.008	0.006
1955	0.009	0.009	0.010	0.007
1956	0.010	0.010	0.011	0.008
1957	0.011	0.011	0.012	0.008
1958	0.011	0.011	0.012	0.008
1959	0.011	0.011	0.012	0.008
1960	0.010	0.010	0.011	0.008
1961	0.010	0.010	0.011	0.007
1962	0.009	0.009	0.010	0.006
1963	0.008	0.008	0.008	0.005
1964	0.007	0.007	0.008	0.004
1965	0.009	0.009	0.011	0.006
1966	0.009	0.009	0.011	0.006
1967	0.025	0.025	0.031	0.017
1968	0.029	0.029	0.034	0.020
1969	0.038	0.038	0.045	0.025
1970	0.036	0.036	0.042	0.023
1971	0.031	0.031	0.035	0.019
1972	0.028	0.028	0.032	0.019
1973	0.036	0.035	0.039	0.021
1974	0.049	0.048	0.053	0.029
1975	0.044	0.044	0.048	0.027
1976	0.071	0.070	0.079	0.043
1977	0.098	0.097	0.113	0.058
1978	0.076	0.075	0.095	0.043
1979	0.086	0.085	0.125	0.047
1980	0.058	0.059	0.081	0.039
1981	0.027	0.027	0.035	0.023
1982	0.014	0.014	0.018	0.013
1983	0.007	0.007	0.009	0.006
1984	0.015	0.016	0.019	0.013
1985	0.006	0.006	0.007	0.004
1986	0.007	0.007	0.008	0.005
1987	0.013	0.013	0.015	0.010
1988	0.020	0.020	0.023	0.016
1989	0.054	0.055	0.063	0.046
1990	0.091	0.093	0.106	0.082
1991	0.075	0.076	0.089	0.068
1992	0.096	0.097	0.115	0.089
1993	0.055	0.056	0.068	0.053
1994	0.039	0.039	0.048	0.038
1995	0.032	0.033	0.040	0.031
1996	0.019	0.020	0.024	0.019
1997	0.017	0.017	0.021	0.016
1998	0.011	0.012	0.014	0.011
1999	0.006	0.006	0.007	0.005
2000	0.006	0.006	0.007	0.005
2001	0.007	0.007	0.008	0.006
2002	0.004	0.004	0.004	0.003
2003	0.003	0.003	0.003	0.002
2004	0.003	0.003	0.004	0.003
2005	0.006	0.006	0.008	0.005
2006	0.009	0.009	0.011	0.008
2007	0.011	0.011	0.013	0.010
2008	0.008	0.008	0.010	0.008
2009	0.007	0.007	0.008	0.006
2010	0.003	0.003	0.004	0.003
2011	0.004	0.005	0.006	0.004
2012	0.003	0.003	0.004	0.003
2013	0.009	0.009	0.011	0.008
2014	0.031	0.032	0.039	0.031
2015	0.045	0.046	0.056	0.045
2016	0.006	0.006	0.007	0.006
2017	0.010	0.010	0.012	0.009
2018	0.011	0.011	0.013	0.009
2019	–	0.003	0.004	0.002

Table 37. Values required to determine Tier level and OFL for the models considered here. These values are presented only to illustrate the effect of incremental changes in the model scenarios.

case	average recruitment millions	Bmsy (1000's t)	current MMB (1000's t)	Fmsy per year	MSY (1000's t)	Fofl per year	OFL (1000's t)	projected MMB (1000's t)	status ratio
19.03	393.84	41.64	82.61	1.18	19.49	1.12	29.51	39.73	0.95
19.03(2020)	383.96	40.39	77.76	1.14	18.90	1.11	26.15	39.38	0.98
20.07	374.43	36.77	66.87	0.98	16.94	0.94	21.13	35.33	0.96
20.10	1,047.74	39.94	72.37	1.68	21.55	1.44	24.18	34.98	0.88

Figures

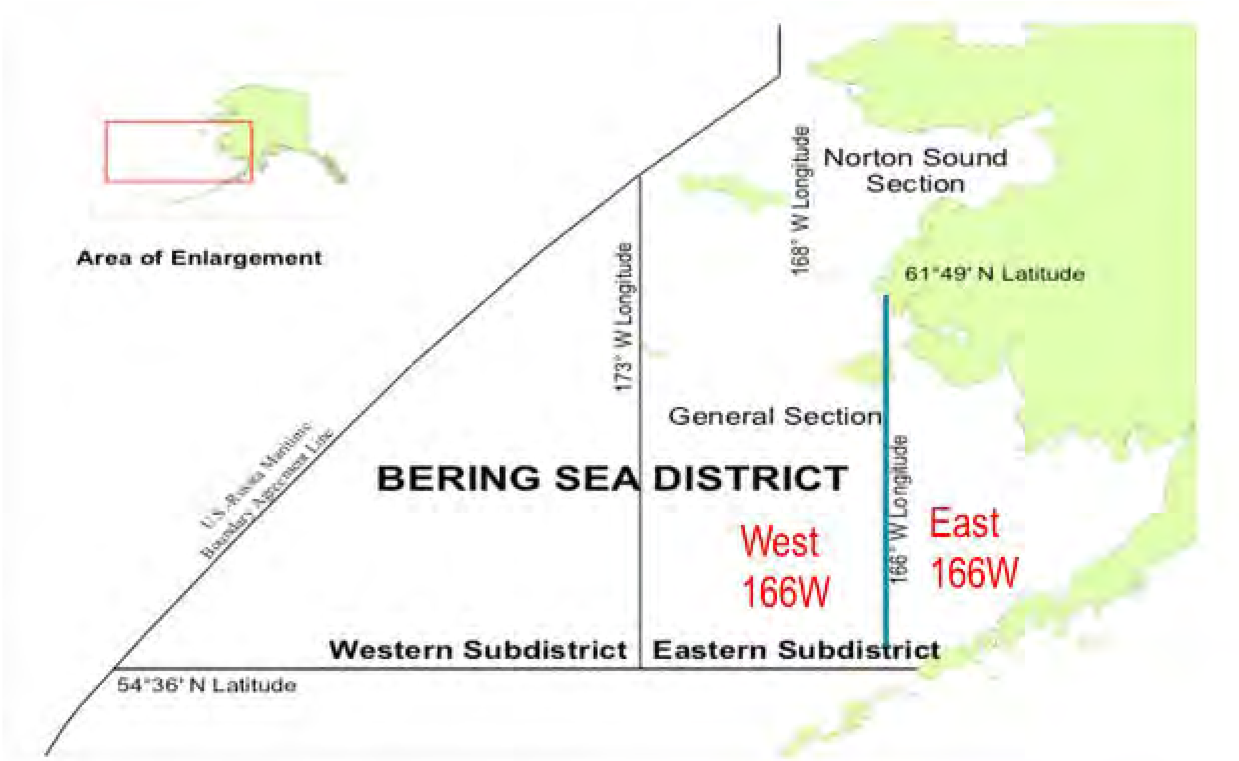


Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008).

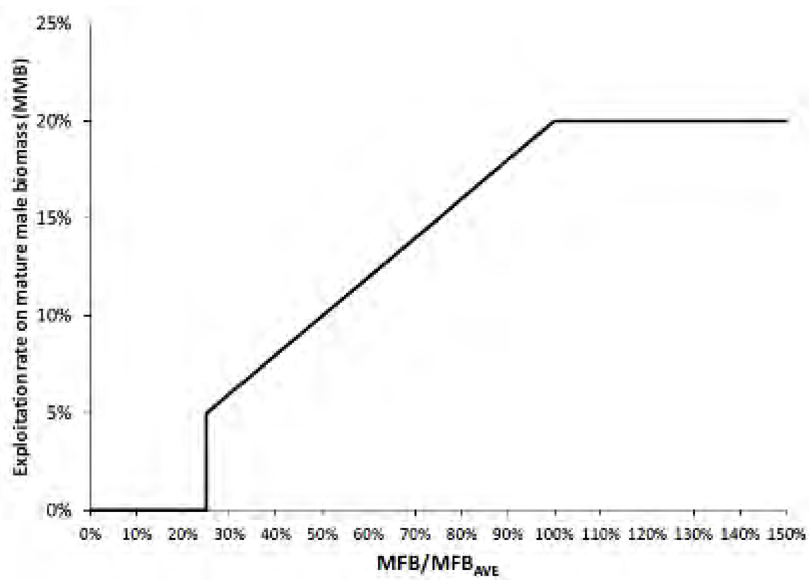


Figure 2. Sloping control rule used by ADFG from 2011 to 2019 as part of its TAC setting process to determine the maximum exploitation rate on mature male biomass as a function of the ratio of current mature female biomass (MFB) to MFB averaged over some time period.

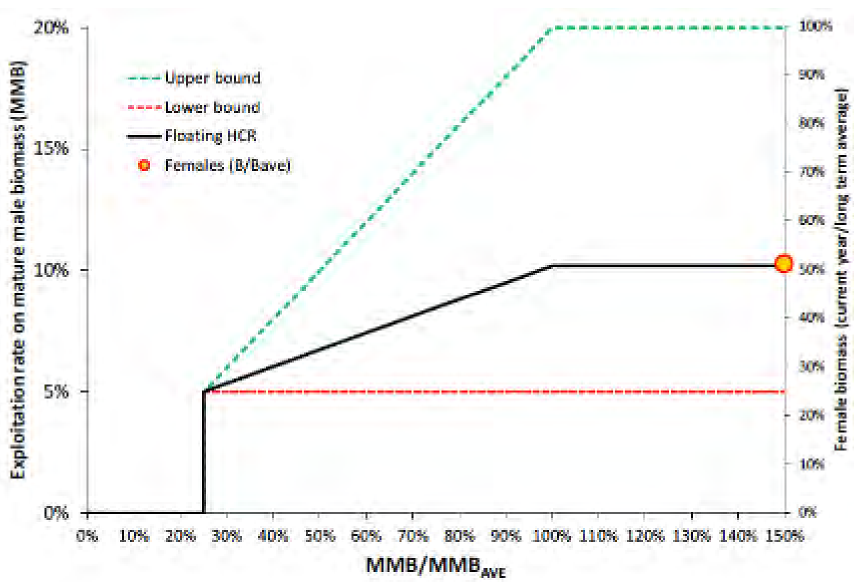


Figure 3. New ADFG "floating" sloping control rule to determine the maximum exploitation rate on mature male biomass (MMB) as a function of the ratio of current MMB to the average MMB over 1982-2018. The ratio of current mature female biomass (MFB) to MFB averaged over 1982-2018 is used to determine the value of the maximum exploitation rate for the control rule, up to a maximum of 20%. ADFG will use this control rule to determine TAC in the future.

Figure 4. 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 in 1984/85 and 1985/86, from 1996/97 to 2004/05, from 2010/11 to 2012/13, and 2016/17 and 2019/20.

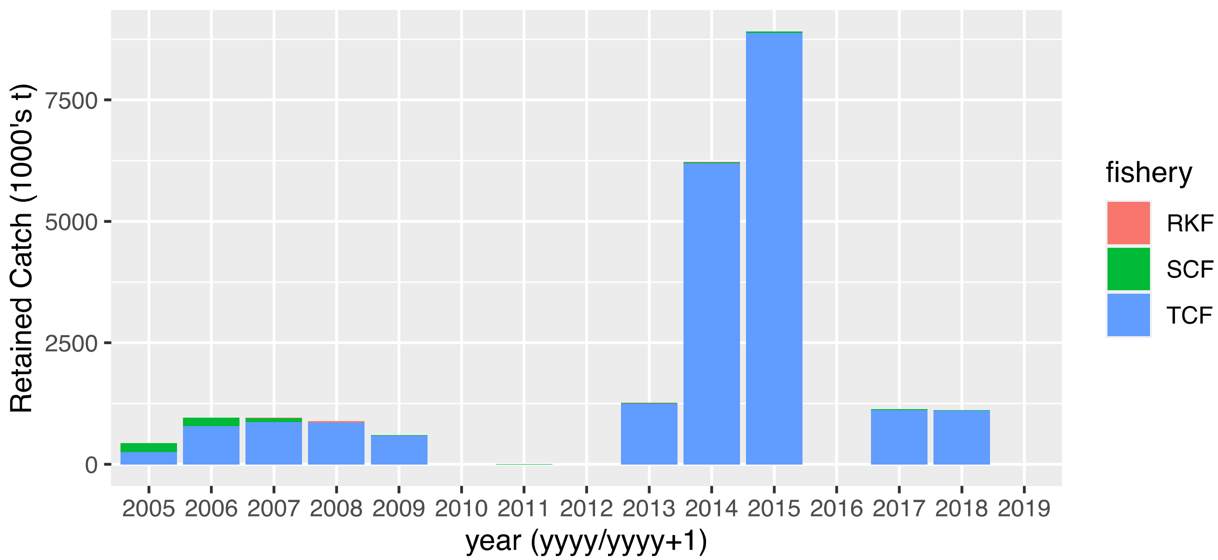


Figure 5. Time series of retained catch biomass (1000's t) in the directed Tanner crab (TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries since 2005. The directed fisheries were both closed from 2010/11 to 2012/13, as well as in 2016/17 and 2019/20. Legal-sized Tanner crab can be incidentally-retained in the snow crab and BBRKC fisheries up to a cap of 5% the target catch.

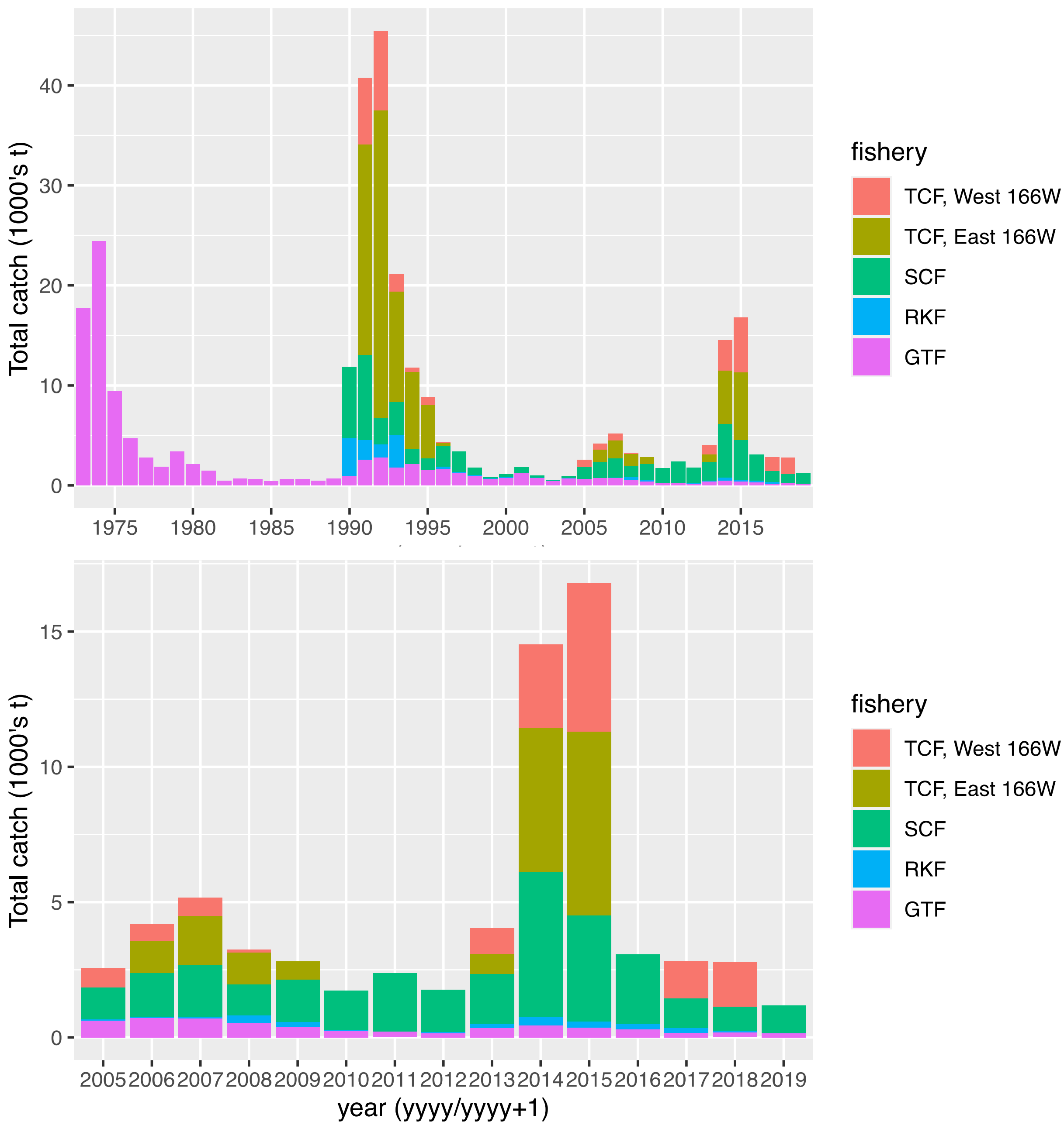


Figure 6. Upper: total catch (retained + discards) of Tanner crab (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Bycatch reporting began in 1973 for the groundfish fisheries and in the early 1990s for the crab fisheries. Lower: detail since 2005.

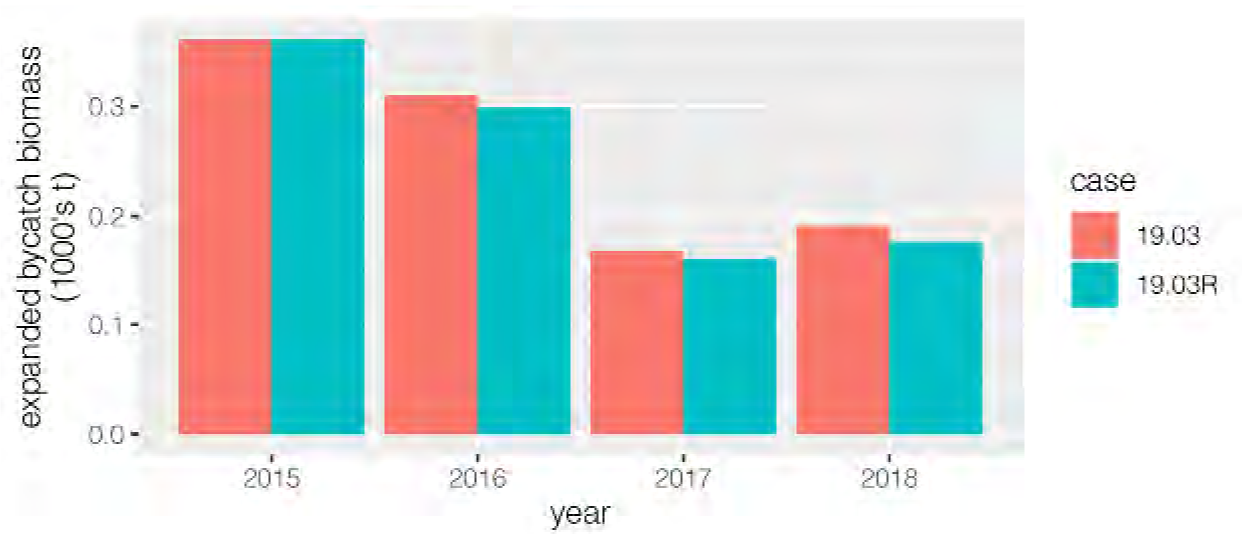


Figure 7. Changes in the expanded estimates of Tanner crab bycatch in the groundfish fisheries from the 2019 assessment to this one due to changes in the estimation algorithm used by AKFIN to align it with that used by the Regional Office. 19.03: 2019 assessment data; 19.03R:

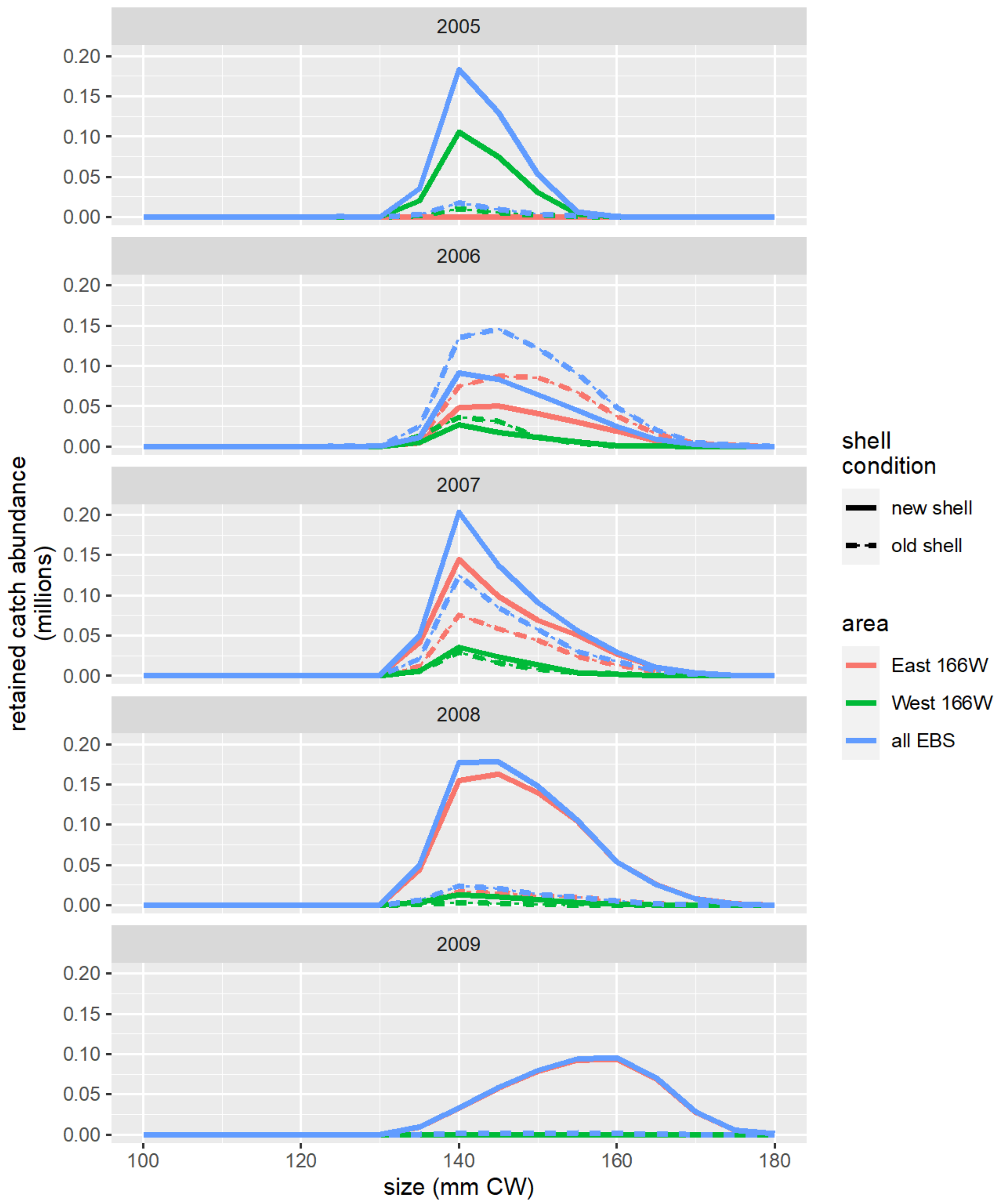


Figure 8. Retained catch size compositions in the directed Tanner crab fisheries since the fishery re-opened in 2013/14. The directed fishery was closed in 2016/17 and 2019/20. Fishery area denoted by color: red—area west of 166ºW, green—area east of 166ºW; blue: all EBS (i.e., total). Shell condition is denoted by solid (new shell) or dotted (old shell) line type.

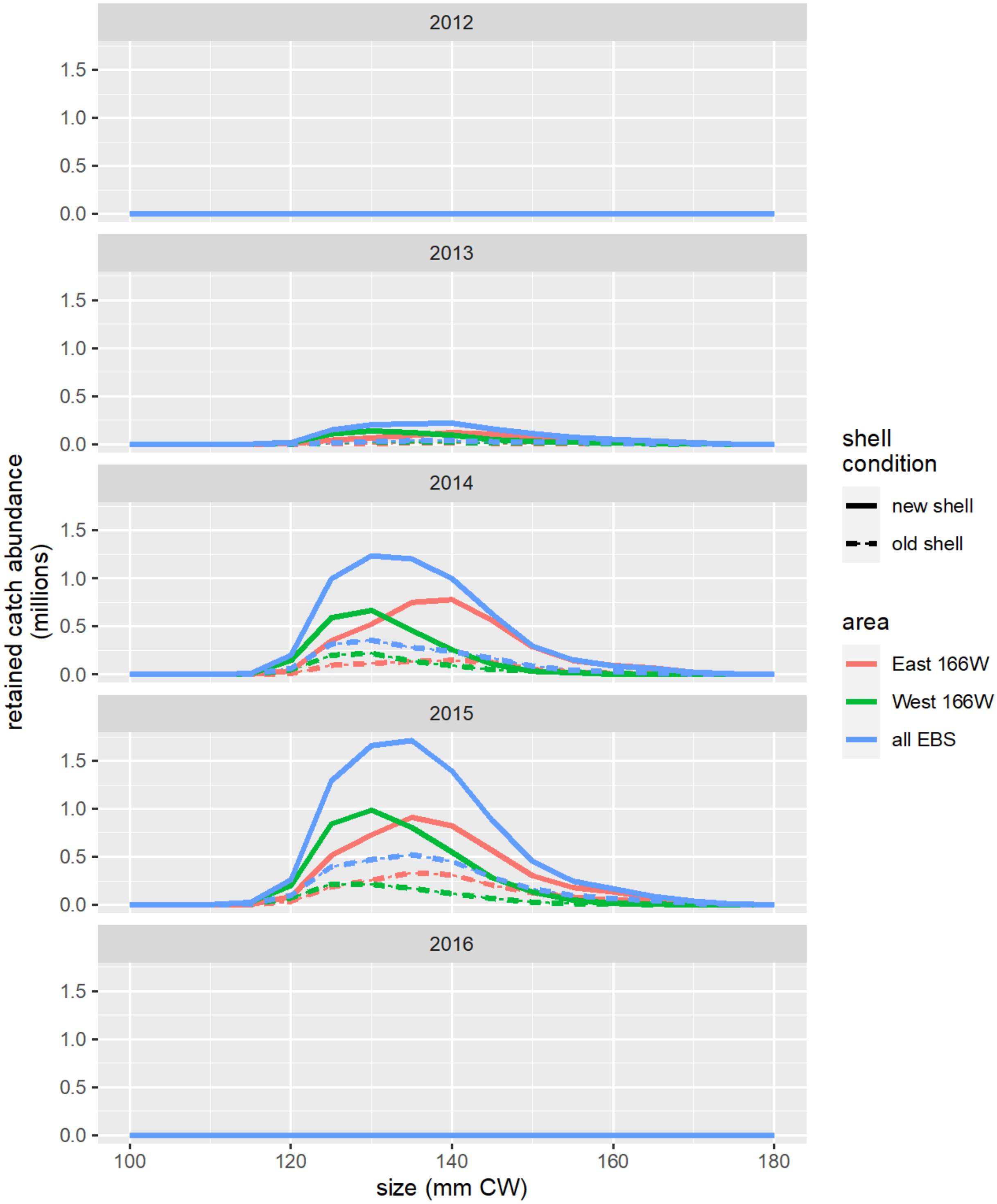


Figure 8 (cont.). Retained catch size compositions in the directed Tanner crab fisheries since the fishery re-opened in 2013/14. The directed fishery was closed in 2016/17 and 2019/20. Fishery area denoted by color: red—area west of 166ºW, green—area east of 166ºW; blue: all EBS (i.e., total). Shell condition is denoted by solid (new shell) or dotted (old shell) line type.

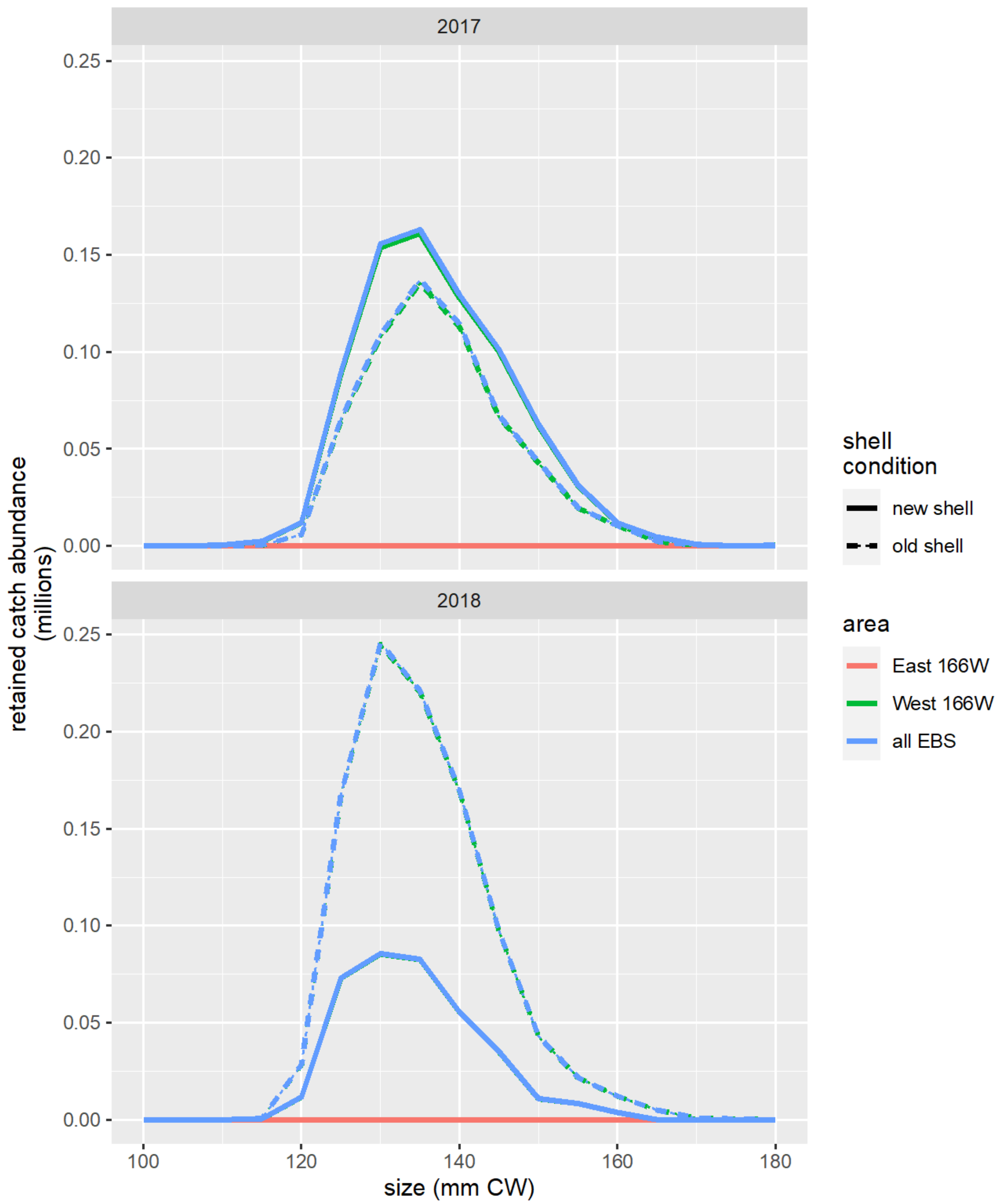


Figure 8 (cont.). Retained catch size compositions in the directed Tanner crab fisheries since the fishery re-opened in 2013/14. The directed fishery was closed in 2016/17 and 2019/20. Fishery area denoted by color: red—area west of 166°W, green—area east of 166°W; blue: all EBS (i.e., total). Shell condition is denoted by solid (new shell) or dotted (old shell) line type.

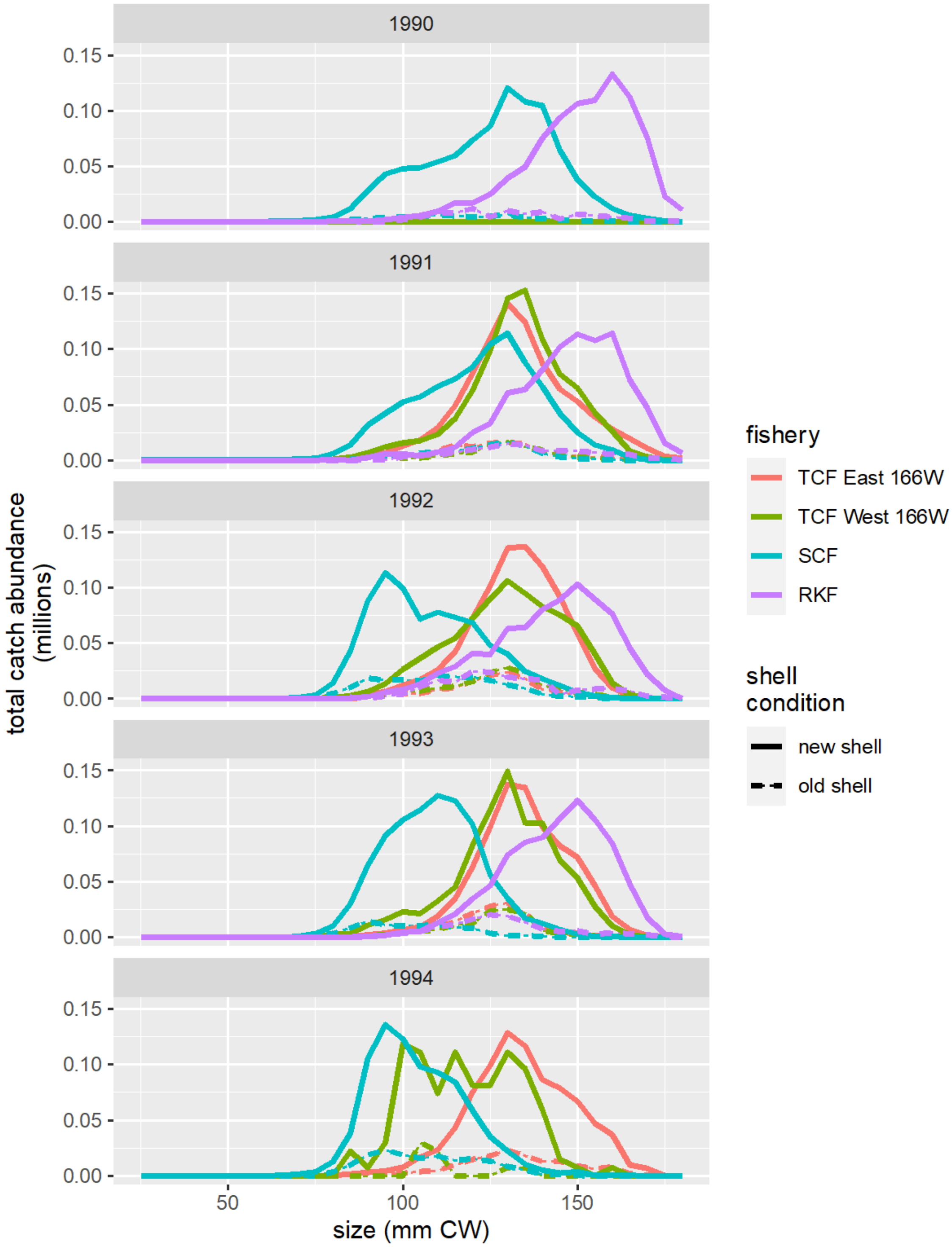


Figure 9. Total catch (retained + discards) size compositions for males, normalized by fleet for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.

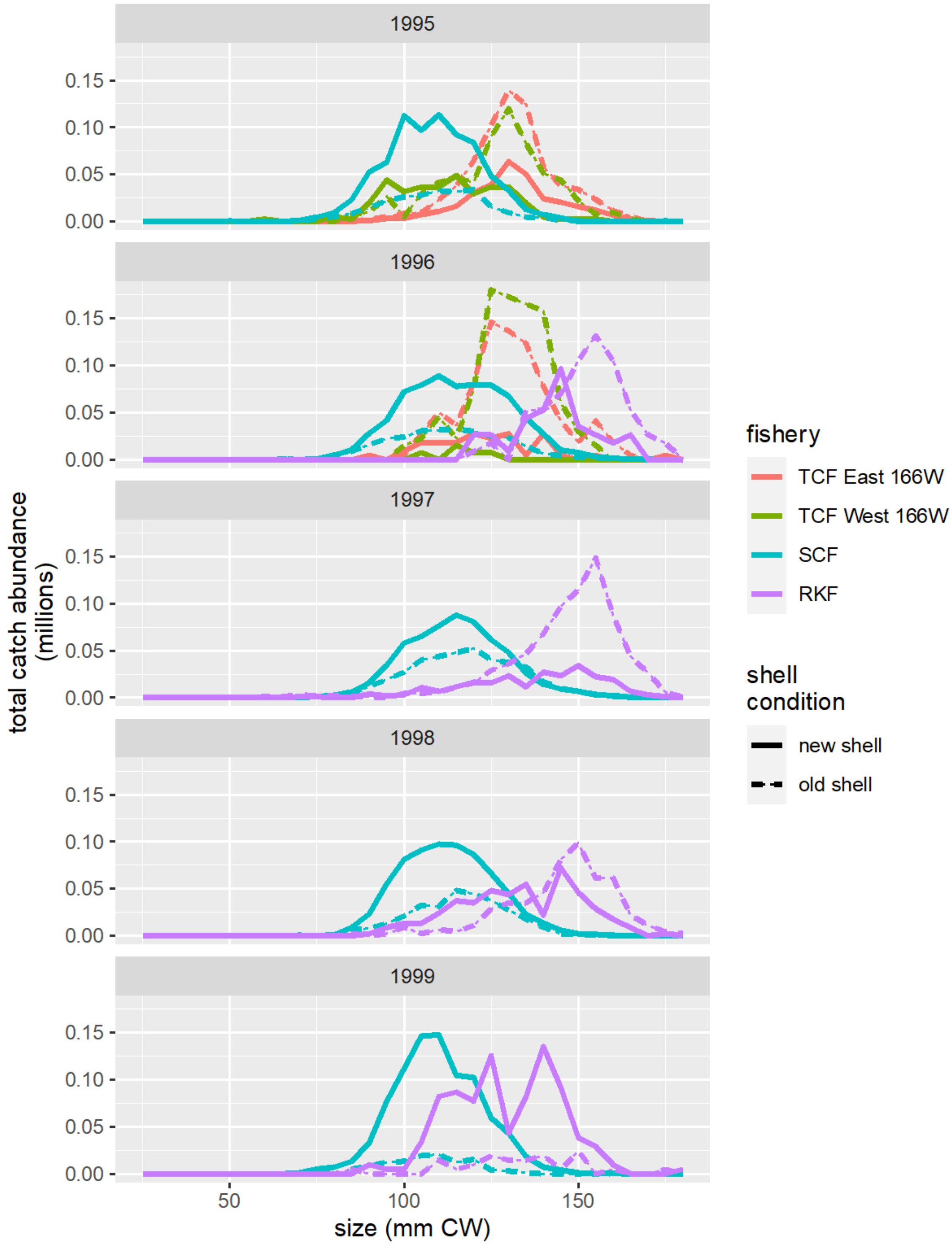


Figure 9 (cont.). Total catch (retained + discards) size compositions for males, normalized by fleet for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.

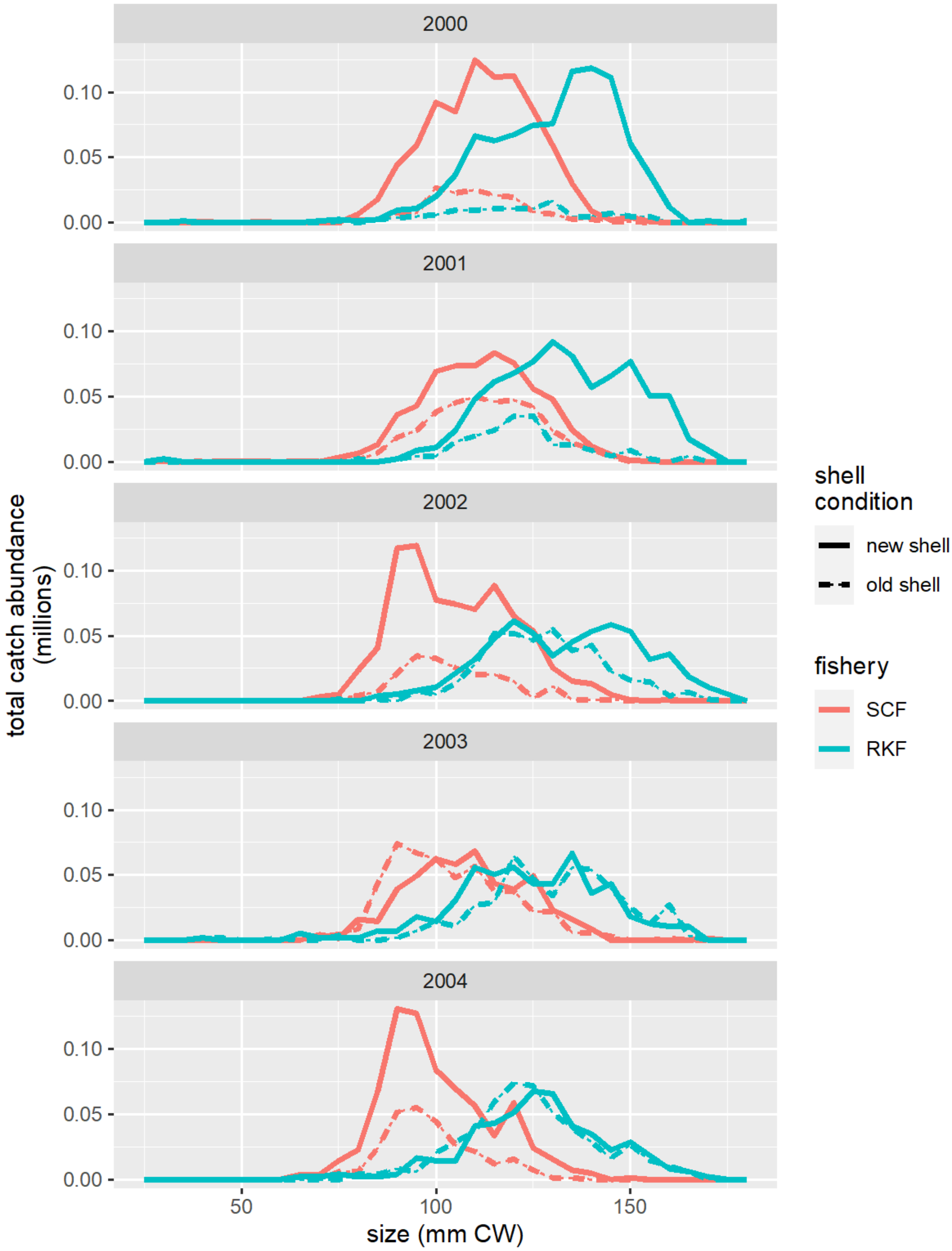
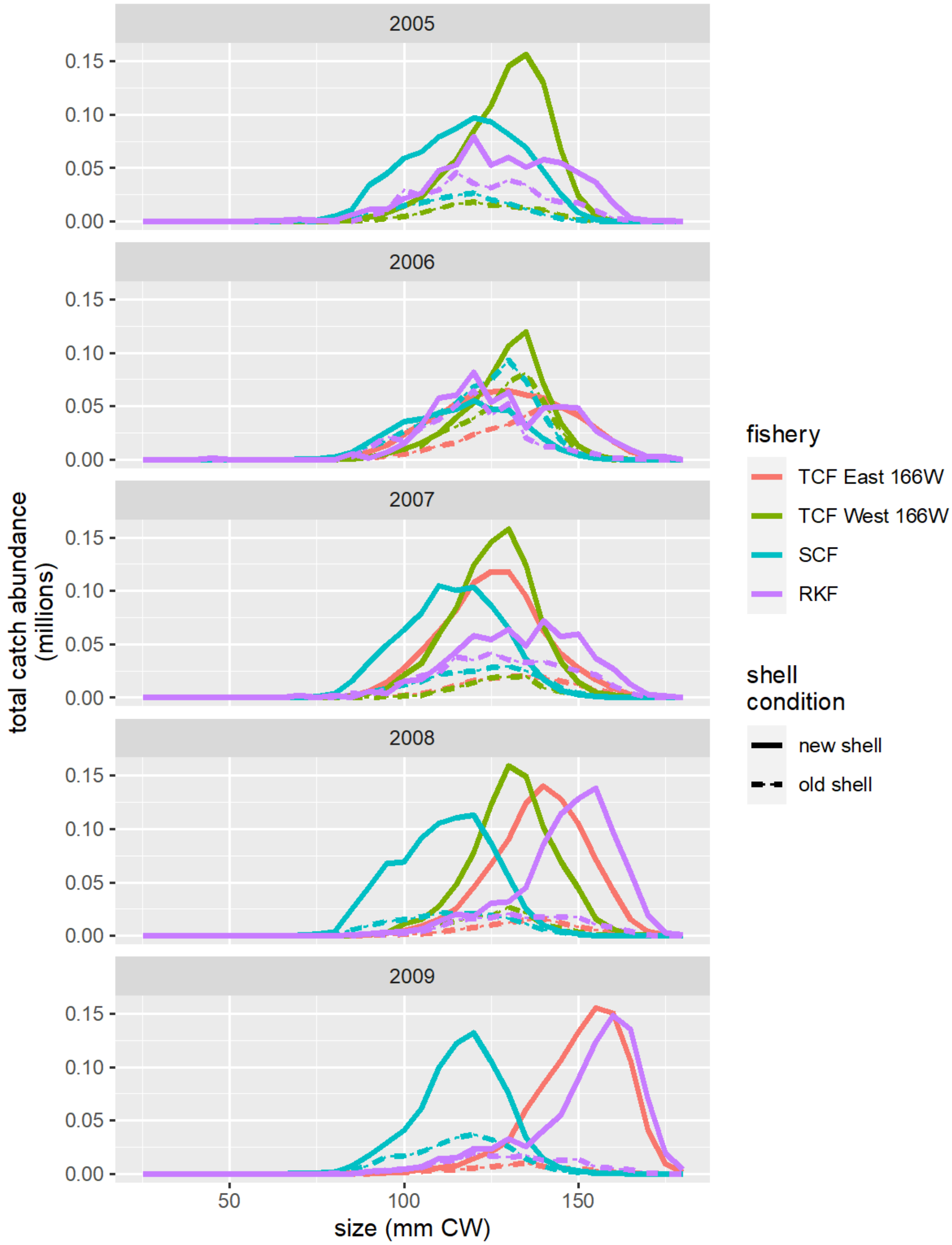


Figure 9 (cont.). Total catch (retained + discards) size compositions for males, normalized by fleet for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.



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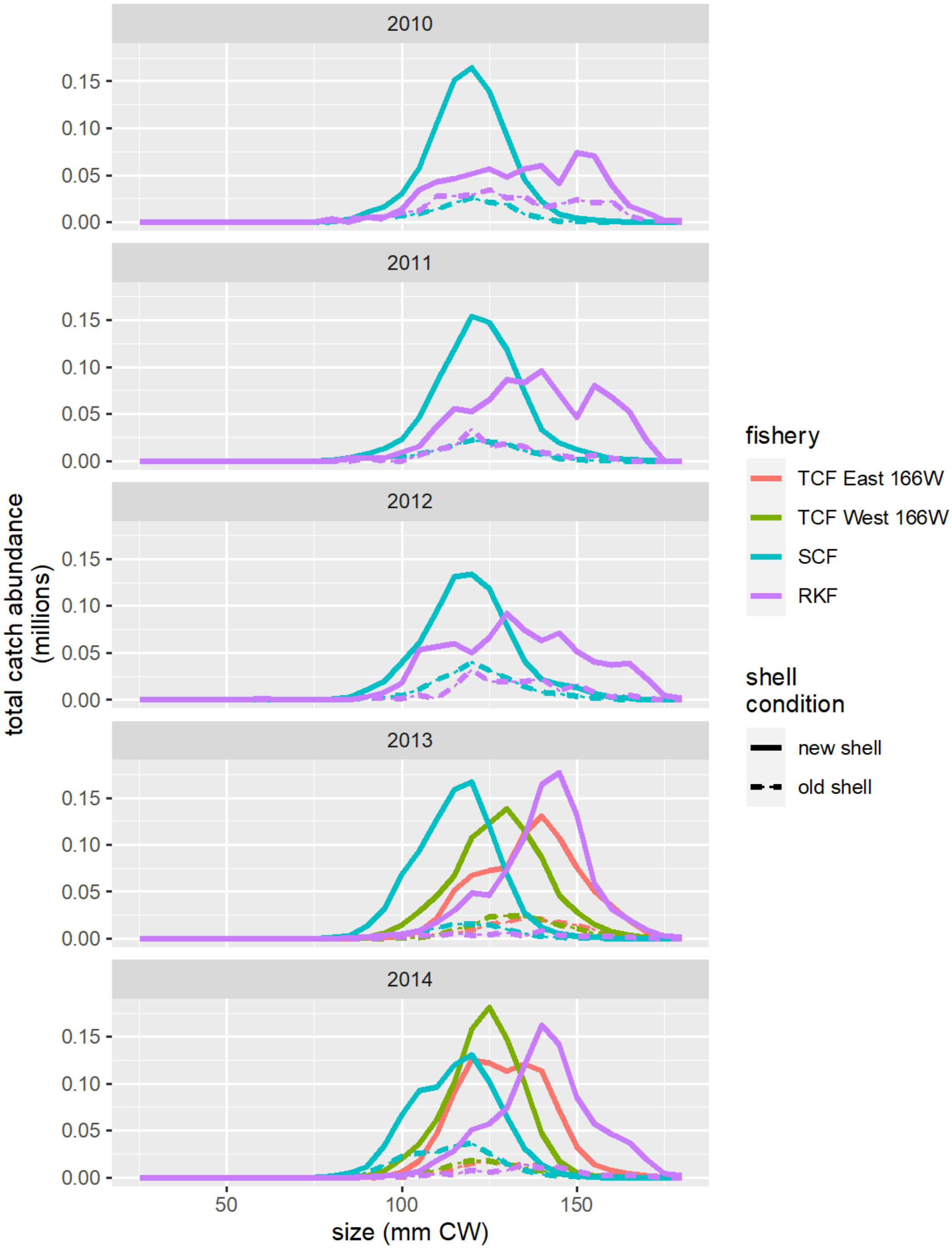


Figure 9 (cont.). Total catch (retained + discards) size compositions for males, normalized by fleet for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.

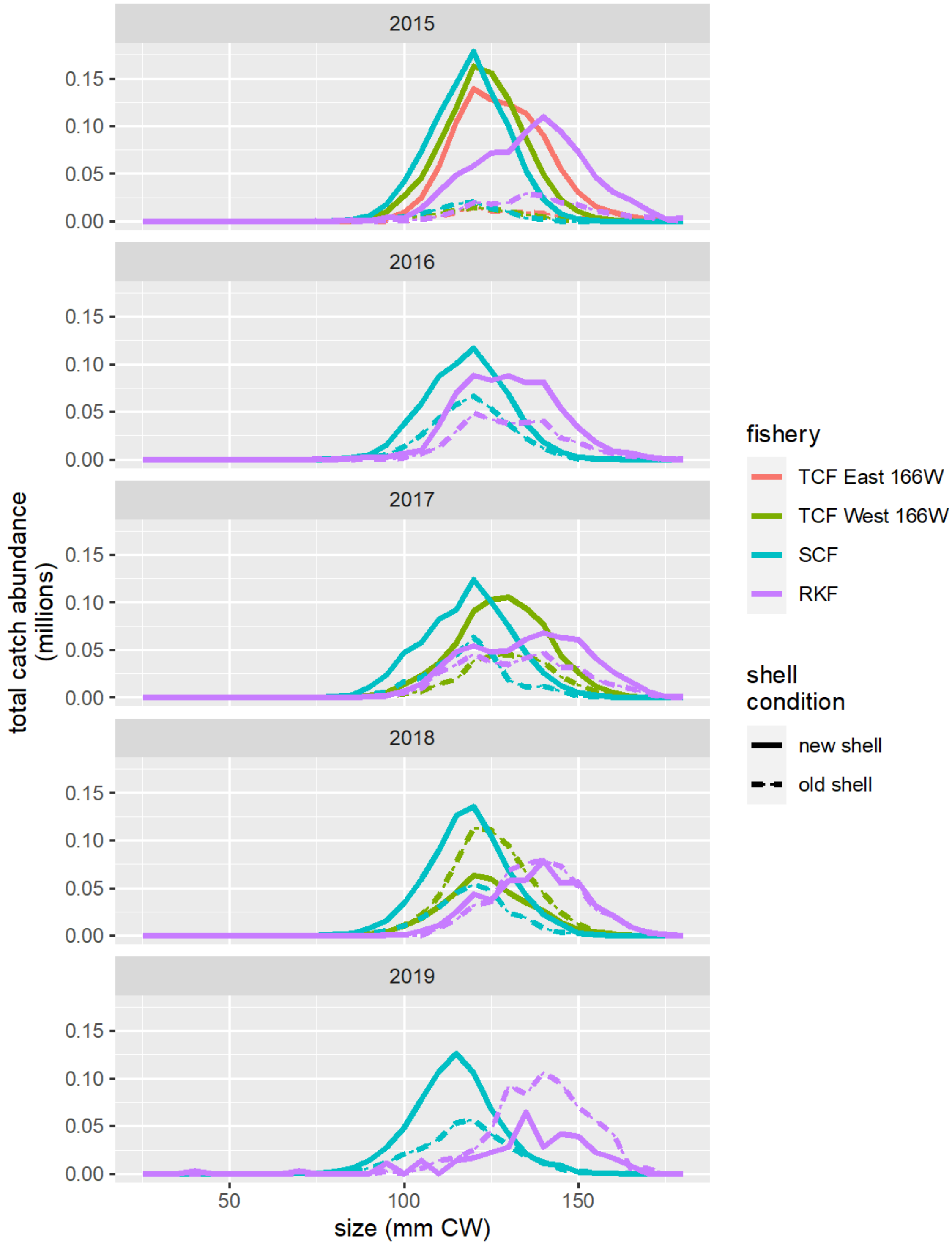


Figure 9 (cont.). Total catch (retained + discards) size compositions for males, normalized by fleet for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.

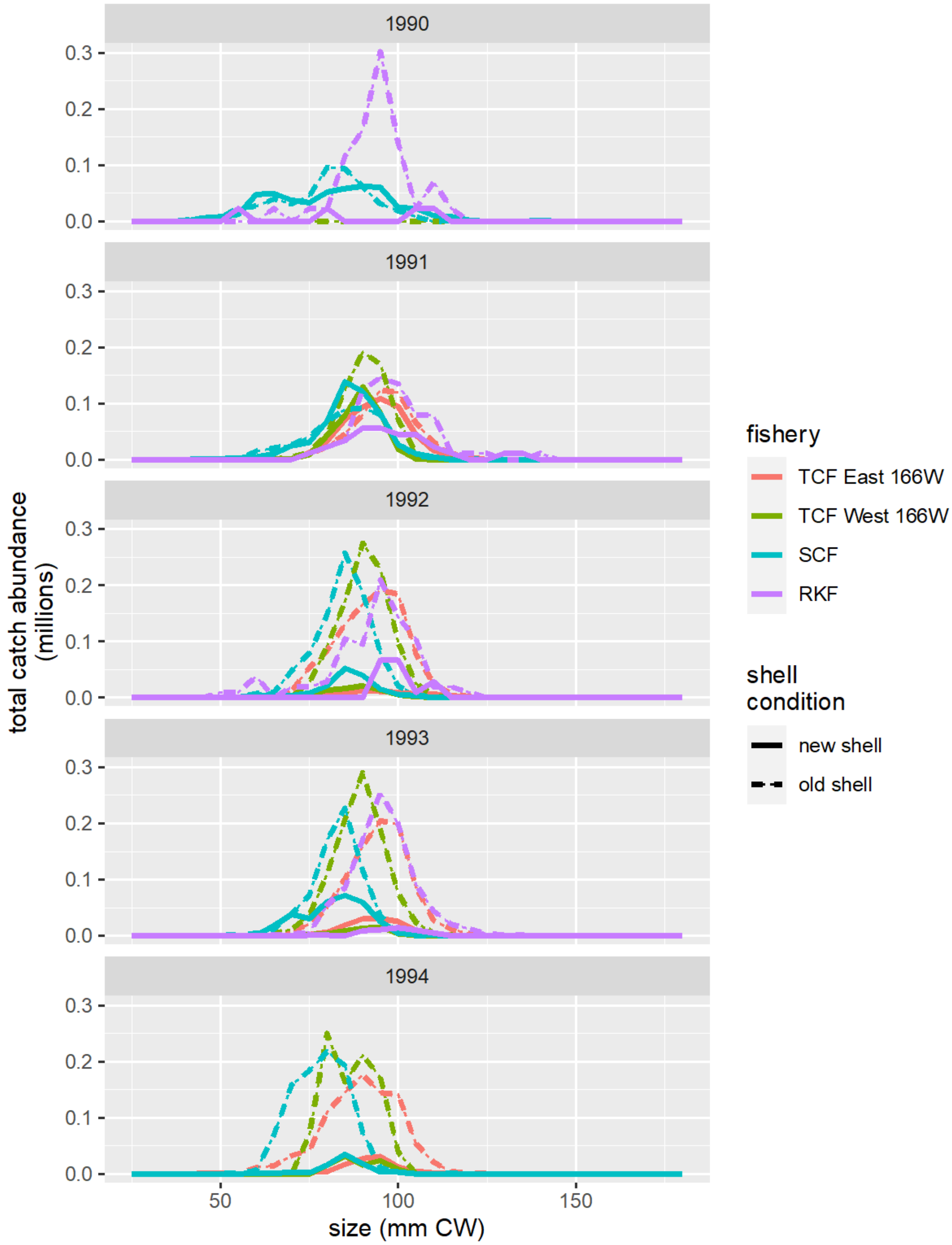


Figure 10. Bycatch size compositions for females, normalized by fleet, for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.

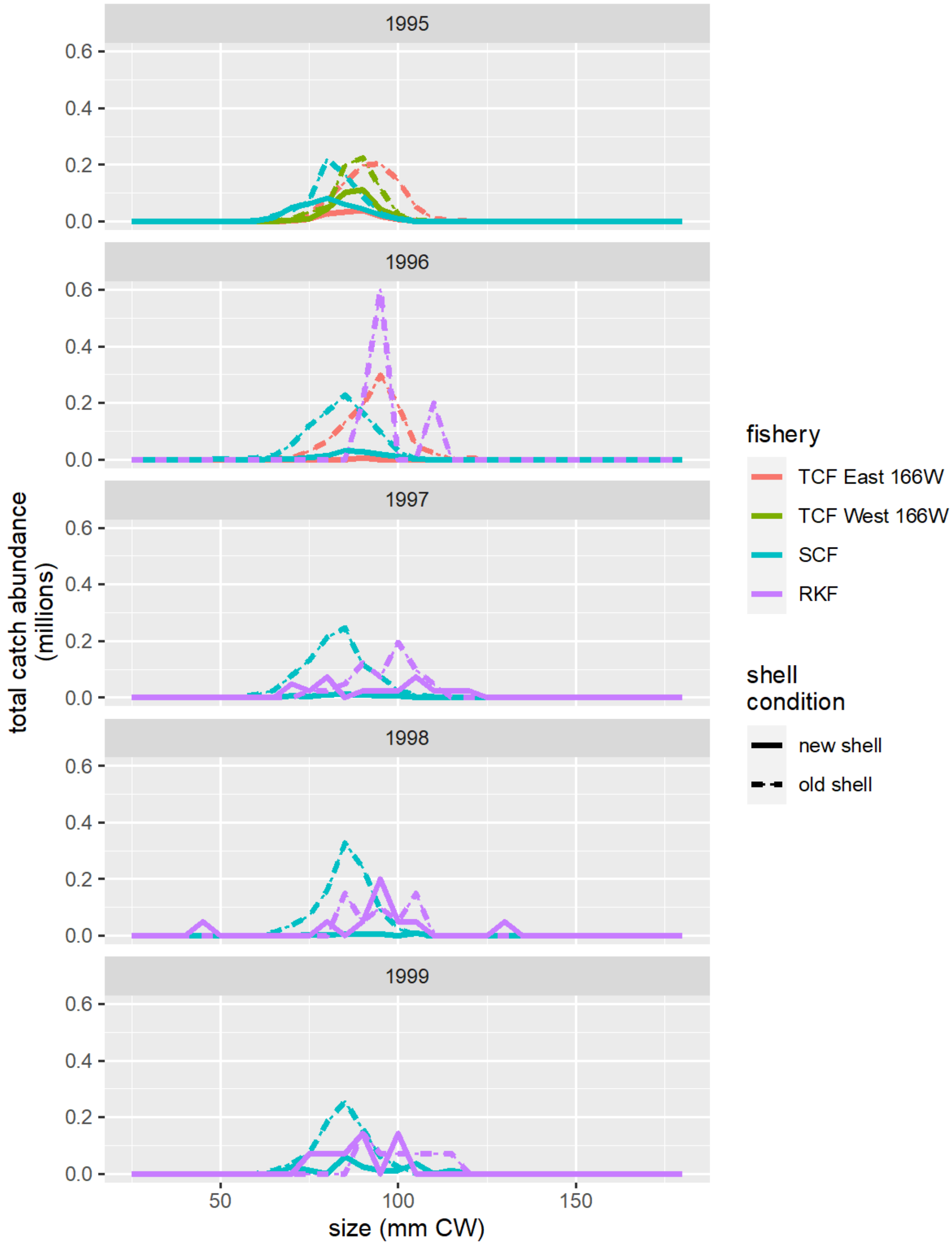


Figure 10 (cont.). Bycatch size compositions for females, normalized by fleet, for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.

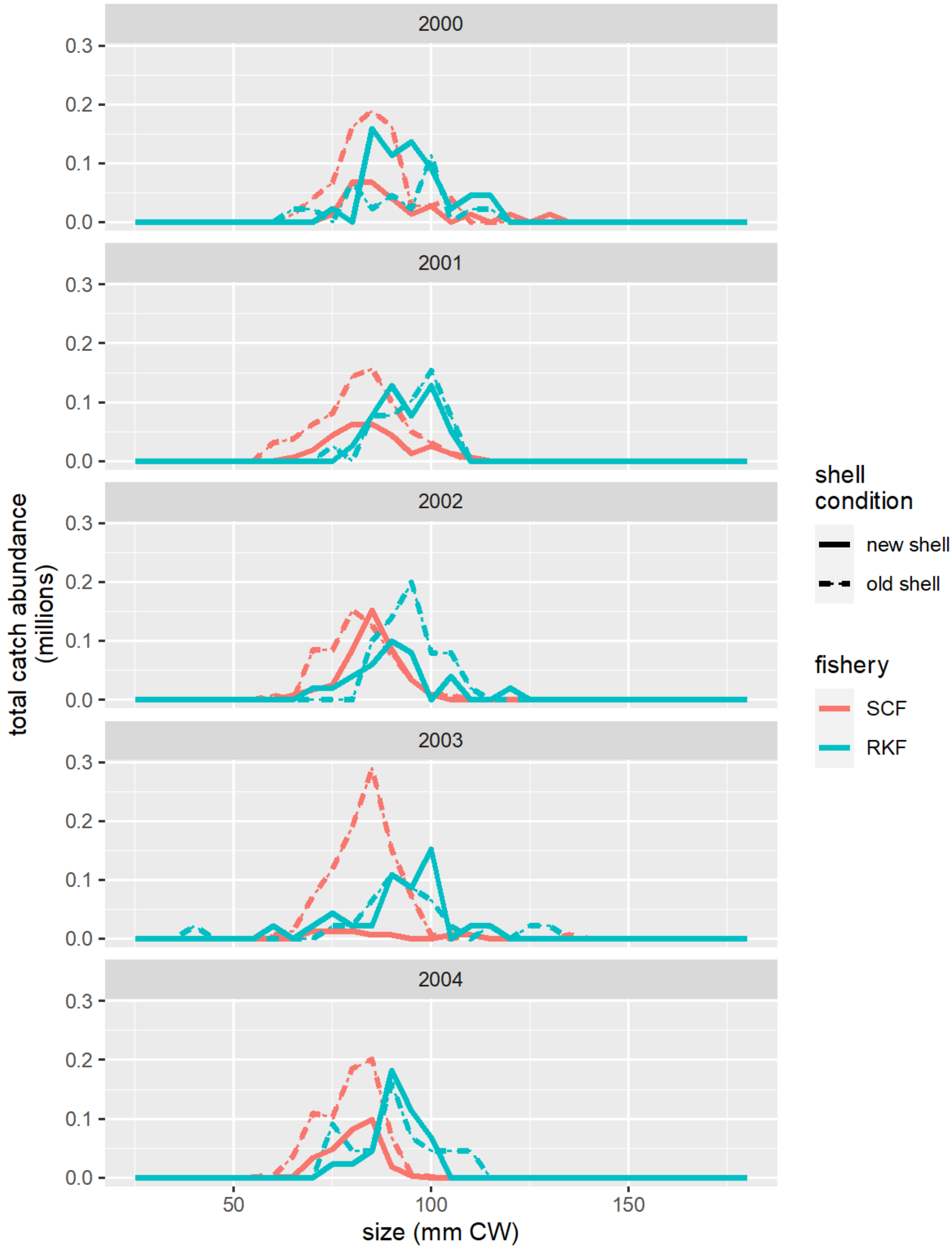


Figure 10 (cont.). Bycatch size compositions for females, normalized by fleet, for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.

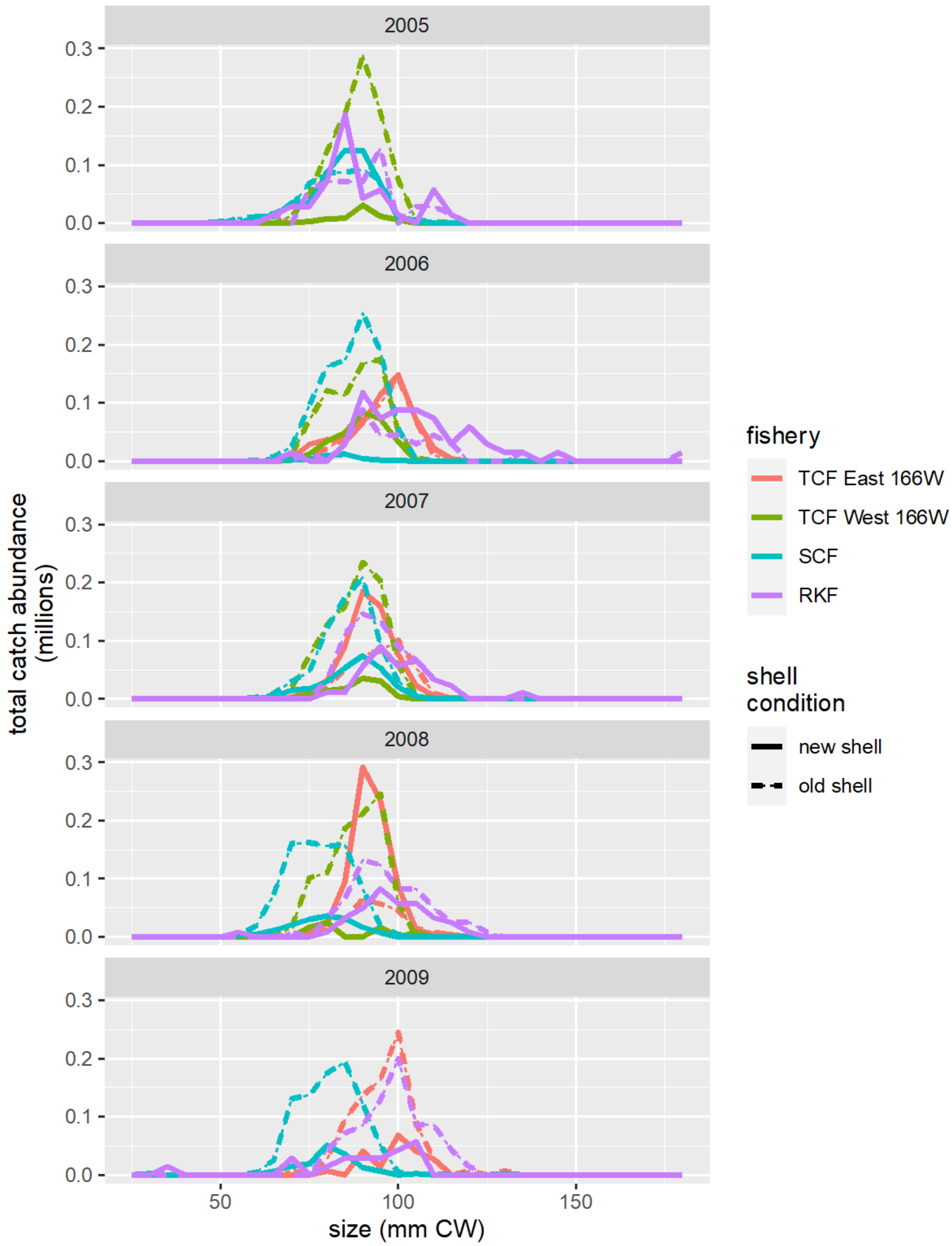
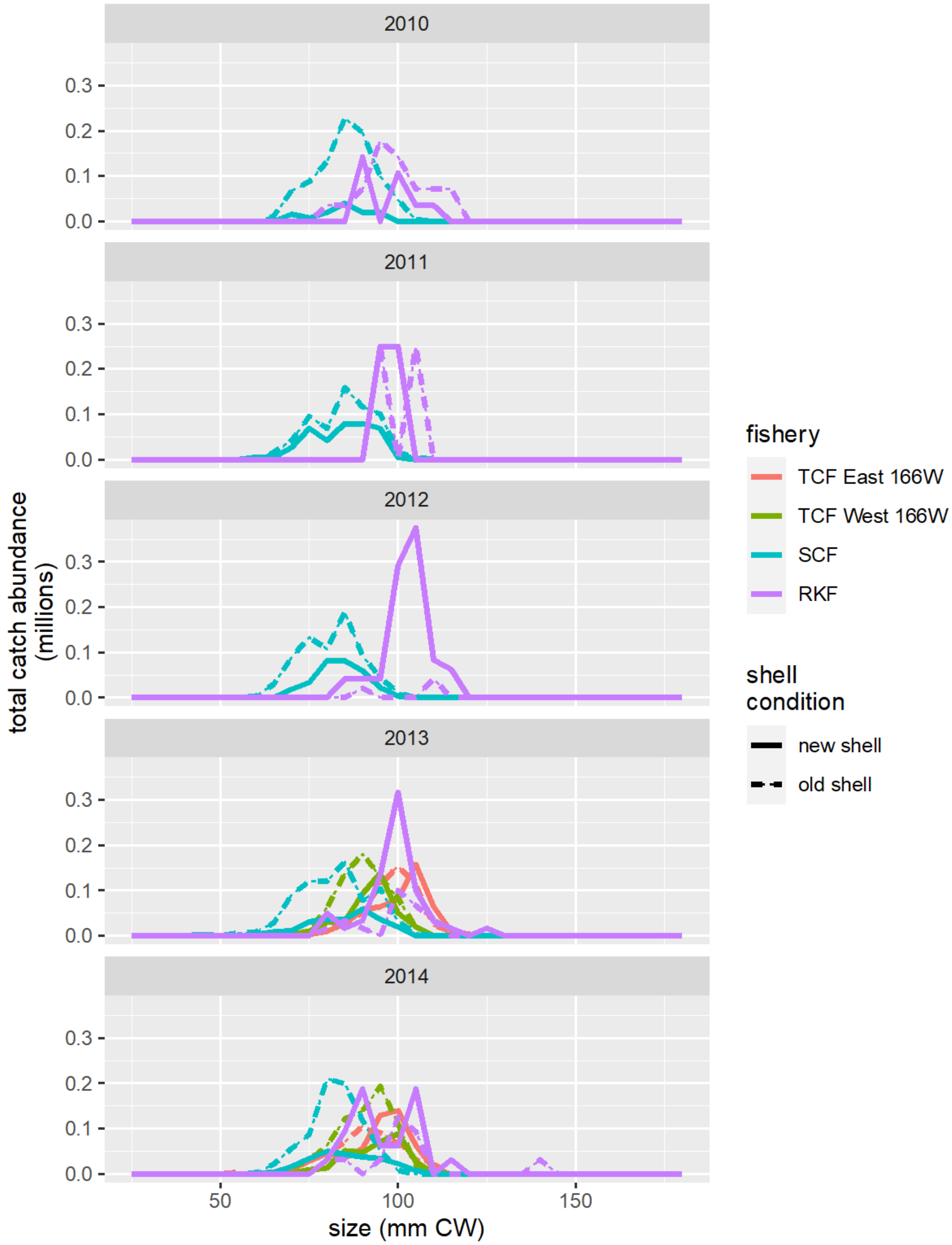


Figure 10 (cont.). Bycatch size compositions for females, normalized by fleet, for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.



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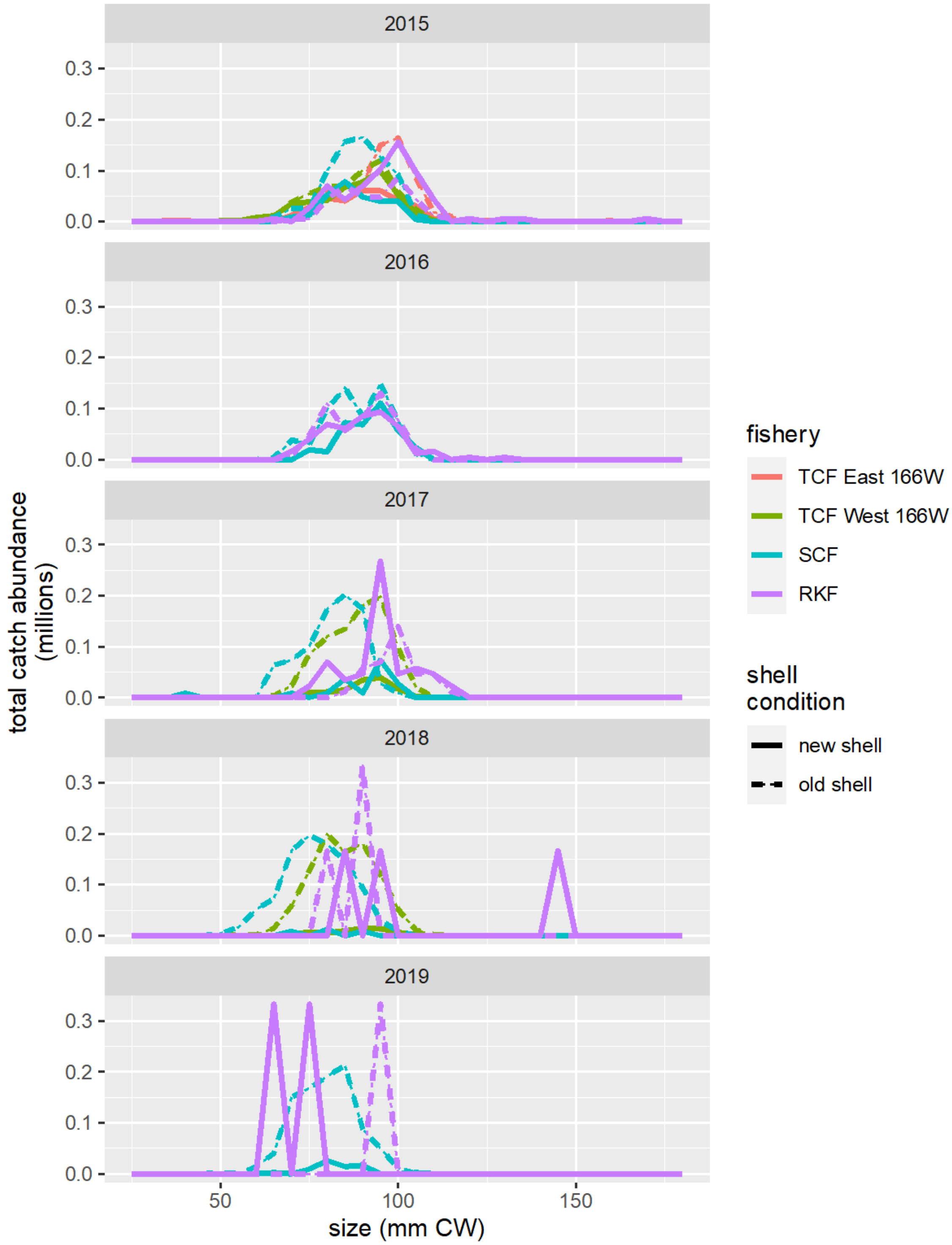


Figure 10 (cont.). Bycatch size compositions for females, normalized by fleet, for the directed Tanner crab (by area, TCF: red and green), snow crab (SCF: cyan), and BBRKC (RKF: purple) fisheries. Solid lines: new shell crab; dotted lines: old shell crab.

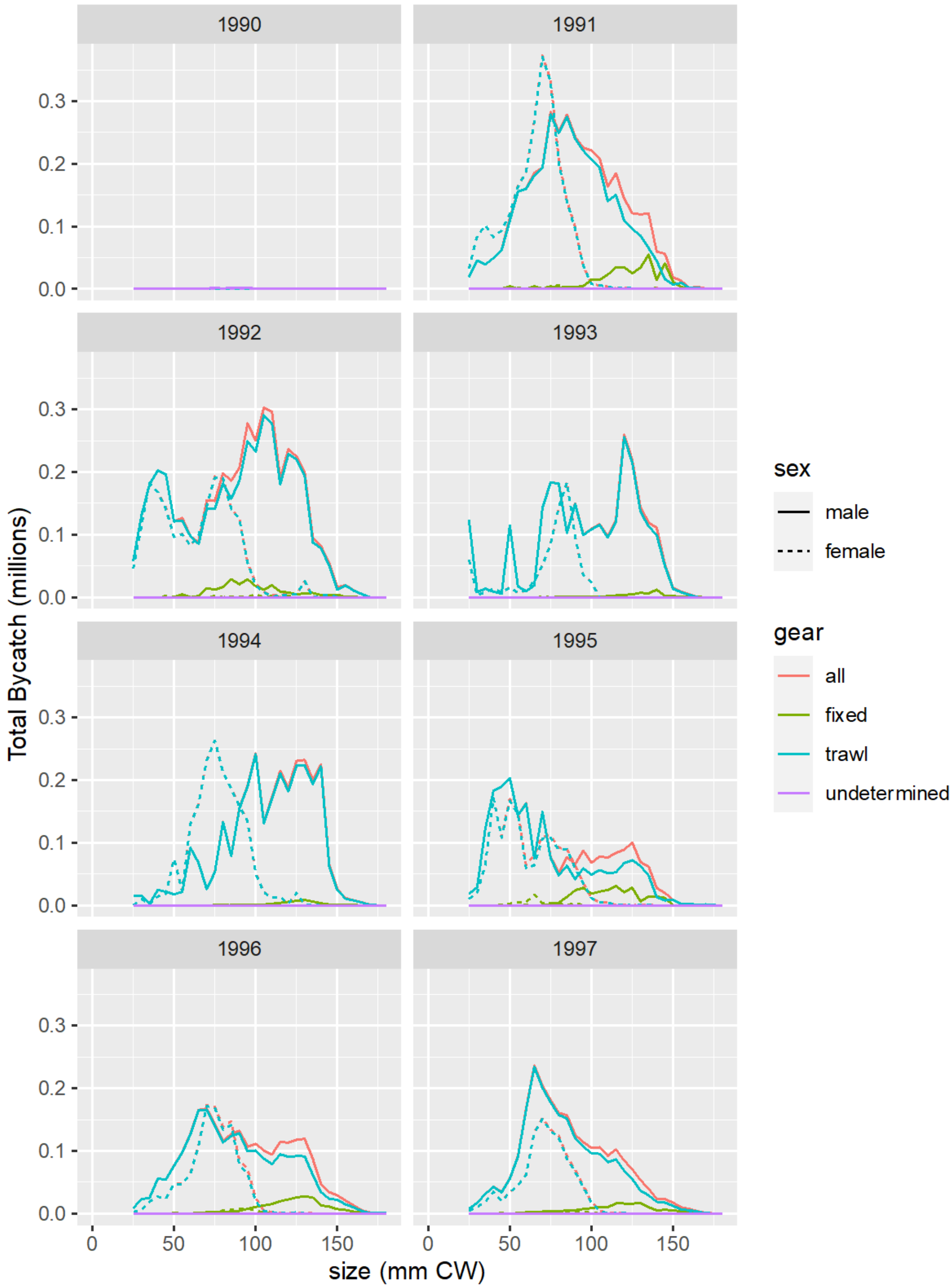
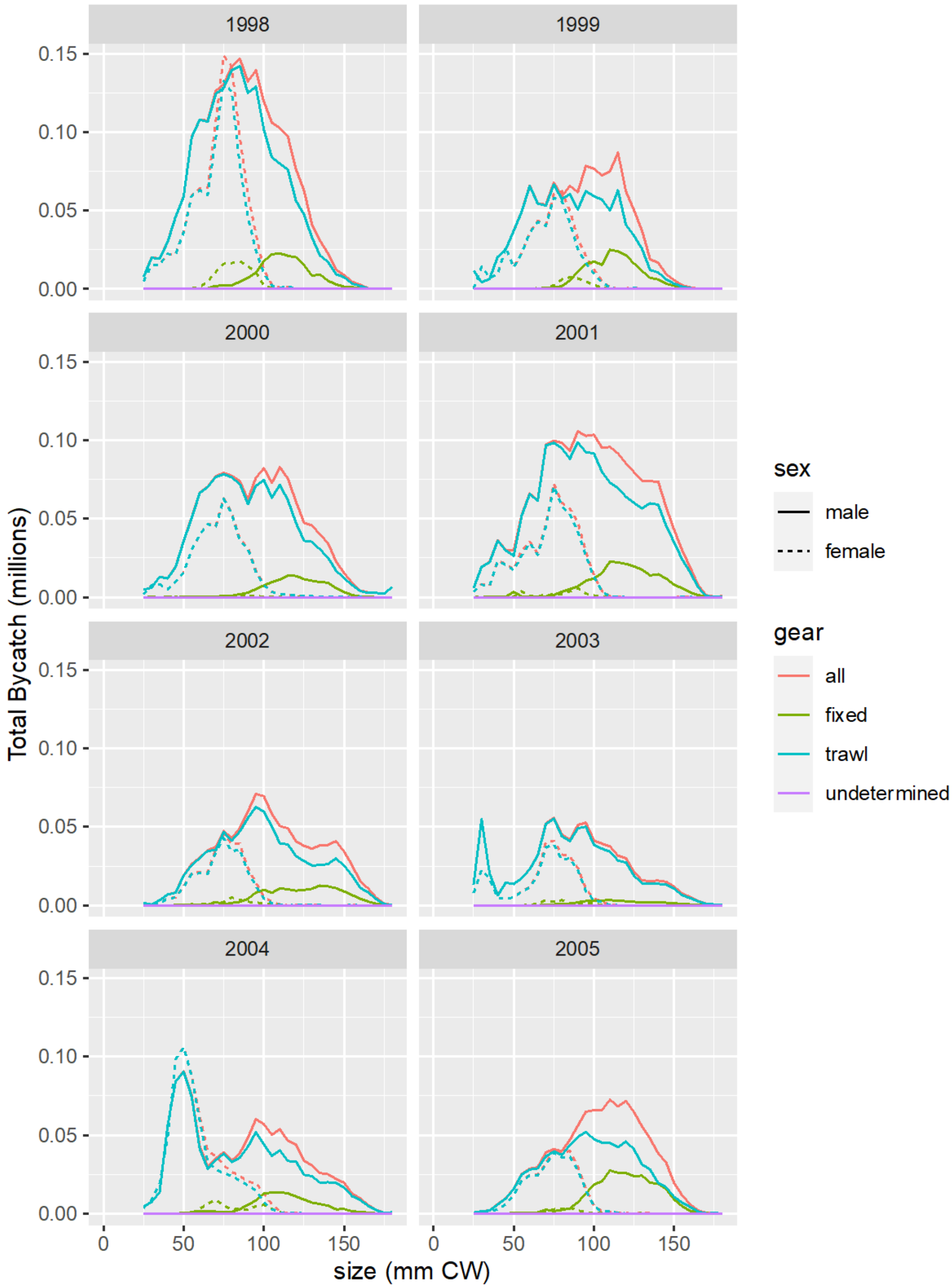


Figure 11. Annual bycatch size compositions in the groundfish fisheries by sex and gear type, expanded to total bycatch starting in 1990. Colors indicate gear type (red: all types, olive: fixed gear, cyan: trawl gear, purple: undetermined). Line type indicates sex (solid: males, dotted: females).



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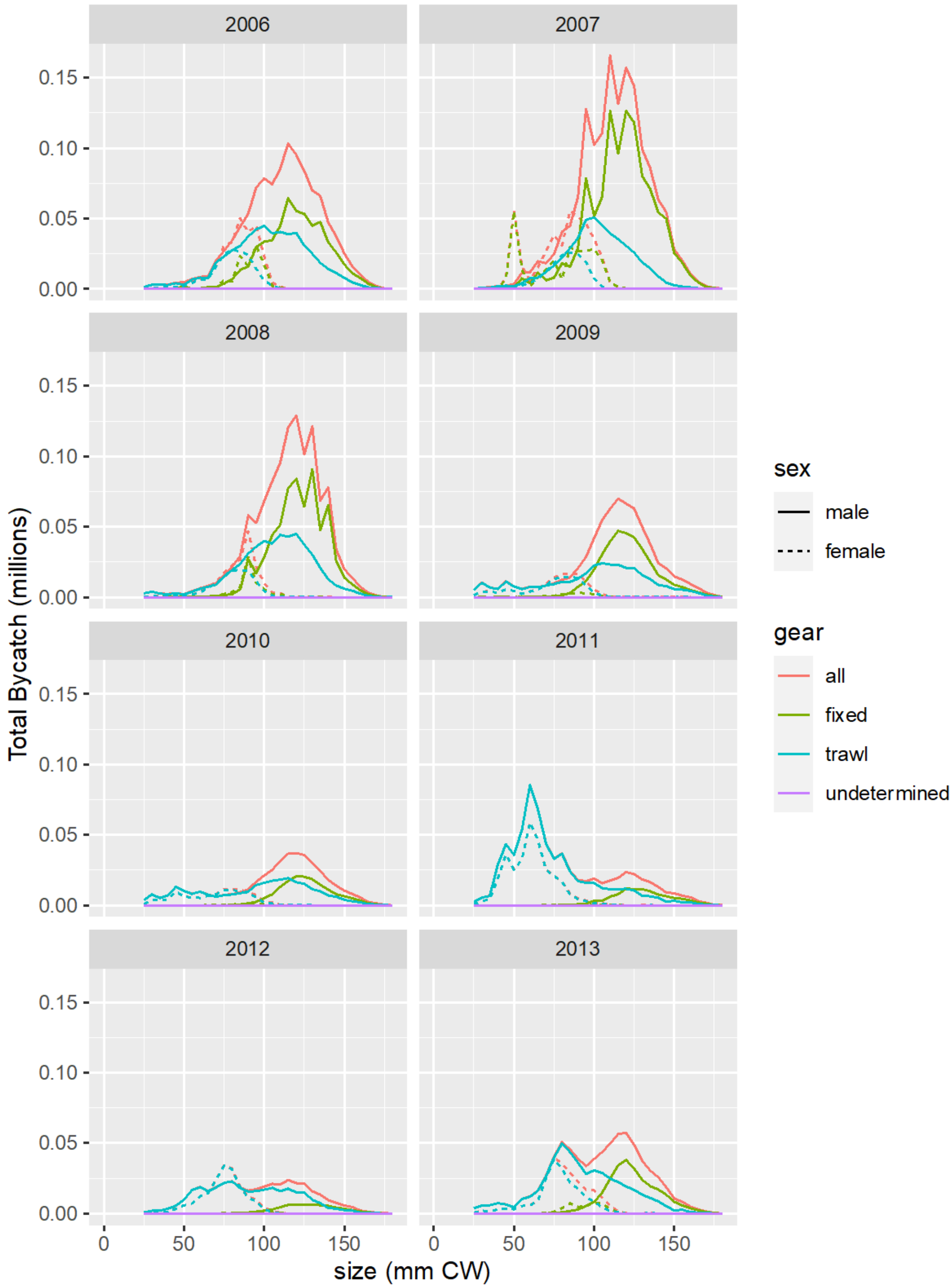

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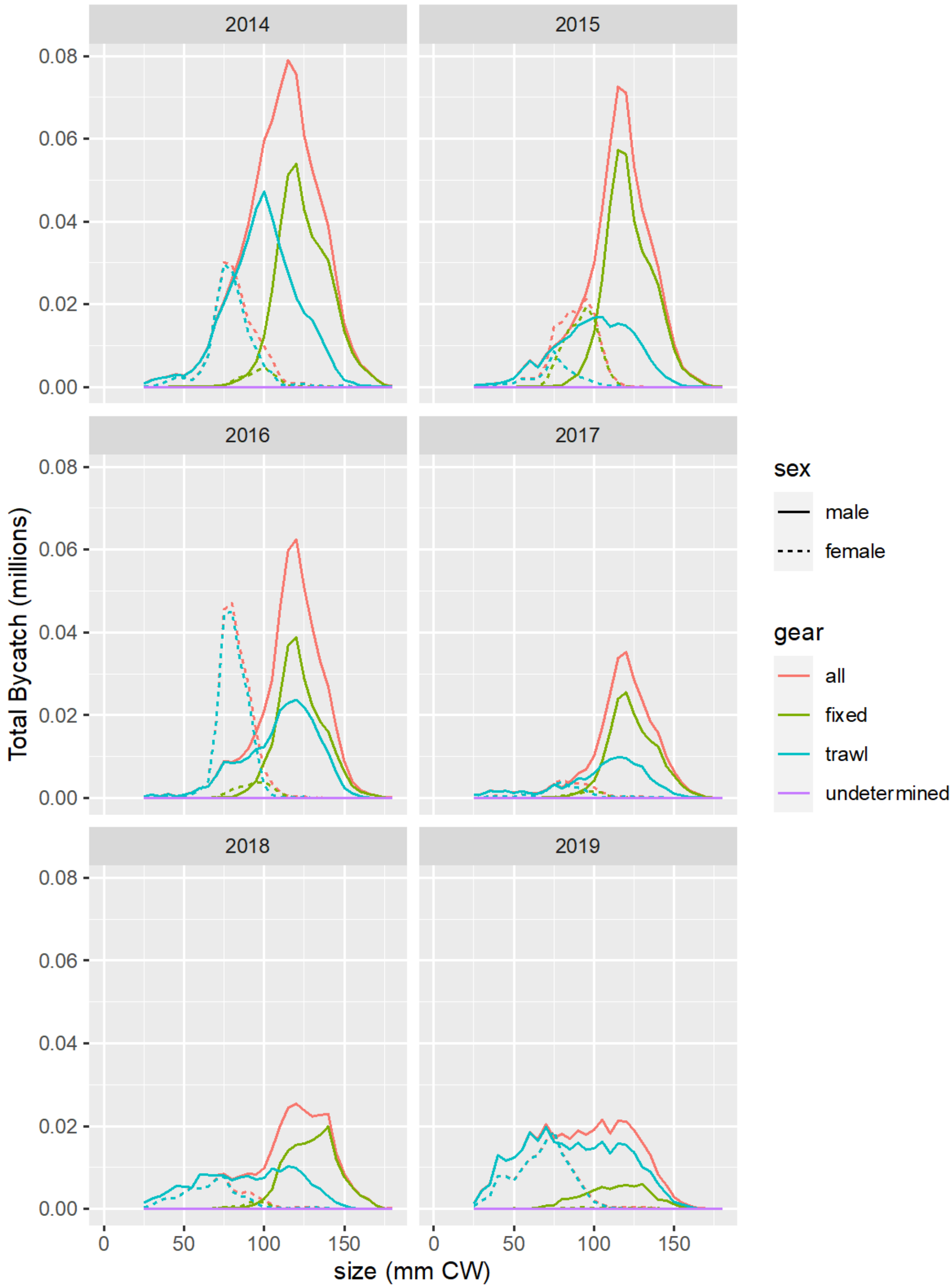

Figure 11 (cont.). Annual bycatch size compositions in the groundfish fisheries by sex and gear type, expanded to total bycatch starting in 1990. Colors indicate gear type (red: all types, olive: fixed gear, cyan: trawl gear, purple: undetermined). Line type indicates sex (solid: males, dotted: females).

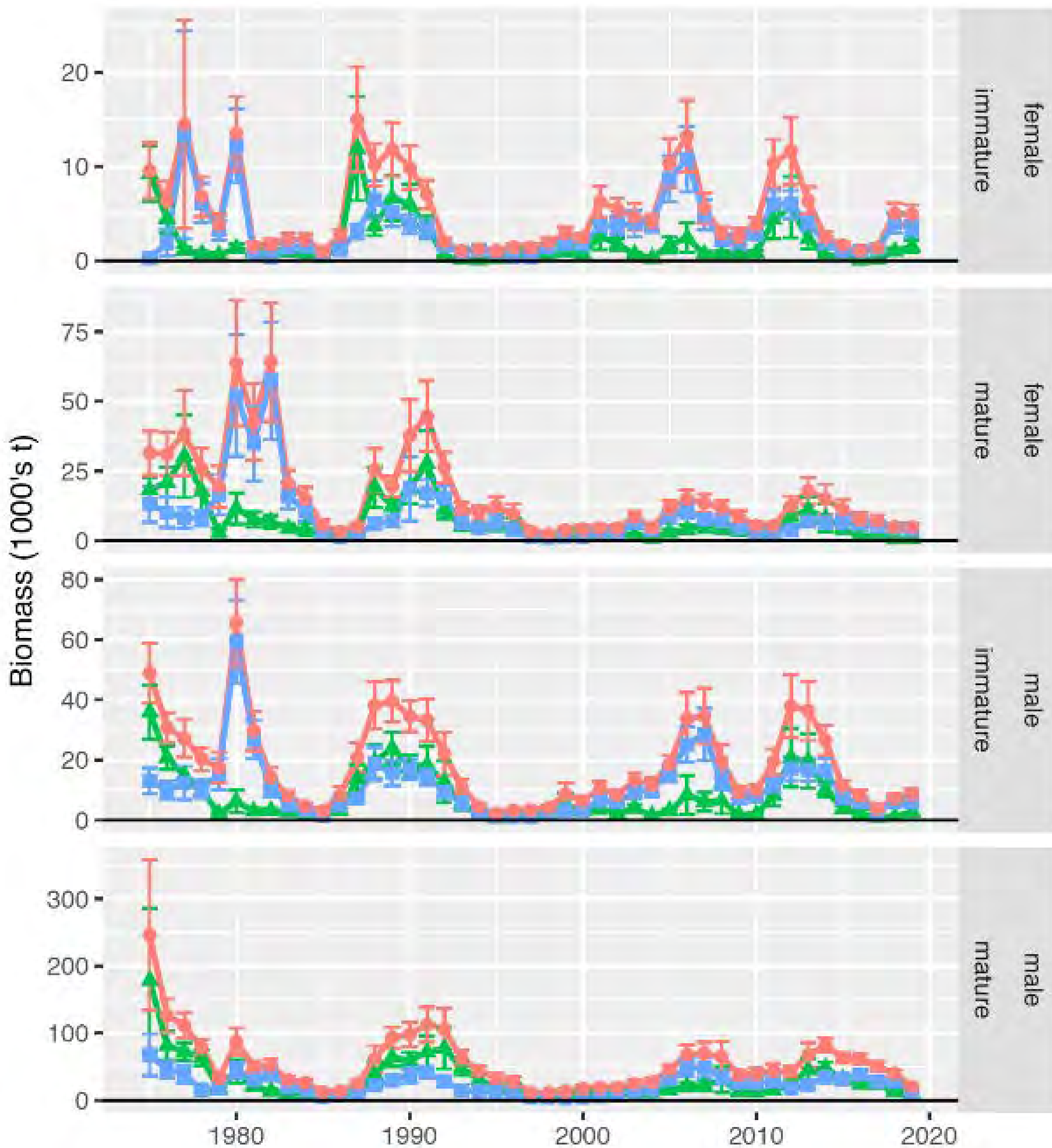

Figure 12. Annual estimates of area-swept biomass from the NMFS EBS bottom trawl survey, by sex, maturity state, and management area. Red lines: total biomass; green lines: biomass in the eastern area; blue: biomass in the western area.

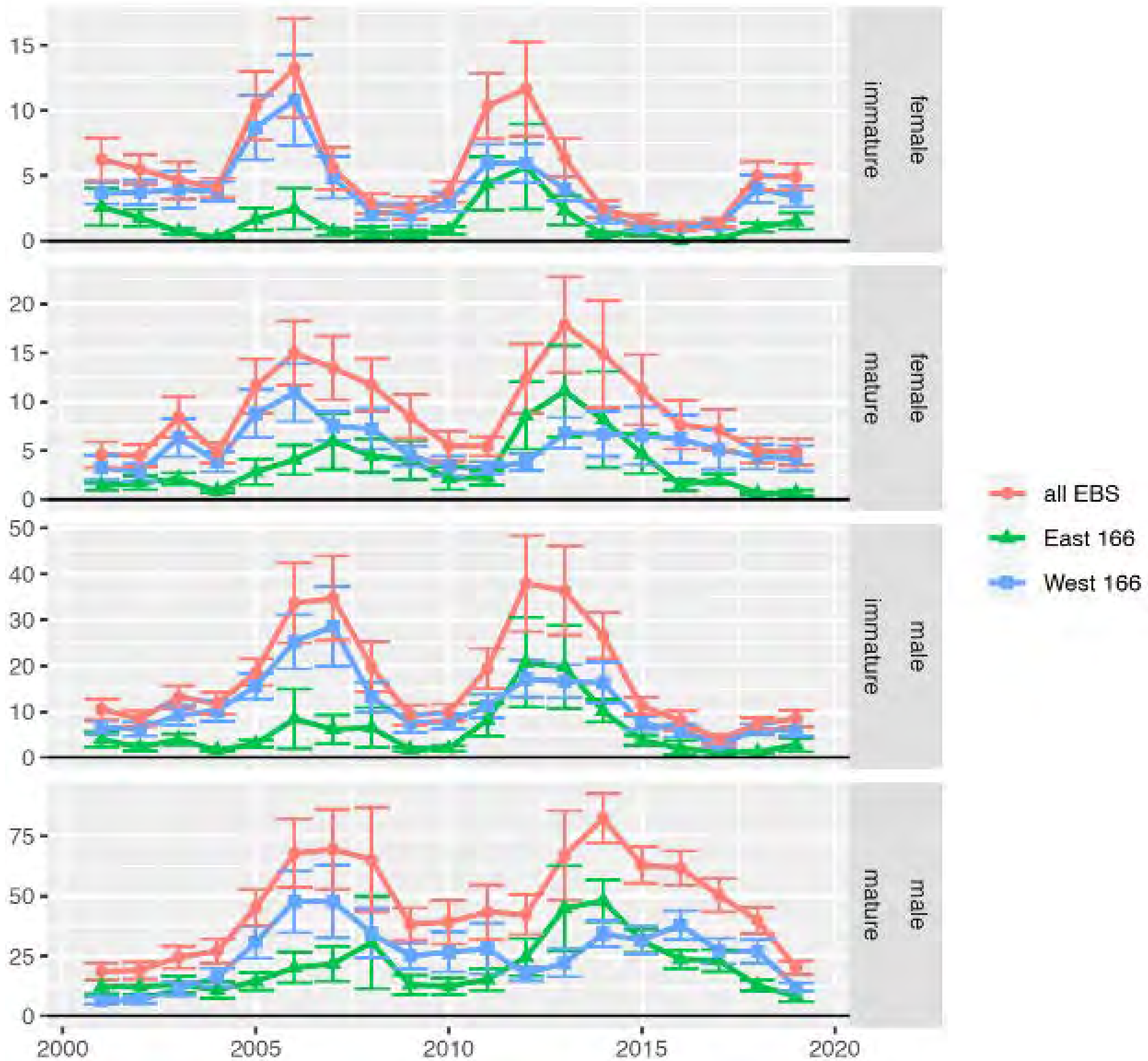

Figure 12 (cont.). Annual estimates of area-swept biomass from the NMFS EBS bottom trawl survey, by sex, maturity state, and management area. Red lines: total biomass; green lines: biomass in the eastern area; blue: biomass in the western area.

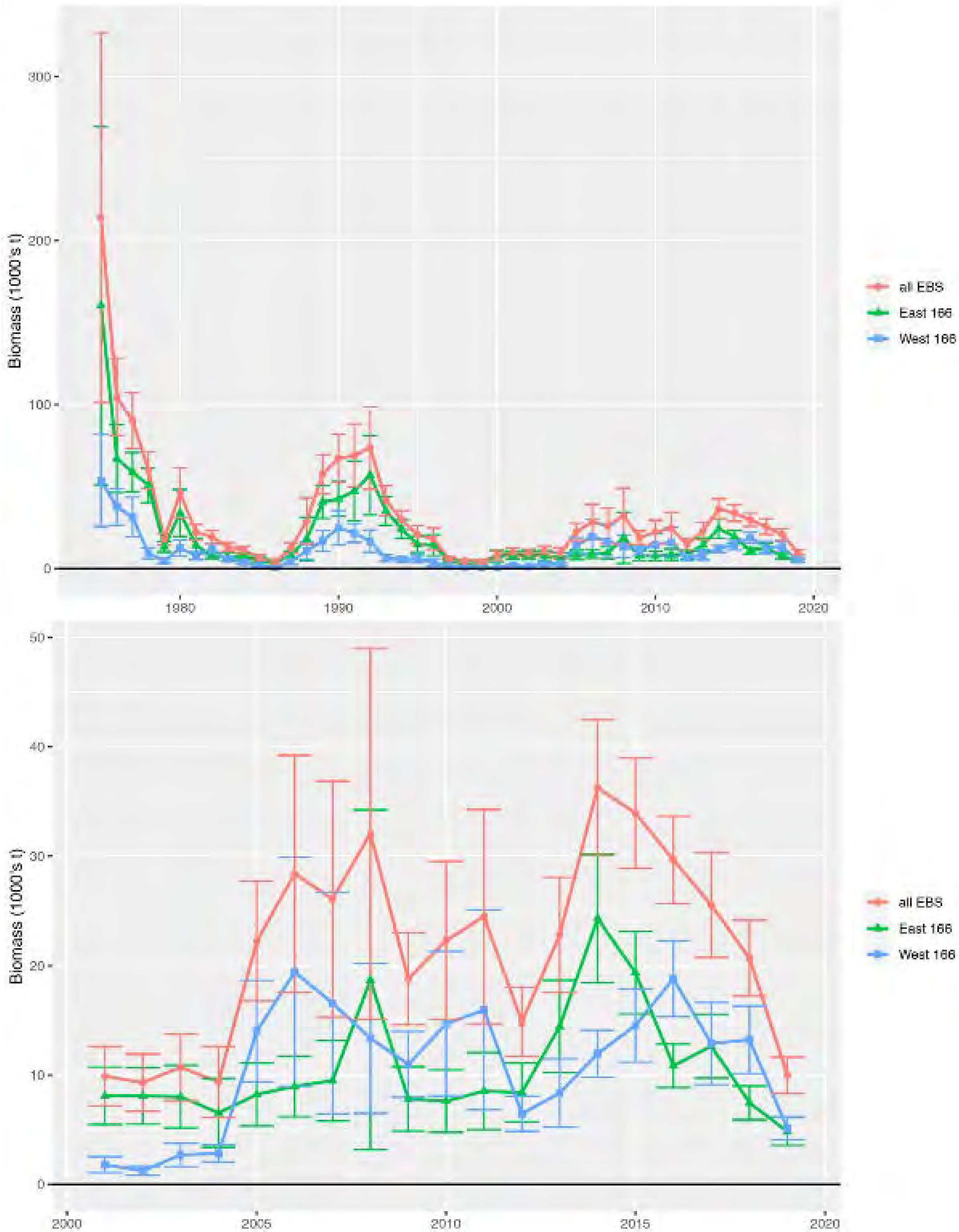

Figure 13. Annual estimates of area-swept biomass from the NMFS EBS bottom trawl survey for preferred-size (>125 mm CW) legal males . Red lines: total biomass; green lines: biomass in the eastern area; blue: biomass in the western area.

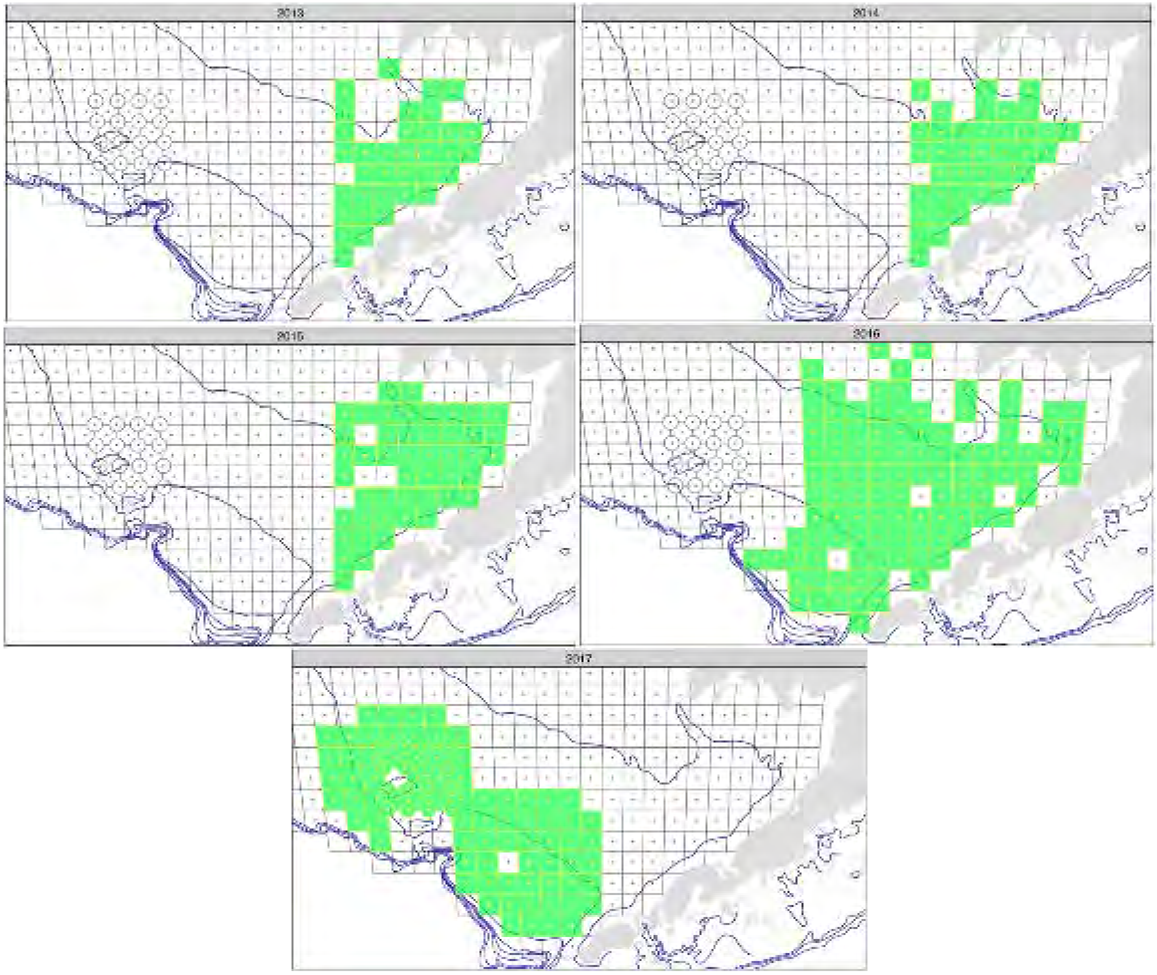

Figure 14. Spatial footprints (stations occupied in green) during the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2017. Squares and circles represent stations in the standard NMFS EBS bottom trawl survey (which extends beyond the area shown in the maps).

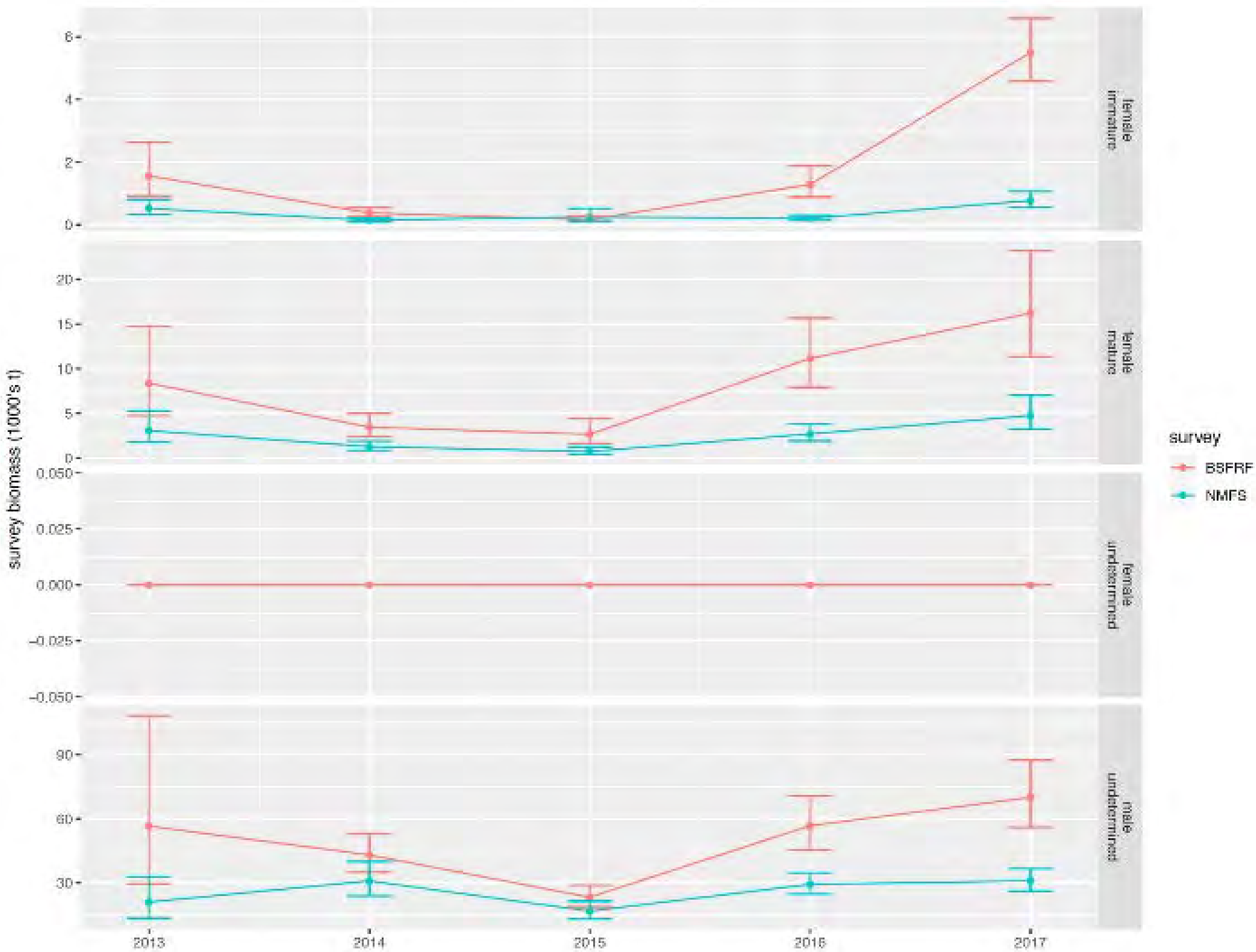

Figure 15. Annual estimates of area-swept biomass from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2017. The SBS studies had different spatial footprints each year, so annual changes in biomass do not necessarily reflect underlying population trends. Red lines: BSFRF; green lines: NMFS.

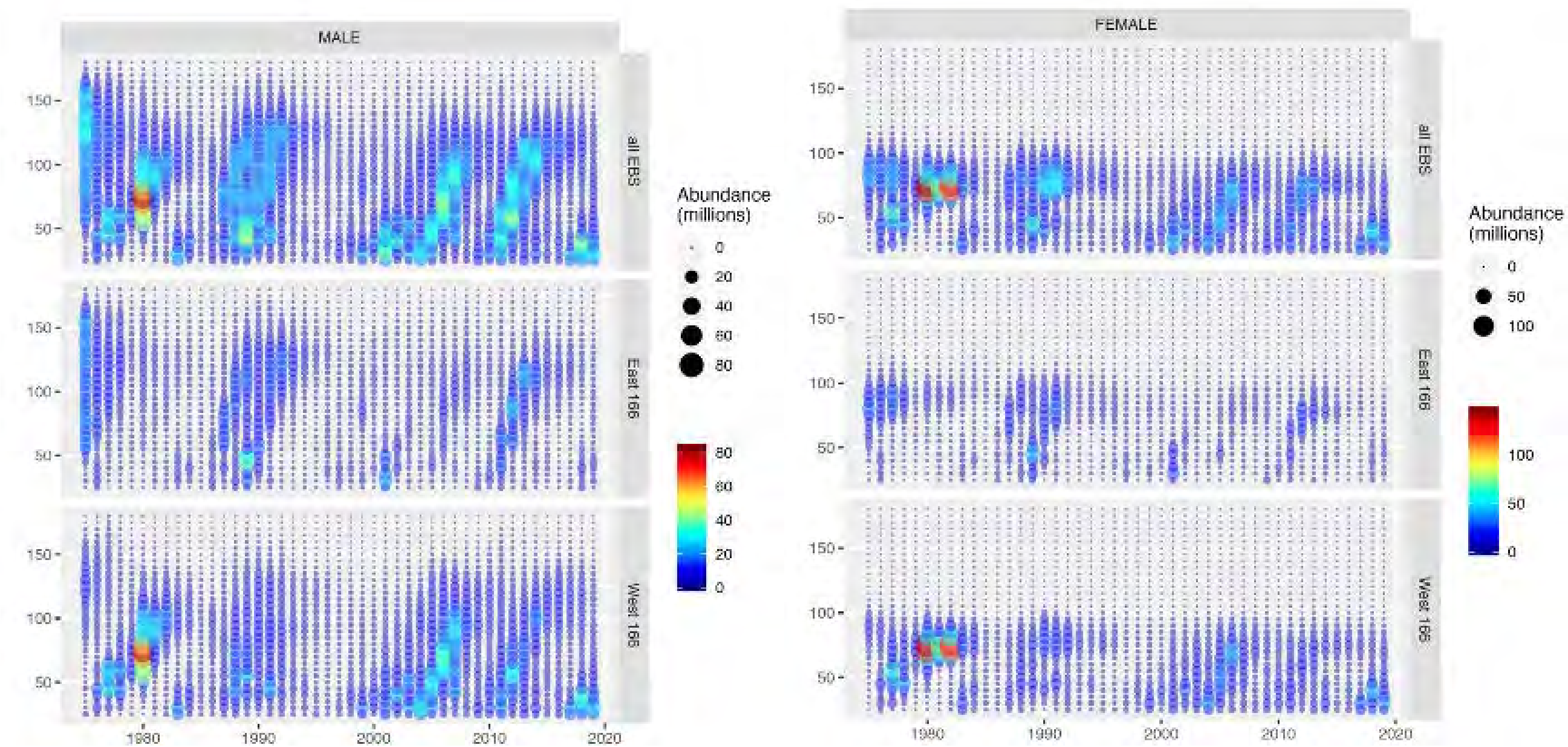

Figure 16. Size compositions from the NMFS EBS bottom trawl survey for 1975-2019.

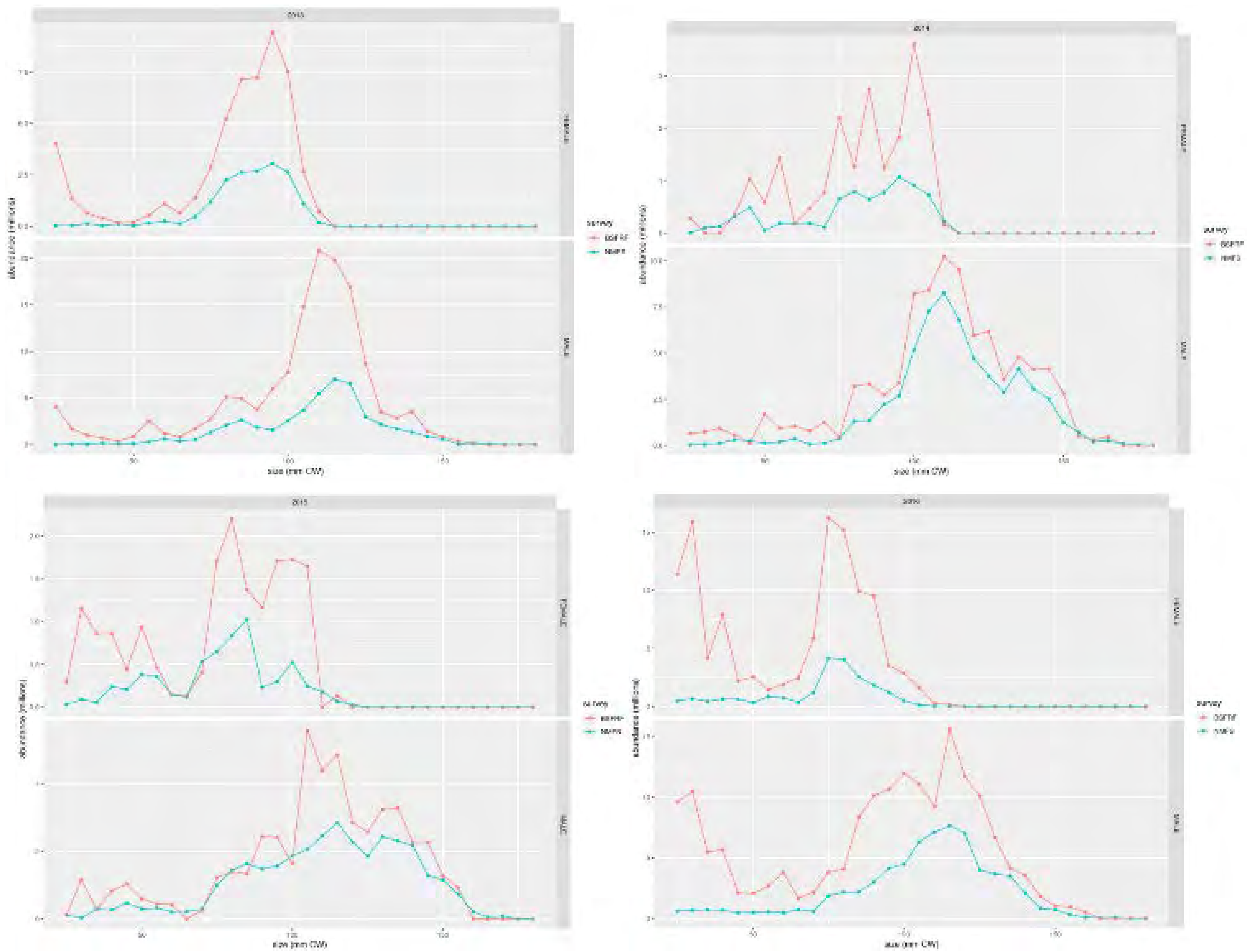

Figure 17. Annual size compositions of area-swept abundance by sex from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2016. Red lines: BSFRF; green lines: NMFS.

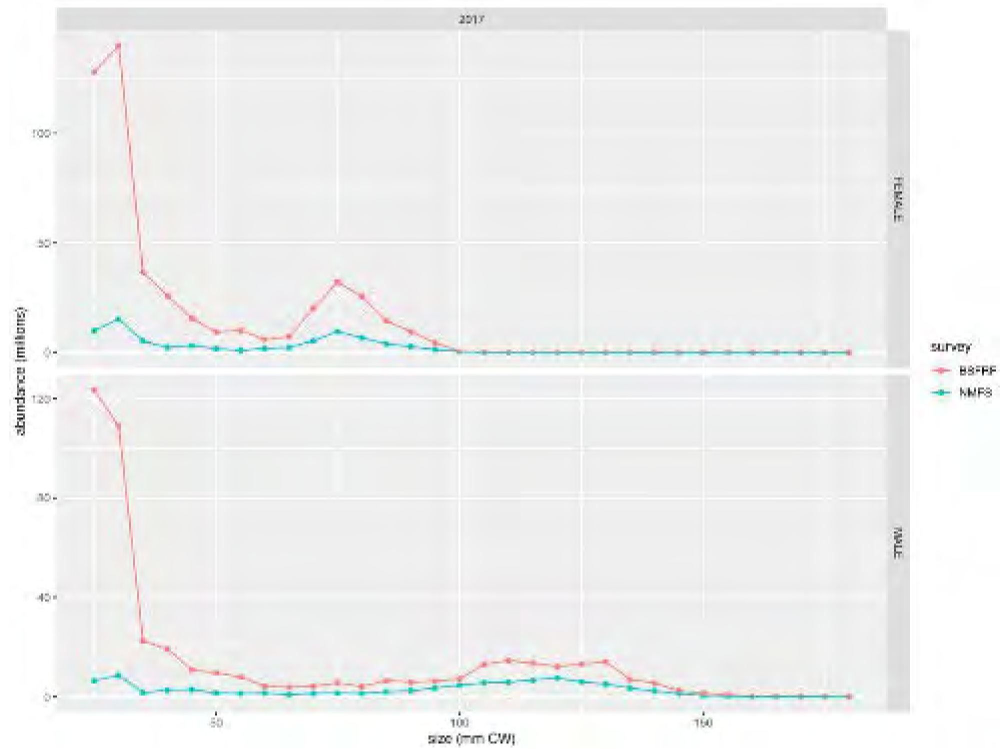

Figure 17 (cont.). Annual size compositions of area-swept abundance by sex from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2017. Red lines: BSFRF; green lines: NMFS

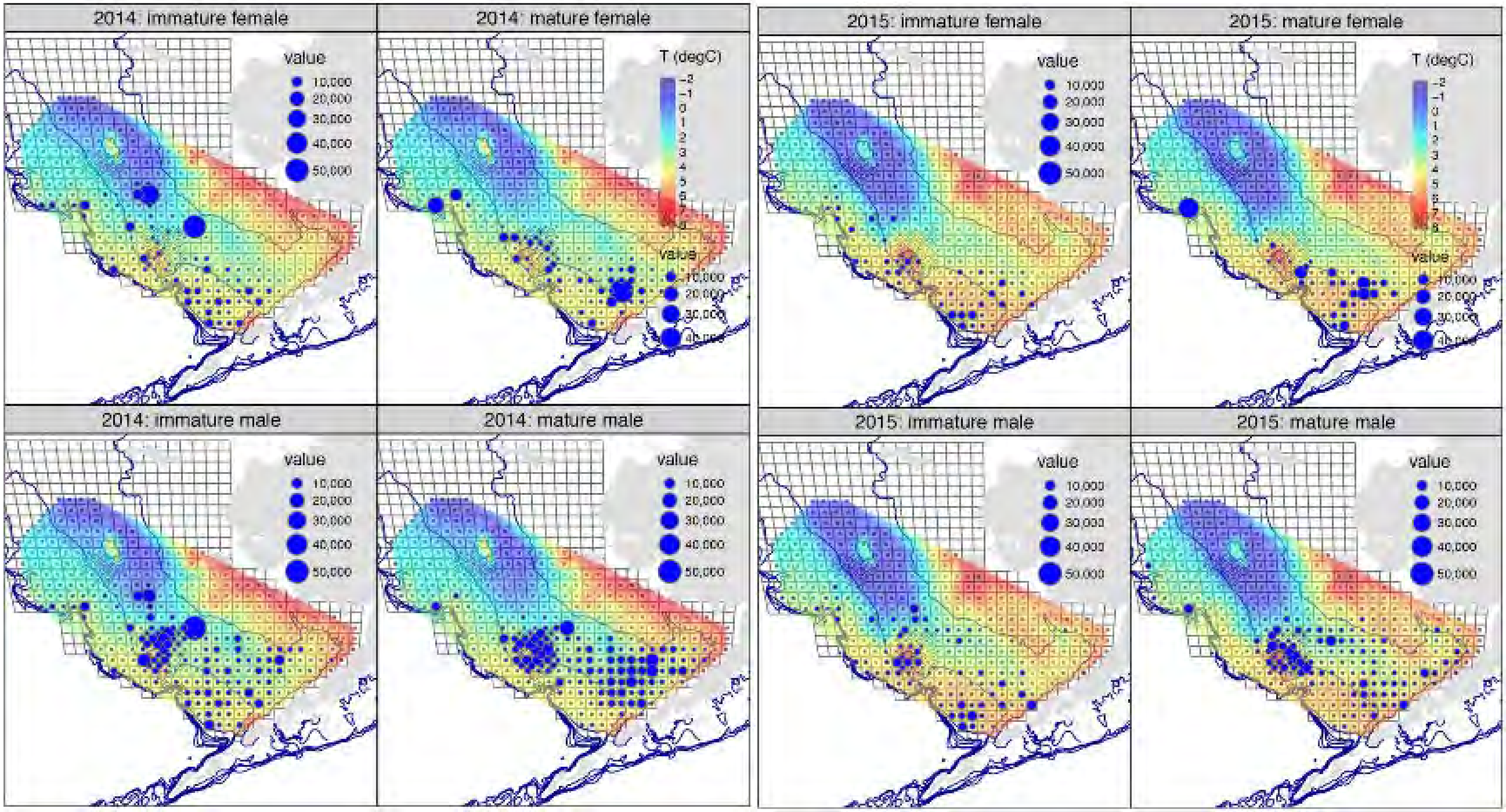

Figure 18. Annual estimates of area-swept abundance (blue circles) from the NMFS EBS bottom trawl survey, by sex and maturity state for 2014 and 2015. Local abundance scales with symbol area. The background "heatmap" represents bottom water temperatures at the time of the survey.

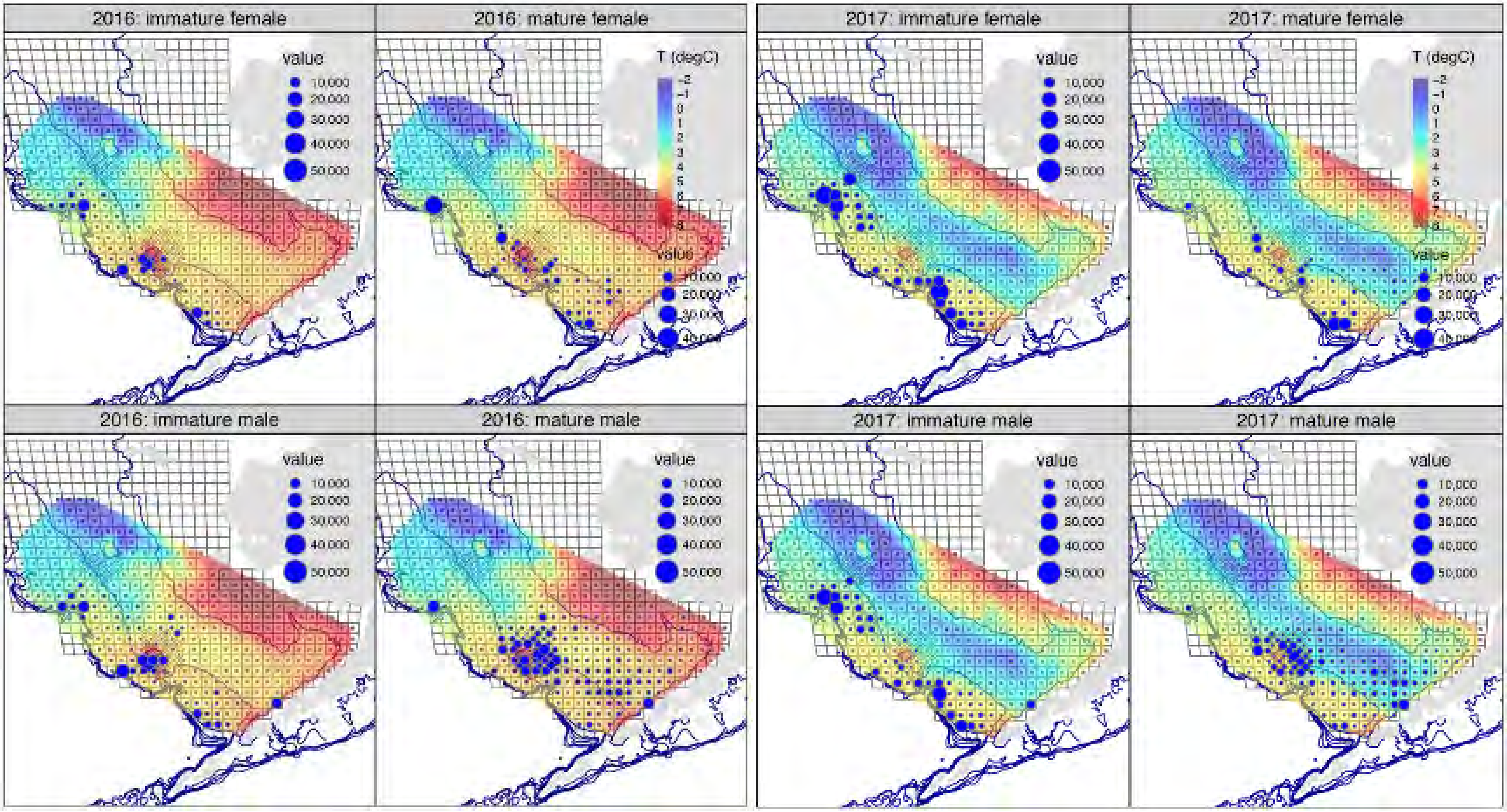

Figure 18 (cont.). Annual estimates of area-swept abundance (blue circles) from the NMFS EBS bottom trawl survey, by sex and maturity state for 2016 and 2017. Local abundance scales with symbol area. The background "heatmap" represents bottom water temperatures at the time of the survey.

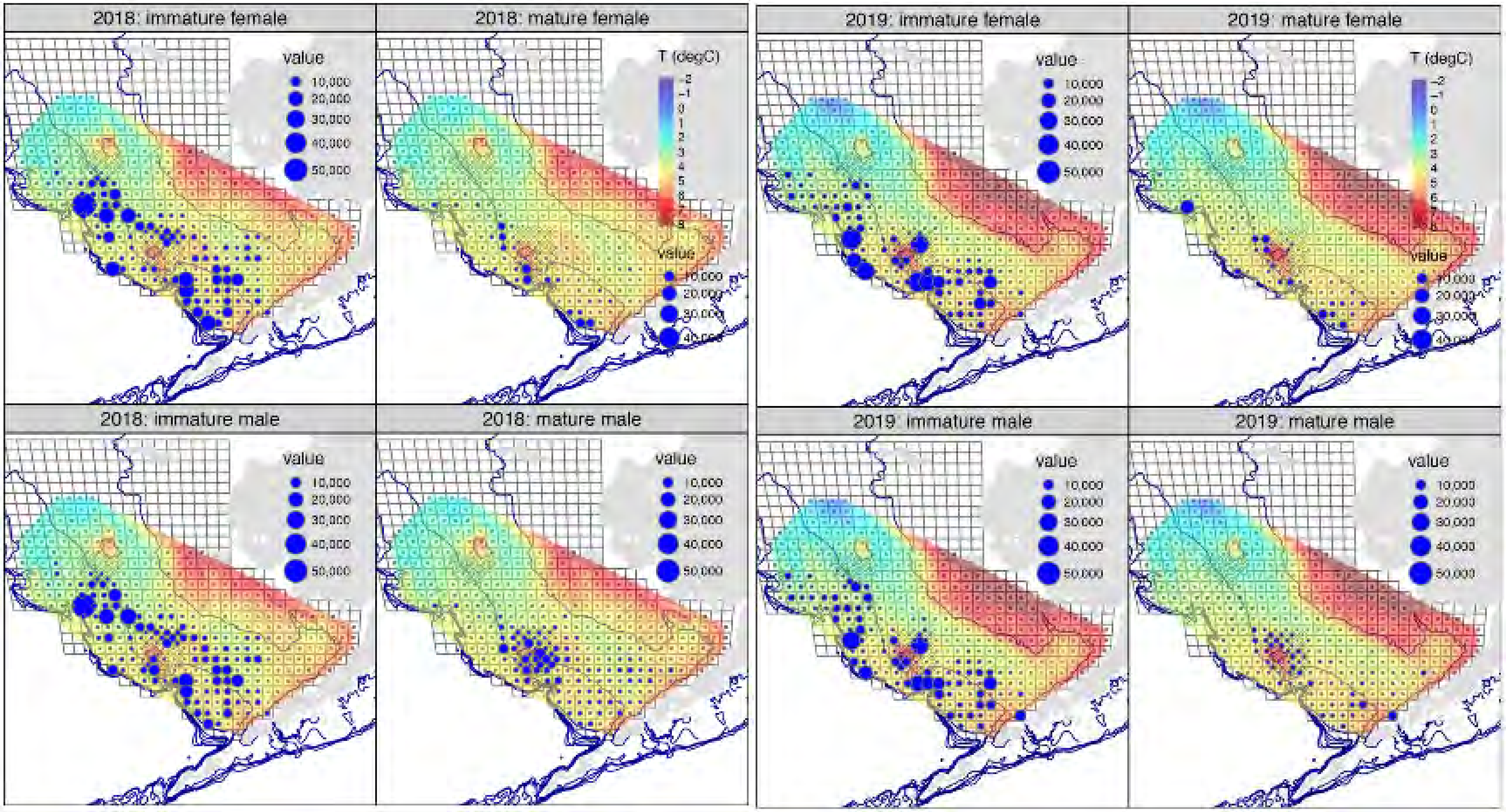

Figure 18 (cont.). Annual estimates of area-swept abundance (blue circles) from the NMFS EBS bottom trawl survey, by sex and maturity state for 2018 and 2019. Local abundance scales with symbol area. The background “heatmap” represents bottom water temperatures at the time of the survey.

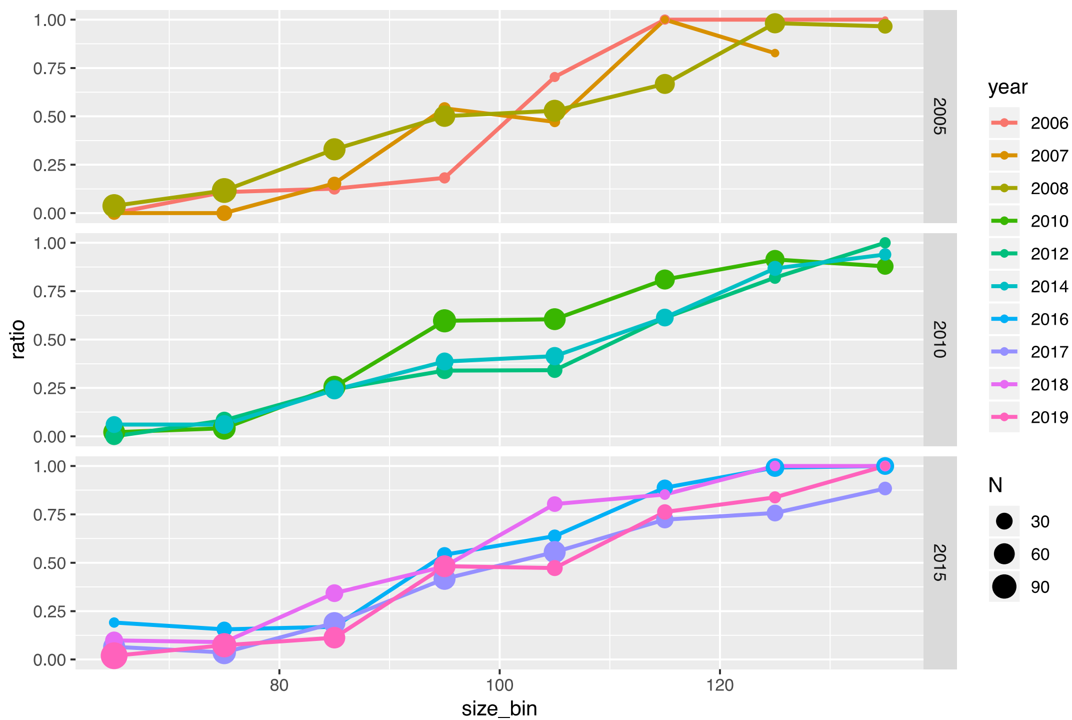

Figure 19. Male maturity ogives (the fraction of new shell mature males, relative to all new shell males) as determined from chela height:carapace width ratios from the NMFS EBS bottom trawl survey for years when chela heights were collected with 0.1 mm precision..

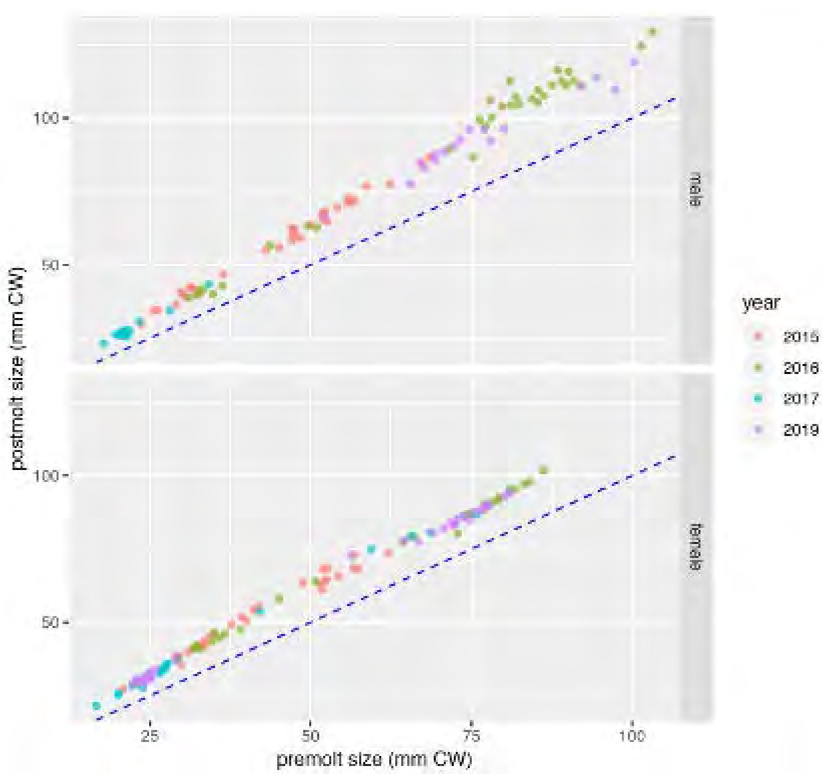

Figure 20. Molt increment data collected collaboratively by NMFS, BSFRF, and ADFG.

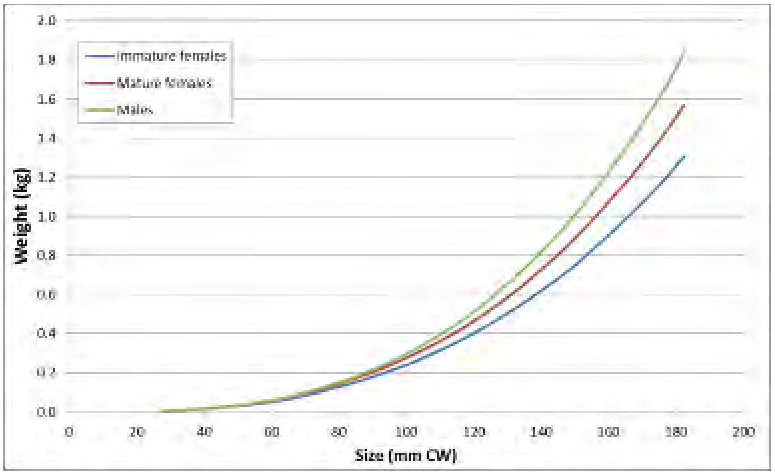

Figure 21. Size-weight relationships developed from NMFS EBS summer trawl survey data.

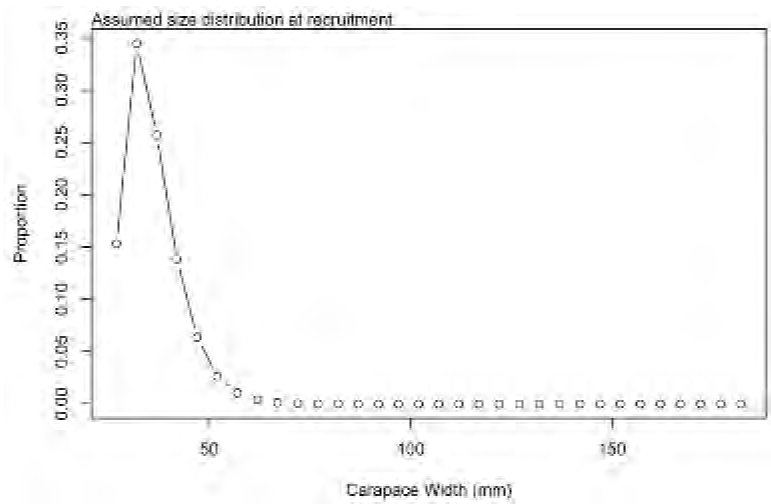

Figure 22. Assumed size distribution for recruits entering the population.

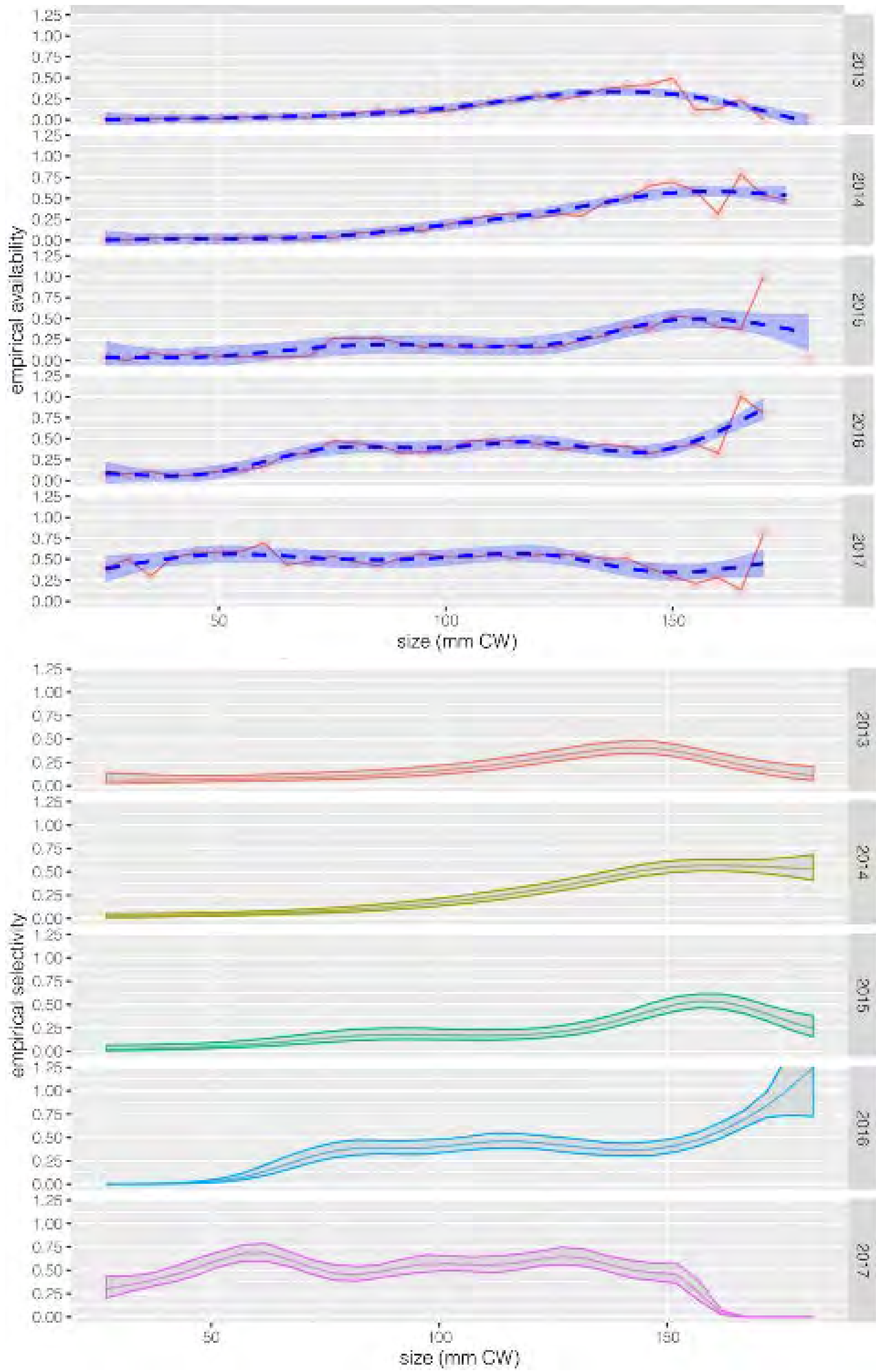

Figure 23. Upper: Empirical availability for males in SBS study areas, by year. Red line and points: annual ratios of NMFS abundance-at-size in SBS study areas to full survey area; dashed blue line and fill: LOESS smooth. Lower: “best”-fitting GAMs using cubic spline smooths to the values in the upper plot.

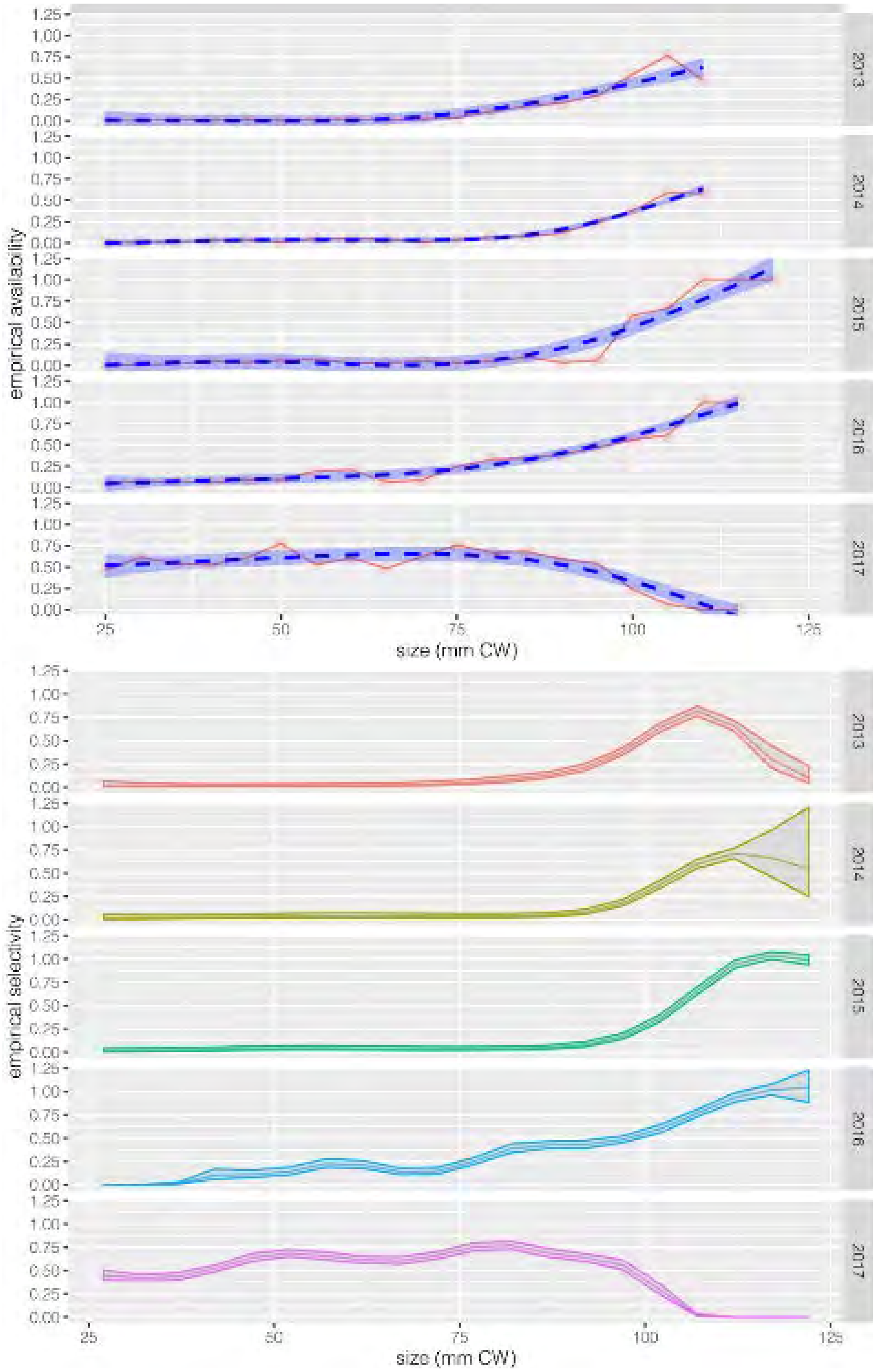

Figure 24. Upper: Empirical availability for females in SBS study areas, by year. Red line and points: annual ratios of NMFS abundance-at-size in SBS study areas to full survey area; dashed blue line and fill: LOESS smooth. Lower: “best”-fitting GAMs using cubic spline smooths to the values in the upper plot.

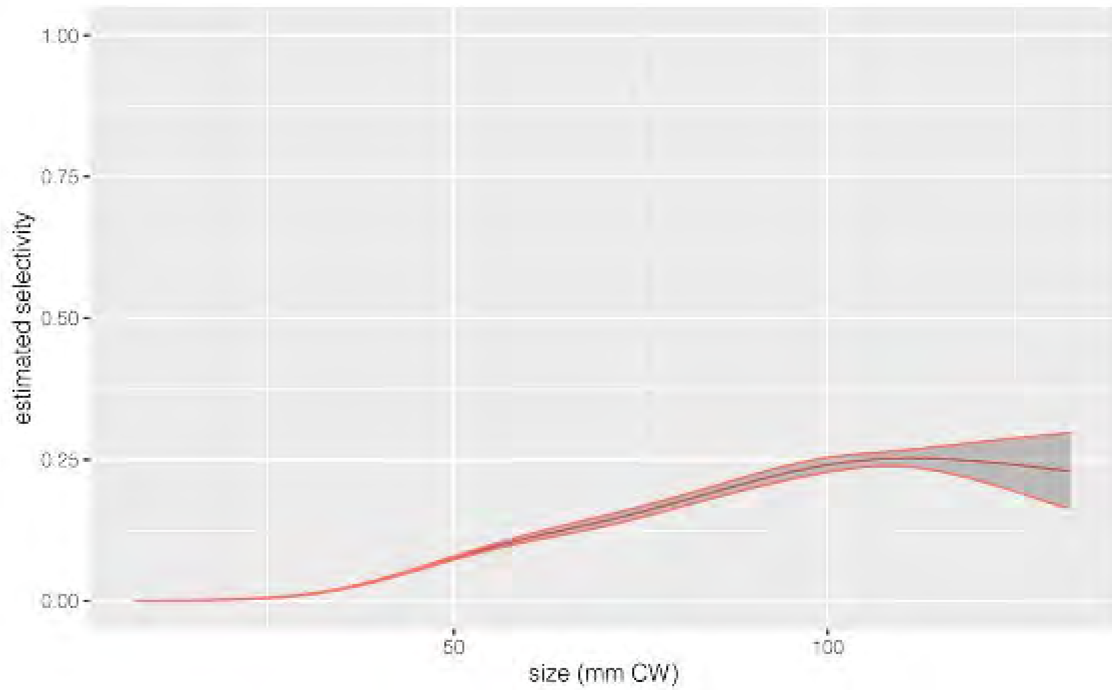

Figure 25. “Best”-fitting selectivity function for females from a catch-ratio analysis of the BSFRF-NMFS SBS data.

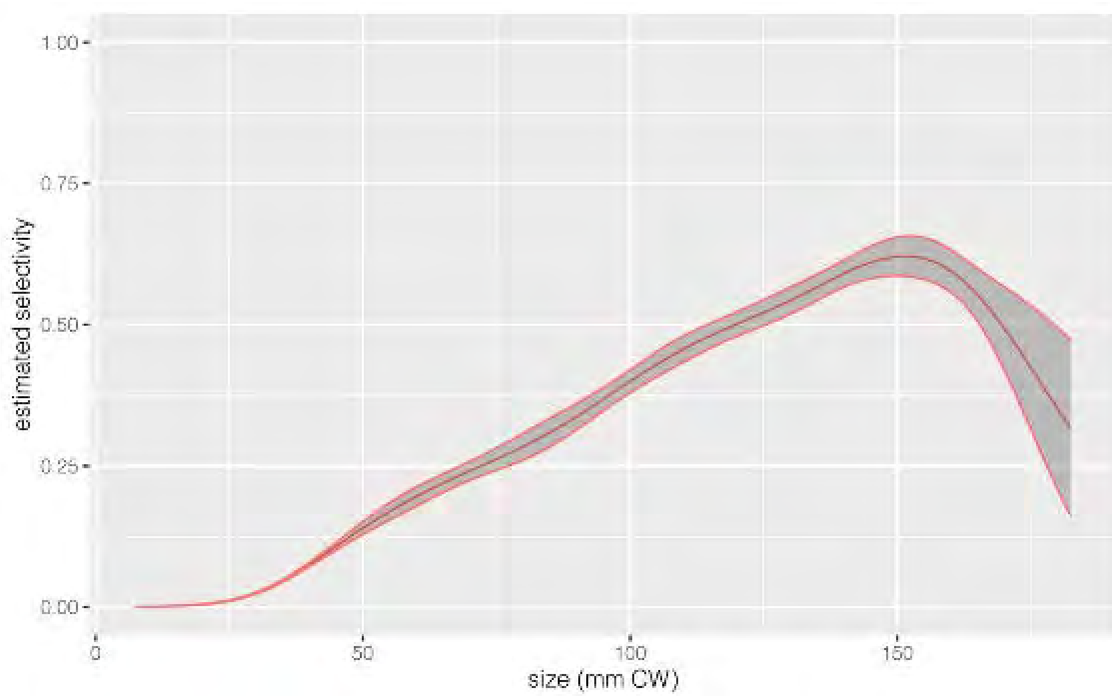

Figure 26. “Best”-fitting selectivity function for males from a catch-ratio analysis of the BSFRF-NMFS SBS data.

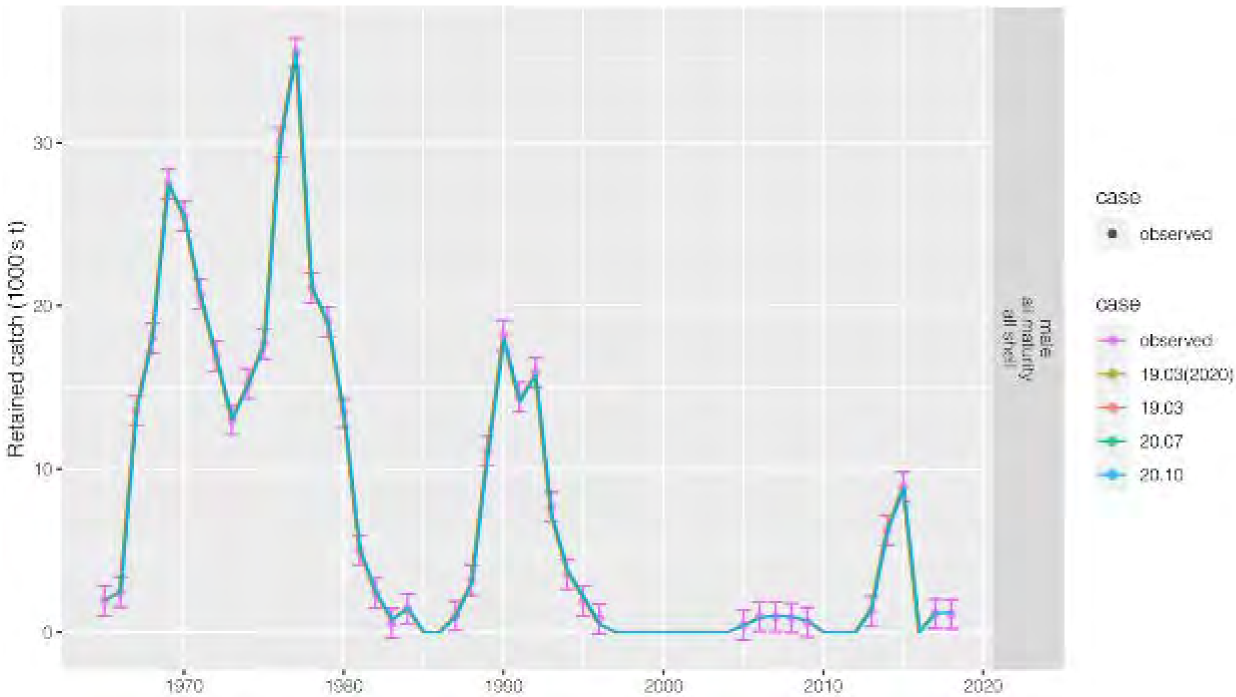

Figure 27. Fits to retained catch biomass in the directed fishery from all model scenarios.

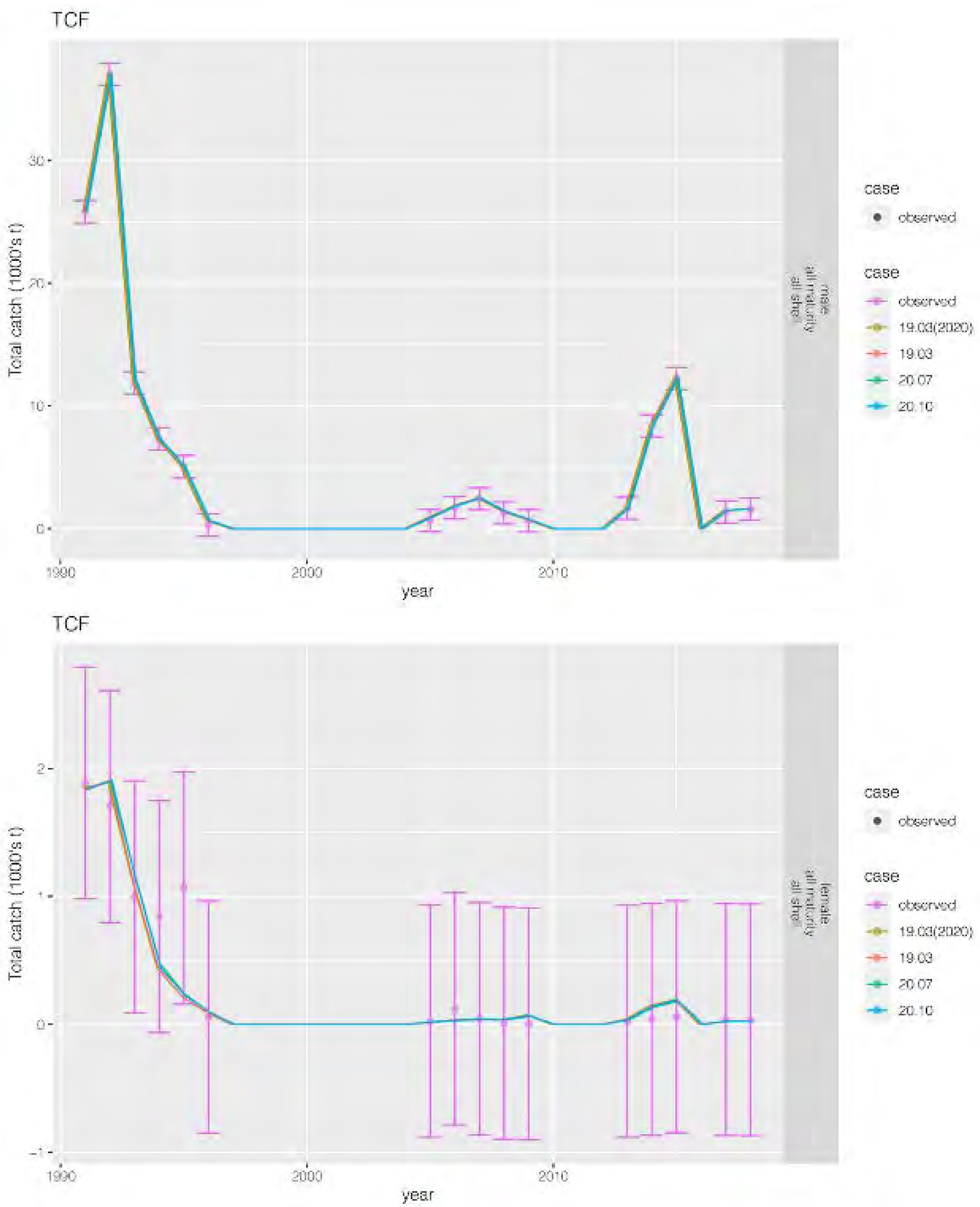

Figure 28. Fits to total catch biomass in the directed fishery from all model scenarios.

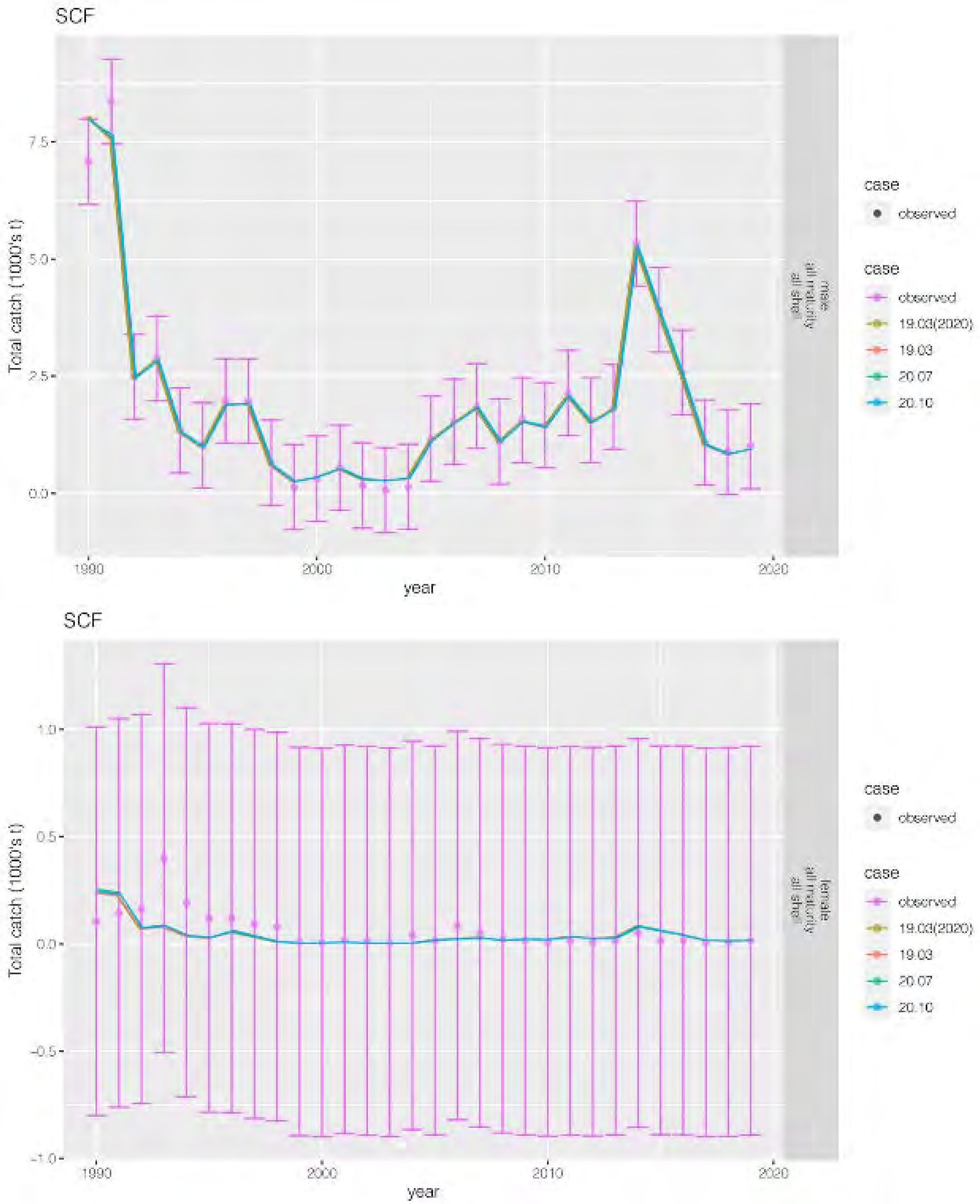

Figure 29. Fits to total catch biomass in the snow crab fishery from all scenarios.

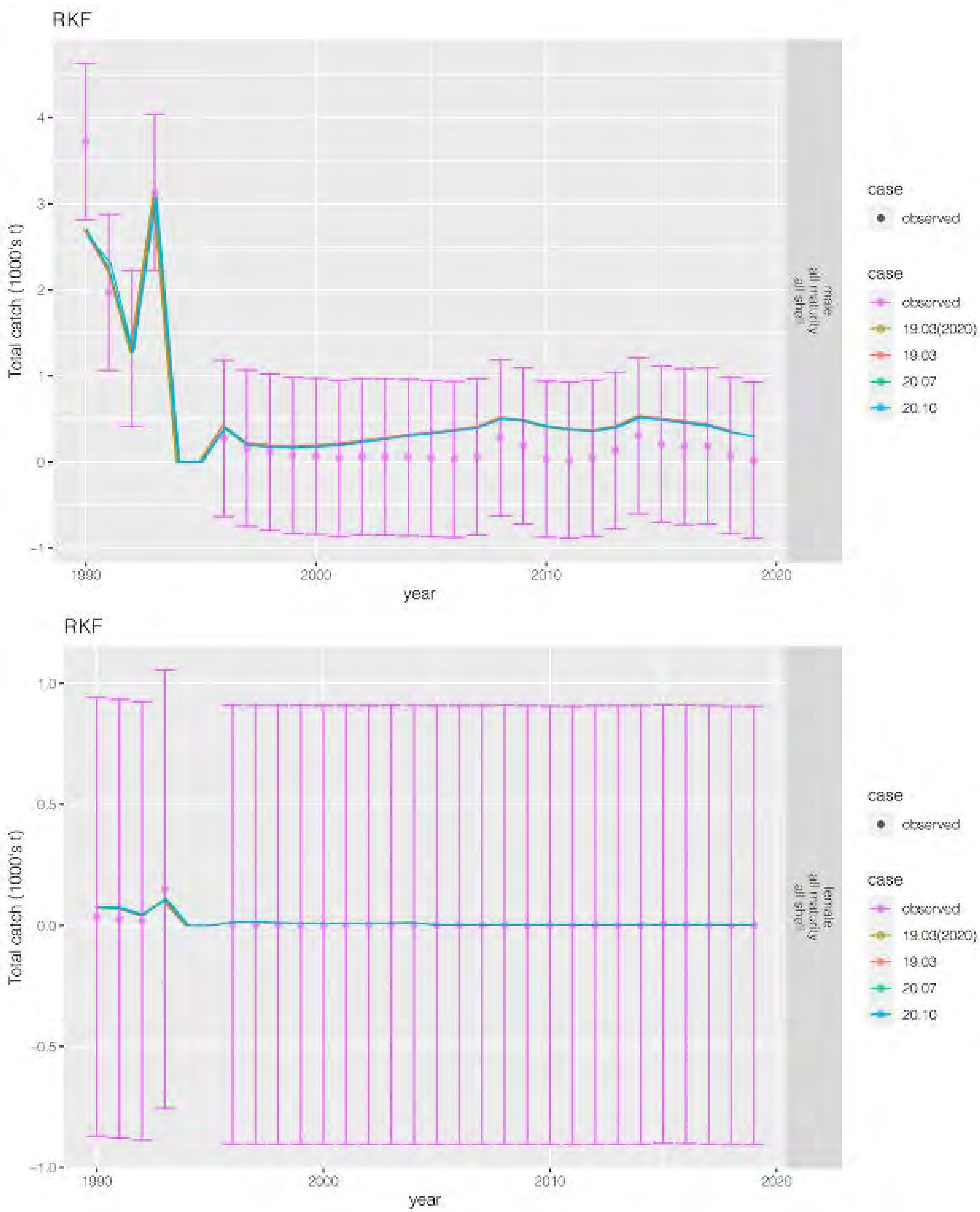

Figure 30. Fits to total catch biomass in the BBRKC fishery from all scenarios.

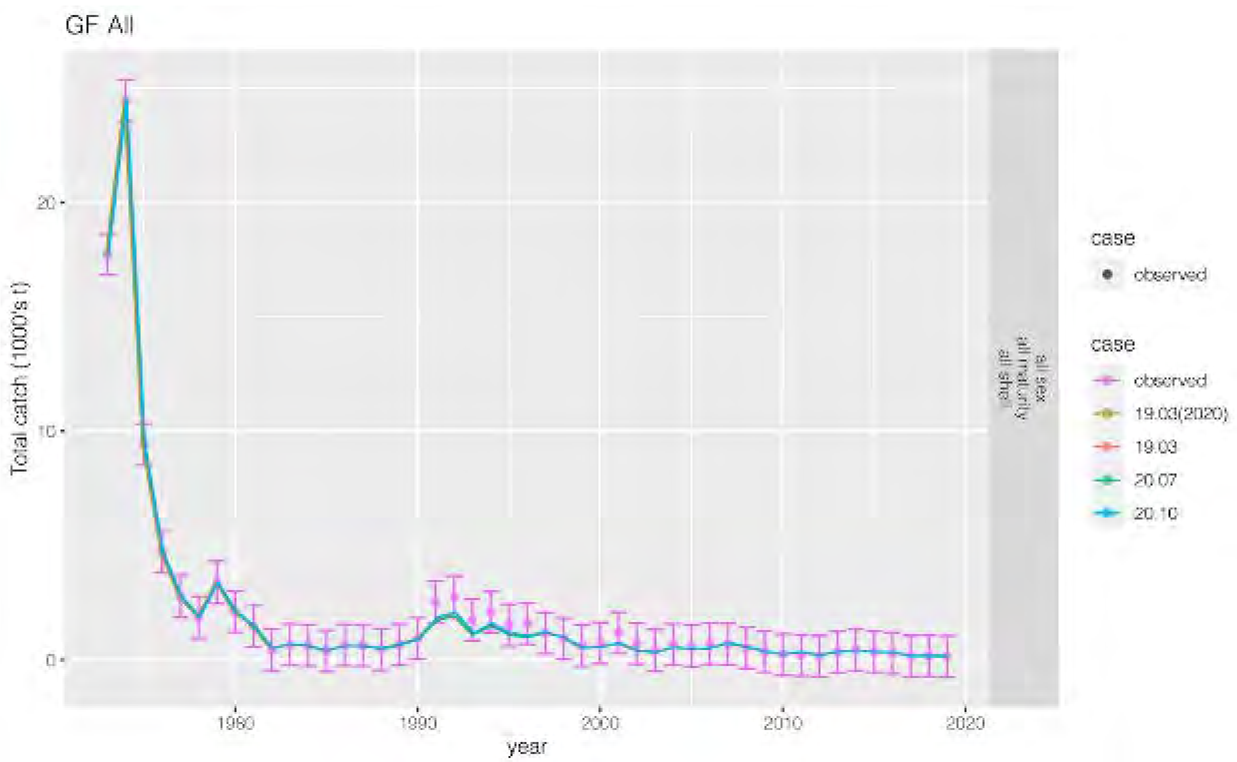

Figure 31. Fits to total catch biomass in the groundfish fisheries for all scenarios.

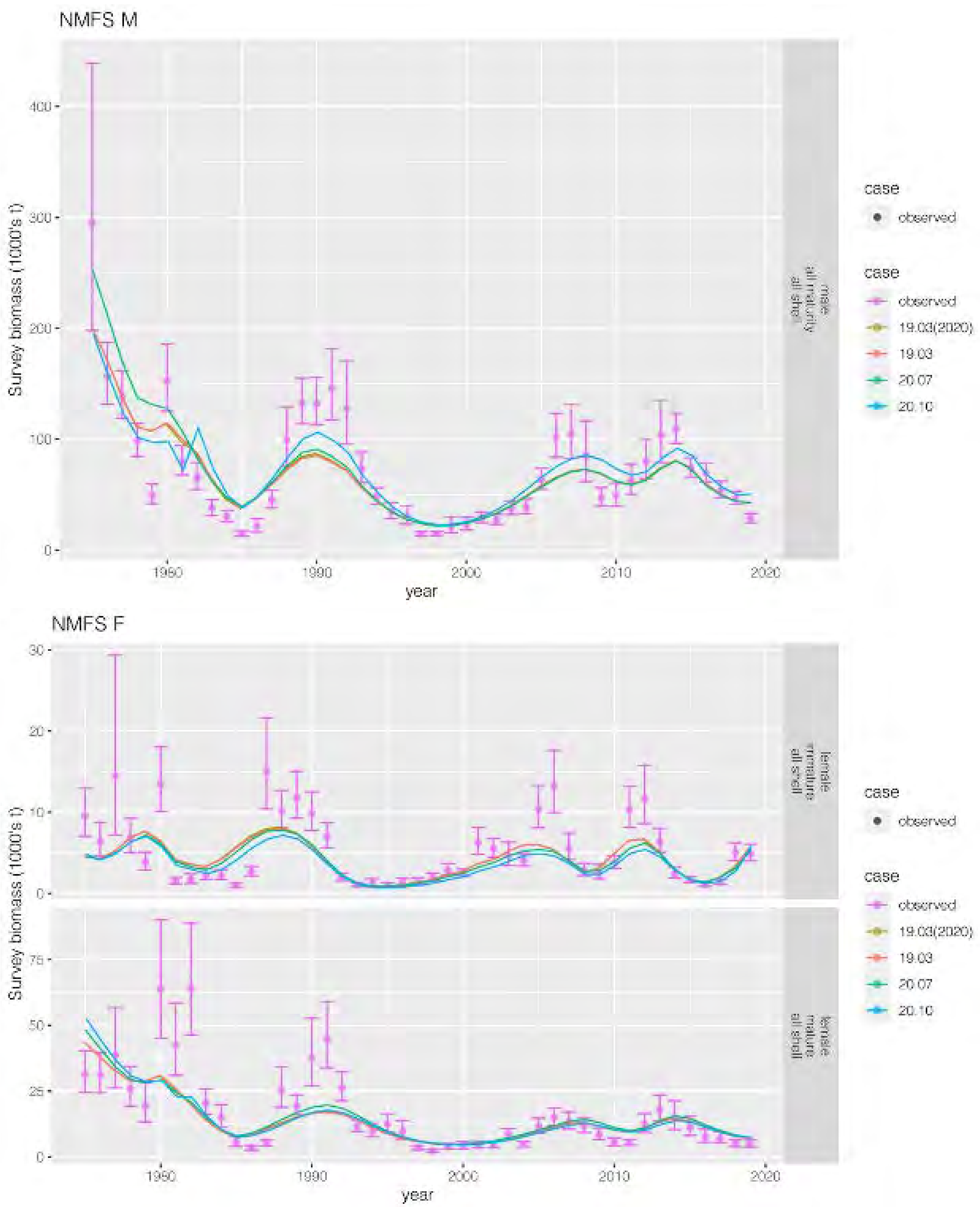

Figure 32. Fits to time series of all male (upper graph), immature female (center graph), and mature female (lower plot) biomass from the NMFS EBS shelf bottom trawl survey.

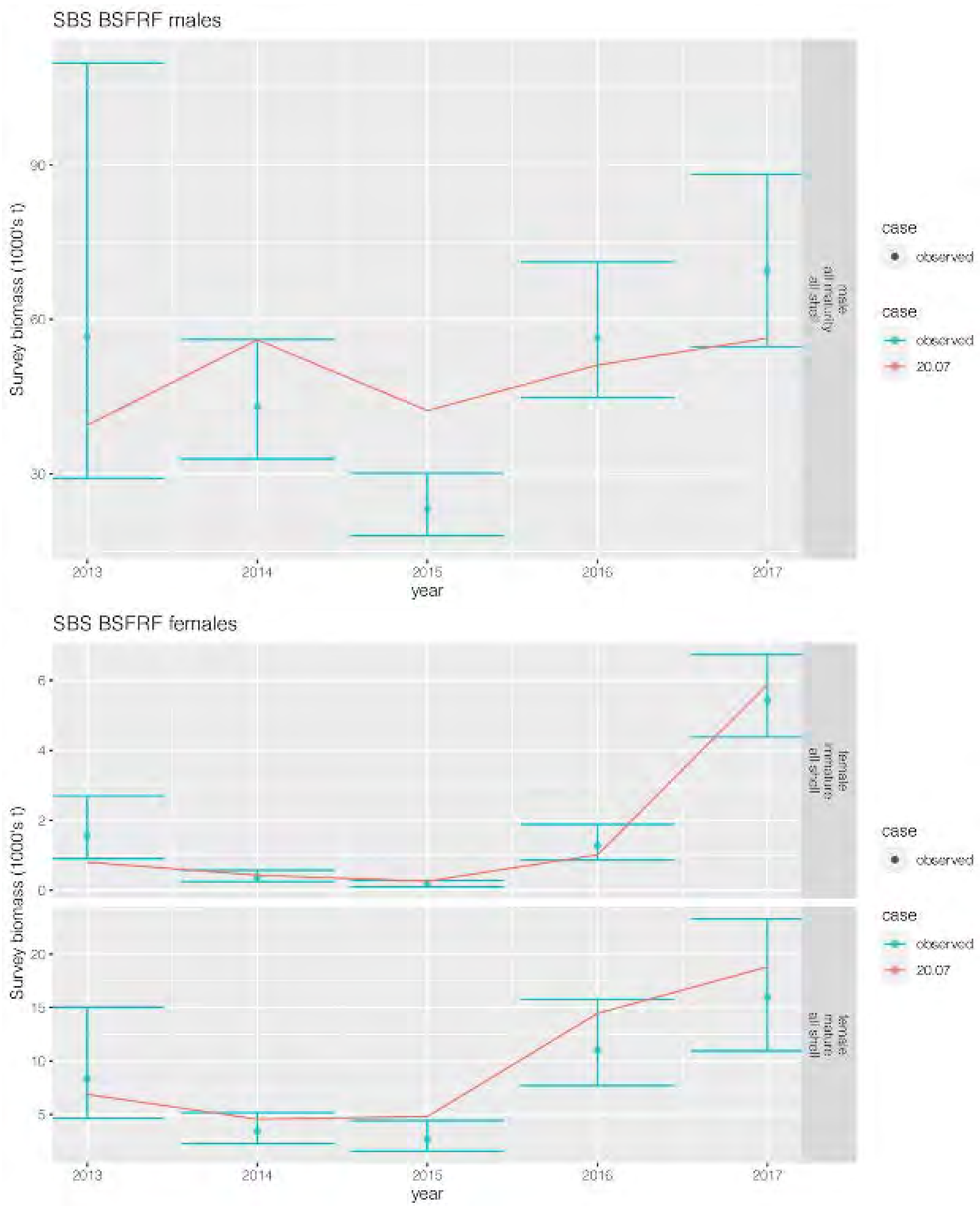

Figure 33. Fits to survey biomass from the BSFRF SBS bottom trawl survey data for scenario 20.07.

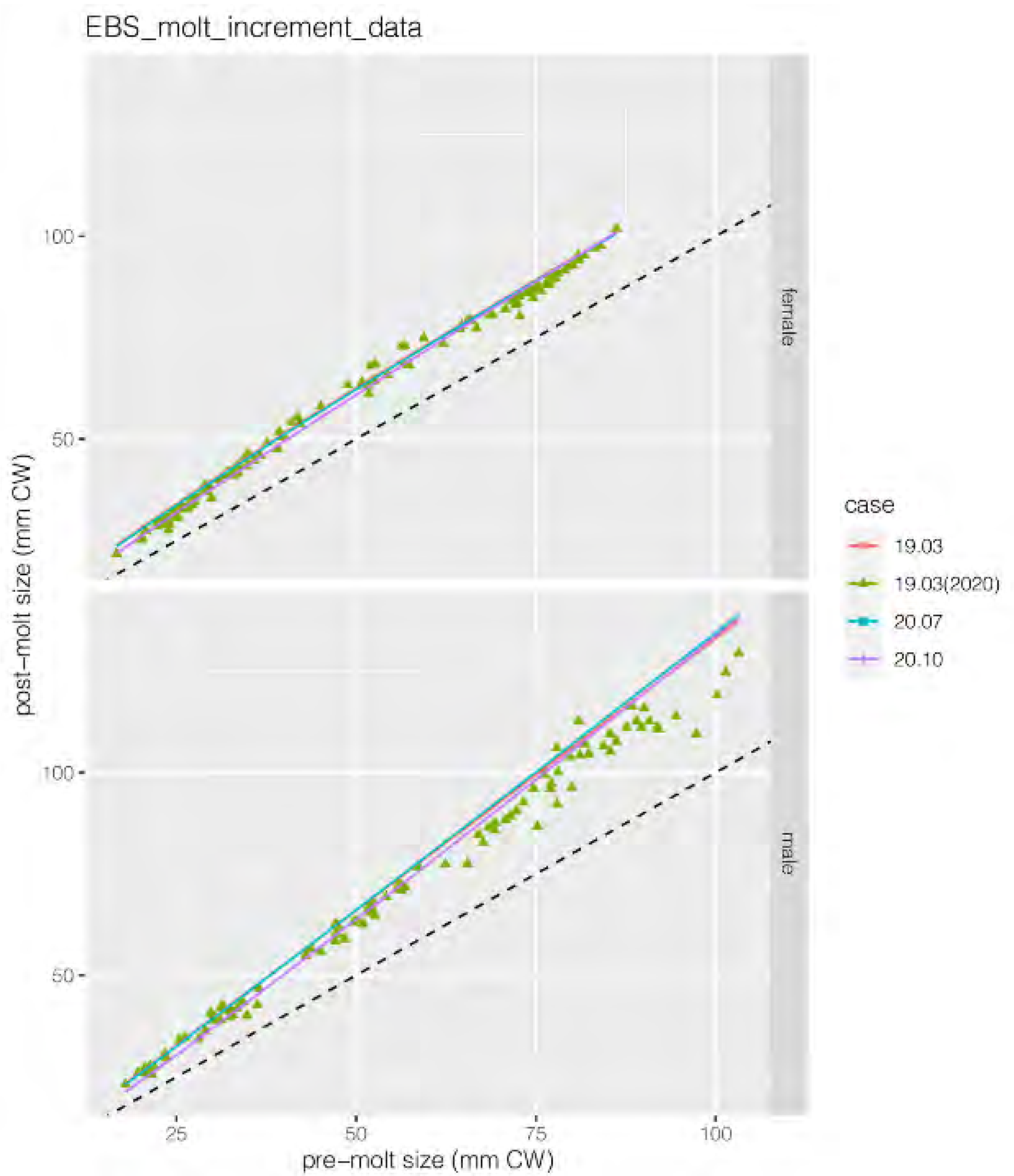

Figure 34. Fits to molt increment data for all scenarios.

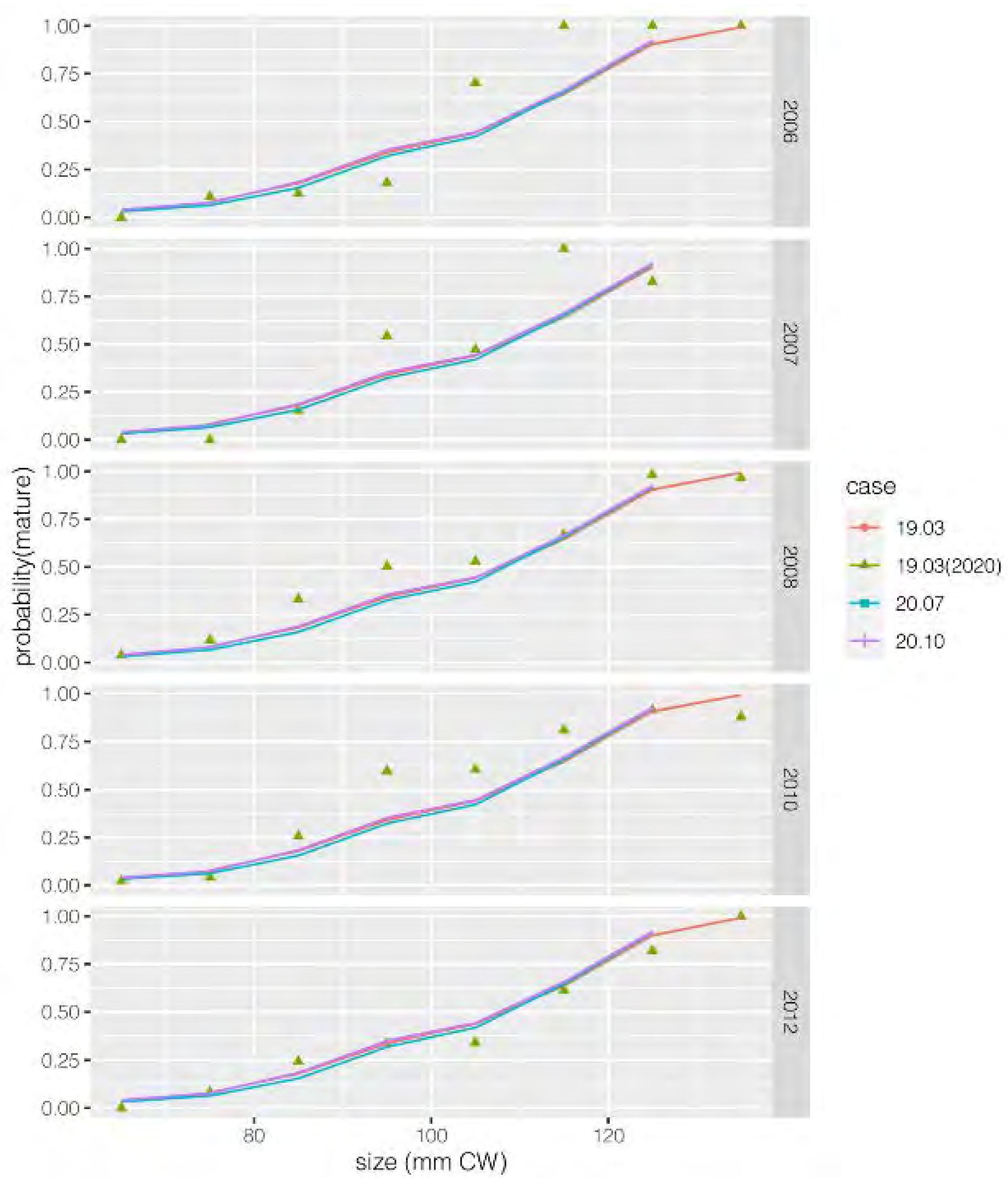

Figure 35. Fits to male maturity ogive data for all scenarios.

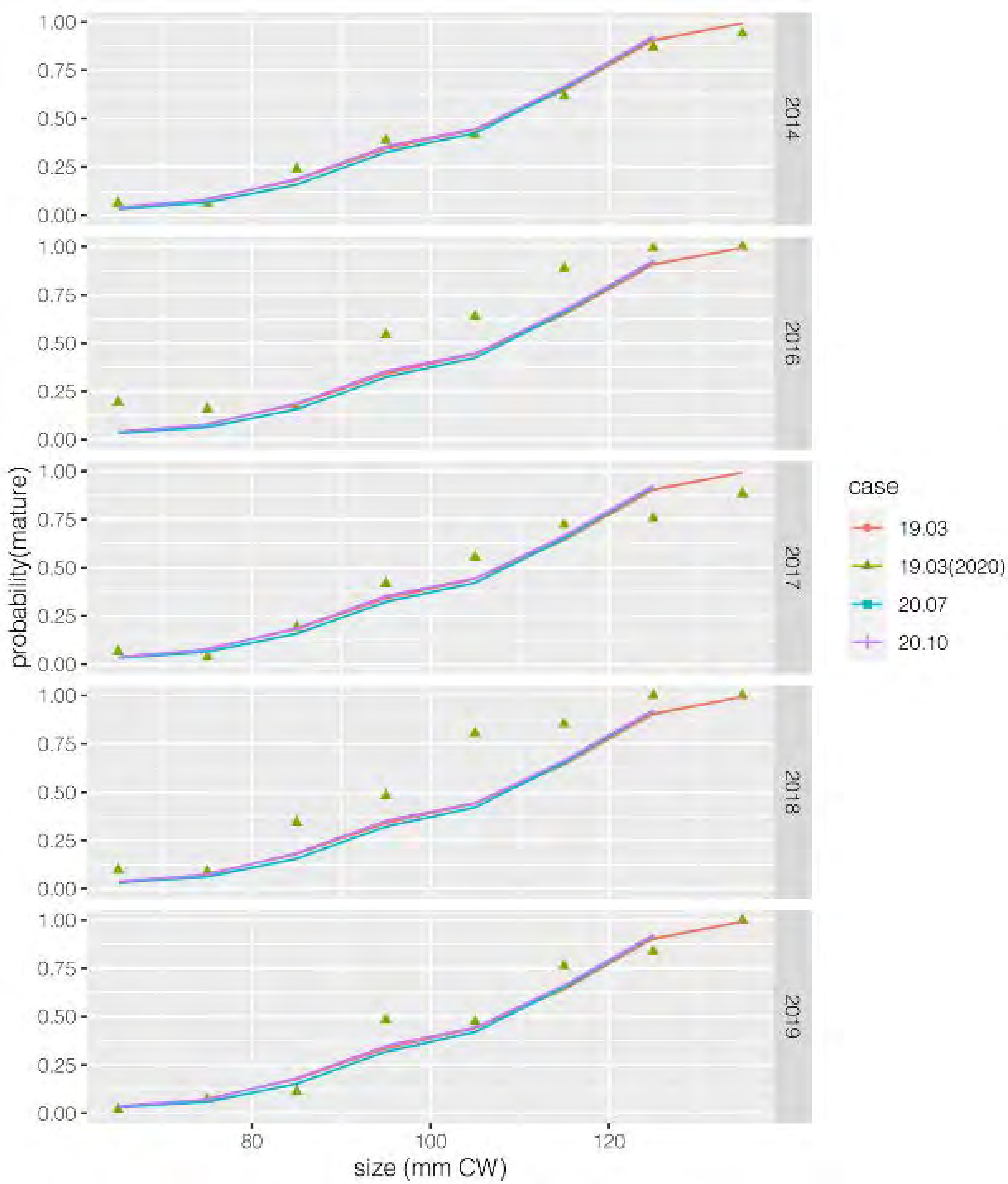

Figure35 (cont.). Fits to male maturity ogive data for all scenarios.

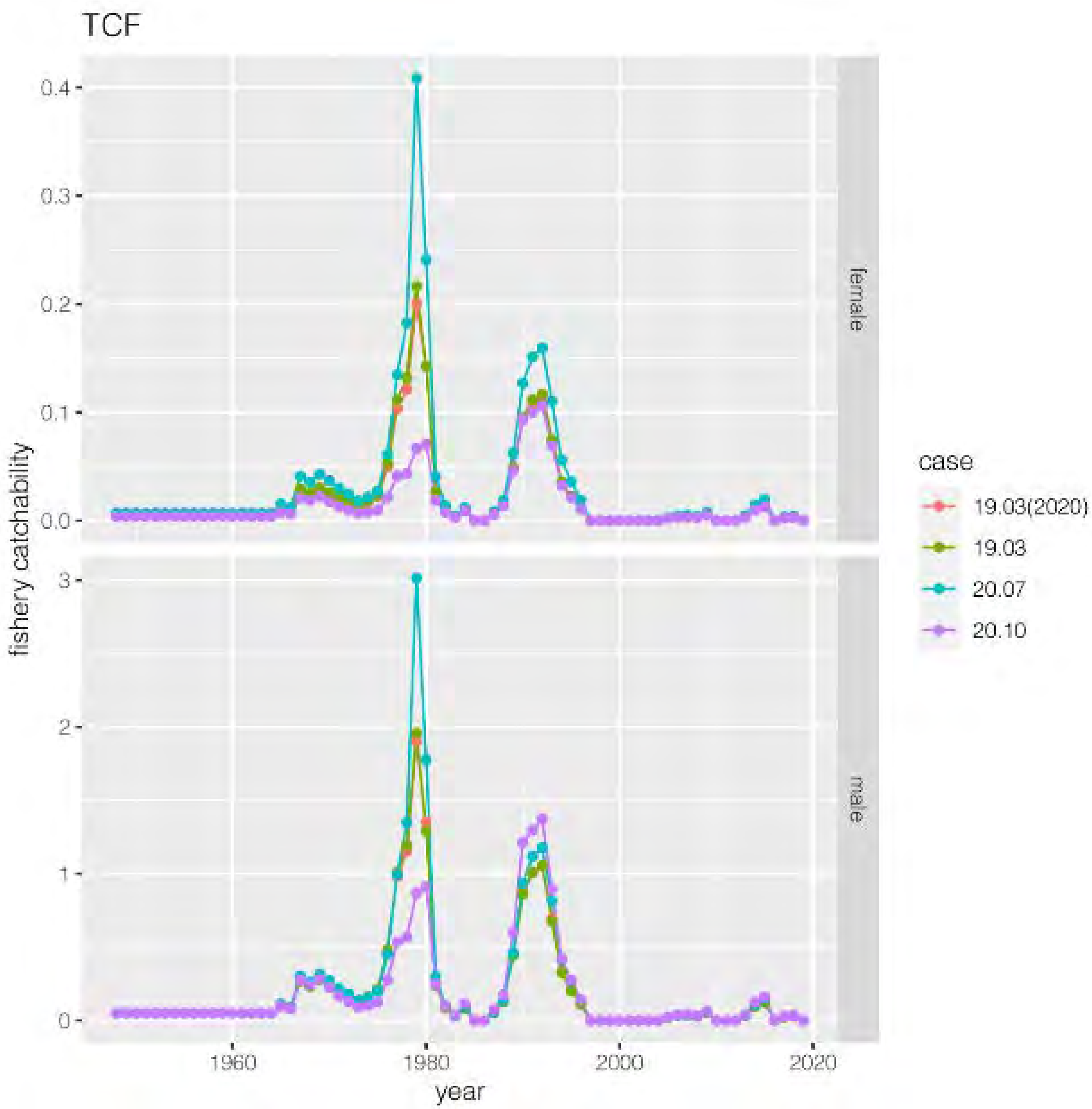

Figure 36. Directed fishery catchability (capture rates) from all model scenarios.

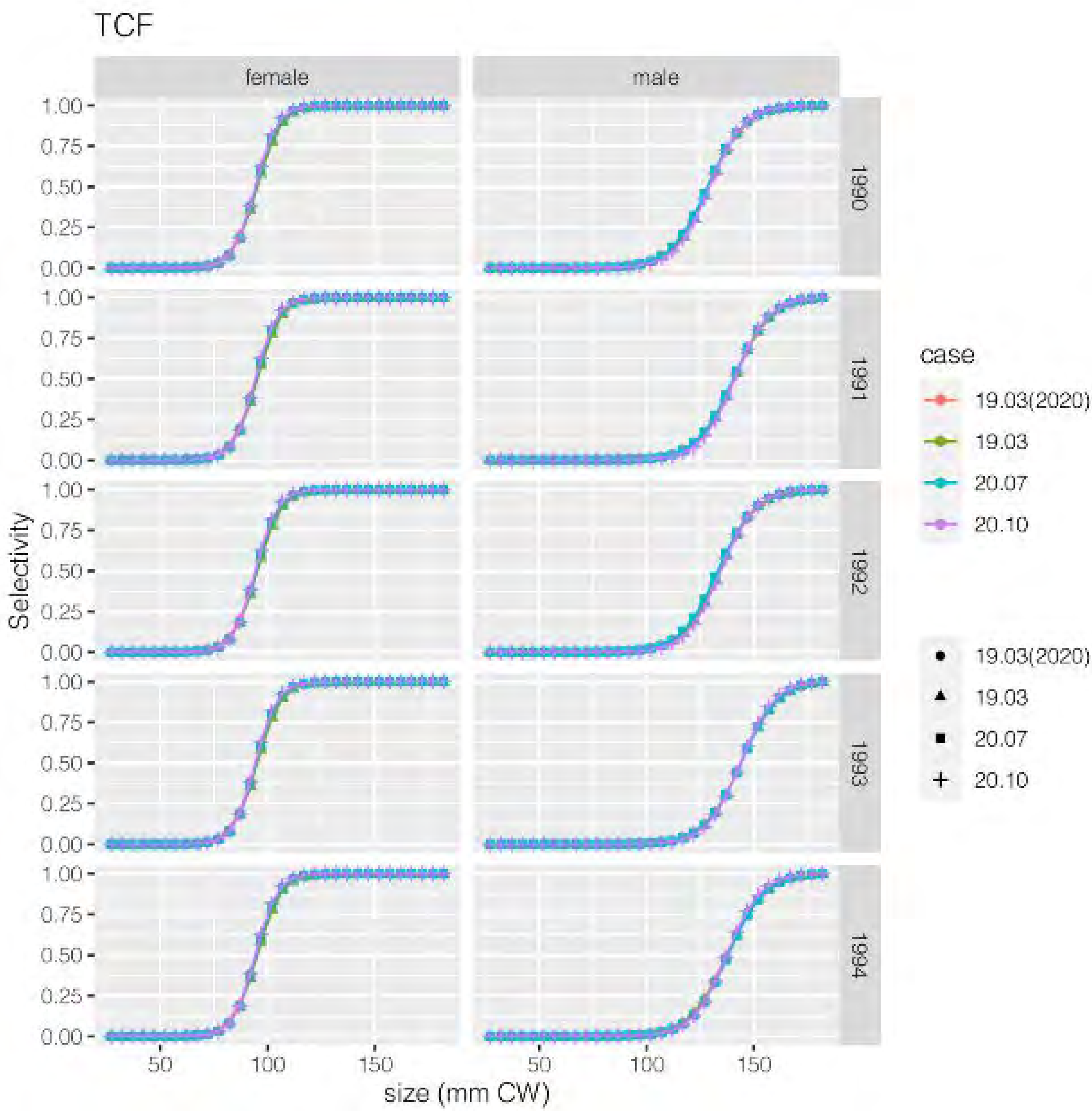

Figure 37. Directed fishery selectivity curves from all scenarios. The size-at-50%-selected parameter varies annually for 1991+.

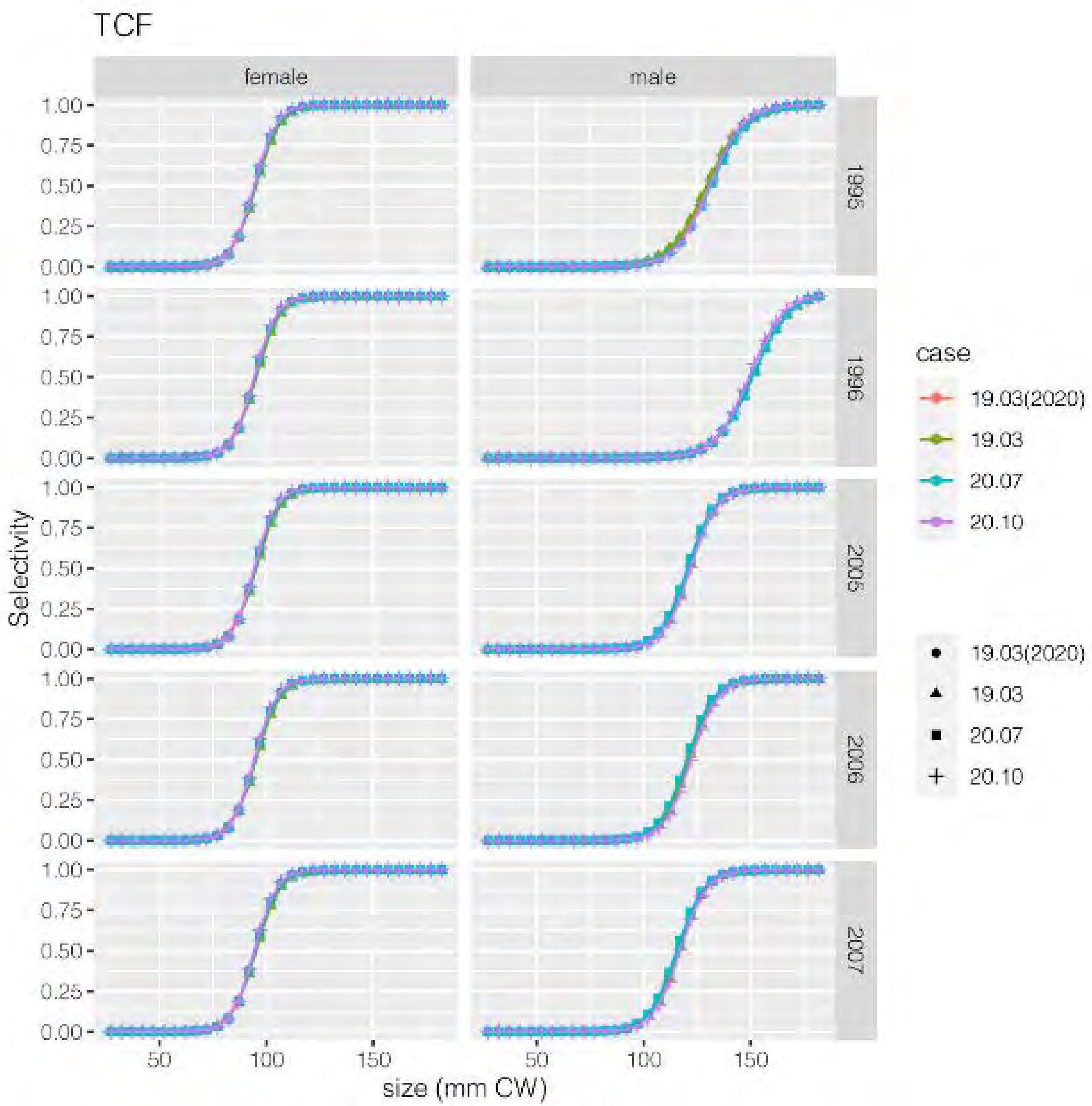

Figure 37 (cont.). Directed fishery selectivity curves from all scenarios. The size-at-50%-selected parameter varies annually for 1991+.

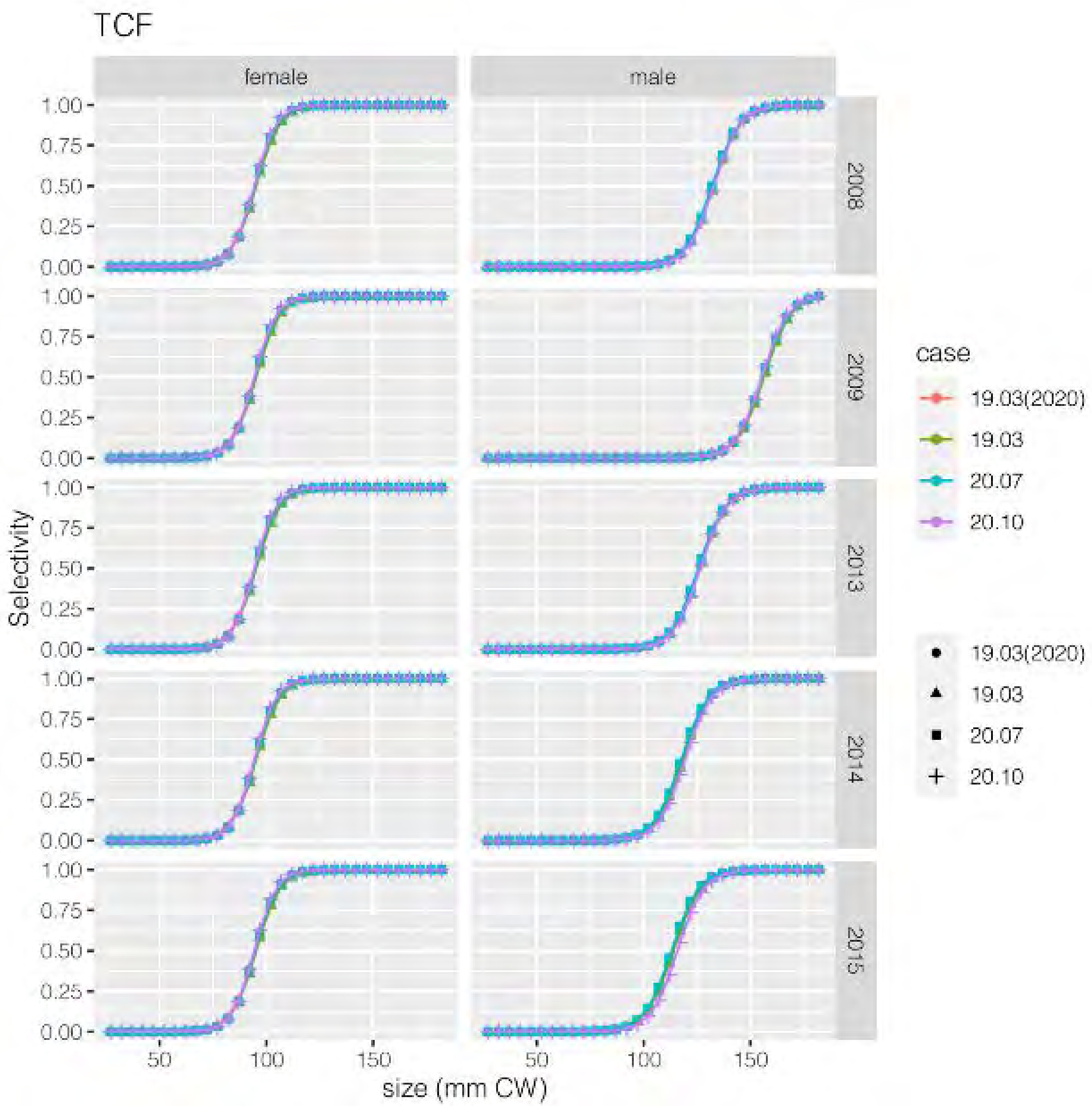

Figure 37 (cont.). Directed fishery selectivity curves from all scenarios. The size-at-50%-selected parameter varies annually for 1991+.

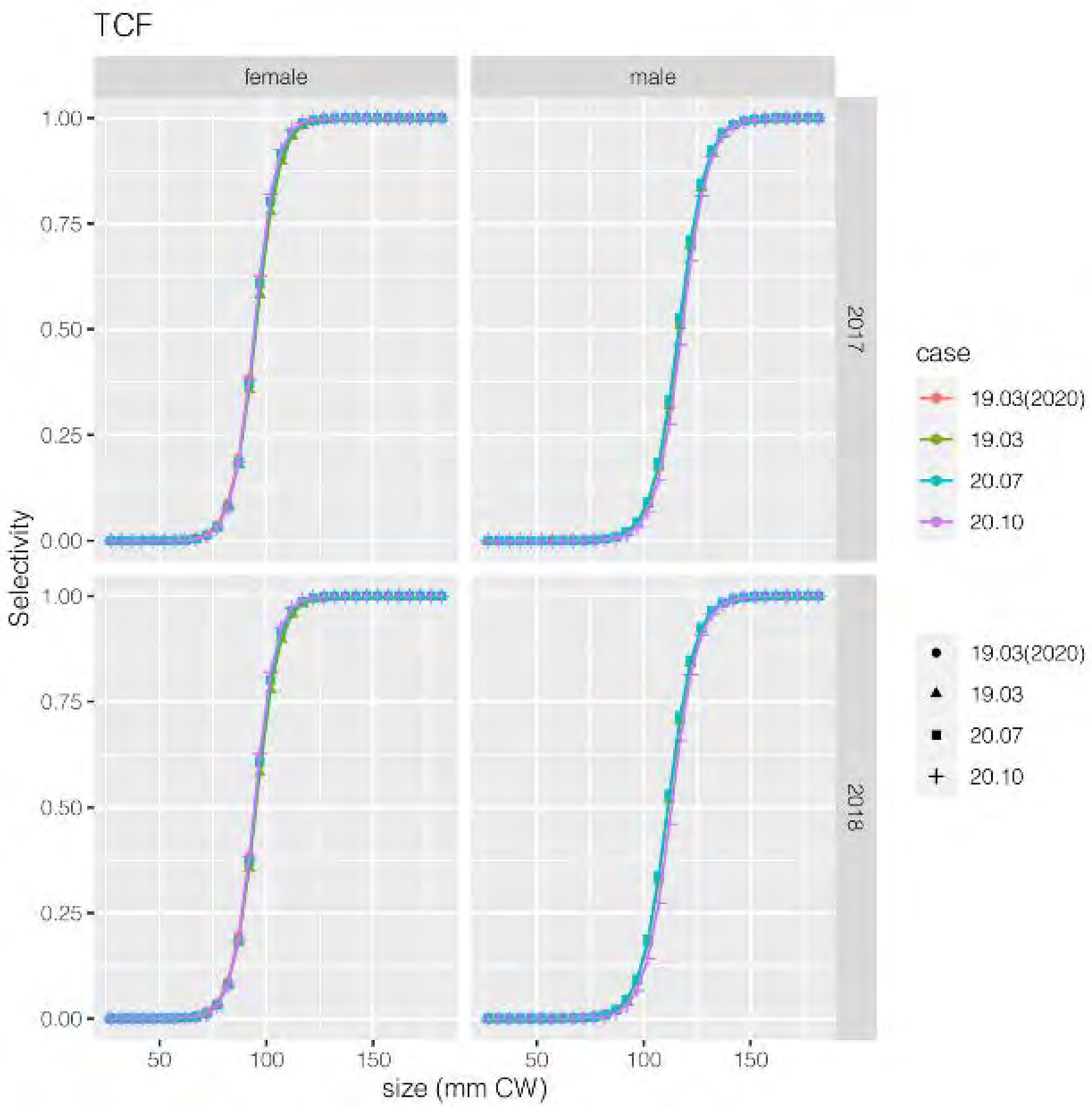

Figure 37 (cont.). Directed fishery selectivity curves from all scenarios. The size-at-50%-selected parameter varies annually for 1991+.

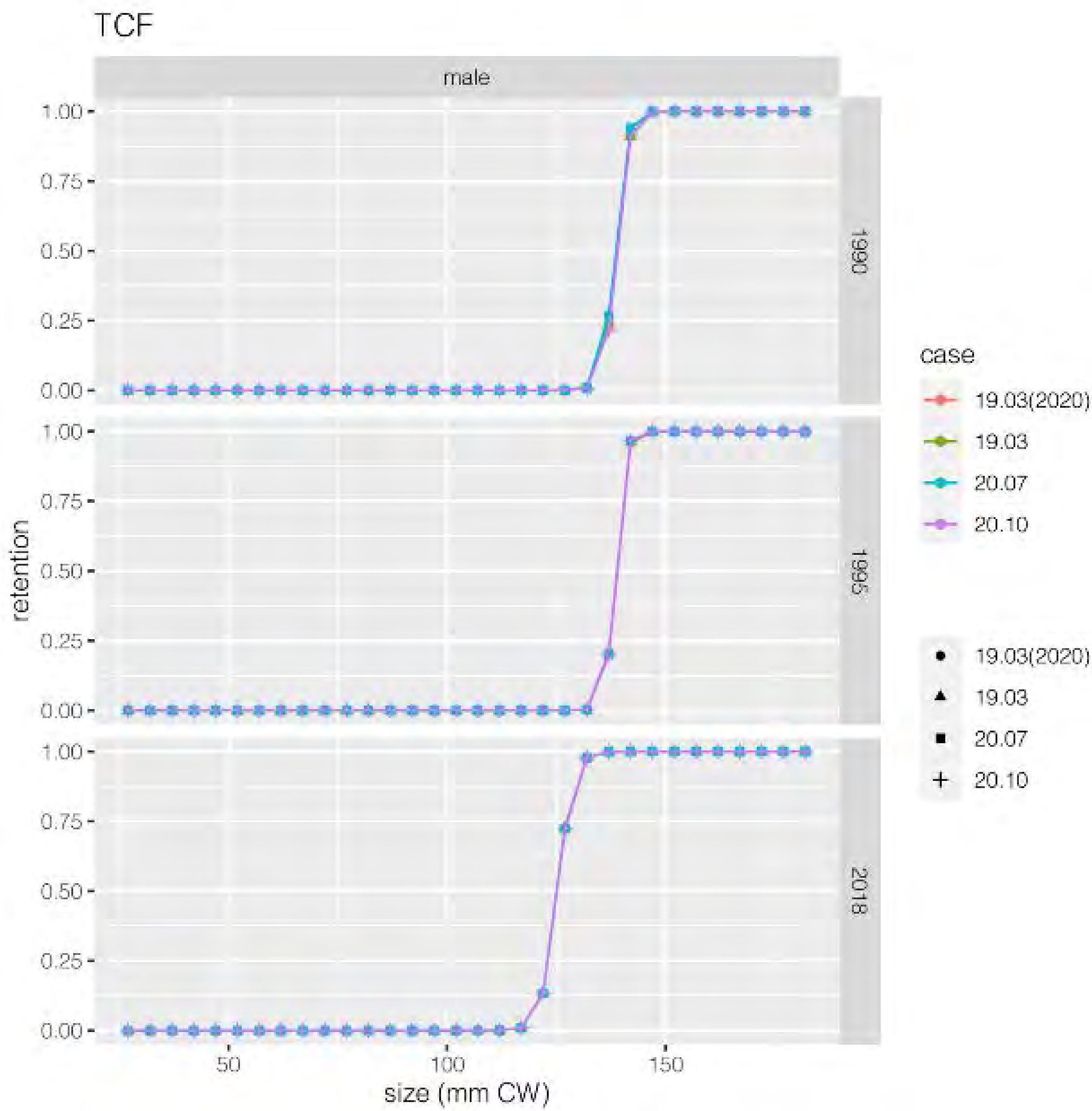

Figure 38. Directed fishery retention curves from all scenarios for the pre-1991, 1991-1996, and post-2004 time periods.

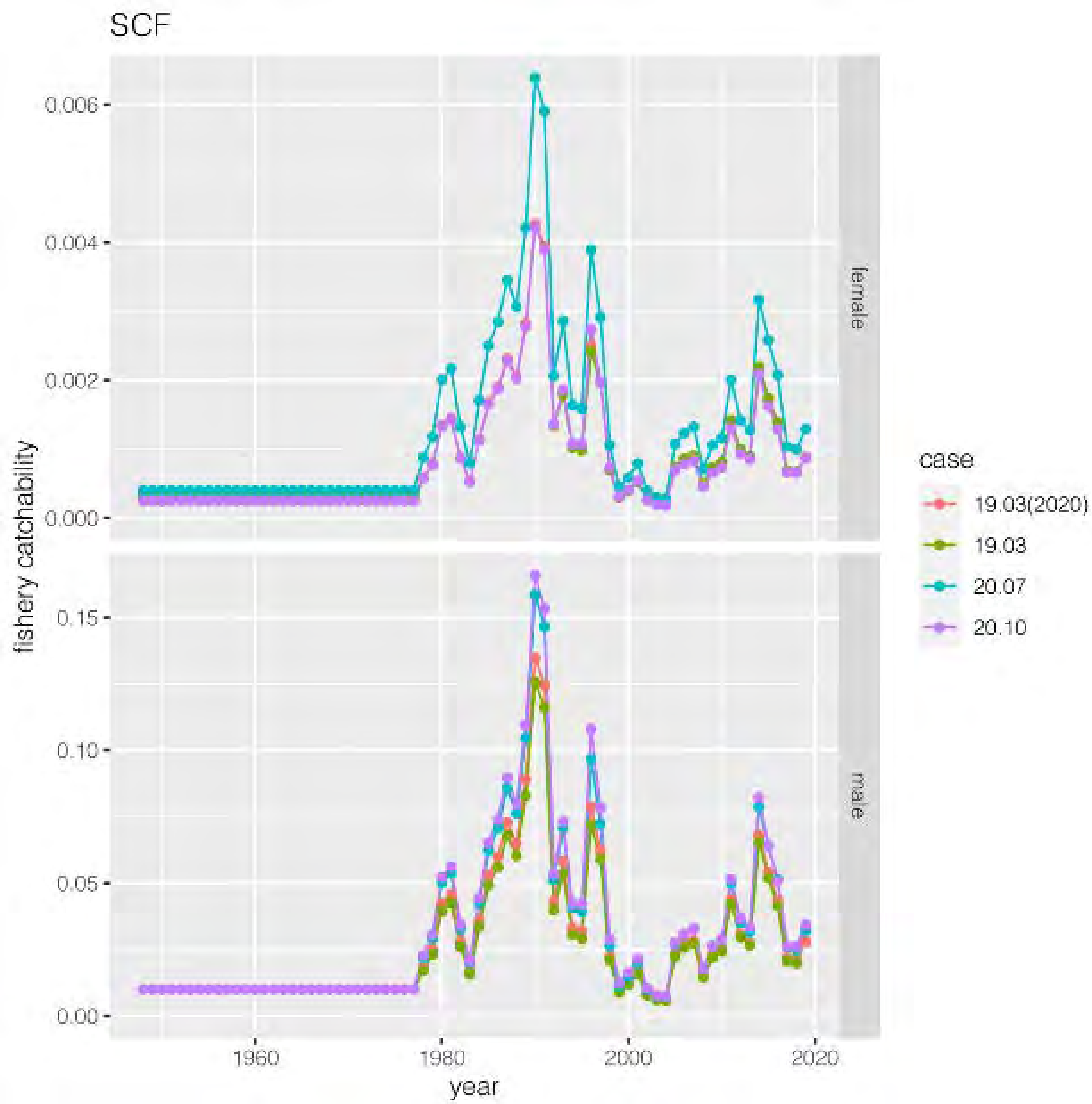

Figure 39. Snow crab fishery catchability (capture rates) from all scenarios.

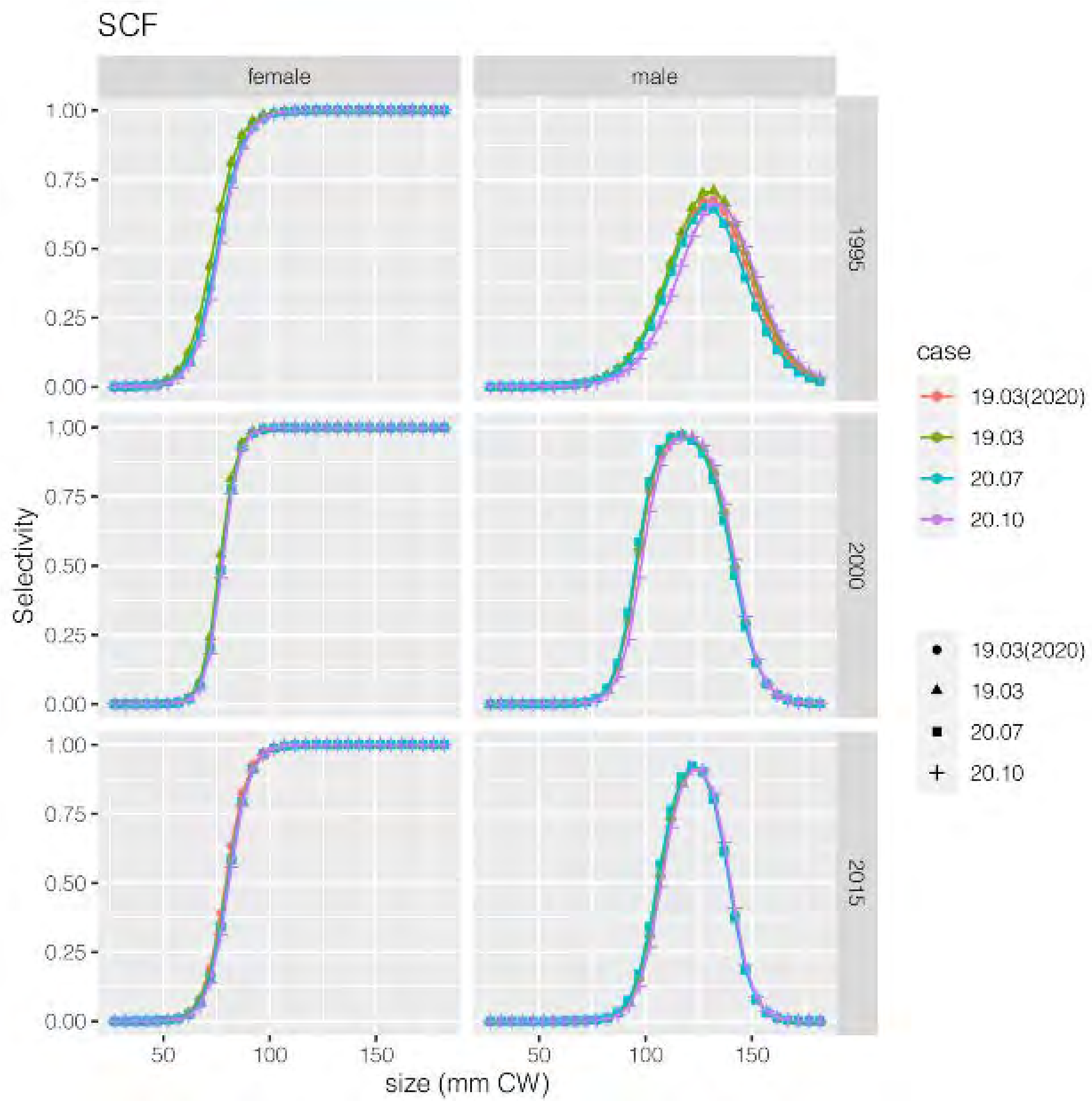

Figure 40. Snow crab fishery selectivity curves from all scenarios for 3 time periods: pre-1997, 1997-2004, 2005+.

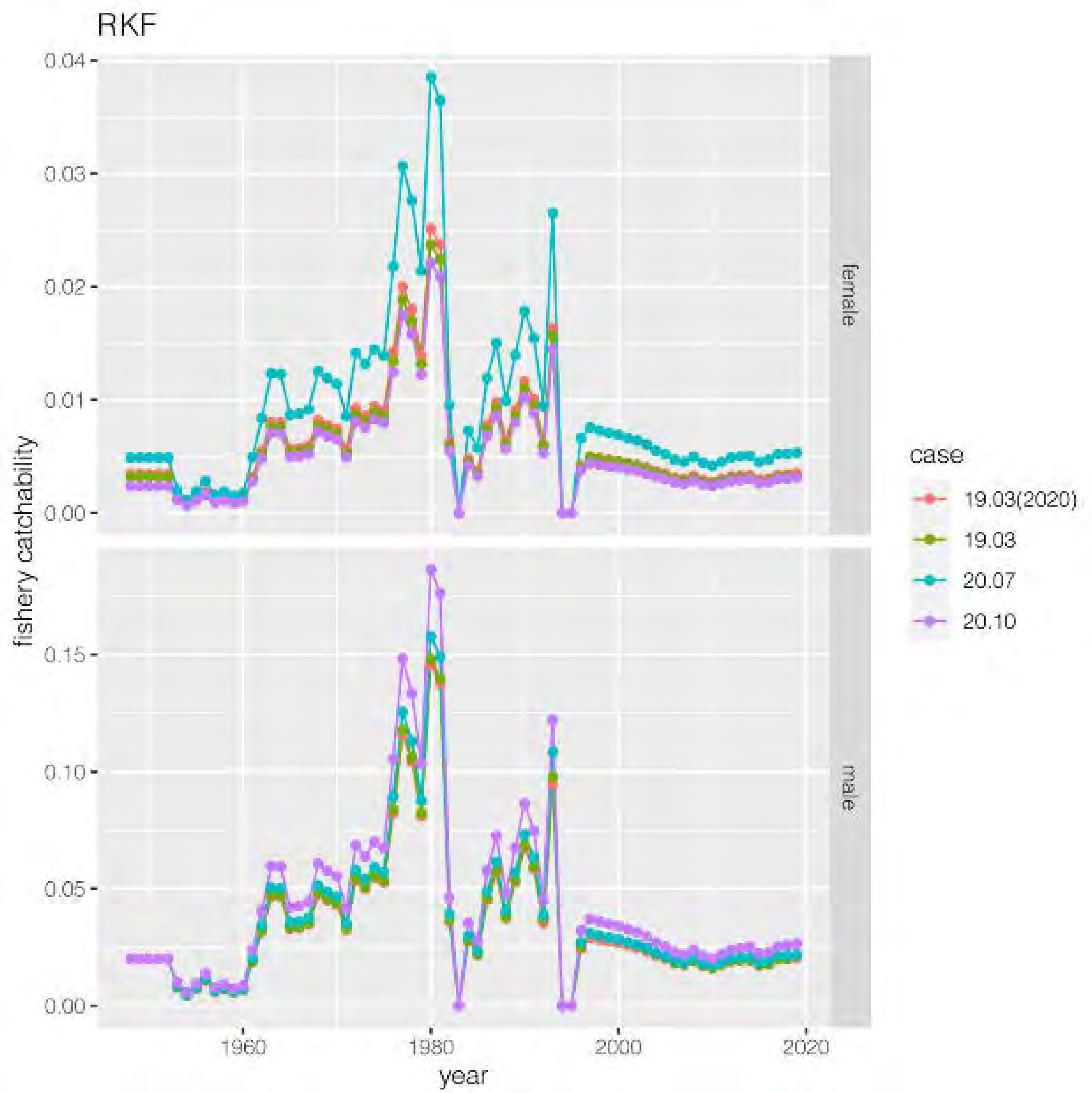

Figure 41. BBRKC fishery catchability (capture rates) from all scenarios.

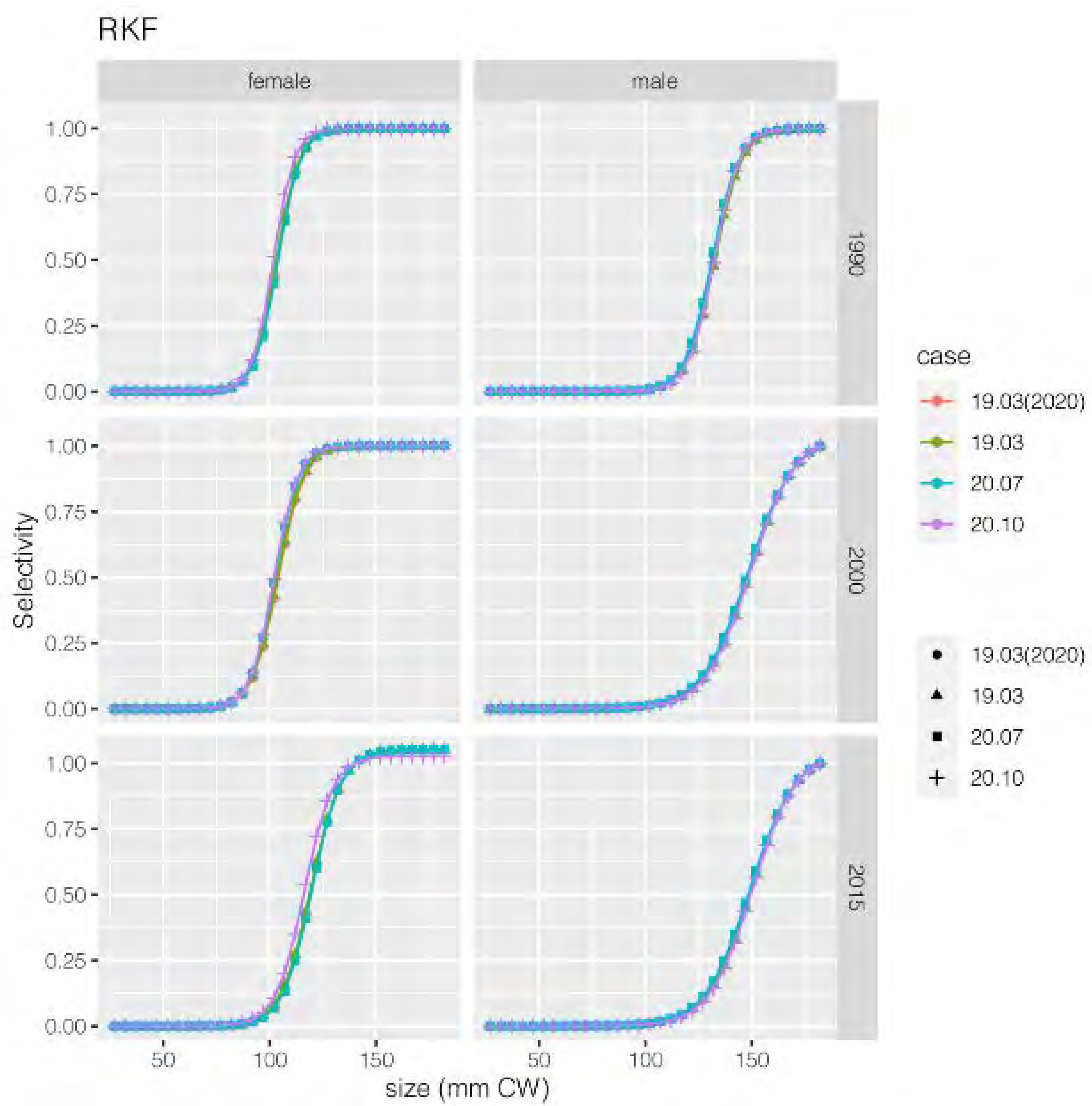

Figure 42. BBRKC fishery selectivity curves from all scenarios for 3 time periods: pre-1997, 1997-2004, 2005+.

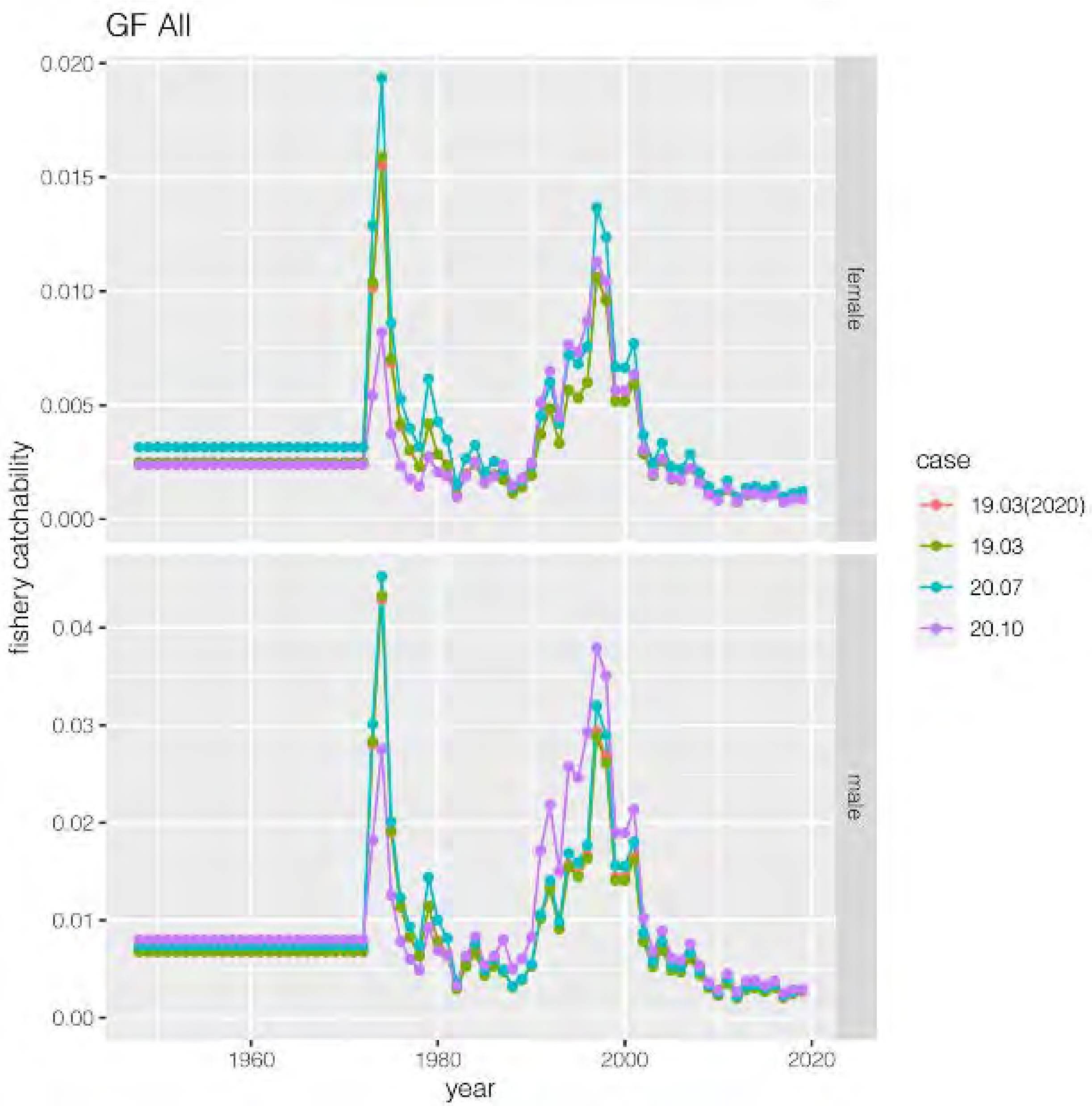

Figure 43. Catchability (capture rates) in the groundfish fisheries from all scenarios.

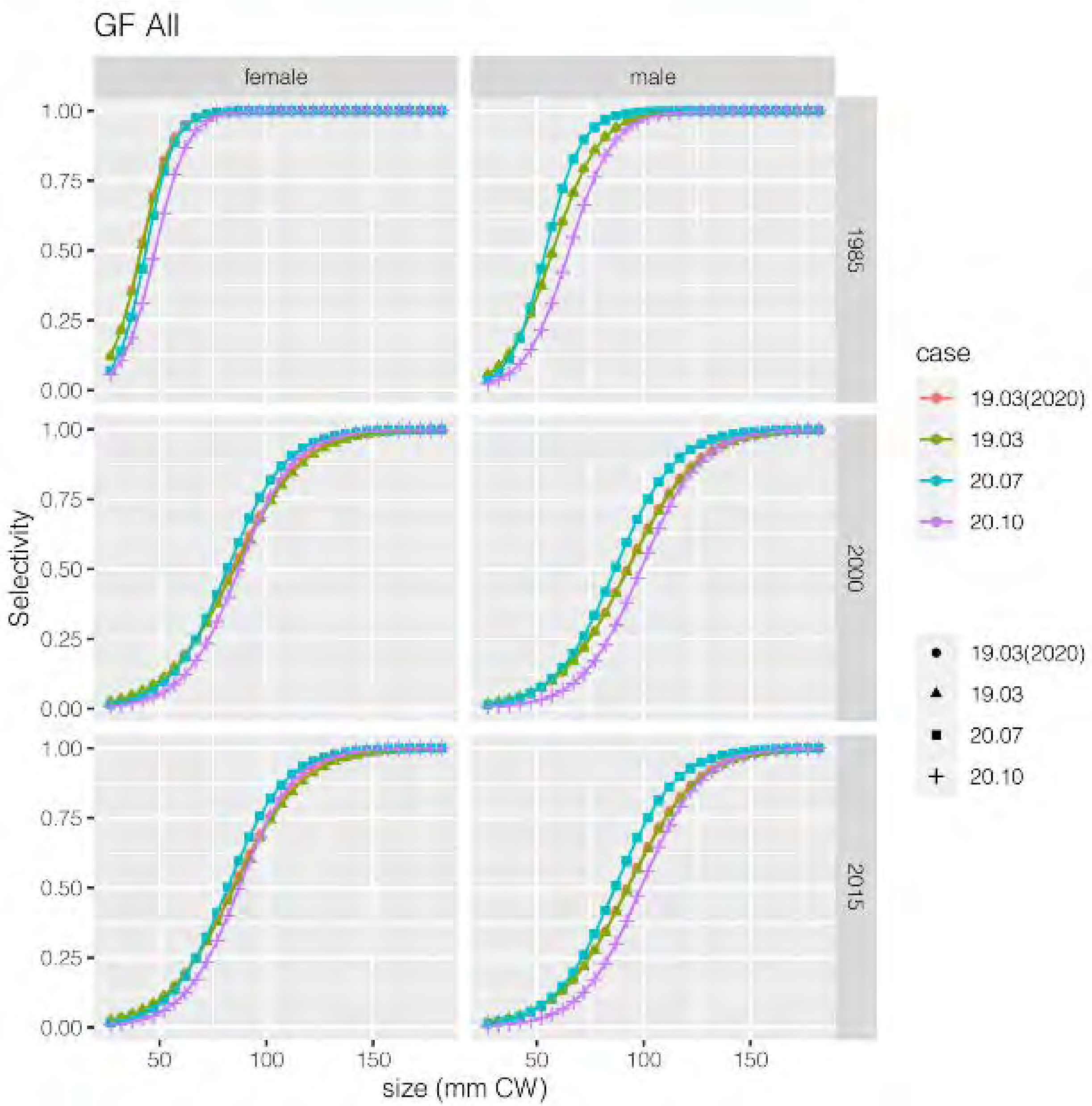

Figure 44. Groundfish fisheries selectivity curves from all scenarios estimated for 3 time periods: pre-1997, 1997-2004, 2005+.

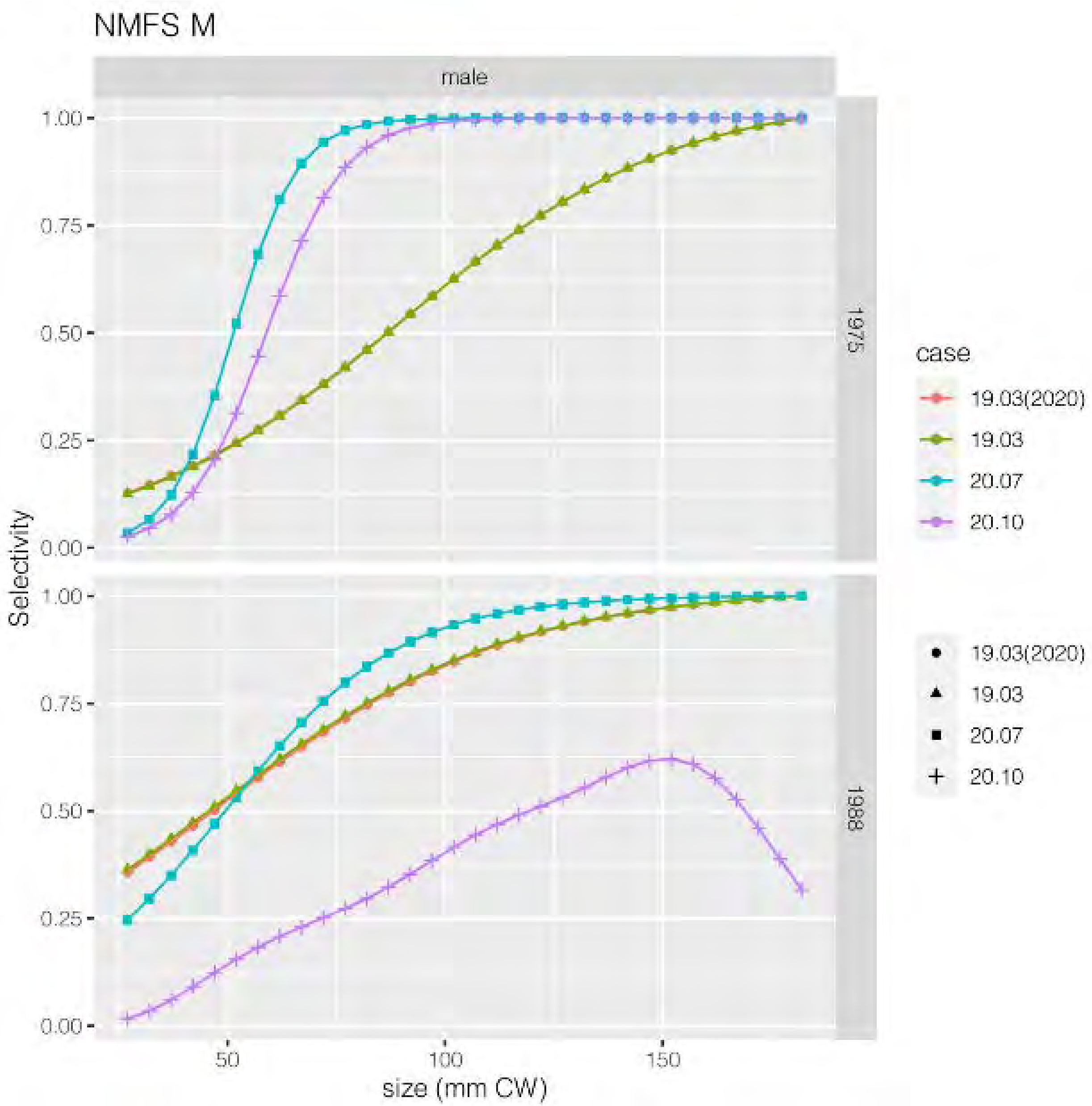

Figure 45. NMFS survey selectivity functions for males from all scenarios for the 1975-1981 and 1982+ time periods.

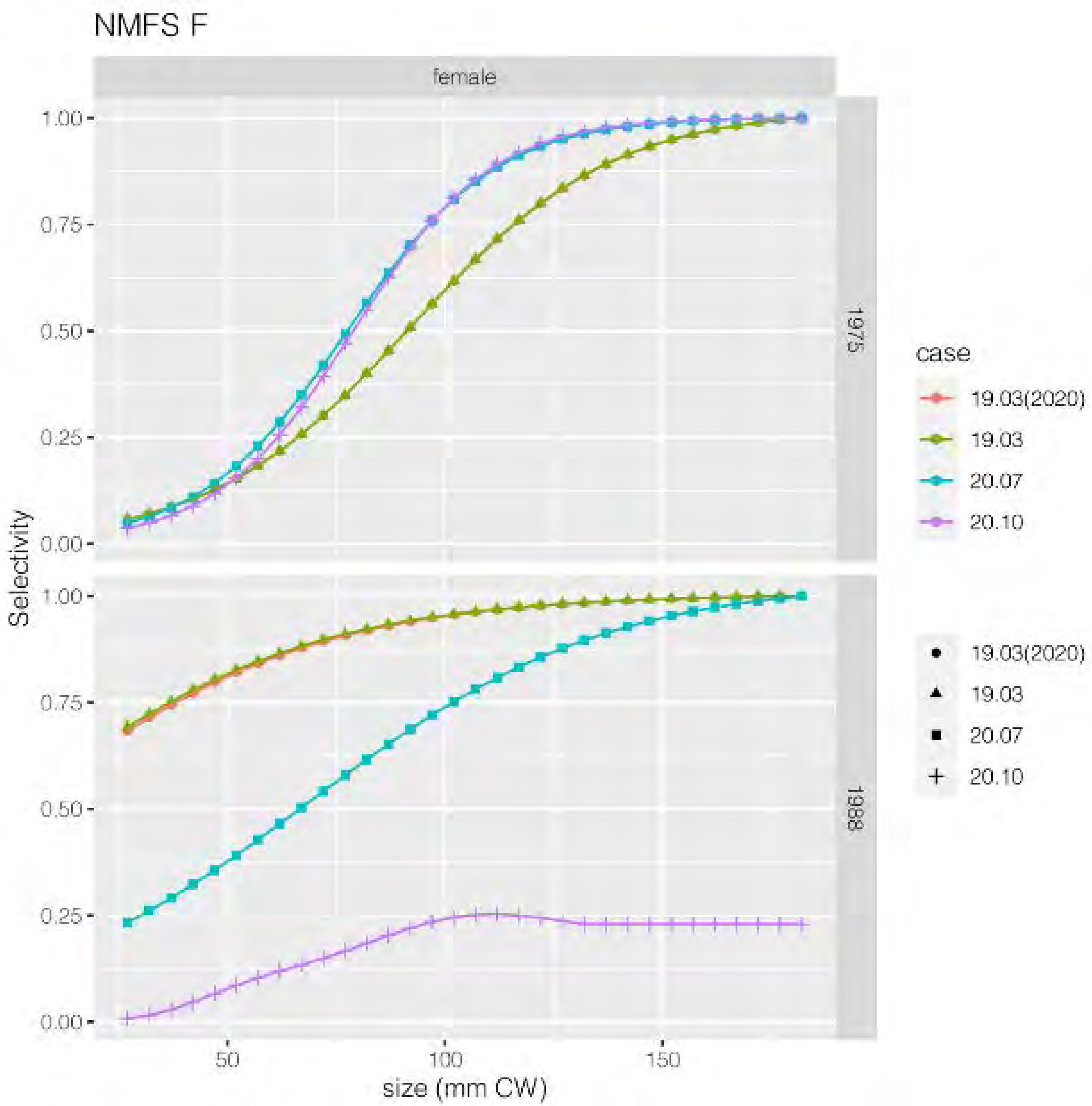

Figure 46. NMFS survey selectivity functions for females from all scenarios for the 1975-1981 and 1982+ time periods.

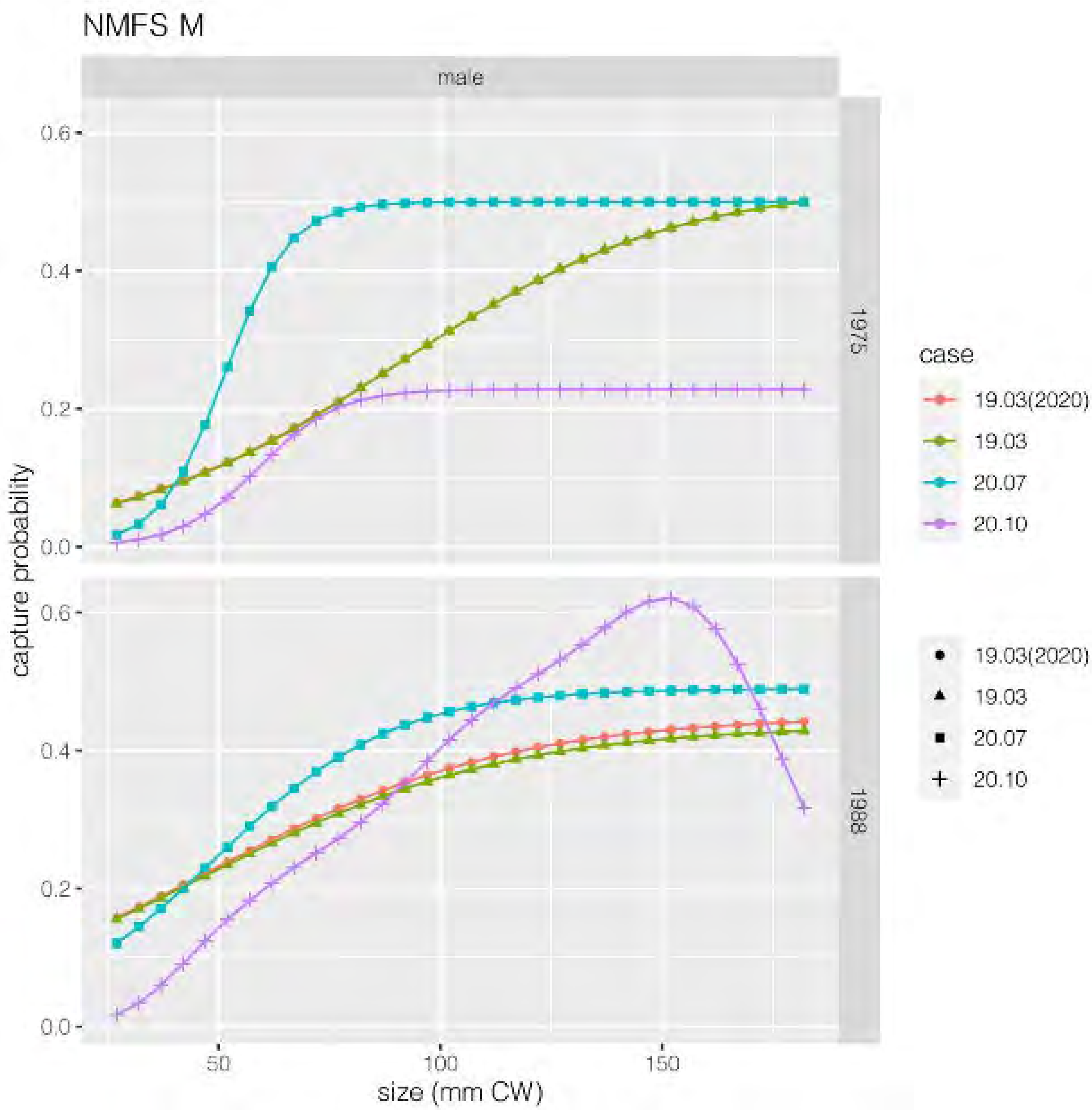

Figure 47. NMFS survey capture probabilities (fully-selected catchability x selectivity) for males from all scenarios for the 1975-1981 and 1982+ time periods.

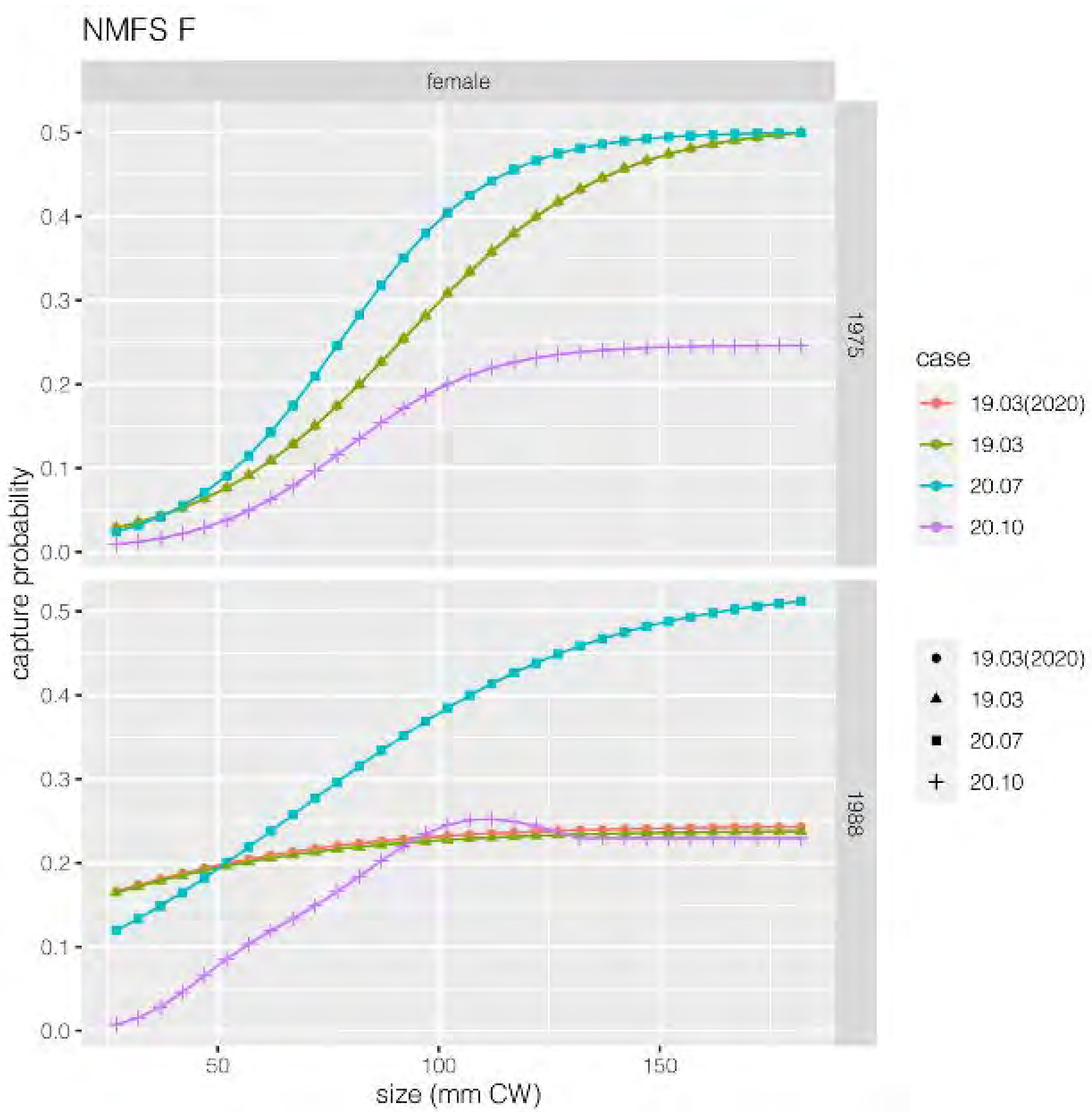

Figure 48. NMFS survey capture probabilities (fully-selected catchability x selectivity) for females from all scenarios for the 1975-1981 and 1982+ time periods.

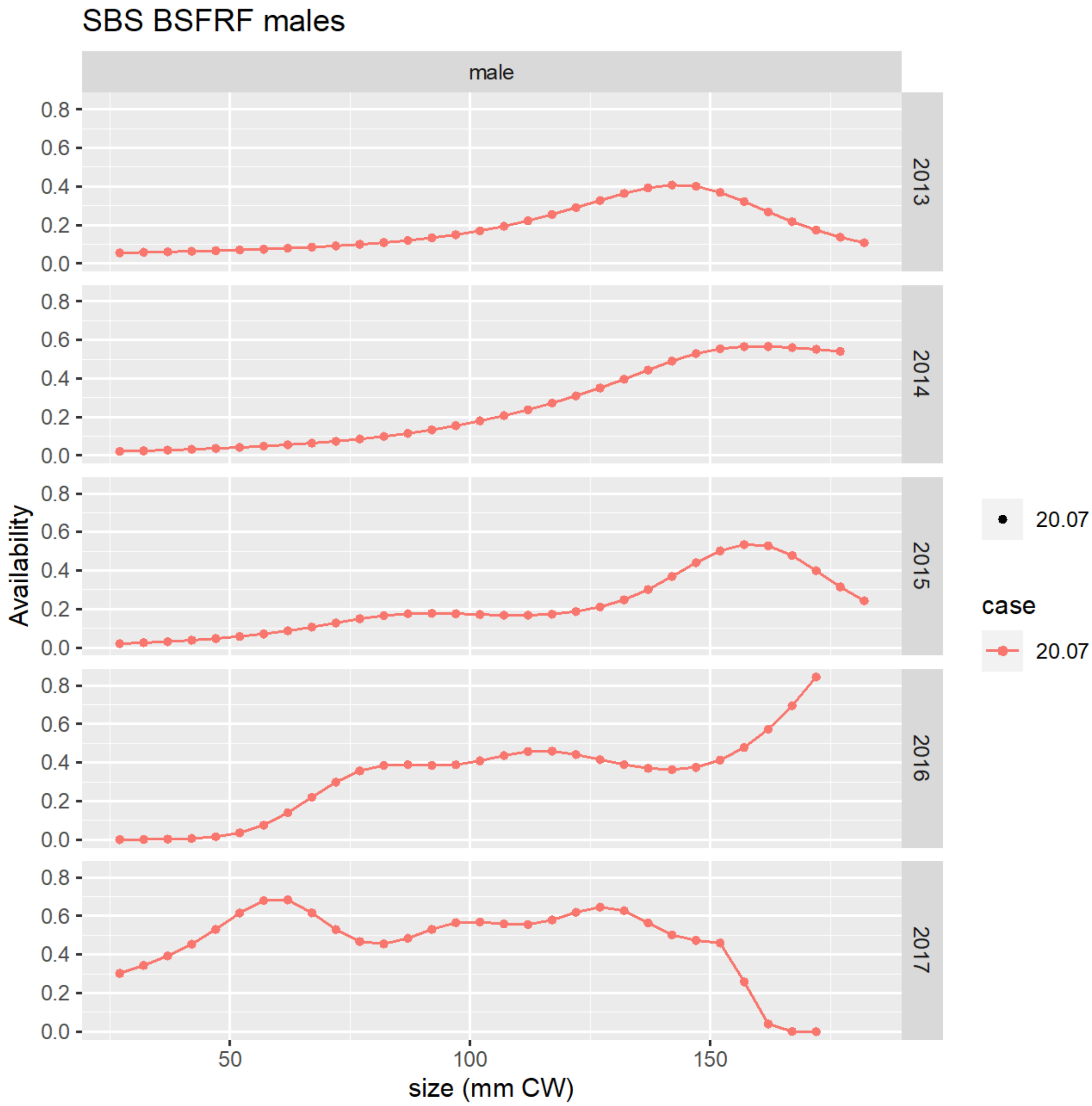

Figure 49. Annual availability functions for males in the BSFRF SBS surveys, for scenarios that include BSFRF SBS data. Availability functions were determined outside the model for Scenario 20.07.

Figure 50. Annual availability functions for females in the BSFRF SBS surveys, for scenarios that include BSFRF SBS data. Availability functions were determined outside the model for Scenario 20.07.

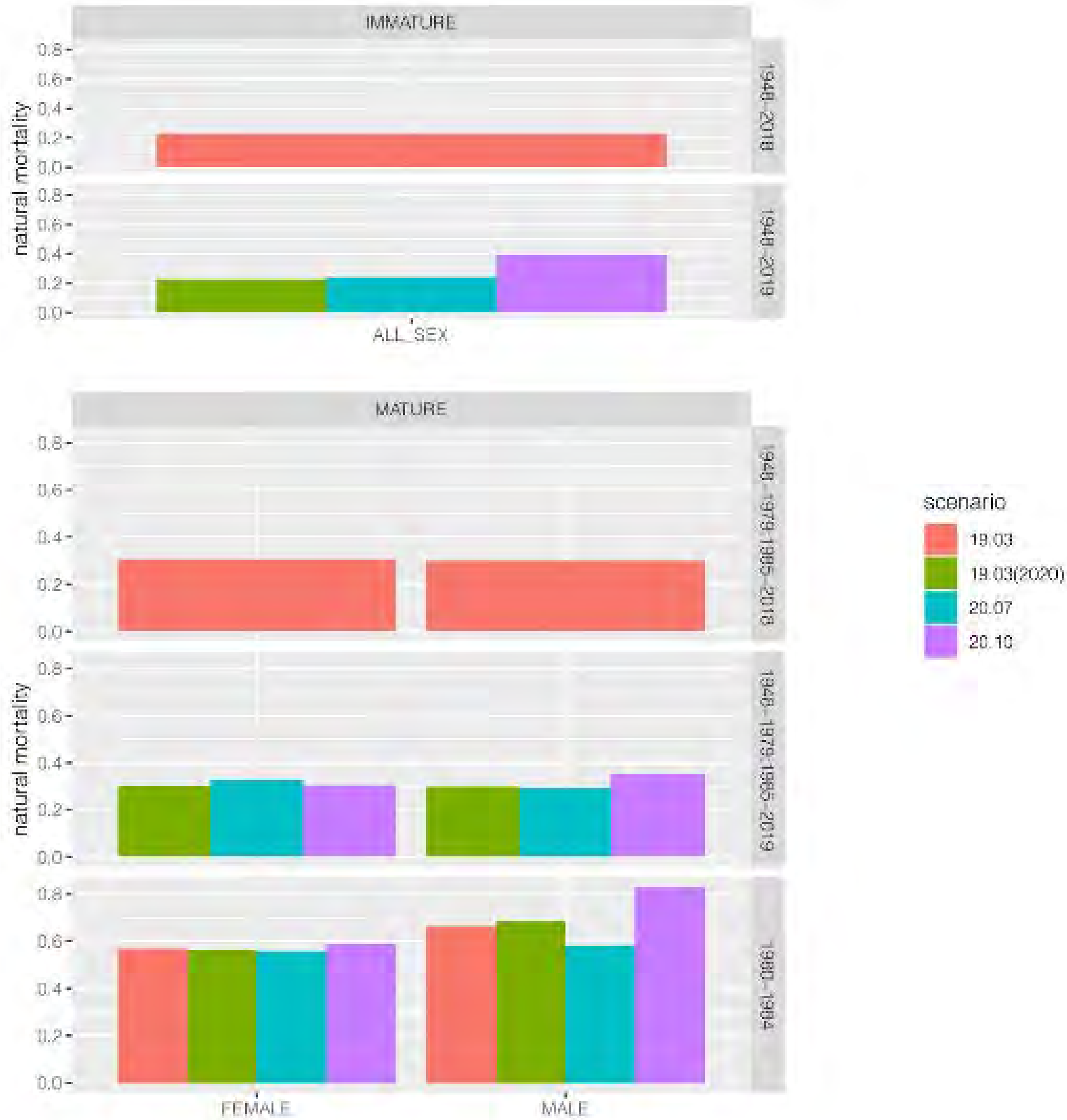

Figure 51. Estimates of natural mortality from all scenarios.

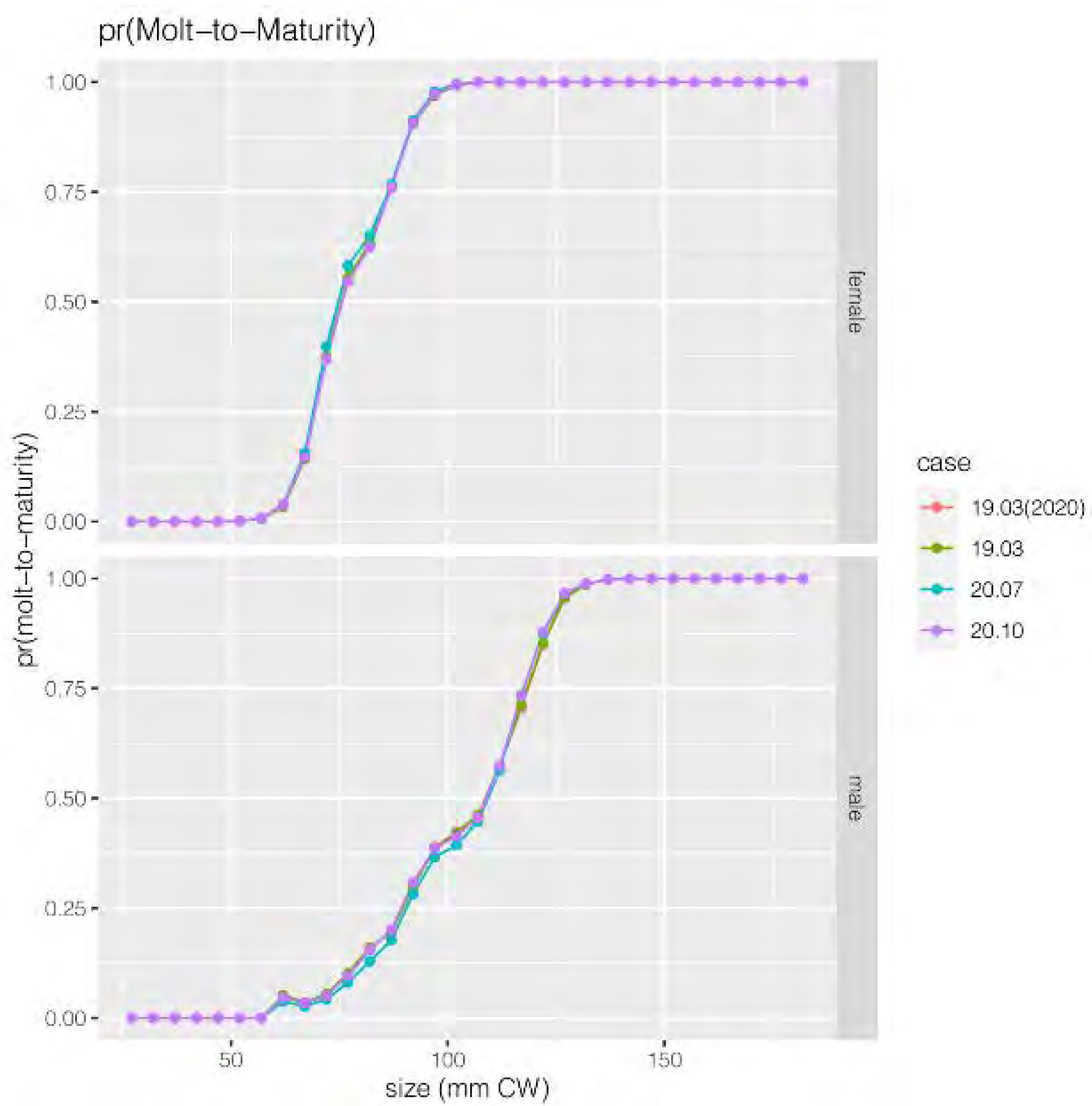

Figure 52. Estimates of the probability of terminal molt from all scenarios.

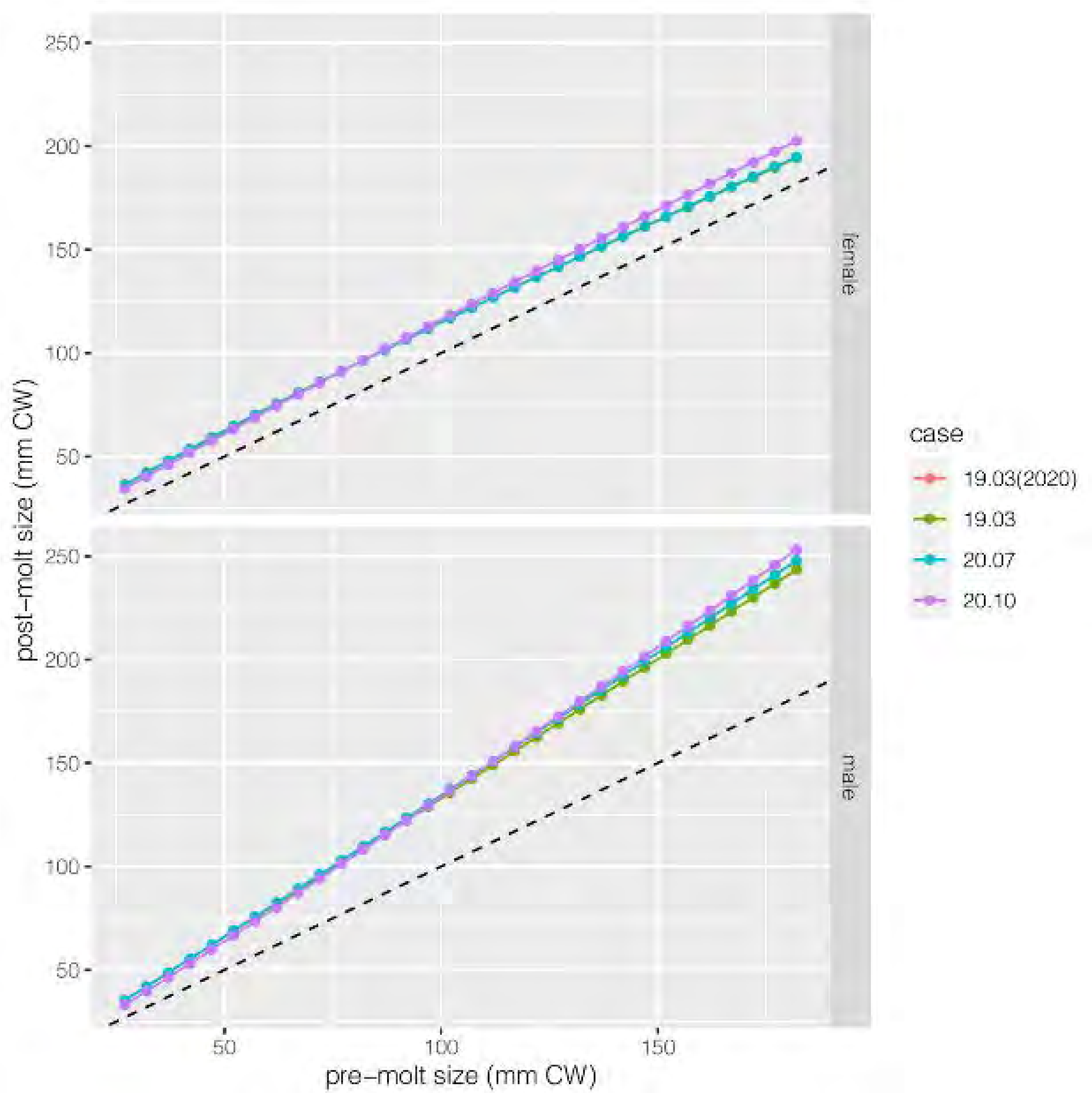

Figure 53. Estimates of mean growth from all scenarios. Dashed line is 1:1.

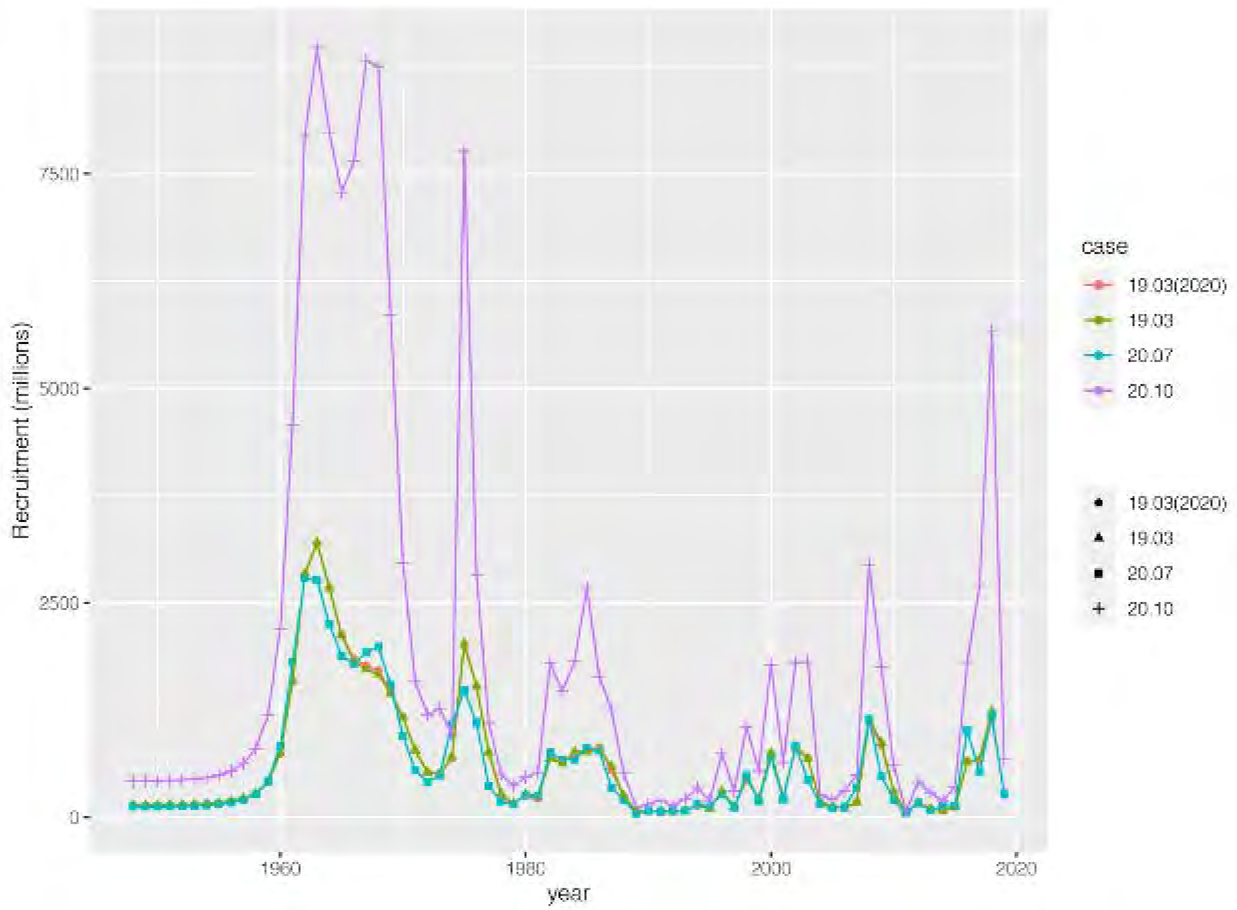

Figure 54. Estimated recruitment time series from all scenarios.

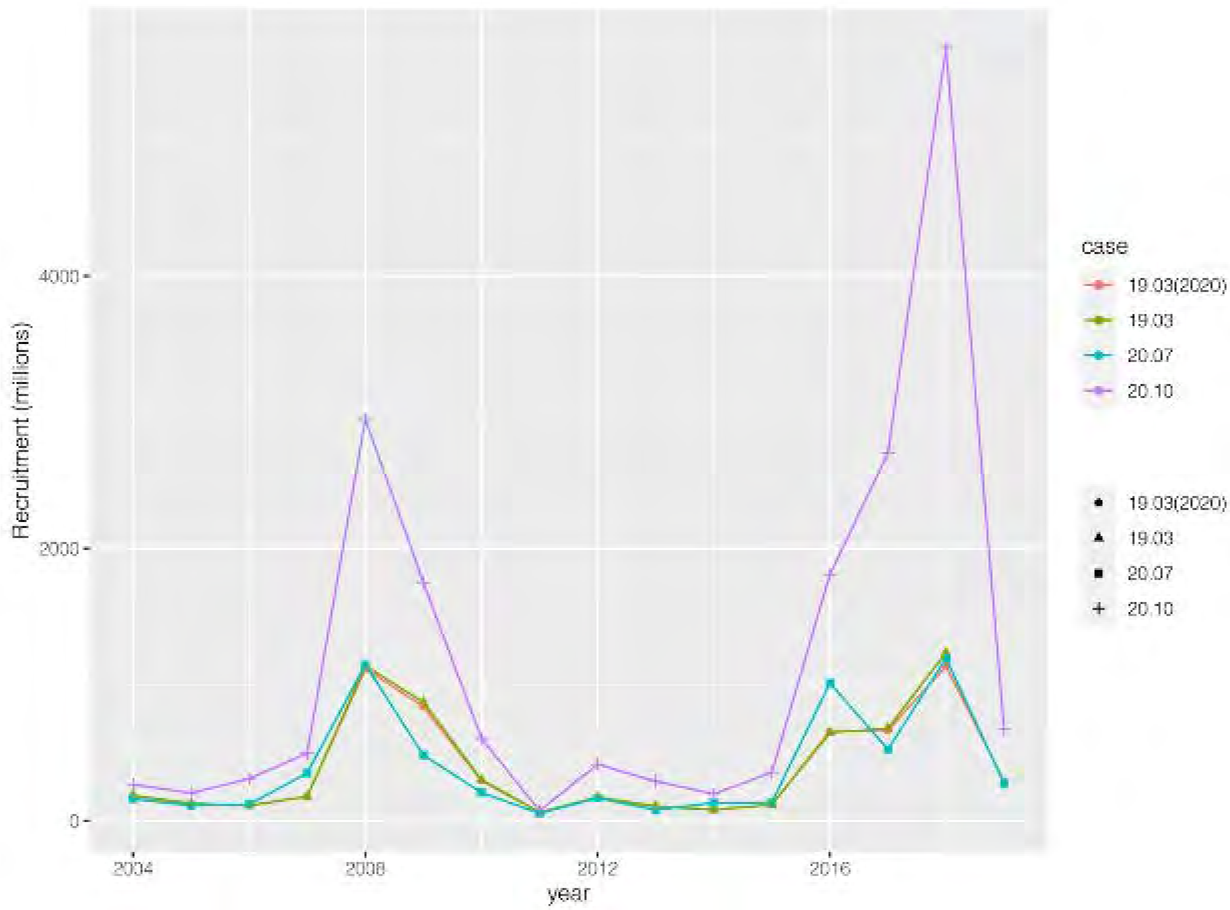

Figure 55. Estimated recent recruitment time series from all scenarios.

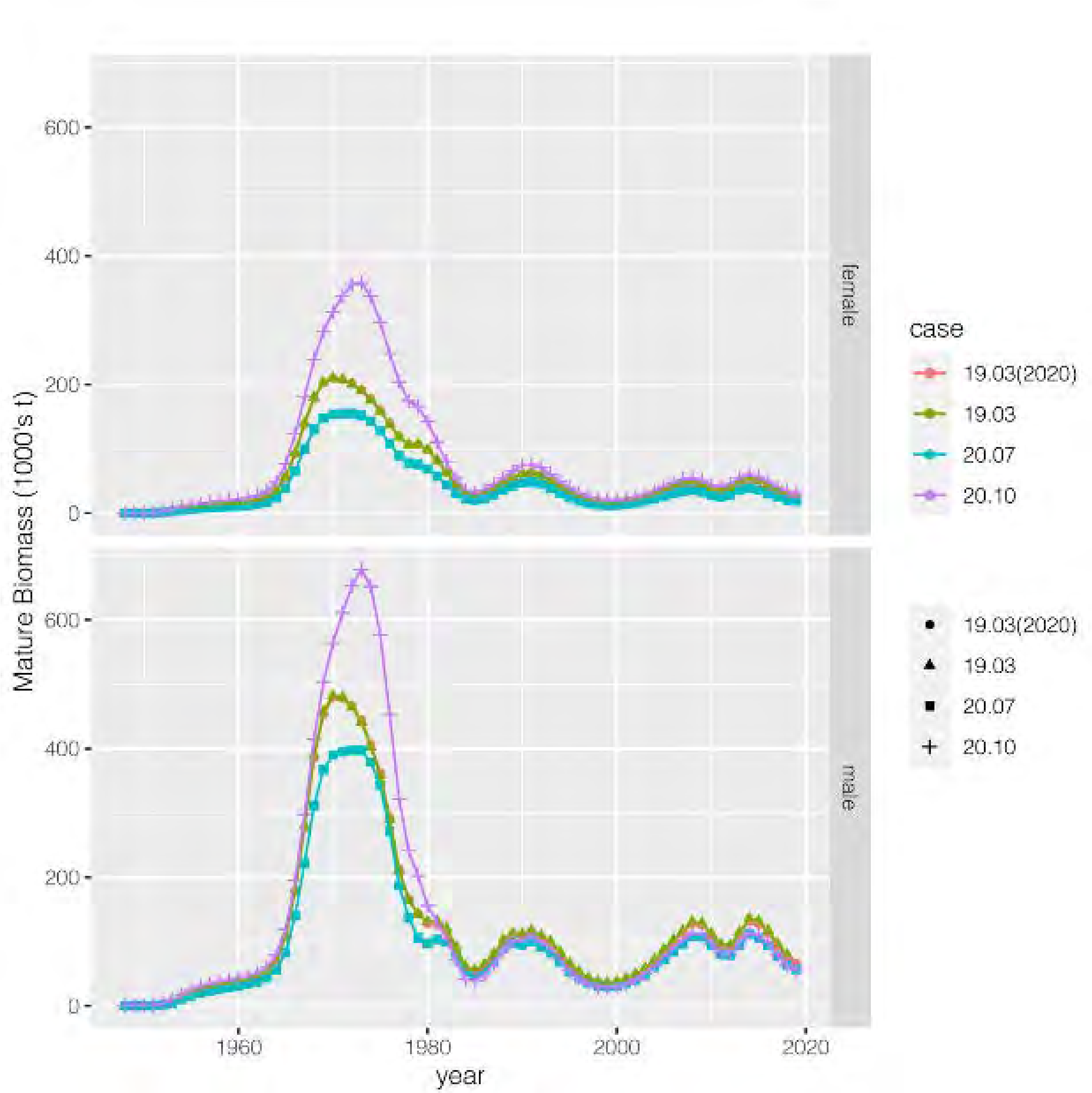

Figure 56. Estimated (Feb. 15) mature biomass time series from all scenarios.

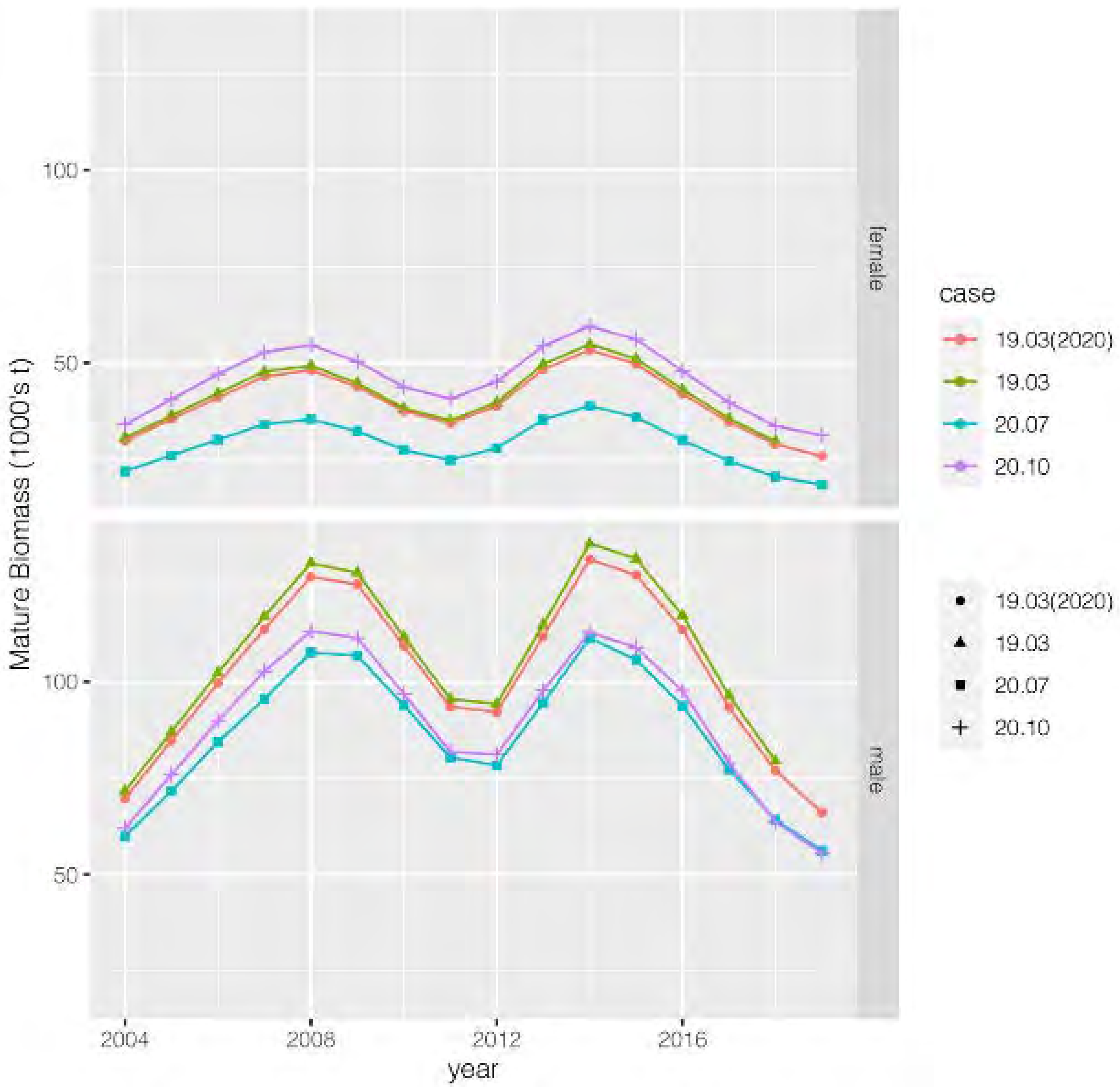

Figure 57. Estimated recent (Feb. 15) mature biomass time series from all scenarios.

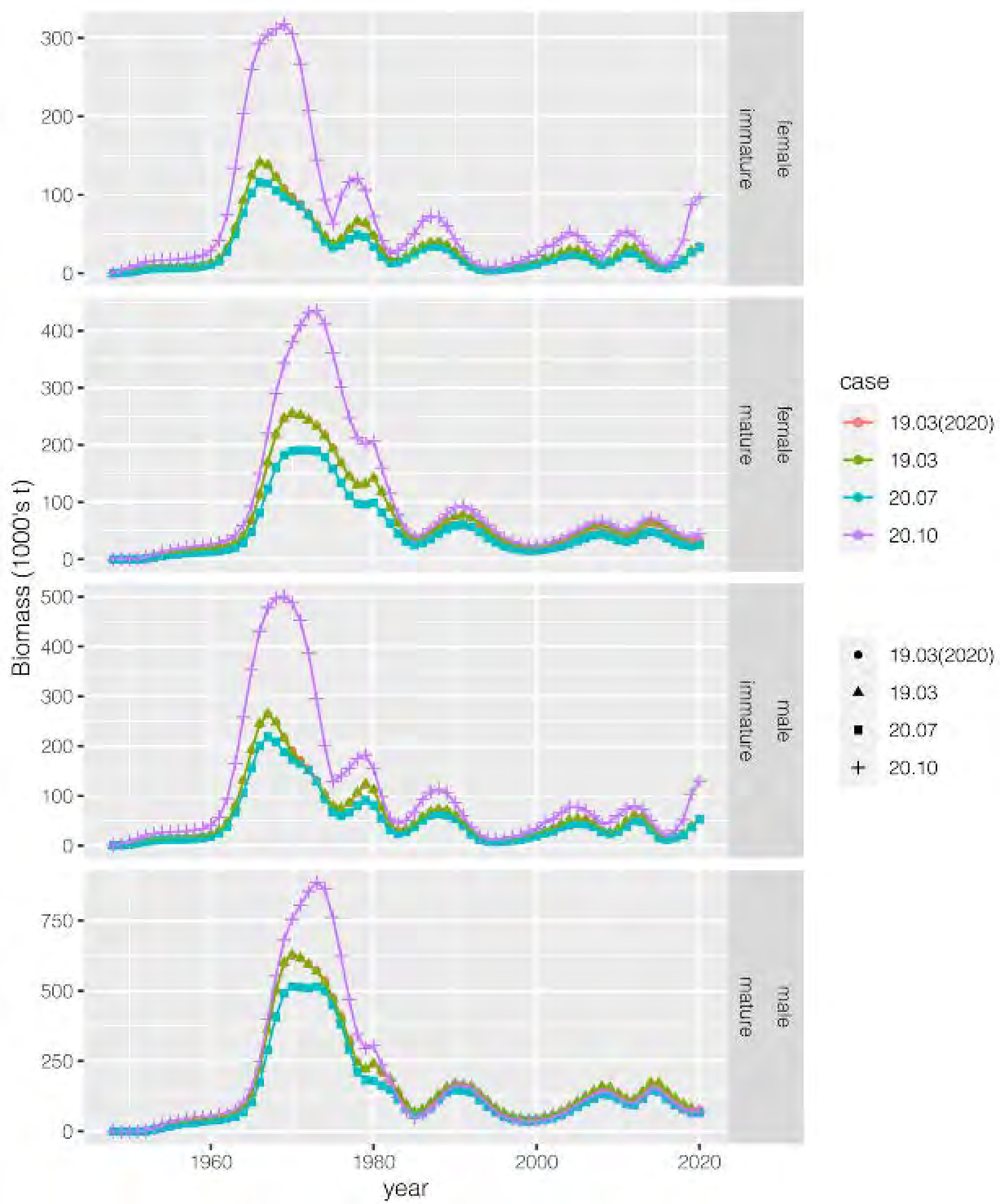

Figure 58. Estimated biomass (on July 1) time series by population category for all scenarios.

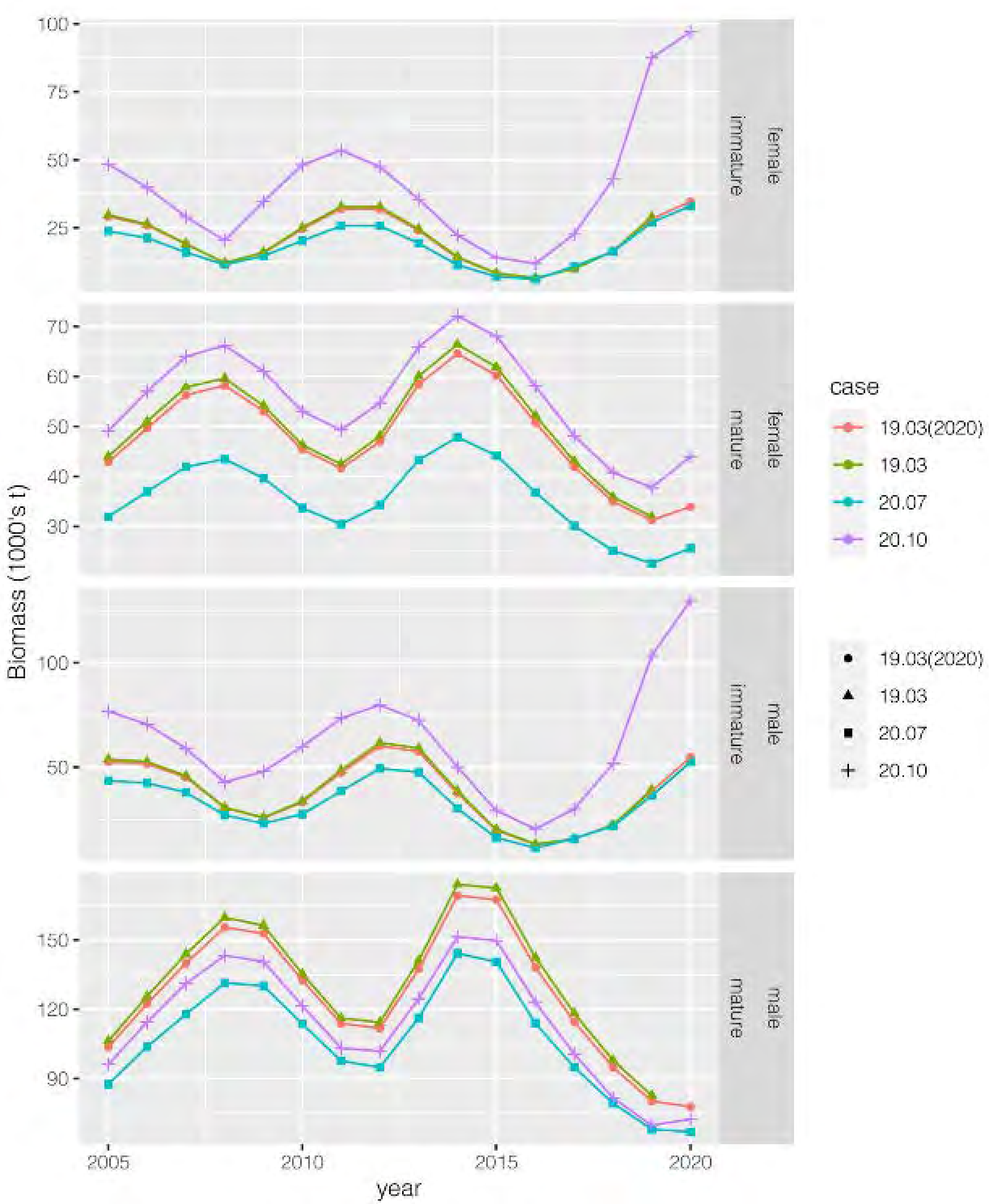

Figure 59. Estimated recent biomass (on July 1) time series by population category for all scenarios.

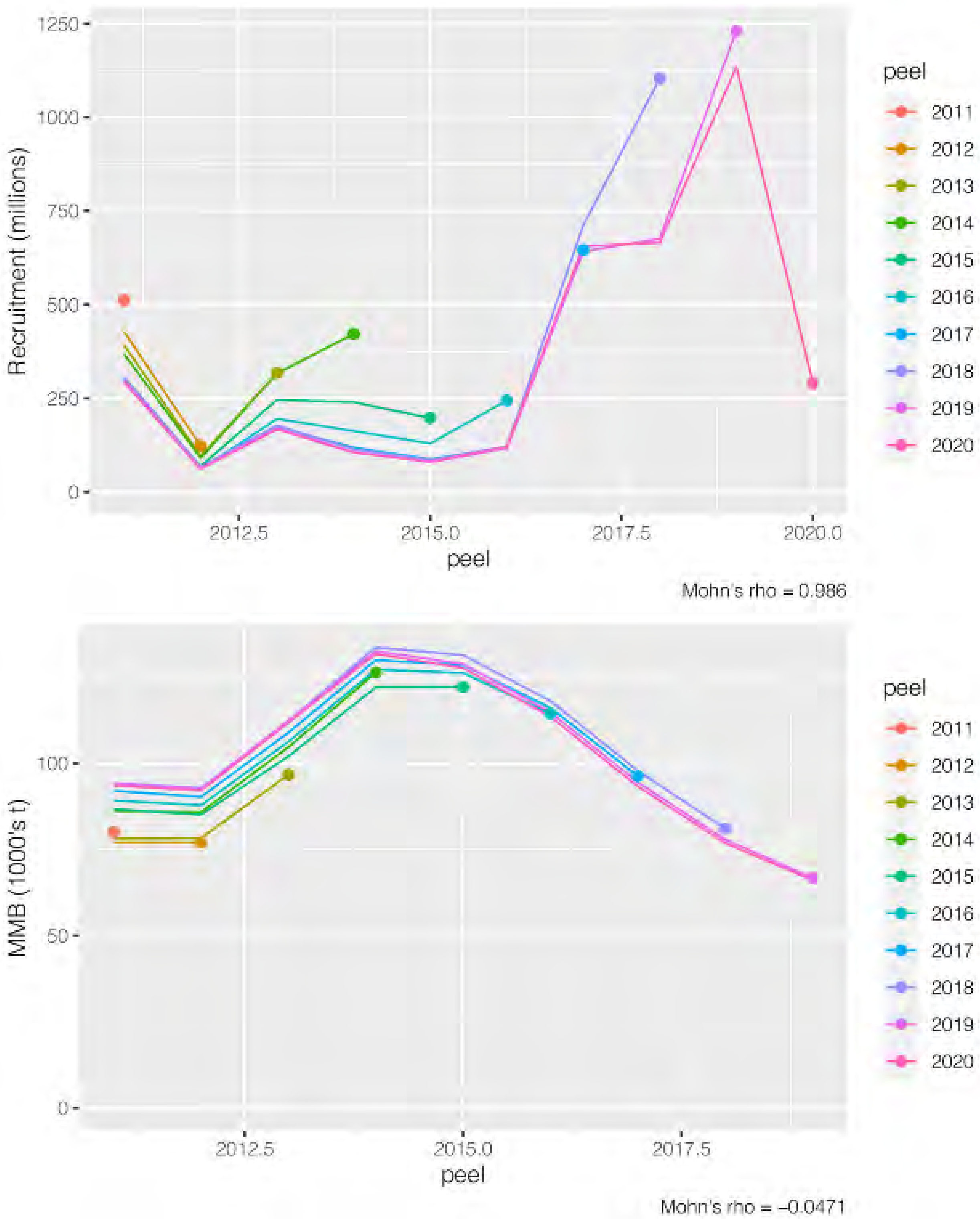

Figure 60. Retrospective patterns for Scenario 19.03(2020). Upper: recruitment. Lower: MMB.

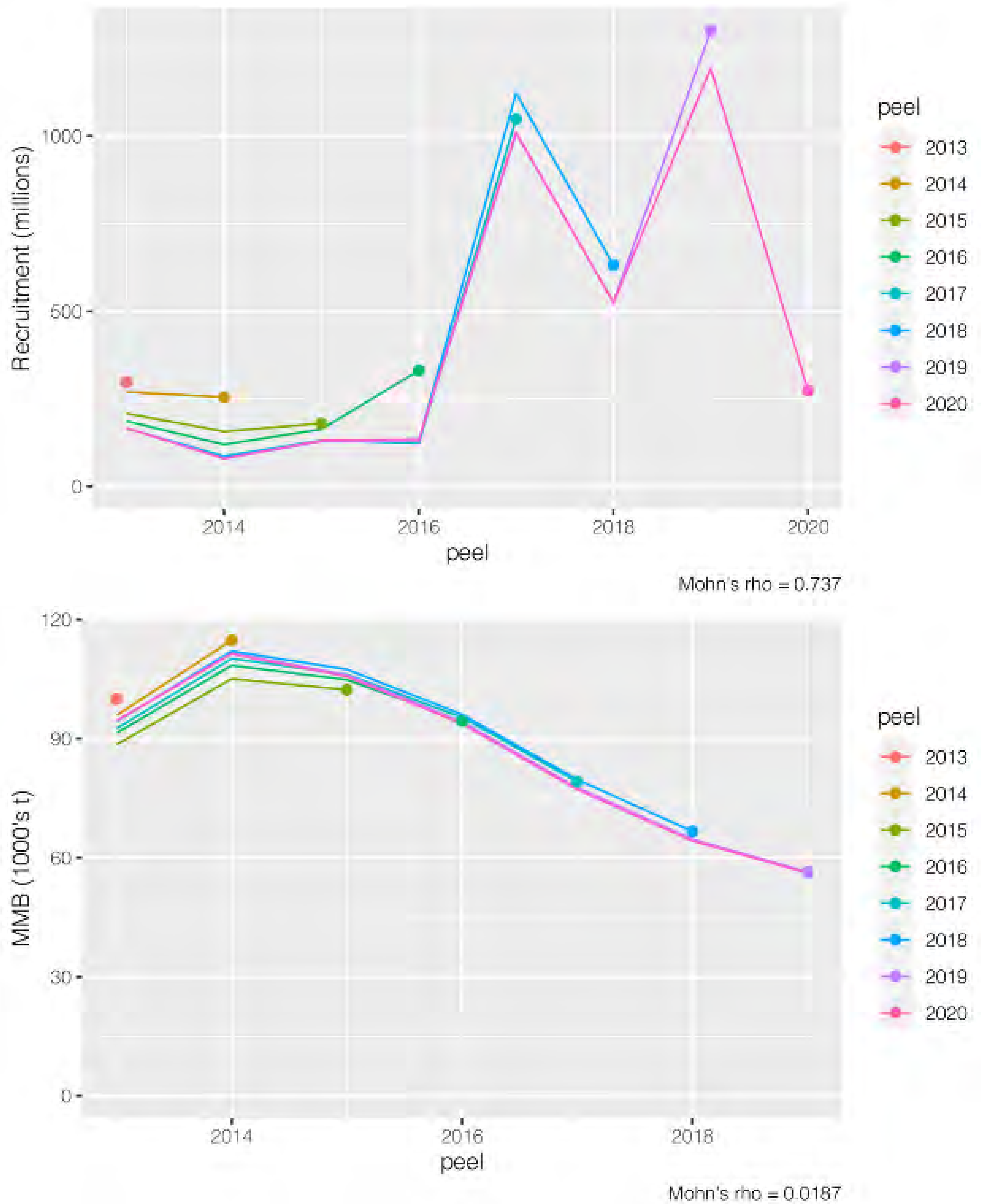

Figure 61. Retrospective patterns for Scenario 20.10. Upper: recruitment. Lower: MMB.

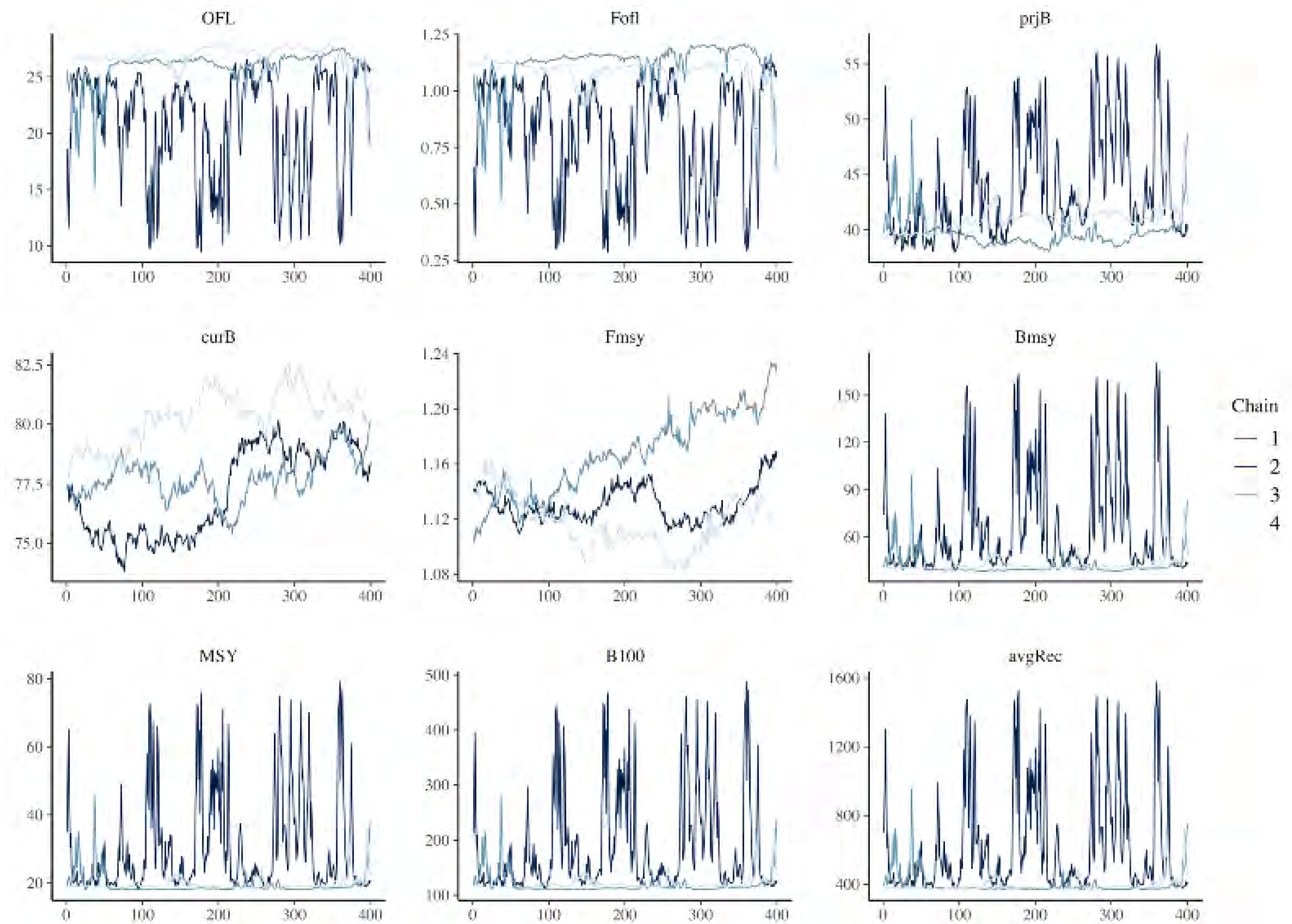

Figure 62. Traces for OFL-related quantities from 4 MCMC chains for Scenario 19.03(2020). Chains were run for 1 million iterations, with a 2,000 step burn-in and every 2,000th iteration saved.

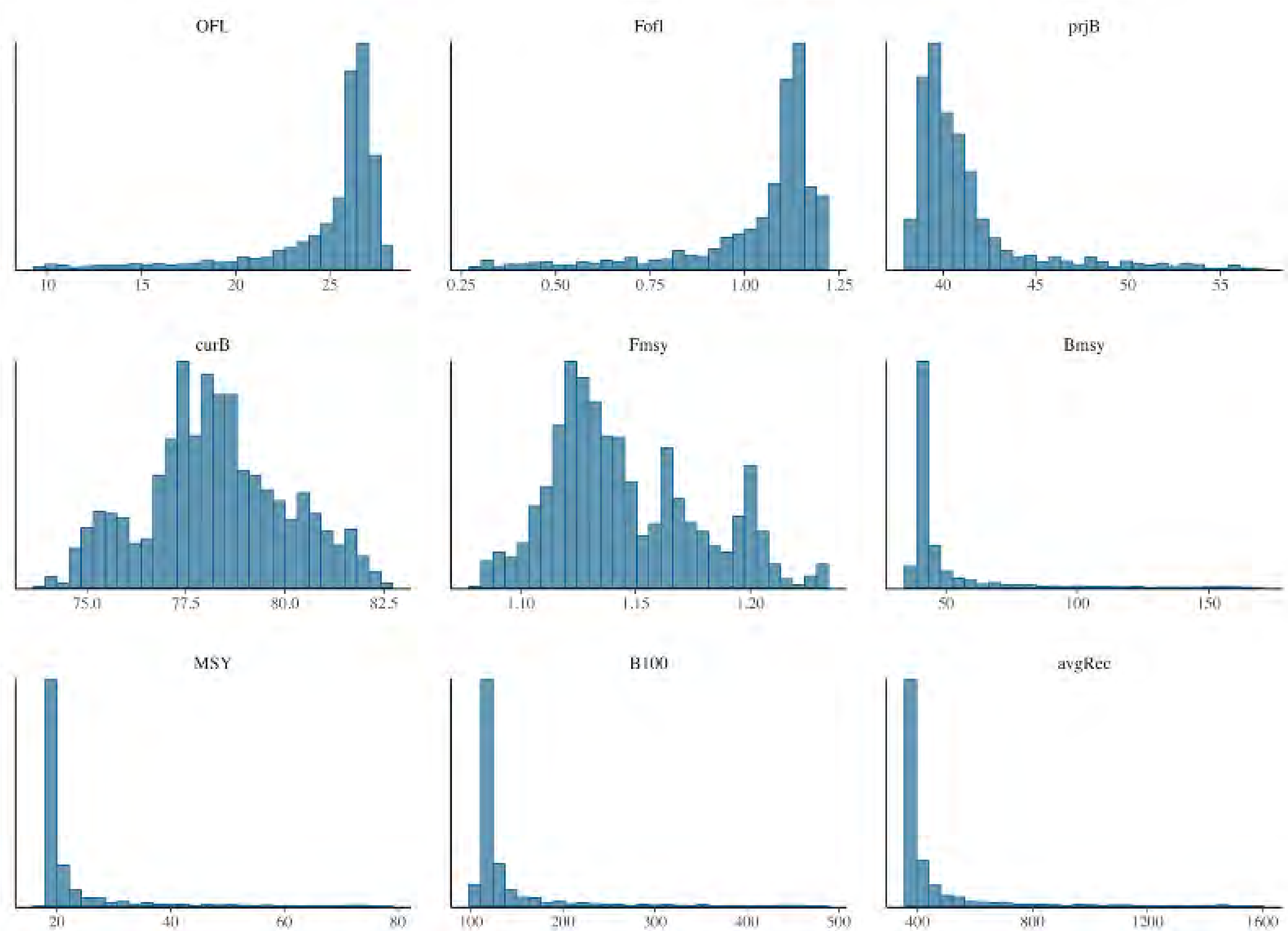

Figure 63. Histograms for OFL-related quantities from 4 MCMC chains for Scenario 19.03(2020). Chains were run for 1 million iterations, with a 2,000 step burn-in and every 2,000th iteration saved.

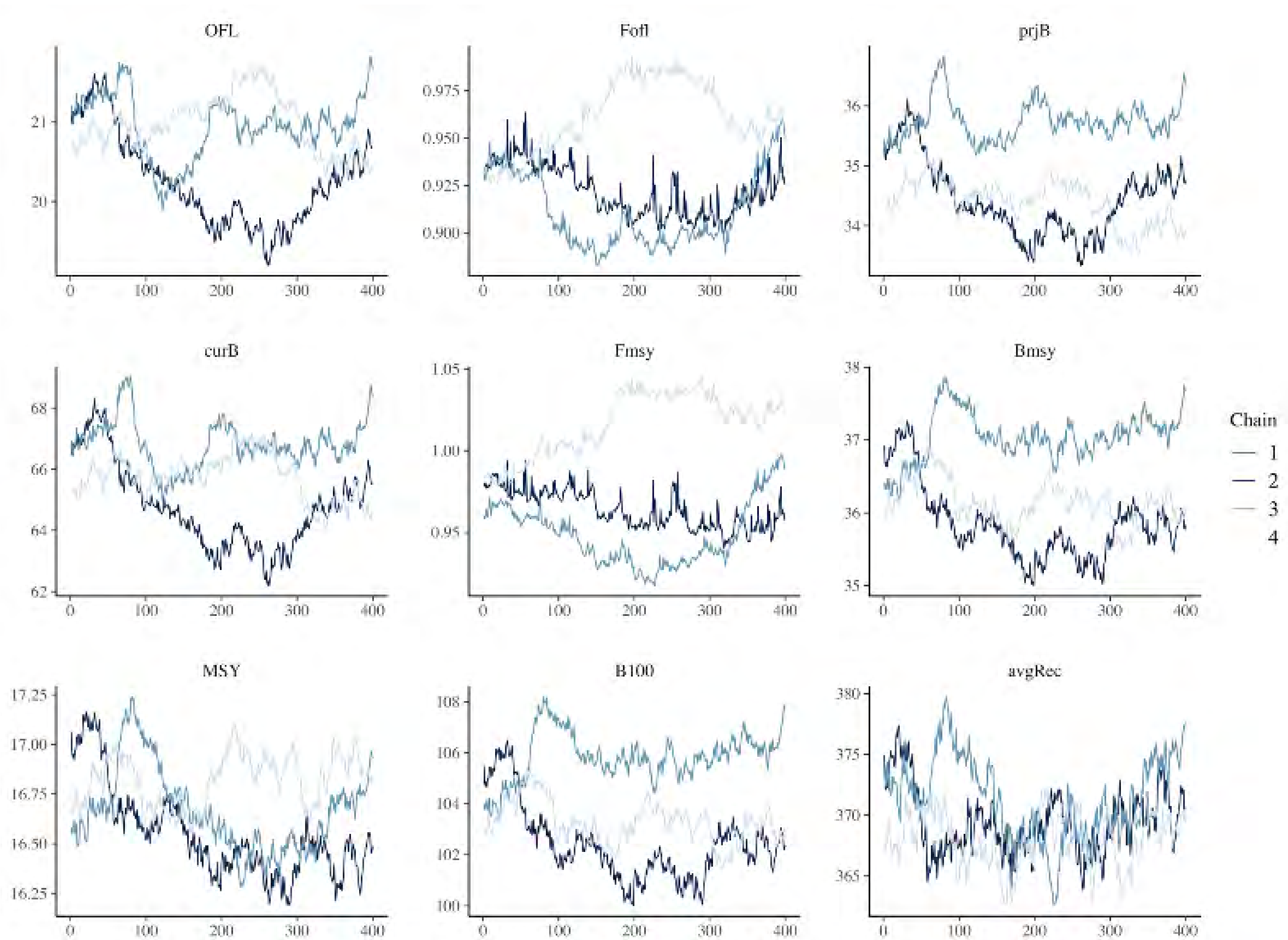

Figure 64. Traces for OFL-related quantities from 4 MCMC chains for Scenario 20.07. Chains were run for 1 million iterations, with a 2,000 step burn-in and every 2,000th iteration saved.

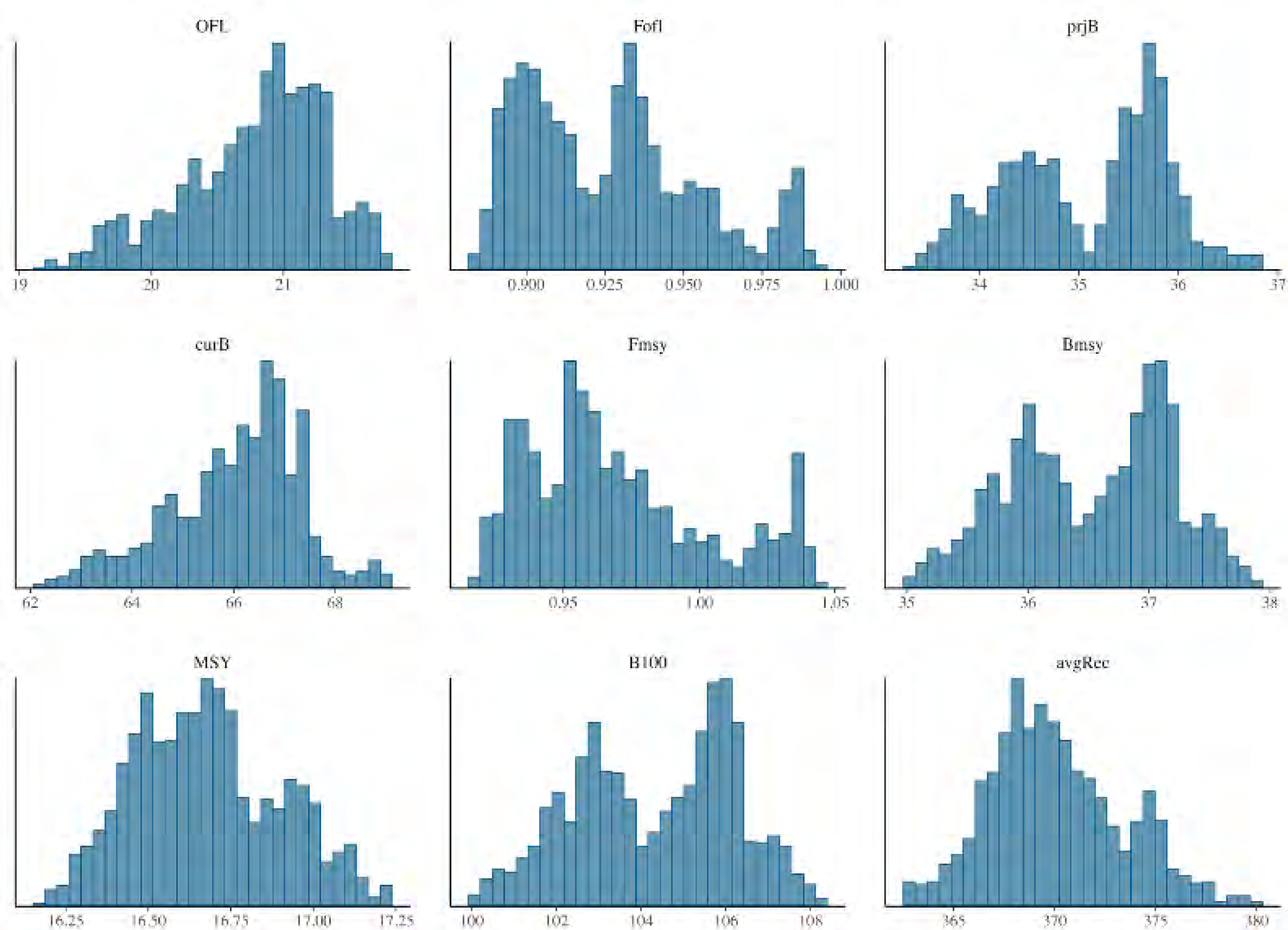

Figure 65. Histograms for OFL-related quantities from 4 MCMC chains for Scenario 20.07. Chains were run for 1 million iterations, with a 2,000 step burn-in and every 2,000th iteration saved.

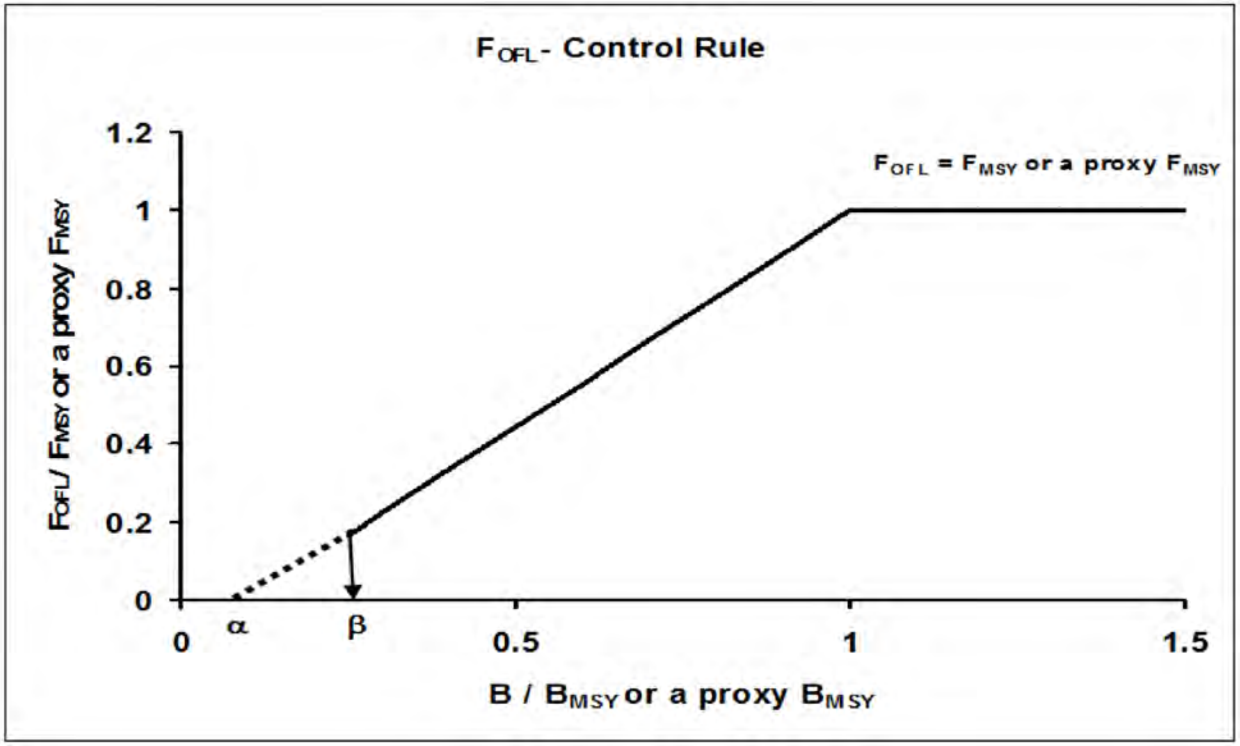

Figure 66. The F_{OFL} harvest control rule.

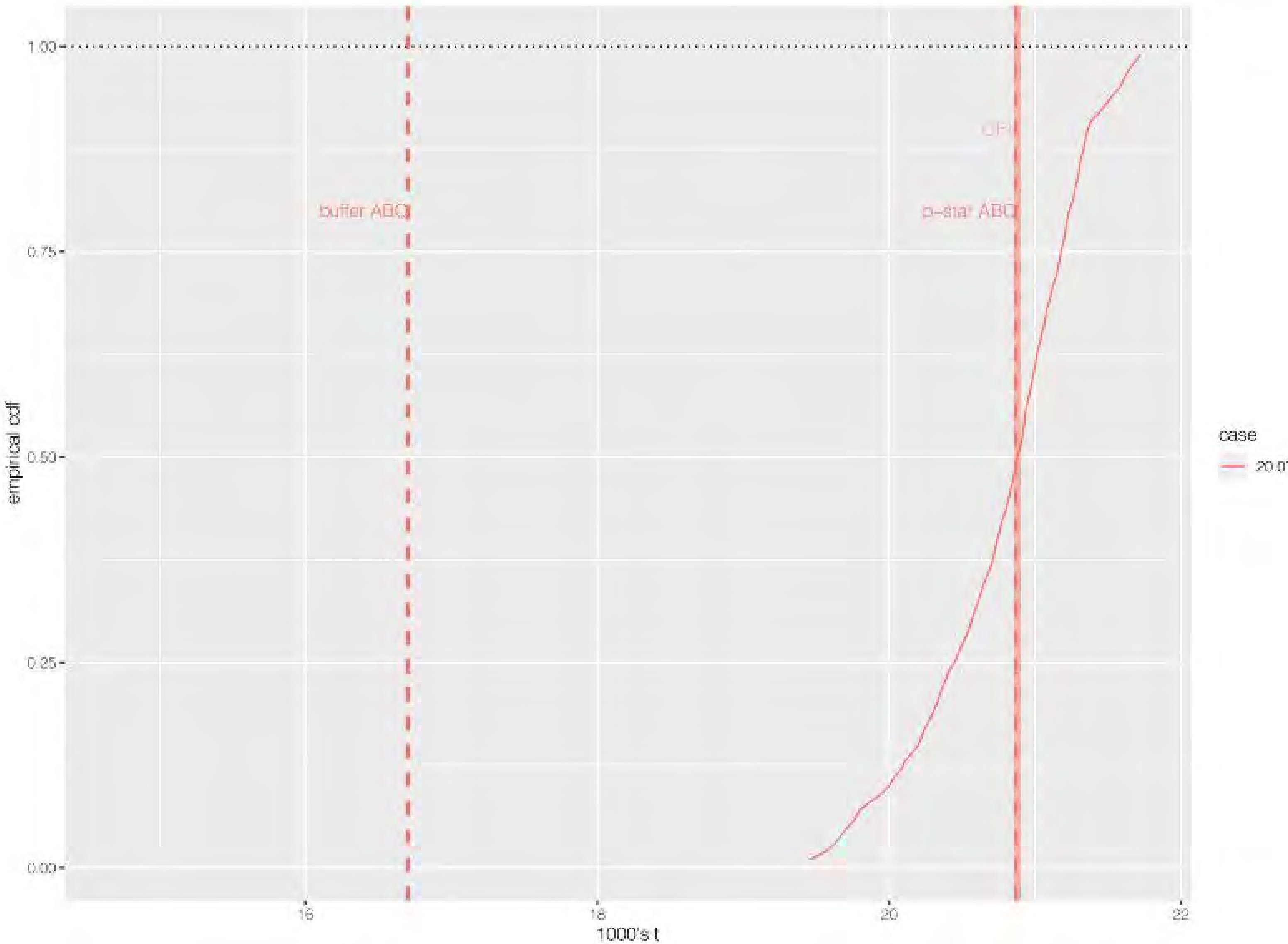

Figure 67. The OFL and ABC from the author's preferred model, scenario 20.07. 4 MCMC chains were merged to obtain the empirical distribution determining the p-star ABC.

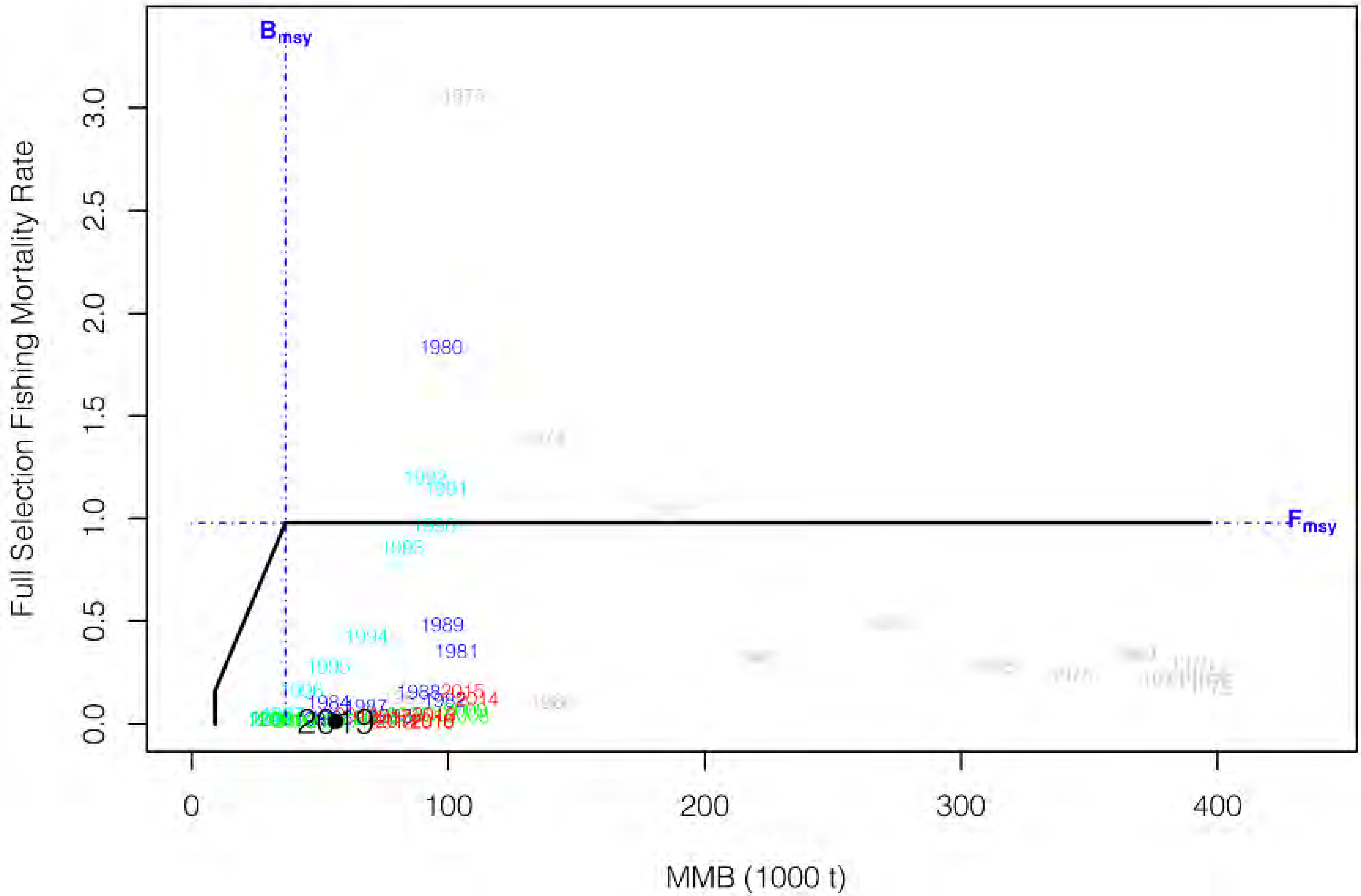

Figure 68. Quad plot for the author's preferred model, Scenario 20.07.

2019 assessment for Pribilof Islands red king crab

Cody Szuwalski

September 16, 2019

Contents

Executive summary

1. Stock: Pribilof islands red king crab (PIRKC), *Paralithodes camtschaticus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch has been periodic since the late 2000s. In general, total bycatch is a small fraction of the OFL.
3. Stock biomass: In recent years, observed mature male biomass (>120mm carapace width) peaked in 2015 and has steadily declined since then. Using a Tier 4 definition of B_{MSY} based on the mean MMB over a period of time during which the stock is assumed to be fished at F_{MSY} results in several models reporting an overfished stock. Using a modified Tier 4 rule that selects a period of time over which the stock is assumed to be at unfished levels and then specifying the B_{MSY} as 35% of the unfished level results in no models reporting an overfished stock.
4. Recruitment: Recruitment is only estimated in the integrated model and appears to be episodic. Survey length composition data suggest a new year class has been established recently, but its size is unclear.
5. Recent management statistics: PIRKC is now on a biennial assessment cycle and was last assessed in 2017. The 2017 recommended model was the random effects model.

Table 1: Historical status and catch specifications for Pribilof Islands red king crab (t).

Year	MSST	Biomass (MMB)	TAC	Retained catch	Total catch	OFL	ABC
2014/15	2871	8894	0	0	1.06	1359	1019
2015/16	2756	9062	0	0	4.32	2119	1467
2016/17	2751	4788	0	0	0.94	1492	1096
2017/18	2751	3439	0	0	1.41	404	303
2018/19	866	5368	0	0	7.22	404	303
2019/20						864	648

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

Year	MSST	Biomass (MMB)	TAC	Retained catch	Total catch	OFL	ABC
2014/15	6.33	19.61	0	0	0	3	2.25
2015/16	6.08	19.98	0	0	0.01	4.67	3.23
2016/17	6.06	10.56	0	0	0	3.29	2.42
2017/18	6.06	7.58	0	0	0	0.89	0.67
2018/19	1.91	11.83	0	0	0.02	0.89	0.67
2019/20						1.9	1.43

6. 2019/2020 OFL projections:

Table 3: Metrics used in designation of status and OFL (t). 'Years' indicate the year range over which recruitment is averaged for use in calculation of B35. 'Status' is the ratio between MMB and BMSY. 'M' is natural mortality.

Year	Tier	BMSY	MMB	Status	FOFL	Years	M
2019/2020	4	1733	5368	3.098	0.21	2000-2018	0.21

Table 4: Metrics used in designation of status and OFL (millions of lb.).

Year	Tier	BMSY	MMB	Status	FOFL	Years	M
2019/2020	4	3.821	11.83	3.098	0.21	2000-2018	0.21

7. Probability distributions of the OFL: No distribution of the OFL was calculated for this assessment cycle.

8. Basis for ABC: ABCs are calculated using a 25% buffer as recommended by the CPT and SSC in 2017.

A. Summary of major changes:

1. Management: This is the first assessment since PIRKC shifted to a biennial management cycle in 2017.
2. Input data: Survey and bycatch data were updated with the most recent data in this draft. Some small adjustments were made to the recent years of bycatch data after a new download from AKFIN.
3. Assessment methodology: In addition to the 3 year running average and random effects model presented in 2017, results from integrated models developed with GMACS are also presented here.
4. Assessment results: Stock status depends upon the definition of B_{MSY}. Scenarios in which B_{MSY} is defined as a range of years of biomass when the stock was fished at F_{MSY} are nearly all overfished. No scenarios in which B_{MSY} is defined as 35% of 'unfished' biomass were overfished.

B. CPT and SSC comments/requests from May 2019:

The CPT and SSC had several comments from May 2019, which are listed below followed by the author's response (CSS):

SSC: The SSC recognizes the assumptions about retained fishery selectivity and bycatch selectivity that must be made in the absence of PIRKC-specific data, resulting in a tradeoff between data and assumptions. The SSC looks forward to a more complete description of these tradeoffs in the September assessment.

CSS: First, I would note that only in an integrated framework can one actually ask these questions, which is a positive point for the integrated assessment in my opinion. Second, I have included several sensitivity runs to explore the impacts of assumptions about poorly known population processes. In general, I think the improvement in understanding of the stock by incorporating other pieces of information in an integrated assessment overshadows the potential problems introduced by incomplete stock-specific information. I discuss this further below.

SSC: The preliminary assessment noted that many of the CVs were exactly equal to one, which suggests a truncation issue. This issue should be investigated for the September assessment.

CSS: After communication with the Kodiak lab, it was determined that CVs exactly equal to 1 occur when the estimate of abundance for a given size class is determined by observations from a single survey station. This can occur in the early years of the survey data for PIRKC (i.e. pre 1990, before the population expanded) and for size classes that are a subset of all available size classes (e.g. >120mm carapace width).

SSC: The CPT recommends that the assessment author re-evaluate the assumption that the target biomass is set over a range of years over which the stock is thought to be near B_{MSY}. The author should propose alternatives (and justifications) for consideration in September 2019.

CSS: I can think of two alternatives for a stock that has been rarely fished over the assessment period:

1. Identify a period of time at which the stock is at 'unfished' levels and set the B_{MSY} to some fraction (e.g. 35%) of unfished biomass. This is still in the spirit of Tier 4 rules, but adjusts for the special circumstances of PIRKC.
2. Use Tier 3 methodologies for the stock so that reference points are a function of life history and recent productivity. This may be somewhat more difficult to justify than option #1, given some parameters determining important population processes are borrowed from another assessment (though the stocks do appear to be genetically indistinct and uncertainty resulting from the Robin Hood approach could be addressed by placing wide priors on these parameters and attempting to use Bayesian methods for assessment).

I present option #1 within this document and look forward to discussion about #2 at the CPT meeting.

SSC: For September 2019, the assessment author proposed to present three assessment models:

- Inverse variance weighted 3-year running average of mature male biomass.
- Random effects model fit to survey male biomass.

- An integrated assessment model fit to male abundance and length composition data from the NMFS summer survey.

The SSC/CPT supports the choice of these models and the additional guidance provided by the CPT:

- Attempt to leverage information from the more data-rich BBRKC assessment.
- Fit the model to biomass rather than total abundance.
- Thoroughly evaluate the relative weights given to different data components in the model, in particular the size composition data and survey biomass.

CSS: Given the discussion on natural mortality in the snow crab assessment and past discussions for PIRKC, I have also added two scenarios exploring the impact of different assumptions about M. In total, I present 7 models for consideration here:

- 19.01 : Inverse variance weighted, 3 year running average
- 19.02 : Random effects model
- 19.1 : GMACS fit to biomass with assumptions borrowed from BBRKC
- 19.2 : 19.1 + with more of the population selected in the trawl bycatch
- 19.3 : 19.1 + molting probability shifted to the left
- 19.4 : 19.1 + increased M (Hamel)
- 19.5 : 19.1 + increased M (Then)

The author's preferred model is 19.4 with the modified Tier 4 definition of B_{MSY}. This combination of model and HCR incorporates all available information for the stock, uses a more defensible prior for M, and addresses inconsistencies in the definition of B_{MSY} for PIRKC.

C. Introduction

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 in the Barents Sea (Jorstad 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 US-Russian boundary (Figure 2). The distribution of red king crab within the Pribilof District is concentrated around the islands (see Figure 3 for distribution in 2019).

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 three stocks: Okhotsk Sea-Aleutian Islands-Norton Sound, Southeast Alaska, and the rest of the EBS (Grant and Cheng 2012).

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 eggs per female 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 was reported for eastern Bering Sea male red king crabs (Somerton 1980). In the recent history of the assessment of PIRKC, crab greater than 120 mm carapace width were used as a measure of mature male bioamss. Early studies predicted that red king crab become mature at approximately age 5 (Powell 1967; Weber 1967); however, Stevens (1990) predicted mean age at maturity in Bristol Bay to be 7 to 12 years, and Loher et al. (2001) predicted age at maturity to be approximately 8 to 9 years after settlement.

Natural mortality of Bering Sea red king crab stocks is poorly known (Bell 2006). 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). Siddeek et al. (2002) reviewed natural mortality estimates from various sources. Natural mortality estimates based upon historical tag-recapture data ranged 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 ranged 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. Natural mortality based on empirical estimates for a maximum age of 21 from Hoenig (1983), Hamel (2015), and Then et al. (2015) are 0.21, 0.26, and 0.30, respectively. Assuming a maximum age of 25 (following BBRKC) results in natural mortalities of 0.18, 0.22, 0.26 for Hoenig, Hamel, and Then methodologies, respectively.

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 crab are approximately: 23% at 10 mm CL, 27% at 50 mm CL, 20% at 80 mm CL and 16 mm for immature crab 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 crab 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).

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 4). 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 a more complete management history).

Amendment 21 to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 2) 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 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 and the OFL.

D. Data

The following sources and years of data are available: NMFS trawl survey (1976-present), retained catch (1993-present), trawl bycatch (1991-present), fixed gear bycatch (1991-present), and pot discards (1998 to present).

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 (Table 5), but no retained catch has been allowed since 1999.

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.

$$w_l = \alpha l^{\beta} \tag{1}$$

$$w_{avg} = \frac{\sum_l w_l N_l}{\sum_l N_l} \tag{2}$$

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 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 recent years, catch of PIRKC in other crab fisheries has been almost non-existent.

Bycatch from groundfish fisheries from 1989 to present are available in the AKFIN database and included in the integrated assessment as a single fishery with selectivity equal to the trawl fishery estimated in the BBRKC assessment (Figure 5). See Calahan et al. 2010 for a description of the methodology used to develop these data.

Catch-at-length

Catch-at-length data are not available for this fishery.

Survey abundance and length composition

The most up-to-date NOAA Fisheries EBS bottom trawl survey results are included in this SAFE report (1976-2019; see Lang et al. 2018 for methodology). Data available for estimating the abundance of crab around the Pribilof Islands are relatively sparse. Male abundance varies widely over the history of the survey time series and uncertainty around area-swept estimates of abundance is large due to relatively low sample sizes (Figure 6). Red king crab have been observed at 35 unique stations of the 44 stations in the Pribilof District over the years 1976 to present (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 1976-present (Figure 7). Male crabs were observed at 12 stations in the Pribilof District during the 2019 survey. Although estimated numbers at length are variable from year to year, 3 to 4 cohorts can be discerned in the length composition data (Figure 8).

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 1980s and remained in that region until the 1990s. Since then, the centers of distribution have generally been located closer to St. Paul Island. Currently, the largest tows were observed north and east of St. Paul Island (Figure 3). Mature male biomass (>120 mm) at the time of the survey has declined in recent years (Figure 9). However, a potential recruitment event occurred in recently (Figure 8) and has been observed in the survey data for the past two years. Given the variability in the survey data, more observations will be needed to corroborate this observation.

E. Analytical approaches

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 past years to set allowable catches. In 2017, biomass and derived management quantities were also estimated by several iterations of a random effects method, one of which was selected by the CPT as the chosen model. The Tier 4 harvest control rule (HCR) is used in conjunction with estimates of MMB to calculate the OFL. In the Tier 4 HCR, natural mortality is 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}. The Tier 4 B_{MSY} proxy for PIRKC was calculated in 2017 as the average of the 1991/92 to the present year of observed survey data projected forward to February 15, removing the observed catch. Given the fishing history of PIRKC, accommodating this stock with the current Tier 4 rule is challenging, so an alternate version is presented in this assessment (see below). This year, an integrated assessment developed with GMACS is also presented for comparison with the other methods. Below are brief descriptions of each methodology

Running average

An inverse variance weighted 3 year running average of mature male biomass at survey time was calculated by:

$$RA_t = \frac{\sum_{t-1}^{t+1} MMB_t/\sigma_t^2}{\sum_{t-1}^{t+1} 1/\sigma_t^2} \quad (3)$$

where MMB_t is the estimated mature male biomass (>=120 mm carapace width) from the survey data and σ_t^2 are the associated variances (Figure 9).

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. This model was developed for use in NPFMC groundfish assessments and uses the same input data as the running average model. The likelihood equation for the random effects model is:

$$\sum_{i=1} 0.5(log(2\pi\sigma_i^2) + \frac{(\hat{B}_i - B_i)^2}{\sigma_i^2}) + \sum_{t=2} 0.5(log(2\pi\sigma_p^2) + \frac{(\hat{B}_{t-1} - \hat{B}_t)^2}{\sigma_p^2}) \quad (4)$$

where B_i is the observed biomass in year i, $\hat{B}_t$ is the model estimated biomass in year t, σ_i^2 is the variance of observed 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 $e^{2\lambda}$, where λ is a parameter estimated in the random effects model.

Iterations performed to address problems in convergence for the 2017 assessment by adding priors on variance components contained an error in the modified .TPL file used (Turnock et al., 2016 & Turnock, pers. comm.). Turnock suggested trying to fit the original model with updated data to see if it converged; it did. Consequently, the presented random effect model is the 'standard' version of the random effects code used in NPFMC ground fish assessments. The general result of fitting of the running average and random effects model is a smoothing of the time series of biomass estimated from the survey (Figure 10).

Integrated assessment model

Results from an integrated assessment framework have been presented since 2014 (Szuwalski, Turnock and Foy, 2015), but this year the integrated assessment was implemented using the general model for assessing crustacean stocks, GMACS (Ianelli, pers. com.). Previous integrated assessments fit to male abundance, but this iteration fit male biomass >120 mm carapace width to facilitate comparison with the other assessment methods. Retained catches and bycatch were fit using assumed selectivities from the BBRKC assessment (Zheng et al., 2018). Growth was estimated and informed by cohorts moving through the population and assumptions about natural mortality and molting probabilities. Molting probabilities and survey catchability were fixed based on the estimates from the 2018 BBRKC assessment. 120 parameters were estimated (Table 6) and 7 parameters were fixed (Table 7). Several different scenarios are presented for the integrated assessment to explore the impact of the assumptions about poorly known population processes on management advice, including sensitivities to trawl selectivity, molting probabilities, and natural mortality. A bin size of 5 mm was selected to model numbes at length in the integrated assessment based on Szuwalski (2015).

Fits to data and estimated and assumed population processes

Survey biomass and length composition data

Fits to the survey biomass varied by model; models with higher M were able to respond more strongly to interannual changes in biomass (Figure 9). The base model (19.1) that informed assumed parameters by estimates from the BBRKC assessment was the only model that did not display an uptick in predicted biomass for the terminal year of biomass. Although a relatively coherent story of 3 to 4 cohorts moving through the population were captured by all models (save 19.5, which identified 4), there were sometimes substantial differences between the fits to the size composition data among models (Figure 11). One of the largest differences comes in the last two years of size composition data. Model 19.1 does not fit what appear to be a newly established cohort, while models 19.2, 19.3, and 19.4 fit them closely. Differences in fits to the size composition data are likely related to differences in estimated survey selectivity (Figure 12). The slope parameter ('growth_cv' in GMACS) for the logistic function varied among models (Table 6). Trajectories of predicted mature male biomass at the time of mating were similar across models, with notable departures in the final year and from model 19.5 (Figure 13). Model 19.4 has the best fits of the models that used parameters estimated in the BBRKC assessment (Table 11).

Retained catches, bycatches, and estimated fishing mortality

Retained catches and bycatches were fit essentially identically by all models (Figure 14), but the inferred influence of the fishery on the population as seen through the estimated fishing mortality varied by model (Figure 15). Model 19.2 has the highest estimated fishing mortality, model 19.1 had the highest bycatch mortality, and model 19.5 had the smallest estimated fishing and bycatch mortality.

Molting probability and growth

Growth was estimated within each model and varied considerably among models (Figure 16). Molting probability was fixed according to the estimates from the 2018 BBRKC assessment, except for one model (19.3), which shifted the curve to the left 10 mm (Figure 17). No growth data exist to fit to, so the information to estimate growth comes from the modes of the survey size composition data, natural mortality, and probability of molting by size. Still, the range of growth increments from all models are roughly consistent with studies done for red king crab elsewhere.

Estimated recruitment

Three to four large year classes are estimated for each model. Model 19.1 does not fit the recent length comp data and does not estimate any recruitment in the 2010s. Model 19.5 estimates an extra cohort in 2001 that the other models do not. The size and exact timing of cohorts that all models agree on vary, depending upon the assumptions made about other life history processes (Figure 18). The second recruitment pulse (around the early 1990s) occurs in different years for different models. This is primarily a result of different fits to somewhat noisy length compositions in 1996-98.

F. Calculation of reference points

Tier 4 OFL and B_{MSY}

Tier 4 control rules use natural mortality as a proxy for F_{MSY} and calculates a proxy for B_{MSY} by averaging the biomass over a period of time when the stock is thought to have been at B_{MSY}. A Tier 4 OFL is calculated by applying a fishing mortality determined by the harvest control rule below to the mature male biomass at the time of fishing.

$$F_{OFL} = \begin{cases} Bycatchonly & if \frac{MMB}{MMB_{MSY}} \leq 0.25 \\ \frac{\lambda M(\frac{MMB}{MMB_{MSY}} - \alpha)}{1-\alpha} & if 0.25 < \frac{MMB}{MMB_{MSY}} < 1 \\ \lambda M & if MMB > MMB_{MSY} \end{cases} \quad (5)$$

Where MMB is the mature male biomass projected to the time of mating, MMB_{MSY} is the average mature male biomass over the years 1991-present, M is natural mortality, and α determines the slope of the descending limb of the HCR (here set to 0.05). Two different versions of B_{MSY} are calculated for the 7 models presented: the status quo and one in which the average MMB from 2000-present is taken as an 'unfished' biomass and B_{MSY} is specified as 35% of that unfished biomass. Selecting a range of years over which the population is unfished is difficult, particularly for a population driven by sporadic recruitment. Here the year 2000 was selected as the beginning of the 'unfished' period because fishing ceased in the 1998/1999 season. The harvest control rule is used to calculate two OFLs for each model using each of these reference points.

A large range of terminal year MMBs were estimated by the presented scenarios (1627-7298 t). Similarly, the resulting B_{MSY} varied widely (status quo range: 4696-5389 t; modified range: 1587-1934 t) along with the calculated OFLs (status quo range: 78-1054 t; modified range: 237-1642 t). In general, fewer stocks were overfished and OFLs were larger with the modified B_{MSY} (Table 10).

Acceptable biological catches

ABCs are calculated for other crab stocks in the Bering Sea by multiplying the OFL by a buffer determined by the CPT and SSC. Stocks with similar levels of uncertainty use a buffer of 25%. The ABC for the author's preferred model 19.4 is 648.

Variables related to scientific uncertainty in the OFL probability distribution

Uncertainties in estimates of biomass for Pribilof Islands red king crab were relatively high due to small sample sizes. The coefficient of variation for the estimate of male abundance for 2018 was 0.33 and has ranged between 0.36 and 0.92 since the 1991 peak in biomass (Figure 9). Recruitment, growth, and survey selectivity were estimated within the integrated assessment, but maturity, survey catchability, fishery selectivity, and natural mortality were fixed to values from the BBRKC assessment. Fitting to data to inform these processes might increase both the accuracy and uncertainty in estimates of management quantities. F_{MSY} was assumed to be equal to natural mortality, which is poorly known. 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 (but probably not much given their small magnitudes).

G. Author Recommendation

The author's preferred model is 19.4 used with the modified definition of B_{MSY} to calculate the OFL for several reasons. First, the modified definition of B_{MSY} is more consistent with the intent of the tier 4 harvest control rule. The objective is to use a period of time within the fishery as a reference for sustainable exploitation; unfortunately, there are only 5 fishing years out of 39 years of the existence of an appreciable population of PIRKC. Using the unfished state of PIRKC as the 'reference' and defining B_{MSY} as a fraction of that level is a suitable compromise between the intent of the tier rule and the reality of the fishery.

The use of an integrated model is also preferable to either of the smoothing algorithms previously used because it incorporates the clearest signal available to inform PIRKC population dynamics available: the length composition data from the survey. The length composition data clearly show cohorts moving through the population; the survey biomass data are exceptionally noisy. The estimated biomasses from the integrated models are also more realistic in their dynamics than either of the smoothers. The decreases seen in the random effects model imposed by fitting to the higher observations are inconsistent with information available on natural mortality for red king crab. The time elapsed from the peaks of biomass to the troughs in the running average and random effects models is much shorter than would be expected with a natural mortality of 0.18 (or even the higher Ms considered here).

The integrated model provides a platform to perform sensitivities to model assumptions and expand understanding of PIRKC population dynamics that is not available with the smoothing algorithms. The integrated models did differ in their estimates of terminal year biomass and this is likely related to the way in which each model fits the length composition data and the assumed M, which should be points for future investigation.

H. Data gaps and research priorities

The largest data gap is the number of observations from which the population size and biomass is extrapolated and this will not likely change in the future. The small sample sizes (and no expected increases in sample size) support the use of as much of the available data as possible in assessment efforts. Catch-at-length data for the trawl fishery are also currently unavailable, but their inclusion would allow trawl fishery selectivity to be estimated and discard mortality specific to PIRKC to be incorporated into the integrated model. 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 in the NMFS survey may also shed some light on divergent changes in abundance in recent years. The Bering Sea Fisheries Research Foundation (BSFRF) selectivity studies sampled crab around the Pribilof Islands in 2017 and 2018, so it is possible some analysis could be performed with those data. Retrospective analyses were not performed because the integrated assessment has not yet been accepted as the base model. Finally, Bayesian methods with diffuse priors for population processes is a potential methodology to better account for the uncertainties.

I. 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; overland et al., 2008). Ocean acidification also appears to have a large detrimental effect on red king crab (Long et al., 2013), which may impact the productivity of this stock in the future.

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Appendix A. Data file for the reference model

***Some portions of the .DAT and .CTL files do not fit on the page. For complete .DAT files or .CTL files, contact the author.**

```
#==========================================================================================
#   Gmacs   Main    Data    File    Version 1.1:    BBRKC   Example
#   GEAR_INDEX  DESCRIPTION
#   1   :   Pot fishery retained    catch.
#   1   :   Pot fishery with    discarded   catch.
#   2   :   Trawl   bycatch
#   3   :   Trawl   survey
#   Fisheries:  1   Pot "Fishery,"  2   Trawl   "by-catch,"
#   Surveys:    3   NMFS    Trawl   "Survey,"
#==========================================================================================
1976    # Start year
2019    # End   year
3   # Number of seasons
3   # Number of fleets (fishing fleets and surveys)
1   # Number of sexes
1   # Number of shell condition types
1   # Number of maturity types
35  # Number of size-classes in the model
3   # Season recruitment occurs
3   # Season molting and growth occurs
3   # Season to calculate SSB
1   # Season for N output
#   size_breaks (a  vector  giving  the break   points  between size    "intervals,"    dim=nclass+1)
35  40  45  50  55  60  65  70  75  80  85  90  95  100 105 110 115 120 125 130 135 140 145 150 155 160
#   Natural mortality   per season  input   type    (1  =   vector  by  "season,"   2   =   matrix  by
1
#   Proportion of the total natural mortality to be applied each    season
0.33 0.33 0.34  #made up; fix soon
# Fishing fleet names (delimited with: no spaces in names)
Pot_Fishery:trawl_bycatch
# Survey names (delimited with: no spaces in names)
NMFS_Trawl
# Are the seasons instantaneous (0) or continuous (1)
1 1 1
#1 1 1 1 1 1 1
# Number of catch data frames
2
# Number of rows in each data frame
6 28
##  ================================================================================ ##
##  CATCH   DATA
##  Type of "catch: 1 = retained, 2= discard, 0 =total
##  Units of catch: 1 = biomass, 2 = numbers"""
##  ================================================================================##
##  Male    retained    pot fishery (tonnes)
#year   seas    fleet   sex obs cv  type    units   mult    effort  discard_mortality
1993    2   1   1   1183    0.05    1   1   1   0   0
1994    2   1   1   607.34  0.05    1   1   1   0   0
1995    2   1   1   407.32  0.05    1   1   1   0   0
1996    2   1   1   90.87   0.05    1   1   1   0   0
1997    2   1   1   343.29  0.05    1   1   1   0   0
1998    2   1   1   246.91  0.05    1   1   1   0   0
```

```
##  trawl bycatch
#year   seas    fleet   sex obs cv  type    units   mult    effort  discard_mortality
1991    2   2   1   2.30835 0.05    2   1   1   0   0.2
1992    2   2   1   45.78308    0.05    2   1   1   0   0.2
1993    2   2   1   39.86201    0.05    2   1   1   0   0.2
1994    2   2   1   6.07316 0.05    2   1   1   0   0.2
1995    2   2   1   0.58299 0.05    2   1   1   0   0.2
1996    2   2   1   0.83782 0.05    2   1   1   0   0.2
1997    2   2   1   0.79465 0.05    2   1   1   0   0.2
1998    2   2   1   2.96197 0.05    2   1   1   0   0.2
1999    2   2   1   6.23081 0.05    2   1   1   0   0.2
2000    2   2   1   2.07843 0.05    2   1   1   0   0.2
2001    2   2   1   10.42956    0.05    2   1   1   0   0.2
2002    2   2   1   6.52286 0.05    2   1   1   0   0.2
2003    2   2   1   2.5817  0.05    2   1   1   0   0.2
2004    2   2   1   8.00301 0.05    2   1   1   0   0.2
2005    2   2   1   6.43697 0.05    2   1   1   0   0.2
2006    2   2   1   16.52315    0.05    2   1   1   0   0.2
2007    2   2   1   2.22395 0.05    2   1   1   0   0.2
2008    2   2   1   9.02576 0.05    2   1   1   0   0.2
2009    2   2   1   2.53139 0.05    2   1   1   0   0.2
2010    2   2   1   8.39336 0.05    2   1   1   0   0.2
2011    2   2   1   6.59366 0.05    2   1   1   0   0.2
2012    2   2   1   15.85071    0.05    2   1   1   0   0.2
2013    2   2   1   2.63377 0.05    2   1   1   0   0.2
2014    2   2   1   1.06727 0.05    2   1   1   0   0.2
2015    2   2   1   4.32168 0.05    2   1   1   0   0.2
2016    2   2   1   0.94395 0.05    2   1   1   0   0.2
2017    2   2   1   1.41398 0.05    2   1   1   0   0.2
2018    2   2   1   7.22089 0.05    2   1   1   0   0.2
##==============================================================================##
##  RELATIVE    ABUNDANCE   DATA
##  Units   of  Abundance:  1   =   "biomass,"  2   =   numbers
##  TODO:   add column  for maturity    for terminal    molt    life-histories
##  ============================================================================##
##  Number  of  relative    abundance   indicies
1
##  Number  of  rows    in  each    index
44
#   Survey  data    (abundance  "indices,"  units   are 1000    mt)
#Year   Season  Fleet   Sex Abundance   CV  Units
1976    1   3   1   165.0820617 1   1
1977    1   3   1   118.6098455 1   1
1978    1   3   1   1249.504275 0.825444585 1
1979    1   3   1   555.786924  0.515229785 1
1980    1   3   1   1268.984093 0.382081279 1
1981    1   3   1   312.2868886 0.584325303 1
1982    1   3   1   1463.679065 0.698000353 1
1983    1   3   1   526.744361  0.533724327 1
1984    1   3   1   317.2336136 0.548811503 1
1985    1   3   1   61.48435668 1   1
1986    1   3   1   137.6189026 0.69839786  1
1987    1   3   1   53.57634662 1   1
1988    1   3   1   106.6465639 1   1
```

```
1989    1   3   1   1529.464076 0.90992879  1
1990    1   3   1   1141.083317 0.928450918 1
1991    1   3   1   4429.984707 0.796181771 1
1992    1   3   1   3304.807041 0.596461097 1
1993    1   3   1   9873.34095  0.921566362 1
1994    1   3   1   9138.77513  0.767521538 1
1995    1   3   1   18055.69546 0.60095161  1
1996    1   3   1   2361.497955 0.371521839 1
1997    1   3   1   6158.829812 0.622539865 1
1998    1   3   1   2323.52199  0.35996772  1
1999    1   3   1   5522.918743 0.666747632 1
2000    1   3   1   4320.463935 0.37363563  1
2001    1   3   1   8603.167987 0.786467508 1
2002    1   3   1   7037.318355 0.685911274 1
2003    1   3   1   5372.970101 0.657890334 1
2004    1   3   1   3621.908657 0.589178579 1
2005    1   3   1   1238.268912 0.585062881 1
2006    1   3   1   7002.930989 0.382674833 1
2007    1   3   1   5223.698293 0.492451158 1
2008    1   3   1   5462.268463 0.506106314 1
2009    1   3   1   2500.339048 0.63776799  1
2010    1   3   1   4404.990634 0.436292304 1
2011    1   3   1   3834.344372 0.648228535 1
2012    1   3   1   4477.112792 0.573312819 1
2013    1   3   1   7749.452256 0.619447168 1
2014    1   3   1   12046.84171 0.784574994 1
2015    1   3   1   15172.86095 0.738783782 1
2016    1   3   1   4150.360114 0.700657951 1
2017    1   3   1   3658.466372 0.645985498 1
2018    1   3   1   928.7018441 0.42596546  1
2019    1   3   1   2086.406334 0.343726969 1
## Number of length frequency matrices
1
## Number of rows in each matrix
32
##  Number  of  bins   in  each   matrix  (columns   of  size   data)
35
##  SIZE COMPOSITION DATA FOR ALL FLEETS
##  =============================================================================== ##
##  SIZE   COMP   LEGEND
##  Sex: 1  "= male,"   "2 = female, 0" #NAME?
##  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
##  =============================================================================== ##
#Retained   males
##Year  Season  Fleet   Sex Type    Shell   Maturity    Nsamp   DataVec
1988    1   3   1   1   0   0   82  0   0   0   0.012195122 0.073170732 0.048780488 0.30487805  0.20731
1989    1   3   1   1   0   0   82  0   0   0   0   0   0   0   0   0   0.024390244 0.048780488 0.14634
1990    1   3   1   1   0   0   200 0   0   0   0   0   0   0   0   0.007508939 0   0   0   0.004962619
1991    1   3   1   1   0   0   102 0   0   0   0   0   0   0   0.029126214 0   0.009708738 0.009708738
1992    1   3   1   1   0   0   76  0   0   0   0.013157895 0   0   0   0   0   0   0   0.026315789 0.0
1993    1   3   1   1   0   0   166 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0.03330
1994    1   3   1   1   0   0   113 0   0   0   0   0   0   0   0   0   0   0   0   0   0.005649717 0.00
```

```
1995    1   3   1   1   0   0   200 0   0   0   0   0   0.00330033  0   0   0   0   0.00330033  0.00330
1996    1   3   1   1   0   0   31  0   0.032258065 0   0   0   0   0   0   0   0   0   0.032258065 0.0
1997    1   3   1   1   0   0   165 0   0   0   0   0   0   0   0   0.006060606 0.006060606 0.030303031
1998    1   3   1   1   0   0   66  0   0   0   0   0   0   0   0   0   0   0   0.015151515 0   0.01515
1999    1   3   1   1   0   0   200 0   0   0   0   0   0.005086686 0.005086686 0.0356068   0.091560343
2000    1   3   1   1   0   0   86  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0.0116
2001    1   3   1   1   0   0   200 0   0   0   0   0   0   0   0   0   0.003012048 0   0.012048193 0.0
2002    1   3   1   1   0   0   105 0   0   0   0   0   0   0   0   0   0   0.00952381  0   0   0   0
2003    1   3   1   1   0   0   67  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
2004    1   3   1   1   0   0   124 0   0.016129032 0.064516128 0.177419353 0.169354837 0.104838709 0.0
2005    1   3   1   1   0   0   14  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0.142857143
2006    1   3   1   1   0   0   76  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0.013157895
2007    1   3   1   1   0   0   76  0   0   0   0   0   0   0   0   0   0   0.012987013 0   0   0.01298
2008    1   3   1   1   0   0   92  0   0   0   0   0   0   0   0   0   0   0.011111111 0.011111111 0.0
2009    1   3   1   1   0   0   51  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0.0
2010    1   3   1   1   0   0   62  0   0   0   0   0   0   0.01369863  0.01369863  0   0   0   0   0
2011    1   3   1   1   0   0   58  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0.0
2012    1   3   1   1   0   0   84  0   0   0.012048193 0   0   0   0   0   0   0   0   0   0.048192772
2013    1   3   1   1   0   0   82  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0.0
2014    1   3   1   1   0   0   162 0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0.01234
2015    1   3   1   1   0   0   200 0   0   0   0   0   0   0   0   0   0   0   0.004950495 0.004950495
2016    1   3   1   1   0   0   62  0   0   0   0   0   0   0   0   0   0   0   0   0.010526316 0.01052
2017    1   3   1   1   0   0   200 0   0   0   0   0   0   0   0   0   0.016129032 0   0   0   0   0
2018    1   3   1   1   0   0   91  0   0   0   0   0   0   0   0   0   0   0   0   0.065934066 0.12087
2019    1   3   1   1   0   0   59  0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0.03389
#   Growth  data
# Type of growth increment (1=growth increment with a CV;2=size-at-release; size-at)
0
#   nobs_growth
0
##  Note    SM  used    loewss  regression  for males   BBRKC   data
##  and cubic   spine   to  interpolate 3   sets    of  female  BBRKC   data
# MidPoint Sex  Increment   CV
#67.5   2   14.766667   1.00E+21
# MidPoint Sex  MidPoint   Time-at-liberty Size-trans matrix Number of points
# Release       Recapture
##  eof
9999
```

Appendix B. Control file for the reference model

```
## ================================================== ##
## LEADING PARAMETER CONTROLS                                          ##
##     Controls for leading parameter vector (theta)                   ##
## LEGEND                                                              ##
##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma      ##"
## ================================================== ##
## ntheta
43
## ================================================== ##
## ival        lb        ub        phz   prior     p1      p2         # parameter       ##
## ================================================== ##
   0.18        0.15    0.2         -4       2    0.18    0.04      # M
  16.5       -10        18         -1       0  -10.0    20.0       # logR0
  12.0       -10        25          1       0   10.0    20.0       # logRini, to estimate if NOT initia
  12.5       -10        25          1       0   10.0    20.0       # logRbar, to estimate if NOT initia
  32.5        25        75         -4       1   72.5     7.25      # recruitment expected value (males
0.8   0.32      1.64        -3       0    0.1     5.0       # recruitment scale (variance component) (ma
   0.9        -10         11         -4       0  -10.0     0.75      # ln(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
 #  -0.63      -10         30          1       0   10.0    20.00        # Deviation for size-class 1 (no
  0       -10         30          1       0   10.0    20.00       # Deviation for size-class 2
  0       -10         30          1       0   10.0    20.00       # Deviation for size-class 3
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 4
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 5
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 6
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 7
  0     -10         30          1       0   10.0    20.00       # Deviation for size-class 8
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 9
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 10
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 11
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 12
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 13
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 14
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 15
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 16
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 17
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 18
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 19
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 20
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 21
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 22
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 23
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 24
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 25
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 26
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 27
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 28
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 29
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 30
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 31
  0      -10         30          1       0   10.0    20.00       # Deviation for size-class 32
```

```
   0      -10         30          1       0   10.0    20.00        # Deviation for size-class 33
   0      -10         30          1       0   10.0    20.00        # Deviation for size-class 34
   0     -10          30          1       0   10.0    20.00        # Deviation for size-class 35
# Use custom natural mortality (0=no, 1=yes, by"    sex and year)
0
# weight-at-length input    method  (1 = allometry  "[w_l = a*l^b],"    2 = vector by sex)
1
# weight parameters (male) A
0.000361
# weight parameter (male) B
3.16
# Proportion mature by sex
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+0
# Proportion legal by sex
0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
## ================================================= ##
## ================================================= ##
## GROWTH PARAMETER CONTROLS                                                                ##
##     Two lines for each parameter if split sex, one line if not                           ##"
## ================================================= ##
# Use growth transition matrix option (1=read in growth-increment matrix; 2=read in size-transition; 3=
8
# growth increment model (1=alpha/beta; 2=estimated by size-class;3=pre-specified/emprical)
1
# molt probability function (0=pre-specified; 1=flat;2=declining logistic)
2
# maximum size-class (males then females)
35
# Maximum size-class for recruitment(males then females)
7
## number of size-increment periods
1
## Year(s) size-incremnt period changes (blank if no changes)

## number of molt periods
1
## Year(s) molt period changes (blank if no changes)

## Beta parameters are relative (1=Yes;0=no)
0
## ================================================= ##
## ival       lb        ub        phz   prior     p1      p2          # parameter       ##
## ================================================= ##
5.8     -100    100     2   0   0   999 # males alpha growth (linear)
-0.13   -2      2       2   0   0   999 # males beta growth (linear)
1       0.5     3.7     -3  0   0   999     # Males (beta)
## ================================================= ##
## MOLTING PROBABILITY CONTROLS                                                             ##
##     Two lines for each parameter if split sex, one line if not                           ##"
## ================================================= ##
## ival       lb        ub        phz   prior     p1      p2          # parameter       ##
## ================================================= ##
## males and combined
   139.77     100.     500.0       -3       0    0.0    999.0         # molt_mu males
```

```
   0.093      0.02     2.0         -3       0    0.0    999.0         # molt_cv males
  # 145.0386     100.     500.0       3       0    0.0    999.0       # molt_mu males
  # 0.053036     0.02     2.0       3       0    0.0    999.0         # molt_cv males
## ================================================= ##
# The custom growth-increment matrix (if available)
#
# custom molt probability matrix (if available)
#
## ================================================= ##
## SELECTIVITY CONTROLS                                                              ##
##     Selectivity P(capture of all sizes). 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 (NIY), 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                            ##"
## ================================================= ##
## Gear-1   Gear-2   Gear-3
## PotFshry TrawlByc NMFS
   1        1        1        # selectivity periods
   0        0        0        # sex specific selectivity
   2        2        2        # male selectivity type
   #2        2        2        # female selectivity type
   0        0        0        # within another gear
## Gear-1   Gear-2   Gear-3
   1        1        1        # retention periods
   0        0        0        # sex specific retention
   2        6        6        # male   retention type
   #6        6        6        # female retention type
   1        0        0        # male   retention flag (0 = no, 1 = yes)"
   #0       0        0        # female retention flag (0 = no, 1 = yes)"
## ================================================= ##
## gear  par   sel                                                   start  end         ##
## index index par sex  ival        lb    ub    prior   p1   p2     phz   period period      ##
## ================================================= ##
# Gear-1
   1      1    1   1    138.00    5    186    0       1    999   -4     1976   2019  #4
   1      2    2   1      0.1    0.1   20    0       1    999   -4     1976   2019  #4
# Gear-2
   2      3    1   1    150.0000    5    185    0       1    999   -4     1976   2019
   2      4    2   1     10.0000    0.1   20    0       1    999   -4     1976   2019
# Gear-3-
   3      5    1   1    106.3990    5    300    0       1    999    4     1976   2019
   3      6    2   1      14.053    0.1   20    0       1    999    4     1976   2019
## ================================================= ##
## Retained                                                                          ##
## gear  par   sel                                                   start  end         ##
## index index par sex  ival  lb    ub     prior   p1   p2     phz   period period      ##
## ================================================= ##
# Gear-1
  -1     7    1   1    138    1    999    0       1    999    -4     1976   2019
  -1     8    2   1    .1    0.1   20    0       1    999    -4     1976   2019
```

```
  # Gear-2
  -2     9    1   1    595    1    999    0       1    999   -3     1976   2019
    # Gear-3
  -3     10    1   1    595    1    999    0       1    999   -3     1976   2019
 ## ================================================== ##
# Number of asyptotic parameters
#1
0
# Fleet   Sex     Year       ival  lb   ub    phz
#    1     1     1976   0.000001   0    1     -3
## ================================================== ##
## 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            ##"
## ================================================== ##
## ival     lb       ub    phz   prior  p1        p2     Analytic?   LAMBDA Emphasis
   0.925     0        2    -6    1      0.925   0.03   0           1             1   # NMFS, 0.896 is tl
## ================================================== ##
## ================================================== ##
## 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 type: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma       ##"
## ================================================== ##
## ival        lb        ub        phz   prior     p1      p2
   0.0001      0.00001   10.0      -4    4         1.0     100   # NMFS
## ================================================== ##
## ================================================== ##
## PENALTIES FOR AVERAGE FISHING MORTALITY RATE FOR EACH GEAR
## ================================================== ##
## Mean_F   Female Offset STD_PHZ1   STD_PHZ2   PHZ_M   PHZ_F
   0.22313         0.0505      0.5      45.50      1       1   # Pot
   0.0183156          1.0      0.5      45.50      1      -1   # Trawl
   0.00               0.0     2.00      20.00     -1      -1   # NMFS trawl survey (0 catch)
## ================================================== ##
## ================================================== ##
## OPTIONS FOR SIZE COMPOSTION DATA                                                  ##
##     One column for each data matrix                                               ##
## LEGEND                                                                            ##
##     Likelihood: 1 = Multinomial with estimated/fixed sample size                  ##
##                 2 = Robust approximation to multinomial                           ##
##                 3 = logistic normal (NIY)                                         ##
##                 4 = multivariate-t (NIY)                                          ##
##                 5 = Dirichlet                                                     ##
## AUTO TAIL COMPRESSION                                                             ##
##     pmin is the cumulative proportion used in tail compression                    ##
## ================================================== ##
#  NMFS
    2    # Type of likelihood
    0    # Auto tail compression (pmin)
    1    # Initial value for effective sample size multiplier
```

```
   -4    # Phz for estimating effective sample size (if appl.)
    1    # Composition aggregator
    1    # LAMBDA
    1    # Emphasis AEP
## ================================================== ##
## ================================================== ##
## 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 (only use if parameters are default)
3
## STDEV in m_dev for Random walk
10
## 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
## Number of Breakpoints in M by size
0
## Size-class of breakpoint
#3
## Specific initial values for the natural mortality devs (0-no, 1=yes)"
1
### ==================================================================================================
## ival        lb        ub        phz   extra    prior     p1      p2         # parameter     ##
## ==================================================================================================
# 1.600000      0         2          3      0                         # Males
# 0.000000     -2         2        -99      0                         # Dummy to retun to base value
# 2.000000      0         4         -1      0                         # Size-specific M
## ================================================== ##
## ================================================== ##
## ================================================== ##
## OTHER CONTROLS
## ================================================== ##
1977       # First rec_dev
2019       # last rec_dev
   1       # Estimated rec_dev phase
  -3       # Estimated rec_ini phase
   1       # VERBOSE FLAG (0 = off, 1 = on, 2 = objective func; 3 diagnostics)"
   3       # Initial conditions (0 = Unfished, 1 = Steady-state fished, 2 = Free parameters, 3 = Free pa
   1       # Lambda (proportion of mature male biomass for SPR reference points).
   0       # Stock-Recruit-Relationship (0 = none, 1 = Beverton-Holt)"
   10       # Maximum phase (stop the estimation after this phase).
   -1       # Maximum number of function calls
## ================================================== ##
## EMPHASIS FACTORS (CATCH)
```

```
## ================================================== ##
#Ret_male Disc_trawl
    1         1
#     500       100         100         50              100               100         50
## ================================================== ##
## EMPHASIS FACTORS (Priors)
## ================================================== ##
# Log_fdevs   meanF       Mdevs  Rec_devs Initial_devs Fst_dif_dev Mean_sex-Ratio
    10000       0           1         2            0           0              10              #(10000)
## EOF
9999
```

Table 5: Observed retained catches and bycatch in tonnes

year	Pot	Trawl bycatch
1976	0	0
1977	0	0
1978	0	0
1979	0	0
1980	0	0
1981	0	0
1982	0	0
1983	0	0
1984	0	0
1985	0	0
1986	0	0
1987	0	0
1988	0	0
1989	0	0
1990	0	0
1991	0	3
1992	0	50
1993	1305	44
1994	670	7
1995	449	1
1996	100	1
1997	379	1
1998	272	3
1999	0	7
2000	0	2
2001	0	12
2002	0	7
2003	0	3
2004	0	9
2005	0	7
2006	0	18
2007	0	2
2008	0	10
2009	0	3
2010	0	9
2011	0	7
2012	0	17
2013	0	3
2014	0	1
2015	0	5
2016	0	1
2017	0	2
2018	0	8
2019	0	0

Table 6: Estimated parameters and selected derived quantities by scenario. ‘Theta’ parameters are scaling parameters and initial numbers at sizes. Vectors of deviations for fishing mortality and recruitment are not displayed–see their respective figures.

Parameter	19.1	19.2	19.3	19.4	19.5
theta[3]	-1.861	-1.498	-1.284	-1.363	-1.190
theta[4]	-2.402	-2.209	-2.260	-2.043	-1.685
theta[10]	-0.218	-0.159	-0.141	-0.153	-0.154
theta[11]	-0.211	-0.152	-0.118	-0.144	-0.146
theta[12]	-0.203	-0.140	-0.110	-0.137	-0.139
theta[13]	-0.180	-0.120	-0.088	-0.111	-0.112
theta[14]	-0.171	-0.113	-0.086	-0.106	-0.109
theta[15]	-0.162	-0.105	-0.075	-0.104	-0.103
theta[16]	-0.137	-0.086	-0.047	-0.076	-0.074
theta[17]	-0.125	-0.075	-0.053	-0.068	-0.069
theta[18]	-0.117	-0.067	-0.042	-0.066	-0.066
theta[19]	-0.092	-0.047	-0.022	-0.038	-0.036
theta[20]	-0.080	-0.038	-0.034	-0.032	-0.034
theta[21]	-0.081	-0.040	-0.031	-0.043	-0.046
theta[22]	-0.062	-0.029	-0.009	-0.024	-0.021
theta[23]	-0.040	-0.007	-0.013	0.001	-0.002
theta[24]	-0.047	-0.030	-0.028	-0.025	-0.021
theta[25]	-0.051	-0.015	-0.025	-0.029	-0.035
theta[26]	-0.030	-0.015	-0.005	-0.008	-0.005
theta[27]	-0.008	0.011	-0.003	0.016	0.013
theta[28]	-0.017	-0.014	-0.017	-0.009	-0.006
theta[29]	-0.025	0.000	-0.028	-0.016	-0.023
theta[30]	-0.004	0.001	0.012	0.005	0.007
theta[31]	0.026	0.029	0.000	0.033	0.031
theta[32]	0.023	0.011	0.007	0.015	0.019
theta[33]	0.009	0.020	-0.003	0.002	-0.010
theta[34]	0.021	0.019	-0.007	0.013	0.009
theta[35]	0.076	0.061	0.038	0.063	0.053
theta[36]	0.097	0.060	0.037	0.064	0.071
theta[37]	0.117	0.075	0.044	0.068	0.068
theta[38]	0.094	0.072	0.074	0.047	0.037
theta[39]	0.130	0.091	0.073	0.077	0.070
theta[40]	0.235	0.146	0.119	0.140	0.144
theta[41]	0.410	0.246	0.212	0.237	0.244
theta[42]	0.638	0.339	0.272	0.337	0.361
theta[43]	0.472	0.267	0.250	0.262	0.284
log_fbar[1]	-2.144	-1.795	-2.218	-2.046	-2.204
log_fbar[2]	-6.710	-6.632	-6.538	-6.507	-6.483
log_slx_pars[5]	4.719	4.709	4.631	4.702	4.688
log_slx_pars[6]	2.004	1.119	-1.898	1.097	1.666
Grwth[1]	9.151	9.250	3.876	9.201	9.317
Grwth[2]	-0.090	-0.086	-0.155	-0.089	-0.091
sd_rbar	0.659	0.924	0.909	1.091	1.641

Table 7: Parameters fixed in the assessment

Fixed.parameter	Value
Survey catchability	0.925
Size at 50% capture in fishery	138.000
SD of above	0.100
Size at 50% capture in trawl fishery	150.000
SD of above	10.000
Size at 50% molting probability	139.770
SD of above	0.093
Natural mortality	0.180

Table 8: Observed male biomass >120 mm carapace width

year	NMFS Trawl_Male_bio	NMFS Trawl_Male_CV
1976	165	1.00
1977	119	1.00
1978	1250	0.83
1979	556	0.52
1980	1269	0.38
1981	312	0.58
1982	1464	0.70
1983	527	0.53
1984	317	0.55
1985	61	1.00
1986	138	0.70
1987	54	1.00
1988	107	1.00
1989	1529	0.91
1990	1141	0.93
1991	4430	0.80
1992	3305	0.60
1993	9873	0.92
1994	9139	0.77
1995	18056	0.60
1996	2361	0.37
1997	6159	0.62
1998	2324	0.36
1999	5523	0.67
2000	4320	0.37
2001	8603	0.79
2002	7037	0.69
2003	5373	0.66
2004	3622	0.59
2005	1238	0.59
2006	7003	0.38
2007	5224	0.49
2008	5462	0.51
2009	2500	0.64
2010	4405	0.44
2011	3834	0.65
2012	4477	0.57
2013	7749	0.62
2014	12047	0.78
2015	15173	0.74
2016	4150	0.70
2017	3658	0.65
2018	929	0.43
2019	2086	0.34

Table 9: Estimated mature male biomass by model in tonnes.

year	19.1	19.2	19.3	19.4	19.5
1976	348	461	558	514	593
1977	327	437	523	475	522
1978	305	411	488	435	456
1979	282	384	451	394	394
1980	258	355	413	354	337
1981	235	325	373	315	285
1982	218	300	336	284	249
1983	208	285	312	263	222
1984	189	260	283	233	188
1985	169	232	252	202	156
1986	149	206	222	174	128
1987	132	183	197	151	106
1988	160	387	235	285	124
1989	247	939	1063	591	189
1990	1741	1935	4786	2111	2898
1991	4699	4052	6432	5013	6439
1992	5557	4623	6690	5679	6976
1993	4477	3462	5231	4416	5384
1994	3762	2746	4255	3571	4254
1995	3216	2233	3509	2934	3373
1996	2881	1971	3072	2541	2814
1997	2540	1645	2525	2169	3049
1998	4486	3138	3217	4251	4552
1999	8253	6683	3912	8294	5596
2000	9420	7746	7092	9276	5674
2001	9748	7988	8320	9277	5303
2002	9313	7630	8278	8596	4626
2003	8560	7016	7727	7669	3898
2004	7691	6309	6991	6690	3218
2005	6899	5654	6234	5823	2648
2006	6277	5133	5655	5124	2283
2007	5761	4678	5072	4549	4012
2008	5491	4475	4715	4246	6343
2009	5252	4270	4366	3954	6495
2010	4818	3885	3919	3508	5955
2011	4307	3460	3453	3042	5168
2012	3835	3088	3023	2636	4439
2013	3496	2834	2733	2346	3842
2014	3197	2552	2425	2084	3254
2015	2859	2270	2122	1808	2706
2016	2574	2049	1863	1595	2265
2017	2317	1902	1660	1449	1908
2018	2061	3214	1781	2532	1601
2019	1961	6794	4502	4894	3034

Table 10: Tier 4 BMSY and alternative Tier 4 BMSY for all models with resulting status and OFLs. Models with an '_alt' suffix are calculated based on the alternative BMSY.

	MMB	BMSY	BMSY_alt	Status	Status_alt	OFL	OFL_alt
Running average	1627	5242	1849	0.31	0.88	78	237
Random effects	1806	4770	1668	0.38	1.08	109	321
19.1	2102	5389	1934	0.39	1.09	108	304
19.2	7298	4696	1737	1.55	4.2	1054	1054
19.3	5358	5053	1747	1.06	3.07	658	1642
19.4	5368	5047	1733	1.06	3.1	864	864
19.5	4444	4919	1587	0.9	2.8	432	1159

Table 11: Negative log likelihood for integrated assessments.

Model	X.log.like.
19.1	-3812
19.2	-3872
19.3	-3792
19.4	-3889
19.5	-3819

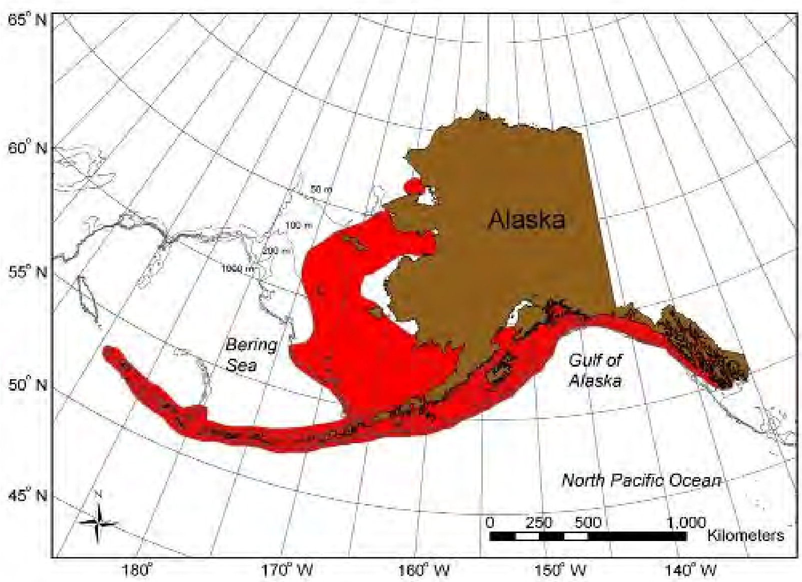

Figure 1: Red king crab distribution in the North Pacific

[[1]]

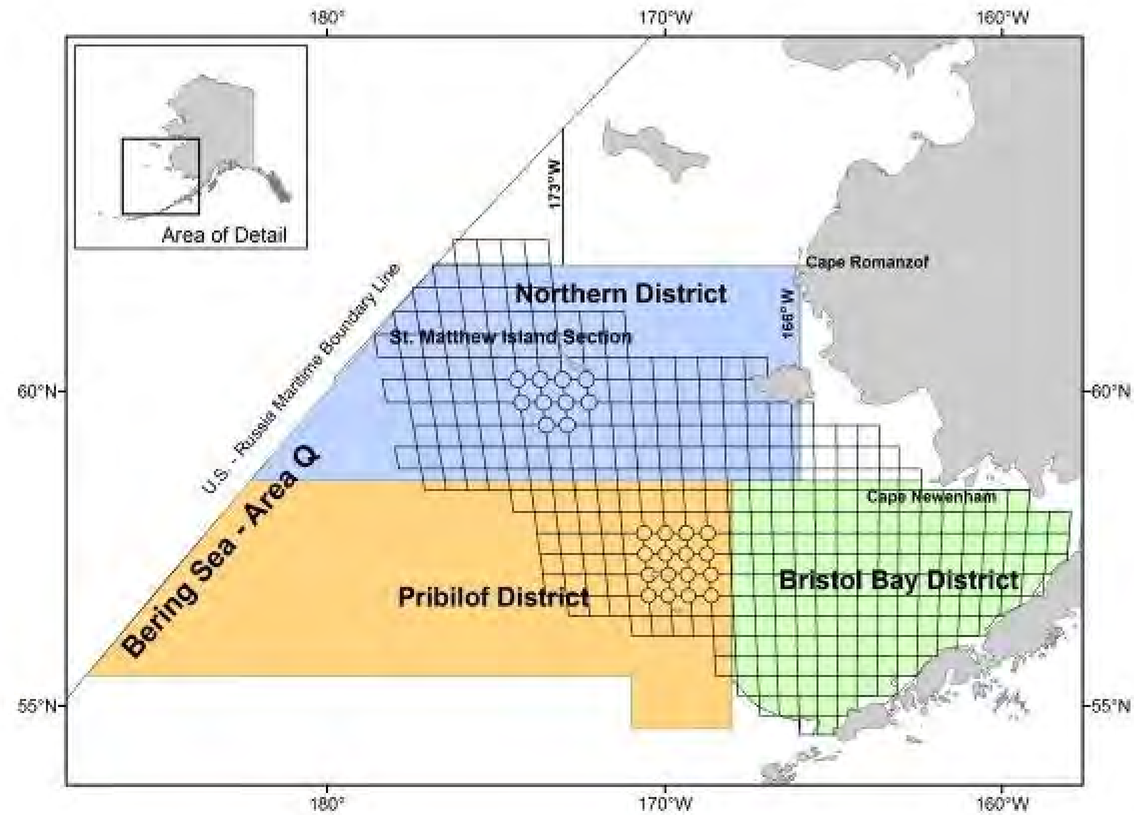

Figure 2: Pribilof Island management area in the Bering Sea

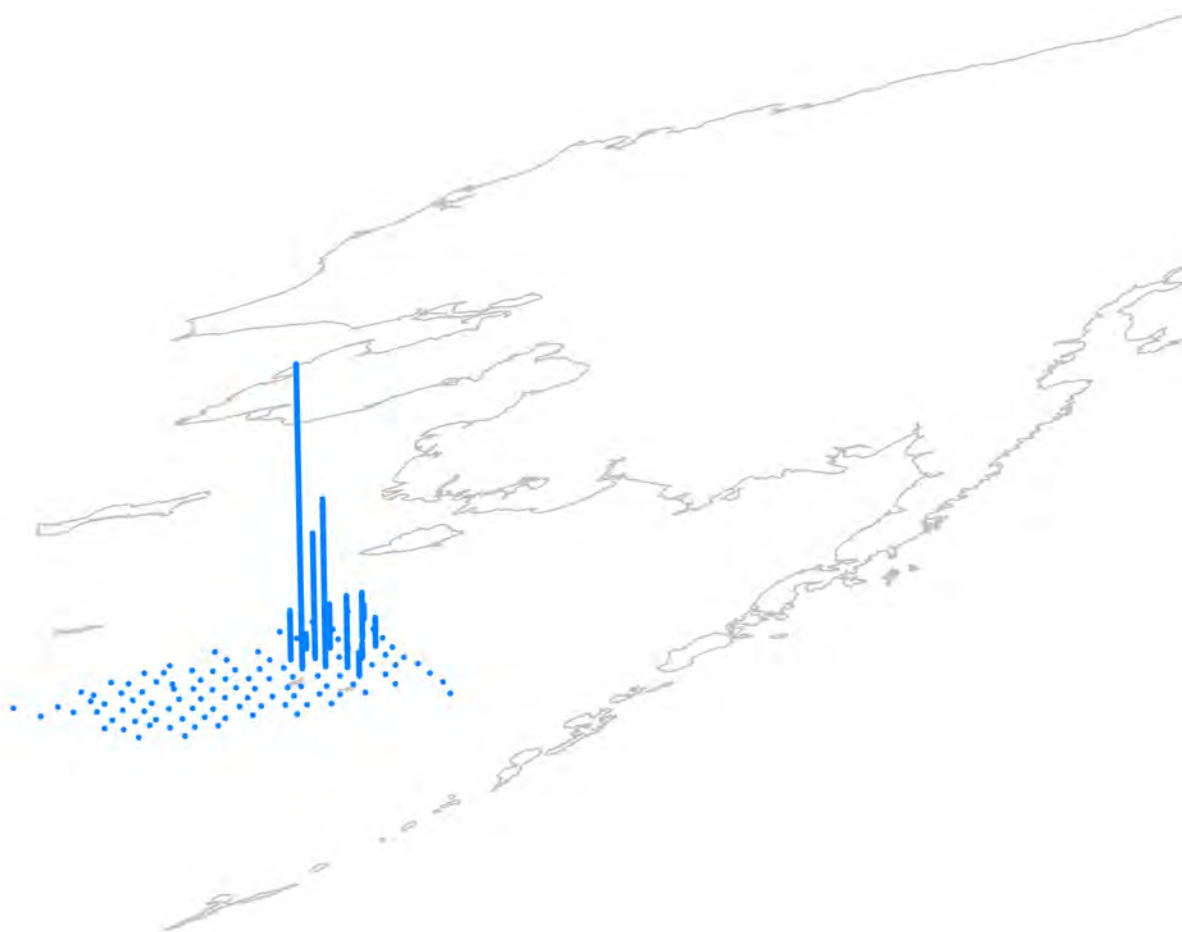

Figure 3: Observed relative male abundance by survey stations in 2019.

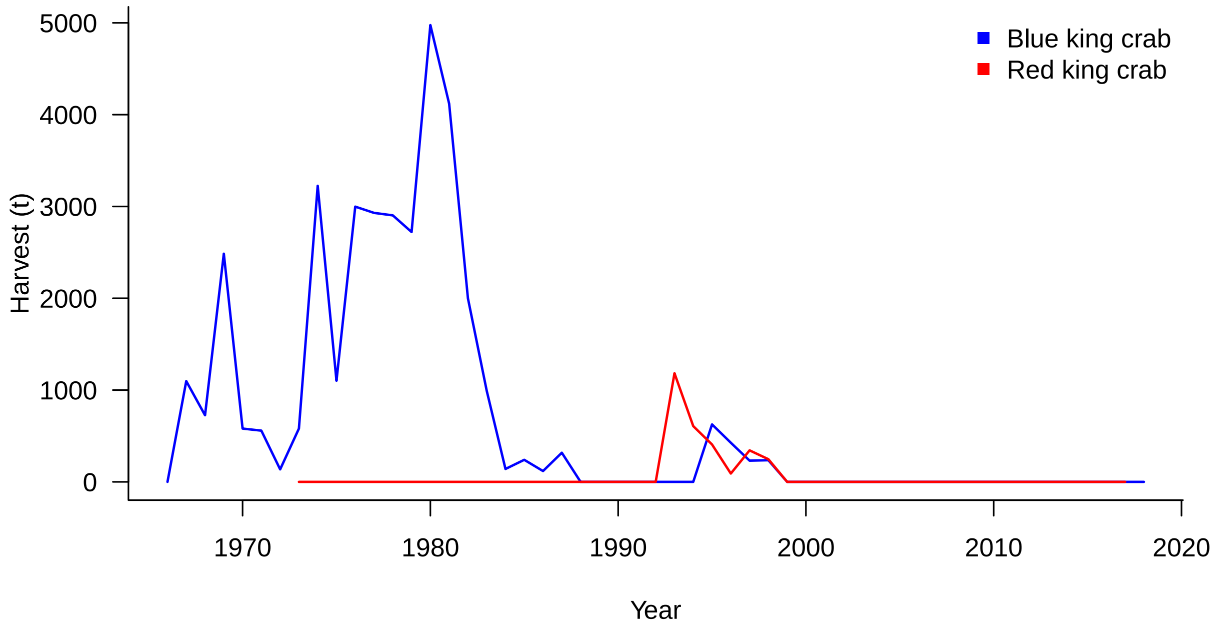

Figure 4: Historical directed harvests of blue king crab and red king crab around the Pribilof Islands.

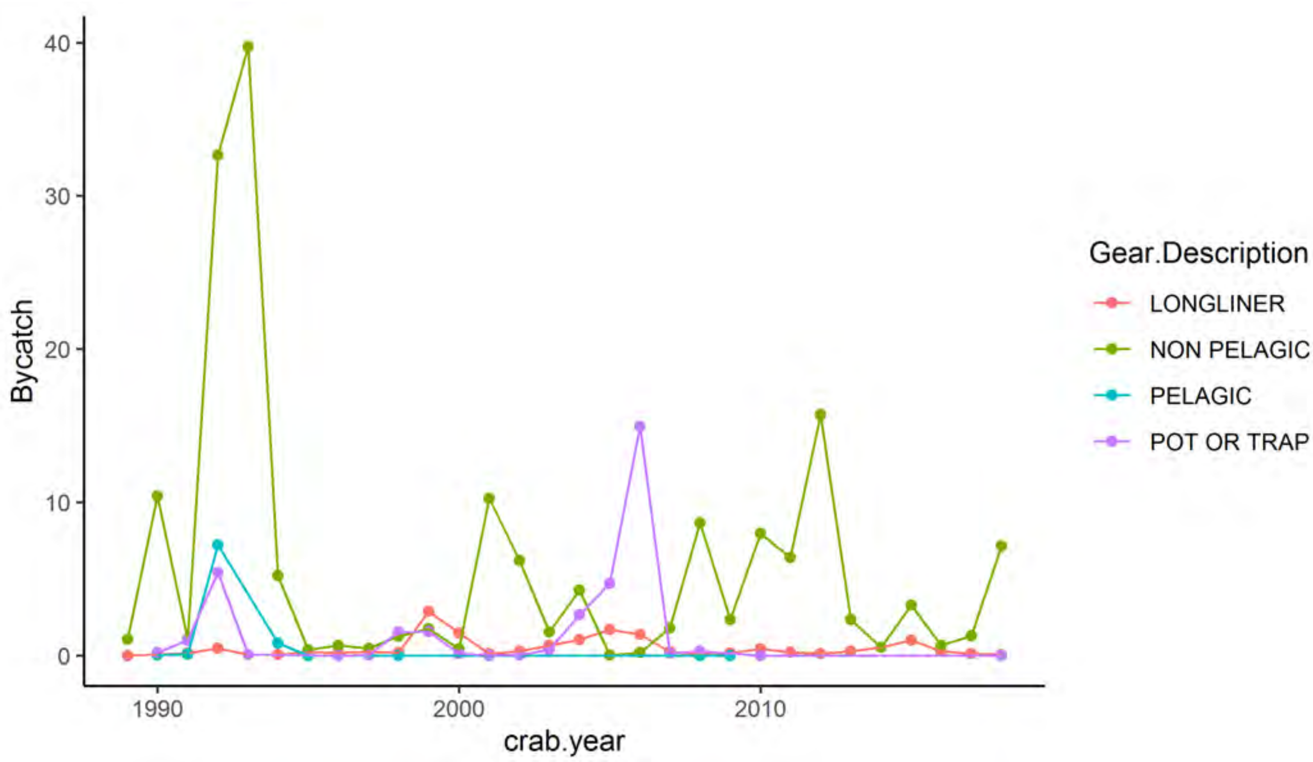

Figure 5: Bycatch by fleet by year in metric tonnes of PIRKC.

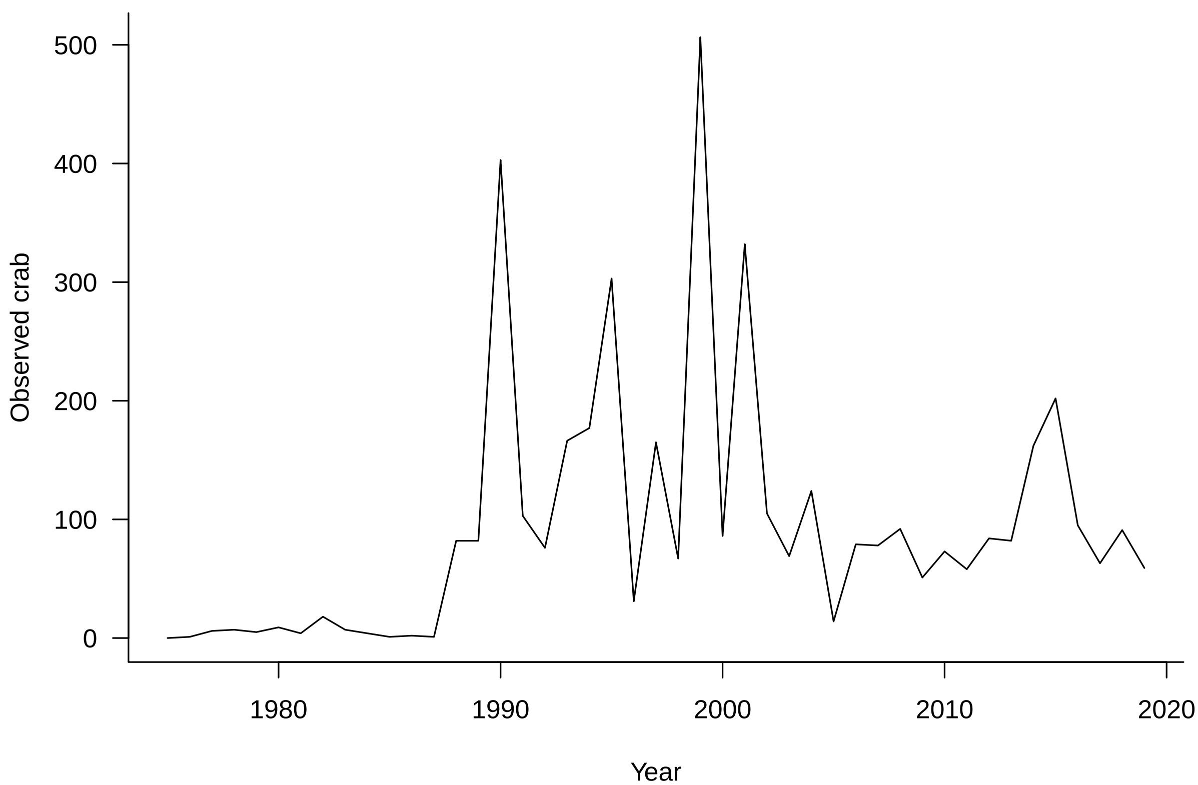

Figure 6: Total number of observed crab by year.

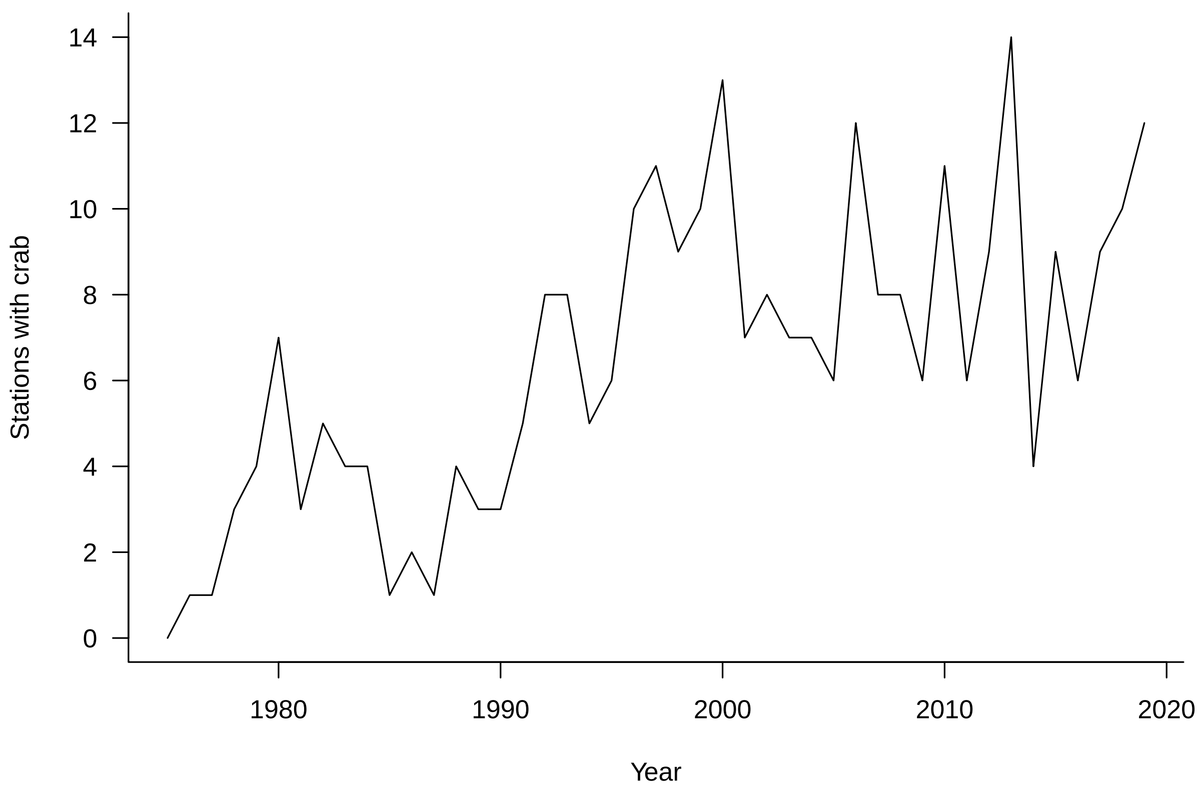

Figure 7: The number of stations at which crab were observed.

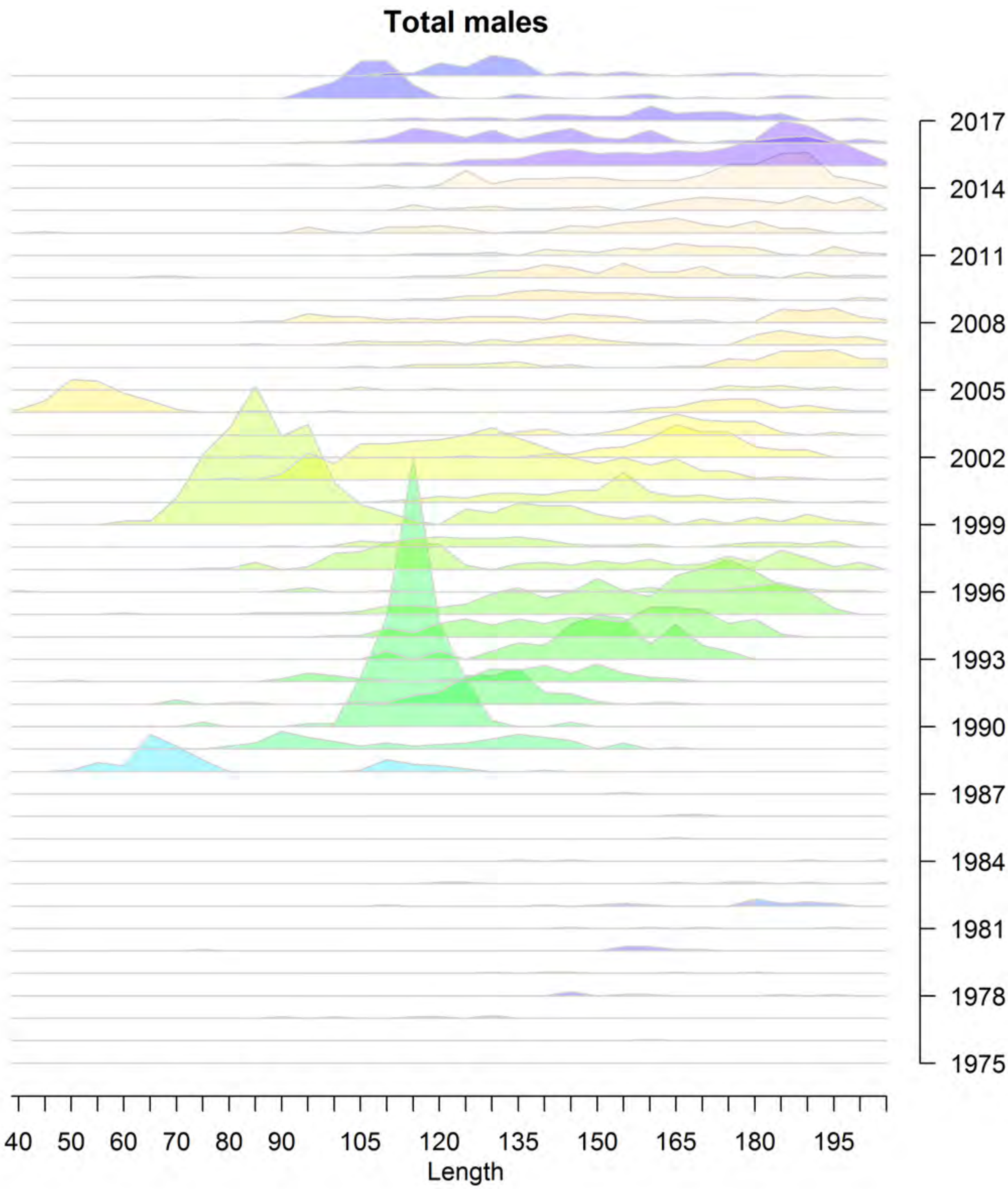

Figure 8: Observed male numbers at length by year.

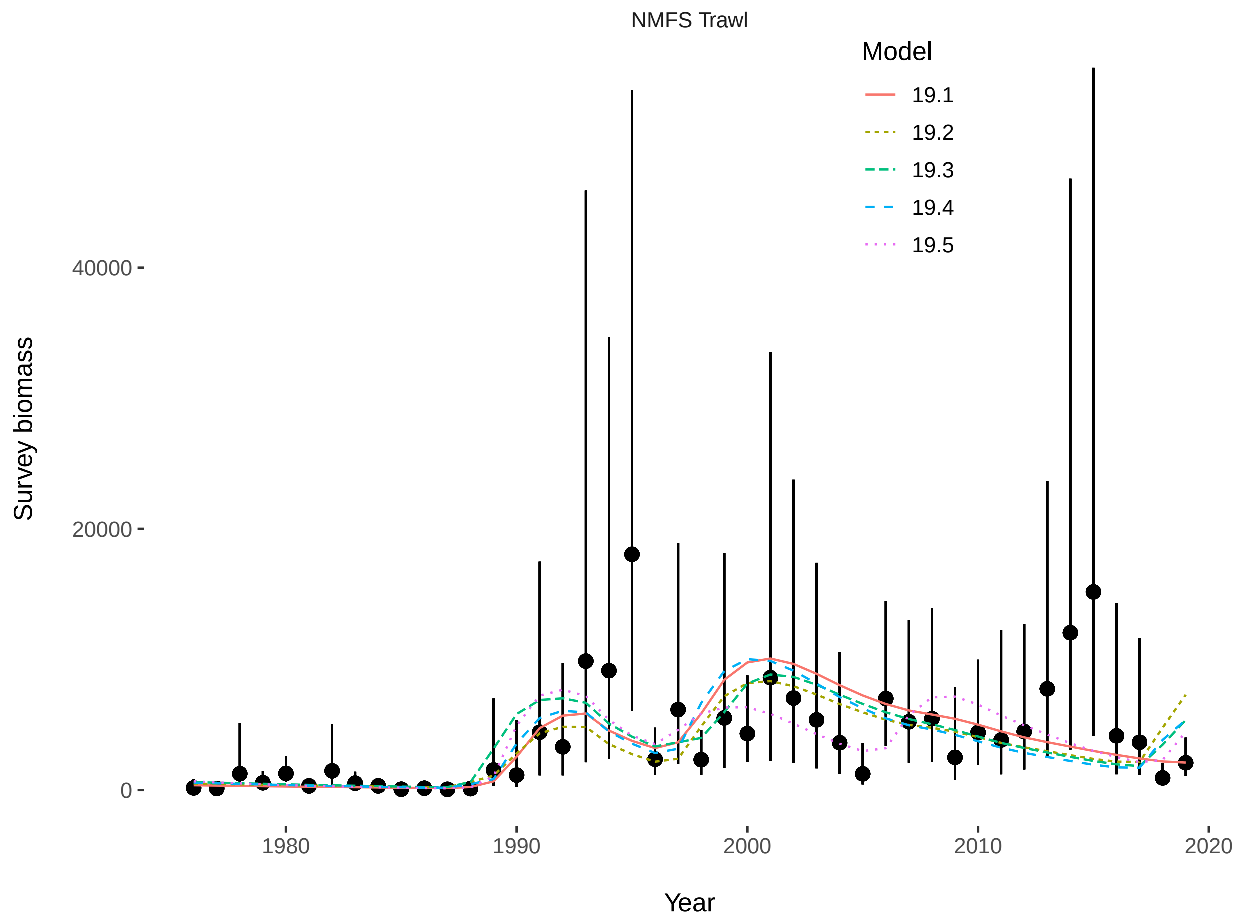

Figure 9: Fits of integrated assesssment scenarios to mature male biomass from the NMFS summer trawl survey.

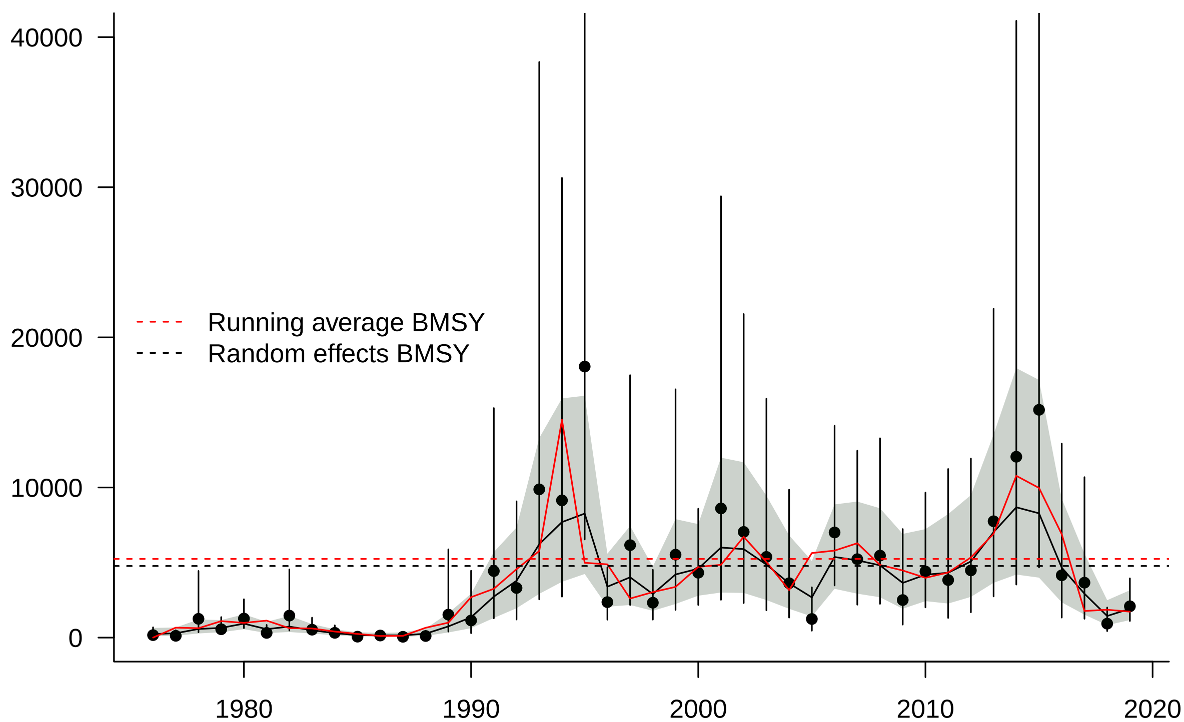

Figure 10: Comparison of estimated MMB among running average and random effects models.

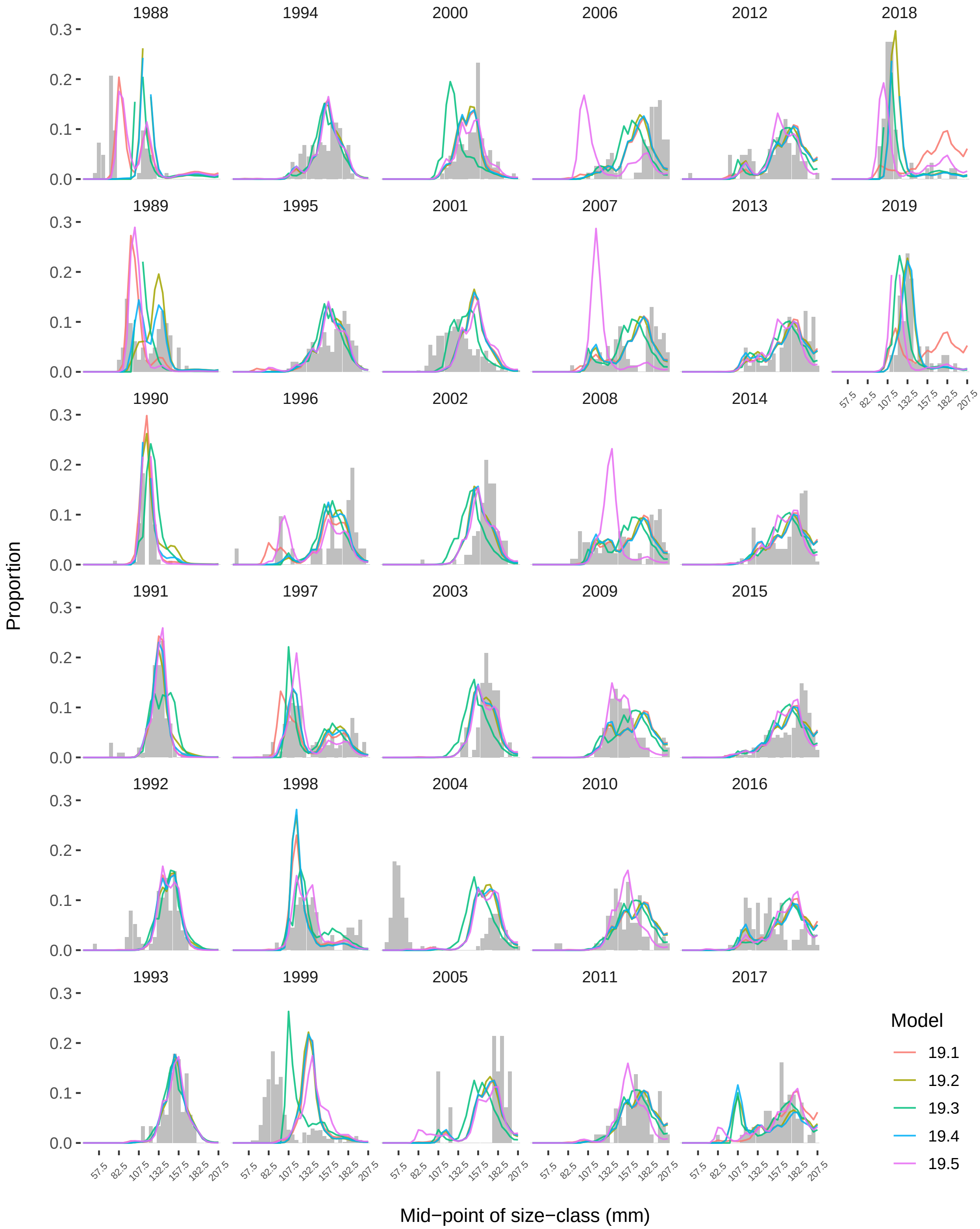

Figure 11: Model fits to survey size composition data.

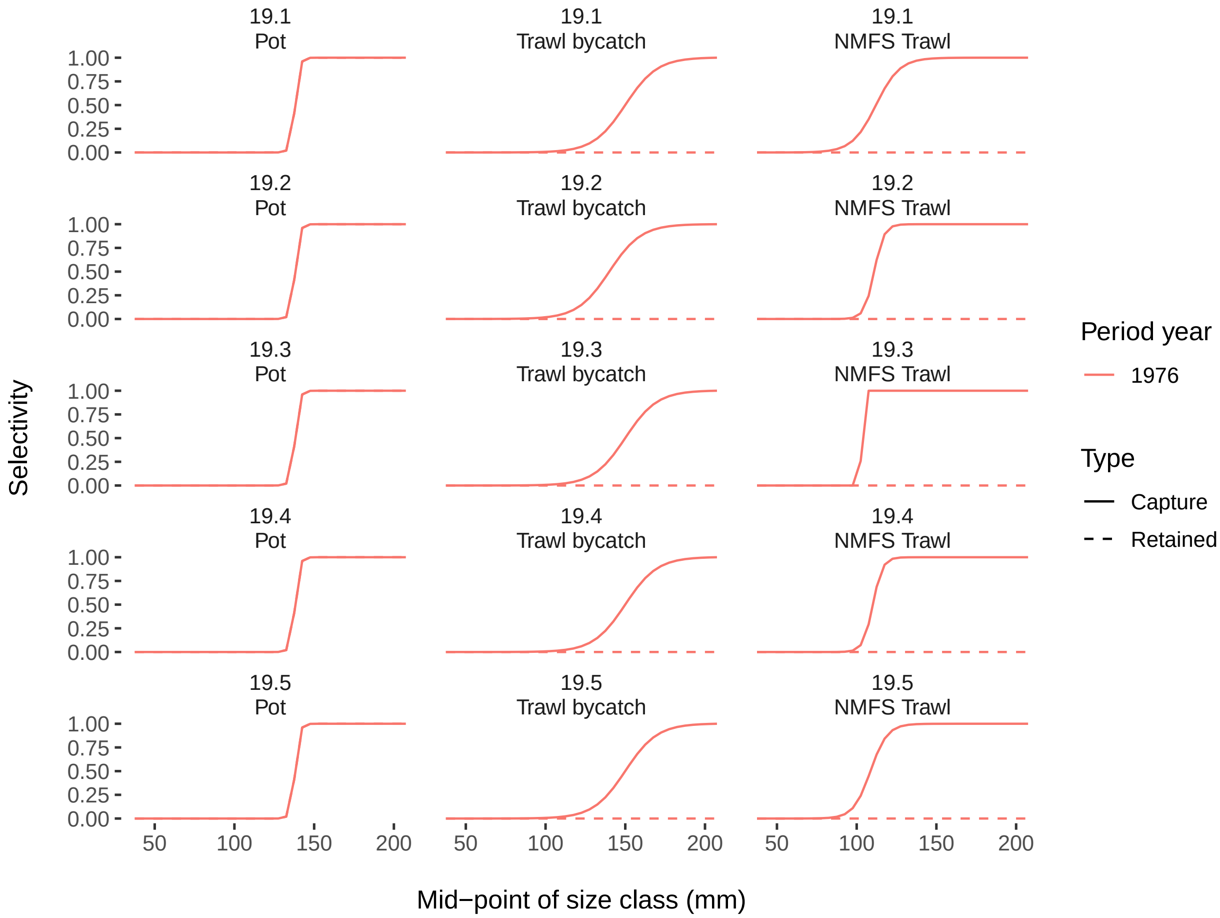

Figure 12: Estimated survey selectivity, assumed fishery selectivity, assumed trawl selectivity.

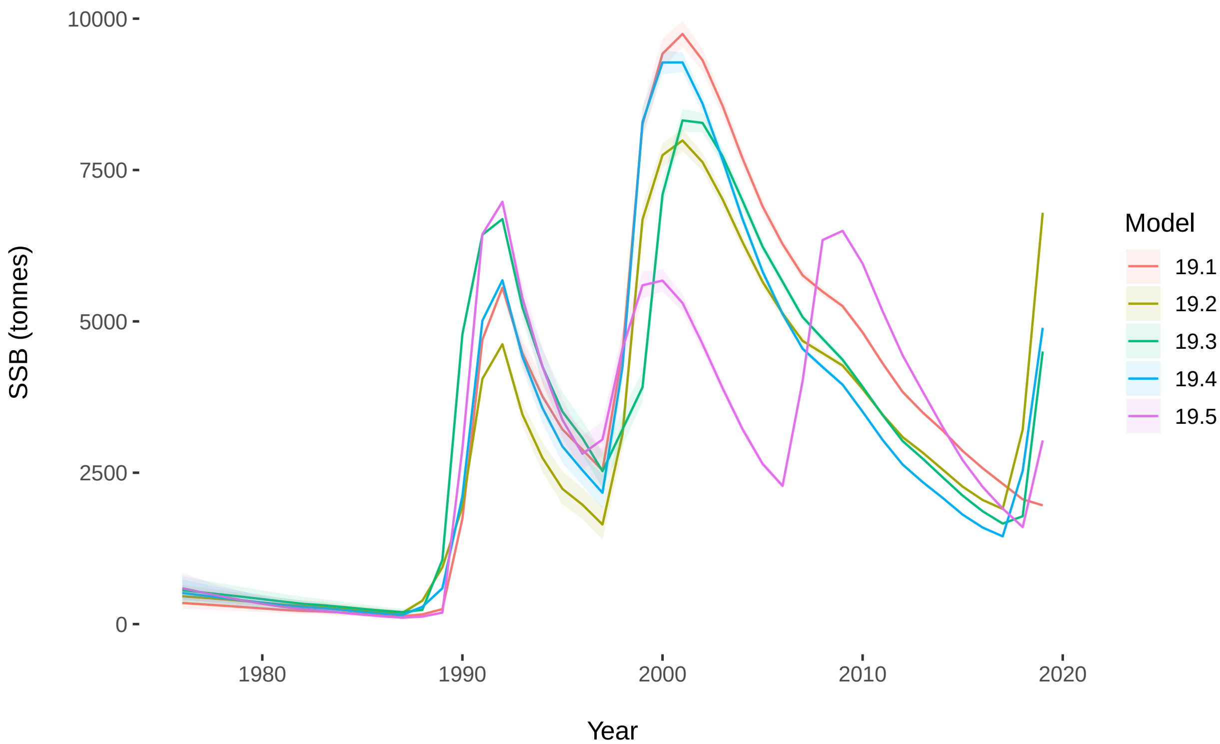

Figure 13: Model predicted mature male biomass at mating time

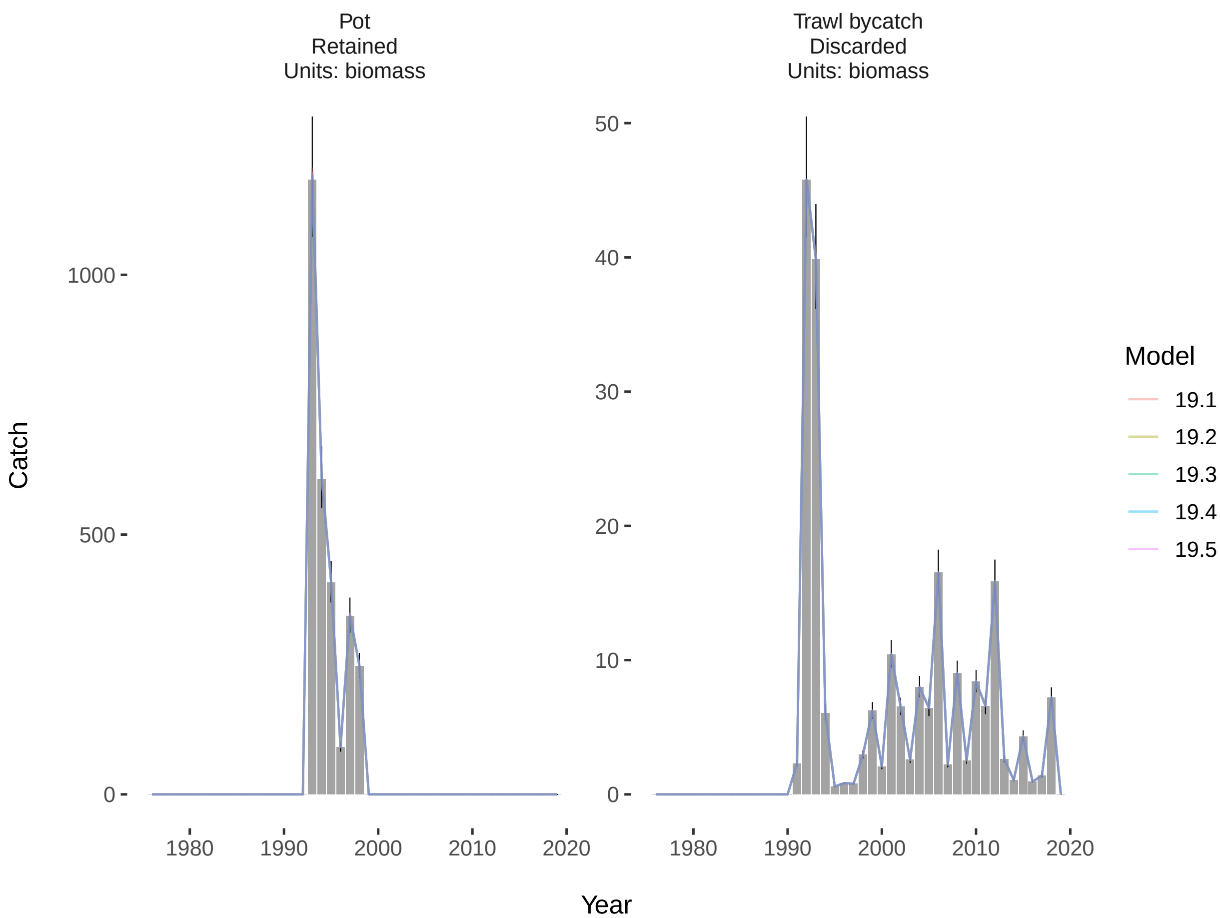

Figure 14: Model fits to catch data.

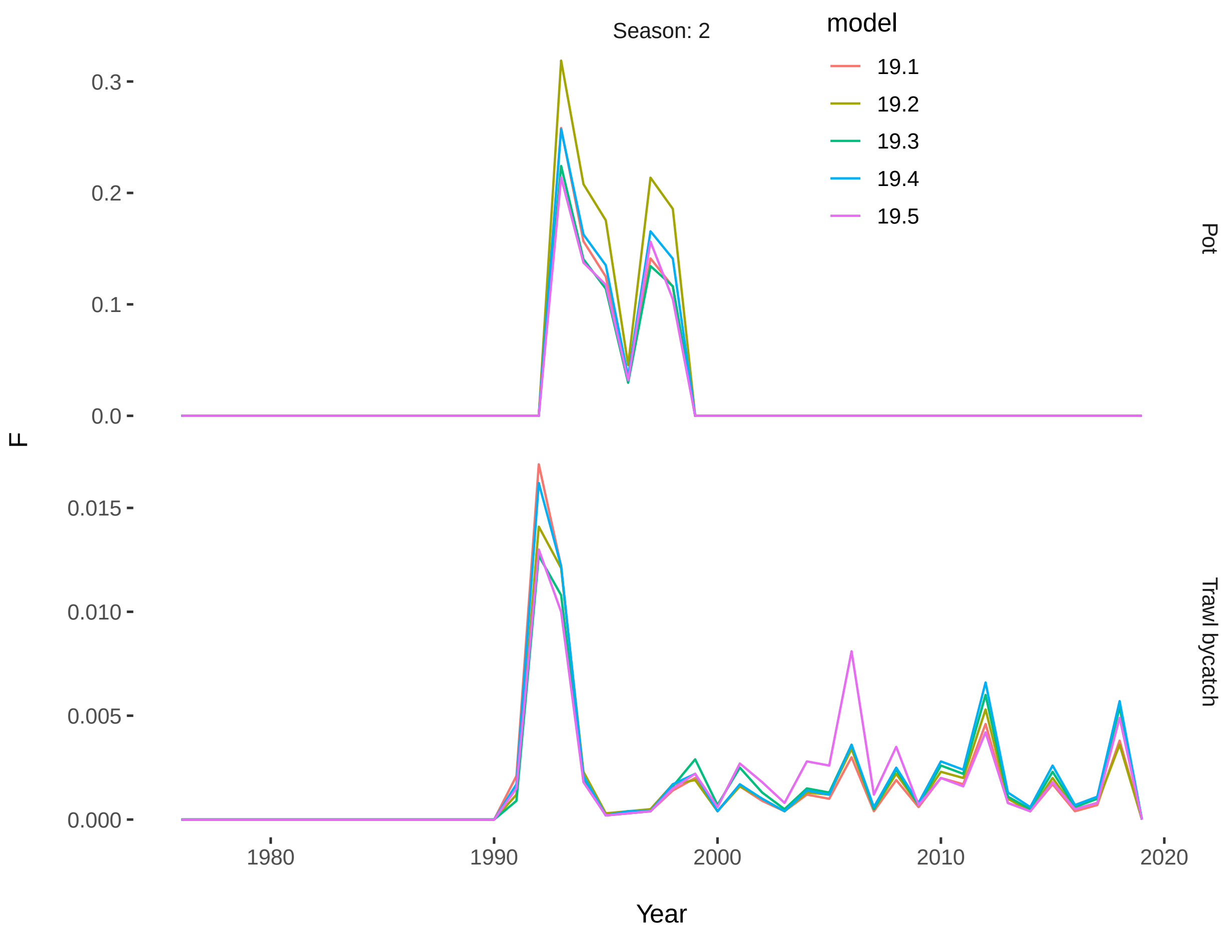

Figure 15: Model predicted fishing mortalities

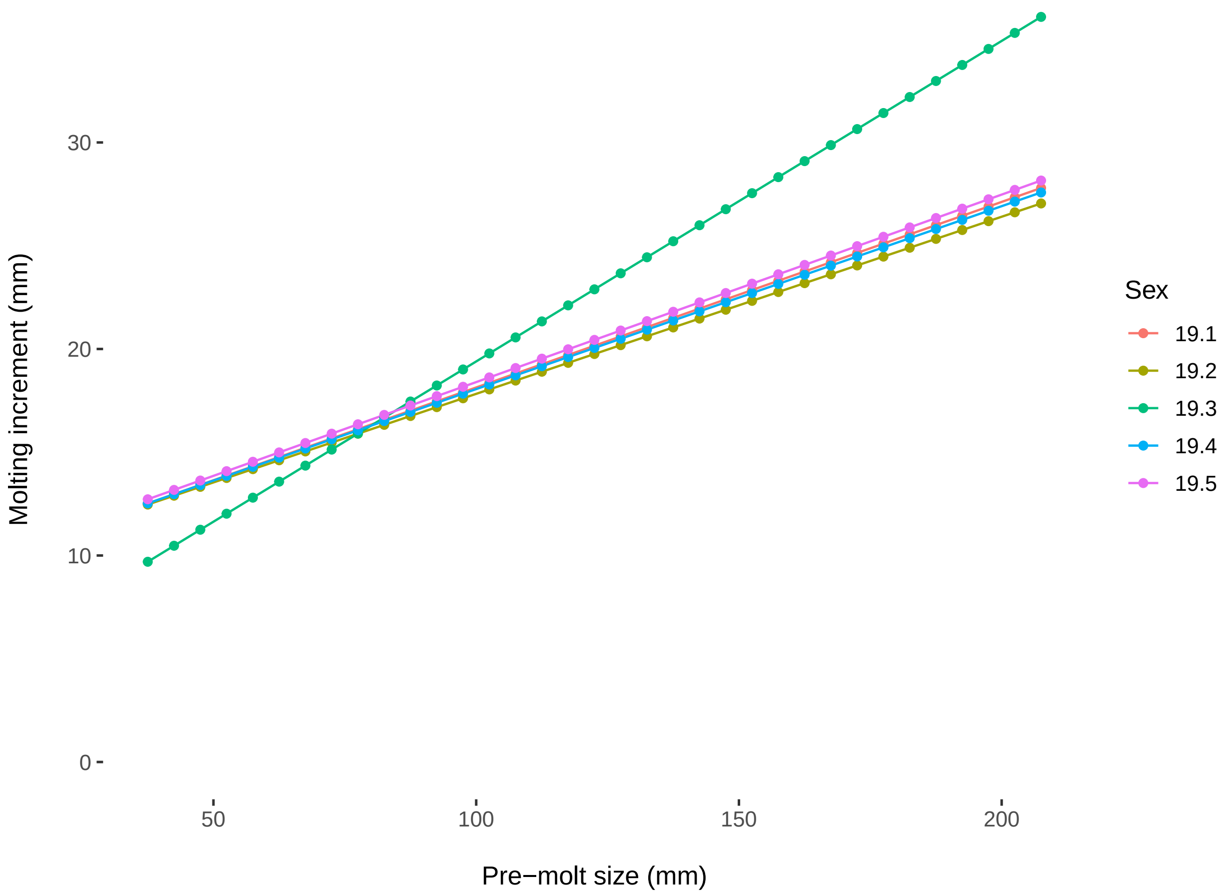

Figure 16: Predicted molt increments

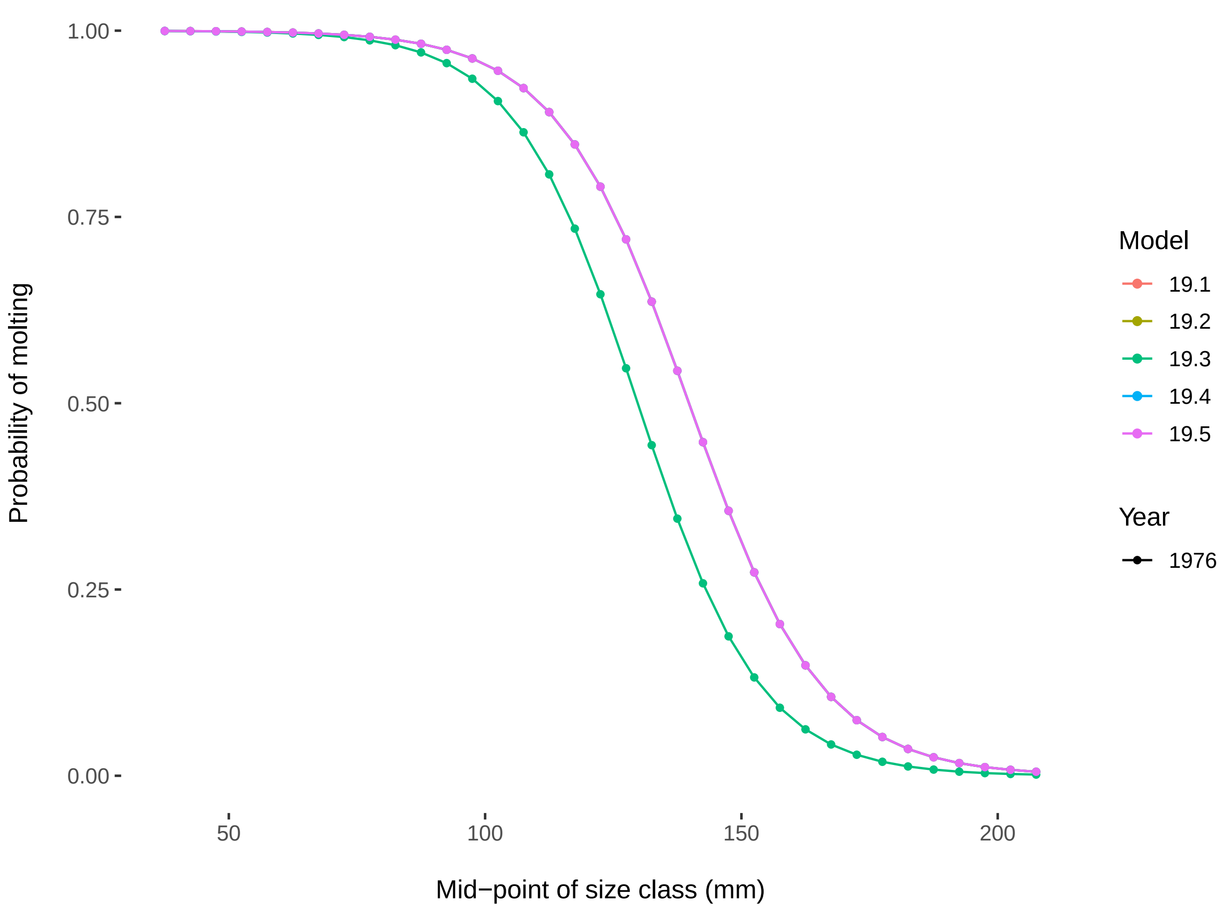

Figure 17: Speified probability of molting by size (mm)

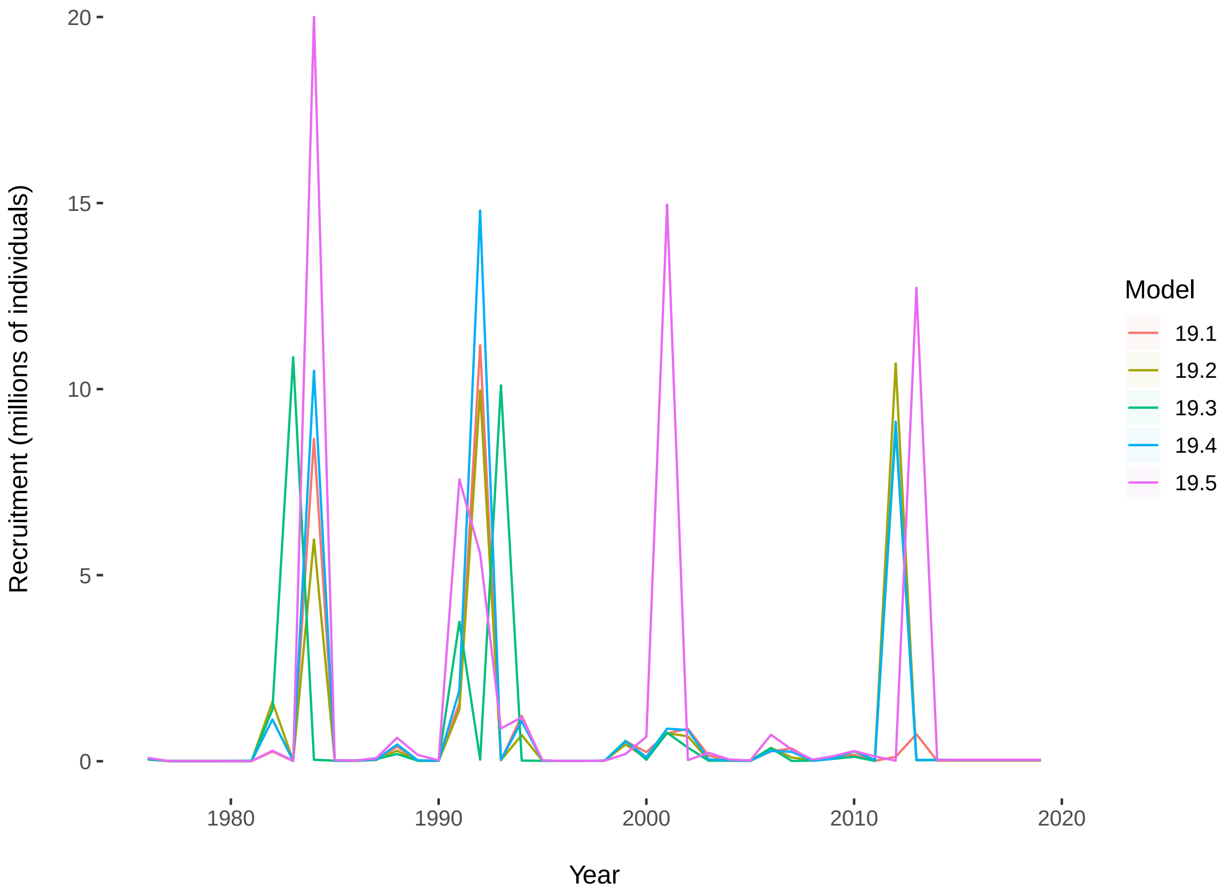

Figure 18: Estimated recruitment.

Update to the 2019 SAFE report for Pribilof Islands red king crab

Cody Szuwalski

September 2020

The Pribilof Islands red king crab (PIRKC) assessment is on a biennial cycle. This year (2020) is an 'off' year in the cycle, so an update to determine whether or not overfishing occurred in 2019/20 is presented here. The next full assessment will occur in 2021.

The most recent full assessment was conducted in September 2019. This report updates that assessment with final retained catch and bycatch mortality estimates in the directed fishery, other crab fisheries, and the groundfish fisheries to determine the status of the stock during the 2019/2020 fishery year (July 1, 2019-June 30, 2020). The 2019 SAFE report determined the overfishing level (OFL) for PIRKC to be 864 t, with an acceptable biological catch of 648 t.

Following completion of the 2019/2020 crab fishery year, data on retained catch and bycatch were obtained from the Alaska Department of Fish and Game (ADFG) and the NMFS Alaska Regional Office (via the Alaska Fisheries Information Network, AKFIN). There was no directed fishery in 2019/20, so no retained catch was recorded. Bycatch in the groundfish fisheries totaled 4.801 t. After applying gear-specific discard mortality rates, this amounted to 3.841 t. Overfishing did not occur for PIRKC during 2019/20 because the total catch mortality did not exceed the ABC.

The following two tables update the management performance tables presented in the 2019 SAFE report.

Table 1: Historical status and catch specifications for Pribilof Islands red king crab (t).

Year	MSST	Biomass (MMB)	TAC	Retained catch	Total catch	OFL	ABC
2014/15	2871	8894	0	0	1.06	1359	1019
2015/16	2756	9062	0	0	4.32	2119	1467
2016/17	2751	4788	0	0	0.94	1492	1096
2017/18	2751	3439	0	0	1.41	404	303
2018/19	866	5368	0	0	7.22	404	303
2019/20	866	6431	0	0	3.84	864	648
2020/21						864	648

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

Year	MSST	Biomass (MMB)	TAC	Retained catch	Total catch	OFL	ABC
2014/15	6.33	19.61	0	0	0	3	2.25
2015/16	6.08	19.98	0	0	0.01	4.67	3.23
2016/17	6.06	10.56	0	0	0	3.29	2.42
2017/18	6.06	7.58	0	0	0	0.89	0.67
2018/19	1.91	11.83	0	0	0.02	0.89	0.67
2019/20	1.91	14.18	0	0	0.01	1.9	1.43
2020/21						1.9	1.43

Table 3: Observed retained catches and bycatch in tonnes

year	Pot	Trawl bycatch
1976	0	0
1977	0	0
1978	0	0
1979	0	0
1980	0	0
1981	0	0
1982	0	0
1983	0	0
1984	0	0
1985	0	0
1986	0	0
1987	0	0
1988	0	0
1989	0	0
1990	0	0
1991	0	3
1992	0	50
1993	1305	44
1994	670	7
1995	449	1
1996	100	1
1997	379	1
1998	272	3
1999	0	7
2000	0	2
2001	0	12
2002	0	7
2003	0	3
2004	0	9
2005	0	7
2006	0	18
2007	0	2
2008	0	10
2009	0	3
2010	0	9
2011	0	7
2012	0	17
2013	0	3
2014	0	1
2015	0	5
2016	0	1
2017	0	2
2018	0	8
2019	0	5

Chapt 1 Snow Crab

2019 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

William T. Stockhausen (AFSC, NMFS)

07 May, 2019

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Executive Summary

1. *Stock:* Pribilof Islands blue king crab (PIBKC), *Paralithodes platypus.*

2. *Catches:* Retained catches have not occurred since 1998/1999. Bycatch has been relatively small in recent years. Bycatch mortality in the crab (e.g., Tanner crab, snow crab) fisheries that incidentally take PIBKC was 0.020 t in 2018/19 . Bycatch mortality for PIBKC in

these fisheries was 0.166 t (0.0004 million lbs) in 2015/16, but this was the first non-zero bycatch mortality in the crab fisheries since 2010/11; the 5-year average was 0.020 t. Most bycatch mortality for PIBKC occurs in the BSAI groundfish fixed gear (pot and hook-and-line) fisheries (5-year average: 0.040 t) and trawl fisheries (5-year average: 0.086 t). In 2018/19, the estimated PIBKC bycatch mortality was 0.005 t in the groundfish fixed gear fisheries and 0.385 t in the groundfish trawl fisheries.

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 over the past 10 years.

5. *Management performance:* The stock is below MSST and consequently is overfished. Overfishing will be evaluated in September when a complete characterization of bycatch in the groundfish fisheries will be available, but overfishing is not occurring as of April 1, 2019. 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 (2019/20) 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 has changed slightly since 2014/15 due to small differences in the random effects model results with the addition of each new year of survey data.]

Table 1: Management performance, all units in metric tons. The OFL is a total catch OFL for each year.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2015/16	2,058 A	361 A	closed	0	1.18	1.16	0.87
2016/17	2,053 A	232 A	closed	0	0.38	1.16	0.87
2017/18	2,053 A	230 A	closed	0	0.33	1.16	0.87
2018/19	2,053 A	230 A	closed	0	0.41	1.16	0.87
2019/20	--	175 B	--	--	--	1.16	0.87

Table 2: Management performance, all units in the table are million pounds.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2015/16	4.537 A	0.796 A	closed	0	0.0026	0.0026	0.002
2016/17	4.526 A	0.511 A	closed	0	0.0008	0.0026	0.002
2017/18	4.526 A	0.507 A	closed	0	0.0007	0.0026	0.002
2018/19	4.526 A	0.507 A	closed	0	0.0009	0.0026	0.002
2019/20	--	0.386 B	--	--	--	0.0026	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 2019/20 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 for 2019/20. 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 (2019/20) MMB-at-mating is also based on the smoothed survey data.

Table 3: Management performance, all units in metric tons. The OFL is a total catch OFL for each year.

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
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	232	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2017/18	4c	4,106	230	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2018/19	4c	4,106	230	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2019/20	4c	4,106	175	0.04	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

Table 4: Management performance, all units in the table are million pounds.

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2015/16	4c	9.06	0.795	0.09	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2016/17	4c	9.07	0.511	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2017/18	4c	9.05	0.507	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2018/19	4c	9.05	0.507	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2019/20	4c	9.05	0.385	0.04	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. *ABC:* The ABC was calculated using a 25% buffer on the OFL, as in the previous assessments since 2015. The ABC is thus 0.87 t (= 0.25x1.16 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 has occurred within the Pribilof Islands Habitat Conservation Zone since 2015/16.

2. Input data

Retained and discard catch time series were updated with 2017/18 and 2018/19 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 2018 survey.

3. Assessment methodology

With the 2017 assessment, PIBKC was moved to a triennial schedule for full assessments following stock prioritization (CPT, 2017). Thus, only a partial assessment was conducted in 2018 (Stockhausen, 2018). However, the NMFS Alaska Regional Office noted that there was a biennial requirement to review the rebuilding status for PIBKC and that it was sensible to have the assessment and report on the same biennial basis. Consequently, the 2019 assessment is a full assessment. In addition, the timing for the 2019 (and subsequent) full assessment was changed from September to May. This change in timing has required the use of several alternative estimates for quantities used in the assessment model. These include survey MMB in the year of the assessment, as well as retained catch and bycatch quantities in the fishery year prior to the assessment. The NMFS EBS Shelf Survey is typically conducted June-August, so biomass estimates from the survey in the year of the assessment are no longer available and a value projected by the random effects model used to smooth survey MMB is used as a substitute to calculate MMB-at-mating for the assessment year (see Appendix C for more details). Also, the crab fishery year runs (by convention) from July 1 to June 30 so estimates of retained catch in the directed fishery and bycatch in the directed and other fisheries are incomplete at the time of the May assessment. For 2019, the directed fishery was closed and thus there will be no retained catch or bycatch for 2018/19. PIBKC bycatch did occur, though, in the Tanner crab and groundfish fisheries prior to April 1, 2019 when the author accessed in-season bycatch records (Tanner crab: Ben Daly, ADFG, pers. comm.; groundfish fisheries: AKFIN Answers databases). The values for bycatch obtained at this time were used as estimates for the 2018/19 year-end values to determine MMB-at-mating for 2018/19. Although these values are probably underestimates of the final values, given the overall small scale of bycatch in recent years this approximation is likely to have no effect on the determination of "overfished"" status while the determination of "overfishing" will be revisited by the NPFMC Crab Plan Team and Science and Statistical Committee in Septemtber with the end-of-year bycatch numbers for 2018/19.

Otherwise, the methodology is the same as in the 2018/19 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 in 2015 and used in the 2015 and 2016 assessments (Stockhausen, 2015, 2016).

4. Assessment results

Total catch mortality in 2018/19 was 0.411 t, which did not exceed the OFL (1.16 t). Consequently, overfishing did not occur in 2018/19. The projected MMB-at-mating for 2019/20 decreased slightly from that in 2018/19 but remained below the MSST. Consequently, the stock remains overfished and a directed fishery is prohibited in 2019/20. The OFL, based on average catch, and ABC are identical to last year's values.

B. Responses to SSC and CPT Comments

CPT comments September 2015:

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:

Results from the random effects model were used to calculate both B_{MSY} and current B for status determination.

SSC comments October 2015:

Specific remarks pertinent to this assessment

none

CPT comments May 2016:

Specific remarks pertinent to this assessment

none

SSC comments June 2016:

Specific remarks pertinent to this assessment

none

CPT comments September 2017:

Specific remarks pertinent to this assessment

Information regarding the model used for status determination criteria (in Appendix C) should be incorporated into the main assessment section. Additionally, more information should be included in the presentation to the CPT (such as parameter tables and process error) in order to fully evaluate model performance.

Responses to CPT Comments:

Information regarding the model used for status determination criteria remains in Appendix C for this assessment. This appendix is produced using an R Markdown script that runs the assessment model and produces the appendix document simultaneously. The main assessment document, previously compsed as a Microsoft Word document, has now been converted to an R Markdown script as well. It may be possible to merge these two documents more fully in the future, but the main assessment document currently contains tables that depend on the results presented in Appendix C and that are formatted in a completely independent step using Microsoft Excel. The two documents can be merged once producing the tables is formulated in R Markdown (a nontrivial task).

As requested, the author will include parameter tables and the estimated process error in his presentation.

SSC comments October 2017:

Specific remarks pertinent to this assessment

none

CPT comments May 2018:

Specific remarks pertinent to this assessment

none

SSC comments June 2018:

Specific remarks pertinent to this assessment

none

CPT comments September 2018:

Specific remarks pertinent to this assessment

none

SSC comments October 2018:

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).

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).

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 occupy the waters adjacent to and northeast of the Pribilof Islands (Armstrong et al. 1987). For assessment purposes, the Pribilof District as defined in Figure 2, with the addition of a 20 nm mile strip to the east of the District (bounded by the dotted red line in Figure 2), is considered to define the stock boundary for PIBKC.

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 (Table 9; Figure 3). Landings increased during the 1970s and peaked at a harvest of 5,000 t in the 1980/81 season (Table 9; Figure 3), with an associated increase in effort to 110 vessels (ADFG 2008). The fishery occurred September through January, but usually lasted less than 6 weeks (Otto and Cummiskey 1990; ADFG 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 (ADFG 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 (Tables 10 and 11). In addition, blue king crab have been taken as bycatch in groundfish fisheries by both fixed and trawl gear, primarily those targeting Pacific cod, flathead sole and yellowfin sole (Tables 10-12).

Amendment 21a to the BSAI Groundfish FMP prohibits the use of trawl gear in the Pribilof Islands Habitat Conservation Area (subsequently renamed the Pribilof Islands Habitat Conservation Zone in Amendment 43; Figure 4), 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 (Figure 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 2018/19 from ADFG data (no retained catch, no bycatch mortality; Tables 10 and 11). The time series of discards in the groundfish pot and trawl fisheries (Tables 10 and 11) were updated for 2009/10 -2018/19 using NMFS Alaska Regional Office (AKRO) estimates obtained from the AKFIN database (as updated on April 1, 2019). Results from the 2018 NMFS EBS bottom trawl survey were added to the assessment (Tables 15 and 16), based on the “new” standardization described in the 2015 assessment (Stockhausen, 2015).

2. Fishery data

2.a. Retained catch

Retained pot fishery catches (live and deadloss landings data) are provided for 1973/74 to 2015/16 (Table 9, Figure 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 2018/19 crab fishing season.

2.b. Bycatch and discards:

Crab pot fisheries

Non-retained (directed and non-directed) pot fishery catches are provided for sublegal males ($<$ 138 mm CL), legal males ($\geq$ 138 mm CL), and females based on data collected by onboard observers in the crab fisheries (Table 10). 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:

$$w = \alpha \cdot z^{\beta} \tag{1}$$

Values for the length-to-weight conversion parameters α and β were applied across the 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:

$$\overline{W} = \frac{\sum w_z \cdot n_z}{\sum n_z} \tag{2}$$

where w_z is crab weight-at-size z (i.e., carapace length) using Equation 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.

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 10, 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. For this assessment, a 20% handling mortality rate was applied to the bycatch estimates to calculate non-retained crab mortality in these pot fisheries (Table 11). In assessments priot to 2017, a handling mortality rate of 50% was applied to bycatch in the pot fisheries. The revised value used here is now consistent with the rates used in other king crab assessments (e.g., Zheng et al., 2016).

Bycatch mortality in the crab fisheries in 2018/19 consisted of 1 observed sublegal male, amounting to 0.020 t in expanded mortality.

Groundfish fisheries

The AKRO estimates of non-retained catch from all groundfish fisheries in 2018/19, as available through the AKFIN database (accessed Aug. 30, 2019), are included in this report (Tables 10-12). Updated estimates for 2009/10-2018/19 were 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, ADFG 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 the 2014-2016 assessments. Detailed results from this process are presented in Appendix A.

To assess crab mortalities in the groundfish fisheries, an 80% handling mortality rate was applied to estimates of bycatch in trawl fisheries, and a 20% handling mortality rate was applied to fixed gear fisheries using pot and hook and line gear (Tables 10-11).

In 2018/19, fisheries targeting yellowfin sole (*Limanda aspera*) accounted for 95% of the bycatch of PIBKC in the groundfish fisheries, with fisheries targeting Pacific cod (*Gadus microcephalus*) accounting for 5%. In contrast, fisheries targeting flathead sole (*Hippoglossoides elassodon*) and northern rock sole (*Lepidopsetta polyxystra*) accounted for 60% and 68% in 2017/18 and 2016/17 respectively (Table 12).

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 13). 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 2018/19, non-pelagic trawl gear was estimated to account for 95% (by weight) of PIBKC bycatch in the groundfish fisheries. In 2015/16, by contrast, non-pelagic trawl gear accounted for only 52% the bycatch. In 2018/19, hook-and-line gear accounted for only 5% of PIBKC bycatch in the groundfish fisheries, although in 2013/14 and 2014/15 this gear type accounted for the total bycatch of PIBKC. Although these appear to be large interannual changes, the actual bycatch amounts involved are fairly small and interannual variability is consequently expected to be rather high.

2.c. Catch-at-length

Not applicable.

3. Survey data

The 2018 NMFS EBS bottom trawl survey was conducted in June and July. Survey results for PIBKC are based on the stock area first defined in the 2013 assessment (Foy, 2013), which includes the Pribilof District and a 20 nm strip adjacent to the eastern edge of the District (Figure 2). The adjacent 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 2018, the survey caught 16 blue king crab in 86 stations across the stock area, while 28, 33, and 23 crab were caught across the same stations in the 2015-2017 surveys, respectively (Table 14). Six immature males were caught in 2018, similar to numbers caught in 2015-2017 (4, 5 and 4, respectively). Three mature males (all legal size) were caught in 2018, compared with 13, 3 and 4 in 2015-2017, respectively. One immature female was caught in 2018; none were caught in 2015, while five were caught in 2016 and seven in 2017. Finally, six mature females were caught in 2018, compared with 11 in 2015, 19 in 2016,and 8 in 2017.

The area-swept estimate of mature male abundance in the stock area at the time of the 2018 survey was 56 thousand crab (cv: 0.56), representing a decrease from 91 thousand crab (cv: 0.50) in 2017 (Table 15). The abundance estimate for immature males in 2018 was 110 thousand crab (cv: 0.57), while it was 68 thousand in 2017. The area-swept estimate for immature female abundance in 2018 was 76 thousand crab (cv: 0.59), smaller than the 188 thousand crab (cv: 0.75) in 2017, while that for mature females was only 58 thousand crab (cv: 1.0), smaller than that of 162 thousand (cv:

0.53) in 2017. Given the large uncertainties associated with the estimates, none of the changes were statistically significant.

The area-swept estimate of mature male biomass in the stock area at the time of the 2018 survey was 154 t (cv: 0.57), while it was 253 t (cv: 0.51) in 2017 (Table 16). The biomass estimate for immature males in 2018 was 96 t (cv: 0.54), compared to 45 t (cv: 0.77) in 2017. The area-swept estimate for immature female biomass in 2018 was 45 t (cv: 0.58); in 2017 it was 107 t (cv: 0.81). For mature females, the estimated swept-area biomass was 76 t (cv: 1.00) ; in 2018 it was 152 t (cv: 0.56).

One feature that characterizes survey-based estimates of abundance and biomass for PIBKC is the large uncertainty (cv's on the order of 0.5-1) associated with the estimates, which complicates the interpretation of sometimes large interannual swings in estimates (Tables 15 and 16, Figures 5-8). 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 15, Figures 5 and 6). Following a general decline to a low-point in 1985 (~500,000 males), abundance increased by a factor of 10 in the early 1990s, 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 trends similar to those in abundance (Table 16, Figures 7 and 8).

Size frequencies for males by shell condition from recent surveys (2015-2018) are illustrated in Figure 9. Size frequencies for all males across the time series are shown in Figure 10. While Figure 10 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 Figure 11 from recent surveys (2015-2018). Size frequencies for all females are shown in 12. These also provide little indication of recent recruitment.

The small numbers of crab caught in recent surveys make it difficult to draw firm conclusions regarding spatial patterns (see figures in Appendix B). That said, 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.

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. Subsequently, a 25% buffer has been used to calculate ABC.

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 (Stockhausen, 2015), 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 C) is used in this assessment.

Since the 2017 assessment, assessments for PIBKC have been moved to an odd-year biennial schedule. The timing of the assessment was also moved from September to May, which has required that several data inputs to the model (assessment year MMB at the time of the survey and retained catch and bycatch values from the crab fishery year prior to the assessment year) be estimated in some fashion. For this (2019) assessment, MMB at the time of survey (July, 2019) was estimated from the observed time series using the random effects as a 1-step ahead prediction–i.e., it is the same value as that from the 2018 survey. The values of year-to-date bycatch in the crab and groundfish fisheries on April 1, 2019 were taken as estimates of the 2018/19 year-end values. Because the directed fishery was closed, retained catch and bycatch in the directed fishery would necessarily be zero.

2. Model Description

See Appendix C.

3. Model Selection and Evaluation

Not applicable

4. Results

See Appendix C.

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 FMSY, 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 ($B_{MSY_{proxy}}$ 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 appeared to be below a threshold for responding to increased production based on the lack of response of the adult stock biomass to slight fluctuations in recruitment (male crab 120-134 mm) (Figure 20 in Foy 2013).
2) An estimate of surplus production using the equation

$$ASP_t = MMB_{t+1} - MMB_t + C_t$$

where C_t denotes total catch mortality in year t suggested that meaningful surplus production 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 climate regime shifts where temperature and current patterns change 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 indicate a production shift.

B. Exploitation rates

Exploitation rates fluctuated during the open fishery periods from 1975 to 1987 and 1995 to 1998 (Figure 20 in Foy 2013) while total catch increased until 1980, then decreased until the fishery was closed in 1987 (Figure 3). Following the re-opening of the fishery in 1995, total catch declined annually until the fishery was closed again in 1999 (Figure 3). The current $F_{MSY_{proxy}} = M$ is 0.18 yr^{-1}, so time periods with greater exploitation rates should not be considered to represent periods with average rates of fishery removals.

C. Recruitment

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 $F_{MSY_{proxy}} = M$ were not sustainable.

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 C. For this stock,

$B_{MSY_{proxy}}$ was calculated using the random effects model-smoothed estimates for MMB_{survey} from the survey time series (Table 17) 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 (Table 18) and was calculated as 4106 t.

In this assessment, "current B" (B) is the MMB_{mating} projected for 2019/20. Details of this calculation are also provided in Appendix C. For 2019/20, B = 175 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 $0.5 \cdot B_{MSY_{proxy}}$. If B drops below the MSST, the stock is considered to be overfished.

2. Parameters and stock sizes

- $B_{MSY_{proxy}}$ (B_{REF}) = 4106 t
- $M = 0.18\ yr^{-1}$
- B = 175 t

3. OFL specification

3.a. Stock status level

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 (Figure 13), where the Stock Status Level (level a, b or c; equations 3-5) is based on the relationship of B to $B_{MSY_{proxy}}$.

Stock Status Level F_{OFL}

$$a. \quad B/B_{MSY_{proxy}} > 1.0 \quad F_{OFL} = \gamma \cdot M \tag{3}$$

$$b. \quad \beta < B/B_{MSY_{proxy}} \leq 1.0 \quad F_{OFL} = \gamma \cdot M[(B/B_{MSY_{proxy}} - \alpha)/(1-\alpha)] \tag{4}$$

$$c. \quad B/B_{MSY_{proxy}} \leq \beta \quad F_{directed} = 0, \quad F_{OFL} \leq F_{MSY} \tag{5}$$

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).

3.b. Basis for MMB-at-mating

The basis for projecting MMB from the survey to the time of mating is discussed in detail in Appendix C.

3.c. Specification of F_{OFL}, OFL and other applicable measures

Table 5: Basis for the OFL (Table 3 repeated). All units in metric tons.

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
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	232	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2017/18	4c	4,106	230	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2018/19	4c	4,106	230	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2019/20	4c	4,106	175	0.04	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

Table 6: Basis for the OFL (Table 4 repeated). All units in millions lbs.

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2015/16	4c	9.06	0.795	0.09	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2016/17	4c	9.07	0.511	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2017/18	4c	9.05	0.507	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2018/19	4c	9.05	0.507	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2019/20	4c	9.05	0.385	0.04	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

The retained portion of the catch for this stock is zero (0 t).

5. Recommendations:

For 2019/20, $B_{MSY_{proxy}} = 4106$ 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

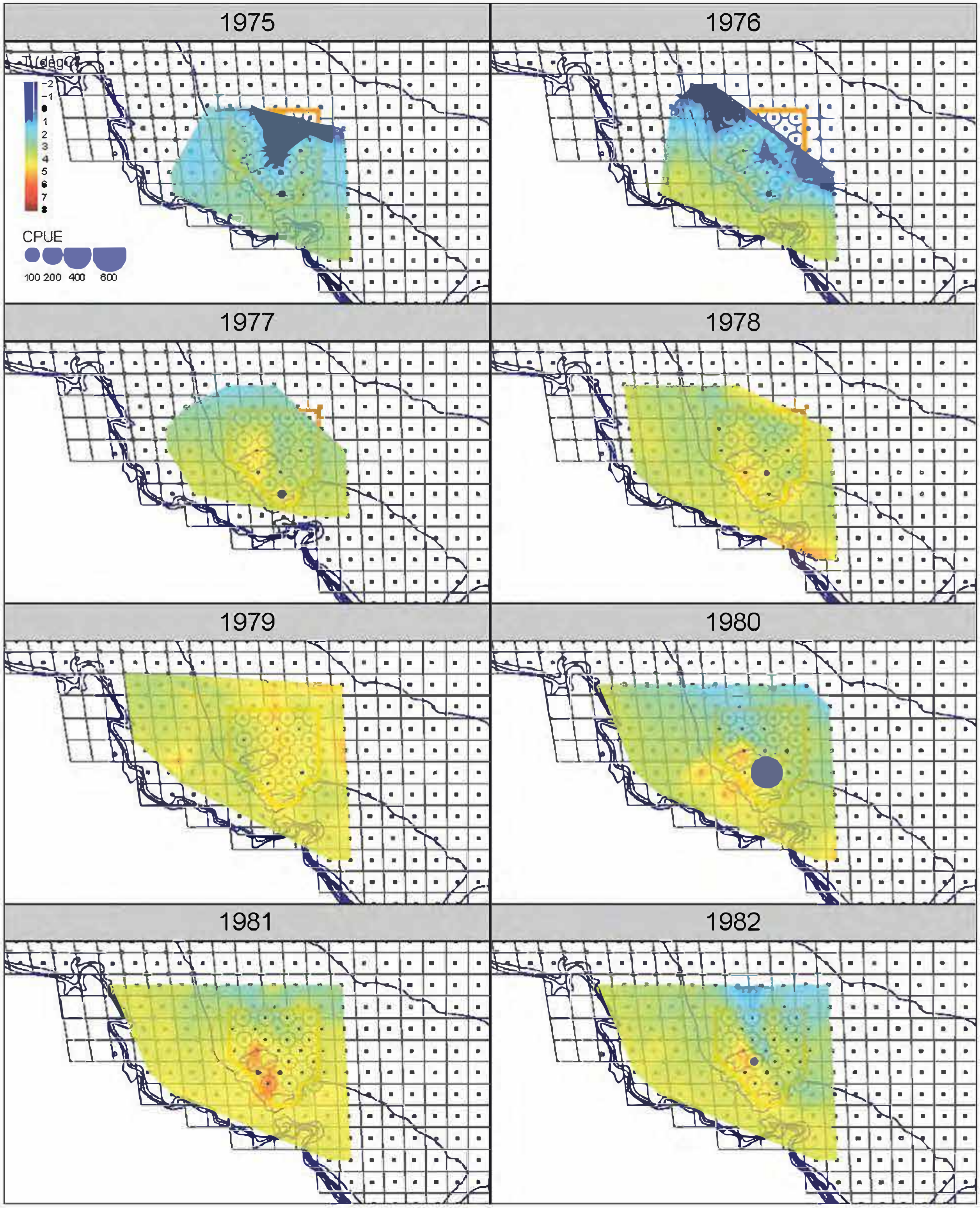

Figure 11: Survey CPUE (biomass) for females PIBKC. Page 1 of 6

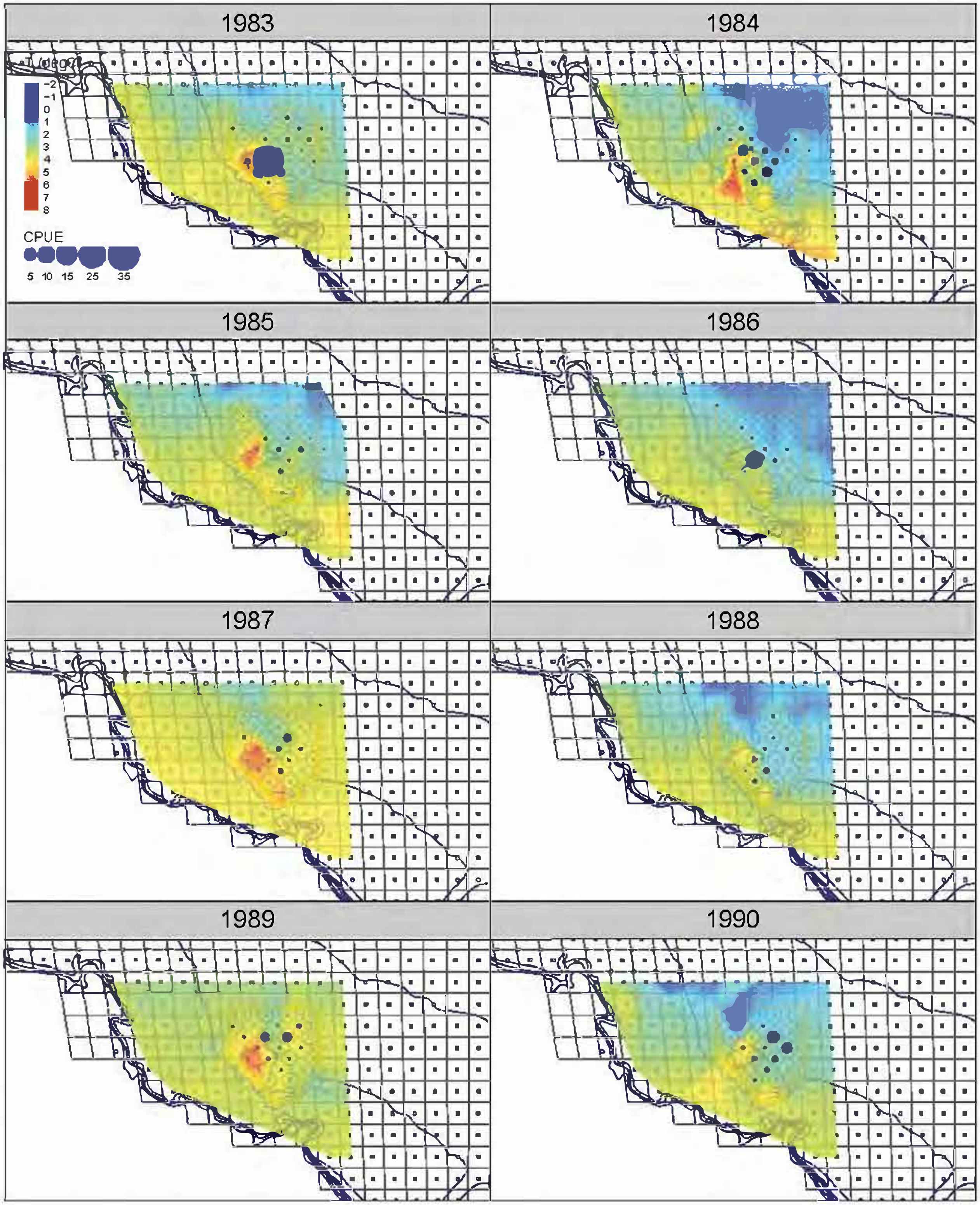

Figure 12: Survey CPUE (biomass) for females PIBKC. Page 2 of 6

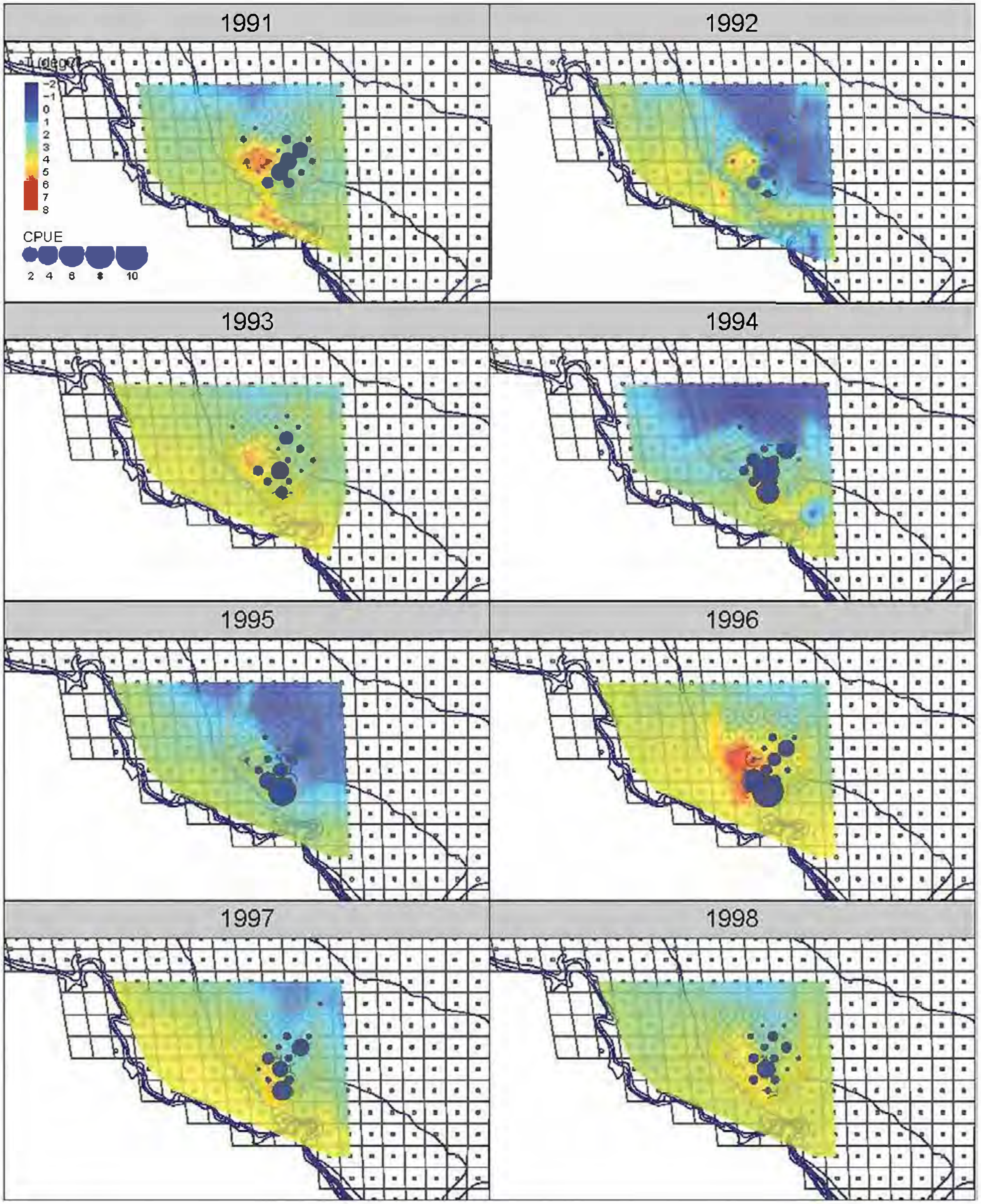

Figure 13: Survey CPUE (biomass) for females PIBKC. Page 3 of 6

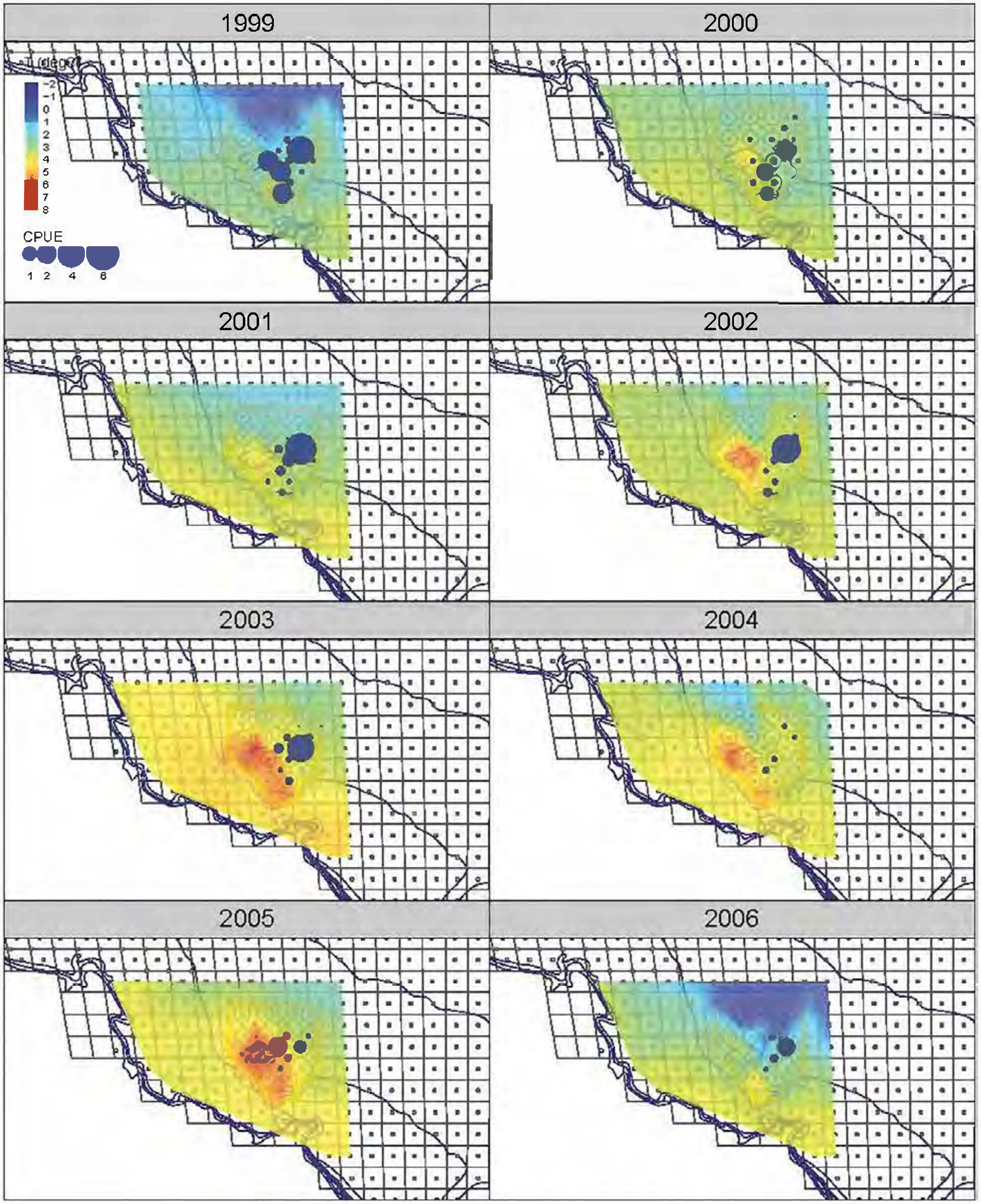

Figure 14: Survey CPUE (biomass) for females PIBKC. Page 4 of 6

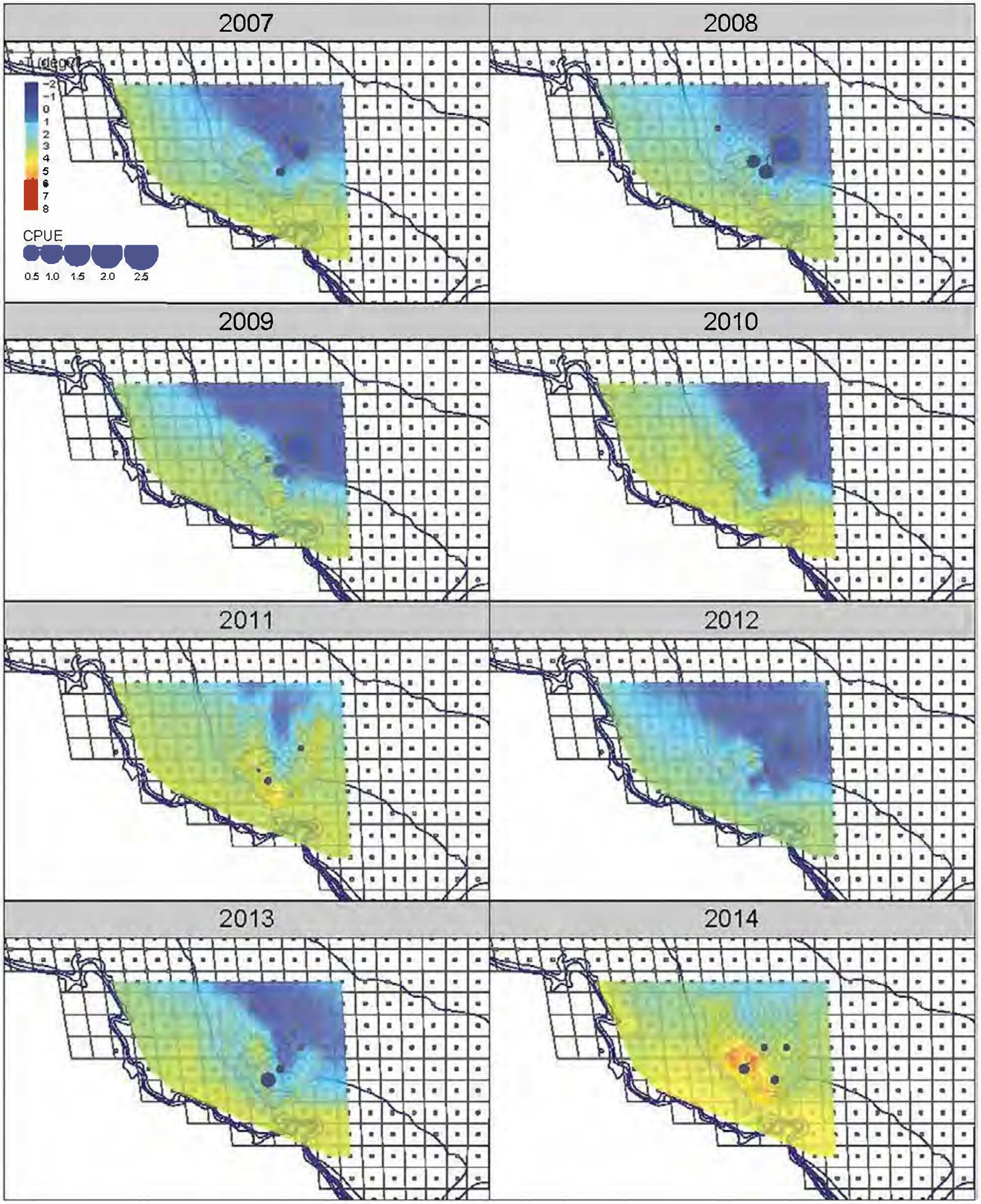

Figure 15: Survey CPUE (biomass) for females PIBKC. Page 5 of 6

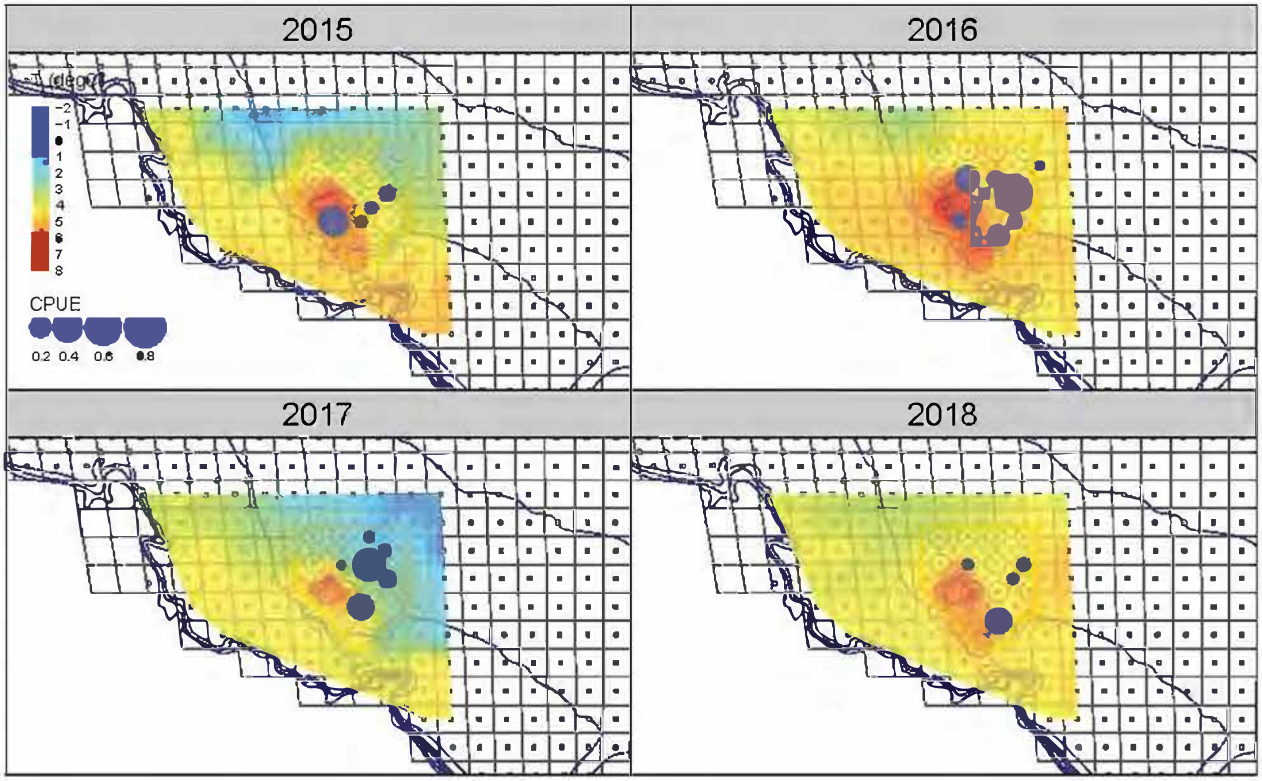

Figure 16: Survey CPUE (biomass) for females PIBKC. Page 6 of 6

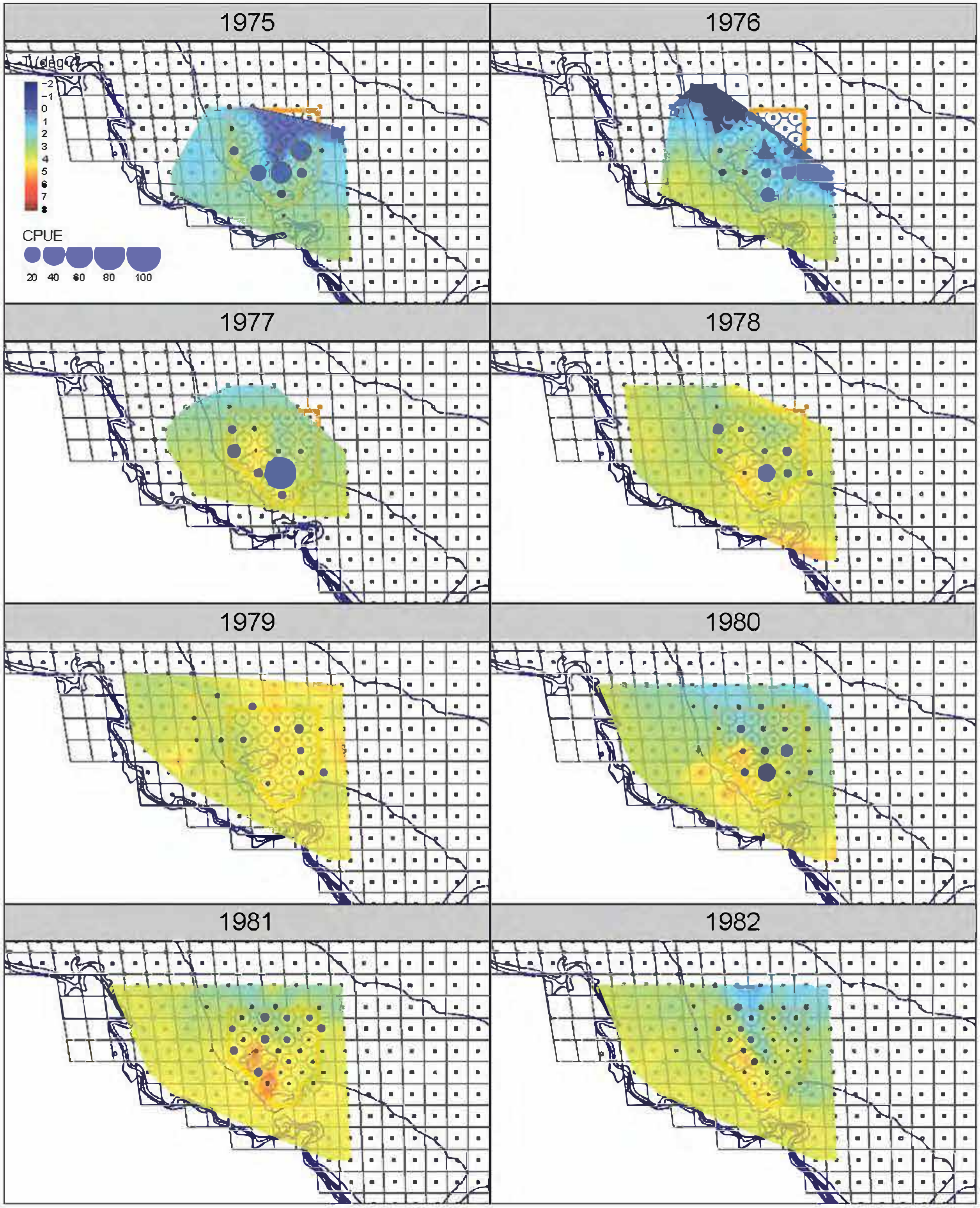

Figure 17: Survey CPUE (biomass) for males PIBKC. Page 1 of 6

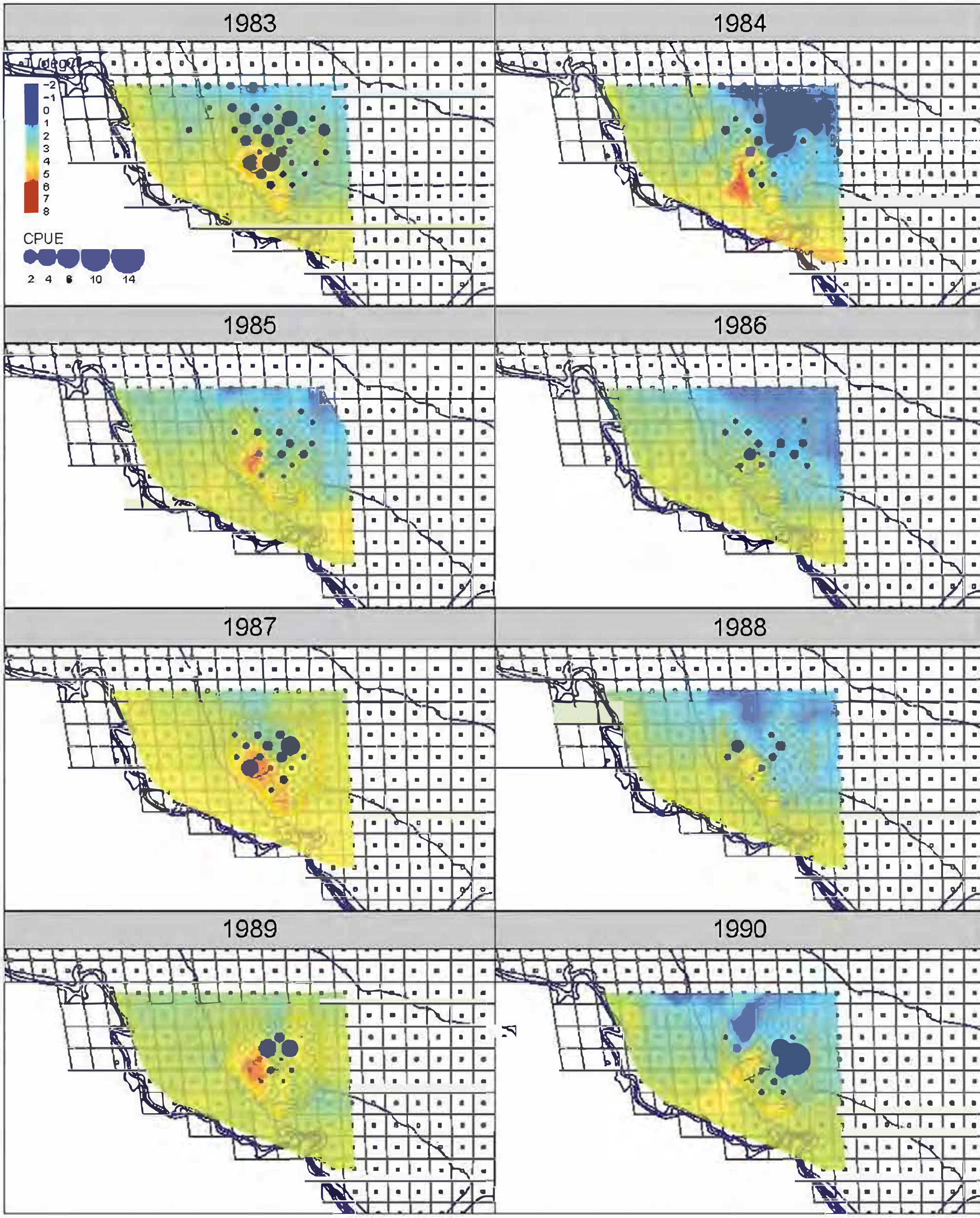

Figure 18: Survey CPUE (biomass) for males PIBKC. Page 2 of 6

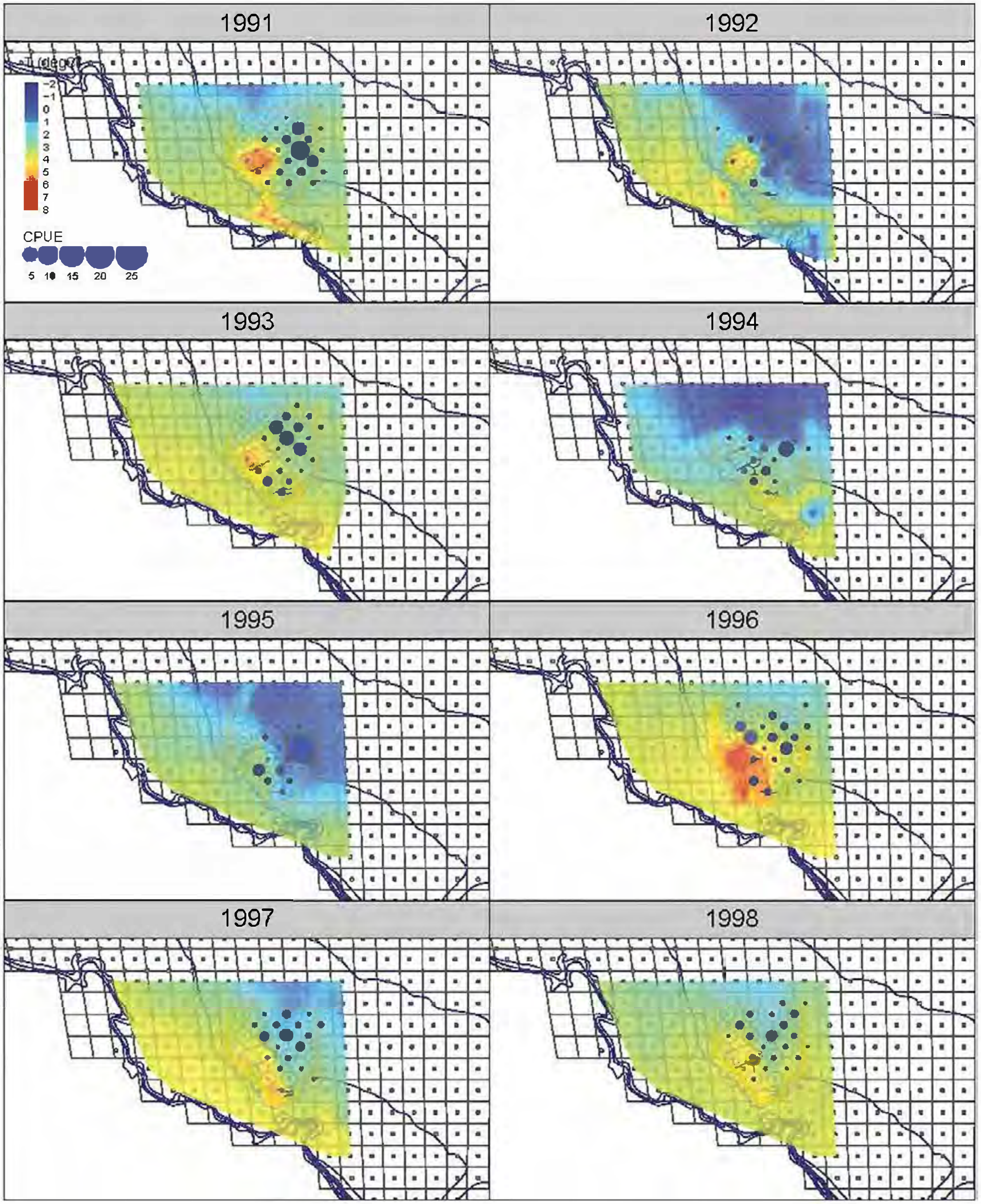

Figure 19: Survey CPUE (biomass) for males PIBKC. Page 3 of 6

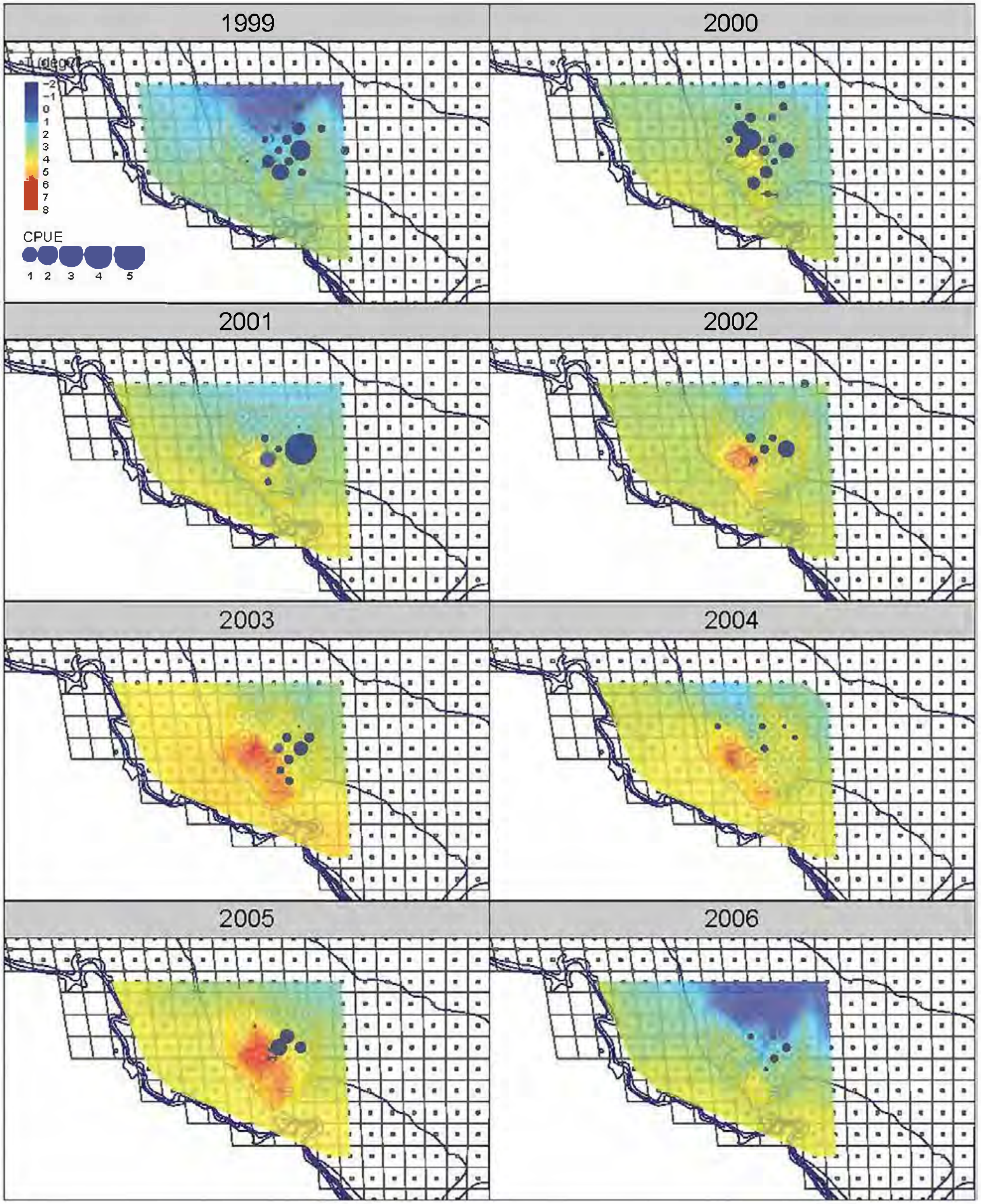

Figure 20: Survey CPUE (biomass) for males PIBKC. Page 4 of 6

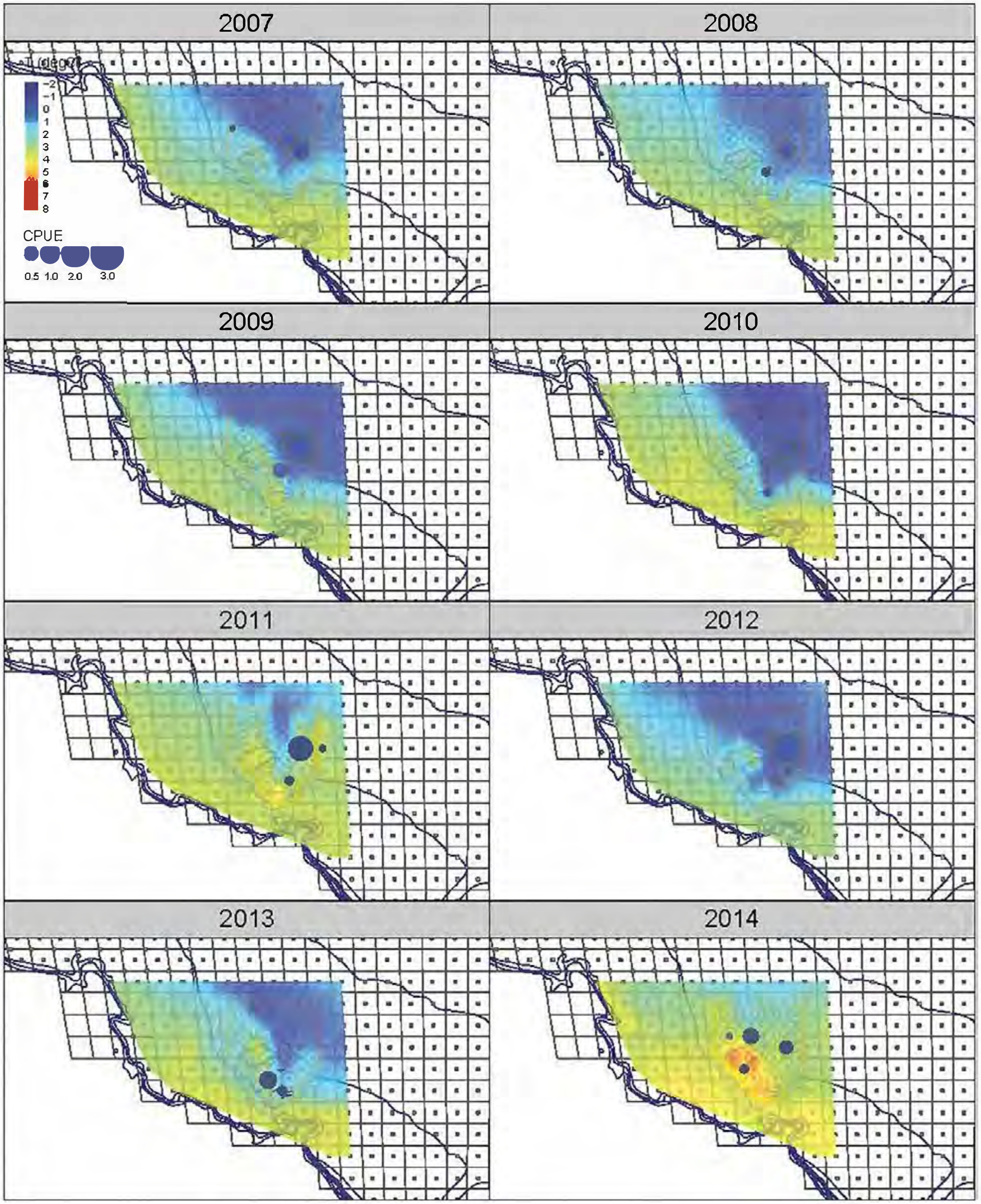

Figure 21: Survey CPUE (biomass) for males PIBKC. Page 5 of 6

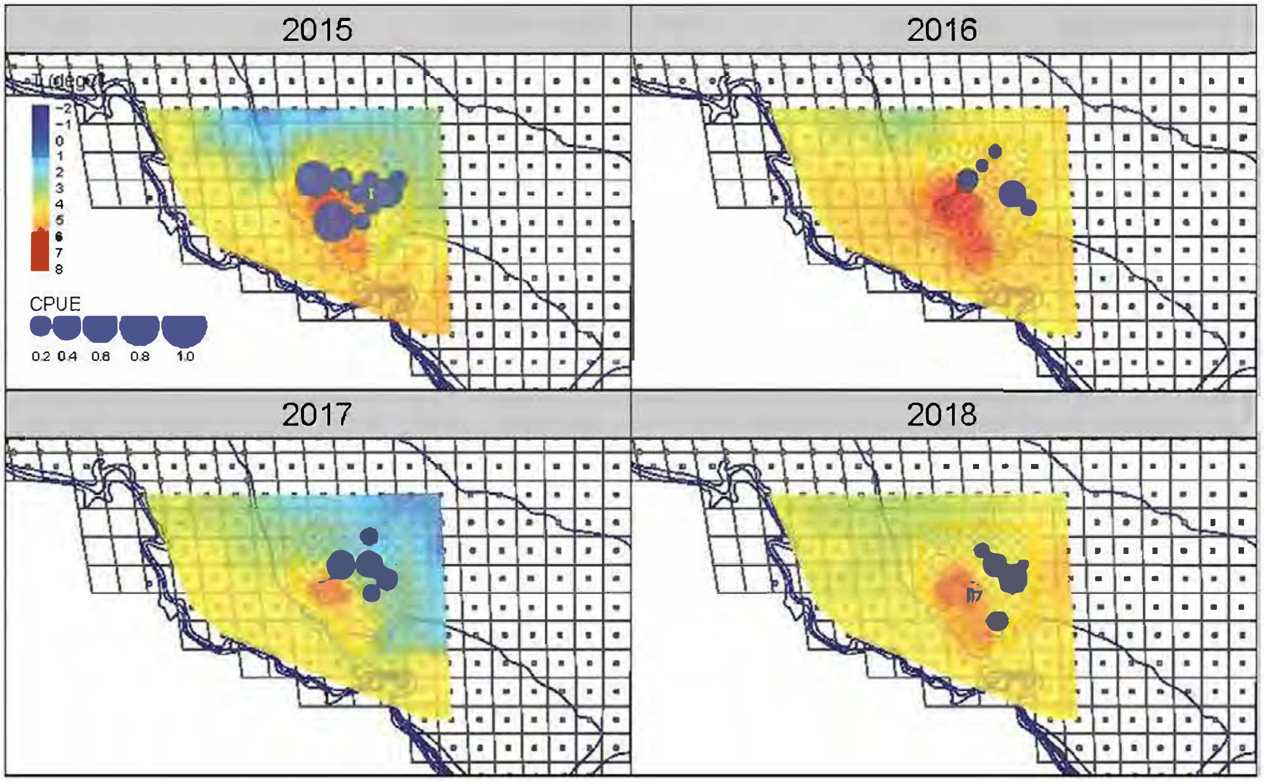

Figure 22: Survey CPUE (biomass) for males PIBKC. Page 6 of 6

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 2019/20 was estimated at 175 t. The $B/B_{MSY_{proxy}}$ ratio corresponding to the biomass reference is 0.06. $B/B_{MSY_{proxy}}$ is $< \beta$, 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 2019/20, 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 $\sigma_{total} = \sqrt{\sigma_w^2 + \sigma_b^2}$. 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 (2018) is 0.5710464, 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 $\gamma \cdot M$ 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 2019/20, $F_{directed} = 0$ 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 based on a 25% buffer of the average catch between 1999/2000 and 2005/2006 would be 0.87 t.

Table 7: Management performance (Table). All units in metric tons. The OFL is a total catch OFL for each year.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2015/16	2,058 A	361 A	closed	0	1.18	1.16	0.87
2016/17	2,053 A	232 A	closed	0	0.38	1.16	0.87
2017/18	2,053 A	230 A	closed	0	0.33	1.16	0.87
2018/19	2,053 A	230 A	closed	0	0.41	1.16	0.87
2019/20	--	175 B	--	--	--	1.16	0.87

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.

Table 8: Management performance (Table 2 repeated). All units in the table are million pounds.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2015/16	4.537 A	0.796 A	closed	0	0.0026	0.0026	0.002
2016/17	4.526 A	0.511 A	closed	0	0.0008	0.0026	0.002
2017/18	4.526 A	0.507 A	closed	0	0.0007	0.0026	0.002
2018/19	4.526 A	0.507 A	closed	0	0.0009	0.0026	0.002
2019/20	--	0.386 B	--	--	--	0.0026	0.002

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.

Given that the ratio of current B to B_{MSY} is 0.06 and that the recent time series of MMB-at-survey time does not show an icreasing trend, there has been no progress towards rebuilding the stock.

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. Jared Weems, a PhD student at University of Alaska, Fairbanks, is conducting research on alternative survey designs, including visual censuses, drop camera, and collector traps to better quantify PIBKC in a study funded by NPRB. Other data gaps include stock-specific natural mortality rates and a lack of understanding regarding processes apparently preventing successful recruitment to the Pribilof District. Jonathan Reum (AFSC) and colleagues are developing a qualitative network model that describes important biological interactions that may influence the productivity of PIBKC. The purpose is to explore the potential efficacy of different management interventions that include new policies on fisheries that target the predators/competitors of PIBKC, as well as out-stocking of benthic PIBKC juveniles assuming implementation of a hatchery program.

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Tables

Table 9: Total retained catches from directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2011; D. Pengilly and J. Webb, ADFG, 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 - 2018/2019	0	0	--

Table 10: 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 ADFG). 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	0.044	0.056
2011/12	0.000	0.000	0.000	0.112	0.007
2012/13	0.000	0.000	0.000	0.170	0.669
2013/14	0.000	0.000	0.000	0.065	0.000
2014/15	0.000	0.000	0.000	0.144	0.000
2015/16	0.103	0.000	0.230	0.744	0.808
2016/17	0.000	0.000	0.000	0.090	0.455
2017/18	0.064	0.000	0.000	0.000	0.397
2018/19	0.000	0.000	0.101	0.026	0.482

Table 11: 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; 0.2) 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	--	--	--	0.013	4.959	4.973
1992/93	--	--	--	0.176	48.633	48.809
1993/94	--	--	--	0.000	27.386	27.386
1994/95	--	--	--	0.007	5.485	5.492
1995/96	--	--	--	0.022	1.027	1.049
1996/97	0.000	0.000	0.161	0.006	0.054	0.221
1997/98	0.000	0.000	0.000	0.292	0.104	0.396
1998/99	0.743	0.459	0.093	3.960	0.063	5.319
1999/00	0.394	0.699	0.858	0.159	0.016	2.125
2000/01	0.000	0.000	0.000	0.023	0.018	0.042
2001/02	0.000	0.000	0.000	0.167	0.023	0.190
2002/03	0.000	0.000	0.000	0.014	0.238	0.252
2003/04	0.000	0.000	0.000	0.069	0.182	0.251
2004/05	0.000	0.000	0.000	0.163	0.002	0.165
2005/06	0.010	0.000	0.000	0.071	1.071	1.152
2006/07	0.021	0.000	0.000	0.028	0.059	0.108
2007/08	0.027	0.000	0.000	0.799	0.106	0.931
2008/09	0.000	0.000	0.000	0.028	0.378	0.407
2009/10	0.000	0.000	0.000	0.043	0.165	0.209
2010/11	0.000	0.000	0.037	0.009	0.045	0.091
2011/12	0.000	0.000	0.000	0.022	0.006	0.028
2012/13	0.000	0.000	0.000	0.034	0.535	0.569
2013/14	0.000	0.000	0.000	0.013	0.000	0.013
2014/15	0.000	0.000	0.000	0.029	0.000	0.029
2015/16	0.021	0.000	0.046	0.149	0.646	0.862
2016/17	0.000	0.000	0.000	0.018	0.364	0.382
2017/18	0.013	0.000	0.000	0.000	0.317	0.330
2018/19	0.000	0.000	0.020	0.005	0.385	0.411

Table 12: Bycatch (in kg) of PIBKC in the groundfish fisheries, by target type.

Crab Fishery Year	% bycatch (biomass) by trip target				total bycatch (# crabs)
	yellowfin sole %	Pacific cod %	flathead sole %	rock sole %	
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
2016/17	16	16	<1	68	580
2017/18	40	<1	60	<1	278
2018/19	95	5	<1	<1	415

Table 13: Bycatch (in kg) of PIBKC in the groundfish fisheries, by gear type.

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
2016/17	84	0	16	0	580
2017/18	100	0	0	0	278
2018/19	95	0	5	0	415

Table 14: Summary of recent NMFS annual EBS bottom trawl surveys for the Pribilof Islands District blue king crab by stock component.

year	Stock Component	Number of tows in District	Tows with crab	Number of crab measured
2018	Immature male	86	4	6
	Mature male	86	3	3
	Legal male	86	3	3
	Immature female	86	1	1
	Mature female	86	3	6
2017	Immature male	86	2	4
	Mature male	86	4	4
	Legal male	86	3	3
	Immature female	86	3	7
	Mature female	86	4	8
2016	Immature male	86	4	5
	Mature male	86	3	3
	Legal male	86	1	1
	Immature female	86	4	5
	Mature female	86	7	19
2015	Immature male	86	2	4
	Mature male	86	8	13
	Legal male	86	5	7
	Immature female	86	0	0
	Mature female	86	4	11
2014	Immature male	86	3	5
	Mature male	86	2	5
	Legal male	86	2	5
	Immature female	86	1	1
	Mature female	86	3	4

Table 15: Abundance time series for Pribilof Islands blue king crab from the NMFS annual EBS bottom trawl survey.

Year	Males								Females					
	immature		mature		legal		total		immature		mature		total	
	abundance	cv	abundance	cv	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	0	0.00	13,147,587	0.61	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	7,369,388	0.97	769,150	0.51	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	851,601	0.82	13,880,051	0.86	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	60,923	1.00	5,926,514	0.66	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	142,416	0.72	1,168,935	0.81	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	781,224	0.77	182,902,919	0.98	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	826,524	0.41	5,433,491	0.44	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	876,256	0.51	7,837,004	0.65	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	463,726	0.54	9,307,969	0.78	9,771,695	0.76
1984	517,574	0.40	770,643	0.22	558,226	0.25	1,288,217	0.21	465,473	0.52	2,769,190	0.38	3,234,663	0.37
1985	67,765	0.60	428,076	0.28	270,242	0.29	495,841	0.27	260,081	0.54	486,184	0.44	746,266	0.36
1986	18,904	1.00	480,198	0.31	460,311	0.31	499,102	0.30	36,684	0.70	2,101,932	0.90	2,138,616	0.88
1987	621,541	0.83	903,180	0.41	830,151	0.42	1,524,721	0.43	401,530	0.74	670,479	0.58	1,072,008	0.48
1988	1,238,053	0.84	237,868	0.51	237,868	0.51	1,475,921	0.71	897,629	0.87	465,463	0.48	1,363,093	0.64
1989	3,514,764	0.59	239,948	0.62	239,948	0.62	3,754,712	0.58	2,636,099	0.74	1,141,756	0.66	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	2,177,329	0.91	2,045,839	0.55	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	805,451	0.46	2,767,448	0.42	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	1,797,343	0.93	2,149,519	0.49	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	880,672	0.61	1,782,657	0.45	2,663,329	0.38
1994	638,520	0.37	1,294,263	0.34	935,269	0.34	1,932,783	0.33	144,763	0.57	5,047,215	0.44	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	658,479	0.92	4,038,556	0.52	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	275,735	0.42	5,045,822	0.48	5,321,557	0.46
1997	467,234	0.53	1,201,296	0.29	932,852	0.28	1,668,530	0.34	320,344	0.67	2,614,374	0.42	2,934,717	0.39
1998	949,447	0.46	967,098	0.25	797,187	0.25	1,916,545	0.31	500,241	0.43	1,829,509	0.44	2,329,750	0.37
1999	159,536	0.37	617,258	0.33	452,740	0.34	776,794	0.33	0	0.00	2,755,976	0.49	2,755,976	0.49
2000	163,835	0.56	725,051	0.30	527,589	0.30	888,885	0.31	0	0.00	1,363,070	0.46	1,363,070	0.46
2001	92,918	0.65	522,239	0.71	445,863	0.74	615,157	0.69	18,516	1.00	1,697,465	0.75	1,715,981	0.74
2002	0	0.00	225,476	0.47	207,146	0.49	225,476	0.47	18,729	1.00	1,221,852	0.79	1,240,582	0.78
2003	45,271	0.72	228,897	0.39	213,572	0.40	274,168	0.34	67,329	0.48	1,120,254	0.76	1,187,583	0.72
2004	87,651	0.59	47,905	0.56	15,584	1.00	135,556	0.42	98,059	0.63	70,035	0.60	168,094	0.51
2005	1,981,338	0.96	91,932	0.71	91,932	0.71	2,073,270	0.92	2,268,113	1.00	289,197	0.56	2,557,310	0.89
2006	138,118	0.49	55,579	0.56	38,242	0.70	193,697	0.42	113,047	0.55	429,541	0.77	542,588	0.62
2007	246,165	0.72	110,080	0.85	54,403	0.75	356,245	0.64	122,483	0.73	165,763	0.90	288,245	0.59
2008	233,919	0.93	18,256	1.00	18,256	1.00	252,174	0.86	342,119	0.90	437,369	0.66	779,488	0.75
2009	267,717	0.63	248,626	0.73	68,117	0.59	516,343	0.68	152,290	0.61	477,095	0.82	629,385	0.76
2010	101,151	0.84	130,465	0.49	64,703	0.48	231,616	0.61	165,632	0.56	249,027	0.69	414,660	0.62
2011	0	0.00	165,525	0.79	129,098	0.87	165,525	0.79	18,089	1.00	36,512	0.70	54,601	0.56
2012	194,522	1.00	272,233	0.80	164,165	0.68	466,755	0.88	34,683	1.00	312,095	0.76	346,777	0.70
2013	76,351	1.00	104,361	0.86	68,726	0.80	180,712	0.64	45,344	0.70	150,300	0.63	195,644	0.53
2014	90,990	0.59	91,856	0.71	91,856	0.71	182,846	0.57	27,721	1.00	74,368	0.60	102,088	0.51
2015	75,575	0.77	233,630	0.37	124,592	0.45	309,205	0.41	0	0.00	202,464	0.65	202,464	0.65
2016	94,022	0.52	55,852	0.56	19,345	1.00	149,874	0.49	131,689	0.50	322,760	0.52	454,450	0.50
2017	68,238	0.77	90,645	0.50	71,937	0.59	158,884	0.46	187,860	0.75	161,799	0.53	349,659	0.54
2018	110,361	0.57	55,776	0.56	55,776	0.56	166,136	0.52	75,906	0.59	57,873	1.00	133,779	0.54

Table 16: Biomass time series for Pribilof Islands blue king crab from the NMFS annual EBS bottom trawl survey.

Year	Males								Females					
	immature		mature		legal		total		immature		mature		total	
	biomass (t)	cv	biomass (t)	cv	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	0	0.00	12,442	0.64	12,442	0.64
1976	4,129	0.94	14,059	0.45	12,649	0.47	18,188	0.45	4,968	0.97	824	0.53	5,792	0.89
1977	3,713	0.44	42,618	0.77	40,366	0.78	46,332	0.73	419	0.83	13,154	0.88	13,572	0.87
1978	2,765	0.51	17,370	0.56	13,517	0.64	20,135	0.51	76	1.00	6,416	0.72	6,492	0.72
1979	61	0.79	10,959	0.32	9,040	0.31	11,021	0.31	92	0.73	1,097	0.79	1,189	0.76
1980	2,084	0.49	23,553	0.43	20,679	0.45	25,637	0.42	699	0.86	211,604	0.98	212,303	0.98
1981	1,704	0.30	11,628	0.17	10,554	0.17	13,332	0.18	497	0.41	5,987	0.47	6,484	0.46
1982	1,152	0.23	7,389	0.19	6,893	0.19	8,541	0.17	553	0.57	8,824	0.68	9,377	0.67
1983	962	0.36	5,409	0.18	4,474	0.17	6,371	0.19	258	0.61	9,990	0.79	10,248	0.78
1984	130	0.36	2,216	0.23	1,824	0.25	2,345	0.22	15	0.69	3,070	0.38	3,085	0.38
1985	39	0.73	1,055	0.27	756	0.28	1,094	0.26	5	0.46	520	0.45	525	0.44
1986	4	1.00	1,505	0.30	1,473	0.31	1,508	0.30	11	0.73	2,420	0.90	2,431	0.90
1987	191	0.78	2,923	0.41	2,781	0.41	3,115	0.40	119	0.86	795	0.58	913	0.53
1988	170	0.71	842	0.53	842	0.53	1,012	0.46	190	0.79	528	0.49	718	0.47
1989	1,275	0.62	828	0.64	828	0.64	2,102	0.55	801	0.67	945	0.58	1,746	0.50
1990	2,004	0.66	3,078	0.60	1,514	0.52	5,082	0.61	1,118	0.93	1,810	0.51	2,929	0.49
1991	1,377	0.39	4,690	0.39	3,326	0.45	6,067	0.37	343	0.48	2,433	0.41	2,776	0.38
1992	1,801	0.51	4,391	0.42	3,035	0.45	6,192	0.43	802	0.96	1,848	0.48	2,649	0.46
1993	1,089	0.54	4,556	0.31	3,203	0.30	5,644	0.30	444	0.62	1,647	0.46	2,092	0.40
1994	619	0.39	3,410	0.34	2,806	0.35	4,029	0.34	87	0.57	4,806	0.45	4,893	0.44
1995	968	0.86	8,360	0.60	6,787	0.62	9,328	0.63	331	0.90	3,948	0.52	4,279	0.50
1996	745	0.61	4,641	0.27	3,873	0.27	5,386	0.28	177	0.42	5,408	0.50	5,585	0.49
1997	381	0.55	3,233	0.28	2,765	0.27	3,614	0.29	194	0.66	2,835	0.43	3,028	0.41
1998	692	0.41	2,798	0.25	2,510	0.25	3,490	0.25	267	0.42	1,914	0.44	2,182	0.39
1999	161	0.40	1,729	0.34	1,426	0.35	1,890	0.33	0	0.00	2,868	0.47	2,868	0.47
2000	113	0.68	2,091	0.30	1,746	0.31	2,205	0.30	0	0.00	1,462	0.46	1,462	0.46
2001	87	0.76	1,599	0.73	1,461	0.76	1,686	0.73	0	1.00	1,816	0.72	1,817	0.72
2002	0	0.00	680	0.51	647	0.52	680	0.51	0	1.00	1,401	0.78	1,401	0.78
2003	19	0.98	702	0.40	671	0.41	721	0.39	21	0.67	1,286	0.75	1,307	0.73
2004	36	0.65	107	0.58	48	1.00	143	0.46	25	0.82	98	0.60	123	0.50
2005	326	0.94	344	0.71	344	0.71	670	0.59	477	1.00	370	0.57	847	0.61
2006	87	0.58	166	0.60	139	0.70	253	0.46	38	0.60	538	0.76	576	0.71
2007	197	0.74	306	0.80	206	0.73	503	0.66	59	0.79	223	0.88	282	0.71
2008	212	0.95	46	1.00	46	1.00	258	0.80	222	0.90	450	0.64	672	0.70
2009	254	0.68	497	0.71	187	0.60	751	0.70	80	0.66	545	0.85	625	0.82
2010	92	0.85	303	0.46	190	0.48	395	0.52	84	0.58	310	0.66	394	0.63
2011	0	0.00	461	0.84	399	0.89	461	0.84	3	1.00	34	0.73	37	0.67
2012	165	1.00	644	0.74	459	0.64	809	0.79	9	1.00	229	0.66	237	0.64
2013	15	1.00	250	0.80	190	0.75	265	0.75	12	0.72	154	0.70	166	0.65
2014	83	0.62	233	0.70	233	0.70	317	0.57	16	1.00	91	0.60	108	0.53
2015	82	0.75	622	0.39	428	0.46	703	0.39	0	0.00	160	0.66	160	0.66
2016	70	0.49	129	0.61	68	1.00	199	0.52	72	0.47	329	0.50	401	0.48
2017	45	0.77	253	0.51	223	0.57	298	0.47	107	0.81	152	0.56	259	0.53
2018	96	0.54	154	0.57	154	0.57	249	0.52	45	0.58	76	1.00	121	0.65

Table 17: Smoothed mature male biomass (MMB) at the time of the survey for Pribilof Islands blue king crab using using the Random Effects Model.

year	raw			RE-smoothed		
	biomass (t)	lower CI (t)	upper CI (t)	biomass (t)	lower CI (t)	upper CI (t)
1975	38,054	20,760	69,754	26,882	16,821	42,960
1976	14,059	8,104	24,391	19,930	13,395	29,653
1977	42,618	17,814	101,958	21,252	13,592	33,229
1978	17,370	8,912	33,852	16,972	11,337	25,408
1979	10,959	7,386	16,262	13,333	9,748	18,236
1980	23,553	13,894	39,925	15,594	11,031	22,045
1981	11,628	9,321	14,507	11,421	9,355	13,944
1982	7,389	5,825	9,374	7,448	6,052	9,167
1983	5,409	4,316	6,778	5,080	4,155	6,211
1984	2,216	1,659	2,959	2,348	1,842	2,993
1985	1,055	754	1,476	1,351	1,021	1,787
1986	1,505	1,030	2,199	1,556	1,157	2,091
1987	2,923	1,761	4,853	1,927	1,352	2,747
1988	842	446	1,591	1,429	948	2,154
1989	828	392	1,749	1,601	1,030	2,489
1990	3,078	1,513	6,261	2,603	1,718	3,942
1991	4,690	2,910	7,556	3,810	2,677	5,423
1992	4,391	2,612	7,382	4,180	2,940	5,943
1993	4,556	3,100	6,694	4,328	3,200	5,853
1994	3,410	2,220	5,240	4,018	2,908	5,550
1995	8,360	4,091	17,086	4,939	3,336	7,312
1996	4,641	3,309	6,509	4,383	3,316	5,793
1997	3,233	2,284	4,575	3,322	2,524	4,372
1998	2,798	2,043	3,833	2,705	2,086	3,508
1999	1,729	1,136	2,631	1,977	1,452	2,691
2000	2,091	1,443	3,031	1,836	1,358	2,482
2001	1,599	689	3,710	1,264	830	1,925
2002	680	369	1,254	784	529	1,163
2003	702	428	1,150	549	382	788
2004	107	53	214	279	180	432
2005	344	152	780	266	169	419
2006	166	81	339	225	143	354
2007	306	125	753	230	142	374
2008	46	16	134	211	126	351
2009	497	219	1,130	294	186	466
2010	303	173	532	321	214	481
2011	461	180	1,180	371	232	595
2012	644	277	1,496	398	247	640
2013	250	102	615	343	214	552
2014	233	104	524	336	215	523
2015	622	382	1,011	391	270	568
2016	129	62	265	246	161	375
2017	253	136	470	228	149	347
2018	154	78	303	194	117	321
2019	-	-	-	194	68	558

Table 18: 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 2019/20 estimates are projected values (see Appendix C).

year	RE Model MMB (t)
1975/76	23,164
1976/77	15,120
1977/78	16,374
1978/79	12,547
1979/80	9,441
1980/81	9,354
1981/82	6,404
1982/83	4,822
1983/84	3,638
1984/85	1,981
1985/86	990
1986/87	1,289
1987/88	1,436
1988/89	1,286
1989/90	1,441
1990/91	2,343
1991/92	3,428
1992/93	3,740
1993/94	3,884
1994/95	3,615
1995/96	3,856
1996/97	3,544
1997/98	2,773
1998/99	2,211
1999/00	1,779
2000/01	1,653
2001/02	1,138
2002/03	706
2003/04	494
2004/05	251
2005/06	239
2006/07	203
2007/08	207
2008/09	189
2009/10	265
2010/11	289
2011/12	334
2012/13	358
2013/14	309
2014/15	302
2015/16	352
2016/17	221
2017/18	205
2018/19	175
2019/20*	175

Figures

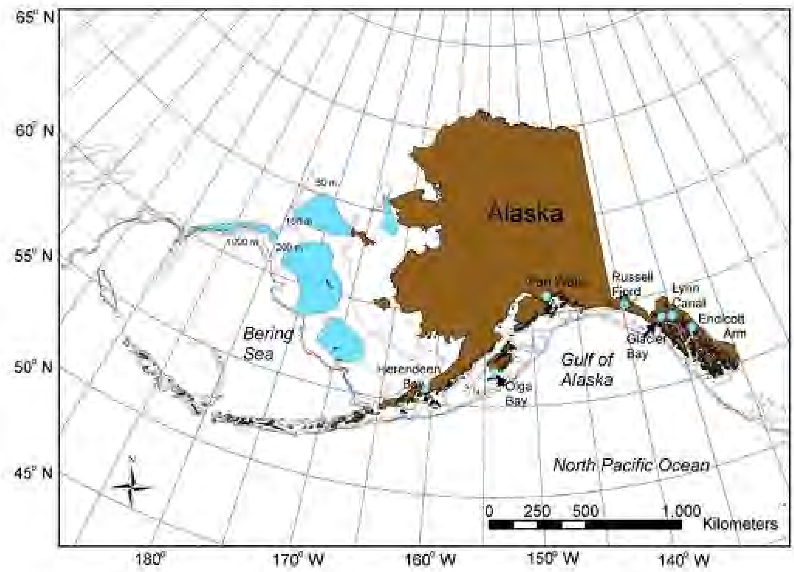

Figure 1: Distribution of blue king crab, *Paralithodes platypus*, in Alaskan waters.

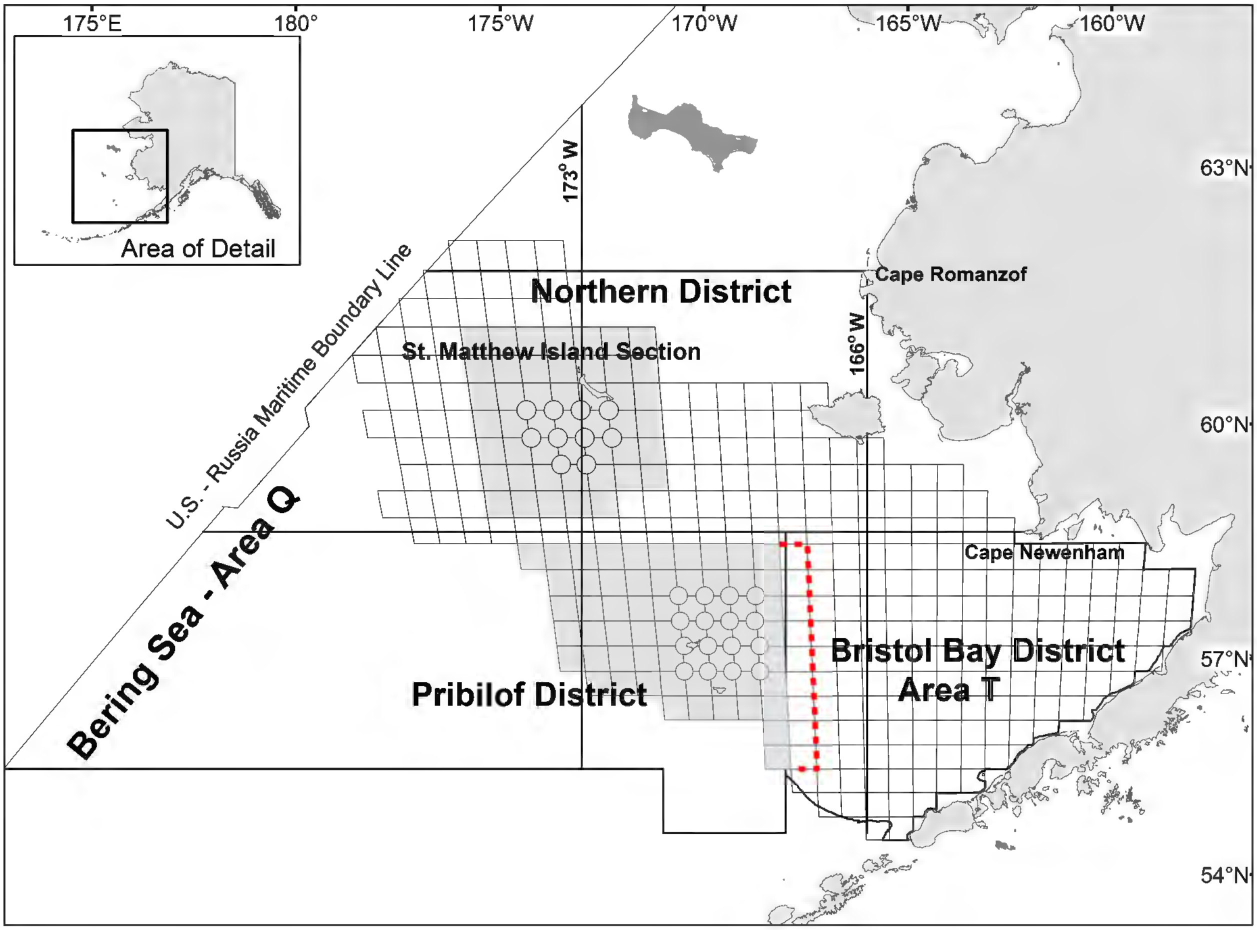

Figure 2: Map of the ADFG King Crab Registration Area Q (Bering Sea), showing (among others) the Pribilof District, which constitutes the stock boundary for PIBKC. The figure also indicates the additional 20nm strip (red dotted line) added in 2013 for calculating biomass and catch data in the Pribilof District.

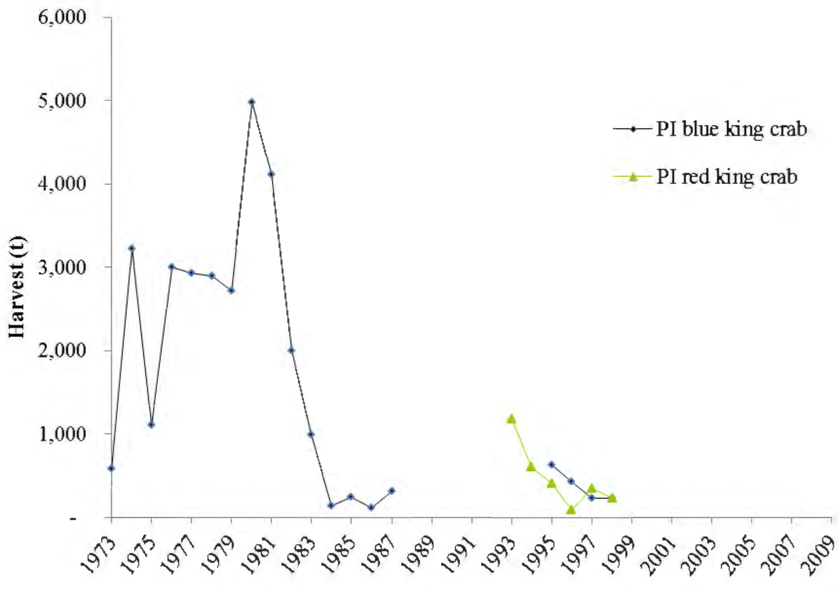

Figure 3: Historical harvests and Guideline Harvest Levels (GHLs) for Pribilof Islands red and blue king crab (from Bowers et al., 2011).

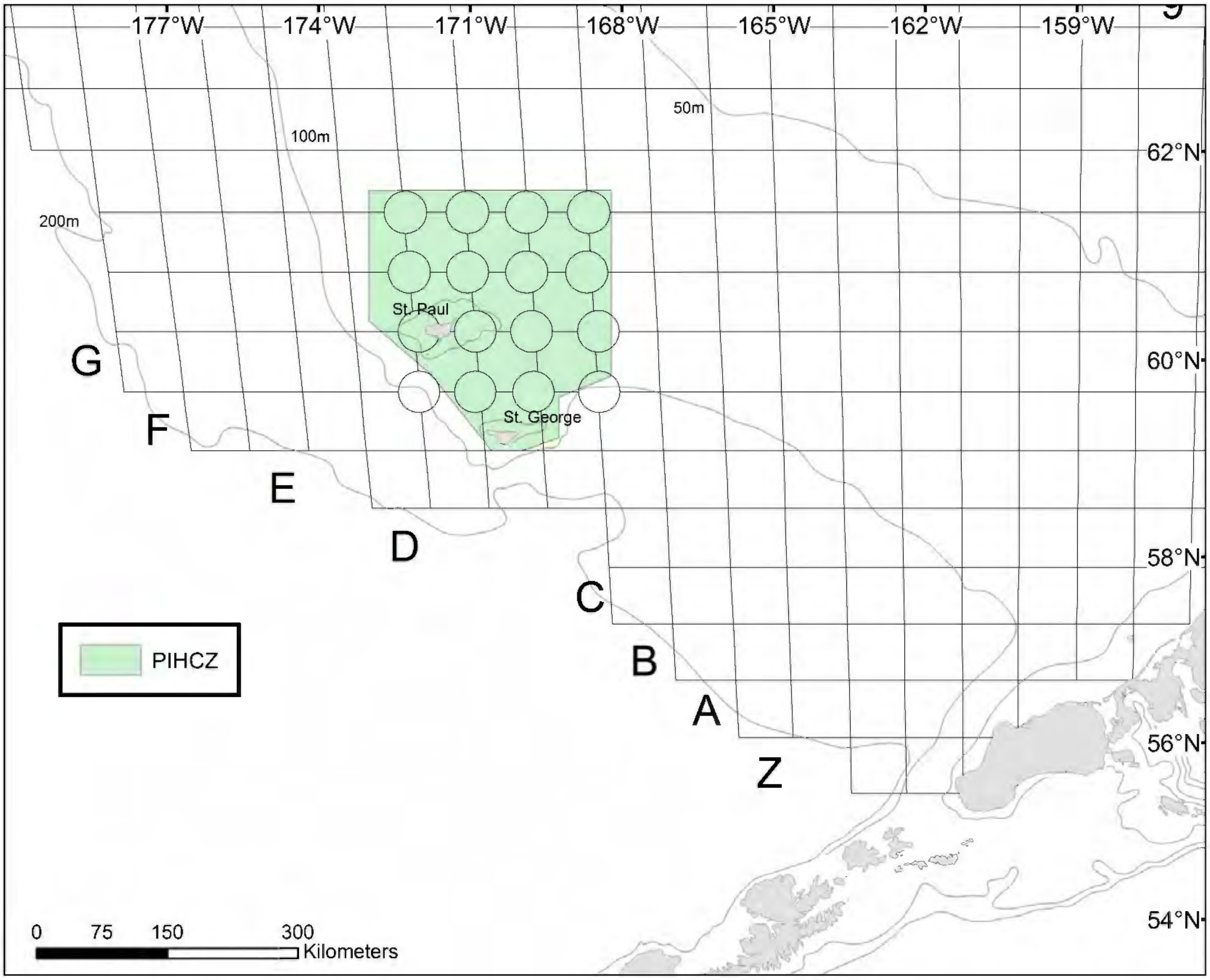

Figure 4: The shaded area shows the Pribilof Islands Habitat Conservation Zone (PIHCZ). Trawl fishing is prohibited year-round in this zone (as of 1995), as is pot fishing for Pacific cod (as of 2015). Also shown is a portion of the NMFS annual EBS bottom trawl survey grid.

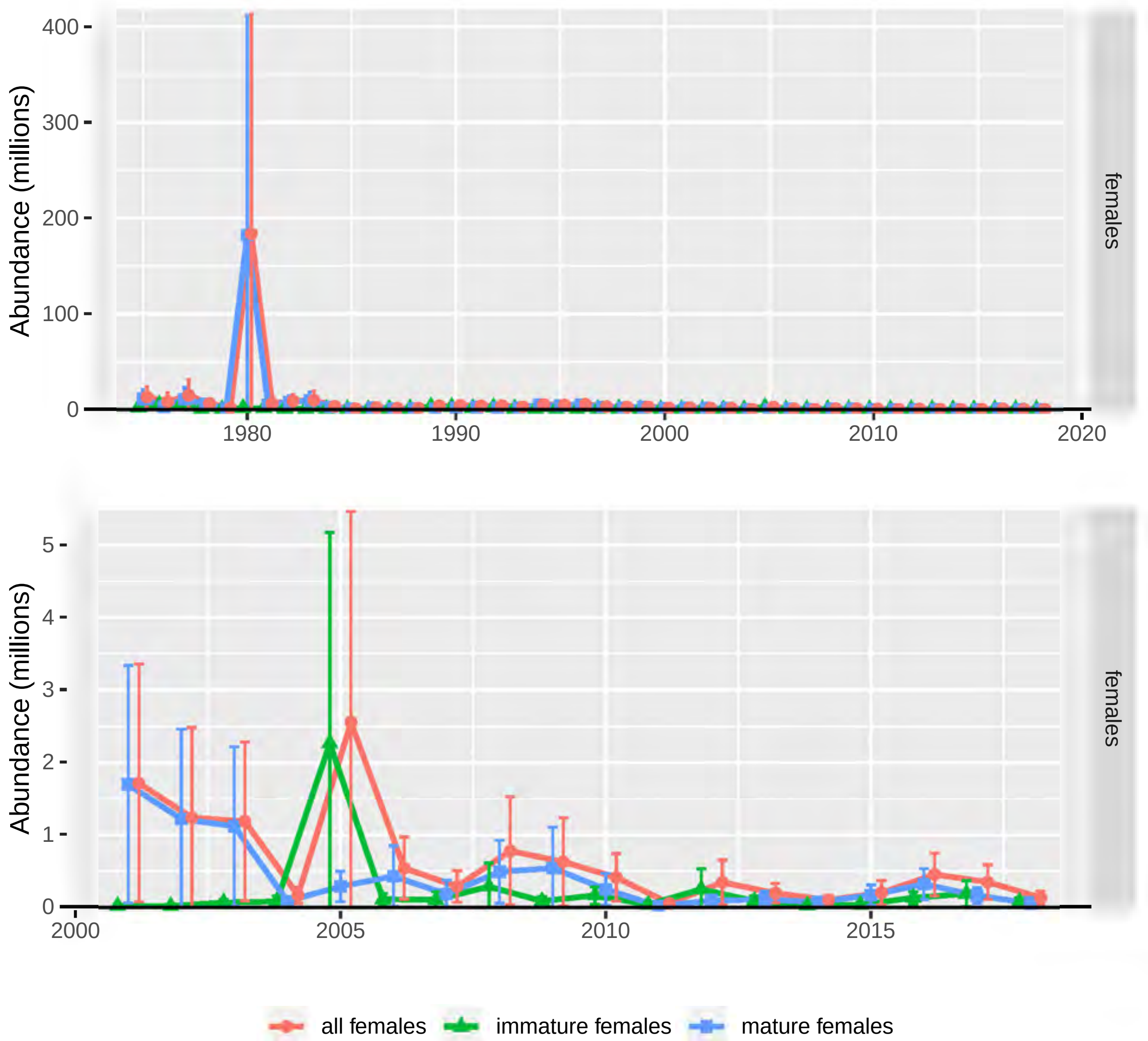

Figure 5: Time series of survey abundance for females (immature, mature, and total).

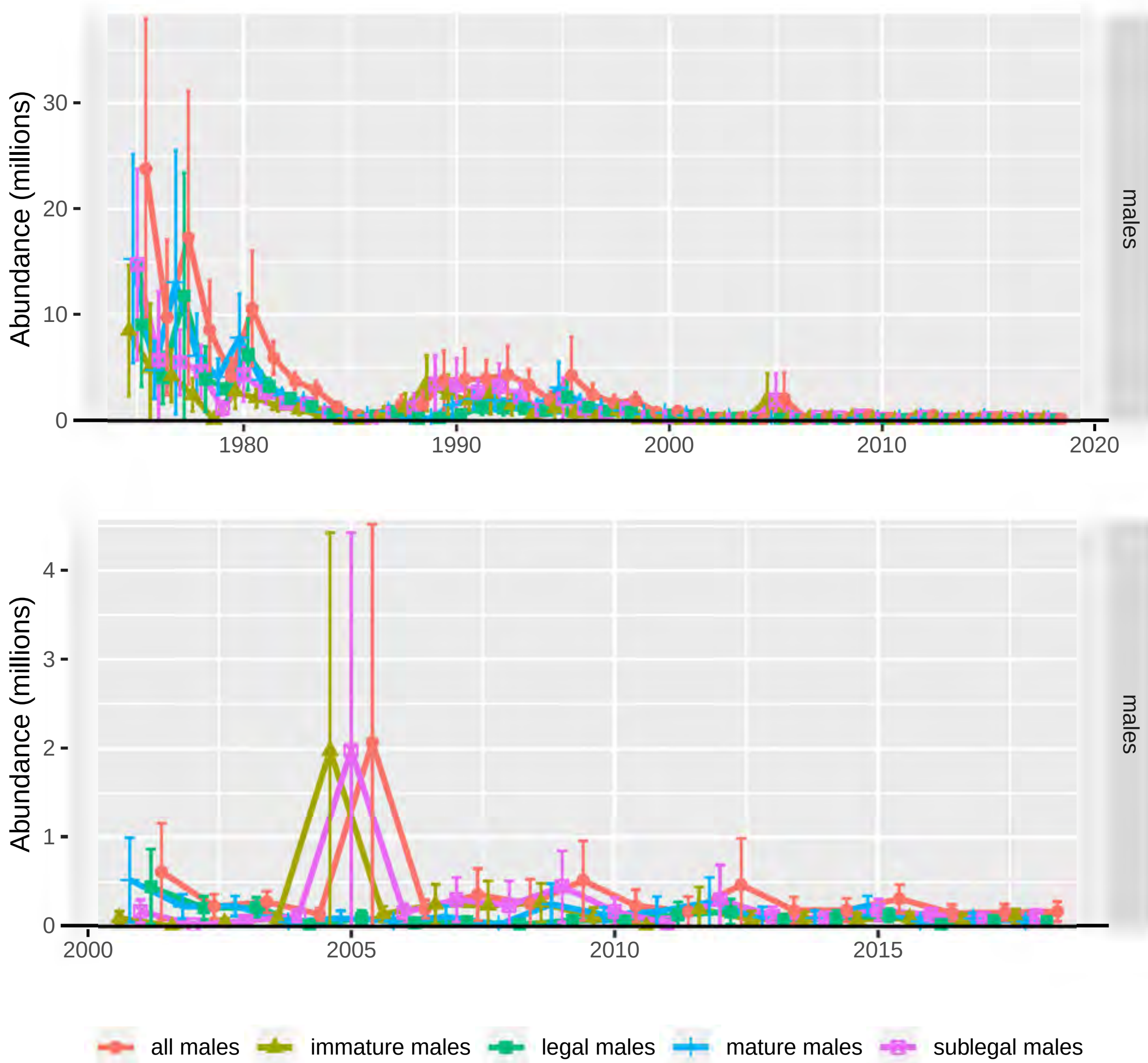

Figure 6: Time series of survey abundance for males in several categories (immature, mature, sublegal, legal and total).

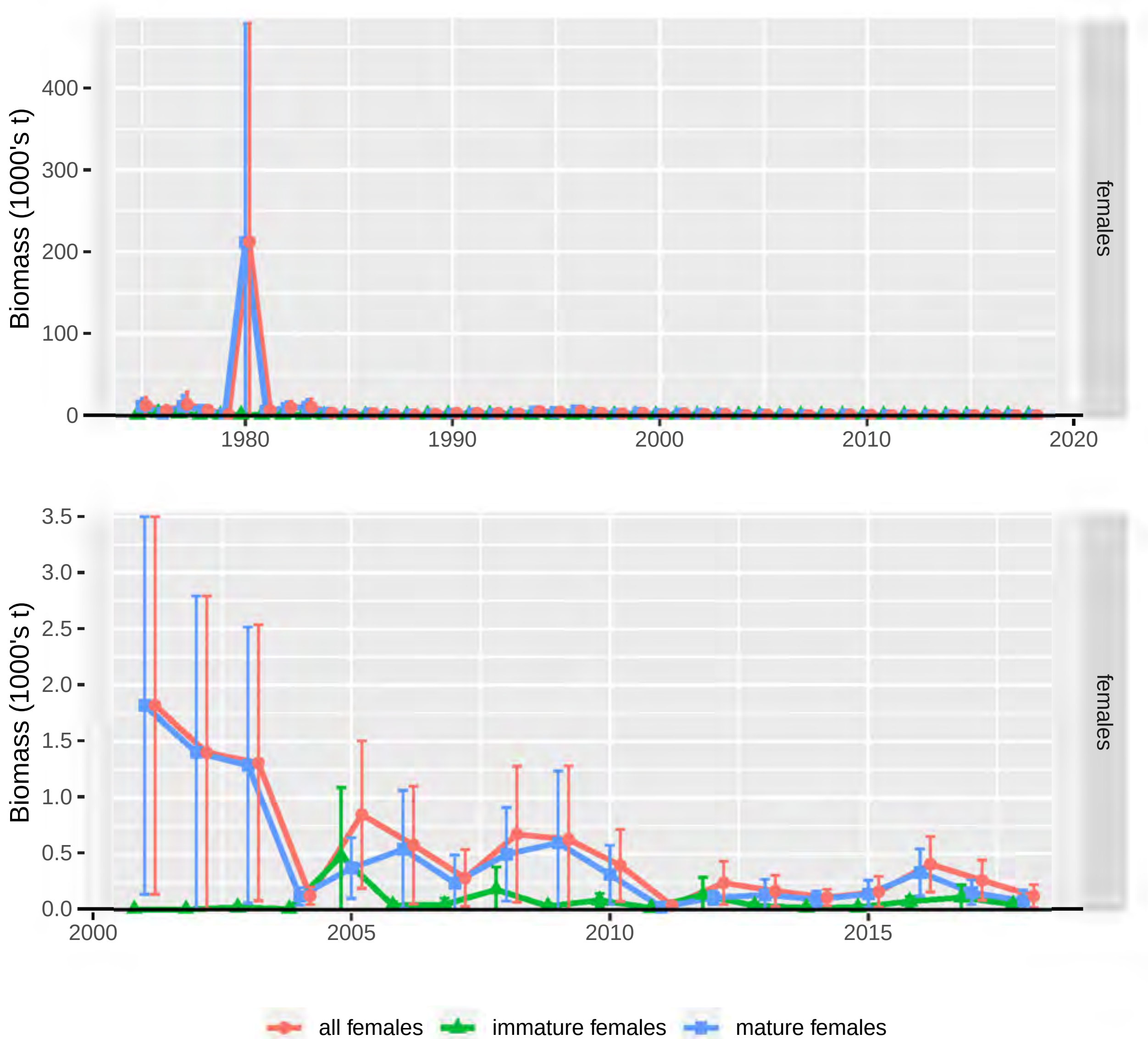

Figure 7: Time series of survey abundance for females (immature, mature, and total).

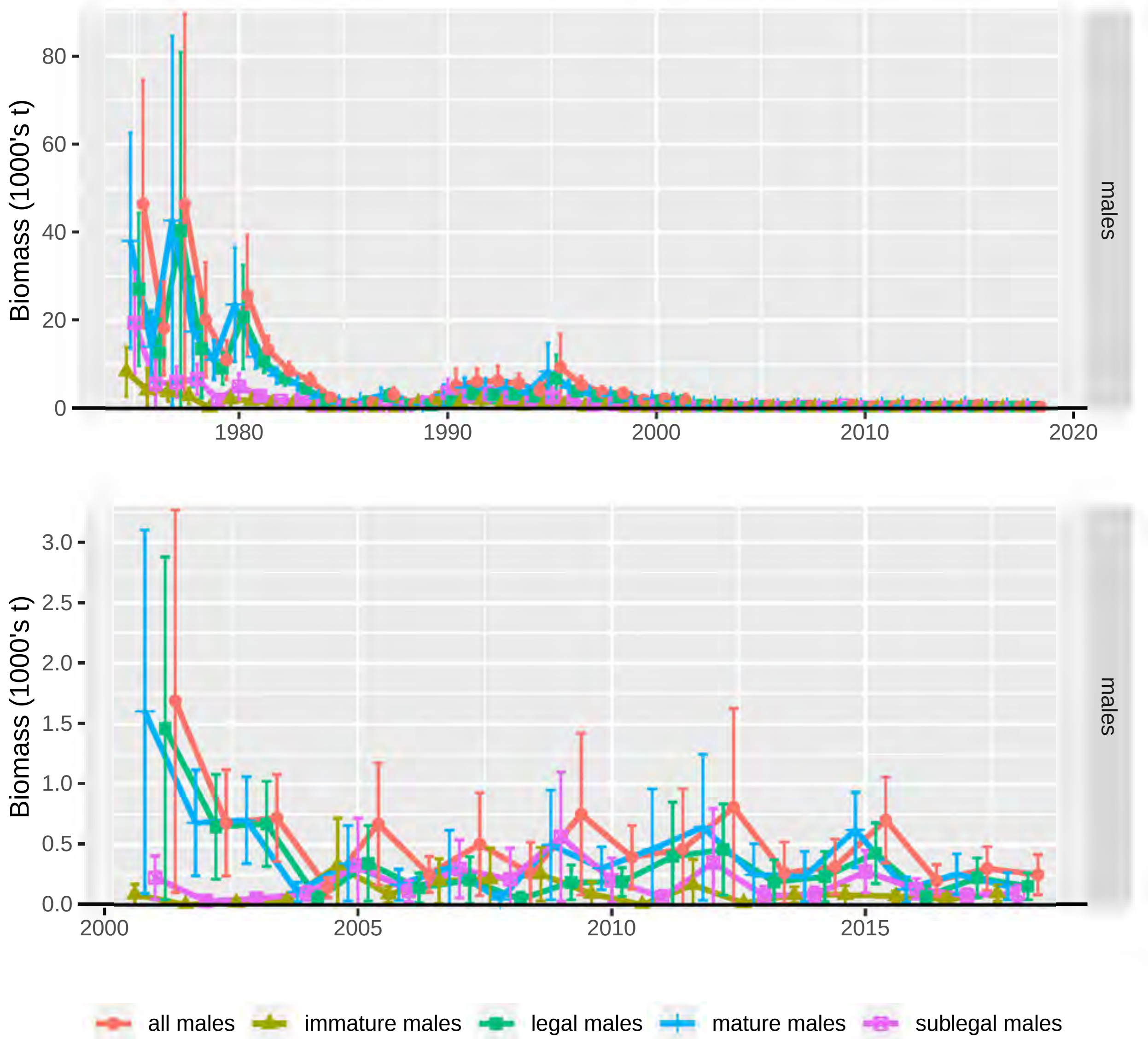

Figure 8: Time series of survey biomass for males in several categories (immature, mature, sublegal, legal and total).

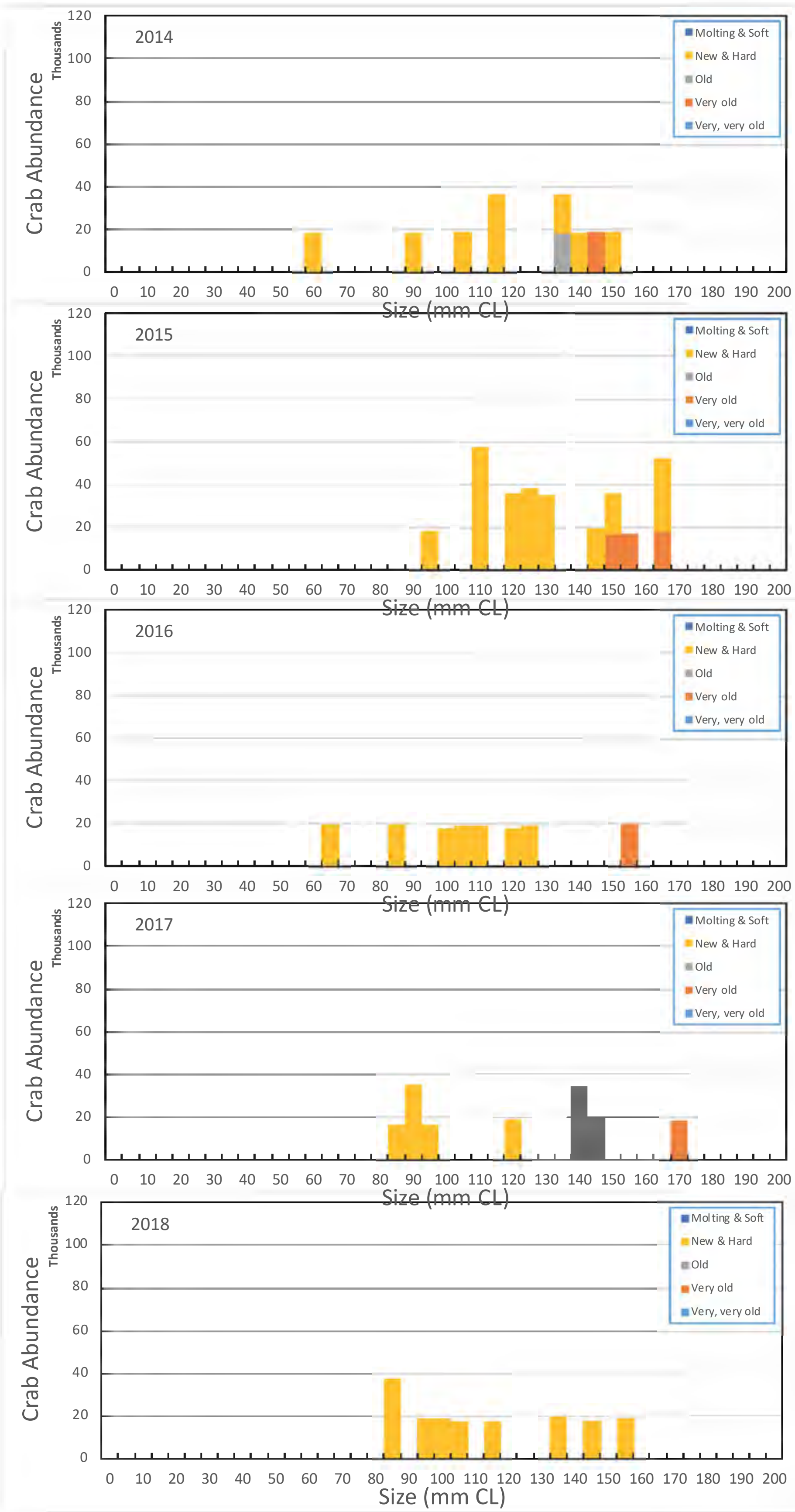

Figure 9: Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from recent NMFS EBS bottom trawl surveys.

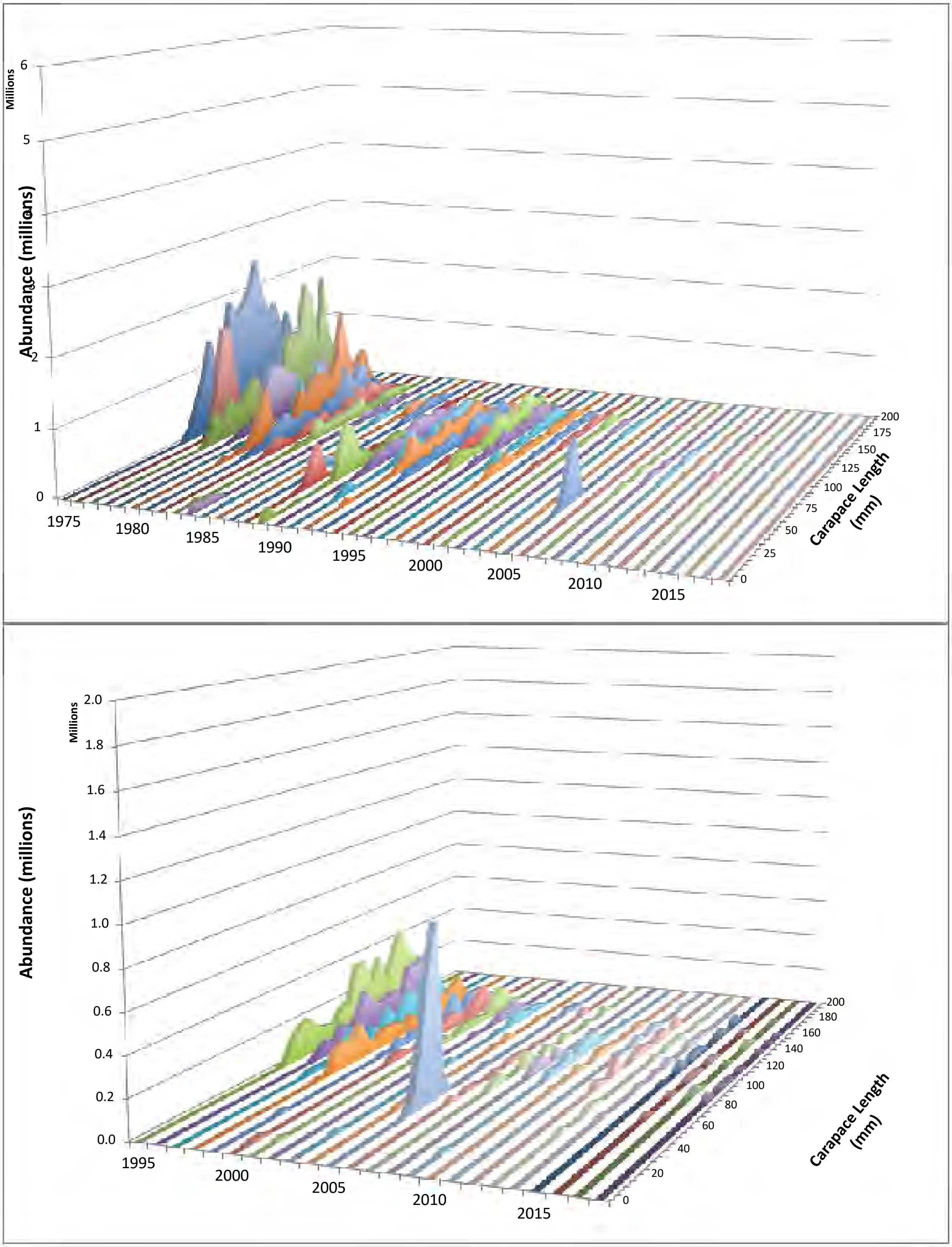

Figure 10: Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islands blue king crab by 5 mm length bins. The top row shows the entire time series, the bottom shows the size compositions since 1995.

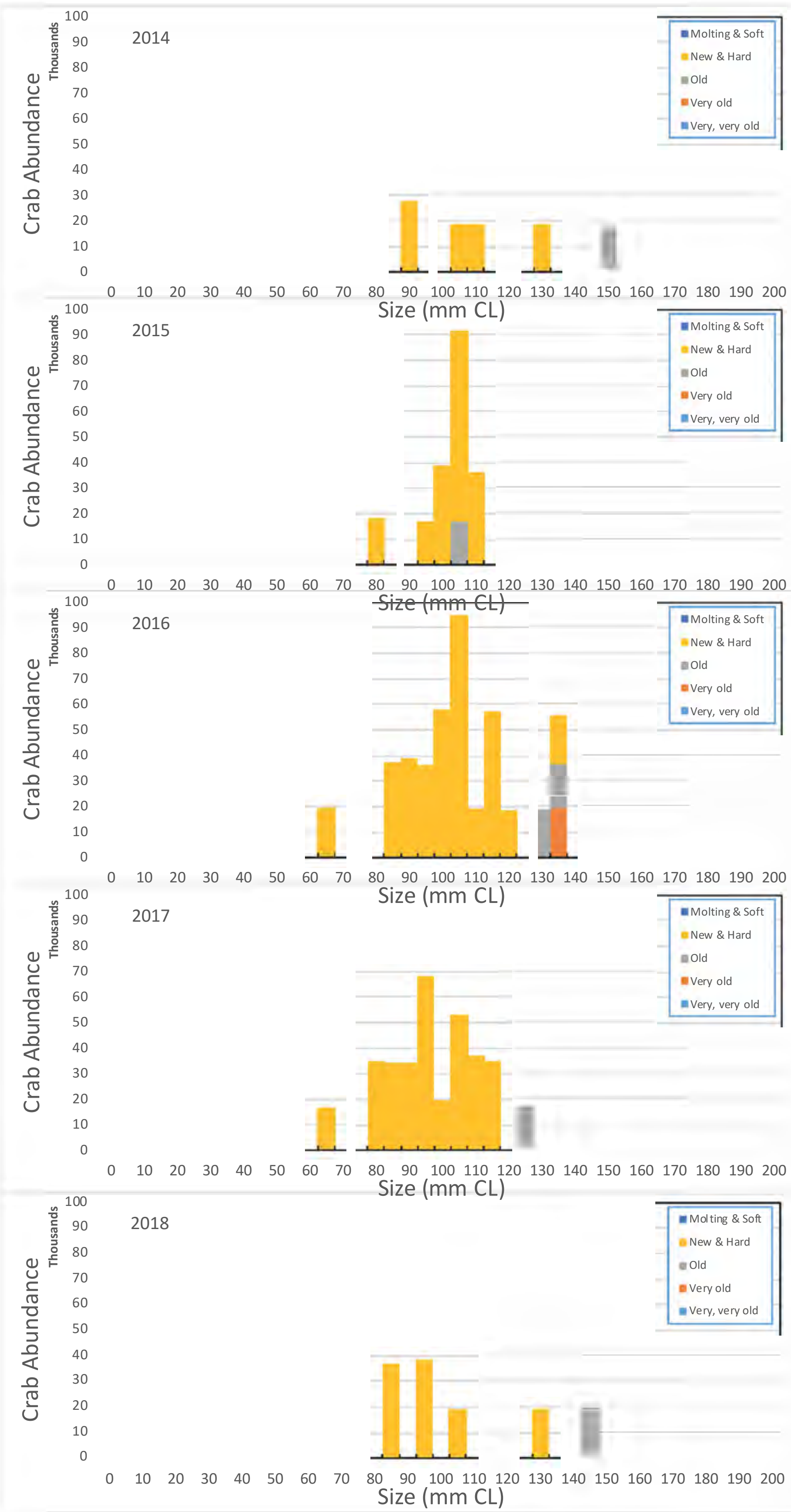

Figure 11: Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from recent NMFS EBS bottom trawl surveys.

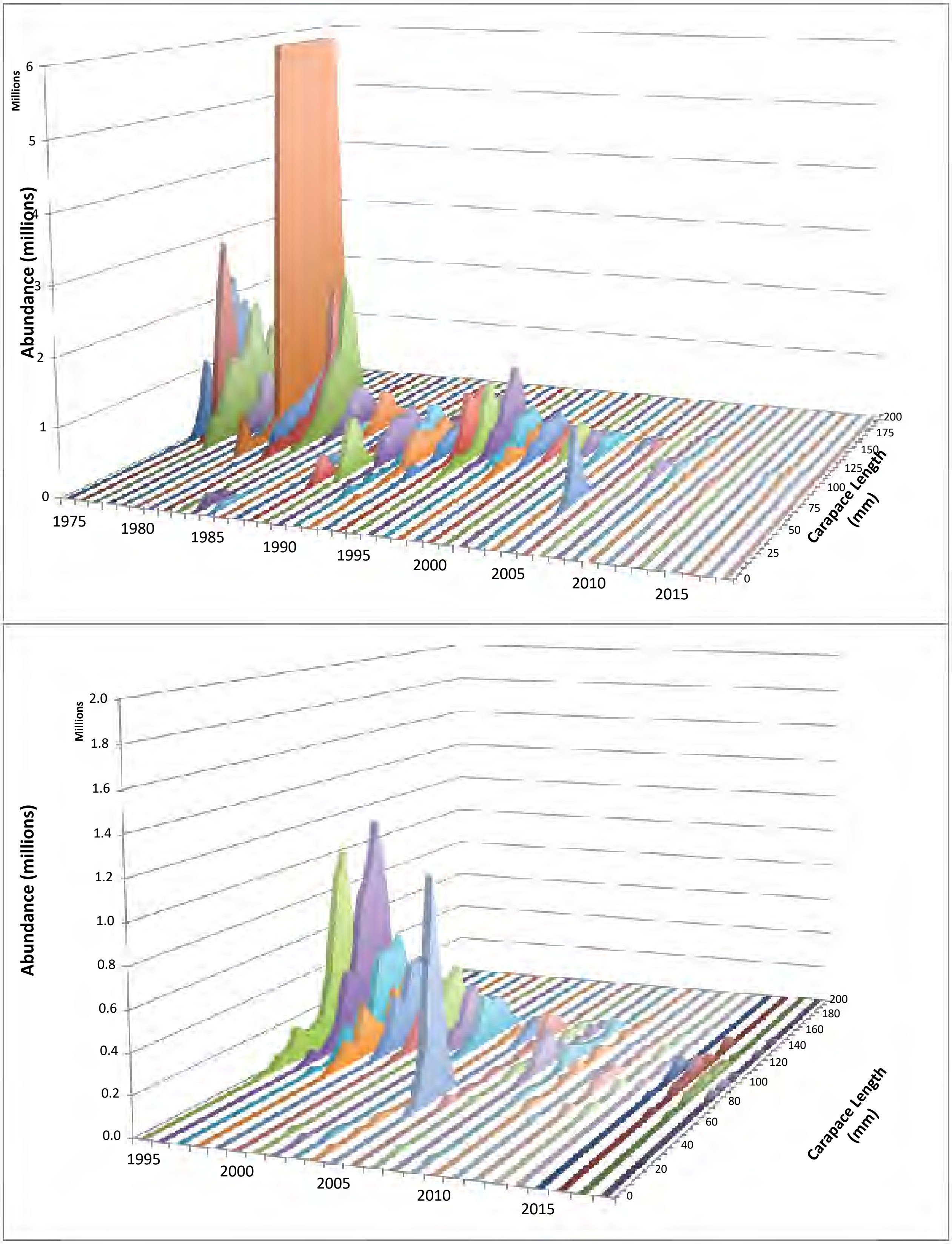

Figure 12: Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islands blue king crab by 5 mm length bins. The top row shows the entire time series, the bottom shows the size compositions since 1995.

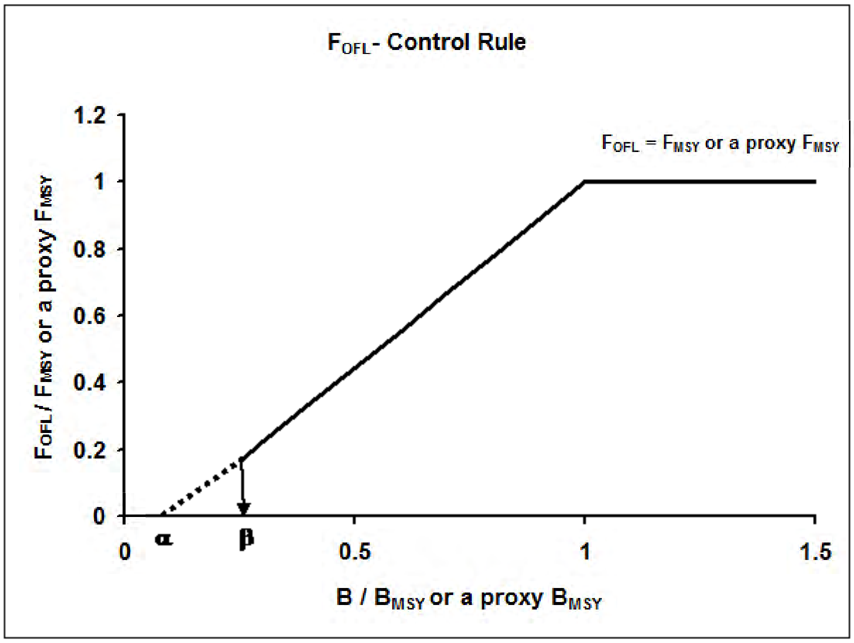

Figure 13: F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β (= 0.25).

Appendix A: PIBKC Bycatch in the Groundfish Fisheries: 2009/10-2018/19

William Stockhausen

02 April, 2019

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Introduction

Bycatch of PIBKC in the groundfish fisheries during 2009/10-2018/19 was downloaded from AKFIN on April 1, 2019 as file ("`~/StockAssessments-Crab/Data/Fishery.AKFIN/2018-19/FromAKFIN.PIBKC.BycatchEstimates.`

Bycatch by gear type

The bycatch of PIBKC by gear type (trawl or fixed) are presented in the following table. Catches using pelagic and non-pelagic trawl gear have been aggregated as “trawl” gear, while catches using hook-and-line (longline) and pot gear have been aggregated as “fixed” gear.

Table 1: Bycatch of PIBKC in the groundfish fisheries, by gear type. Biomass is in kilograms.

	fixed				trawl			
year	vessel count	haul count	biomass	number	vessel count	haul count	biomass	number
2009	4228	431820	216	87	2051	90347	207	193
2010	5415	609789	44	16	1858	38463	56	35
2011	4611	397979	112	54	1098	22300	7	8
2012	5024	502872	170	72	3785	69175	669	340
2013	8277	2172175	65	41	2247	35730	0	0
2014	8155	2026114	144	65	1899	58843	0	0
2015	7892	1470800	744	352	3198	68219	808	257
2016	5304	1094121	88	56	3280	53174	455	524
2017	3089	350289	0	0	2393	39520	397	278
2018	2748	422518	26	19	3327	62871	482	397

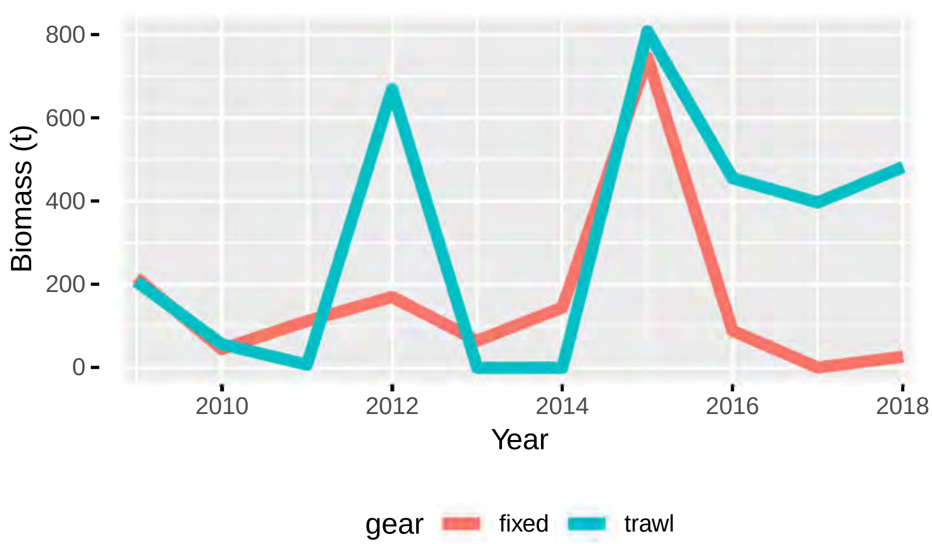

Figure 1: Bycatch of PIBKC in the groundfish fisheries by gear type.

Bycatch by target type

Bycatch of PIBKC in the groundfish fisheries is presented by groundfish target type in this section. Groundfish targets with less than 10 kg bycatch over the 2009-2018 period have been dropped from the table and figure.

Table 2: Bycatch of PIBKC in the groundfish fisheries by target type. Biomass is in kilograms.

	Flathead Sole		Pacific Cod		Pollock - bottom		Rock Sole - BSAI		Yellowfin Sole - BSAI	
year	biomass	number	biomass	number	biomass	number	biomass	number	biomass	number
2009	71	54	216	87	7	20	0	0	129	119
2010	56	35	42	14	0	0	0	0	0	0
2011	0	0	119	62	0	0	0	0	0	0
2012	24	12	170	72	0	0	0	0	645	328
2013	0	0	64	41	0	0	0	0	0	0
2014	0	0	143	64	0	0	0	0	0	0
2015	147	58	742	351	0	0	0	0	661	199
2016	0	0	87	55	0	0	368	432	87	92
2017	240	101	0	0	0	0	0	0	157	177
2018	0	0	26	19	24	101	0	0	458	296

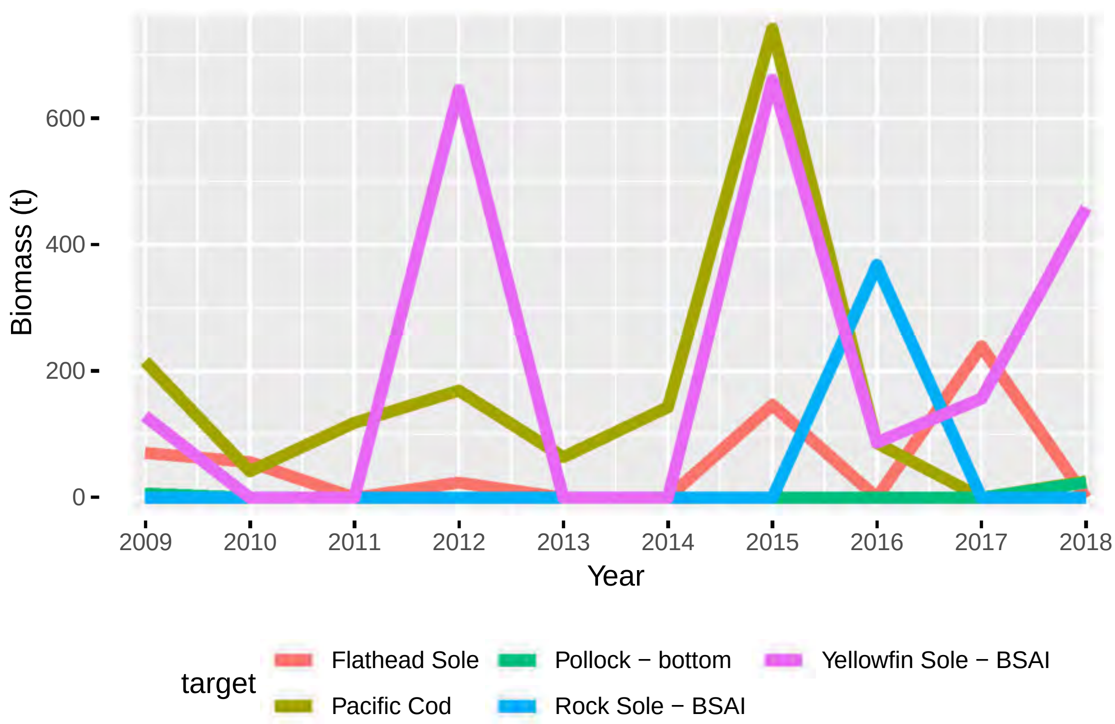

Figure 2: Bycatch of PIBKC in the groundfish fisheries, by target type.

Spatial patterns of bycatch

Spatial patterns of PIBKC bycatch, by ADFG stat area, in the groundfish fisheries are illustrated by gear type in Figures 4-5. All plots are on the same scale.

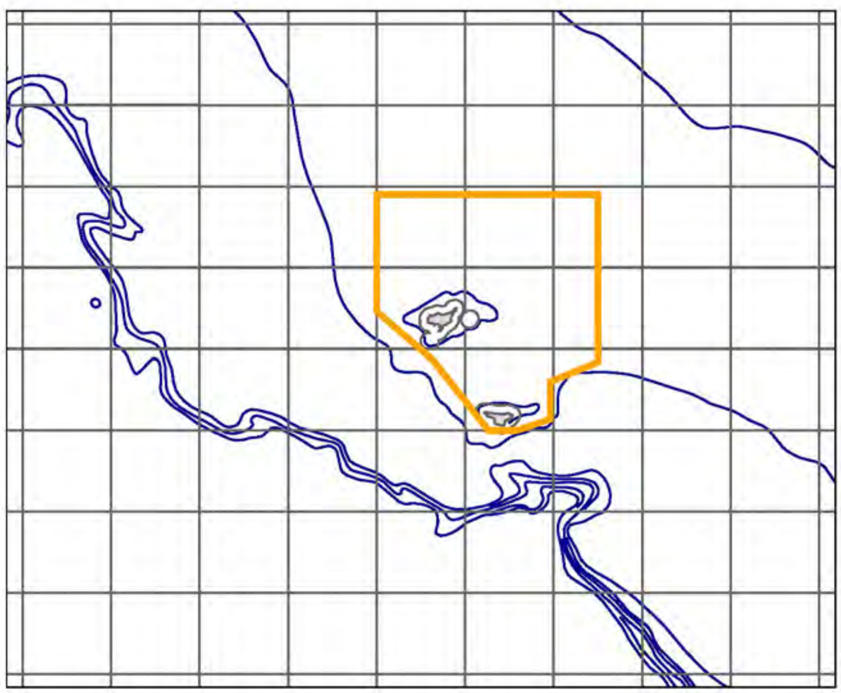

Figure 3: Basemap for subsequent maps, with EBS bathymetry (blue lines), ADFG stat areas (black rectangles), and the Pribilof Islands Habitat Conservation Area (orange outline).

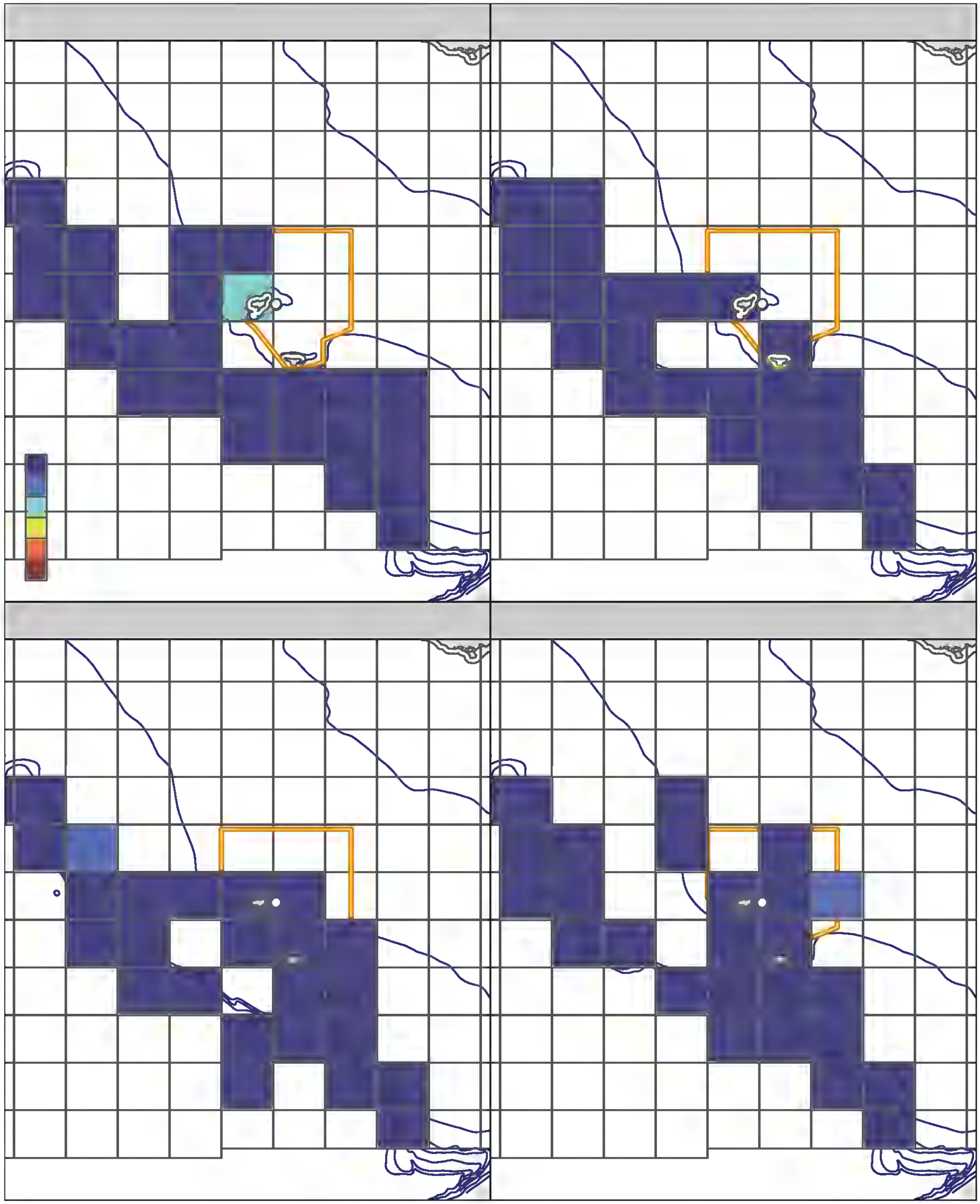

Figure 4: (1 of 3). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries.

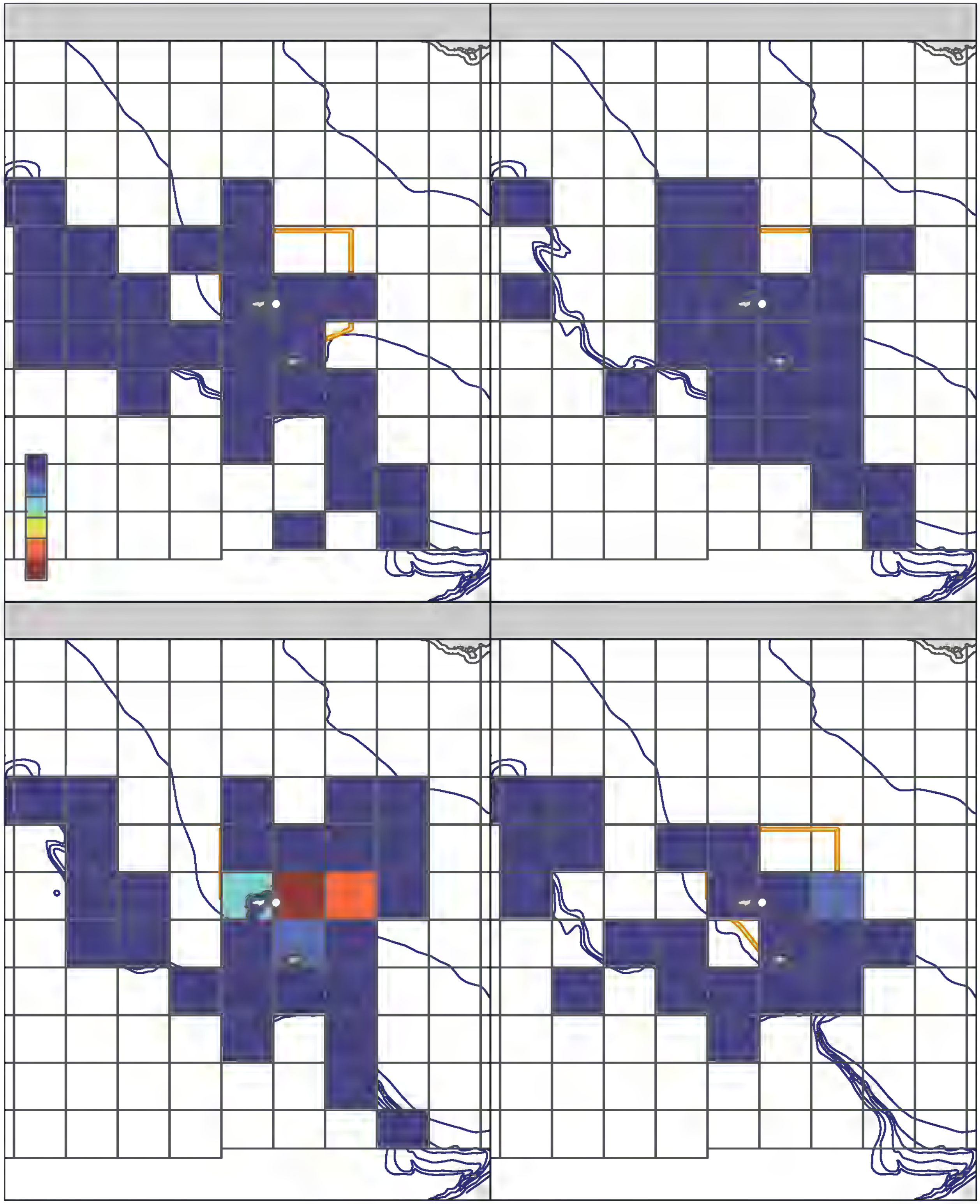

Figure 5: (2 of 3). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries.

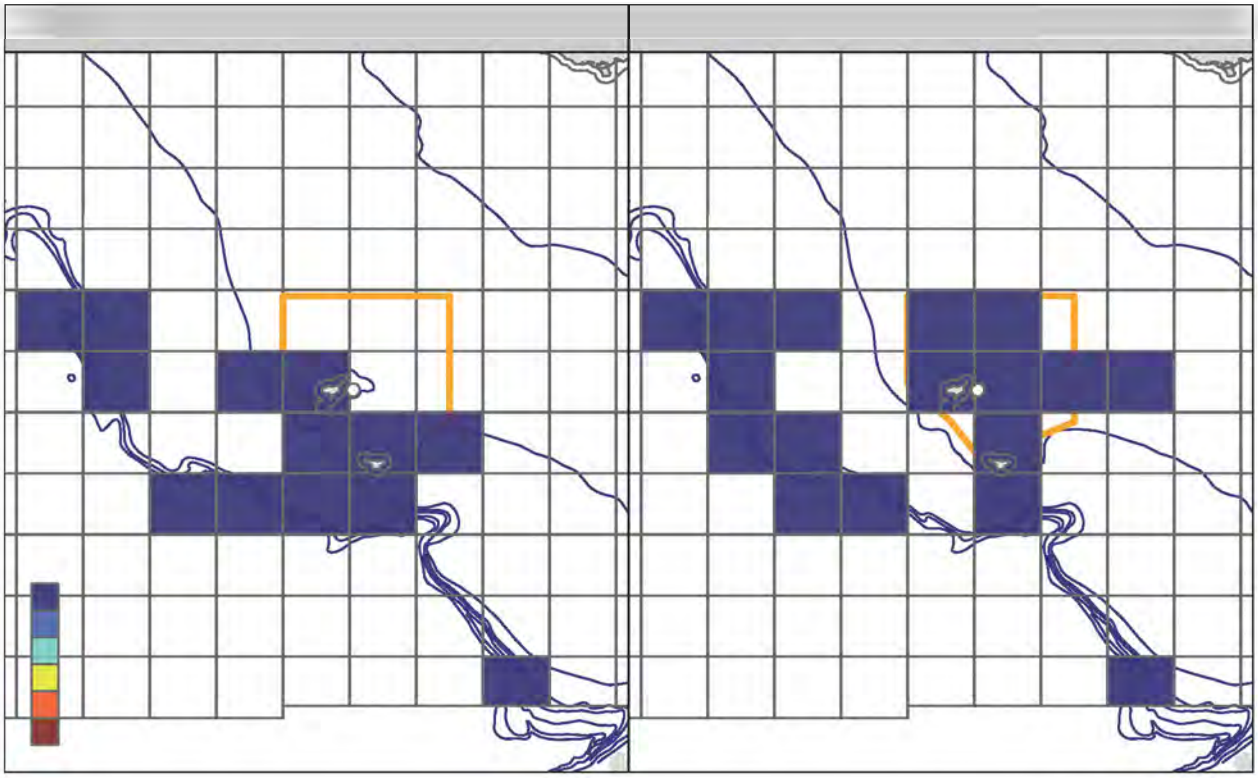

Figure 6: (3 of 3). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries.

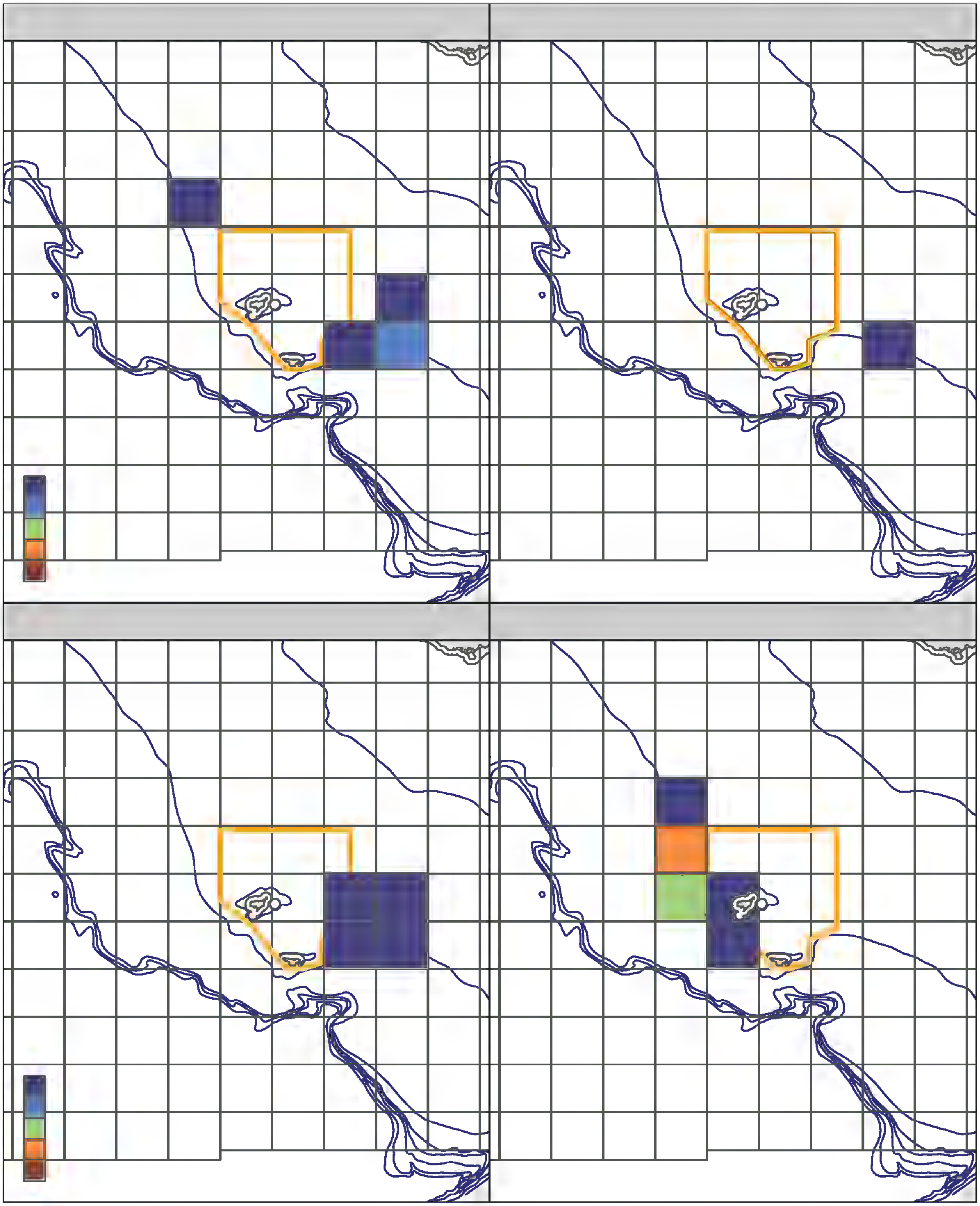

Figure 7: (1 of 3). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries.

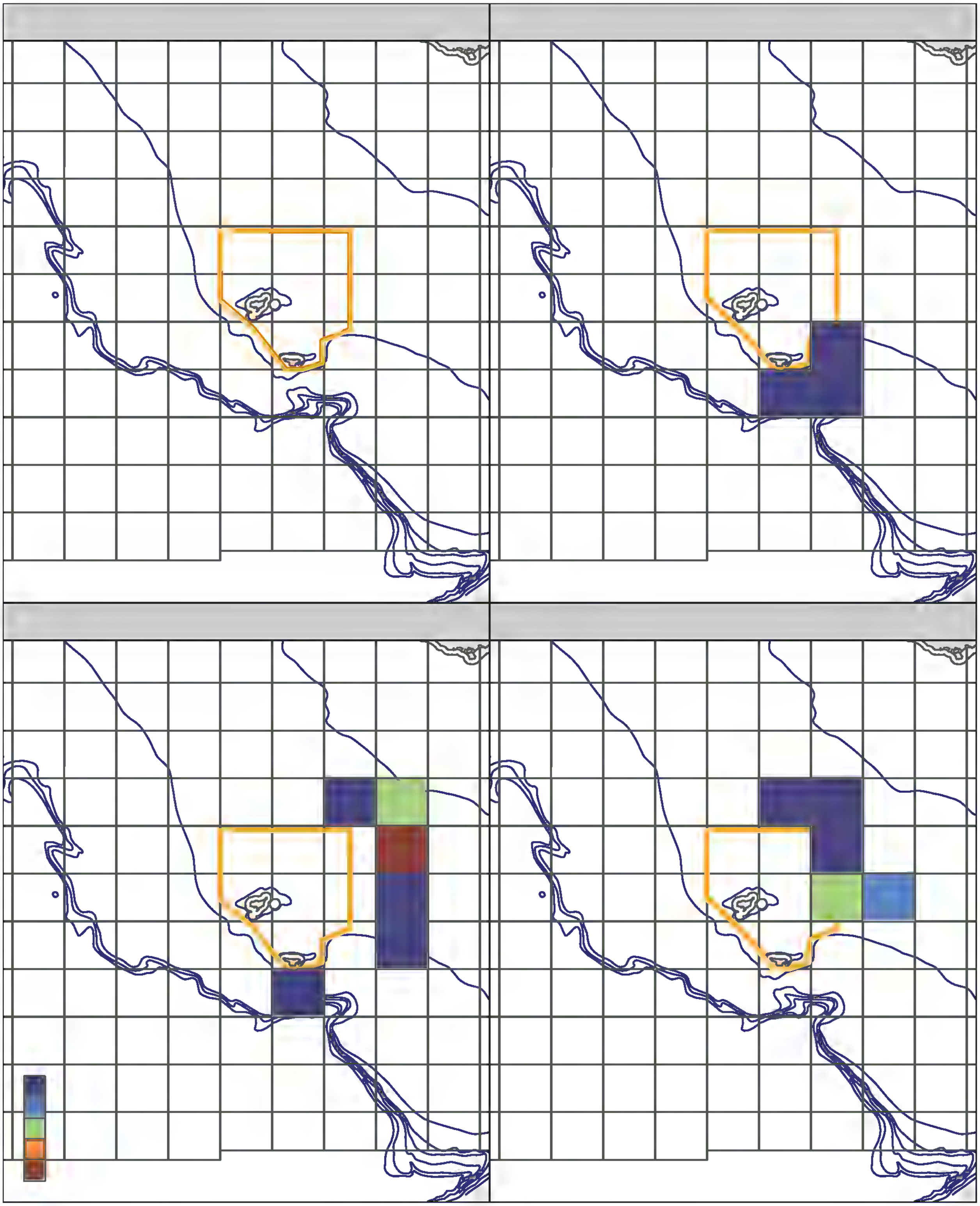

Figure 8: (2 of 3). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries.

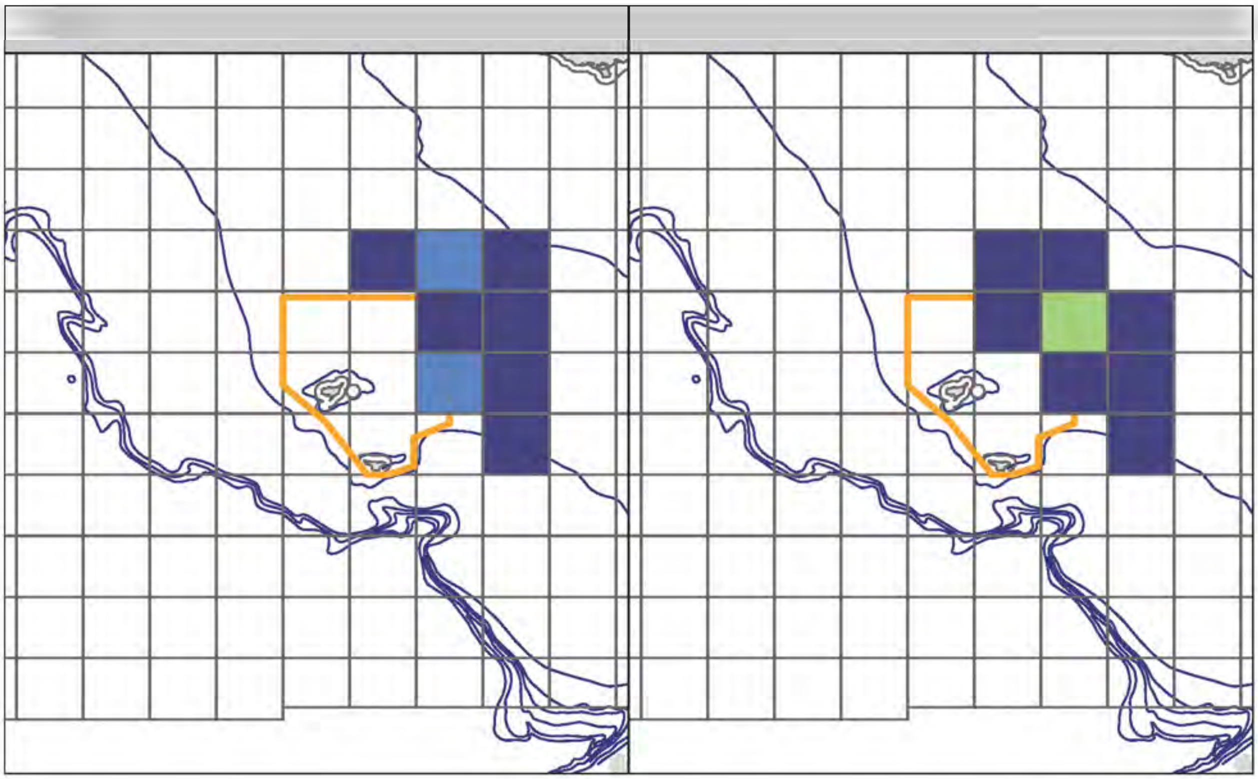

Figure 9: (3 of 3). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries.

Appendix B: NMFS Survey Data for the PIBKC Assessment

William Stockhausen

02 April, 2019

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Introduction

This report presents results from time series of aggregate abundance, biomass and size compositions from the annual NMFS EBS bottom trawl survey for Pribilof Islands blue king crab (PIBKC), i.e. blue king crab in the Pribilof District of the eastern Bering Sea (Figure 1), based on haul data and survey strata files downloaded from AKFIN on April 1, 2019.

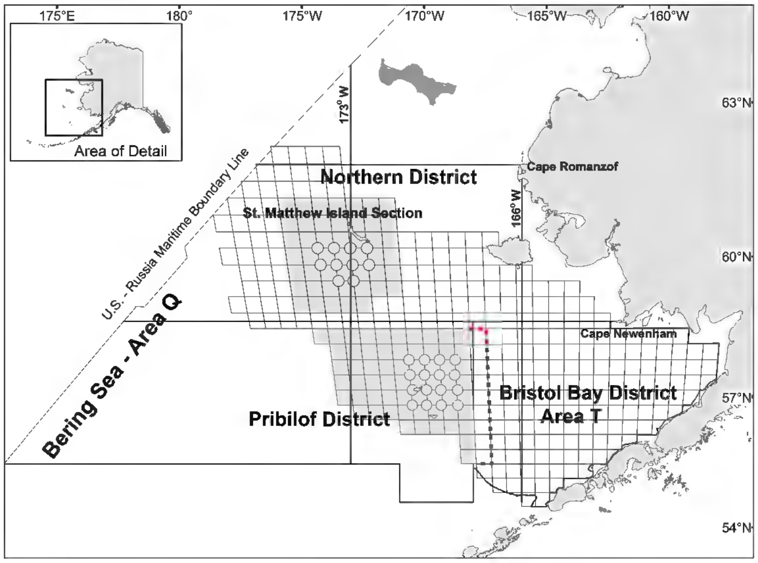

Figure 1: Map of the Pribilof District, which defines the stock area for the Pribilof Islands blue king crab stock. The grid indicates the locations of NMFS EBS survey stations.

Aggregate (abundance, biomass) time series were calculated for different components of the PIBKC stock, including immature and mature females and immature, mature, sublegal, and legal male crab based of the following size-based criteria:

Table 1: Size groupings for various components of the PIBKC stock used in this report.

sex	size.range	category
female	< 100 mm CL	immature female
male	< 120 mm CL	immature male
female	> 99 mm CL	mature female
male	> 119 mm CL	mature male
male	< 135 mm CL	sublegal male
male	> 134 mm CL	legal male
female	all	all females
male	all	all males

Annual survey abundance and biomass

Annual survey abundance and biomass for PIBKC were calculated from the survey haul data as if the survey were conducted using a random-stratified sampling design (it uses a fixed grid).

The following plots illustrate time series trends in Tanner crab survey abundance and biomass by sex and area.

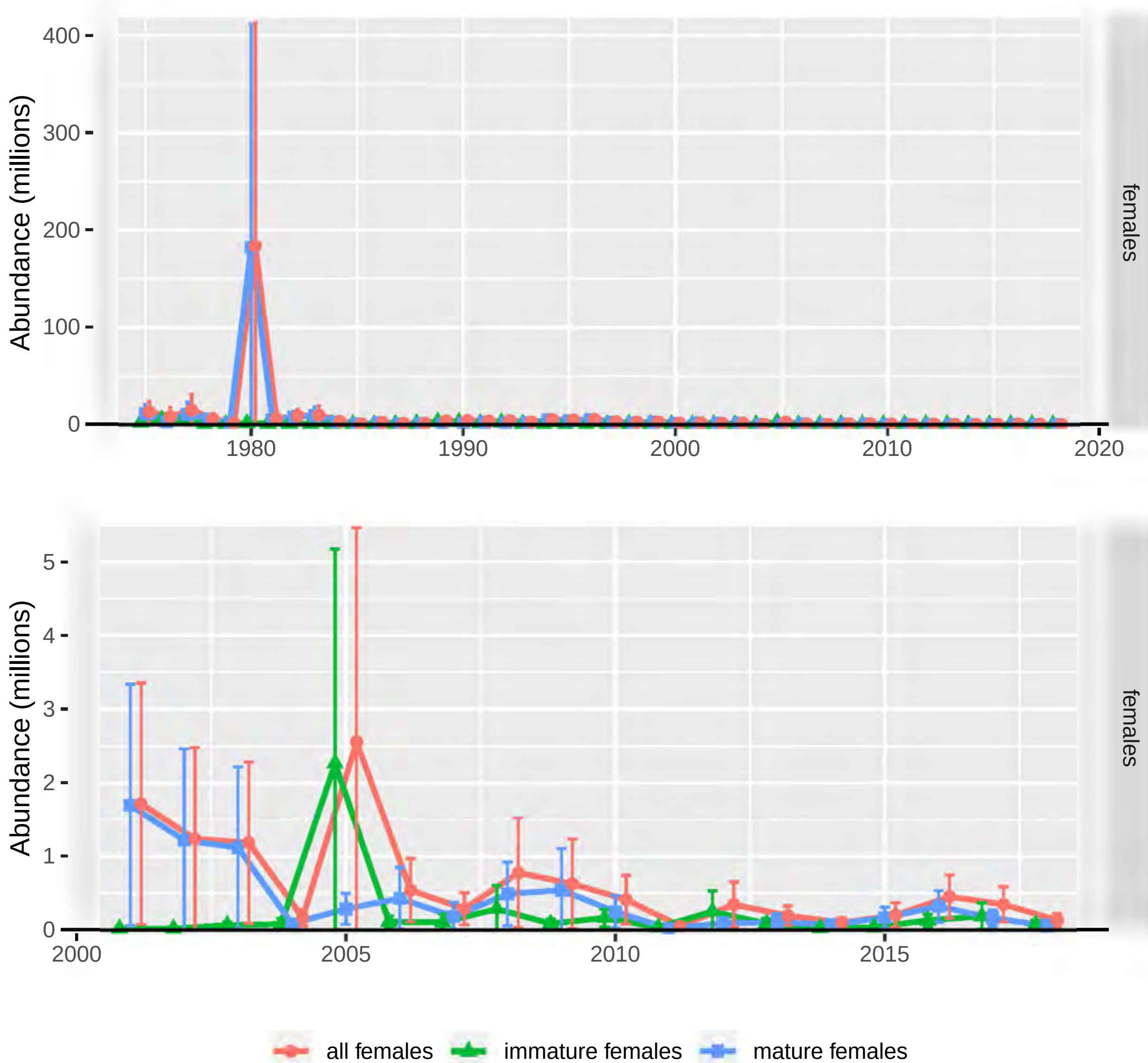

Figure 2: NMFS survey abundance time series for female PIBKC. Upper plot is entire time series, lower plot since 2001.

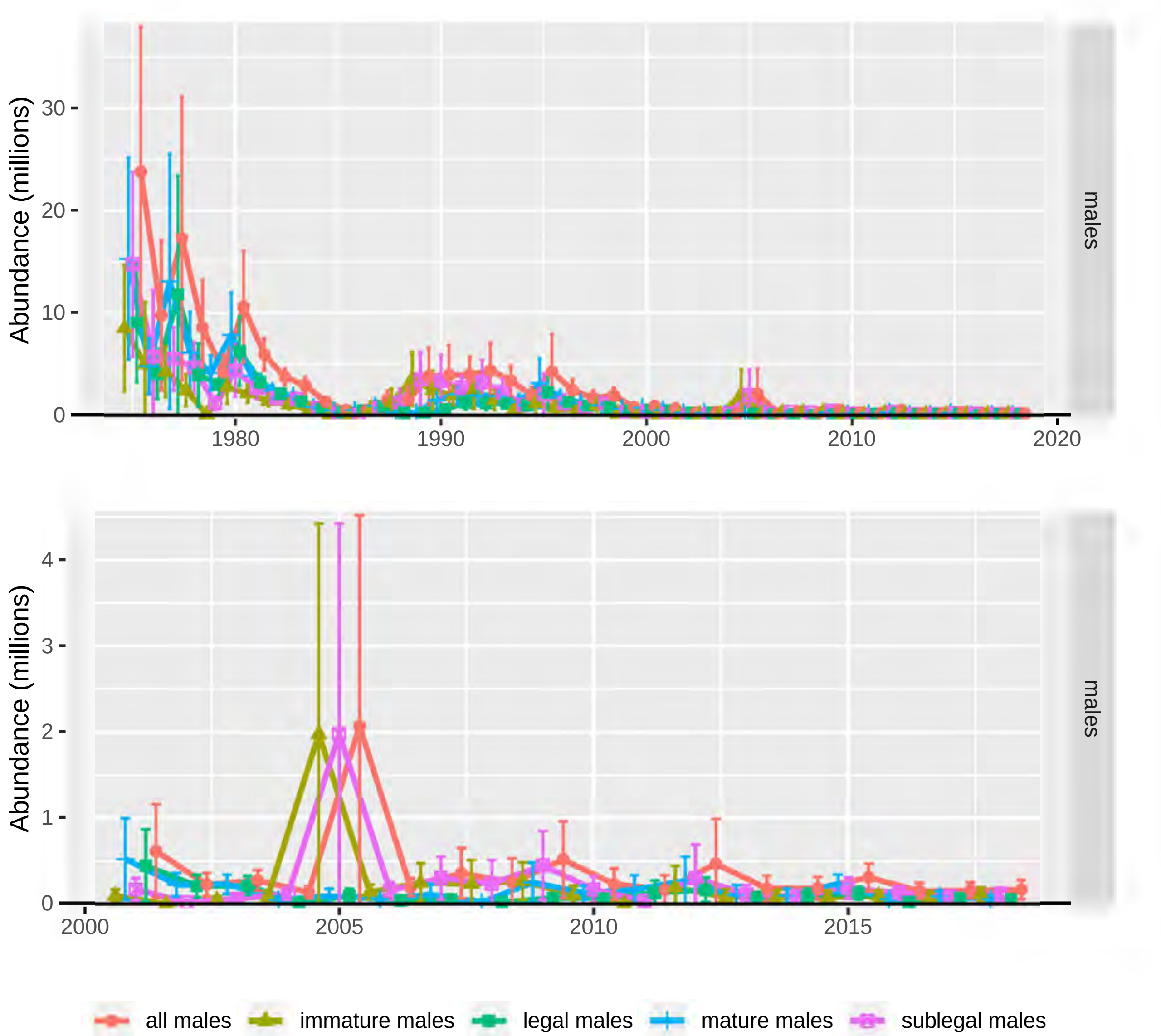

Figure 3: NMFS survey abundance time series for male PIBKC. Upper plot is entire time series, lower plot since 2001.

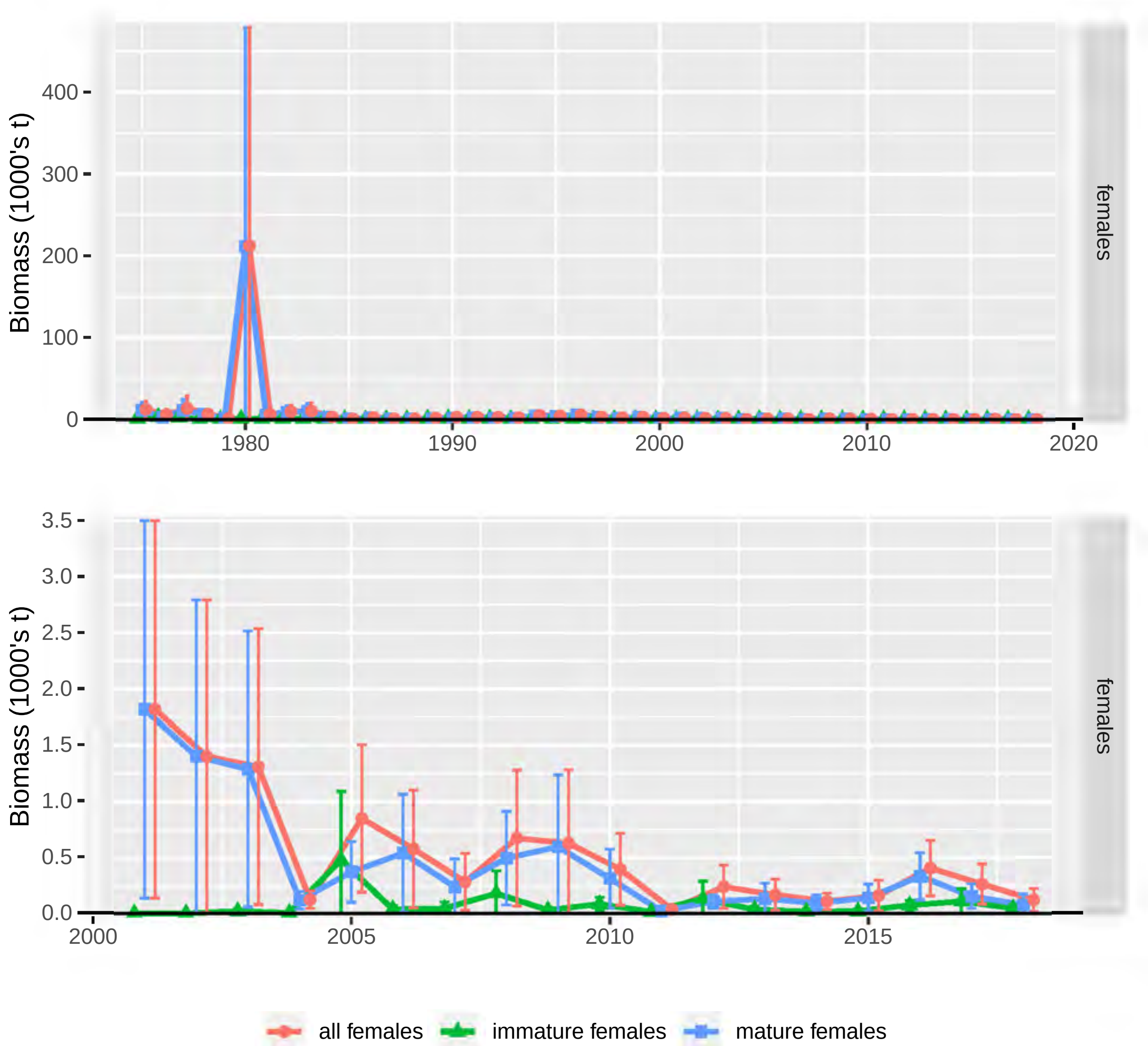

Figure 4: NMFS survey biomass time series for female PIBKC. Upper plot is entire time series, lower plot since 2001.

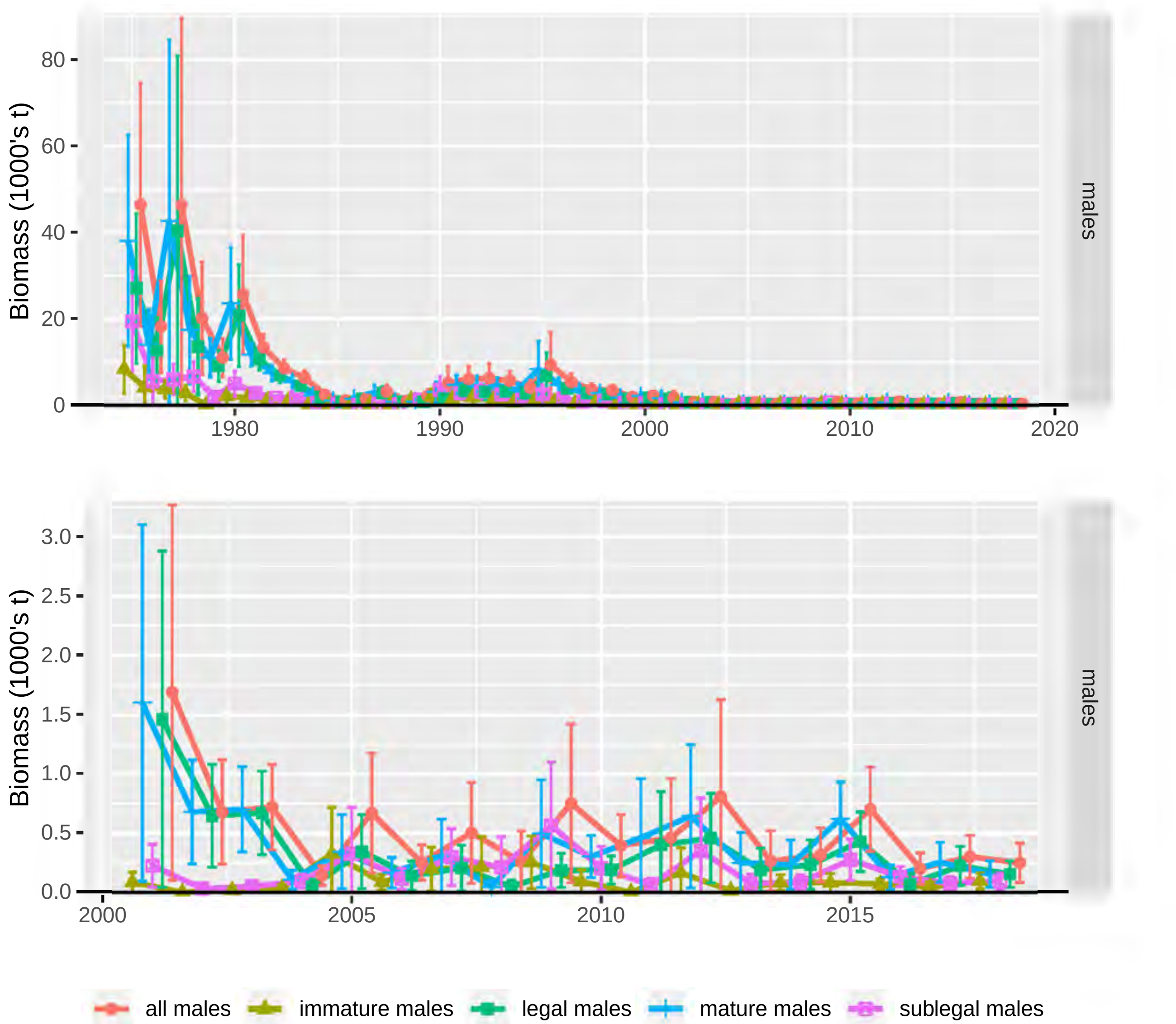

Figure 5: NMFS survey biomass time series for male PIBKC. Upper plot is entire time series, lower plot since 2001.

The following two tables document the annual sampling effort (the number of survey hauls, the number of survey hauls with non-zero catch, and the number of crab caught) by the NMFS bottom trawl survey in the Pribilof District by PIBKC population category.

Table 2: Sample sizes (number of survey hauls, number hauls where crab were caught, number of crab caught) for the NMFS EBS trawl survey in the Pribilof District each year, for female population components.

	survey	immature females		mature females		all females	
year	number of hauls	non-0 hauls	no. crab	non-0 hauls	no. crab	non-0 hauls	no. crab
1975	45	6	72	7	193	9	265
1976	59	2	55	5	37	5	92
1977	58	3	45	5	100	5	145
1978	58	4	11	8	97	8	108
1979	58	3	4	3	21	5	25
1980	70	8	17	10	326	11	343
1981	84	16	49	19	184	23	233
1982	84	11	49	22	250	24	299
1983	86	8	23	16	280	18	303
1984	86	7	27	14	142	15	169
1985	86	7	15	8	28	12	43
1986	86	2	2	8	106	10	108
1987	86	5	23	7	35	11	58
1988	85	6	41	7	17	9	58
1989	86	8	144	9	27	13	171
1990	86	7	88	9	77	10	165
1991	85	10	57	12	105	15	162
1992	86	6	83	9	59	11	142
1993	85	8	46	13	88	15	134
1994	86	6	25	12	254	13	279
1995	86	5	43	11	215	12	258
1996	86	6	13	10	213	12	226
1997	86	4	17	11	137	13	154
1998	85	9	44	11	92	15	136
1999	86	3	10	10	145	10	155
2000	85	2	2	13	72	13	74
2001	86	1	1	9	93	10	94
2002	86	1	1	6	66	7	67
2003	86	4	4	7	69	9	73
2004	85	2	4	4	5	5	9
2005	84	1	43	5	15	6	58
2006	86	4	6	3	22	6	28
2007	86	2	6	3	10	5	16
2008	86	3	16	4	27	6	43
2009	86	3	5	3	33	4	38
2010	86	5	9	4	15	7	24
2011	86	2	2	1	1	3	3
2012	86	2	11	5	5	6	16
2013	86	3	4	2	6	5	10
2014	86	1	1	3	4	4	5
2015	86	2	2	4	9	4	11
2016	86	5	7	7	17	8	24
2017	86	3	7	4	8	6	15
2018	86	3	4	1	3	4	7

Table 3: Sample sizes (number of survey hauls, number hauls where crab were caught, number of crab caught) for the NMFS EBS trawl survey in the Pribilof District each year, for male population components.

	survey	immature males		mature males		sublegal males		legal males		all males	
	number	non-0	no.	non-0	no.	non-0	no.	non-0	no.	non-0	no.
year	of hauls	hauls	crab	hauls	crab	hauls	crab	hauls	crab	hauls	crab
1975	45	11	305	13	553	11	530	13	328	13	858
1976	59	3	105	11	91	9	122	10	74	12	196
1977	58	7	56	10	129	9	73	9	112	10	185
1978	58	8	60	11	130	10	112	10	78	12	190
1979	58	2	2	14	90	8	25	13	67	14	92
1980	70	10	41	21	133	12	64	21	110	21	174
1981	84	19	99	36	184	23	128	36	155	38	283
1982	84	19	70	35	114	21	84	31	100	38	184
1983	86	15	47	32	93	18	74	29	66	35	140
1984	86	10	27	20	37	17	37	16	27	25	64
1985	86	3	4	14	24	8	13	11	15	14	28
1986	86	1	1	13	26	2	2	13	25	13	27
1987	86	5	34	15	50	6	38	14	46	16	84
1988	85	5	52	5	12	5	52	5	12	9	64
1989	86	8	160	4	11	8	160	4	11	10	171
1990	86	8	90	10	59	11	126	7	23	14	149
1991	85	16	92	19	103	20	129	14	66	22	195
1992	86	12	89	14	73	13	119	12	43	17	162
1993	85	12	75	19	96	15	115	17	56	21	171
1994	86	8	32	18	68	12	51	18	49	19	100
1995	86	7	66	18	177	15	118	14	125	19	243
1996	86	7	32	19	87	11	54	19	65	20	119
1997	86	7	25	17	65	10	39	16	51	19	90
1998	85	12	56	20	56	15	66	17	46	21	112
1999	86	7	9	13	34	9	18	11	25	15	43
2000	85	4	9	16	40	9	20	13	29	16	49
2001	86	3	5	6	28	4	9	5	24	7	33
2002	86	0	0	6	12	1	1	6	11	6	12
2003	86	2	2	7	14	3	3	7	13	9	16
2004	85	3	5	3	3	5	7	1	1	6	8
2005	84	3	54	2	5	3	54	2	5	4	59
2006	86	4	7	3	3	4	8	2	2	6	10
2007	86	4	14	2	6	4	17	2	3	4	20
2008	86	2	13	1	1	2	13	1	1	3	14
2009	86	5	16	3	15	5	27	3	4	5	31
2010	86	2	6	5	8	3	10	4	4	5	14
2011	86	0	0	3	9	2	2	2	7	3	9
2012	86	1	9	4	13	1	14	4	8	4	22
2013	86	1	3	2	6	2	5	2	4	3	9
2014	86	3	5	2	5	3	5	2	5	4	10
2015	86	2	4	8	13	6	10	5	7	9	17
2016	86	4	5	3	3	5	7	1	1	5	8
2017	86	2	4	4	4	3	5	3	3	5	8
2018	86	4	6	3	3	4	6	3	3	5	9

The following two tables document the estimated annual PIBKC abundance and associated uncertainty (as the coefficient of variation) in the NMFS bottom trawl survey by PIBKC populaton category. The estimated abundance and uncertainity for each category is calculated using a swept-area approach as if the EBS trawl survey were conducted using a stratified-random sampling design, rather than as a grid-based design. While re-calculated from the "raw" survey data using a completely independent approach, the estimates are the same (to 4 or 5 decimal places) as those provided in the annual survey Technical Memoranda.

Table 4: Estimated annual abundance of female PIBKC population components from the NMFS EBS trawl survey.

	immature females		mature females		all females	
year	abundance millions	cv	abundance millions	cv	abundance millions	cv
1975	2.127	0.740	11.020	0.687	13.148	0.608
1976	5.001	0.956	3.138	0.838	8.139	0.910
1977	4.064	0.786	10.667	0.890	14.732	0.857
1978	0.494	0.603	5.493	0.684	5.987	0.656
1979	0.178	0.604	1.133	0.838	1.311	0.767
1980	1.498	0.477	182.186	0.981	183.684	0.976
1981	1.176	0.296	5.084	0.482	6.260	0.423
1982	1.162	0.415	7.551	0.671	8.713	0.626
1983	0.691	0.673	9.080	0.771	9.772	0.763
1984	0.522	0.467	2.713	0.382	3.235	0.366
1985	0.260	0.541	0.486	0.437	0.746	0.360
1986	0.037	0.698	2.102	0.898	2.139	0.882
1987	0.420	0.754	0.652	0.599	1.072	0.478
1988	0.972	0.804	0.391	0.471	1.363	0.642
1989	2.991	0.669	0.787	0.533	3.778	0.576
1990	2.502	0.775	1.721	0.474	4.223	0.555
1991	1.343	0.455	2.230	0.389	3.573	0.353
1992	2.277	0.758	1.670	0.459	3.947	0.521
1993	0.911	0.567	1.752	0.441	2.663	0.378
1994	0.503	0.681	4.689	0.448	5.192	0.437
1995	0.751	0.808	3.946	0.521	4.697	0.491
1996	0.289	0.460	5.033	0.486	5.322	0.463
1997	0.320	0.669	2.614	0.423	2.935	0.388
1998	0.747	0.428	1.583	0.473	2.330	0.365
1999	0.172	0.789	2.584	0.477	2.756	0.490
2000	0.035	0.698	1.328	0.465	1.363	0.463
2001	0.019	1.000	1.697	0.753	1.716	0.745
2002	0.019	1.000	1.222	0.794	1.241	0.782
2003	0.067	0.483	1.120	0.764	1.188	0.721
2004	0.081	0.740	0.087	0.517	0.168	0.510
2005	2.268	1.000	0.289	0.565	2.557	0.886
2006	0.113	0.548	0.430	0.766	0.543	0.617
2007	0.104	0.842	0.184	0.813	0.288	0.592
2008	0.287	0.881	0.492	0.688	0.779	0.748
2009	0.086	0.585	0.543	0.811	0.629	0.755
2010	0.166	0.558	0.249	0.691	0.415	0.622
2011	0.037	0.698	0.018	1.000	0.055	0.563
2012	0.251	0.873	0.096	0.426	0.347	0.695
2013	0.089	0.637	0.107	0.846	0.196	0.534
2014	0.028	1.000	0.074	0.604	0.102	0.507
2015	0.035	0.699	0.167	0.671	0.202	0.655
2016	0.132	0.504	0.323	0.519	0.454	0.504
2017	0.188	0.746	0.162	0.533	0.350	0.535
2018	0.076	0.595	0.058	1.000	0.134	0.537

Table 5: Estimated annual abundance of male PIBKC population components from the NMFS EBS trawl survey.

	immature males		mature males		sublegal males		legal males		all males	
	abundance	cv	abundance	cv	abundance	cv	abundance	cv	abundance	cv
year	millions		millions		millions		millions		millions	
1975	8.476	0.567	15.288	0.502	14.712	0.479	9.051	0.501	23.764	0.466
1976	4.960	0.954	4.782	0.445	5.729	0.882	4.012	0.471	9.742	0.589
1977	4.216	0.457	13.044	0.743	5.491	0.440	11.769	0.771	17.260	0.625
1978	2.421	0.502	6.141	0.496	4.639	0.419	3.923	0.616	8.562	0.428
1979	0.079	0.704	4.108	0.326	1.170	0.449	3.017	0.310	4.187	0.324
1980	2.733	0.466	7.842	0.408	4.331	0.458	6.244	0.420	10.575	0.400
1981	2.099	0.324	3.834	0.180	2.688	0.317	3.246	0.177	5.934	0.207
1982	1.371	0.281	2.354	0.181	1.654	0.255	2.071	0.188	3.725	0.172
1983	1.031	0.357	1.851	0.186	1.561	0.309	1.321	0.170	2.882	0.220
1984	0.518	0.397	0.771	0.225	0.730	0.290	0.558	0.247	1.288	0.212
1985	0.068	0.598	0.428	0.281	0.226	0.340	0.270	0.294	0.496	0.269
1986	0.019	1.000	0.480	0.305	0.039	0.698	0.460	0.313	0.499	0.298
1987	0.622	0.834	0.903	0.414	0.695	0.748	0.830	0.416	1.525	0.434
1988	1.238	0.842	0.238	0.509	1.238	0.842	0.238	0.509	1.476	0.708
1989	3.515	0.588	0.240	0.624	3.515	0.588	0.240	0.624	3.755	0.585
1990	2.450	0.596	1.470	0.626	3.349	0.596	0.572	0.538	3.920	0.578
1991	1.920	0.373	2.014	0.363	2.697	0.332	1.238	0.444	3.935	0.343
1992	2.436	0.588	1.935	0.420	3.217	0.520	1.154	0.453	4.371	0.475
1993	1.484	0.520	1.876	0.310	2.245	0.432	1.114	0.300	3.359	0.339
1994	0.639	0.374	1.294	0.341	0.998	0.343	0.935	0.345	1.933	0.332
1995	1.147	0.889	3.102	0.600	2.062	0.744	2.186	0.615	4.249	0.675
1996	0.719	0.625	1.712	0.281	1.162	0.547	1.269	0.263	2.431	0.334
1997	0.467	0.525	1.201	0.294	0.736	0.464	0.933	0.284	1.669	0.342
1998	0.949	0.458	0.967	0.246	1.119	0.414	0.797	0.253	1.917	0.309
1999	0.160	0.373	0.617	0.334	0.324	0.388	0.453	0.345	0.777	0.327
2000	0.164	0.563	0.725	0.296	0.361	0.385	0.528	0.297	0.889	0.312
2001	0.093	0.645	0.522	0.710	0.169	0.595	0.446	0.744	0.615	0.690
2002	0.000	0.000	0.225	0.473	0.018	1.000	0.207	0.495	0.225	0.473
2003	0.045	0.717	0.229	0.389	0.061	0.589	0.214	0.402	0.274	0.341
2004	0.088	0.590	0.048	0.563	0.120	0.460	0.016	1.000	0.136	0.417
2005	1.981	0.964	0.092	0.712	1.981	0.964	0.092	0.712	2.073	0.921
2006	0.138	0.495	0.056	0.564	0.155	0.503	0.038	0.699	0.194	0.419
2007	0.246	0.717	0.110	0.854	0.302	0.644	0.054	0.745	0.356	0.639
2008	0.234	0.928	0.018	1.000	0.234	0.928	0.018	1.000	0.252	0.862
2009	0.268	0.631	0.249	0.732	0.448	0.697	0.068	0.588	0.516	0.676
2010	0.101	0.841	0.130	0.486	0.167	0.728	0.065	0.482	0.232	0.608
2011	0.000	0.000	0.166	0.792	0.036	0.698	0.129	0.868	0.166	0.792
2012	0.195	1.000	0.272	0.797	0.303	1.000	0.164	0.678	0.467	0.879
2013	0.076	1.000	0.104	0.862	0.112	0.745	0.069	0.804	0.181	0.644
2014	0.091	0.591	0.092	0.710	0.091	0.591	0.092	0.710	0.183	0.566
2015	0.076	0.766	0.234	0.367	0.185	0.525	0.125	0.446	0.309	0.408
2016	0.094	0.517	0.056	0.563	0.131	0.458	0.019	1.000	0.150	0.488
2017	0.068	0.773	0.091	0.503	0.087	0.637	0.072	0.589	0.159	0.456
2018	0.110	0.572	0.056	0.563	0.110	0.572	0.056	0.563	0.166	0.521

Table 6: Estimated annual abundance of female PIBKC population components from the NMFS EBS trawl survey.

	immature females		mature females		all females	
	biomass	cv	biomass	cv	biomass	cv
year	1000's t		1000's t		1000's t	
1975	1.270	0.730	11.172	0.691	12.442	0.636
1976	3.178	0.963	2.613	0.807	5.792	0.891
1977	2.313	0.784	11.259	0.896	13.572	0.874
1978	0.321	0.611	6.171	0.738	6.492	0.717
1979	0.108	0.634	1.081	0.805	1.189	0.760
1980	0.728	0.446	211.575	0.986	212.303	0.983
1981	0.687	0.297	5.797	0.496	6.484	0.458
1982	0.613	0.406	8.764	0.694	9.377	0.669
1983	0.384	0.722	9.864	0.784	10.248	0.781
1984	0.054	0.698	3.031	0.382	3.085	0.380
1985	0.005	0.457	0.520	0.448	0.525	0.445
1986	0.011	0.727	2.420	0.901	2.431	0.896
1987	0.128	0.866	0.785	0.590	0.913	0.526
1988	0.240	0.645	0.478	0.490	0.718	0.473
1989	1.032	0.601	0.714	0.470	1.746	0.497
1990	1.314	0.764	1.615	0.454	2.929	0.491
1991	0.659	0.493	2.117	0.397	2.776	0.376
1992	1.106	0.740	1.543	0.463	2.649	0.463
1993	0.455	0.573	1.636	0.457	2.092	0.399
1994	0.320	0.703	4.573	0.454	4.893	0.443
1995	0.386	0.764	3.893	0.518	4.279	0.496
1996	0.166	0.486	5.418	0.504	5.585	0.491
1997	0.189	0.670	2.839	0.429	3.028	0.407
1998	0.420	0.431	1.761	0.460	2.182	0.392
1999	0.113	0.797	2.755	0.459	2.868	0.467
2000	0.023	0.699	1.439	0.462	1.462	0.460
2001	0.000	1.000	1.816	0.722	1.817	0.722
2002	0.000	1.000	1.401	0.776	1.401	0.775
2003	0.021	0.667	1.286	0.745	1.307	0.734
2004	0.005	0.711	0.118	0.516	0.123	0.504
2005	0.477	1.000	0.370	0.570	0.847	0.606
2006	0.038	0.602	0.538	0.760	0.576	0.712
2007	0.045	0.995	0.237	0.826	0.282	0.707
2008	0.178	0.882	0.493	0.659	0.672	0.705
2009	0.030	0.576	0.595	0.840	0.625	0.818
2010	0.083	0.575	0.311	0.660	0.394	0.634
2011	0.015	0.836	0.022	1.000	0.037	0.674
2012	0.131	0.936	0.106	0.436	0.237	0.637
2013	0.035	0.657	0.131	0.816	0.166	0.654
2014	0.016	1.000	0.091	0.605	0.108	0.529
2015	0.020	0.708	0.139	0.687	0.160	0.662
2016	0.073	0.468	0.331	0.496	0.405	0.478
2017	0.108	0.811	0.153	0.558	0.262	0.533
2018	0.045	0.575	0.076	1.000	0.121	0.654

Table 7: Estimated annual abundance of male PIBKC population components from the NMFS EBS trawl survey.

	immature males		mature males		sublegal males		legal males		all males	
	biomass	cv	biomass	cv	biomass	cv	biomass	cv	biomass	cv
year	1000's t		1000's t		1000's t		1000's t		1000's t	
1975	8.341	0.525	38.054	0.501	19.378	0.466	27.016	0.499	46.395	0.475
1976	4.129	0.944	14.059	0.451	5.539	0.811	12.649	0.468	18.188	0.452
1977	3.713	0.443	42.618	0.768	5.966	0.463	40.366	0.784	46.332	0.729
1978	2.765	0.509	17.370	0.558	6.618	0.412	13.517	0.642	20.135	0.506
1979	0.061	0.785	10.959	0.315	1.981	0.452	9.040	0.311	11.021	0.315
1980	2.084	0.492	23.553	0.430	4.958	0.464	20.679	0.446	25.637	0.417
1981	1.704	0.299	11.628	0.174	2.779	0.297	10.554	0.175	13.332	0.175
1982	1.152	0.232	7.389	0.187	1.647	0.217	6.893	0.192	8.541	0.175
1983	0.962	0.357	5.409	0.178	1.897	0.297	4.474	0.175	6.371	0.187
1984	0.130	0.362	2.216	0.229	0.521	0.268	1.824	0.247	2.345	0.222
1985	0.039	0.733	1.055	0.267	0.338	0.374	0.755	0.283	1.094	0.263
1986	0.004	1.000	1.505	0.303	0.035	0.897	1.473	0.307	1.508	0.302
1987	0.191	0.783	2.923	0.411	0.334	0.536	2.781	0.414	3.115	0.397
1988	0.170	0.707	0.842	0.529	0.170	0.707	0.842	0.529	1.012	0.457
1989	1.275	0.620	0.827	0.637	1.275	0.620	0.827	0.637	2.102	0.551
1990	2.004	0.661	3.078	0.600	3.567	0.665	1.514	0.515	5.082	0.610
1991	1.377	0.386	4.690	0.386	2.741	0.336	3.326	0.450	6.067	0.373
1992	1.801	0.512	4.391	0.423	3.157	0.446	3.035	0.446	6.192	0.432
1993	1.088	0.545	4.556	0.307	2.442	0.409	3.203	0.301	5.644	0.305
1994	0.619	0.388	3.410	0.345	1.224	0.350	2.806	0.351	4.029	0.343
1995	0.968	0.863	8.360	0.604	2.541	0.673	6.787	0.615	9.328	0.629
1996	0.745	0.605	4.641	0.269	1.512	0.524	3.873	0.265	5.386	0.279
1997	0.381	0.545	3.233	0.276	0.849	0.451	2.765	0.271	3.614	0.294
1998	0.692	0.413	2.798	0.249	0.980	0.354	2.510	0.255	3.490	0.252
1999	0.161	0.402	1.729	0.337	0.464	0.414	1.426	0.347	1.890	0.333
2000	0.113	0.679	2.091	0.296	0.459	0.373	1.746	0.305	2.205	0.304
2001	0.087	0.764	1.599	0.735	0.225	0.628	1.461	0.759	1.686	0.733
2002	0.000	0.000	0.680	0.506	0.033	1.000	0.647	0.525	0.680	0.506
2003	0.019	0.984	0.702	0.400	0.050	0.723	0.671	0.411	0.721	0.390
2004	0.036	0.649	0.107	0.583	0.094	0.487	0.048	1.000	0.143	0.455
2005	0.326	0.942	0.344	0.710	0.326	0.942	0.344	0.710	0.670	0.589
2006	0.087	0.585	0.166	0.603	0.114	0.616	0.139	0.699	0.253	0.462
2007	0.197	0.737	0.306	0.798	0.298	0.632	0.206	0.734	0.503	0.661
2008	0.212	0.952	0.046	1.000	0.212	0.952	0.046	1.000	0.258	0.797
2009	0.254	0.680	0.497	0.713	0.565	0.740	0.187	0.604	0.751	0.698
2010	0.092	0.853	0.303	0.461	0.205	0.702	0.190	0.483	0.395	0.522
2011	0.000	0.000	0.461	0.843	0.062	0.705	0.399	0.886	0.461	0.843
2012	0.165	1.000	0.644	0.735	0.350	1.000	0.459	0.643	0.809	0.786
2013	0.015	1.000	0.250	0.797	0.075	0.824	0.190	0.752	0.265	0.754
2014	0.083	0.623	0.233	0.699	0.083	0.623	0.233	0.699	0.317	0.567
2015	0.082	0.747	0.622	0.394	0.275	0.494	0.428	0.458	0.703	0.395
2016	0.071	0.486	0.130	0.613	0.133	0.495	0.068	1.000	0.201	0.515
2017	0.046	0.767	0.255	0.514	0.076	0.599	0.224	0.573	0.300	0.470
2018	0.096	0.540	0.154	0.571	0.096	0.540	0.154	0.571	0.249	0.522

Size compositions

Annual size compositions for PIBKC in the NMFS EBS trawl survey were calculated by sex, shell condition, and 5mm size (carapace width) bin, accumulating individuals > 200 mm CL in the last size bin (195-200 mm CL). There is no need here to distinguish among the population components used above to present abundance and biomass trends (e.g., immature females) in the following size compositions because those components were based on size ranges that can be extracted from the size compositions.

By sex

Size compositions for PIBKC from the NMFS EBS trawl survey are presented here by sex for the entire survey time period (1975-present) and for 2001-present.

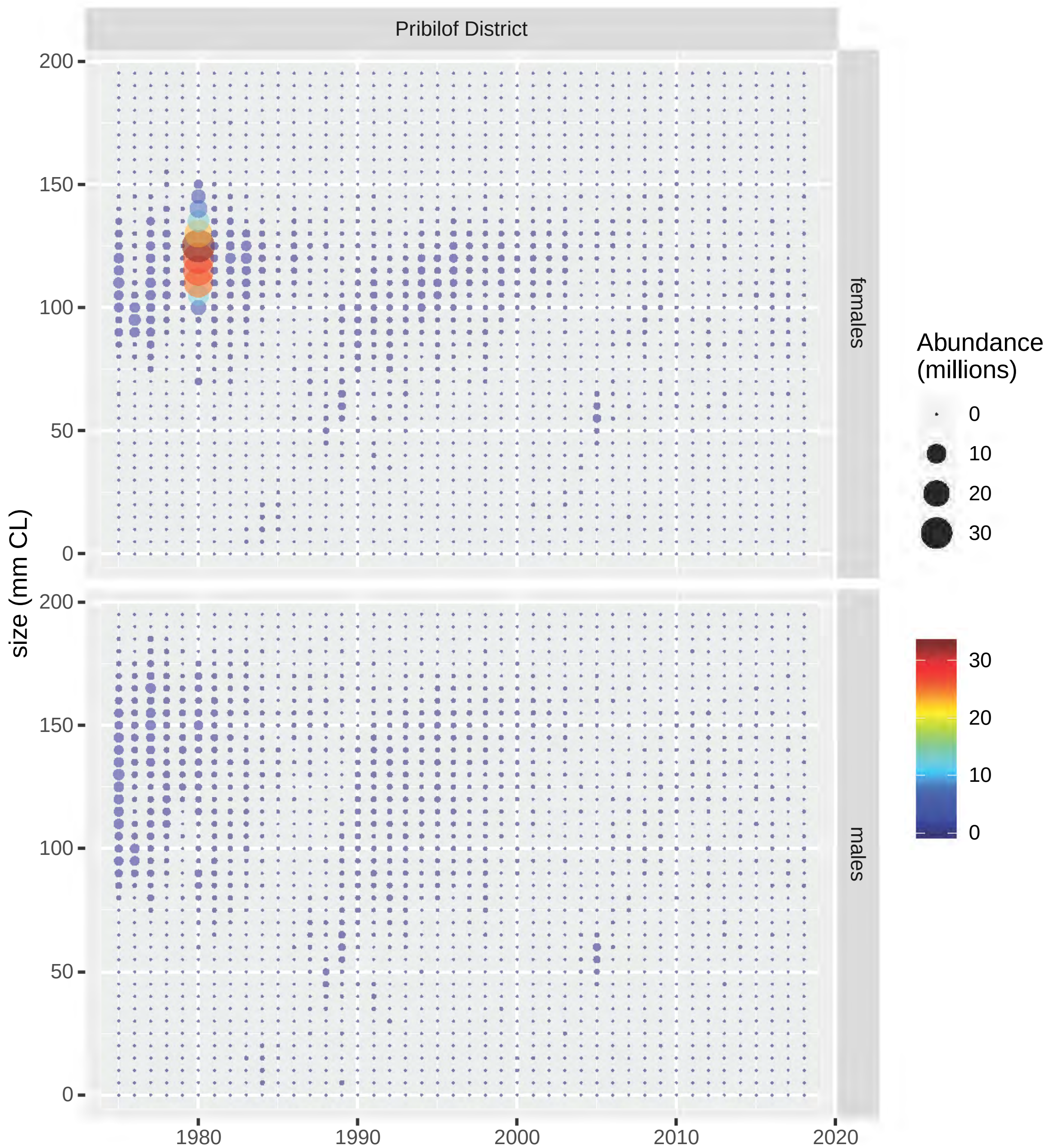

Figure 6: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, over the entire survey period.

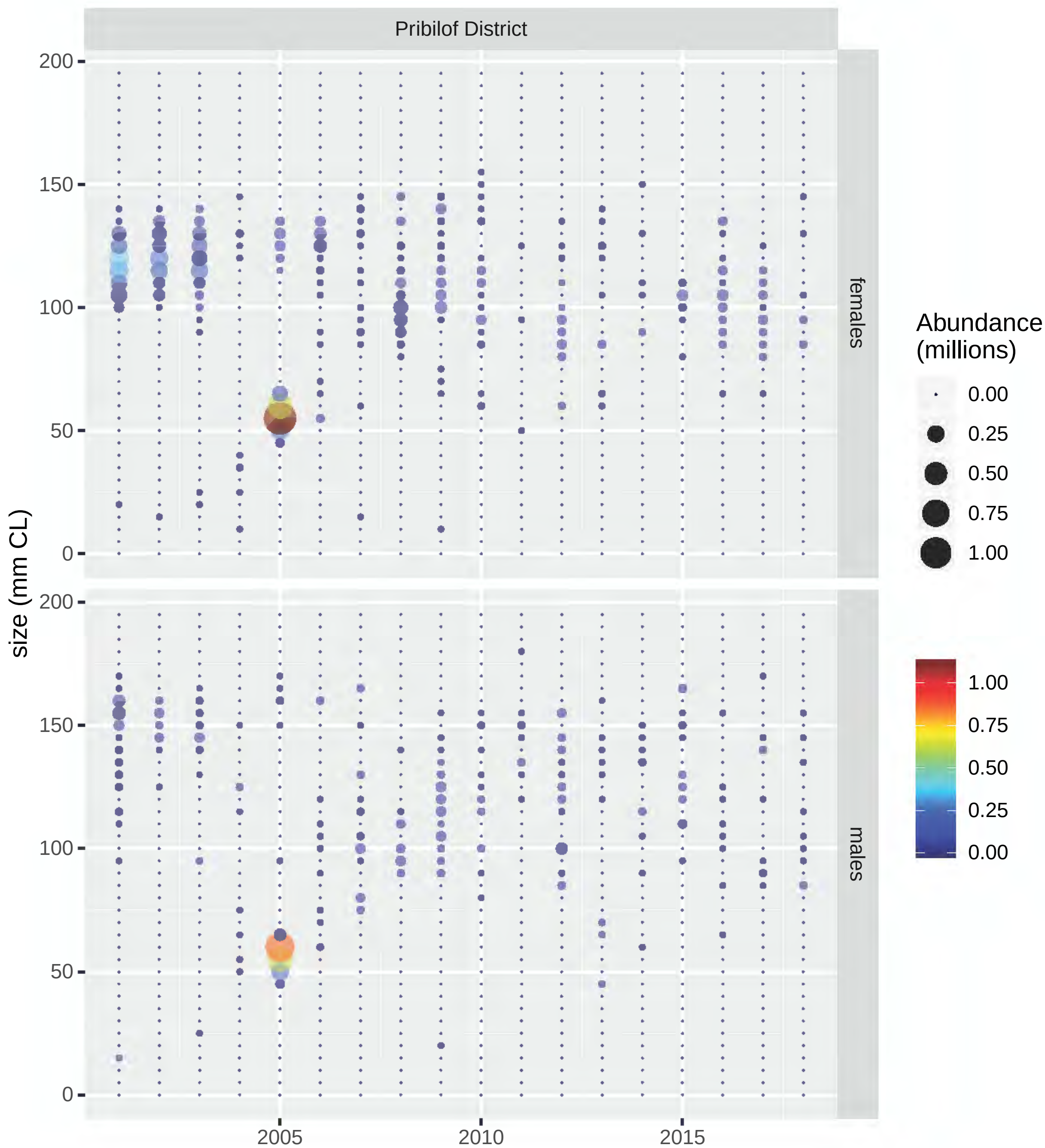

Figure 7: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, since 2001.

By sex and shell condition

Size compositions for PIBKC from the NMFS EBS trawl survey are presented here by sex for the entire survey time period (1975-present) and for 2001-present.

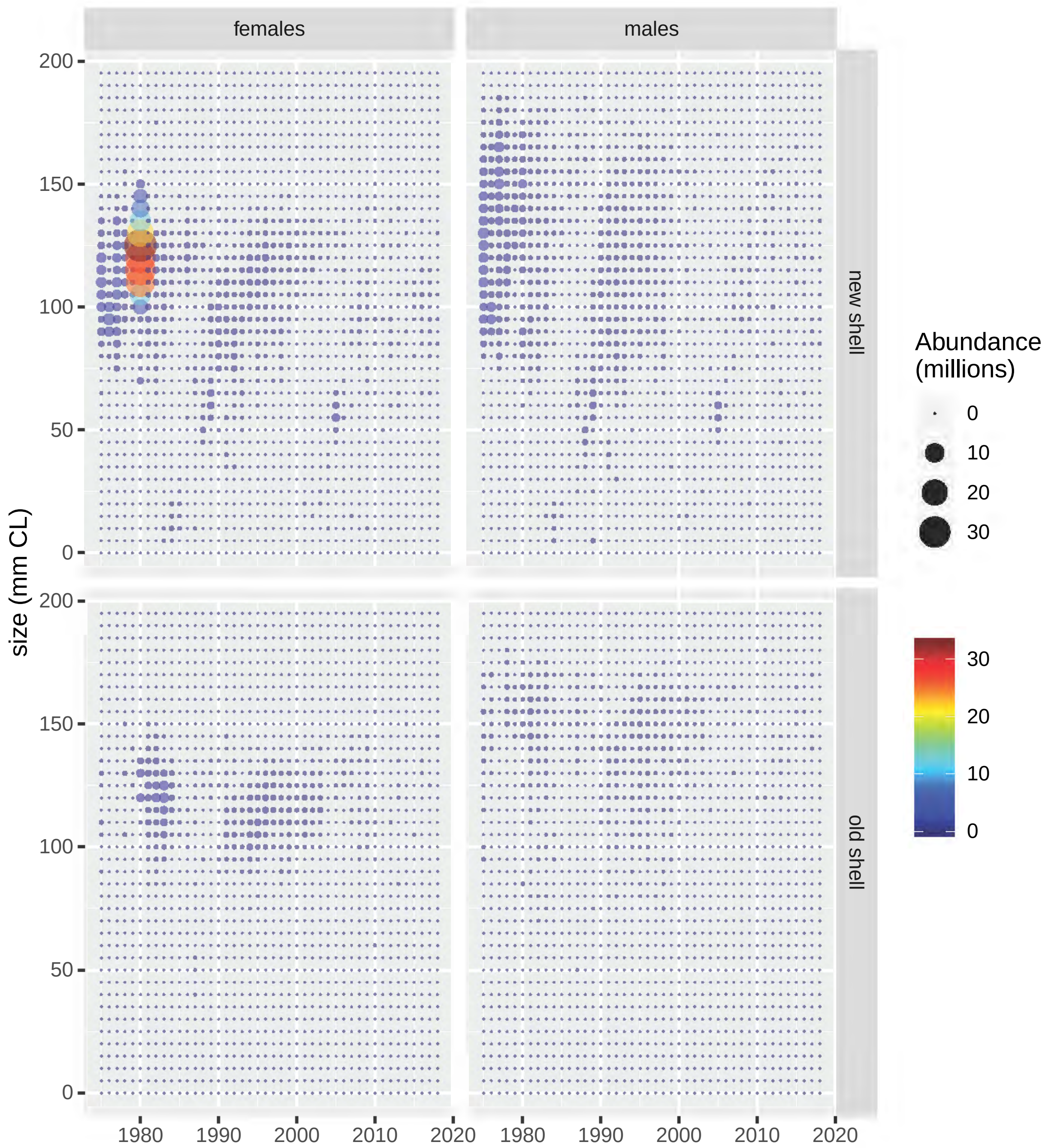

Figure 8: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex and shell condition, for entire survey period.

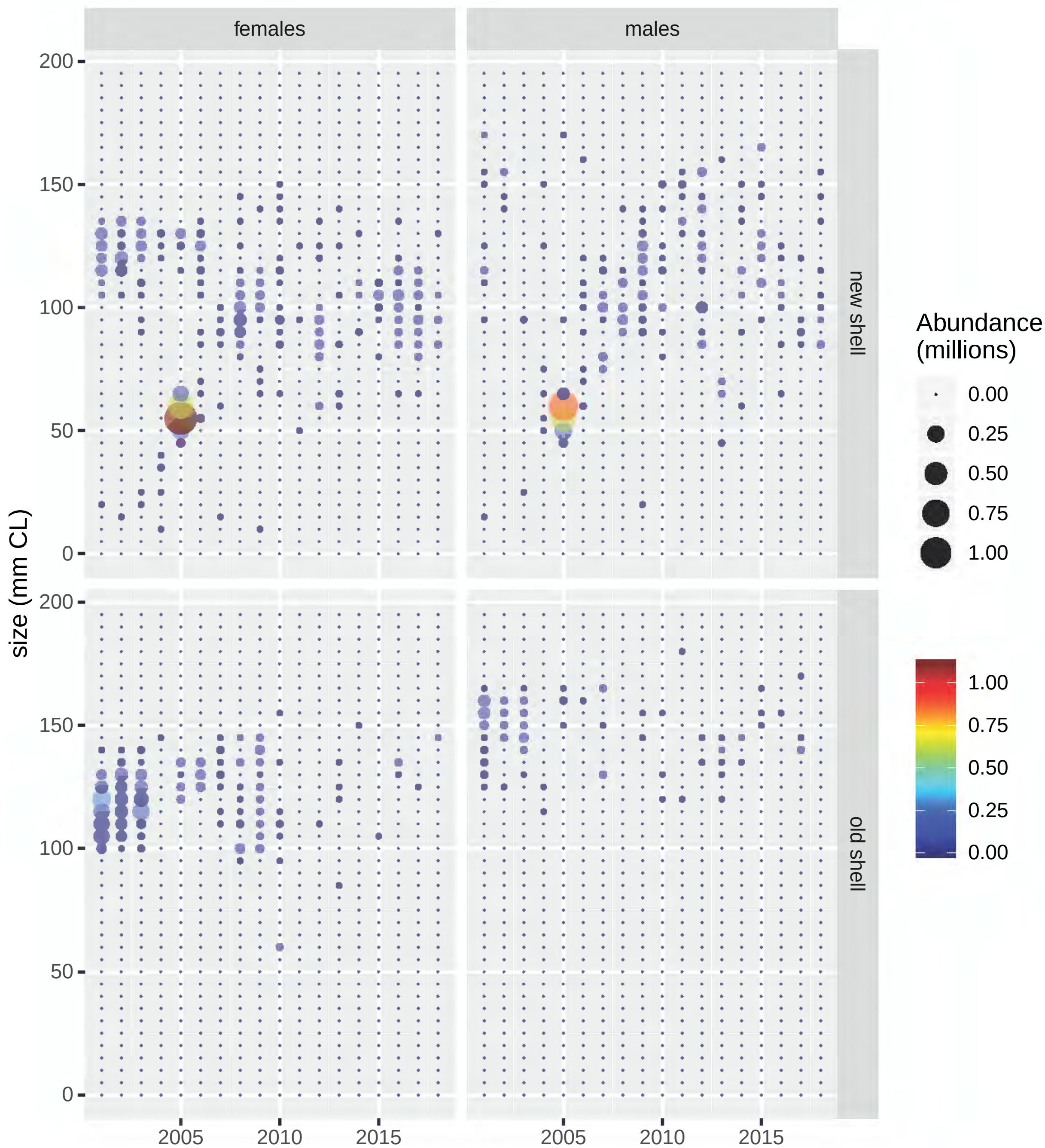

Figure 9: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex and shell condition, since 2000.

Spatial patterns

Spatial patterns of sex-specific CPUE in the survey are shown in this section. The basemap common to all subsequent maps is shown in the following figure:

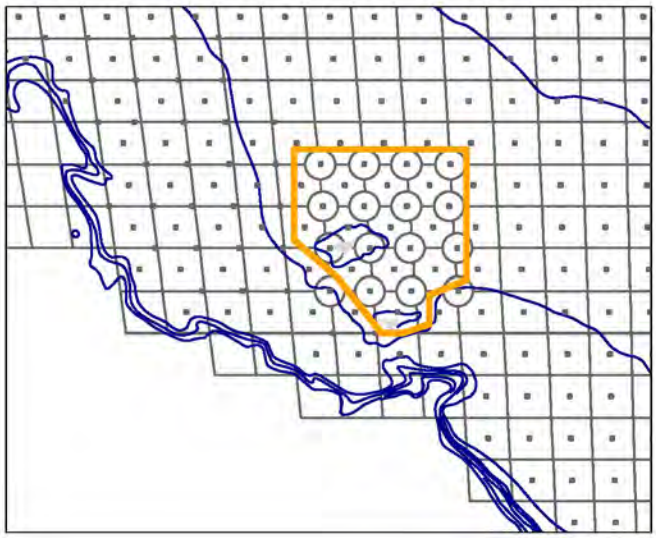

Figure 10: Basemap for future maps, with EBS bathymetry (blue lines), NMFS EBS trawl survey station grid (black) lines, and the Pribilof Islands Habitat Conservation Area (orange outline).

In subsequent plots, bottom temperature at the time of the survey will also be shown as a background "color"heatmap" whereas the estimated CPUE at eaCH station will be shown as a circle whose area is scaled to the estimate.

Appendix C: PIBKC 2019 Status Determination

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Introduction

This is an appendix to the 2019 stock assessment chapter for the Pribilof Islands blue king crab stock (PIBKC). It presents results for 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.

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 longterm spawning stock biomass when the stock is fished at maximum sustainable yield (MSY). Thus, the stock is overfished if $B/B_{MSY} < 0.5$, where B is the "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, the 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 trawl 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:

$$MMB_{s_y} = \sum_z w_z \cdot P_z \cdot n_{z,y}$$

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. $MMB_{m_y} = \left[MMB_{f_y} - RM_y - DM_y \right] \cdot e^{-M \cdot t_{fm}}$

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** on 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 yet 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:
    - $MMB_f = MMB_s \cdot e^{-M \cdot t_{sf}}$

- $RM_{OFL} = \left(1 - e^{-F_{OFL}}\right) \cdot MMB_s \cdot e^{-M \cdot t_{sf}}$
- $DM_{OFL} = \theta \cdot \frac{MMB_f}{p_{male}}$
- $OFL = RM_{OFL} + DM_{OFL}$

3. project MMB-at-mating from the "current" survey MMB and the OFL:
   - $MMB_m = \left[MMB_{f_y} - \left(RM_{OFL} + p_{male} \cdot DM_{OFL}\right)\right] \cdot e^{-M \cdot t_{fm}}$
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: ./Data2019AM.Fisheries.csv
- survey data : ./Data2019AM.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):

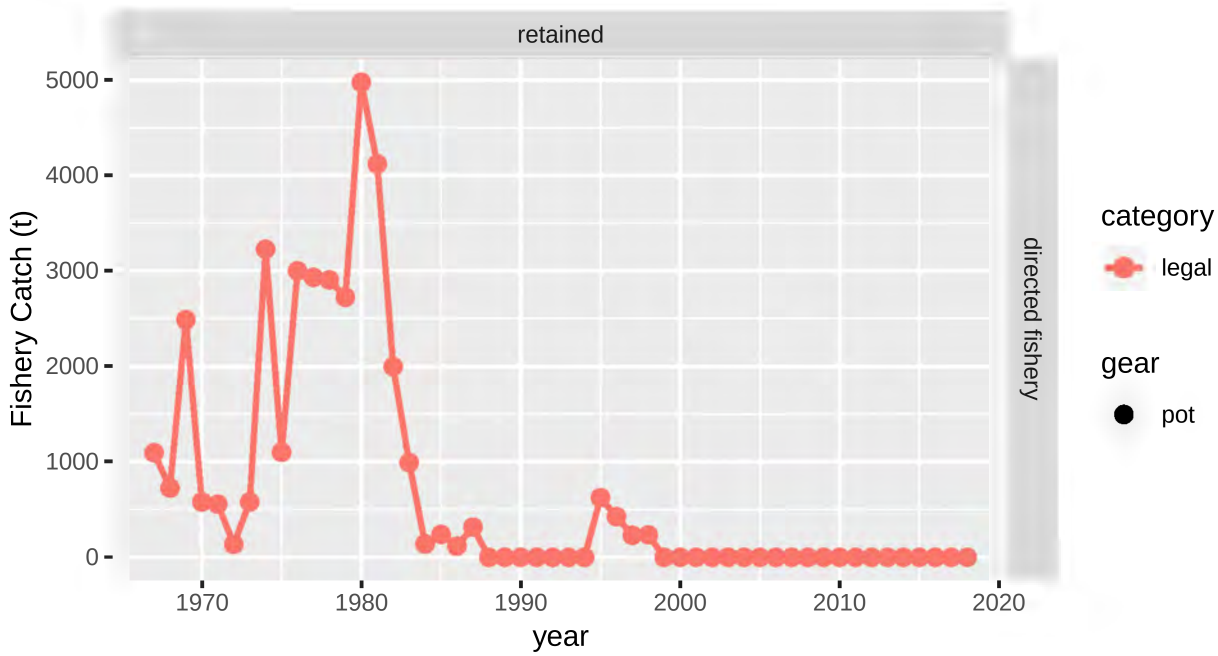

Figure 1: Time series of retained PIBKC catch in the directed fishery.

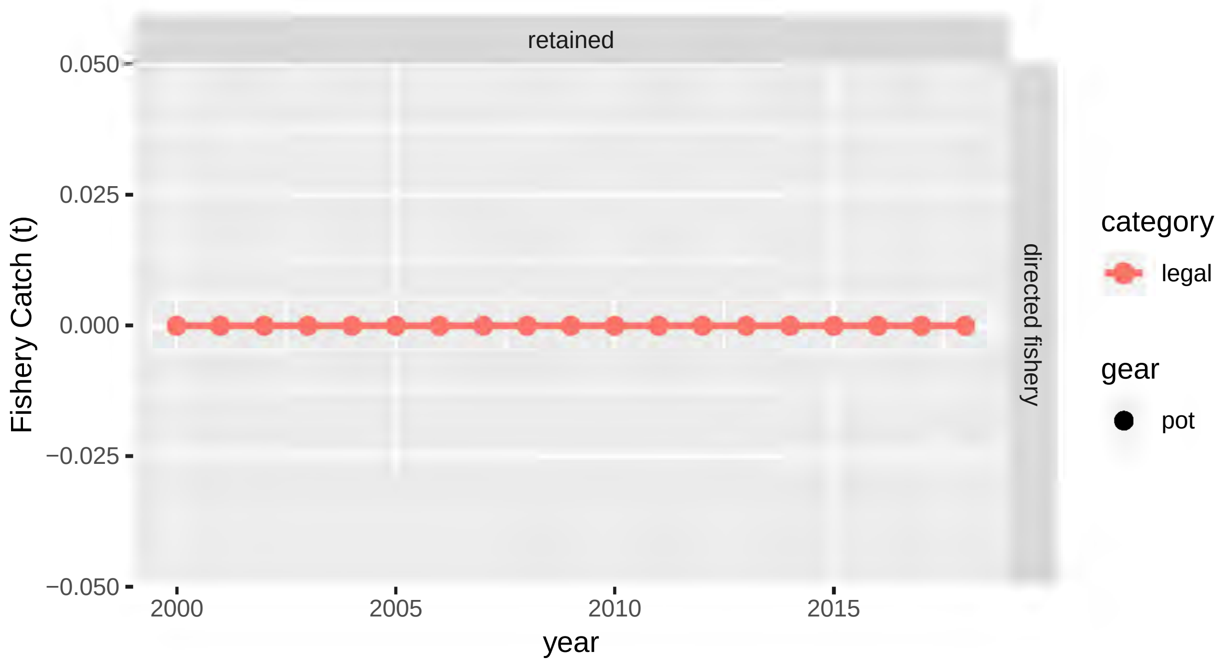

Figure 2: Time series of retained PIBKC catch in the directed fishery (recent time period).

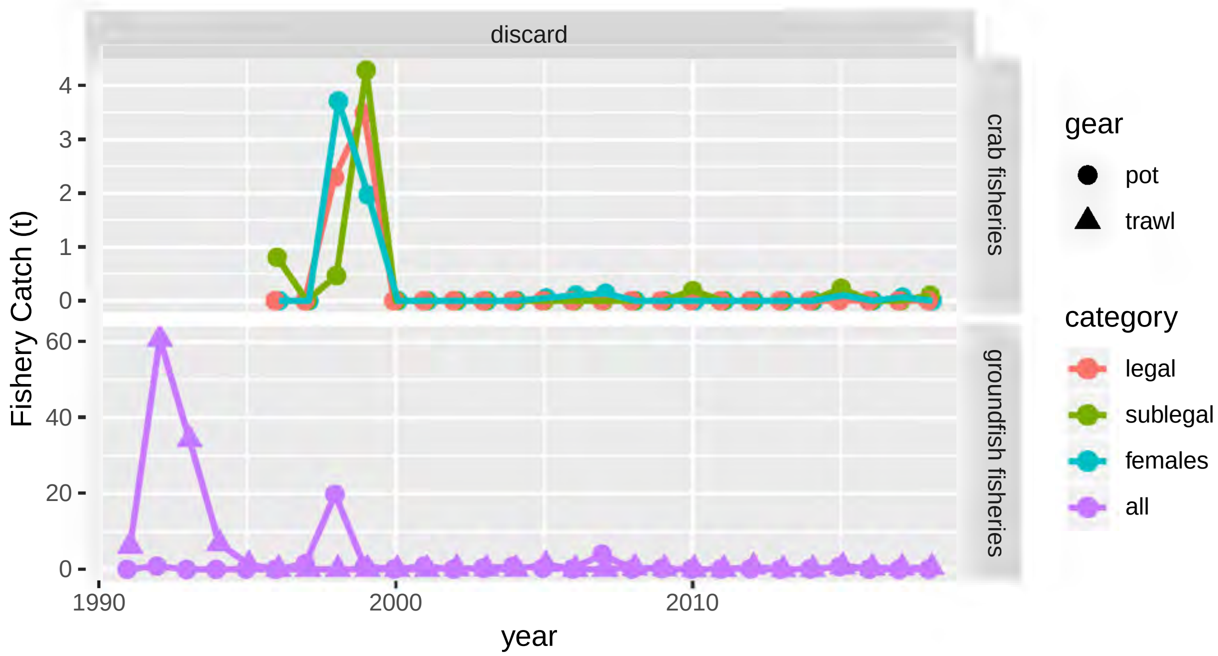

Figure 3: Time series of PIBKC bycatch in the crab and groundfish fisheries.

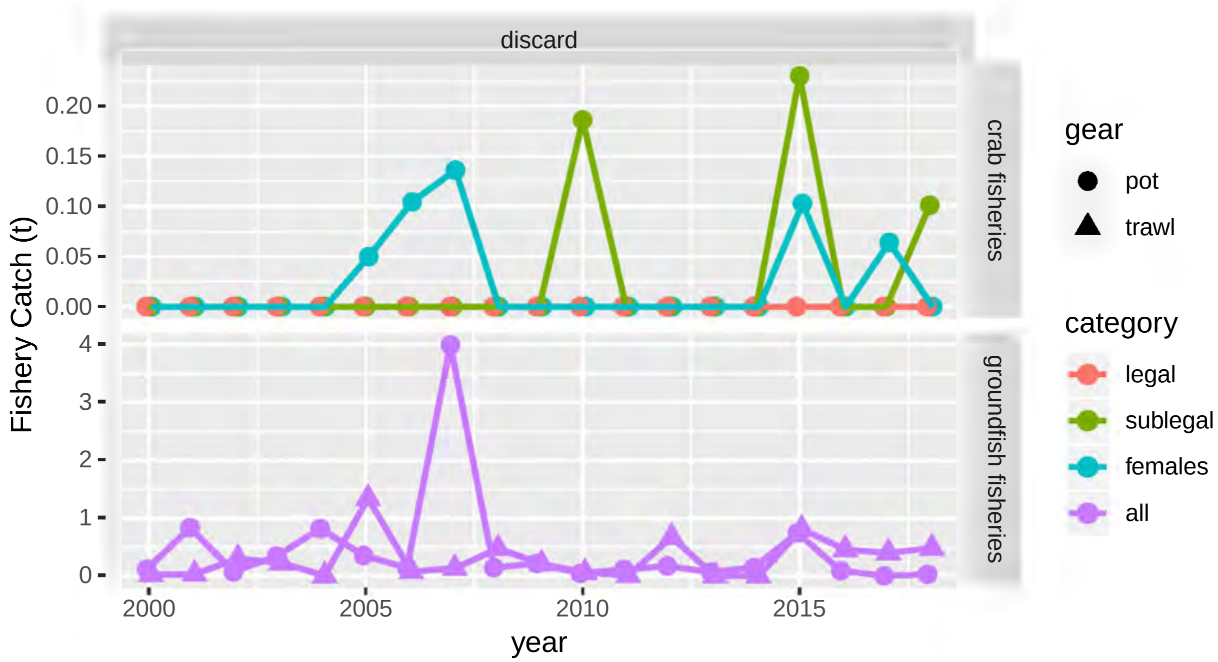

Figure 4: Time series of PIBKC bycatch in the crab and groundfish fisheries (recent time period).

The following figures illustrate the time series of PIBKC survey biomass in the NMFS EBS bottom trawl survey:

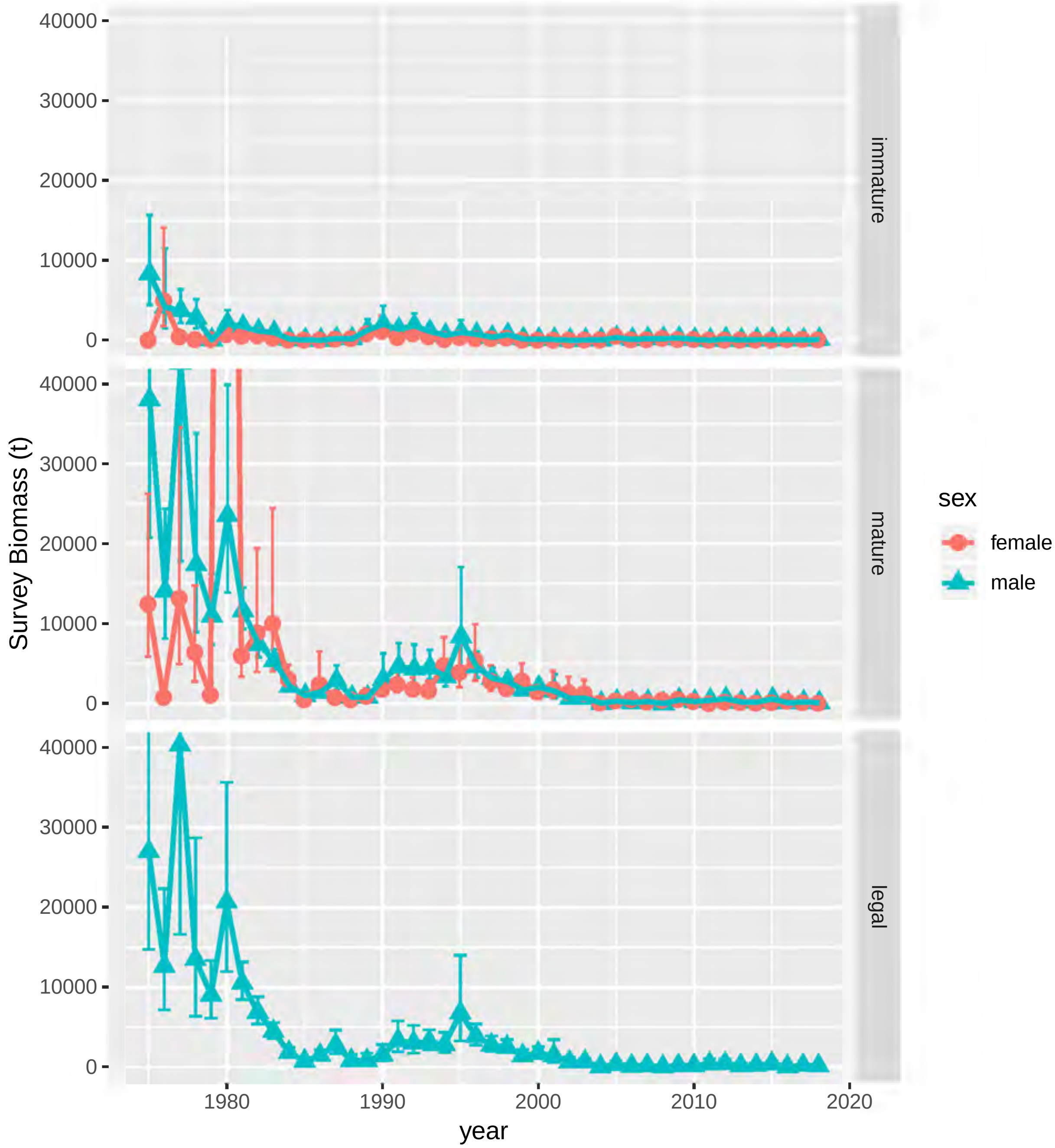

Figure 5: Time series of NMFS EBS bottom trawl survey biomass for PIBKC. Confidence intervals shown are 80% CI's, assuming lognormal error distributions.

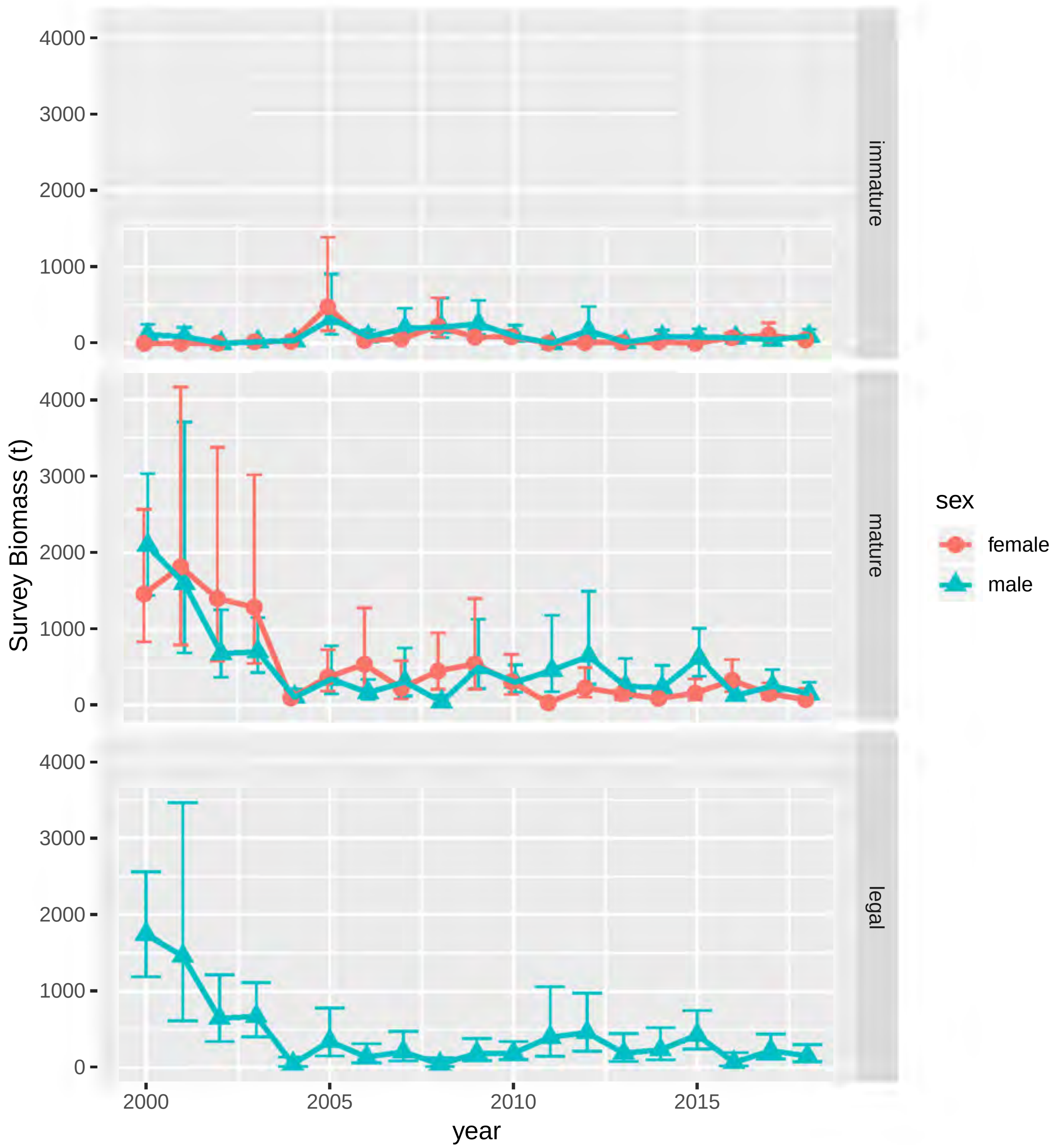

Figure 6: Time series of NMFS EBS bottom trawl survey biomass for PIBKC (recent time period). Confidence intervals shown are 80% CI's, assuming lognormal error distributions.

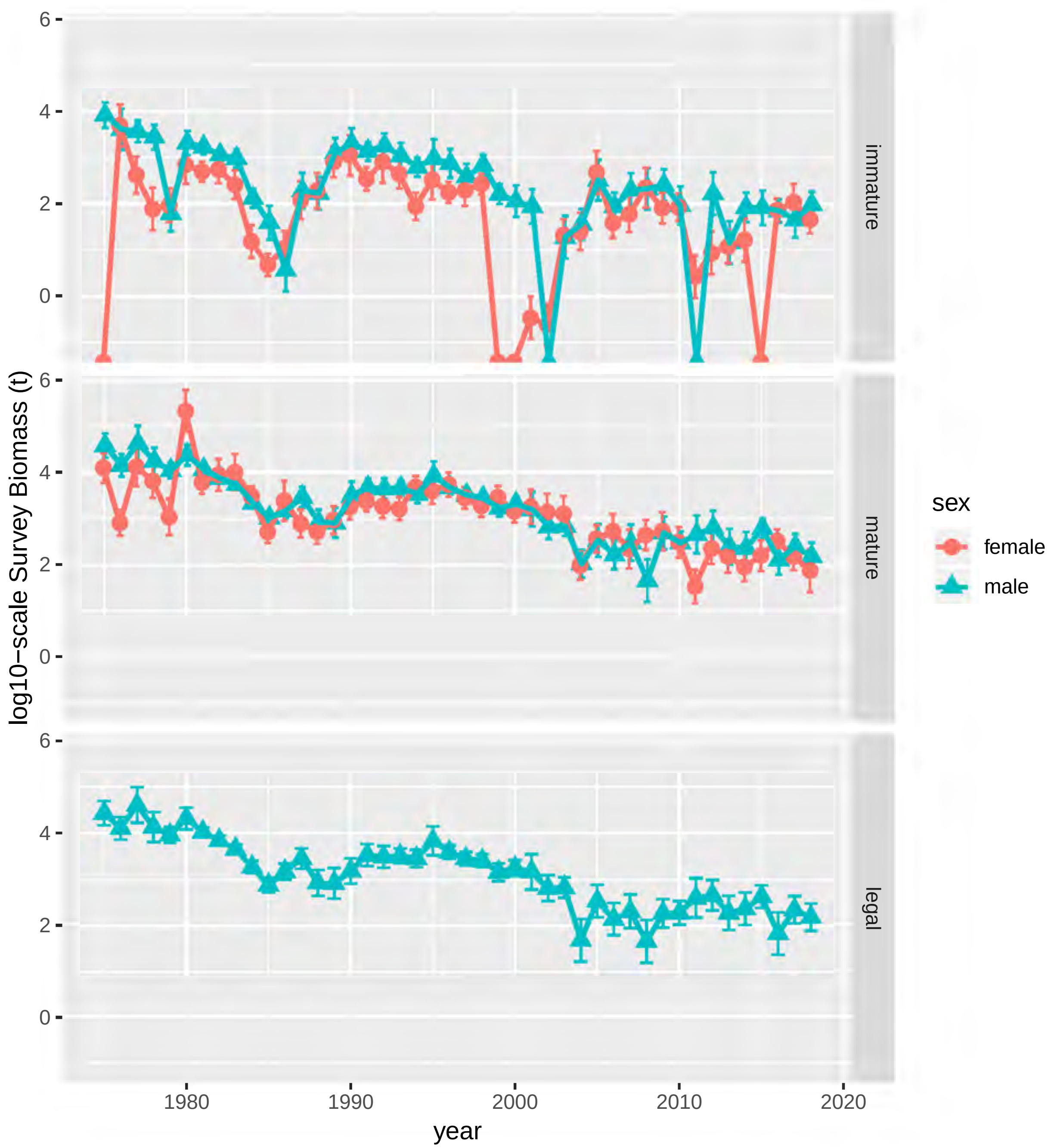

Figure 7: Log10-scale time series for the NMFS EBS bottom trawl survey biomass for PIBKC. Confidence intervals shown are 80% CI's, assuming lognormal error distributions.

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

$$\Lambda = \sum_y \left[ln(2\pi\phi) + \left(\frac{< ln(MMB_s) >_y - < ln(MMB_s) >_{y-1}}{\phi} \right)^2 \right] + \sum_y \left(\frac{ln(MMB_{s_y}) - < ln(MMB_s) >_y}{\sigma_{s_y}} \right)^2$$

The model is coded in C++ and uses AD Model Builder C++ libraries (Fournier et al., 2012) to minimize the objective function.

Calculating the OFL for the upcoming 2019/20 fishing year requires a value of survey biomass for 2019. The NMFS EBS Bottom Trawl Survey is conducted June-August but the timing of the 2019 assessment was moved from September (after the 2019 NMFS EBS Bottom Trawl Survey) to May (before the survey) so the value for the 2019 survey biomass is based on a 1-step prediction from the RE-smoothed time series. For the random-walk model used here, the best 1-step prediction for the 2019 survey biomass is simply the estimated 2018 survey biomass (the uncertainty of the predicted 2019 value is larger, though, than that for the 2018 estimate).

Smoothing results

For comparison, the raw and RE-smoothed survey MMB time series are shown below in Figures 8-10, on both arithmetic and natural log scales:

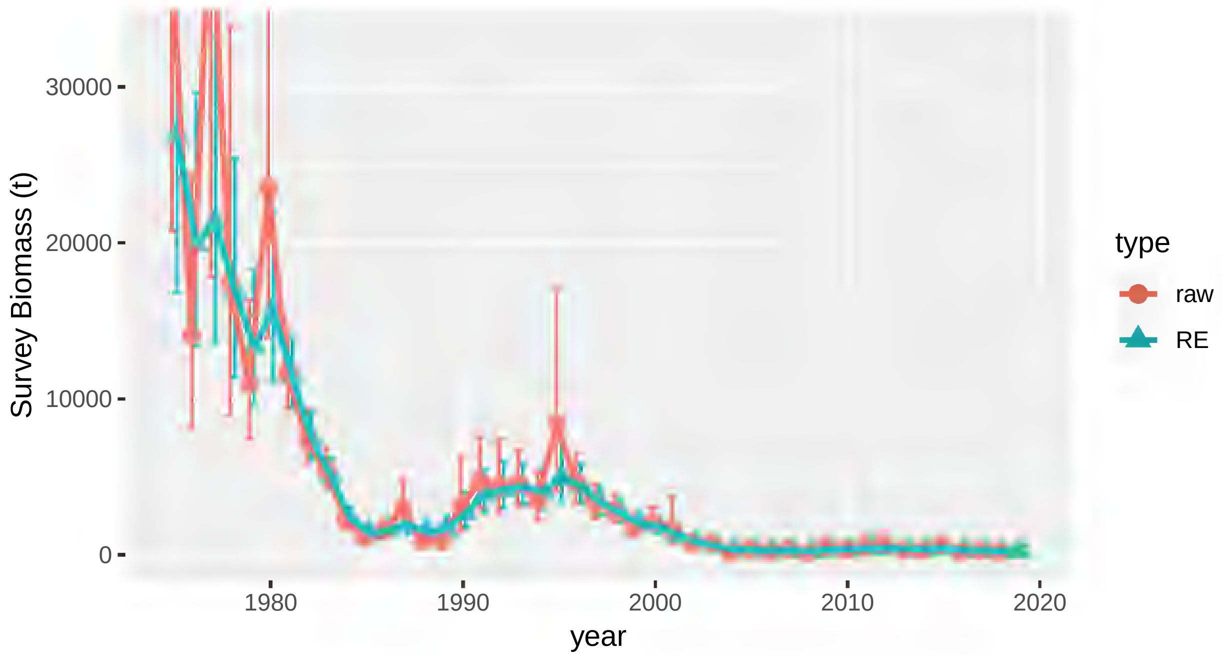

Figure 8: Arithmetic-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions. The final smoothed value is a 1-step prediction.

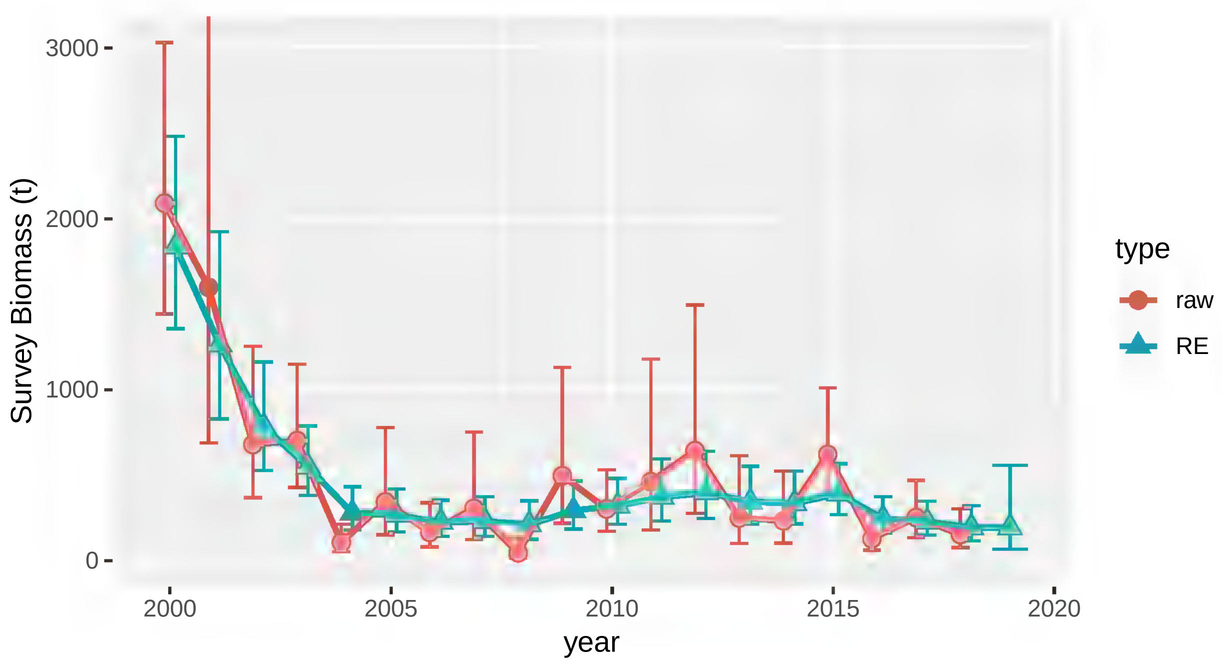

Figure 9: Arithmetic-scale raw and smoothed survey MMB time series, since 2000. Confidence intervals shown are 80% CIs, assuming lognormal error distributions. The final smoothed value is a 1-step prediction.

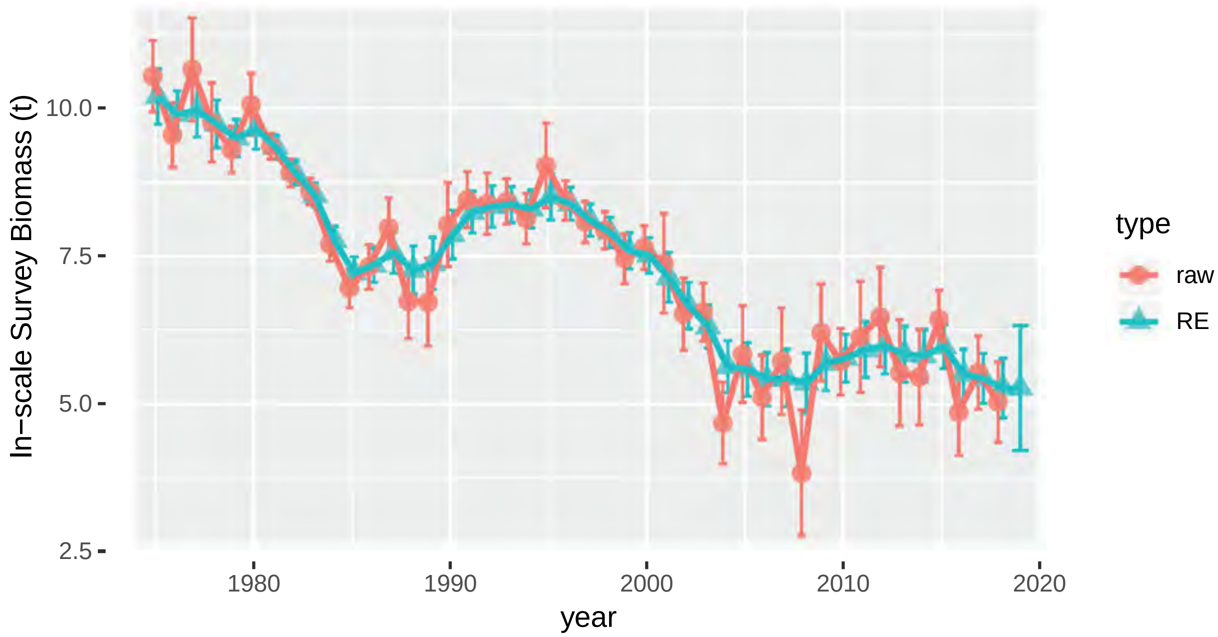

Figure 10: Log-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions. The final smoothed value is a 1-step prediction.

Status determination

Overfishing status

For PIBKC, the total fishing mortality in 2018/19 was 0.4107838 t while the OFL was 1.16 t. Thus, overfishing did not occur in 2018/19.

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

The time series for MMB-at-mating using the RE-smoothed survey MMB time series is shown in the following figure. Note that because the fishery will not yet have been conducted in the year of the assessment, values for MMB at the time of the fishery and the time of mating are unavailable (a predicted value for MMB-at-mating in the assessment year will be determined as part of the OFL calculation).

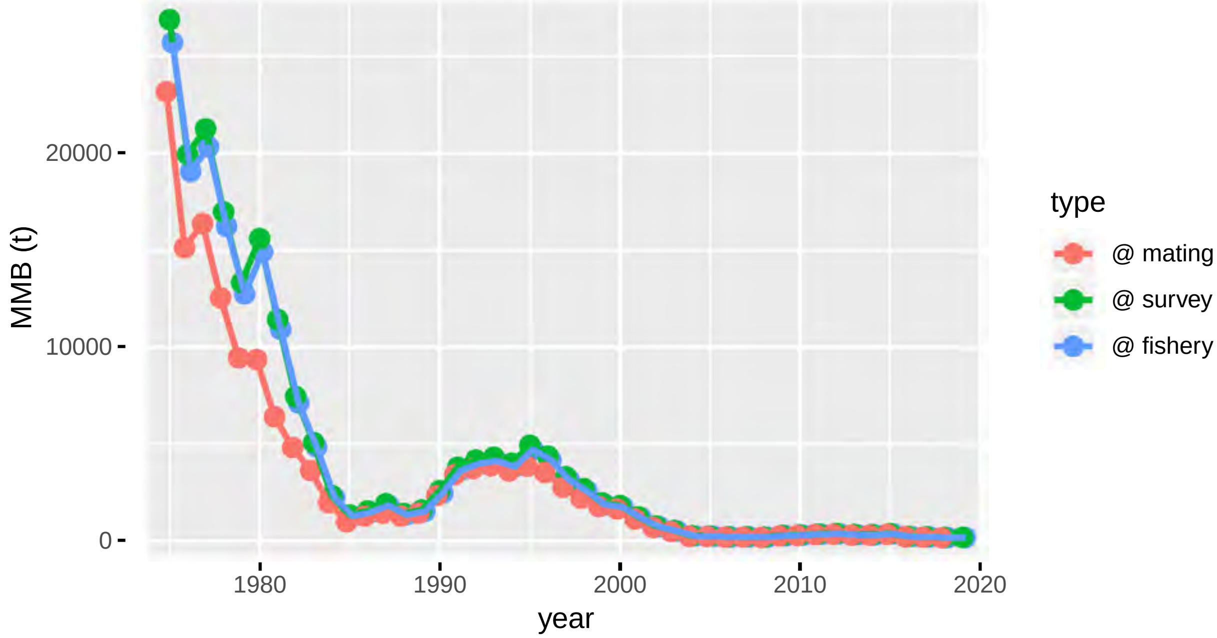

Figure 11: Estimated time series for MMB using the RE method at the time of the survey (the random effects time series), at the time of the fishery, and at the time of mating. The value for MMB at the time of the survey in the assessment year is a 1-step ahead prediction because the survey has not yet been conducted while values for MMB at the time of the fishery and the time of mating are unavailable (a predicted value for MMB-at-mating in the assessment year will be determined as part of the OFL calculation).

The value for $B_{MSY_{proxy}}$ and the estimated current (2019) MMB *at the time of the survey* from the RE-smoothed results are:

Table 1: Estimated $B_{MSY_{proxy}}$ and current MMB at the time of the survey using the RE-smoothed survey data.

	Current survey MMB (t)	$B_{MSY_{proxy}}$ (t)
RE-smoothed	194	$4,106$

Values for θ, used in the projected MMB calculations, based on averaging over the last three years, are:

Table 2: Estimated value for the θ coefficient.

	Estimation Type	theta
1	RE-smoothed	0.0008647

Results from the calculations for B ("current" MMB), overfished status, and an illustrative Tier

4-based OFL for 2019/20 (not used for PIBKC) are:

Table 3: More results from the OFL determination.

	quantity	units	RE.smoothed
1	B ("current" MMB)	t	174.67
2	B_{MSY}	t	4,106.40
3	stock status	–	overfished
4	F_{OFL}	$year^{-1}$	0.00
5	RM_{OFL}	t	0.00
6	DM_{OFL}	t	0.32
7	OFL	t	0.32

Because B/B_{MSY} using RE-smoothed MMB-at-mating from the Table above is 0.0425, the stock is overfished. Furthermore, because $B/B_{MSY} < \beta(= 0.25)$, directed fishing on PIBKC is prohibited.

Tables

Fishery data

Table 4: Annual retained catch biomass and bycatch (not mortality; in t), as available, in the directed fishery, the other crab fisheries, and the groundfish fisheries.

	crab fisheries			directed fishery	groundfish fisheries	
		pot		pot	pot	trawl
		discard		retained	discard	discard
	females	legal	sublegal	legal	all	all
year	t	t	t	t	t	t
1966	0.00000	NA	NA	0.00000	0.00000	NA
1967	NA	NA	NA	1,097.69285	NA	NA
1968	NA	NA	NA	725.74734	NA	NA
1969	NA	NA	NA	2,485.68463	NA	NA
1970	NA	NA	NA	580.59787	NA	NA
1971	NA	NA	NA	557.91827	NA	NA
1972	NA	NA	NA	136.07763	NA	NA
1973	NA	NA	NA	580.59787	NA	NA
1974	NA	NA	NA	3,225.03973	NA	NA
1975	NA	NA	NA	1,102.22877	NA	NA
1976	NA	NA	NA	2,998.24369	NA	NA
1977	NA	NA	NA	2,930.20488	NA	NA
1978	NA	NA	NA	2,902.98935	NA	NA
1979	NA	NA	NA	2,721.55252	NA	NA
1980	NA	NA	NA	4,975.90519	NA	NA
1981	NA	NA	NA	4,118.61614	NA	NA
1982	NA	NA	NA	2,000.34110	NA	NA
1983	NA	NA	NA	993.36667	NA	NA
1984	NA	NA	NA	140.61355	NA	NA
1985	NA	NA	NA	240.40381	NA	NA
1986	NA	NA	NA	117.93394	NA	NA
1987	NA	NA	NA	317.51446	NA	NA
1988	NA	NA	NA	0.00000	NA	NA
1989	NA	NA	NA	0.00000	NA	NA
1990	NA	NA	NA	0.00000	NA	NA
1991	NA	NA	NA	0.00000	0.06700	6.19900
1992	NA	NA	NA	0.00000	0.87900	60.79100
1993	NA	NA	NA	0.00000	0.00000	34.23200
1994	NA	NA	NA	0.00000	0.03500	6.85600
1995	NA	NA	NA	625.95708	0.10800	1.28400
1996	0.00000	0.00000	0.80739	426.37656	0.03100	0.06700
1997	0.00000	0.00000	0.00000	231.33196	1.46200	0.13000
1998	3.71492	2.29518	0.46720	235.86788	19.80000	0.07900
1999	1.96859	3.49266	4.29098	0.00000	0.79500	0.02000
2000	0.00000	0.00000	0.00000	0.00000	0.11600	0.02300
2001	0.00000	0.00000	0.00000	0.00000	0.83300	0.02900
2002	0.00000	0.00000	0.00000	0.00000	0.07100	0.29700
2003	0.00000	0.00000	0.00000	0.00000	0.34500	0.22700
2004	0.00000	0.00000	0.00000	0.00000	0.81600	0.00200
2005	0.04990	0.00000	0.00000	0.00000	0.35300	1.33900
2006	0.10433	0.00000	0.00000	0.00000	0.13800	0.07400
2007	0.13608	0.00000	0.00000	0.00000	3.99300	0.13200
2008	0.00000	0.00000	0.00000	0.00000	0.14100	0.47300
2009	0.00000	0.00000	0.00000	0.00000	0.21563	0.20677
2010	0.00000	0.00000	0.18597	0.00000	0.04434	0.05629
2011	0.00000	0.00000	0.00000	0.00000	0.11175	0.00710
2012	0.00000	0.00000	0.00000	0.00000	0.16994	0.66875
2013	0.00000	0.00000	0.00000	0.00000	0.06464	0.00000
2014	0.00000	0.00000	0.00000	0.00000	0.14430	0.00010
2015	0.10281	0.00000	0.23013	0.00000	0.74427	0.80776
2016	0.00000	0.00000	0.00000	0.00000	0.09043	0.45500
2017	0.06400	0.00000	0.00000	0.00000	0.00025	0.39664
2018	0.00000	0.00000	0.10104	0.00000	0.02613	0.48169

Survey data

Table 5: Input ('raw') male survey abundance data (numbers of crab).

	immature		legal		mature		total	
year	value	cv	value	cv	value	cv	value	cv
1975	8, 475, 780.89	0.57	9, 051, 485.73	0.50	28, 435, 755.89	1.11	36, 911, 536.79	1.07
1976	12, 328, 947.42	1.92	4, 012, 289.16	0.47	5, 551, 254.42	0.96	17, 880, 201.84	1.50
1977	5, 067, 465.88	1.28	11, 768, 927.37	0.77	26, 924, 033.45	1.60	31, 991, 499.33	1.48
1978	2, 482, 381.42	1.50	3, 922, 873.85	0.62	12, 067, 151.89	1.16	14, 549, 533.30	1.08
1979	221, 771.00	1.42	3, 017, 118.91	0.31	5, 276, 802.27	1.14	5, 498, 573.27	1.09
1980	3, 513, 951.44	1.24	6, 244, 057.67	0.42	190, 745, 260.90	1.39	194, 259, 212.34	1.38
1981	2, 925, 999.23	0.73	3, 245, 951.07	0.18	9, 267, 921.40	0.62	12, 193, 920.63	0.63
1982	2, 247, 538.58	0.80	2, 071, 467.90	0.19	10, 190, 817.25	0.83	12, 438, 355.84	0.80
1983	1, 494, 458.75	0.90	1, 321, 394.69	0.17	11, 159, 269.86	0.97	12, 653, 728.61	0.98
1984	983, 046.34	0.91	558, 226.46	0.25	3, 539, 833.29	0.60	4, 522, 879.63	0.58
1985	327, 846.69	1.14	270, 241.72	0.29	914, 260.33	0.72	1, 242, 107.02	0.63
1986	55, 588.48	1.70	460, 310.63	0.31	2, 582, 129.95	1.20	2, 637, 718.43	1.18
1987	1, 023, 070.70	1.58	830, 150.65	0.42	1, 573, 658.67	1.00	2, 596, 729.37	0.91
1988	2, 135, 682.52	1.71	237, 867.82	0.51	703, 331.18	0.99	2, 839, 013.70	1.35
1989	6, 150, 862.84	1.33	239, 947.52	0.62	1, 381, 703.37	1.28	7, 532, 566.21	1.16
1990	4, 627, 193.67	1.51	571, 708.33	0.54	3, 516, 258.12	1.17	8, 143, 451.79	1.13
1991	2, 725, 893.73	0.84	1, 237, 558.37	0.44	4, 781, 533.72	0.78	7, 507, 427.45	0.70
1992	4, 233, 139.11	1.51	1, 154, 465.28	0.45	4, 084, 797.20	0.91	8, 317, 936.31	1.00
1993	2, 364, 196.25	1.13	1, 114, 300.52	0.30	3, 658, 157.09	0.76	6, 022, 353.33	0.72
1994	783, 283.02	0.95	935, 268.63	0.34	6, 341, 478.39	0.78	7, 124, 761.41	0.77
1995	1, 805, 281.89	1.81	2, 186, 408.91	0.62	7, 140, 267.33	1.12	8, 945, 549.23	1.17
1996	995, 165.22	1.04	1, 269, 274.66	0.26	6, 757, 837.30	0.77	7, 753, 002.53	0.80
1997	787, 577.26	1.19	932, 852.28	0.28	3, 815, 669.55	0.72	4, 603, 246.80	0.73
1998	1, 449, 688.57	0.89	797, 187.26	0.25	2, 796, 606.53	0.69	4, 246, 295.10	0.67
1999	159, 535.74	0.37	452, 740.30	0.34	3, 373, 234.05	0.82	3, 532, 769.79	0.82
2000	163, 834.62	0.56	527, 589.35	0.30	2, 088, 120.40	0.76	2, 251, 955.02	0.77
2001	111, 434.07	1.65	445, 863.41	0.74	2, 219, 704.16	1.46	2, 331, 138.23	1.43
2002	18, 729.46	1.00	207, 145.98	0.49	1, 447, 328.02	1.27	1, 466, 057.48	1.25
2003	112, 599.69	1.20	213, 572.37	0.40	1, 349, 151.10	1.15	1, 461, 750.78	1.06
2004	185, 710.36	1.22	15, 583.88	1.00	117, 939.32	1.17	303, 649.68	0.93
2005	4, 249, 450.99	1.96	91, 932.30	0.71	381, 129.58	1.28	4, 630, 580.58	1.81
2006	251, 165.41	1.04	38, 242.00	0.70	485, 119.46	1.33	736, 284.87	1.04
2007	368, 647.45	1.45	54, 402.91	0.75	275, 842.91	1.75	644, 490.36	1.23
2008	576, 037.92	1.83	18, 255.62	1.00	455, 624.48	1.66	1, 031, 662.41	1.61
2009	420, 006.90	1.24	68, 117.04	0.59	725, 721.22	1.55	1, 145, 728.13	1.43
2010	266, 783.19	1.40	64, 702.83	0.48	379, 492.70	1.18	646, 275.89	1.23
2011	18, 089.34	1.00	129, 097.71	0.87	202, 037.20	1.49	220, 126.54	1.36
2012	229, 204.82	2.00	164, 164.90	0.68	584, 327.37	1.56	813, 532.19	1.57
2013	121, 694.76	1.70	68, 726.09	0.80	254, 660.86	1.49	376, 355.62	1.18
2014	118, 710.86	1.59	91, 855.85	0.71	166, 223.38	1.31	284, 934.24	1.07
2015	75, 575.44	0.77	124, 591.54	0.45	436, 094.37	1.02	511, 669.81	1.06
2016	225, 711.04	1.02	19, 344.90	1.00	378, 612.24	1.08	604, 323.27	0.99
2017	256, 098.21	1.52	71, 937.24	0.59	252, 444.72	1.04	508, 542.93	0.99
2018	186, 266.58	1.17	55, 775.69	0.56	113, 648.88	1.56	299, 915.46	1.06

Table 6: Input ('raw') male survey biomass data, in t.

	immature		legal		mature		total	
year	value	cv	value	cv	value	cv	value	cv
1975	8,340.95	0.52	27,016.47	0.50	38,053.59	0.50	46,394.54	0.47
1976	4,128.67	0.94	12,648.94	0.47	14,058.93	0.45	18,187.61	0.45
1977	3,713.34	0.44	40,365.94	0.78	42,618.32	0.77	46,331.66	0.73
1978	2,765.31	0.51	13,516.82	0.64	17,369.71	0.56	20,135.02	0.51
1979	61.27	0.79	9,039.95	0.31	10,959.38	0.32	11,020.66	0.31
1980	2,083.76	0.49	20,678.62	0.45	23,552.92	0.43	25,636.68	0.42
1981	1,704.25	0.30	10,553.54	0.17	11,628.25	0.17	13,332.49	0.18
1982	1,151.96	0.23	6,893.43	0.19	7,388.96	0.19	8,540.92	0.17
1983	962.34	0.36	4,474.40	0.17	5,408.73	0.18	6,371.08	0.19
1984	129.72	0.36	1,824.02	0.25	2,215.66	0.23	2,345.38	0.22
1985	39.02	0.73	755.50	0.28	1,054.79	0.27	1,093.81	0.26
1986	3.73	1.00	1,473.32	0.31	1,504.69	0.30	1,508.43	0.30
1987	191.45	0.78	2,781.34	0.41	2,923.38	0.41	3,114.84	0.40
1988	170.05	0.71	842.43	0.53	842.43	0.53	1,012.48	0.46
1989	1,274.88	0.62	827.50	0.64	827.50	0.64	2,102.37	0.55
1990	2,004.14	0.66	1,514.33	0.52	3,077.51	0.60	5,081.65	0.61
1991	1,377.43	0.39	3,325.77	0.45	4,689.67	0.39	6,067.10	0.37
1992	1,800.51	0.51	3,034.80	0.45	4,391.01	0.42	6,191.52	0.43
1993	1,088.50	0.54	3,202.55	0.30	4,555.60	0.31	5,644.10	0.30
1994	618.98	0.39	2,805.73	0.35	3,410.36	0.34	4,029.34	0.34
1995	967.73	0.86	6,786.93	0.62	8,360.23	0.60	9,327.96	0.63
1996	744.89	0.61	3,873.06	0.27	4,640.62	0.27	5,385.51	0.28
1997	381.39	0.55	2,765.39	0.27	3,232.58	0.28	3,613.97	0.29
1998	692.25	0.41	2,509.92	0.25	2,797.93	0.25	3,490.19	0.25
1999	160.65	0.40	1,426.16	0.35	1,729.24	0.34	1,889.89	0.33
2000	113.32	0.68	1,745.75	0.31	2,091.34	0.30	2,204.66	0.30
2001	87.07	0.76	1,460.92	0.76	1,598.74	0.73	1,685.81	0.73
2002	0.00	0.00	647.07	0.52	679.80	0.51	679.80	0.51
2003	19.06	0.98	671.20	0.41	702.01	0.40	721.07	0.39
2004	36.01	0.65	48.43	1.00	106.88	0.58	142.89	0.46
2005	325.78	0.94	344.06	0.71	344.06	0.71	669.84	0.59
2006	86.89	0.58	139.22	0.70	165.89	0.60	252.77	0.46
2007	196.77	0.74	205.56	0.73	306.46	0.80	503.23	0.66
2008	211.71	0.95	45.98	1.00	45.98	1.00	257.69	0.80
2009	254.30	0.68	186.51	0.60	497.11	0.71	751.41	0.70
2010	91.64	0.85	190.05	0.48	302.93	0.46	394.57	0.52
2011	0.00	0.00	398.98	0.89	461.36	0.84	461.36	0.84
2012	164.71	1.00	458.98	0.64	643.94	0.74	808.65	0.79
2013	14.53	1.00	189.92	0.75	250.14	0.80	264.66	0.75
2014	83.15	0.62	233.39	0.70	233.39	0.70	316.54	0.57
2015	81.69	0.75	428.26	0.46	621.71	0.39	703.40	0.39
2016	70.34	0.49	67.74	1.00	128.55	0.61	198.89	0.52
2017	45.20	0.77	222.52	0.57	252.78	0.51	297.98	0.47
2018	95.57	0.54	153.55	0.57	153.55	0.57	249.12	0.52

Table 7: Input ('raw') female survey abundance data (numbers of crab).

	immature		mature		total	
year	value	cv	value	cv	value	cv
1975	0.00	0.00	13, 147, 586.68	0.61	13, 147, 586.68	0.61
1976	7, 369, 388.06	0.97	769, 149.65	0.51	8, 138, 537.71	0.91
1977	851, 600.68	0.82	13, 880, 050.65	0.86	14, 731, 651.34	0.86
1978	60, 923.05	1.00	5, 926, 514.32	0.66	5, 987, 437.37	0.66
1979	142, 416.25	0.72	1, 168, 934.53	0.81	1, 311, 350.78	0.77
1980	781, 223.69	0.77	182, 902, 918.90	0.98	183, 684, 142.60	0.98
1981	826, 523.82	0.41	5, 433, 490.77	0.44	6, 260, 014.59	0.42
1982	876, 255.79	0.51	7, 837, 003.99	0.65	8, 713, 259.78	0.63
1983	463, 726.39	0.54	9, 307, 968.75	0.78	9, 771, 695.14	0.76
1984	465, 472.58	0.52	2, 769, 190.35	0.38	3, 234, 662.94	0.37
1985	260, 081.29	0.54	486, 184.43	0.44	746, 265.72	0.36
1986	36, 684.23	0.70	2, 101, 931.80	0.90	2, 138, 616.03	0.88
1987	401, 529.77	0.74	670, 478.72	0.58	1, 072, 008.49	0.48
1988	897, 629.21	0.87	465, 463.37	0.48	1, 363, 092.58	0.64
1989	2, 636, 098.81	0.74	1, 141, 755.85	0.66	3, 777, 854.65	0.58
1990	2, 177, 329.21	0.91	2, 045, 839.41	0.55	4, 223, 168.62	0.56
1991	805, 450.59	0.46	2, 767, 448.02	0.42	3, 572, 898.61	0.35
1992	1, 797, 343.33	0.93	2, 149, 519.20	0.49	3, 946, 862.54	0.52
1993	880, 672.33	0.61	1, 782, 656.74	0.45	2, 663, 329.07	0.38
1994	144, 763.08	0.57	5, 047, 215.18	0.44	5, 191, 978.25	0.44
1995	658, 479.28	0.92	4, 038, 555.59	0.52	4, 697, 034.87	0.49
1996	275, 735.14	0.42	5, 045, 822.06	0.48	5, 321, 557.20	0.46
1997	320, 343.56	0.67	2, 614, 373.74	0.42	2, 934, 717.30	0.39
1998	500, 241.34	0.43	1, 829, 509.02	0.44	2, 329, 750.36	0.37
1999	0.00	0.00	2, 755, 975.76	0.49	2, 755, 975.76	0.49
2000	0.00	0.00	1, 363, 069.69	0.46	1, 363, 069.69	0.46
2001	18, 516.37	1.00	1, 697, 465.09	0.75	1, 715, 981.46	0.74
2002	18, 729.46	1.00	1, 221, 852.43	0.79	1, 240, 581.89	0.78
2003	67, 328.63	0.48	1, 120, 254.01	0.76	1, 187, 582.64	0.72
2004	98, 059.03	0.63	70, 034.56	0.60	168, 093.59	0.51
2005	2, 268, 112.83	1.00	289, 197.28	0.56	2, 557, 310.11	0.89
2006	113, 047.12	0.55	429, 540.72	0.77	542, 587.84	0.62
2007	122, 482.70	0.73	165, 762.60	0.90	288, 245.30	0.59
2008	342, 119.25	0.90	437, 368.86	0.66	779, 488.11	0.75
2009	152, 290.08	0.61	477, 095.11	0.82	629, 385.19	0.76
2010	165, 632.29	0.56	249, 027.32	0.69	414, 659.61	0.62
2011	18, 089.34	1.00	36, 511.72	0.70	54, 601.06	0.56
2012	34, 682.61	1.00	312, 094.57	0.76	346, 777.18	0.70
2013	45, 343.64	0.70	150, 299.88	0.63	195, 643.52	0.53
2014	27, 720.50	1.00	74, 367.54	0.60	102, 088.04	0.51
2015	0.00	0.00	202, 464.39	0.65	202, 464.39	0.65
2016	131, 689.04	0.50	322, 760.45	0.52	454, 449.50	0.50
2017	187, 859.97	0.75	161, 799.38	0.53	349, 659.35	0.54
2018	75, 905.77	0.59	57, 873.19	1.00	133, 778.96	0.54

Table 8: Input ('raw') female survey biomass data, in t.

	immature		mature		total	
year	value	cv	value	cv	value	cv
1975	0.00	0.00	12,442.27	0.64	12,442.27	0.64
1976	4,967.70	0.97	823.80	0.53	5,791.50	0.89
1977	418.58	0.83	13,153.87	0.88	13,572.45	0.87
1978	76.40	1.00	6,415.74	0.72	6,492.14	0.72
1979	91.67	0.73	1,097.29	0.79	1,188.96	0.76
1980	699.46	0.86	211,603.71	0.98	212,303.16	0.98
1981	497.16	0.41	5,986.82	0.47	6,483.97	0.46
1982	553.17	0.57	8,823.72	0.68	9,376.89	0.67
1983	258.05	0.61	9,989.87	0.79	10,247.93	0.78
1984	15.35	0.69	3,069.56	0.38	3,084.90	0.38
1985	4.87	0.46	519.81	0.45	524.67	0.44
1986	11.02	0.73	2,419.78	0.90	2,430.80	0.90
1987	118.72	0.86	794.61	0.58	913.33	0.53
1988	190.14	0.79	527.64	0.49	717.78	0.47
1989	800.78	0.67	944.75	0.58	1,745.53	0.50
1990	1,118.45	0.93	1,810.45	0.51	2,928.89	0.49
1991	342.70	0.48	2,433.24	0.41	2,775.93	0.38
1992	801.57	0.96	1,847.65	0.48	2,649.23	0.46
1993	444.39	0.62	1,647.13	0.46	2,091.51	0.40
1994	87.01	0.57	4,805.95	0.45	4,892.96	0.44
1995	331.03	0.90	3,947.94	0.52	4,278.97	0.50
1996	176.52	0.42	5,408.25	0.50	5,584.77	0.49
1997	193.64	0.66	2,834.78	0.43	3,028.42	0.41
1998	267.35	0.42	1,914.46	0.44	2,181.81	0.39
1999	0.00	0.00	2,868.27	0.47	2,868.27	0.47
2000	0.00	0.00	1,461.82	0.46	1,461.82	0.46
2001	0.34	1.00	1,816.35	0.72	1,816.69	0.72
2002	0.24	1.00	1,400.74	0.78	1,400.98	0.78
2003	20.94	0.67	1,286.42	0.75	1,307.36	0.73
2004	25.20	0.82	97.71	0.60	122.91	0.50
2005	477.27	1.00	369.83	0.57	847.10	0.61
2006	38.16	0.60	537.85	0.76	576.01	0.71
2007	58.77	0.79	223.43	0.88	282.19	0.71
2008	222.03	0.90	449.54	0.64	671.57	0.70
2009	80.22	0.66	544.69	0.85	624.91	0.82
2010	84.08	0.58	310.16	0.66	394.24	0.63
2011	2.69	1.00	34.14	0.73	36.83	0.67
2012	8.70	1.00	228.76	0.66	237.46	0.64
2013	12.06	0.72	153.85	0.70	165.91	0.65
2014	16.43	1.00	91.11	0.60	107.54	0.53
2015	0.00	0.00	159.65	0.66	159.65	0.66
2016	72.47	0.47	328.67	0.50	401.14	0.48
2017	106.89	0.81	152.11	0.56	259.01	0.53
2018	45.28	0.58	76.01	1.00	121.29	0.65

Table 9: A comparison of estimates for MMB (in t) at the time of the survey. Note that, for the assessment year, the survey has not yet been conducted so the 'raw' value is unavailable and the smoothed value is a 1-step ahead prediction.

		raw			RE	
year	value	lci	uci	value	lci	uci
1975	38,053.59	20,759.61	69,754.48	26,881.80	16,821.13	42,959.73
1976	14,058.93	8,103.53	24,391.05	19,930.10	13,395.23	29,653.00
1977	42,618.32	17,814.39	101,958.08	21,252.30	13,592.39	33,228.91
1978	17,369.71	8,912.49	33,852.16	16,972.20	11,337.17	25,408.07
1979	10,959.38	7,385.67	16,262.32	13,333.10	9,748.29	18,236.18
1980	23,552.92	13,894.39	39,925.46	15,594.10	11,030.66	22,045.46
1981	11,628.25	9,320.75	14,507.00	11,421.30	9,354.86	13,944.20
1982	7,388.96	5,824.58	9,373.50	7,448.42	6,052.31	9,166.58
1983	5,408.73	4,315.80	6,778.45	5,079.98	4,154.76	6,211.24
1984	2,215.66	1,659.01	2,959.08	2,347.94	1,841.79	2,993.18
1985	1,054.79	753.94	1,475.68	1,350.90	1,021.27	1,786.92
1986	1,504.69	1,029.62	2,198.96	1,555.54	1,157.15	2,091.09
1987	2,923.38	1,761.10	4,852.75	1,926.81	1,351.61	2,746.79
1988	842.43	445.93	1,591.49	1,428.72	947.70	2,153.88
1989	827.50	391.56	1,748.76	1,600.62	1,029.53	2,488.50
1990	3,077.51	1,512.59	6,261.49	2,602.68	1,718.45	3,941.88
1991	4,689.67	2,910.49	7,556.46	3,810.19	2,677.11	5,422.85
1992	4,391.01	2,612.05	7,381.55	4,179.89	2,939.92	5,942.85
1993	4,555.60	3,100.43	6,693.73	4,328.19	3,200.38	5,853.45
1994	3,410.36	2,219.61	5,239.91	4,017.60	2,908.18	5,550.24
1995	8,360.23	4,090.73	17,085.84	4,938.60	3,335.75	7,311.64
1996	4,640.62	3,308.54	6,509.03	4,382.94	3,315.98	5,793.22
1997	3,232.58	2,284.30	4,574.53	3,322.04	2,523.97	4,372.45
1998	2,797.93	2,042.57	3,832.65	2,704.77	2,085.68	3,507.62
1999	1,729.24	1,136.48	2,631.17	1,976.51	1,451.63	2,691.17
2000	2,091.34	1,442.89	3,031.19	1,835.78	1,358.03	2,481.61
2001	1,598.74	688.93	3,710.05	1,264.25	830.09	1,925.49
2002	679.80	368.60	1,253.75	784.09	528.68	1,162.87
2003	702.01	428.47	1,150.19	548.53	381.99	787.67
2004	106.88	53.46	213.67	278.66	179.67	432.19
2005	344.06	151.76	780.00	266.14	168.86	419.48
2006	165.89	81.25	338.67	225.18	143.05	354.47
2007	306.46	124.64	753.49	230.31	141.81	374.03
2008	45.98	15.82	133.66	210.68	126.46	350.98
2009	497.11	218.63	1,130.34	294.11	185.61	466.03
2010	302.93	172.57	531.78	321.07	214.15	481.35
2011	461.36	180.34	1,180.27	371.44	231.84	595.10
2012	643.94	277.26	1,495.58	397.61	246.94	640.21
2013	250.14	101.79	614.66	343.39	213.72	551.75
2014	233.39	103.97	523.89	335.70	215.28	523.48
2015	621.71	382.23	1,011.25	391.25	269.61	567.77
2016	128.55	62.34	265.09	245.61	160.99	374.71

2017	252.78	135.99	469.85	227.90	149.47	347.47
2018	153.55	77.73	303.35	194.18	117.29	321.48
2019	0.00	0.00	0.00	194.18	67.56	558.12

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Update to the 2019 SAFE Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

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Summary

The Pribilof Islands blue king crab (PIBKC) assessment is on a biennial cycle. 2020 is the “off “year in the cycle, so only an update to determine whether or not overfishing occurred in 2019/20 is presented here. The next full assessment will occur in 2021.

The most recent full assessment was conducted in May 2019 (Stockhausen, 2019). This report updates that assessment with final retained catch and bycatch mortality estimates in the directed fishery, other crab fisheries, and the groundfish fisheries to determine the final status of whether or not overfishing occurred during the 2019/20 crab fishery year (July 1, 2019-June 30, 2020). The 2019 SAFE Report determined the overfishing limit (OFL) for PIBKC to be 1.16 t, with an acceptable biological catch (ABC) of 0.87.

Following completion of the 2019/20 crab fishery year, data on retained catch and bycatch was obtained from the Alaska Department of Fish and Game (ADFG) and the NMFS Alaska Regional Office (via the Alaska Fisheries Information Network [AKFIN]) for crab fisheries and groundfish fisheries, respectively. No retained catch or bycatch was taken by the directed fishery in 2019/20 because it was closed due to its overfished status (Table 3). Also, no bycatch of PIKBC was observed in other crab fisheries (i.e., snow crab; Table 4). Bycatch in the groundfish fisheries totaled 0.527 t across all gear types in 2019/20 (Table 5). After applying gear-specific discard mortality rates, this amounted to 0.416 t total catch mortality (Table 5). Because this was less than the OFL for 2019/20 (1.16 t), **overfishing did not occur on this stock in 2019/20**.

The following two tables update the management performance tables presented in the 2019 SAFE Report with the final fishing mortality estimates for 2019/20:

Table 1. Management performance; all units in metric tons.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2016/17	2,053	232	closed	0	0.38	1.16	0.87
2017/18	2,053	230	closed	0	0.33	1.16	0.87
2018/19	2,053	230	closed	0	0.41	1.16	0.87
2019/20	--	175	closed	0	0.42	1.16	0.87
2020/21	--	175	--	--	--	1.16	0.87

Table 2. Management performance; all units in millions of pounds.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2016/17	4.526	0.511	closed	0	0.0008	0.0026	0.002
2017/18	4.526	0.507	closed	0	0.0007	0.0026	0.002
2018/19	4.526	0.507	closed	0	0.0009	0.0026	0.002
2019/20	--	0.386	closed	0	0.0009	0.0026	0.002
2020/21	--	0.386	--	--	--	0.0026	0.002

Shaded values – Based on data available to the Crab Plan Team at the time of the assessment

References

Stockhausen, W.T. 2019. 2019 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite 306, Anchorage, AK 99501-2252.

Tables

Table 3. Retained catch in the directed PIBKC fishery.

Year	Retained Catch	
	Abundance	Biomass (t)
1973/1974	174,420	579
1974/1975	908,072	3,224
1975/1976	314,931	1,104
1976/1977	855,505	2,999
1977/1978	807,092	2,929
1978/1979	797,364	2,901
1979/1980	815,557	2,719
1980/1981	1,497,101	4,976
1981/1982	1,202,499	4,119
1982/1983	587,908	1,998
1983/1984	276,364	995
1984/1985	40,427	139
1985/1986	76,945	240
1986/1987	36,988	117
1987/1988	95,130	318
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
1996/1997	127,712	425
1997/1998	68,603	232
1998/1999	68,419	234
1999/2000 - 2019/2020	0	0

Table 4. Estimated bycatch of PIBKC in the crab and groundfish fisheries. These values do not include discard mortality rates.

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	0.044	0.056
2011/12	0.000	0.000	0.000	0.112	0.007
2012/13	0.000	0.000	0.000	0.170	0.669
2013/14	0.000	0.000	0.000	0.065	0.000
2014/15	0.000	0.000	0.000	0.144	0.000
2015/16	0.103	0.000	0.230	0.744	0.808
2016/17	0.000	0.000	0.000	0.077	0.455
2017/18	0.064	0.000	0.000	0.000	0.378
2018/19	0.000	0.000	0.101	0.020	0.466
2019/20	0.000	0.000	0.000	0.009	0.518

Table 5. Estimated bycatch mortality of PIBKC in the crab and groundfish fisheries. A discard mortality rate of 0.2 has been applied to PIBKC taken with crab pots or groundfish fixed gear; a rate of 0.8 has been applied to PIBKC taken with groundfish trawl gear.

fishery year	crab (pot) fisheries (t)			groundfish fisheries (t)		total bycatch mortality (t)
	females	legal males	sublegal males	fixed gear	trawl gear	
1991/92	--	--	--	0.013	4.959	4.973
1992/93	--	--	--	0.176	48.633	48.809
1993/94	--	--	--	0.000	27.386	27.386
1994/95	--	--	--	0.007	5.485	5.492
1995/96	--	--	--	0.022	1.027	1.049
1996/97	0.000	0.000	0.161	0.006	0.054	0.221
1997/98	0.000	0.000	0.000	0.292	0.104	0.396
1998/99	0.743	0.459	0.093	3.960	0.063	5.319
1999/00	0.394	0.699	0.858	0.159	0.016	2.125
2000/01	0.000	0.000	0.000	0.023	0.018	0.042
2001/02	0.000	0.000	0.000	0.167	0.023	0.190
2002/03	0.000	0.000	0.000	0.014	0.238	0.252
2003/04	0.000	0.000	0.000	0.069	0.182	0.251
2004/05	0.000	0.000	0.000	0.163	0.002	0.165
2005/06	0.010	0.000	0.000	0.071	1.071	1.152
2006/07	0.021	0.000	0.000	0.028	0.059	0.108
2007/08	0.027	0.000	0.000	0.799	0.106	0.931
2008/09	0.000	0.000	0.000	0.028	0.378	0.407
2009/10	0.000	0.000	0.000	0.043	0.165	0.209
2010/11	0.000	0.000	0.037	0.009	0.045	0.091
2011/12	0.000	0.000	0.000	0.022	0.006	0.028
2012/13	0.000	0.000	0.000	0.034	0.535	0.569
2013/14	0.000	0.000	0.000	0.013	0.000	0.013
2014/15	0.000	0.000	0.000	0.029	0.000	0.029
2015/16	0.021	0.000	0.046	0.149	0.646	0.862
2016/17	0.000	0.000	0.000	0.015	0.364	0.379
2017/18	0.013	0.000	0.000	0.000	0.303	0.315
2018/19	0.000	0.000	0.020	0.004	0.373	0.397
2019/20	0.000	0.000	0.000	0.002	0.415	0.416

Saint Matthew Island Blue King Crab Stock Assesssment 2020

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Executive Summary

1. **Stock**: Blue king crab, *Paralithodes platypus*, Saint Matthew Island (SMBKC), Alaska.
2. **Catches**: Peak historical harvest was 4,288 t (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 t (0.461 million pounds), less than half the 529.3 t (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 t (0.655 million pounds), but the fishery performance was relatively poor with a retained catch of 140 t (0.309 million pounds). The retained catch in 2015/16 was even lower at 48 t (0.105 million pounds) and the fishery has remained closed since 2016/17.
3. **Stock biomass**: The 1978-2019 NMFS trawl survey mean biomass is 5,605 t with the 2019 value being the 15th lowest (3,170 t; the tenth lowest since 2000). This 2019 biomass of $\geq$ 90 mm carapace length (CL) male crab is 57% of the long term mean at 6.99 million pounds (with a CV of 34%), and an 83% increase from the 2018 biomass. The most recent 3-year average of the NMFS survey is 40% of the mean value, indicating a decline in biomass compared to historical survey estimates, notably in 2010 and 2011 that were over four times the current average. However, the 2019 value is substantially larger than the two previous years (3,170 t compared to 1,731 t in 2018 and 1,794 t in 2017). Due to cancellation of the 2020 bottom trawl surveys there is no additional abundance data in the model for 2020. The ADFG pot survey last occured in 2018, when the relative biomass index was the lowest in the time series (12% of the mean from the 11 surveys conducted since 1995). The assessment model estimates temper this increase and suggest that the stock (in survey biomass units) is presently at about 26% of the long term model-predicted survey biomass average, similar to the last three years. The trend from these values suggests a steady state in the last few years, which does not fit the 2019 observed survey data point well.
4. **Recruitment**: Recruitment is based on estimated number of male crab within the 90-104 mm CL size class in each year. The 2019 trawl-survey area-swept estimate of 0.403 million male SMBKC in this size class is the twelfth lowest in the 42 years since 1978 and follows two of the lowest previously observed values in 2017 and 2018. The recent six-year (2014 - 2019) average recruitment is only 47% of the long-term mean. In the pot-survey, the abundance of this size group in 2017 was also the second-lowest in the time series (22% of the mean for the available pot-survey data) whereas in 2018 the value was the lowest observed at only 10% of the mean value.
5. **Management performance**: In this assessment, estimated total male catch is the sum of fishery-reported retained catch, estimated male discard mortality in the directed fishery, and estimated male

[1]1983/84 refers to a fishing year that extends from 1 July 1983 to 30 June 1984.

bycatch mortality in the groundfish fisheries. Based on the reference model for SMBKC, the estimate for mature male biomass was below the minimum stock-size threshold (MSST) in 2018/19 and is in an "overfished" condition, despite a directed fishery closure since the 2016/17 season (and hence overfishing has not occurred) (Tables 1, 3, and 4). Computations which indicate the relative impact of fishing (i.e., the "dynamic B_0") suggests, that the current spawning stock biomass has been reduced to 55% of what it would have been in the absence of fishing, assuming the same level of recruitment as estimated.

Table 1: Status and catch specifications (1000 t) for the reference model.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained catch	Total male catch	OFL	ABC
2016/17	1.97	2.23	0.00	0.00	0.001	0.14	0.11
2017/18	1.85	2.05	0.00	0.00	0.003	0.12	0.10
2018/19	1.74	1.15	0.00	0.00	0.001	0.04	0.03
2019/20	1.67	1.06	0.00	0.00	0.001	0.04	0.03
2020/21		1.12				0.05	0.04

Table 2: Status and catch specifications (million pounds) for the reference model.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained catch	Total male catch	OFL	ABC
2016/17	4.3	4.91	0.000	0.000	0.002	0.31	0.25
2017/18	4.1	2.85	0.000	0.000	0.007	0.27	0.22
2018/19	3.84	2.54	0.000	0.000	0.002	0.08	0.07
2019/20	3.68	2.34	0.000	0.000	0.002	0.096	0.08
2020/21		2.48				0.112	0.08

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 $\geq$ 105 mm CL considered mature. The B_{MSY} proxy is obtained by averaging estimated MMB over a specific reference period, and current CPT/SSC guidance recommends using the full assessment time frame (1978 - 2019) as the default reference period.

Table 3: Basis for the OFL (1000 t) from the reference model.

Year	Tier	B_{MSY}	Biomass (MMB_{mating})	B/B_{MSY}	F_{OFL}		Basis for B_{MSY}	Natural mortality
2016/17	4b	3.67	2.23	0.61	0.09	1	1978-2016	0.18
2017/18	4b	3.86	2.05	0.53	0.08	1	1978-2017	0.18
2018/19	4b	3.7	1.15	0.35	0.043	1	1978-2017	0.18
2019/20	4b	3.48	1.06	0.31	0.042	1	1978-2018	0.18
2020/21	4b	3.34	1.12	0.34	0.047	1	1978-2019	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 data. This assessment includes no new survey data points due to the cancellation of the 2020 NMFS trawl-survey.
The triennial ADF&G pot surveys were last conducted in 2018, and are back on a triennial cycle, with the next survey planned for 2021. Due to the lack of bycatch in other crab fisheries and new survey data there is no new size compositon data. The assessment was updated with 2010-2019 groundfish trawl and fixed gear bycatch estimates based on NMFS Alaska Regional Office (AKRO) data. The directed fishery has been closed since 2016/17, so no recent fishery data are available.

Changes in Assessment Methodology

This assessment uses the General Model for Alaska Crab Stocks (GMACS) framework. The model is configured to track three stages of length categories and was first presented in May 2011 by W.Gaeuman, ADF&G, and accepted by the CPT in May 2012. A difference from the original approach and that used here is that natural and fishing mortalities are continuous within 5 discrete time blocks within a year (using the appropriate catch equation rather than assuming an applied pulse removal). The time blocks within a year in GMACS are controlled by changing the proportion of natural mortality that is applied each block. Diagnostic output includes estimates of the "dynamic B_0" which simply computes the ratio of the estimated spawning biomass relative to the spawning biomass that would have occurred had there been no historical fishing mortality. Details of this implementation and other model details are provided in Appendix A.

Changes in Assessment Results

Both surveys indicate a decline over the past few years. The "reference" model is that which was selected for use in 2019. The base model presented here is the reference model with updated groundfish bycatch data for the 2019/20 crab season (model 16.0 base). One additional model is presented for consideration, which is a small variant of the base model, model 16.0a (**fixR**), which fixes recruitment in the most recent year to the average of the last seven years to avoid unrealistically high recruitment estimates. Additionally, retrospective analyses without the terminal year of survey data and runs with "fake" survey data were performed to assess the uncertainty in the 2020 biomass estimates and reference point calculations due to the lack of a 2020 survey; the methods and results are detailed in Appendix C.

In addition to the two models for considerations, one additional model is presented here to assess sensitivity of data inputs to the model, attempting to deal with the disparity between the two survey time series (**no pot**). The **no pot** configuration runs the base model 16.0 without the ADF&G pot survey data, therefore only having the NMFS trawl survey as the abundance index.

B. Responses to SSC and CPT

CPT and SSC Comments on Assessments in General

Comment: *Regarding general code development, the SSC and CPT outstanding requests continue to be as follows:*

1. *add the ability to conduct retrospective analyses*

   Retrospective runs/simulations are presented here in Appendix C as part of the analyses done to assess uncertainty in the model output (Figure 28). The ability to automate these in GMACS is still under developement but the author was able to do them by manually editing the data files.

2. *Continued exploration of data weighting (Francis and other approaches) and evaluation of models with and without the 1998 natural mortality spike. The authors are encouraged to bring other models forward for CPT and SSC consideration*

   We continued with the iterative re-weighting for composition data (Table 16). We did not address models without the natural mortality spike. These have been considered previously.

Comment: *Regarding potential model scenarios for Sept. 2020, the SSC and CPT requests are:*

1. *Explore model without ADf&G pot survey data*

   Model 20.1 explores this sensitivity to the data inputs and is shown here in the model scenarios.

2. *Random walk or exploration of catchability*

   The intial model of time blocks for Q did not show much potential for this in May 2020, therefore it was not a focus for the Sept. 2020 runs. More coding work is needed to make a true random walk for catchability GMACS and this will be added to GMACS model development, hopefully during the Jan 2021 modeling workshop.

Comment: *Explore potential explanations for the discrepancy in the time trends of the two types of survey data, including movement hypotheses using spatial models (not necessarily VAST)*

Limited progress due to time availability and current world events. This will be a large focus on upcoming work on this model as the scenario without the ADF&G pot survey data (20.1) shows the differences in the current status of the stock between the two abundance surveys (Figure 13).

Comment: *Explore May 2020 model with VAST estimates*

Progress is underway to refine the SMBKC VAST estimates using preliminary code that incorporates the island effect. Jon Richar (NMFS) is working on these estimates. At the time of this final SAFE there are no additional improvements to this data set and therefore the VAST model is not presented as a model option. Future work on VAST models for this stock includes VAST data output for the NMFS trawl survey incorporating the island effect and VAST output using both survey data sets together.

Comment: *Please use the correct model number (e.g., if 19.0 is the same model as was first adopted in 16.0 then it is still 16.0.)*

Completed. Base model is 16.0.

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, has detected regional population differences between blue king crab collected from St. Matthew Island and the Pribilof Islands[2]. The 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 (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. It was 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 t (1.202 million pounds) in 1977, and harvests peaked in 1983 when 164 vessels landed 4,288 t (9.454 million pounds) (Fitch et al. 2012; Table 7).

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 4,990 t (11.0 million pounds) as defined by the Fishery Management Plan (FMP) 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 (see survey data in next section). 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 State of Alaska 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.

[2]NOAA grant Bering Sea Crab Research II, NA16FN2621, 1997.

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 t (1.167 million pounds), closing again by regulation on 1 February 2010. Seven participating vessels landed a catch of 209 t (0.461 million 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. This prompted ADF&G to close the fishery again for the 2013/14 season. The fishery was reopened for the 2014/15 season with a low TAC of 297 t (0.655 million pounds) and in 2015/16 the TAC was further reduced to 186 t (0.411 million pounds) then completely closed the 2016/17 season.

Although historical observer data are limited due to low sampling effort, 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 t or 0.193 million pounds) of the reported retained catch weight, assuming 20% handling mortality.

These data suggest a 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. The St. Matthew Island golden king crab fishery, the third commercial crab fishery to have taken place in the area, typically occurred in areas with depths exceeding blue king crab distribution. The 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 were updated to include the most recently available fishery and survey estimates. The only new data in the 2020 assessment model is updated bycatch estimates, no new survey or size composition data were added. The assessment uses updated 1993-2019 groundfish and fixed gear bycatch estimates based on NMFS AKRO data. The directed fishery has been closed since the 2016/17 season, and therefore no directed fishery catch data are available. 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 7); results from the annual NMFS eastern Bering Sea trawl survey (1978-2019; Table 8); results from the ADF&G SMBKC pot survey (every third year during 1995-2013, then 2015-2018; Table 9); mean somatic mass given length category by year (Table 10); size-frequency information from ADF&G crab-observer pot-lift sampling (1990/91-1998/99, 2009/10-2012/13, and 2014/15-2016/17; Table 5); and the NMFS groundfish-observer bycatch biomass estimates (1992/93-2019/20; 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

[3]D. Pengilly, ADF&G, pers. comm.

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 not covered by the other survey (Figure 5). Crab-observer sampling protocols are detailed in the crab-observer training manual (ADF&G 2013). Groundfish SMBKC bycatch data come from the NMFS Regional office and have been compiled to coincide with the SMBKC management area.

Other Data Sources

The growth transition matrix used is based on Otto and Cummiskey (1990), as in the past. 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.

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. 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 $\geq$ 90 mm 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 $\geq$ 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 a survey-based approach was requested for the Fall 2011 assessment. In May 2012 the CPT approved a slightly revised and better documented version of the alternative model for assessment. Subsequently, the model developed and used since 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 $\geq$ 90 mm in CL, but combined stages 3 and 4 of the earlier model, resulting in three stages (male size classes) defined 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.

In 2016 the accepted SMBKC assessment model made use of the modeling framework GMACS encompassing a three-stage model structure (Webber et al. 2016). In that assessment, an effort was made to match the 2015 SMBKC stock assessment model to bridge a framework which provided greater flexibility and opportunity to evaluate model assumptions more fully.

Assessment Methodology

This assessment model again uses the modeling framework GMACS and is detailed in Appendix A.

Model Selection and Evaluation

Two models are presented with the reference model being the same configuration as approved last year (Palof et al. 2019), one sensitivity is considered which excludes the ADF&G pot survey data. In addition to this sensitivty, we evaluated the impacts of adding new data (here just groundfish bycatch) to the reference model. In summary, the following lists the models presented and the naming convention used:

1. **16.0 - 2019 Model**: 2019 accepted model
2. **16.0 - 2020 Reference Model**: updated with 2019/20 groudfish bycatch
3. **16.0a - 2020 Reference Model with fixed terminal year recruitment**: terminal year recruitment fixed as the average of the last seven years
4. **20.1 - no ADF&G pot survey data**: model 16.0 - excludes ADF&G pot survey data - abundace and length comps

Note the change in naming convention (per SSC comments). The base model is model 16.0 since that was the year of model development and acceptance.

Results

a. Sensitivity to new data

There is no new survey data for the September 2020 model runs, the only additional data is groundfish bycatch data for the 2019/20 crab season. Additionally, the groundfish bycatch data was updated for past years due to some changes in the weights used to estimate crab bycatch in the groundfish fisheries (per. comm. NMFS AKRO). The 2020 reference model is compared here to the 2019 accepted model, which is shown in Figures 6 and 7 with recruitment and spawning biomass shown in Figures 8 and 9, respectively. The 2019 accepted model and the 2020 base model have identical fits to the survey data, as well as identical estimates of SSB and recruitment. This is expected since there are no new influential data in the 2020 model. As has been noted in the past, the reference model still does not capture the recent survey declines in the ADF&G pot survey, or fit post 2005 trawl survey data points well.

b. Effective sample sizes and weighting factors

Observed and estimated effective sample sizes are compared in Table 11. Data weighting factors, standard deviation of normalized residuals (SDNRs), and median absolute residual (MAR) are presented in Table 16. Currently the SDNR and MAR are not outputting correctly for the survey data in GMACS. This is on the list to address at the Januaury 2021 modeling workshop. In Sept. 2019 the SDNR for the trawl survey was acceptable at 1.66 in the reference model. Francis (2011) weighting was applied in 2017 but given the relatively few size bins in this assessment, this application was suspended for this assessment.

In Sept. 2019 the SDNRs for the pot surveys showed a similar pattern in each of the scenarios, but are much higher suggesting an inconsistency between the pot survey data and the model structure and other data components. Rather than re-weighting, we chose to retain the values as specified, noting that down-weighting these data would effectively exclude the signal from this series. The MAR values for the trawl and pot surveys showed the same pattern among each of the scenarios as the SDNR. The MAR values for the trawl survey and pot survey size compositions were adequate, ranging from 0.60 to 0.68 for the reference case. The SDNRs for the directed pot fishery and other size compositions were similar to previous estimates.

c. Parameter estimates

Model parameter estimates for each of the GMACS scenarios are summarized in Tables 12, 13, and 14. These parameter estimates are compared in Table 15. Negative log-likelihood values and management measures for each of the model configurations are compared in Tables 4 and 17.

There are differences in parameter estimates among models as reflected in the log-likelihood components and the management quantities. The parameter estimates in the "no pot" scenario differ greatly from the reference model, as expected, due to the removal of recent ADF&G pot survey data points that pulled the MMB trend downward (Table 15). Also, the size composition residuals are smaller for the trawl survey in the **nopot** model, presumably because they are allowed to fit these size compositions better due to the removal of the size composition data from the ADF&G pot survey.

Selectivity estimates for the directed fishery show some variability between models (Figure 10). Estimated recruitment is similar in both models until the mid-2000s when the **no pot** model (20.1) has consistently higher recruitment, contributing to higher MMB for this model in recent years (Figure 11). Estimated mature male biomass on 15 February also is considerably higher in the **no pot** model (Figure 13). The **no pot** model has a better fit to recent years of the NMFS trawl survey data, fitting most of the post-2010 data ranges (fit line encompasses the error bars), compared to the reference model that only fits three of the last 10 years. The improved fit of the trawl survey corresponds to increased MMB estimates in the last 10 years. Not surprisingly this time frame also corresponds to sharp declines in the ADF&G pot survey abundance estimates that started in the post-2010 data.

Estimated natural mortality in each year (M_t) is presented in Figure 14, showing the mortality event in the late 90s. Estimates of fishing morality, from the reference model (16.0), are shown to assist with the rebuilding and reference point time frame discussions (Figure 26). Fishing mortality can not be ruled out as being an influential factor in the current stock status.

d. Evaluation of the fit to the data.

The reference model fit to total male ($\geq$ 90 mm CL) trawl survey biomass tends to miss the recent peak around 2010 and fits recent survey data points on the lower end of their error bars (Figures 15). These fits are most likely being pulled down by the recent decline in the ADF&G pot survey data points, since the **no pot** model captures more of the error bars for these data points when the NMFS trawl survey data is the only abundance index in the model. However, this model, similar to the additional CV models presenting in May 2020, tend to overfit the recent trawl survey data points (Figure 15).

The reference or base model fit to the pot survey CPUE is similar to past reference models, fitting the overall trends in the data but not capturing some of the high and low points (Figure 16).

For the trawl survey the standardized residuals are more balanced in model 20.1 (**no pot**), without the ADF&G pot survey data, especially in recent years. The reference model has a clear residual pattern in the last 15 years, continually under predicting the observed data points (Figure 17). The standardized residuals for the ADF&G pot survey have similar patterns to past reference model iterations (Figure 18).

Fits to the size compositions for trawl survey, pot survey, and commercial observer data are reasonable but miss the largest size category in some years (Figures 19, 20, and 21) for both scenarios. Representative residual plots of the composition data generally have a poor fit to the three composition data sources (Figures 22, 23 and 24). The model fits to different types of retained and discarded catch values performed as expected given the assumed levels of uncertainty on the input data (Figure 25).

e. Retrospective and historical analyses

This is the fourth year GMACS has been used for this stock. As such, retrospective patterns and historical analyses of GMACS assessments are limited. However, completion of a retrospective analysis, for the base model, was completed (Figure 28) and is presented in detail in Appendix C.

f. Uncertainty and sensitivity analyses.

Estimated standard deviations of parameters and selected management measures for the models are summarized for each individual model in Tables 12, 13, 14, and compiled in Table 15. Model estimates of mature male biomass and OFL in 2020 are presented in Section F.

Uncertainty surrounding the lack of a 2020 trawl survey data point was examined using two approaches and the results are contained in Appendix C. Overall, the authors did not find much additional uncertainty for the reference model due to the lack of a 2020 data point. The current trajectory of the stock (MMB and recruitment) suggests a low status (below B_{MSY}) that would not change even with the addition of hypothetical 2020 data point (Approach 3, Appendix C). Appendix C goes into more detail for these analyses and a more thourough discussion of the authors recommendations.

g. Comparison of alternative model scenarios.

The estimates of mature male biomass (Figure 13) for the **no pot** model differs from the reference model (16.0) due to the removal of the pot survey abundance and size composition data. This abundance time series contrasts with the NMFS trawl survey and when present tends to lower the scale of the population estimate. This difference is greatest in the last 10 years, recognizing the contrast between these abundance time series and the influence of the ADF&G pot survey on the current population status.

In summary, the **no pot** model scenario was provided to explore the sensitivity of this model. Currently, the reference model is still the most appropriate model for settting reference points and model specifications. Research on alternative model specifications that may address the disparities between the trawl and pot survey data are ongoing, as is proposed spatial analyses of these data sets. Additionally, the overfished status of this stock lends itself to maintaining the status quo base model until an appropriate resolution is found to deal with the trawl and pot survey data fit issues. The two reference models presented here, 16.0 and 16.0a, only differ in the estimation of 2019 recruitment. Model 16.0a fixes the 2019 recruitment to be the average of the last seven years of the model, effectively limiting the model's ability to estimate unreasonably high recruitment in the lack of a 2020 data point. However, fixing terminal year recruitment has a minimal effect on the status of the stock, projected MMB, or the resulting OFL for 2020 (Table 4). The recommended model for 2020 would be the reference model (16.0) to maintain consistency for this stock during the rebuilding time frame and with the lack of a 2020 data point for the trawl survey.

F. Calculation of the OFL and ABC

The overfishing level (OFL) is the total catch associated with the F_{OFL} fishing mortality. The SMBKC stock is currently managed as Tier 4, 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 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 - 2019, 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 2019 for all scenarios are summarized in Table 4. The currently recommended ABC is 75% of the OFL (ABC buffer = 25%).

Table 4: Comparisons of management measures for the model scenarios. Biomass and OFL are in tons.

Component	Ref	fixR	nopot
MMB_{2020}	1060.665	1065.996	3707.925
B_{MSY}	3335.710	3391.948	3548.160
MMB/B_{MSY}	0.337	0.334	1.171
F_{OFL}	0.047	0.047	0.180
OFL_{2020}	50.674	48.819	618.969
ABC_{2020}	38.005	36.614	464.226

G. Rebuilding Analysis

This stock was declared overfished in fall of 2018 and a rebuilding plan went before the Council for final review in June 2020. The most updated rebuilding plan can be found on the NPFMC website for the June 2020 meeting.

H. Data Gaps and Research Priorities

The following topics have been listed as areas where more research on SMBKC is needed:

1. Growth increments and molting probabilities as a function of size.
2. Trawl survey catchability and selectivities.
3. Pot survey catchability and selectivities.
4. Temporal changes in spatial distributions near the island.
5. Natural mortality.

I. Projections and outlook

The outlook for recruitment is pessimistic and the abundance relative to the proxy B_{MSY} is low. The NMFS survey results in 2019 noted ocean conditions warmer than normal with an absence of a "cold pool" in the region. This could have detrimental effects on the SMBKC stock and should be carefully monitored. Relative to the impact of historical fishing, we again conducted a "dynamic-B_0" analysis. This procedure simply projects the population based on estimated recruitment but removes the effect of fishing. For the reference case, this suggests that the impact of fishing has reduced the stock to about 55% of what it would have been in the absence of fishing (Figure 27, supporting the hypothesis that fishing pressure is not the sole contributer to the decline of this stock in recent years. The other non-fishing contributors to the observed depleted stock trend (ignoring stock-recruit relationship) may reflect variable survival rates due to environmental conditions and also range shifts.

J. Acknowledgements

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Tables

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
2016/17 - 2018/19			FISHERY CLOSED			

Table 6: Groundfish SMBKC male bycatch biomass (t) 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. Estimates used after 2008/09 are from NMFS Alaska Regional Office.

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	0.500
1994	0.318	0.091
1995	0.635	0.136
1996	0.500	0.045
1997	0.500	0.181
1998	0.500	0.907
1999	0.500	1.361
2000	0.500	0.500
2001	0.500	0.862
2002	0.726	0.408
2003	0.998	1.134
2004	0.091	0.635
2005	0.500	0.590
2006	2.812	1.451
2007	0.045	69.717
2008	0.272	6.622
2009	0.638	7.522
2010	0.360	9.564
2011	0.170	0.796
2012	0.011	0.739
2013	0.163	0.341
2014	0.010	0.490
2015	0.010	0.711
2016	0.229	1.630
2017	0.048	5.842
2018	0.001	1.140
2019	0.030	1.038

Table 7: Fishery characteristics and update. Columns include 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. Note that management (GHL) units are in pounds, for conserving space, conversion to tons is ommitted.

			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
2016/17				FISHERY CLOSED				
2017/18				FISHERY CLOSED				
2018/19				FISHERY CLOSED				
2019/20				FISHERY CLOSED				

Table 8: NMFS EBS trawl-survey area-swept estimates of male crab abundance (10^6 crab) and male ($\geq$ 90 mm CL) 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
2017	0.091	0.323	0.663	1.077	0.657	3.955	0.600	42
2018	0.154	0.232	0.660	1.047	0.298	3.816	0.281	62
2019	0.403	0.482	1.170	2.056	0.352	6.990	0.337	105

Table 9: 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 ADF&G SMBKC pot surveys. Source: 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	0.19	777
2017	0.177	0.429	1.083	1.689	0.25	643
2018	0.076	0.161	0.508	0.745	0.14	286

Table 10: 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
2017	0.7	1.2	1.9
2018	0.7	1.2	1.9
2019	0.7	1.2	1.9

Table 11: Observed and input sample sizes for observer data from the directed pot fishery, the NMFS trawl survey, and the ADF&G pot survey.

	Number measured			Input 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
2017		42	643		21	100
2018		62	286		31	100
2019		105			50	

Table 12: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the reference (16.0) model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.573	0.138
$\log(\bar{R})$	13.899	0.200
$\log(n^0_1)$	14.950	0.175
$\log(n^0_2)$	14.509	0.211
$\log(n^0_3)$	14.326	0.207
q_{pot}	3.838	0.253
$\log(\bar{F}^{\text{df}})$	-2.125	0.052
$\log(\bar{F}^{\text{tb}})$	-9.470	0.073
$\log(\bar{F}^{\text{fb}})$	-8.093	0.073
log Stage-1 directed pot selectivity 1978-2008	-0.819	0.179
log Stage-2 directed pot selectivity 1978-2008	-0.452	0.129
log Stage-1 directed pot selectivity 2009-2017	-0.483	0.162
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.320	0.066
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.725	0.126
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.040	0.007
OFL	50.674	17.412

Table 13: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the reference model with fixed terminal year recruitment 'fixR' (16.0a).

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.573	0.138
$\log(\bar{R})$	13.870	0.198
$\log(n^0_1)$	14.950	0.175
$\log(n^0_2)$	14.508	0.211
$\log(n^0_3)$	14.326	0.207
q_{pot}	3.833	0.253
$\log(\bar{F}^{\text{df}})$	-2.126	0.052
$\log(\bar{F}^{\text{tb}})$	-9.472	0.073
$\log(\bar{F}^{\text{fb}})$	-8.094	0.073
log Stage-1 directed pot selectivity 1978-2008	-0.820	0.179
log Stage-2 directed pot selectivity 1978-2008	-0.452	0.129
log Stage-1 directed pot selectivity 2009-2017	-0.484	0.162
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.320	0.066
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.727	0.125
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.047	0.007
OFL	48.819	9.115

Table 14: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the 'no pot' (20.1) model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.829	0.235
$\log(\bar{R})$	14.225	0.203
$\log(n^0_1)$	14.945	0.174
$\log(n^0_2)$	14.459	0.211
$\log(n^0_3)$	14.290	0.205
$\log(\bar{F}^{\text{df}})$	-2.319	0.056
$\log(\bar{F}^{\text{tb}})$	-9.716	0.079
$\log(\bar{F}^{\text{fb}})$	-8.341	0.079
log Stage-1 directed pot selectivity 1978-2008	-0.817	0.178
log Stage-2 directed pot selectivity 1978-2008	-0.482	0.133
log Stage-1 directed pot selectivity 2009-2017	-0.982	0.182
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.376	0.062
log Stage-2 NMFS trawl selectivity	-0.000	0.000
F_{OFL}	0.047	0.000
OFL	618.969	144.208

Table 15: Comparisons of parameter estimates for the model scenarios.

Parameter	Ref	fixR	nopot
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.573	1.573	1.829
$\log(\bar{R})$	13.899	13.870	14.225
$\log(n^0_1)$	14.950	14.950	14.945
$\log(n^0_2)$	14.509	14.508	14.459
$\log(n^0_3)$	14.326	14.326	14.290
q_{pot}	3.838	3.833	-
$\log(\bar{F}^{\text{df}})$	-2.125	-2.126	-2.319
$\log(\bar{F}^{\text{tb}})$	-9.470	-9.472	-9.716
$\log(\bar{F}^{\text{fb}})$	-8.093	-8.094	-8.341
log Stage-1 directed pot selectivity 1978-2008	-0.819	-0.820	-0.817
log Stage-2 directed pot selectivity 1978-2008	-0.452	-0.452	-0.482
log Stage-1 directed pot selectivity 2009-2017	-0.483	-0.484	-0.982
log Stage-2 directed pot selectivity 2009-2017	-0.000	-0.000	-0.000
log Stage-1 NMFS trawl selectivity	-0.320	-0.320	-0.376
log Stage-2 NMFS trawl selectivity	-0.000	-0.000	-0.000
log Stage-1 ADF&G pot selectivity	-0.725	-0.727	-
log Stage-2 ADF&G pot selectivity	-0.000	-0.000	-
F_{OFL}	0.047	0.047	0.180
OFL	50.674	48.819	618.969

Table 16: Comparisons of data weights, SDNR and MAR (standard deviation of normalized residuals and median absolute residual) values for the model scenarios.

Component	Ref	fixR	nopot
NMFS trawl survey weight	1.00	1.00	1.00
ADF&G pot survey weight	1.00	1.00	
Directed pot LF weight	1.00	1.00	1.00
NMFS trawl survey LF weight	1.00	1.00	1.00
ADF&G pot survey LF weight	1.00	1.00	
SDNR NMFS trawl survey	0.00	0.00	0.00
SDNR ADF&G pot survey	0.00	0.00	
SDNR directed pot LF	0.70	0.70	0.77
SDNR NMFS trawl survey LF	1.30	1.30	1.23
SDNR ADF&G pot survey LF	0.95	0.95	
MAR NMFS trawl survey	0.00	0.00	0.00
MAR ADF&G pot survey	0.00	0.00	
MAR directed pot LF	0.52	0.52	0.46
MAR NMFS trawl survey LF	0.60	0.60	0.78
MAR ADF&G pot survey LF	0.68	0.68	

Table 17: Comparisons of negative log-likelihood values for the selected model scenarios. It is important to note that comparisons among models may be limited since the number of parameters between models changes (e.g., **nopot** model).

Component	Ref	fixR	nopot
Pot Retained Catch	-68.50	-68.51	-56.27
Pot Discarded Catch	4.89	4.89	6.29
Trawl bycatch Discarded Catch	-7.99	-7.99	6.11
Fixed bycatch Discarded Catch	-7.95	-7.95	4.84
NMFS Trawl Survey	8.84	8.62	-4.42
ADF&G Pot Survey CPUE	84.62	84.93	
Directed Pot LF	-103.99	-103.99	-102.34
NMFS Trawl LF	-252.91	-252.93	-256.22
ADF&G Pot LF	-91.02	-91.05	
Recruitment deviations	59.56	60.01	59.37
F penalty	9.66	9.66	9.66
M penalty	6.46	6.46	6.45
Prior	13.71	13.71	12.11
Total	-344.61	-344.12	-314.40
Total estimated parameters	147.00	146.00	144.00

Table 18: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey and mature male biomass (MMB) in tons on 15 February for the **model configuration used in 2019**.

Year	n_1	n_2	n_3	MMB	CV MMB
1978	3109715	2000299	1666848	4550	0.178
1979	4376763	2355384	2282776	6433	0.124
1980	3779544	3257707	3463738	10256	0.083
1981	1439955	3221560	4866873	10705	0.062
1982	1618361	1833987	4894696	7604	0.072
1983	811849	1447417	3468928	4537	0.099
1984	662337	858825	1983059	3022	0.124
1985	928011	622498	1406806	2656	0.144
1986	1366392	705833	1186990	2600	0.140
1987	1330701	989214	1278483	3074	0.129
1988	1241066	1061590	1484711	3360	0.126
1989	2898487	1033510	1638093	3849	0.121
1990	1877184	1956744	1939926	4970	0.094
1991	1938968	1673531	2420850	4992	0.095
1992	2099715	1593816	2382018	5175	0.085
1993	2372747	1673953	2494925	5427	0.077
1994	1608587	1844929	2573586	5200	0.070
1995	1749039	1461936	2471794	5073	0.073
1996	1780265	1429663	2364609	4775	0.075
1997	912655	1434576	2265018	4155	0.094
1998	603985	936010	1844896	2740	0.110
1999	369997	310550	711971	1680	0.102
2000	408474	312747	786233	1822	0.084
2001	372448	335395	853220	1973	0.076
2002	129931	322415	917072	2077	0.070
2003	290682	180441	940677	1961	0.071
2004	187364	224669	903940	1943	0.071
2005	468821	180737	886078	1860	0.072
2006	702839	325974	875801	2003	0.072
2007	403315	506459	961977	2337	0.069
2008	835694	391131	1082101	2461	0.060
2009	682211	603380	1179630	2497	0.054
2010	624238	577600	1251605	2110	0.057
2011	496132	520319	1099028	1528	0.070
2012	228196	415162	788179	998	0.108
2013	251502	235864	506691	1158	0.097
2014	204364	220853	566085	1090	0.103
2015	162705	185039	537244	1070	0.105
2016	169495	152401	534064	1116	0.102
2017	131331	146586	538681	1116	0.101
2018	141883	122799	535054	1085	0.100
2019	250747	121140	521618	1022	0.103

Table 19: 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 tons on 15 February for the 2020 reference model.

Year	n_1	n_2	n_3	MMB	CV MMB
1978	3151217	2048032	1704813	4676	0.176
1979	4405644	2394327	2341979	6576	0.122
1980	3774514	3287008	3535569	10427	0.083
1981	1435061	3228410	4941160	10851	0.062
1982	1622665	1833539	4959495	7725	0.072
1983	826815	1449709	3522402	4646	0.099
1984	673504	867978	2029459	3119	0.123
1985	940551	631919	1451162	2759	0.143
1986	1398609	716293	1230084	2694	0.139
1987	1351732	1011045	1322901	3183	0.127
1988	1256200	1080852	1534825	3474	0.123
1989	2919885	1048636	1691144	3969	0.119
1990	1888479	1974231	1993985	5088	0.093
1991	1953255	1686052	2476052	5111	0.094
1992	2112699	1606335	2435840	5290	0.085
1993	2392964	1685630	2547439	5543	0.077
1994	1638537	1860336	2625259	5314	0.070
1995	1766633	1483754	2525427	5201	0.073
1996	1804613	1446768	2421768	4904	0.075
1997	941521	1454055	2323563	4296	0.094
1998	618296	958642	1906137	2860	0.109
1999	381326	315898	737767	1735	0.102
2000	421648	320952	811560	1879	0.084
2001	383990	345593	879772	2034	0.076
2002	134380	332345	945496	2142	0.071
2003	302039	186255	969851	2022	0.072
2004	191454	233042	932326	2006	0.072
2005	479484	185831	914401	1919	0.072
2006	718464	333716	903047	2062	0.072
2007	409910	517899	990132	2402	0.069
2008	844891	398703	1112005	2526	0.061
2009	692584	611117	1209302	2557	0.055
2010	634017	586098	1281337	2168	0.058
2011	509421	528796	1129162	1588	0.072
2012	239665	425751	819051	1062	0.109
2013	264030	246289	539320	1227	0.098
2014	216047	231419	599794	1160	0.104
2015	171673	195187	571890	1140	0.106
2016	178308	160859	568985	1187	0.103
2017	138175	154391	572956	1186	0.101
2018	147990	129272	568274	1151	0.101
2019	262671	126752	553209	1081	0.103

Figures

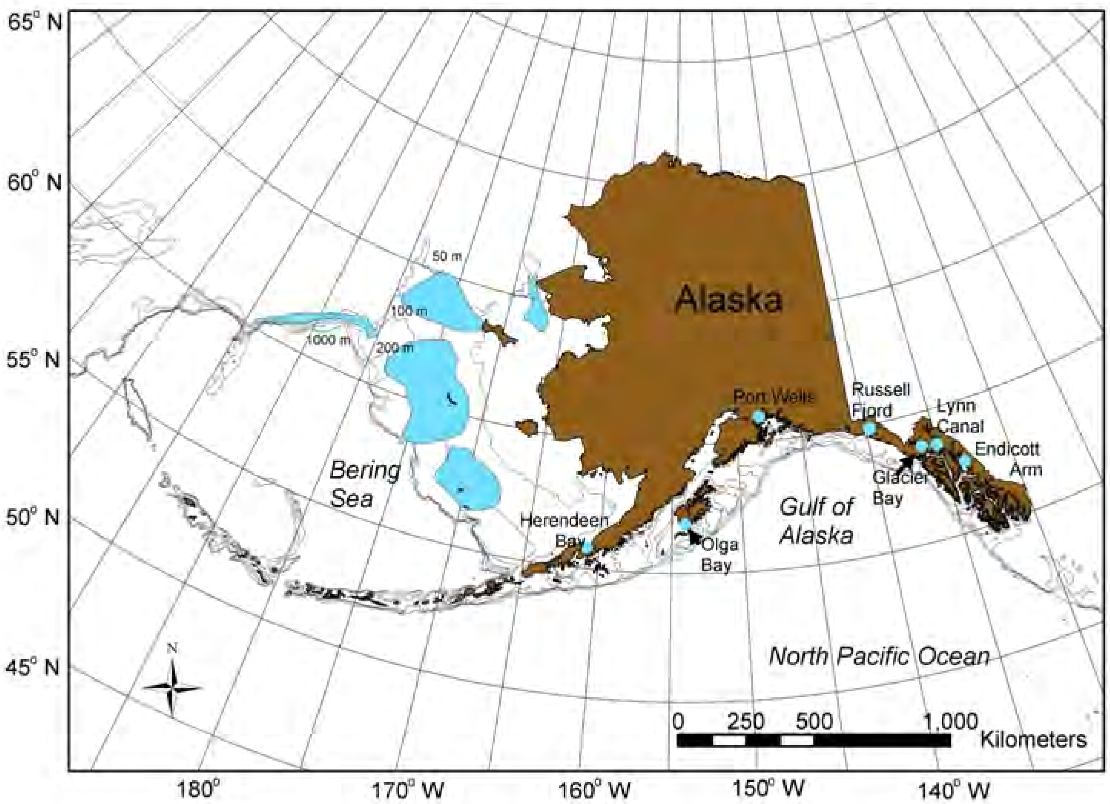


Figure 1: Distribution of blue king crab (Paralithodes platypus) in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters (shown in blue).

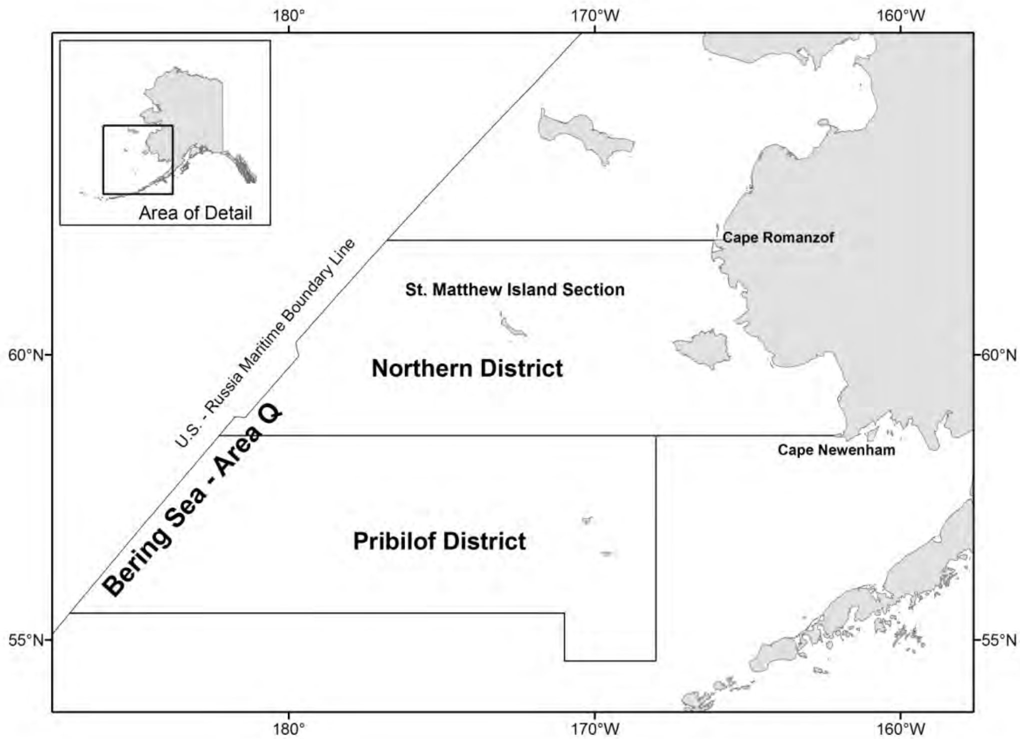


Figure 2: Blue king crab Registration Area Q (Bering Sea)

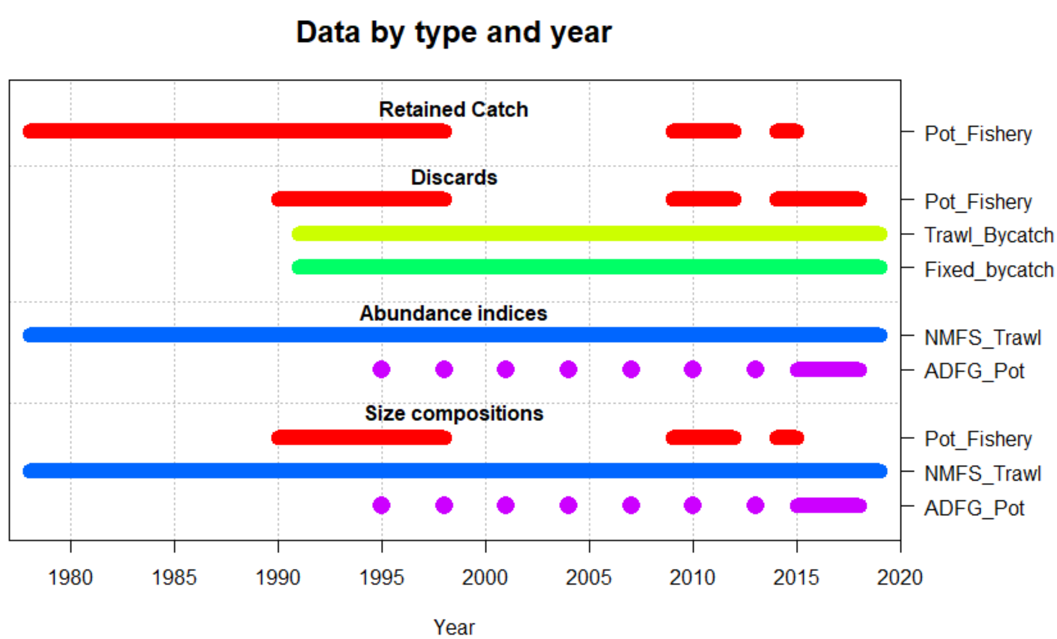


Figure 3: Data extent for the SMBKC assessment.

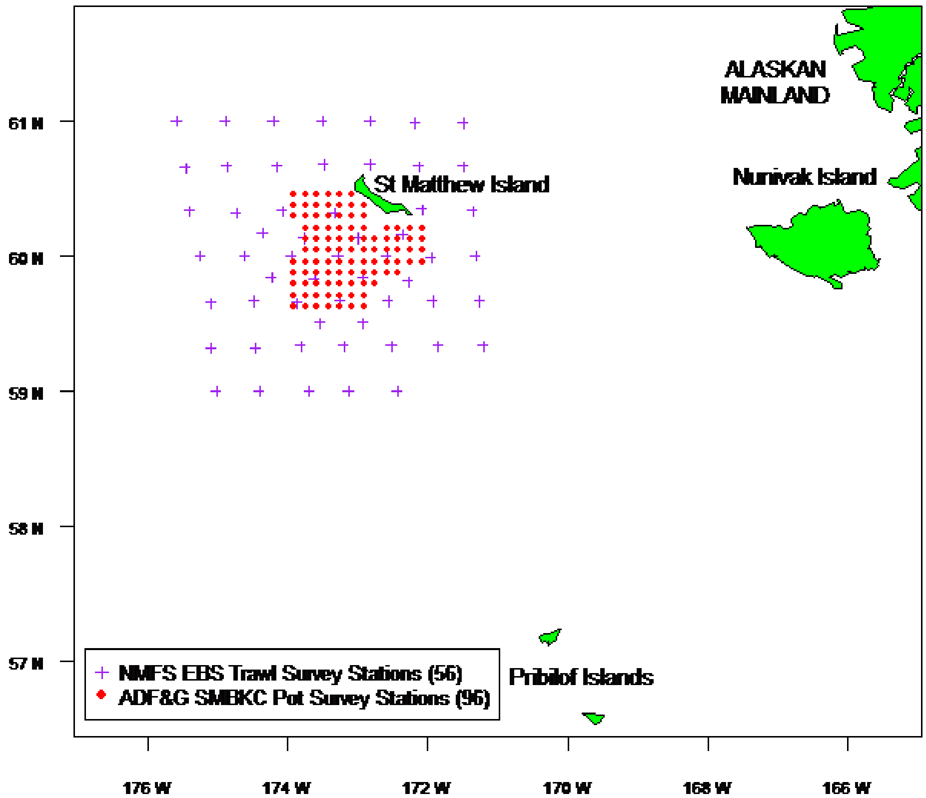


Figure 4: Trawl and pot-survey stations used in the SMBKC stock assessment.

Figure 5: Catches (in numbers) of male blue king crab > 90mm CL from the 2011-2019 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock.

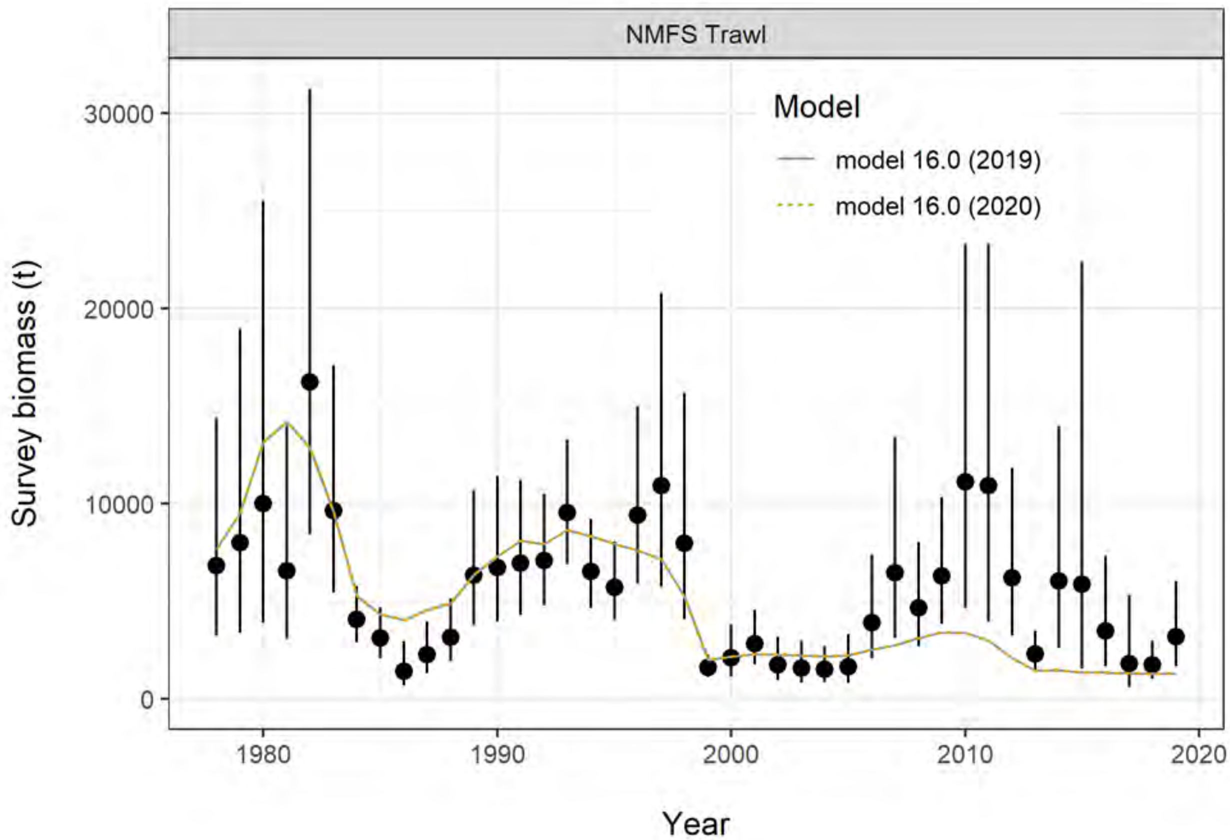


Figure 6: Fits to NMFS area-swept trawl estimates of total (> 90mm) male survey biomass for the reference model only (16.0 ref for 2020 and 16.0 2019 accepted model). Error bars are plus and minus 2 standard deviations.

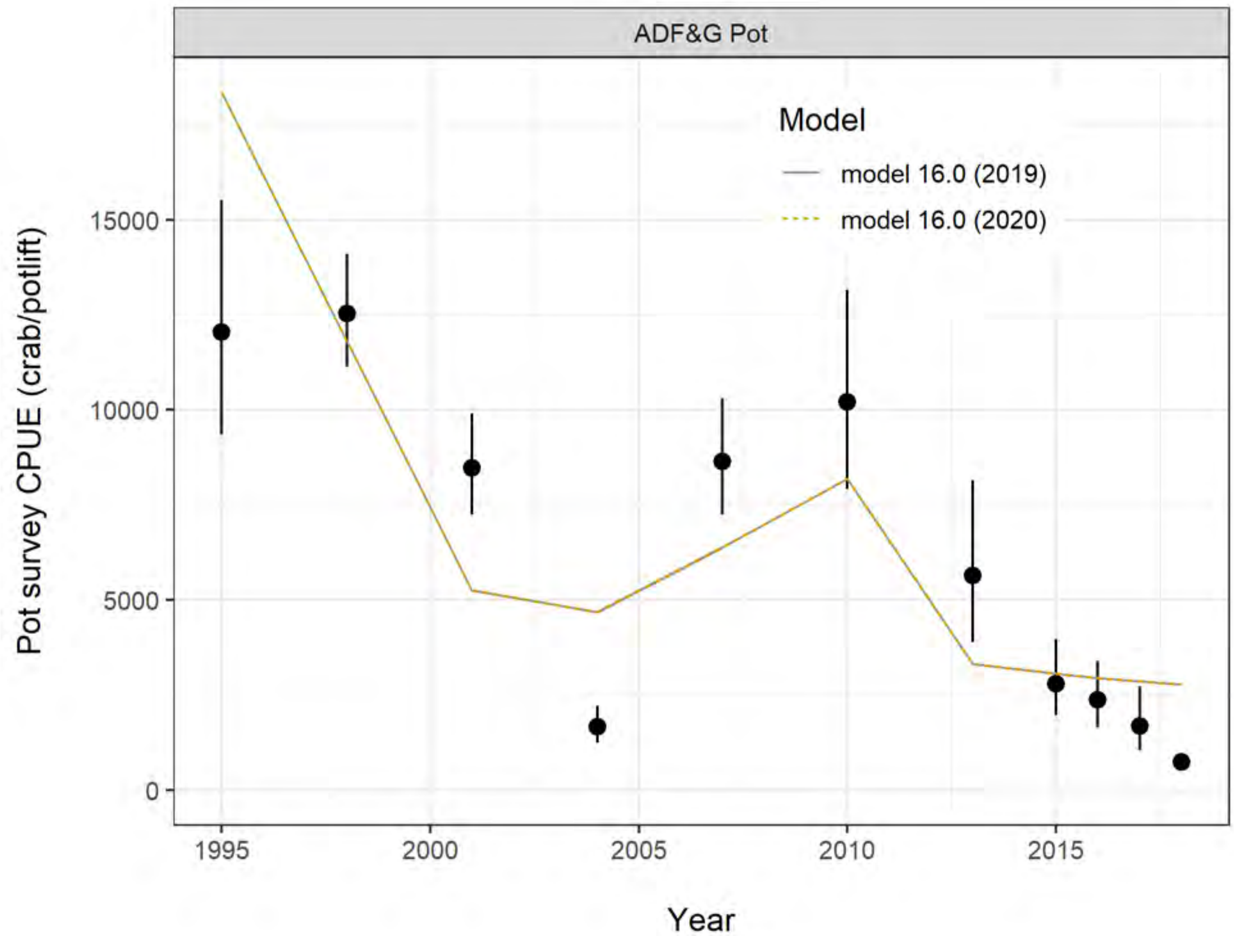


Figure 7: Comparisons of fits to CPUE from the ADFG pot surveys for the reference model 16.0 reference model in 2019 and 2020. Error bars are plus and minus 2 standard deviations.

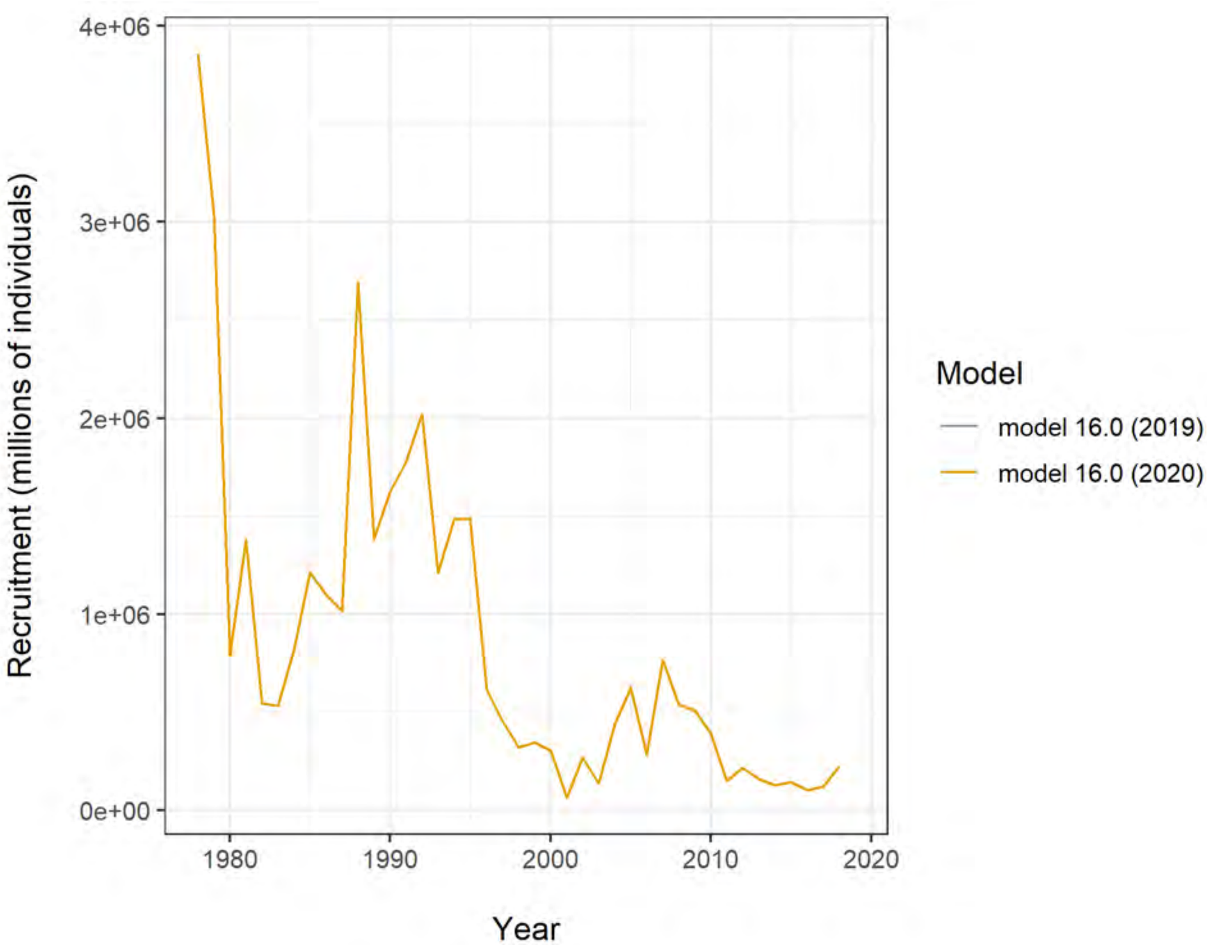


Figure 8: Reference model estimated recruitment (2019 and 2020) for comparison from 1978-2018, does not show recent recruitment, i.e. 2019.

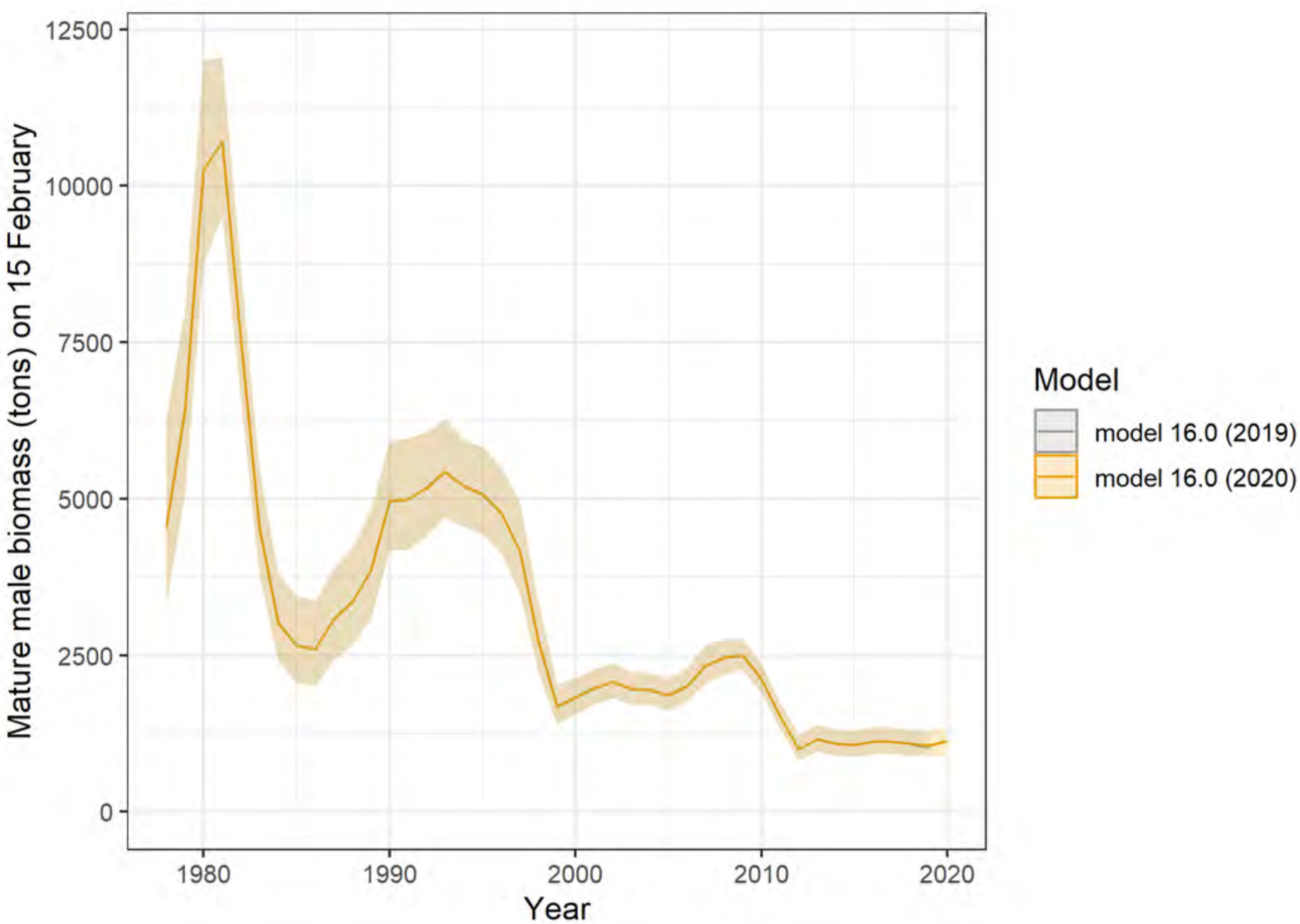


Figure 9: Sensitivity of new data in 2020 on estimated mature male biomass (MMB); 1978-2020.

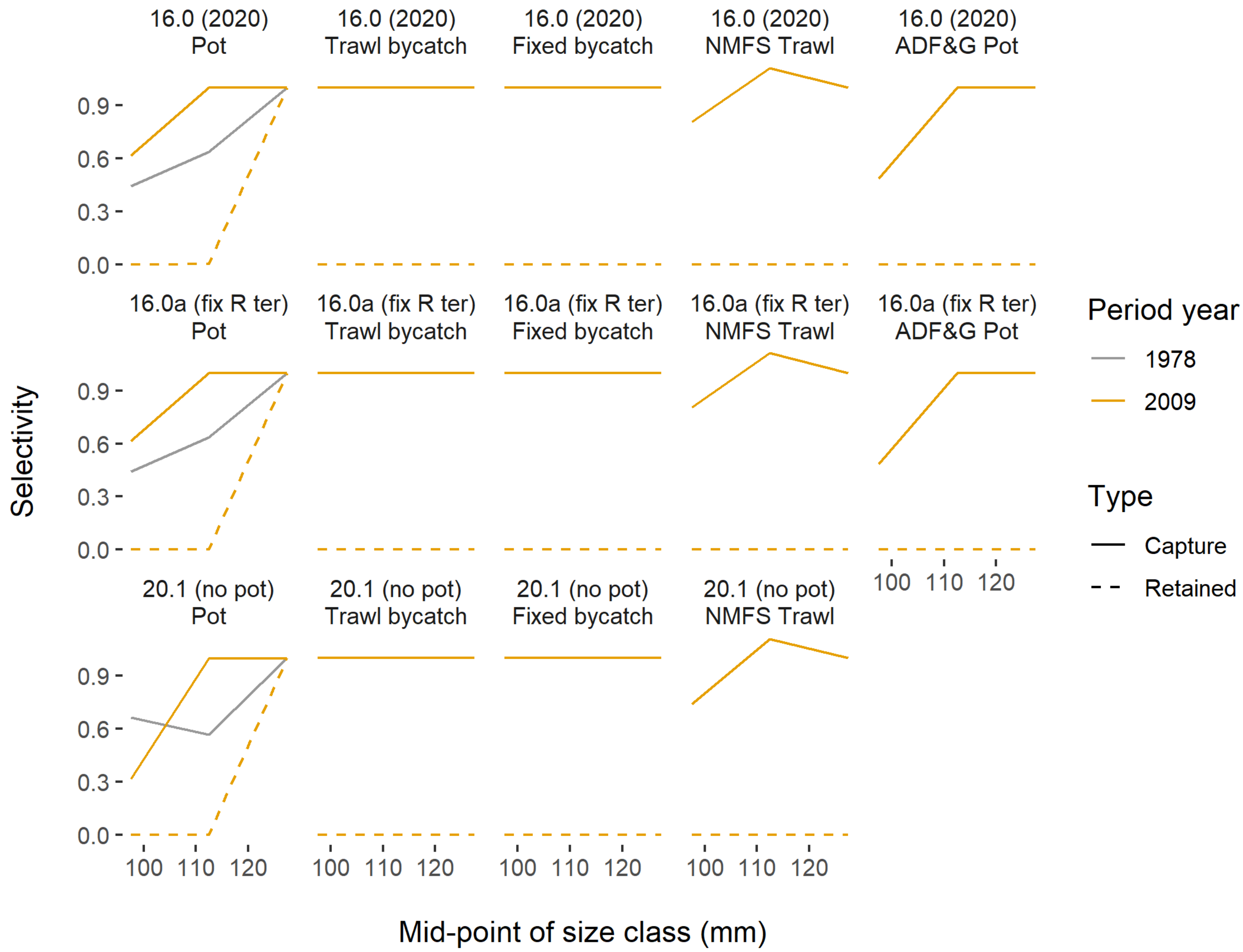


Figure 10: Comparisons of the estimated stage-1 and stage-2 selectivities for the different model scenarios (the stage-3 selectivities are all fixed at 1). Estimated selectivities are shown for the directed pot fishery, the trawl bycatch fishery, the fixed bycatch fishery, the NMFS trawl survey, and the ADFG pot survey. Two selectivity periods are estimated in the directed pot fishery, from 1978-2008 and 2009-2019.

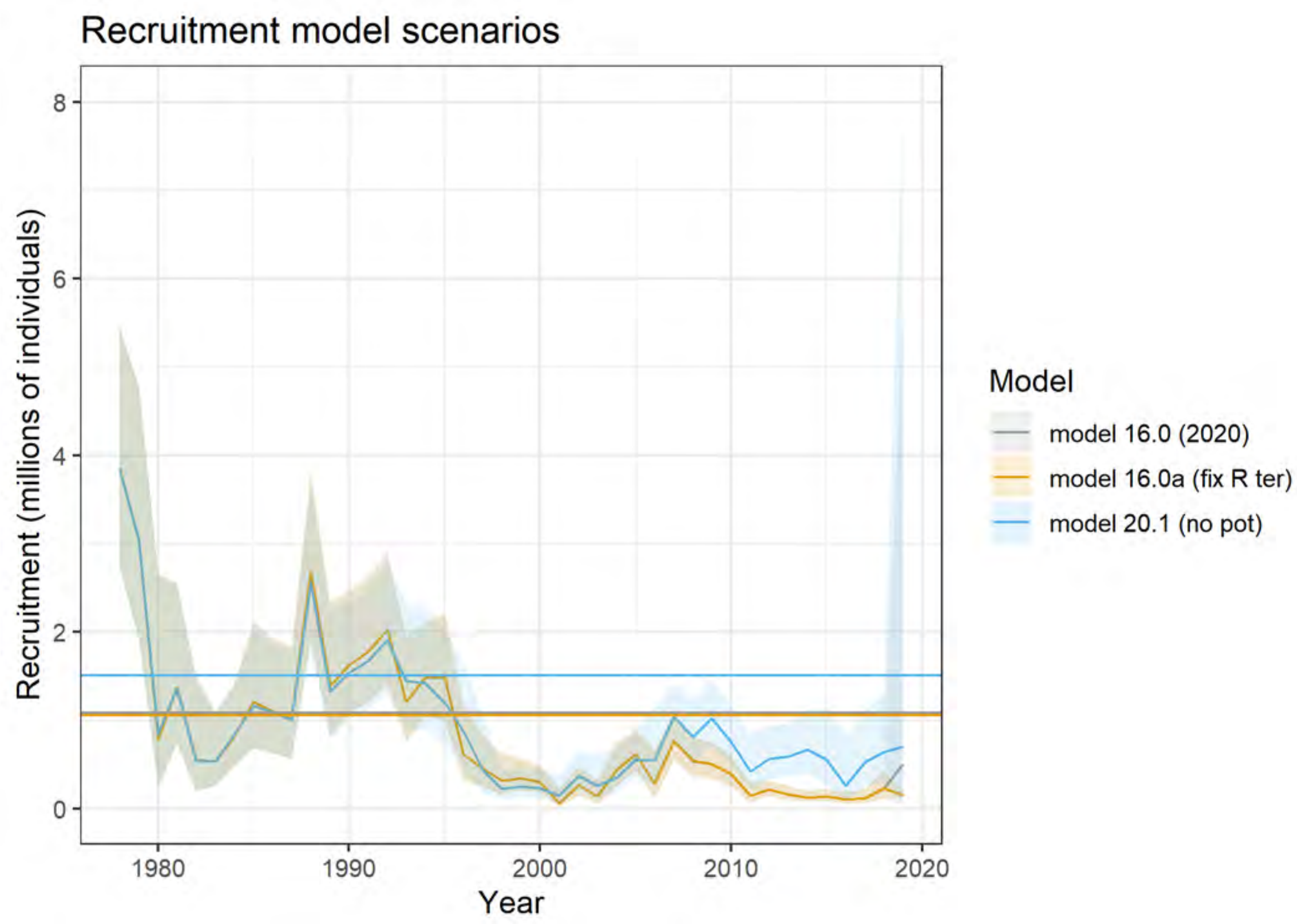


Figure 11: Estimated recruitment 1979-2019 comparing model alternatives. The solid horizontal lines in the background represent the estimate of the average recruitment parameter ($\bar{R}$) in each model scenario. Note the high uncertainty in recruitment in both the ref and the nopot model due to the lack of 2020 data.

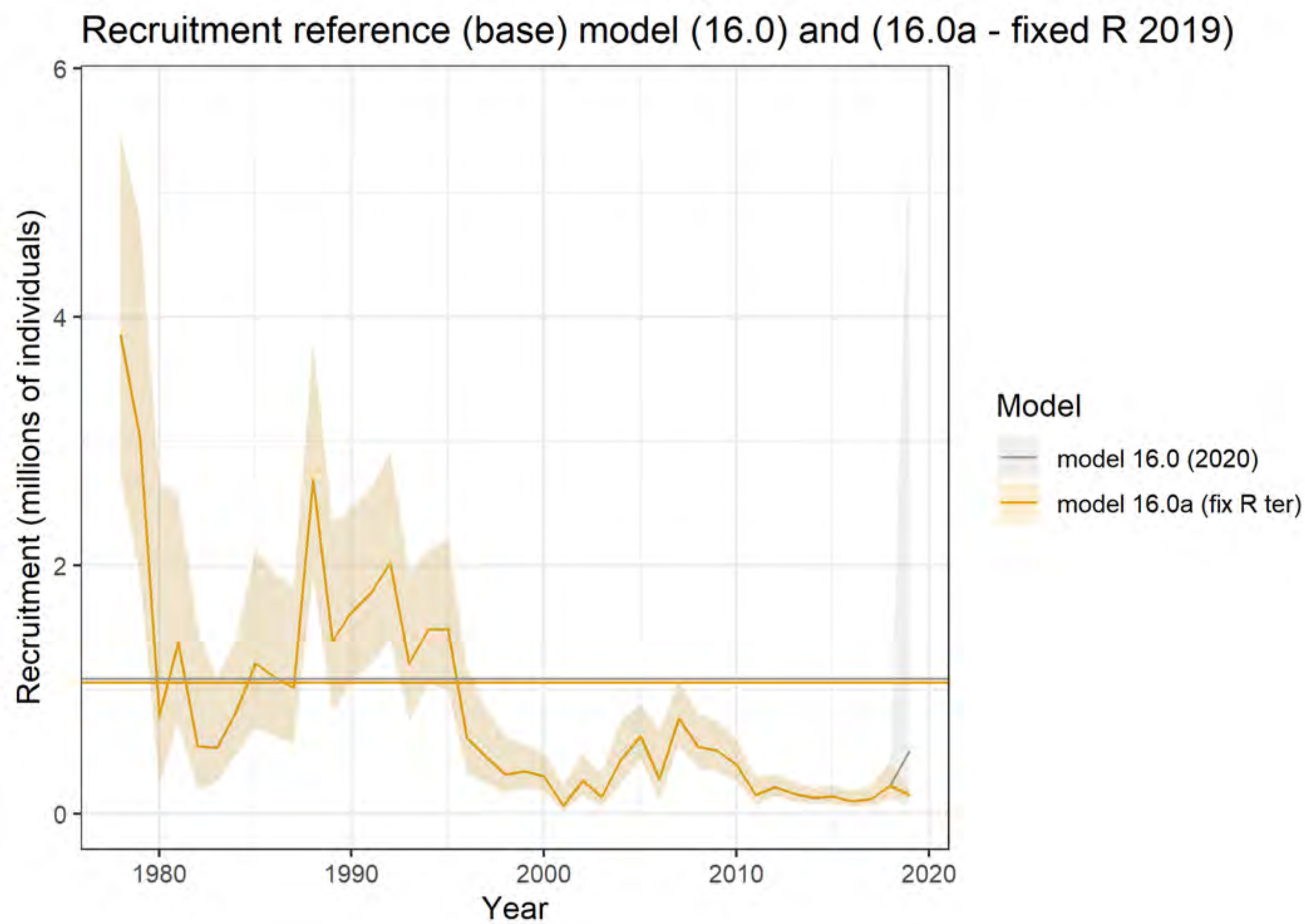


Figure 12: Estimated recruitment 1979-2019 comparing ref model (16.0) and model with fixed recruitment in the terminal year (16.0a). The solid horizontal lines in the background represent the estimate of the average recruitment parameter ($\bar{R}$) in each model scenario.

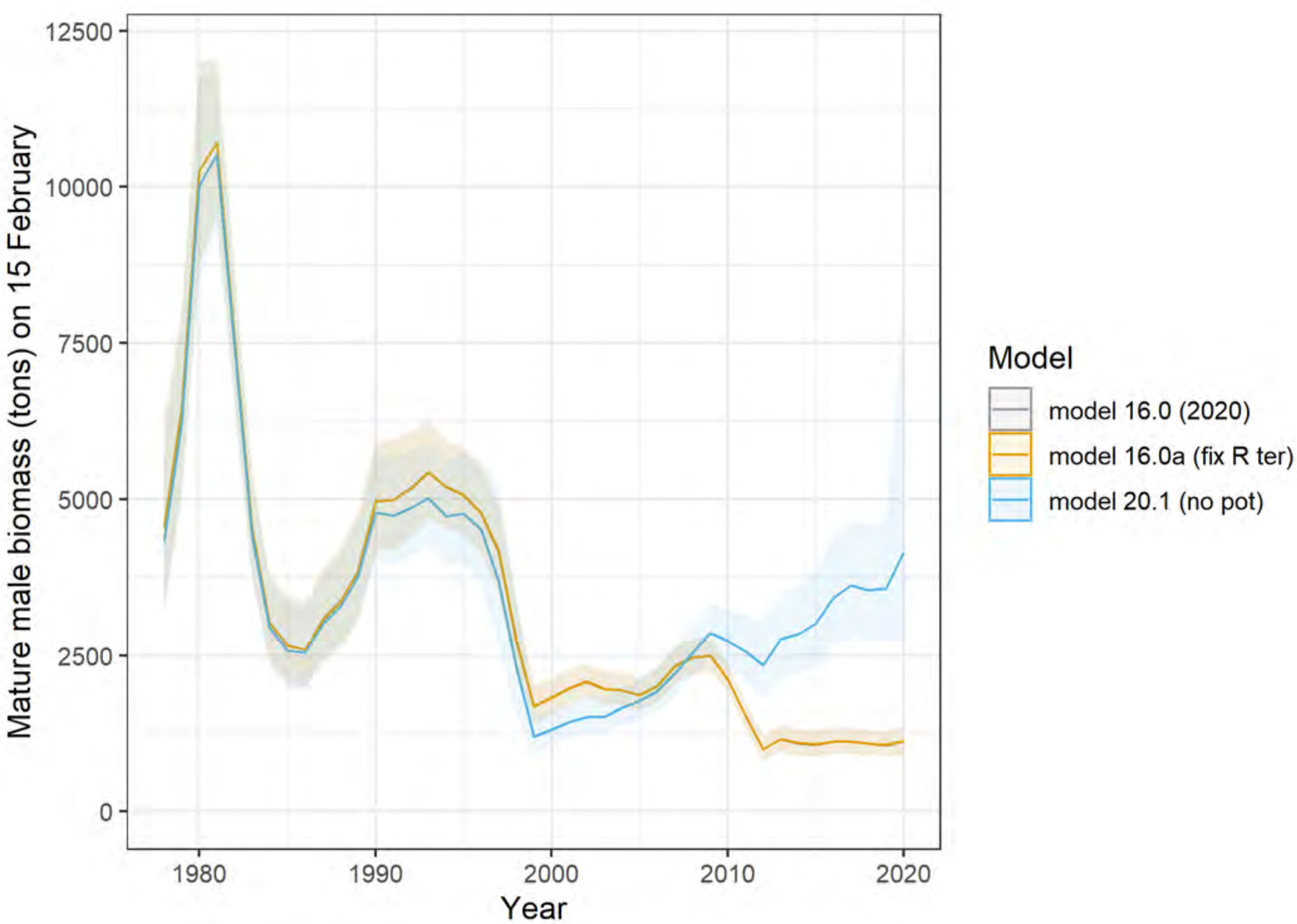


Figure 13: Comparisons of estimated mature male biomass (MMB) time series on 15 February during 1978-2020 for each of the model scenarios.

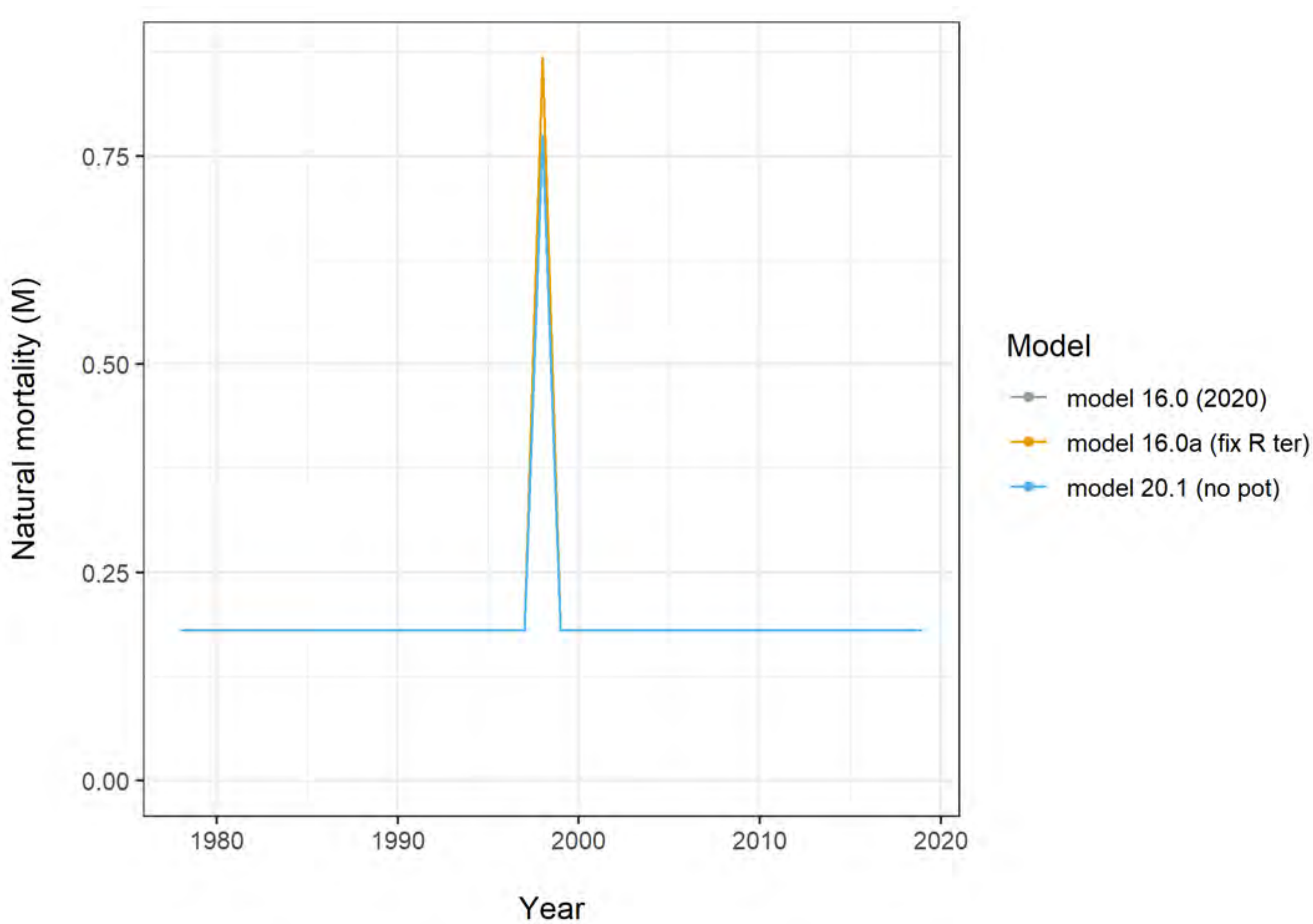


Figure 14: Time-varying natural mortality (M_t). Estimated pulse period occurs in 1998/99 (i.e. M_{1998}).

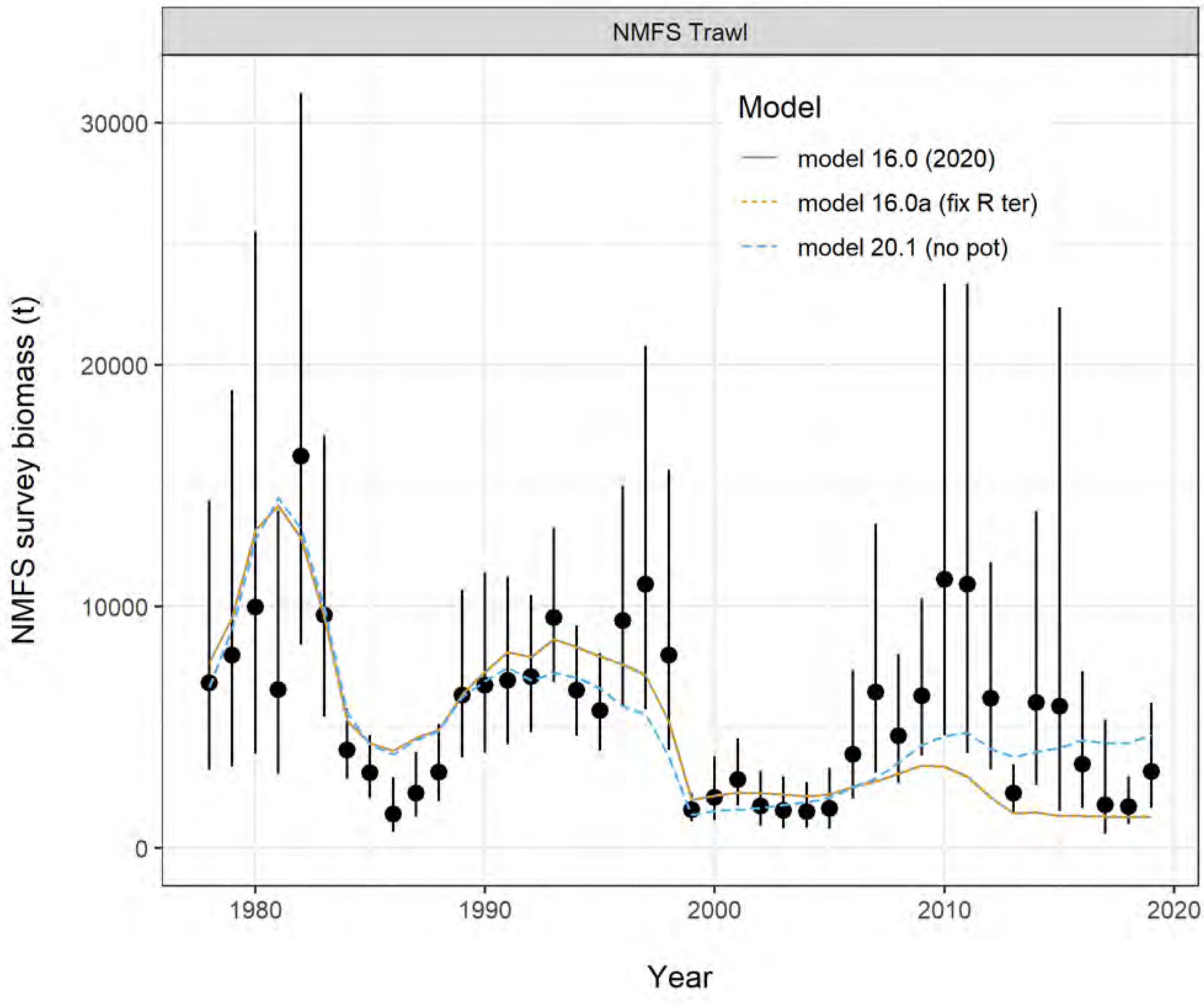


Figure 15: Comparisons of area-swept estimates of total (90+ mm CL) male survey biomass (tons) and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

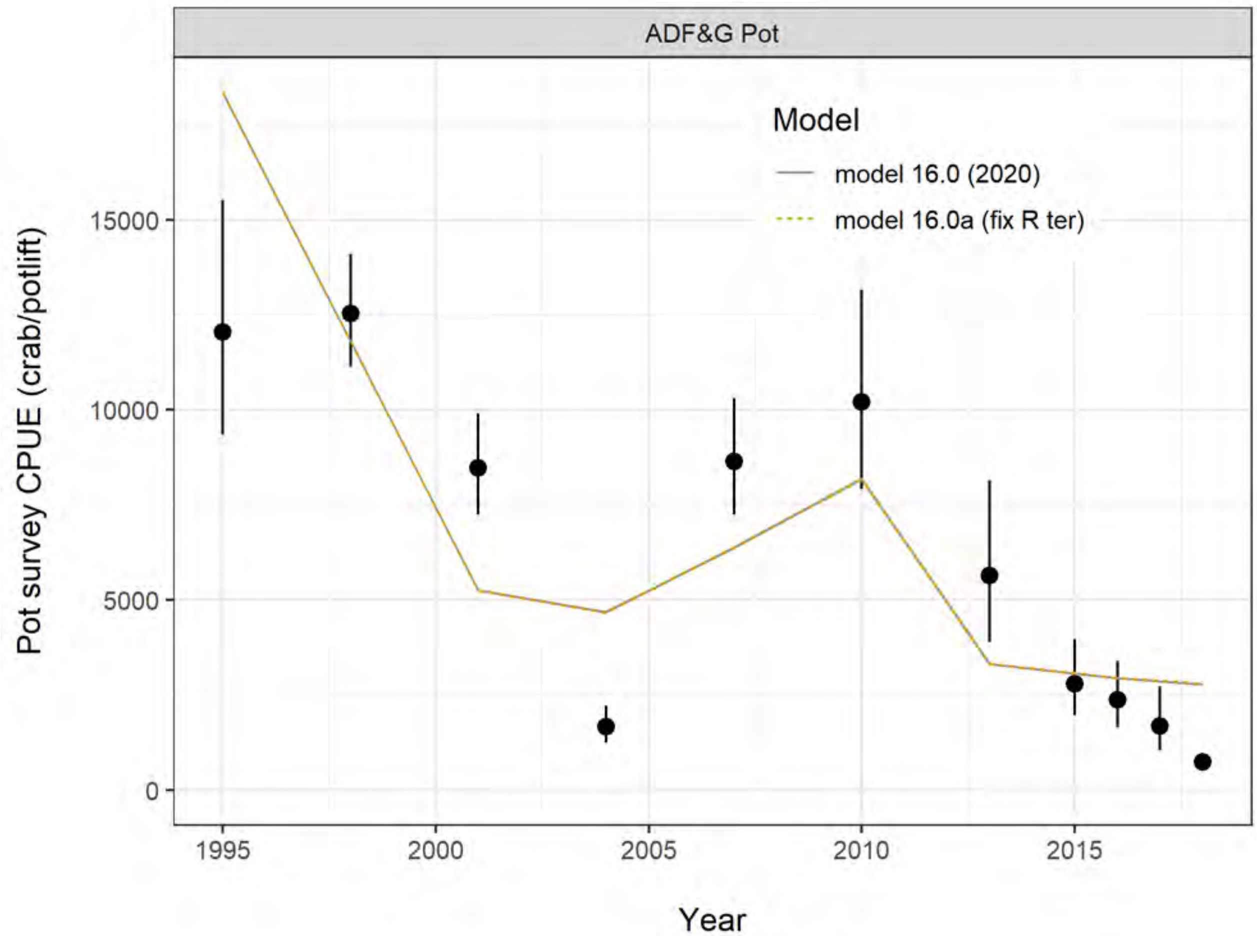


Figure 16: Comparisons of total (90+ mm CL) male pot survey CPUEs and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

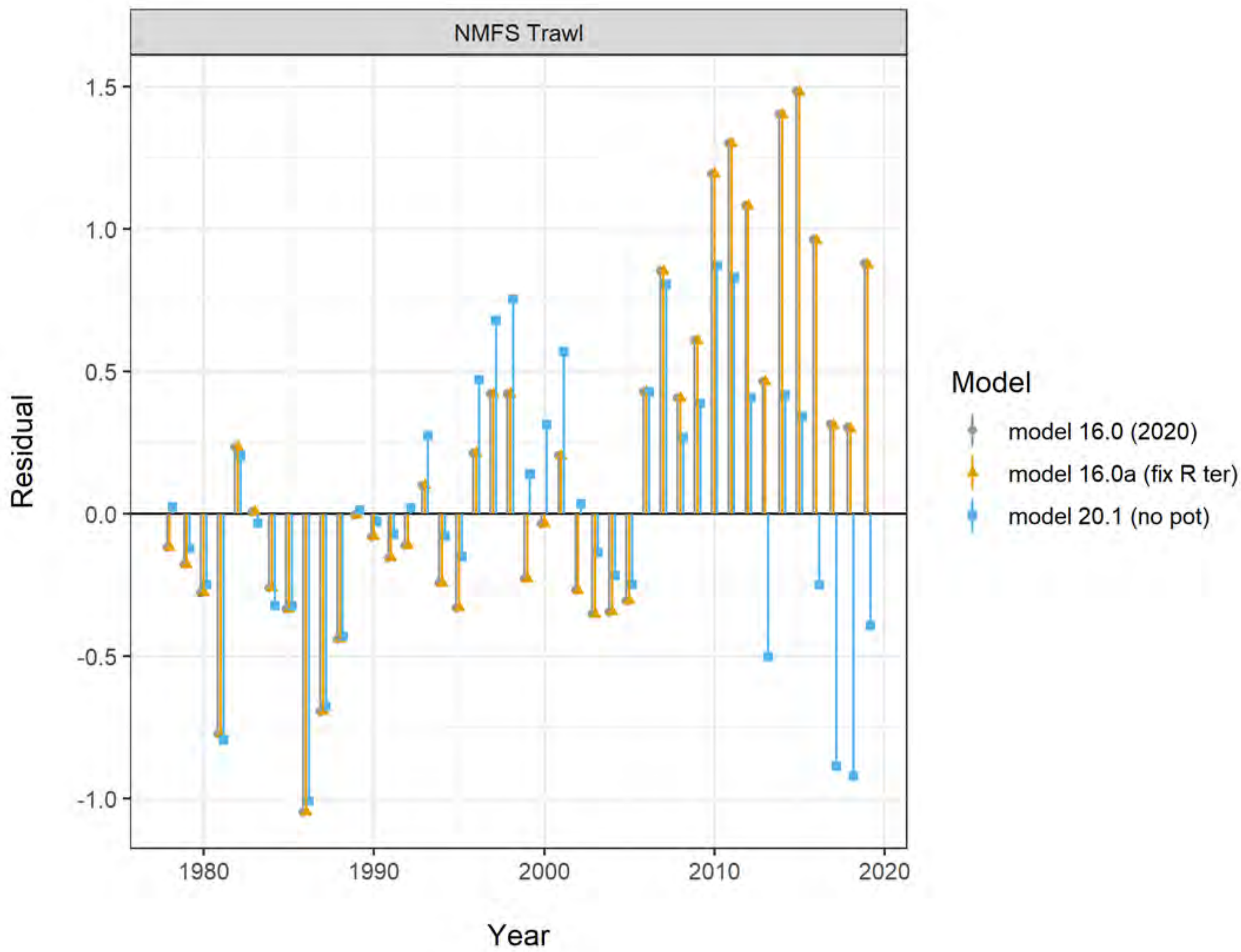


Figure 17: Standardized residuals for area-swept estimates of total male survey biomass for the model scenarios.

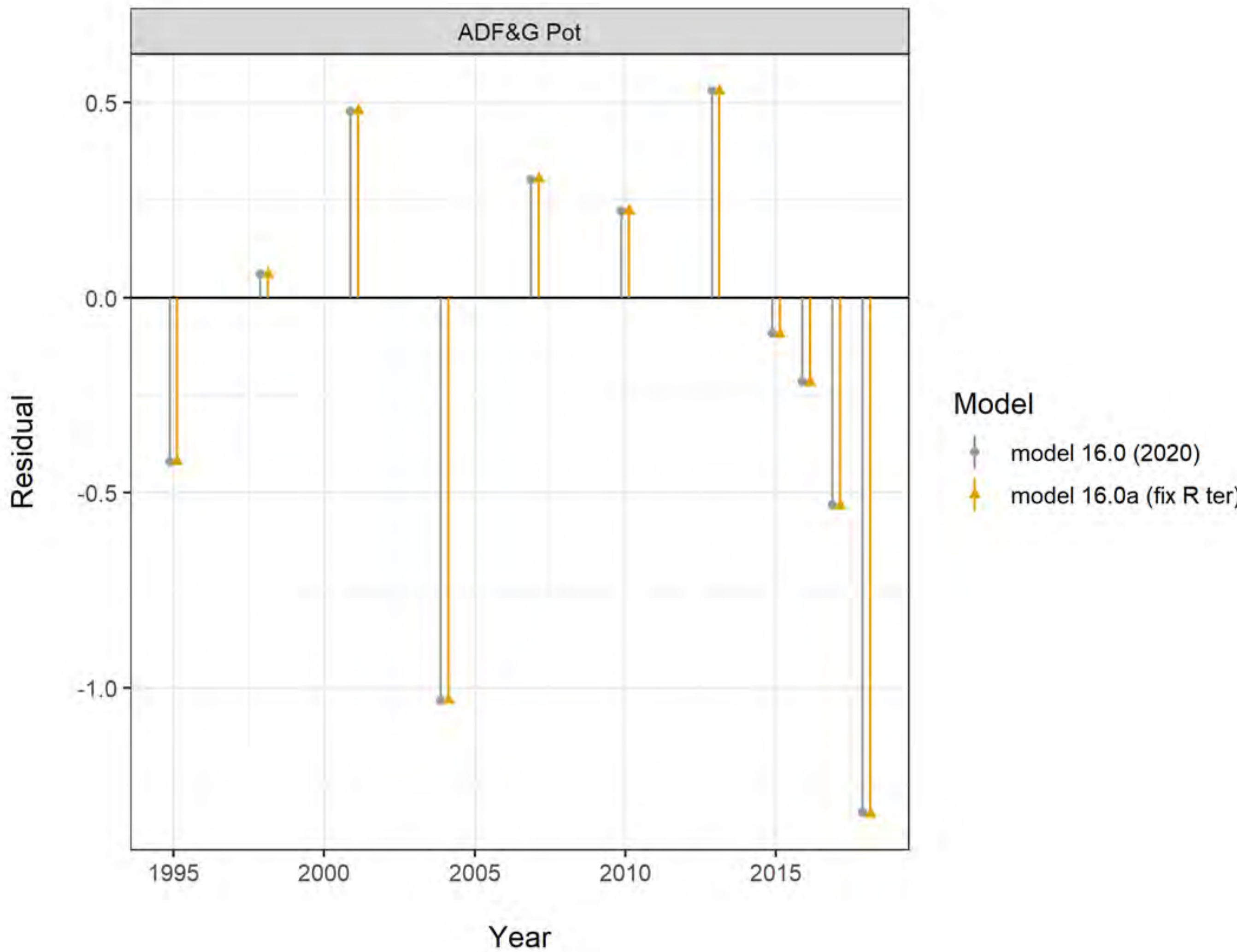


Figure 18: Standardized residuals for total male pot survey CPUEs for each of the GMACS model scenarios.

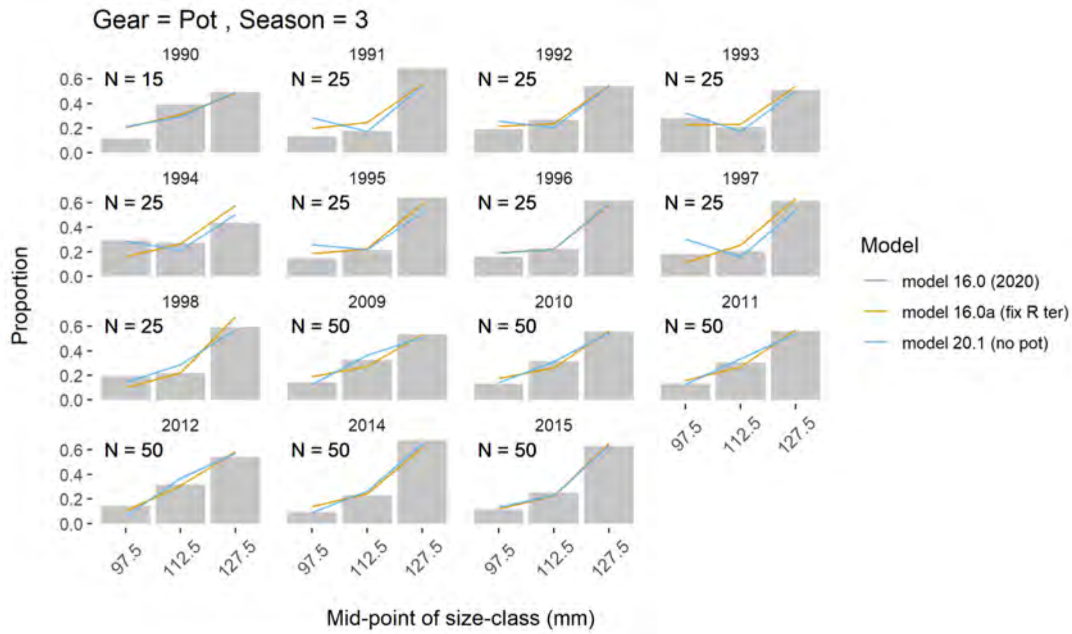


Figure 19: Observed and model estimated size-frequencies of SMBKC by year retained in the directed pot fishery for the model scenarios.

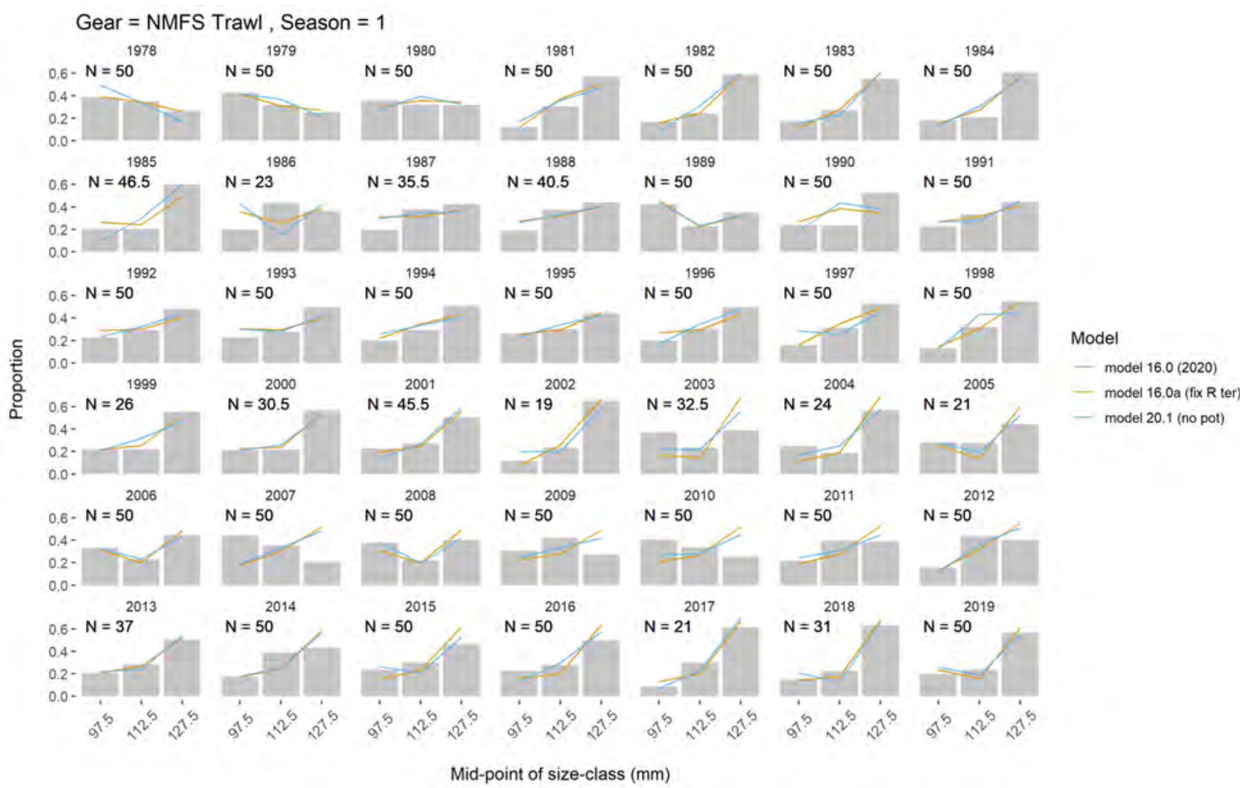


Figure 20: Observed and model estimated size-frequencies of discarded male SMBKC by year in the NMFS trawl survey for the model scenarios.

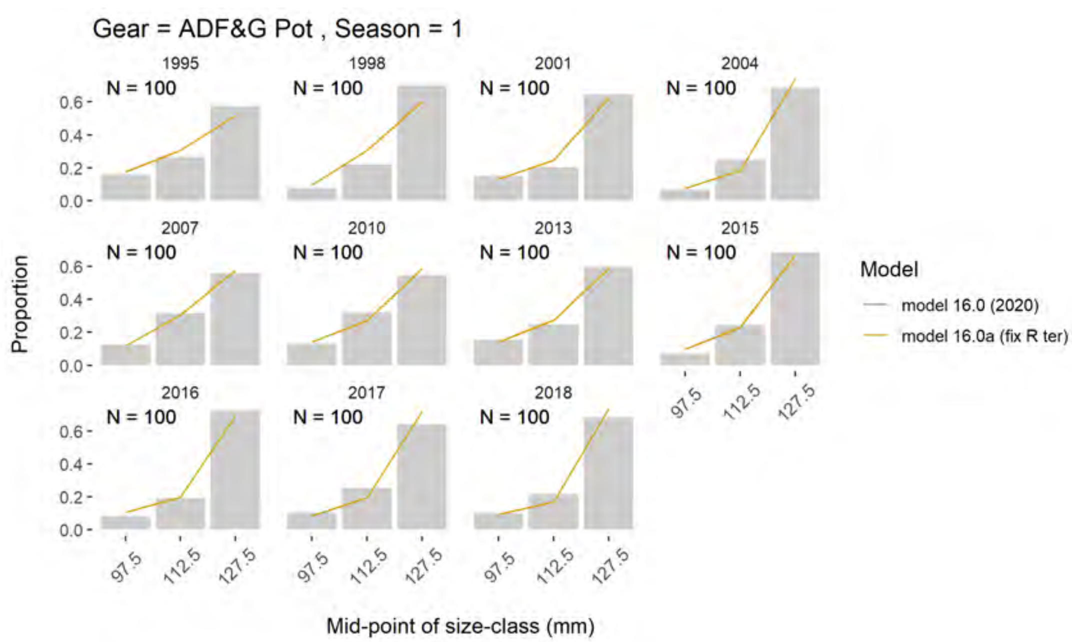


Figure 21: Observed and model estimated size-frequencies of discarded SMBKC by year in the ADFG pot survey for the model scenarios.

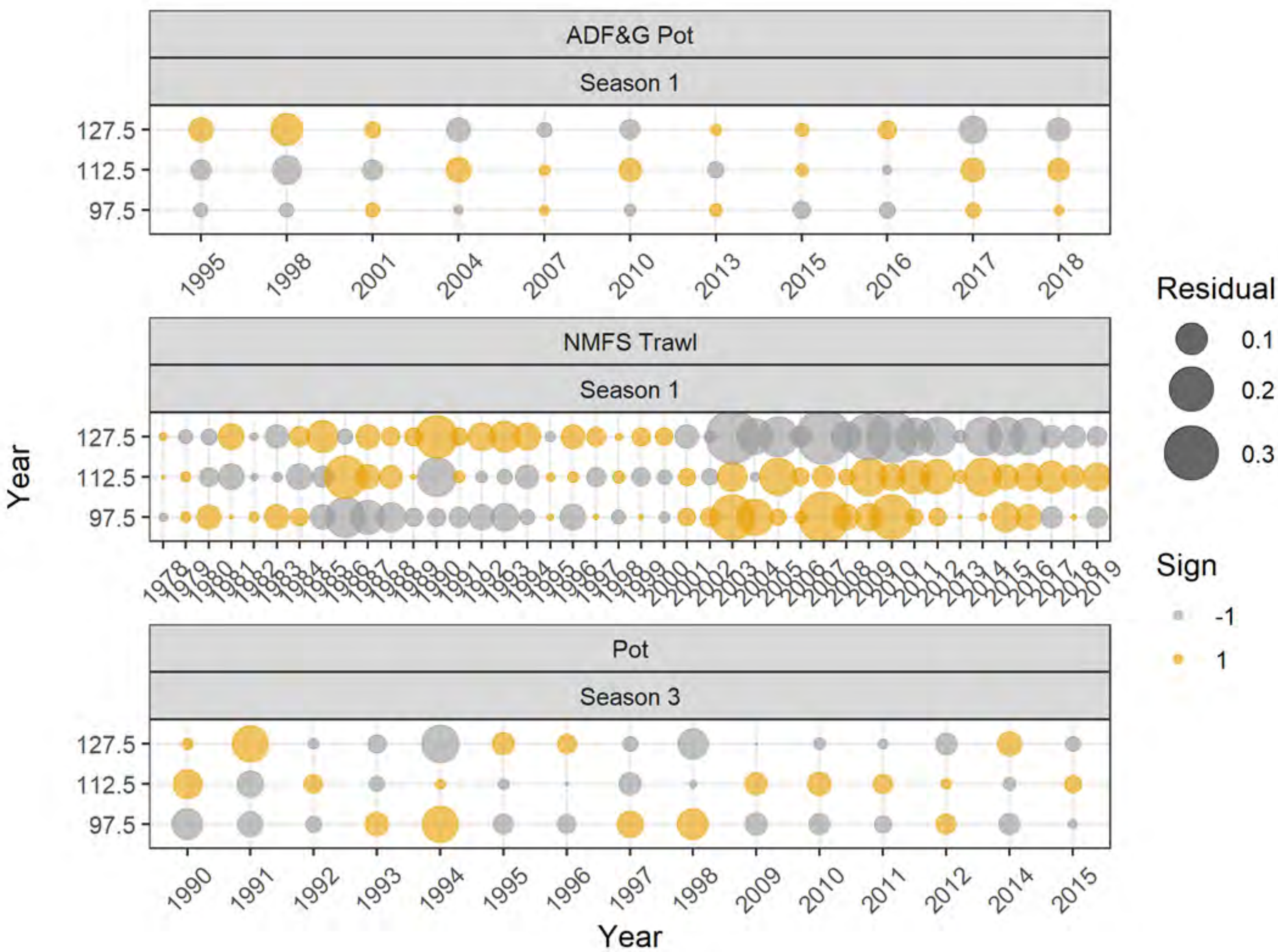


Figure 22: Bubble plots of residuals by stage and year for the all the size composition data sets (ADFG pot survey, NMFS trawl survey, and the directed pot fishery) for SMBKC in the 'reference' model (16.0).

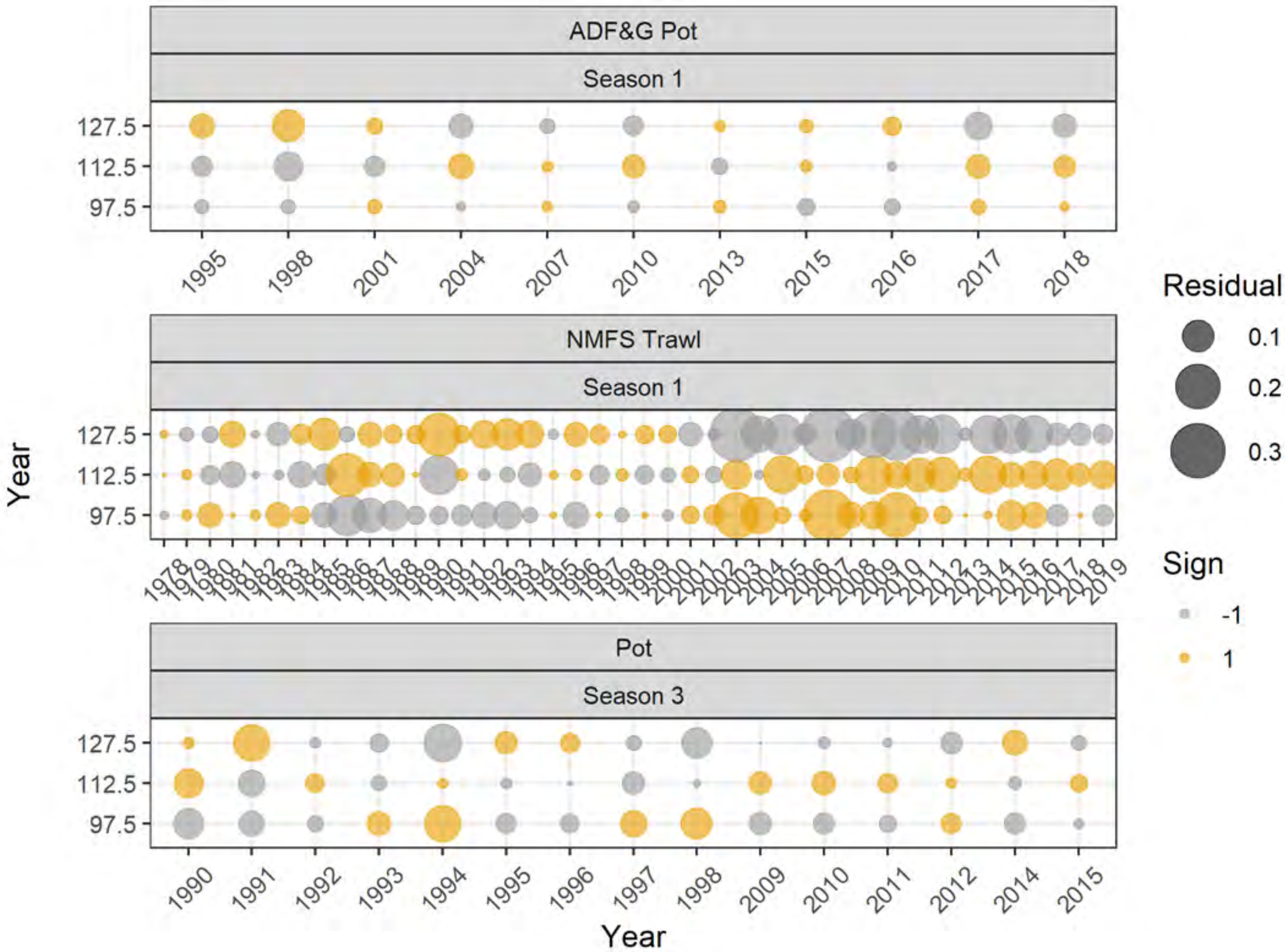


Figure 23: Bubble plots of residuals by stage and year for the all the size composition data sets (NMFS trawl survey, and the directed pot fishery) for SMBKC in the 'fixR' model (16.0a).

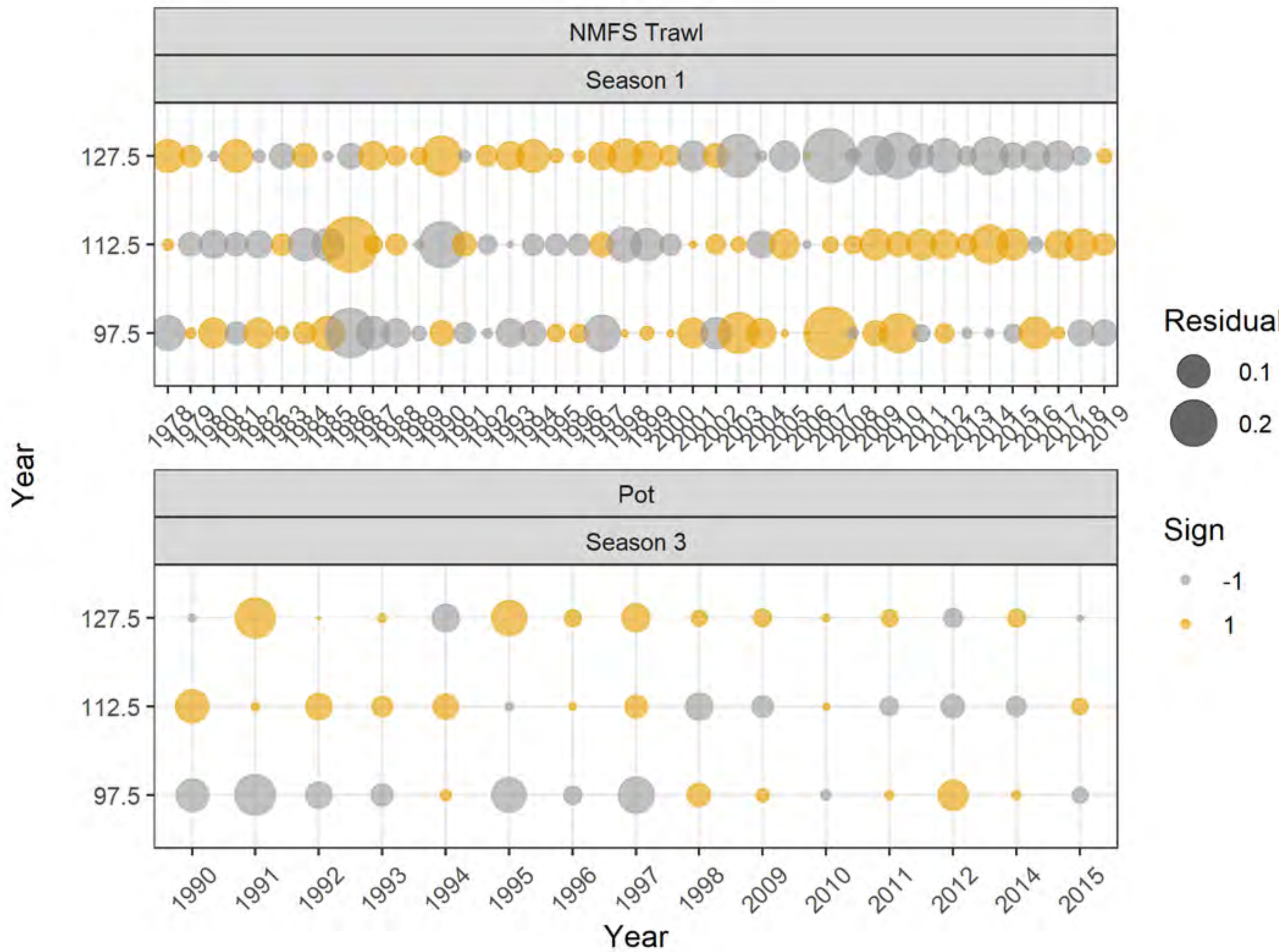


Figure 24: Bubble plots of residuals by stage and year for the all the size composition data sets (NMFS trawl survey, and the directed pot fishery) for SMBKC in the 'no pot' model (20.1).

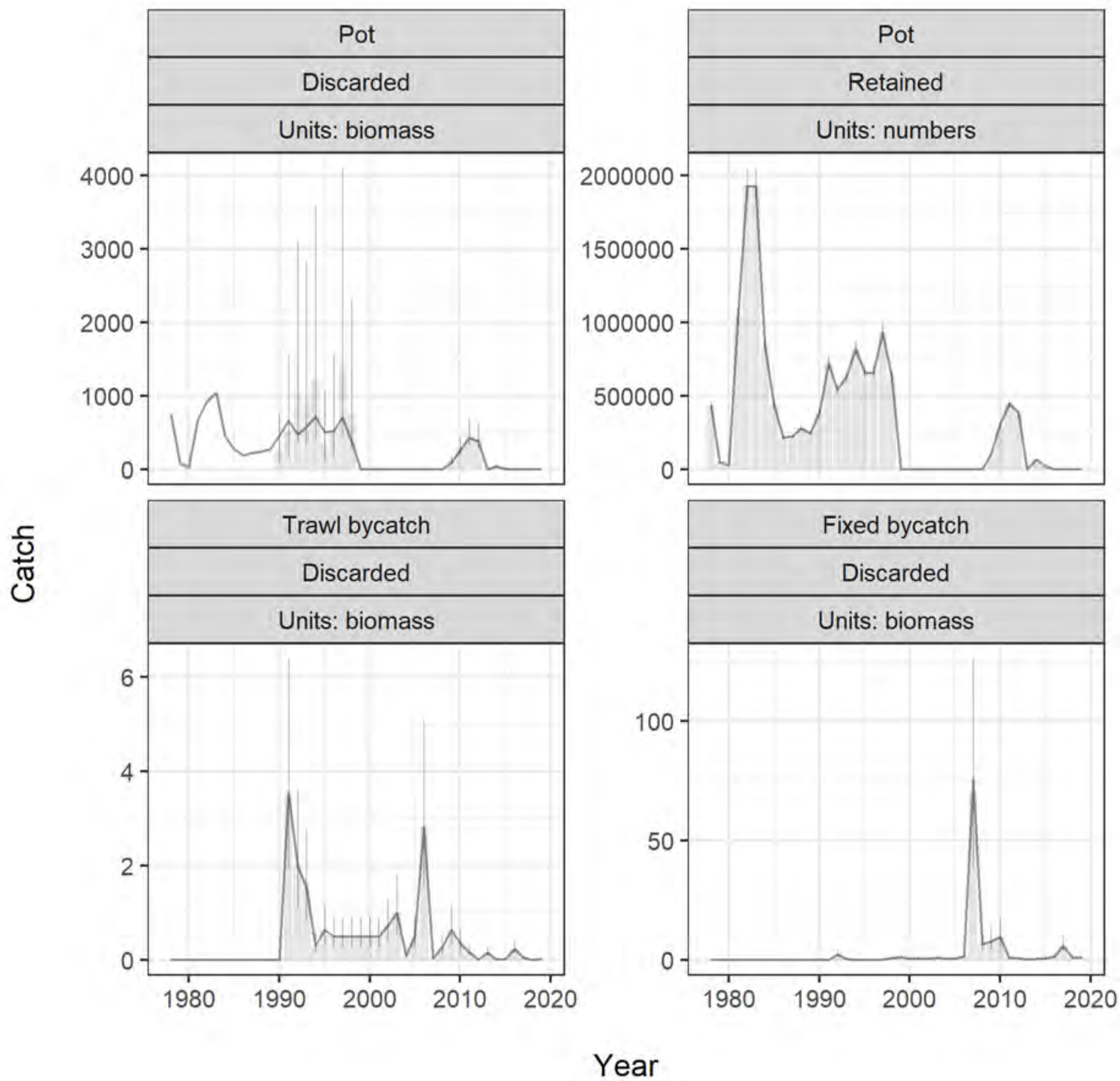


Figure 25: Comparison of observed and model predicted retained catch and bycatches in each of the GMACS models. Note that difference in units between each of the panels, some panels are expressed in numbers of crab, some as biomass (tons).

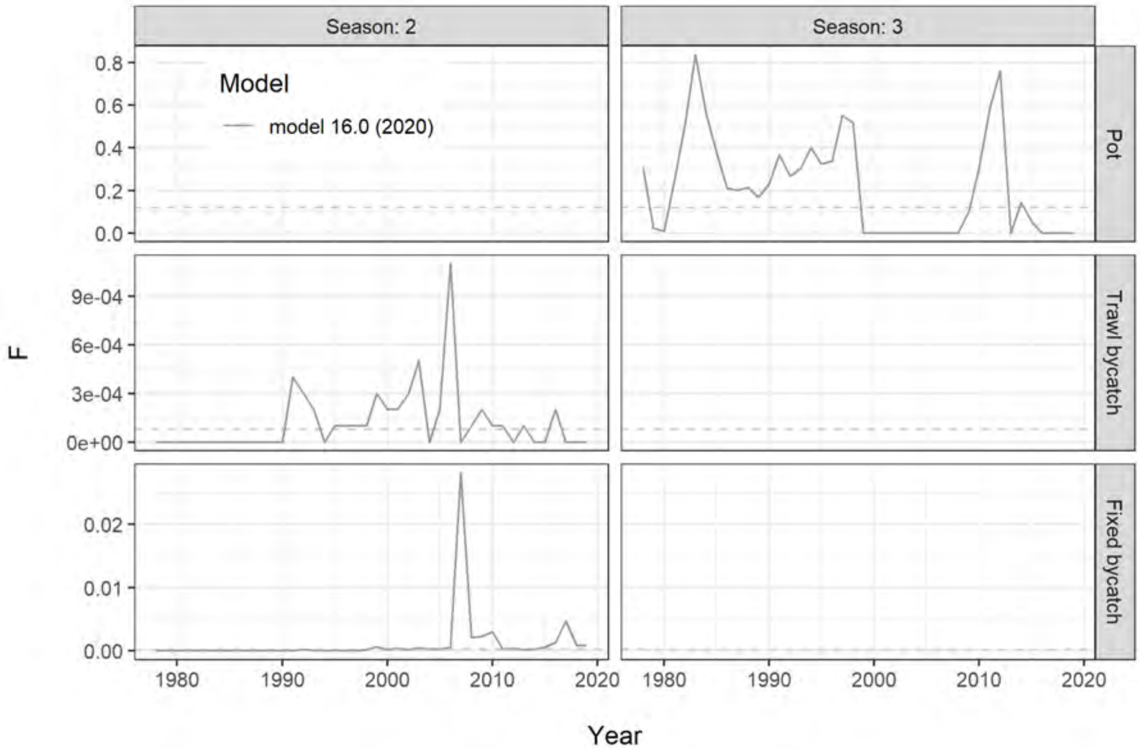


Figure 26: Fishing mortality estimates from the reference model (16.0) for directed and bycatch fleets

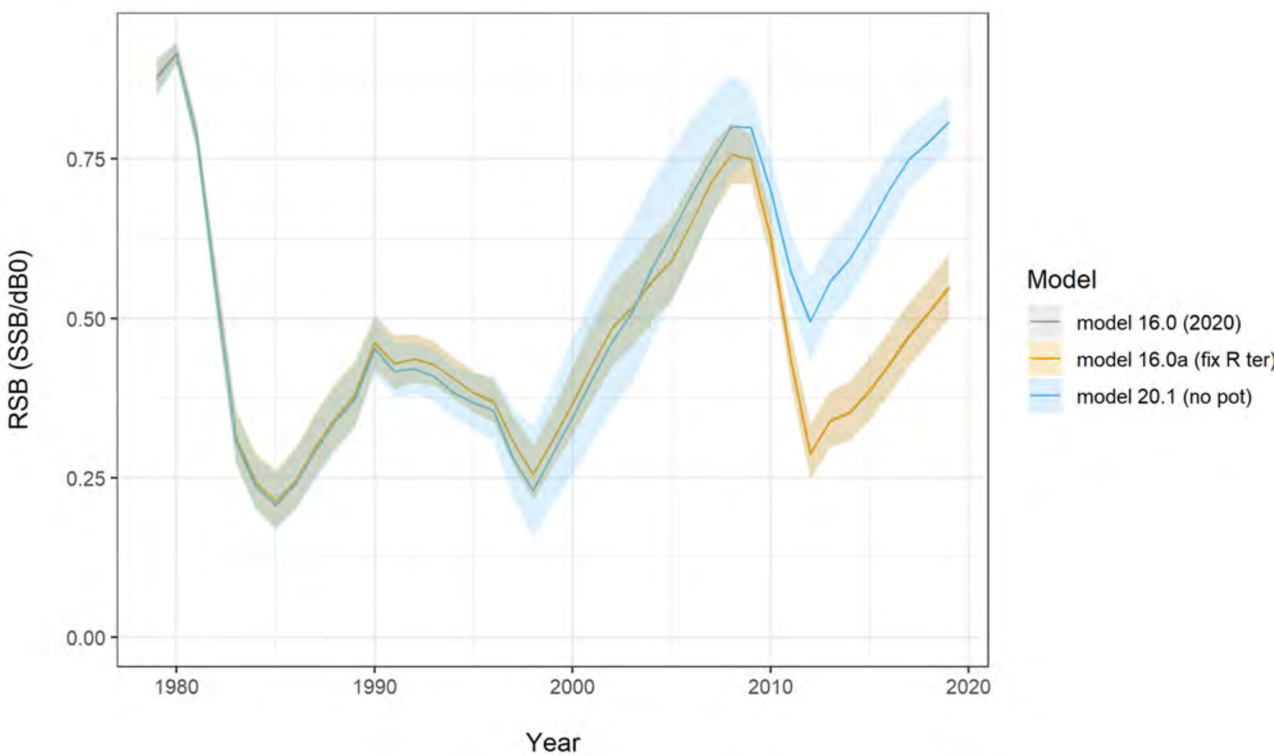


Figure 27: Comparison of mature male biomass relative to the dynamic B zero value, (15 February, 1978-2019) for each of the model scenarios.

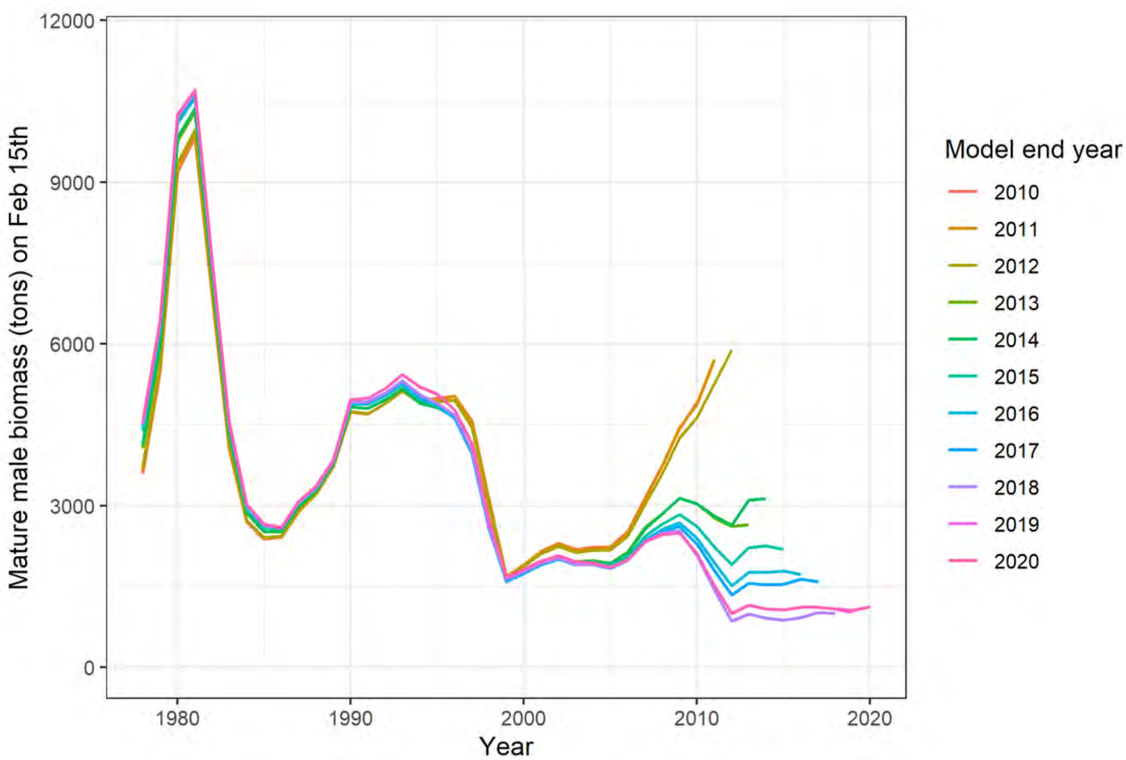


Figure 28: Retrospective pattern in mature male biomass (MMB (t)) for the reference (base) model (16.0), Mohn's rho = -0.346

Appendix A: SMBKC Model Description

1. Introduction

The GMACS model has been specified to account only for male crab $\geq$ 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 inch carapace width (CW), whereas 105 mm CL is the management proxy for mature-male size (state regulation *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 estimated at 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), scaled relative to the portions of the year, is applied in each of these seasons where $\sum_{t=1}^{t=5} \tau_t = 1$. Each model year consists of the following processes with time-breaks denoted here by "Seasons." However, it is important to note that actual seasons are survey-to-fishery, fishery-to Feb 15, and Feb 15 to July 1. The following breakdown accounts for events and fishing mortality treatments:

1. Season 1 (survey period)
    - Beginning of the SMBKC fishing year (1 July)
    - $\tau_1 = 0$
    - Surveys
2. Season 2 (natural mortality until pulse fishery)
    - 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 reftab:smbkc-fishery)
3. Season 3 (pulse fishery)
    - $\tau_3 = 0$
    - fishing mortality applied
4. Season 4 (natural mortality until spawning)
    - $\tau_4 = 0.63 - \sum_{i=1}^{i=4} \tau_i$
    - Calculate MMB (15 February)
5. Season 5 (natural mortality and somatic growth through to June 30th)
    - $\tau_5 = 0.37$
    - 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 20. 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 varies and thus τ_4 varies also.

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

$$\boldsymbol{r}_{t,y} = \begin{cases} 0 & \text{for} \quad t < 5 \\ \bar{R}\phi_l \delta_y^R & \text{for} \quad t = 5. \end{cases} \tag{4}$$

where $\bar{R}$ is the average annual recruitment and δ_y^R are the recruitment deviations each year y

$$\delta_y^R \sim \mathcal{N}\left(0, \sigma_R^2\right). \tag{5}$$

Using boldface upper-case letters to indicate a matrix, we describe the size transition matrix $\boldsymbol{G}$ as

$$\boldsymbol{G} = \left[\begin{array}{ccc} 1 - \pi_{12} - \pi_{13} & \pi_{12} & \pi_{13} \\ 0 & 1 - \pi_{23} & \pi_{23} \\ 0 & 0 & 1 \end{array} \right], \tag{6}$$

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

$$M_{t,y} = \bar{M}\tau_t + \delta_y^M \text{ where } \delta_y^M \sim \mathcal{N}\left(0, \sigma_M^2\right) \tag{7}$$

Fishing mortality by year y and season t is denoted $F_{t,y}$ and calculated as

$$F_{t,y} = F_{t,y}^{\text{df}} + F_{t,y}^{\text{tb}} + F_{t,y}^{\text{fb}} \tag{8}$$

where $F_{t,y}^{\text{df}}$ is the fishing mortality associated with the directed fishery, $F_{t,y}^{\text{tb}}$ is the fishing mortality associated with the trawl bycatch fishery, $F_{t,y}^{\text{fb}}$ is the fishing mortality associated with the fixed bycatch fishery. Each of these are derived as

$$\begin{aligned} F_{t,y}^{\text{df}} &= \bar{F}^{\text{df}} + \delta_{t,y}^{\text{df}} \quad \text{where} \quad \delta_{t,y}^{\text{df}} \sim \mathcal{N}\left(0, \sigma_{\text{df}}^2\right), \\ F_{t,y}^{\text{tb}} &= \bar{F}^{\text{tb}} + \delta_{t,y}^{\text{tb}} \quad \text{where} \quad \delta_{t,y}^{\text{df}} \sim \mathcal{N}\left(0, \sigma_{\text{tb}}^2\right), \\ F_{t,y}^{\text{fb}} &= \bar{F}^{\text{fb}} + \delta_{t,y}^{\text{fb}} \quad \text{where} \quad \delta_{t,y}^{\text{df}} \sim \mathcal{N}\left(0, \sigma_{\text{fb}}^2\right), \end{aligned} \tag{9}$$

where $\delta_{t,y}^{\text{df}}$, $\delta_{t,y}^{\text{tb}}$, and $\delta_{t,y}^{\text{fb}}$ 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

$$\boldsymbol{S}_{t,y} = \left[\begin{array}{ccc} 1 - e^{-Z_{1,t,y}} & 0 & 0 \\ 0 & 1 - e^{-Z_{2,t,y}} & 0 \\ 0 & 0 & 1 - e^{-Z_{3,t,y}} \end{array} \right]. \tag{11}$$

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 21.

4. Model Parameters

Table 22 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 23 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 17). 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

$$\sigma^{\text{I}}_{t,y} = \frac{1}{\lambda}\sqrt{\log\left(1 + \left(CV^{\text{I}}_{t,y}\right)^2\right)} \tag{16}$$

$$\delta^{\text{I}}_{t,y} = \log\left(I^{\text{obs}}/I^{\text{pred}}\right)/\sigma^{\text{I}}_{t,y} + 0.5\sigma^{\text{I}}_{t,y} \tag{17}$$

and the likelihood is

$$\sum \log\left(\delta^{\text{I}}_{t,y}\right) + \sum 0.5\left(\sigma^{\text{I}}_{t,y}\right)^2 \tag{18}$$

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 20: 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
2017	0.00	0.44	0.00	0.19	0.37
2018	0.00	0.44	0.00	0.19	0.37
2019	0.00	0.44	0.00	0.19	0.37

Table 21: 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 and 2016/17 - 2018/19)
Groundfish trawl bycatch biomass	1992/93 - 2018/19	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93 - 2018/19	NMFS groundfish observer program
NMFS trawl-survey biomass index (area-swept estimate) and CV	1978-2019	NMFS EBS trawl survey
ADF&G pot-survey abundance index (CPUE) and CV	1995-2018	ADF&G SMBKC pot survey
NMFS trawl-survey stage proportions and total number of measured crab	1978-2019	NMFS EBS trawl survey
ADF&G pot-survey stage proportions and total number of measured crab	1995-2018	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 and 2016/17 - 2018/19)

Table 22: 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	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 23: 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	3.0	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 2009-2017	0	0.4	1	Uniform(0,1)	3
Stage-2 directed fishery selectivity 2009-2017	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. Data files for the reference model (16.0)

The reference model (16.0) data file for 2020

```
#======================================================================================================
# Gmacs Main  Data  File  Version 1.1:  SM20 Sept 2020 version.
# 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
2019  # End year (updated) last year of fishery does NOT include current survey year
5    # Number of seasons
5    # Number of fleets (fisheries 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
# maximum size-class (males then females)
3
# size_breaks (a vector giving the break points between size intervals with dimension nclass+1)
90  105  120  135
# 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)
0.000   0.070   0.000   0.560   0.370
0.000   0.060   0.000   0.570   0.370
0.000   0.070   0.000   0.560   0.370
0.000   0.050   0.000   0.580   0.370
0.000   0.070   0.000   0.560   0.370
0.000   0.120   0.000   0.510   0.370
0.000   0.100   0.000   0.530   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
```

```
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000 0.440 0.000 0.190 0.370
0.000   0.440   0.000   0.190   0.370 # (updated)
#0  0.0025  0  0.6245  0.373
# Fishing fleet names (delimited with spaces no spaces in names)
Pot_Fishery Trawl_Bycatch Fixed_bycatch
# Survey names (delimited with spaces no spaces in names)
NMFS_Trawl ADFG_Pot
# Are the fleets instantaneous (0) or continuous (1)
1 1 1 1 1
# Number  of  catch data  frames
4
# Number  of  rows  in  each  data  frame
27  18 29  29 #(updated - all should increase 1 if value for current year NO placeholder for direct fishery if closed)
##  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   3     1     1     436126  0.03   1     2     1     0     0.2
1979   3     1     1     52966   0.03   1     2     1     0     0.2
1980   3     1     1     33162   0.03   1     2     1     0     0.2
1981   3     1     1     1045619 0.03   1     2     1     0     0.2
1982   3     1     1     1935886 0.03   1     2     1     0     0.2
1983   3     1     1     1931990 0.03   1     2     1     0     0.2
1984   3     1     1     841017  0.03   1     2     1     0     0.2
1985   3     1     1     436021  0.03   1     2     1     0     0.2
1986   3     1     1     219548  0.03   1     2     1     0     0.2
1987   3     1     1     227447  0.03   1     2     1     0     0.2
1988   3     1     1     280401  0.03   1     2     1     0     0.2
1989   3     1     1     247641  0.03   1     2     1     0     0.2
1990   3     1     1     391405  0.03   1     2     1     0     0.2
1991   3     1     1     726519  0.03   1     2     1     0     0.2
1992   3     1     1     545222  0.03   1     2     1     0     0.2
1993   3     1     1     630353  0.03   1     2     1     0     0.2
1994   3     1     1     827015  0.03   1     2     1     0     0.2
1995   3     1     1     666905  0.03   1     2     1     0     0.2
1996   3     1     1     660665  0.03   1     2     1     0     0.2
1997   3     1     1     939822  0.03   1     2     1     0     0.2
1998   3     1     1     635370  0.03   1     2     1     0     0.2
2009   3     1     1     103376  0.03   1     2     1     0     0.2
2010   3     1     1     298669  0.03   1     2     1     0     0.2
2011   3     1     1     437862  0.03   1     2     1     0     0.2
2012   3     1     1     379386  0.03   1     2     1     0     0.2
2014   3     1     1     69109   0.03   1     2     1     0     0.2
2015   3     1     1     24407   0.03   1     2     1     0     0.2
#2016   3     1     1     10.000  0.03   1     2     1     0     0.2
#2017   3     1     1     10.000  0.03   1     2     1     0     0.2
#2018   3     1     1     10.000  0.03   1     2     1     0     0.2 # placeholder no fishery
# Male  discards  Pot fishery
1990   3     1     1    254.9787861    0.6    2     1     1     0     0.2
1991   3     1     1    531.4483252    0.6    2     1     1     0     0.2
1992   3     1     1    1050.387026    0.6    2     1     1     0     0.2
1993   3     1     1    951.4626128    0.6    2     1     1     0     0.2
1994   3     1     1    1210.764588    0.6    2     1     1     0     0.2
1995   3     1     1    363.112032     0.6    2     1     1     0     0.2
1996   3     1     1    528.5244687    0.6    2     1     1     0     0.2
1997   3     1     1    1382.825328    0.6    2     1     1     0     0.2
1998   3     1     1    781.1032977    0.6    2     1     1     0     0.2
2009   3     1     1    123.3712279    0.2    2     1     1     0     0.2
2010   3     1     1    304.6562225    0.2    2     1     1     0     0.2
2011   3     1     1    481.3572126    0.2    2     1     1     0     0.2
2012   3     1     1    437.3360731    0.2    2     1     1     0     0.2
2014   3     1     1    45.4839749     0.2    2     1     1     0     0.2
2015   3     1     1    21.19378597    0.2    2     1     1     0     0.2
2016   3     1     1    0.021193786    0.2    2     1     1     0     0.2
```

```
2017   3     1     1    0.021193786    0.2    2     1     1     0     0.2
2018   3     1     1    0.214868020    0.2    2     1     1     0     0.2  # (updated)
#   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   0.500   0.31    2   1   1   0   0.8
1997    2   2   1   0.500   0.31    2   1   1   0   0.8
1998    2   2   1   0.500   0.31    2   1   1   0   0.8
1999    2   2   1   0.500   0.31    2   1   1   0   0.8
2000    2   2   1   0.500   0.31    2   1   1   0   0.8
2001    2   2   1   0.500   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   0.500   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   0.638   0.31    2   1   1   0   0.8
2010    2   2   1   0.360   0.31    2   1   1   0   0.8
2011    2   2   1   0.170   0.31    2   1   1   0   0.8
2012    2   2   1   0.011   0.31    2   1   1   0   0.8
2013    2   2   1   0.163   0.31    2   1   1   0   0.8
2014    2   2   1   0.010   0.31    2   1   1   0   0.8
2015    2   2   1   0.010   0.31    2   1   1   0   0.8
2016    2   2   1   0.229   0.31    2   1   1   0   0.8
2017    2   2   1   0.048   0.31    2   1   1   0   0.8 # updated in 2020 was 0.052, now 0.48?
2018    2   2   1   0.001   0.31    2   1   1   0   0.8 # (data is 0 but small value for placeholder)
2019  2 2 1 0.030 0.31  2 1 1 0 0.8 # (updated )
#   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   0.500   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   0.500   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   7.522   0.31    2   1   1   0   0.5
2010    2   3   1   9.564   0.31    2   1   1   0   0.5
2011    2   3   1   0.796   0.31    2   1   1   0   0.5
2012    2   3   1   0.739   0.31    2   1   1   0   0.5
2013    2   3   1   0.341   0.31    2   1   1   0   0.5
2014    2   3   1   0.490   0.31    2   1   1   0   0.5
2015    2   3   1   0.711   0.31    2   1   1   0   0.5
2016    2   3   1   1.630   0.31    2   1   1   0   0.5 # updated from 1.632
2017    2   3   1   5.842   0.31    2   1   1   0   0.5 # updates was 6.032
2018    2   3   1   1.140   0.31    2   1   1   0   0.5 # updated was 1.281
2019  2 3 1 1.038 0.31  2 1 1 0 0.5 # (updated - bycatch_groundfish.R)
##  RELATIVE  ABUNDANCE DATA
##  Units of abundance: 1 = biomass, 2 = numbers
##  for SMBKC pot survey Units are in  crabs for Abundance.
##  Number  of  relative  abundance indicies
2
##  Number  of  rows  in  each  index
53
# Survey data (abundance indices, units are mt for trawl survey and crab/potlift for pot survey)
#   Year,   Seas,   Fleet,  Sex,    Maturity,   Abundance,  CV  units
1   1978    1   4   1   0   6832.819    0.394   1
```

```
1   1979    1   4   1   0   7989.881    0.463   1
1   1980    1   4   1   0   9986.83 0.507   1
1   1981    1   4   1   0   6551.132    0.402   1
1   1982    1   4   1   0   16221.933   0.344   1
1   1983    1   4   1   0   9634.25 0.298   1
1   1984    1   4   1   0   4071.218    0.179   1
1   1985    1   4   1   0   3110.541    0.21    1
1   1986    1   4   1   0   1416.849    0.388   1
1   1987    1   4   1   0   2278.917    0.291   1
1   1988    1   4   1   0   3158.169    0.252   1
1   1989    1   4   1   0   6338.622    0.271   1
1   1990    1   4   1   0   6730.13 0.274   1
1   1991    1   4   1   0   6948.184    0.248   1
1   1992    1   4   1   0   7093.272    0.201   1
1   1993    1   4   1   0   9548.459    0.169   1
1   1994    1   4   1   0   6539.133    0.176   1
1   1995    1   4   1   0   5703.591    0.178   1
1   1996    1   4   1   0   9410.403    0.241   1
1   1997    1   4   1   0   10924.107   0.337   1
1   1998    1   4   1   0   7976.839    0.355   1
1   1999    1   4   1   0   1594.546    0.182   1
1   2000    1   4   1   0   2096.795    0.31    1
1   2001    1   4   1   0   2831.44 0.245   1
1   2002    1   4   1   0   1732.599    0.32    1
1   2003    1   4   1   0   1566.675    0.336   1
1   2004    1   4   1   0   1523.869    0.305   1
1   2005    1   4   1   0   1642.017    0.371   1
1   2006    1   4   1   0   3893.875    0.334   1
1   2007    1   4   1   0   6470.773    0.385   1
1   2008    1   4   1   0   4654.473    0.284   1
1   2009    1   4   1   0   6301.47 0.256   1
1   2010    1   4   1   0   11130.898   0.466   1
1   2011    1   4   1   0   10931.232   0.558   1
1   2012    1   4   1   0   6200.219    0.339   1
1   2013    1   4   1   0   2287.557    0.217   1
1   2014    1   4   1   0   6029.22 0.449   1
1   2015    1   4   1   0   5877.433    0.77    1
1   2016    1   4   1   0   3485.909    0.393   1
1   2017    1   4   1   0   1793.76 0.599   1
1   2018    1   4   1   0   1730.742    0.281   1
1   2019    1   4   1   0   3170.467    0.337   1   #   (updated    -   EBSsurvey_analysis.R)
2   1995    1   5   1   0   12042   0.13    2
2   1998    1   5   1   0   12531   0.06    2
2   2001    1   5   1   0   8477    0.08    2
2   2004    1   5   1   0   1667    0.15    2
2   2007    1   5   1   0   8643    0.09    2
2   2010    1   5   1   0   10209   0.13    2
2   2013    1   5   1   0   5643    0.19    2
2   2015    1   5   1   0   2805    0.18    2
2   2016    1   5   1   0   2378    0.186   2
2   2017    1   5   1   0   1689    0.25    2
2   2018    1   5   1   0   745 0.14    2   #   no  smbkc   pot survey  in  2019
##  Number  of  length  frequency matrices
3
##  Number  of  rows  in  each  matrix
15  42  11 # (updated)
##  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  3 1 1 0 0 0 15  0.1133  0.3933  0.4933
  1991  3 1 1 0 0 0 25  0.1329  0.1768  0.6902
  1992  3 1 1 0 0 0 25  0.1905  0.2677  0.5417
  1993  3 1 1 0 0 0 25  0.2807  0.2097  0.5096
  1994  3 1 1 0 0 0 25  0.2942  0.2714  0.4344
  1995  3 1 1 0 0 0 25  0.1478  0.2127  0.6395
```

```
  1996  3 1 1 0 0 0 25  0.1595  0.2229  0.6176
  1997  3 1 1 0 0 0 25  0.1818  0.2053  0.6128
  1998  3 1 1 0 0 0 25  0.1927  0.2162  0.5911
  2009  3 1 1 0 0 0 50  0.1413  0.3235  0.5352
  2010  3 1 1 0 0 0 50  0.1314  0.3152  0.5534
  2011  3 1 1 0 0 0 50  0.1314  0.3051  0.5636
  2012  3 1 1 0 0 0 50  0.1417  0.3178  0.5406
  2014  3 1 1 0 0 0 50  0.0939  0.2275  0.6786
  2015  3 1 1 0 0 0 50  0.1148  0.2518  0.6333 #no fishery so not updated
##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
  2017  1 4 1 0 0 0 21  0.0849  0.2994  0.6157
  2018  1 4 1 0 0 0 31  0.1475  0.2219  0.6306
  2019  1 4 1 0 0 0 50  0.1961  0.2346  0.5692 # no survey so not updated
  ##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
  2017  1 5 1 0 0 0 100  0.1048  0.2540  0.6412
  2018  1 5 1 0 0 0 100  0.10201 0.21611 0.68188 # no survey so not updated
##  Growth data (increment)
# Type of growth increment (0=ignore;1=growth increment with a CV;2=size-at-release; size-at)
0
# nobs_growth
0
#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
## eof
9999
```

The reference model (16.0) control file for 2020

```
## ============================================= updated for sept 2020 base model     ##
## LEADING PARAMETER CONTROLS                                                          ##
# 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)
  13.39     -7.0       20        1      0    -7       20         # log(Rbar) (MUST be PHASE 1)
  80.0      30.0      310       -2      1    72.5    7.25        # Recruitment size distribution expected value
  0.25       0.1        7       -4      0    0.1     9.0         # Recruitment size scale (variance component)
  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 numbers at length
 14.0       5.00    20.00        1      0    5.00  20.00         # logN0 vector of initial numbers at length
 13.5       5.00    20.00        1      0    5.00  20.00         # logN0 vector of initial numbers at length

# weight-at-length input method (1 = allometry i.e. w_l = a*l^b, 2 = vector by sex, 3 = matrix by sex)
3
# 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
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932 # (updated - should this change?)
# Proportion mature by sex
0 1 1
# Proportion legal by sex
0 0 1

## GROWTH PARAM CONTROLS                                                                   ##
# Use custom transition matrix (0=no, 1=growth matrix, 2=transition matrix, i.e. growth and molting)
1
# growth increment model (0=prespecified;1=alpha/beta; 2=estimated by size-class;3=pre-specified/emprical)
0
# molt probability function (0=pre-specified; 1=flat;2=declining logistic)
2
# Maximum size-class for recruitment(males then females)
1
## number of size-increment periods
1
## Two lines for each parameter if split sex, one line if not                              ##
## number of molt periods
1
## Year(s) molt period changes (blank if no changes)
## Beta parameters are relative (1=Yes;0=no)
1
## ===================================================================================== ##
# 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

# The custom growth matrix (if not using just fill with zeros)
# Alternative TM (loosely) based on Otto and Cummiskey (1990)
   0.1761   0.0000   0.0000
   0.7052   0.2206   0.0000
   0.1187   0.7794   1.0000
#   0.1761   0.7052   0.1187
#   0.0000   0.2206   0.7794
#   0.0000   0.0000   1.0000

# custom molt probability matrix


## ===================================================================================== ##
## 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
```

```
   0        0        0        0        0         # within another gear
   0        0        0        0        0         # extra parameters
## 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        6        6        6        6         # male retention type
   1        0        0        0        0         # male retention flag (0 -> no, 1 -> yes)
   0        0        0        0        0         # extra parameters
## 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    -2     1978   2008
   1     1     1   0    0.4    0.001 1.0    0       0      1    3     2009   2019 # update end yr
   1     2     2   0    0.4    0.001 1.0    0       0      1    3     2009   2019 # update end yr
   1     3     3   0    1.0    0.001 2.0    0       0      1    -2     2009   2019 # update end yr
# Gear-2
   2     7     1   0    40      10.0  200    0      10    200   -3     1978   2019 # update end yr
   2     8     2   0    60      10.0  200    0      10    200   -3     1978   2019 # update end yr
# Gear-3
   3     9     1   0    40      10.0  200    0      10    200   -3     1978   2019 # update end yr
   3    10     2   0    60      10.0  200    0      10    200   -3     1978   2019 # update end yr
# Gear-4
   4     11    1   0    0.7     0.001 1.0    0       0      1   4     1978   2020 # update end yr
   4     12    2   0    0.8     0.001 1.0    0       0      1   4     1978   2020 # update end yr
   4     13    3   0    0.9     0.001 1.0    0       0      1   -5     1978   2020 # update end yr
# Gear-5
   5     14    1   0    0.4     0.001 1.0    0       0      1   4     1978   2020 # update end yr
   5     15    2   0    0.7     0.001 1.0    0       0      1   4     1978   2020 # update end yr
   5     16    3   0    1.0     0.001 2.0    0       0      1   -2     1978   2020 # update end yr
## Retained
# Gear-1
  -1     17    1   0    120        50 200    0      1    900    -7     1978   2019 # update end yr
  -1     18    2   0    123       110 200    0      1    900    -7     1978   2019 # update end yr
# Gear-2
  -2     19    1   0   595    1    999    0      1    999   -3     1978   2019 # update end yr
# Gear-3
  -3     20    1   0   595    1    999    0      1    999   -3     1978   2019 # update end yr
# Gear-4
  -4     21    1   0   595    1    999    0      1    999   -3     1978   2020 # update end yr
# Gear-5
  -5     22    1   0   595    1    999    0      1    999   -3     1978   2020 # update end yr

# Number of asymptotic parameters
1
# Fleet   Sex     Year       ival  lb   ub    phz
      1     1     1978   0.000001   0    1     -3

## ==================================================================================== ##
## 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 Emphasis
   1.0     0.5     1.2   -4    0       0        9.0   0           1             1 # NMFS trawl
 0.003      0        5     3    0       0        9.0   0           1             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 (PHASE -4)
```

```
   0.0000001      0.00000001   10.0      -4    4         1.0     100   # ADF&G
## ================================================================================ ##

## ================================================================================ ##
## PENALTIES FOR AVERAGE FISHING MORTALITY RATE FOR EACH GEAR
## ================================================================================ ##
## Mean_F   Female Offset STD_PHZ1   STD_PHZ2   PHZ_M   PHZ_F Fbar_l Fbar_h Fdev_L Fdev_h Foff_l Foff_h
   0.2             0.0     3.0      50.0       1       -1     -12     4     -10     10    -10     10  # Pot
   0.0001          0.0     4.0      50.0       1       -1     -12     4     -10     10    -10     10  # Trawl
   0.0001          0.0     4.0      50.0       1       -1     -12     4     -10     10    -10     10  # Fixed
   0.00            0.0     2.00     20.00     -1       -1     -12     4     -10     10    -10     10  # NMFS
   0.00            0.0     2.00     20.00     -1       -1     -12     4     -10     10    -10     10  # 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
  1   1   1   # Emphasis
## ================================================================================ ##

## ================================================================================ ##
## 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
6
## Phase of estimation (only use if parameters are default)
3
## 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
## Number of Breakpoints in M by size
0
## Size-class of breakpoint
#3
## Specific initial values for the natural mortality devs (0-no, 1=yes)
1
## ==================================================================================== ##
## ival        lb        ub        phz   extra    prior     p1      p2        # parameter     ##
## ==================================================================================== ##
 1.600000      0         2         3      0                        # Males
 0.000000     -2         2       -99      0                        # Dummy to retun to base value
# 2.000000      0         4        -1      0                        # Size-specific M
## ================================================================================ ##

## ================================================================================ ##
```

```
## OTHER CONTROLS
## ==================================================================================== ##
1978      # First rec_dev
2019      # last rec_dev (updated annually)
   3      # Estimated rec_dev phase
  -3      # Estimated sex_ratio
 0.5      # initial sex-ratio
  -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)
   1      # Lambda (proportion of mature male biomass for SPR reference points)
   0      # Stock-Recruit-Relationship (0 = None, 1 = Beverton-Holt)
  10      # Maximum phase (stop the estimation after this phase).
  -1      # Maximum number of function calls
## ==================================================================================== ##
## EMPHASIS FACTORS (CATCH)
## ==================================================================================== ##
#Ret_POT Disc_POT Disc_trawl Disc_fixed
       1        1          1          1

## ==================================================================================== ##
## EMPHASIS FACTORS (Priors)
## ==================================================================================== ##
# Log_fdevs   meanF       Mdevs  Rec_devs Initial_devs Fst_dif_dev Mean_sex-Ratio
      10000       1           1         1            0           0              1             #(10000)
## EOF
9999
```

Appendix C. Assessing uncertainty in model output due to lack of terminal year survey data for St. Matthew blue king crab (SMBKC)

Introduction

NMFS trawl surveys during the summer of 2020 were cancelled due to logistic difficulties caused by the global pandemic COVID-19. Therefore, the crab assessment authors met to discuss approaches to address the potential of additional uncertainty in the current year models - specifically the projected mature male biomass and associated reference points. The objective of these approaches/simulations was to provide the crab plan team (CPT) and the scientific and statistical committee (SSC) a range of potential additional uncertainty that could be applied to the buffers used on the OFL calculations to produce an appropriate ABC for the 2020/21 crab season.

Objectives

```
1. Can we characterize the additional uncertainty in the current years estimates due to
the lack of terminal year survey data? If so, what does it look like?

2. Is the model uncertainty characterized in objective #1 currently included in the ABC
buffer applied to this stock or do we need to apply additional uncertainty measures?
```

Approaches

Approach 1 (and 2): retrospective patterns with and without terminal survey data

Retrospective analysis are typically performed on models to characterize the tendencies of a model to over or under estimate current trends in biomass, recruitment, etc. Retrospective patterns are described as a clear tendency for a model to either over or under estimate. Approach 1 compares the output of retrospective models with the terminal year of survey data and ones where the terminal year of trawl survey data are removed (both abundance and size composition data). Approach 2 was to do this for the last year's model - 2019 - which is included in the analysis.

A number of key model outputs were compared for these retrospective runs. These include: average recruitment, B_{msy}, status of the stock, terminal year MMB, and reference point calculations (OFL).

Results

Retrospective analysis of the base model show a retrospective pattern that tends to overestimate mature male biomass (MMB) in the terminal year (Figure 1 and 2). Using a peel of the last 5 years estimates of MMB the estimated Mohn's ρ is -0.346, which suggests a retrospecive pattern in the MMB estimates for the base model. Since 2018 the MMB estimates have been relatively stable, however, they are the lowest in the model history and reflect a time of overfished declaration for the stock.

In general, models that lacked the terminal year of survey data performed similarly to models with the survey data for each model end year (Figure 3). In cases where the model outputs differed the model without the terminal year of survey data tended to have results similar to the previous years model. For the last 5 years of retrospective model runs the models with and without the terminal year of survey data performed very similarly. These results support the hypothesis that for SMBKC in the last few years no additional uncertainty is present in the mmb estimates with the lack of the terminal year survey data (Figure 4).

Figures 5 through 10 display the small differences between these model runs in each model end year. There are some small differences in the model with and without the terminal year of survey data, but most of these exist around between 2013 and 2015 where the population was transitioning from healthy levels to overfished. This is most evident in the terminal MMB, F_{OFL}, and OFL comparisons for 2013 (Figures 6, 9, and 10).

Hypothetically if the uncertainty about the quantities of interest increased due to the lack of a terminal year of survey data the resuling average CVs for the quantities would be larger in runs without the terminal year of survey data. Table 2 summarises the average CVs over all years for the "normal" retrospective runs and those without the terminal year of survey data. There are small differences in the average CVs, with those in the "missing survey" retrospective runs being slightly larger on average, but this difference is small and does not suggest increase uncertainty in the "missing survey" runs.

The average percent difference between these quantities was approximately 1% overall and was the highest in OFL comparisons at an average difference of 4% (Table 1). Most differences were small and even unnoticeable in years where the population trajectory was similar to the previous year. The underlying model processes (growth, mortality, selectivity, etc.) drive the current year's model estimates without the presence of new abundance or size data, and the uncertainty about these processes has not increased with the lack of one year of survey data.
Based on this analysis the author does not recommend additional uncertainty in the ABC buffer for SMBKC for the 2020 base model.

Approach 3: encompassing expected variability

This approach was designed to run models with "fake" 2020 data to determine how much a data point in 2020 could have potential influenced the model outcome. The same key model outputs were compared in this approach as in approach 1.

This approach evaluates the impact of different hypothetical 2020 survey outcomes, and is based on a SSC recommendation in its June minutes. Using the NMFS trawl survey time series fit in the proposed base or reference model the multiplicative residuals were calculated (predicted survey fit/observed survey data point) for each year. The 25th and 75th percentiles of the multiplicative residual distribution were obtained, which would represent a typical low and high value for the survey (Martin Dorn per comm.).

A predicted survey value was obtained for 2020 by running the base model with a hypothetical survey value with a very high CV (100), so that the model did not attempt to fit the observation. For SMBKC the hypothetical survey value was an average of the last 4 years of the survey to best estimate the hypothetical 2020 data point even though the CV for this data point was large. Once the base model was fit with this hypothetical data point the resulting estimate for the 2020 survey was used to complete two additional model runs. These runs multiplied the predicted 2020 survey data point by the 25th and 75th percentiles of the multiplicative residuals to simulate a "low" and "high" survey data point. The CV for these runs was set equal to the median survey CV. These two runs were evaluated along side the 2020 base model to determine the sensitivity of model output and management quantities on the 2020 survey data point.

Results

Overall, the model output and management quantities did not differ much between the base and the low and high hypothetical survey data runs for 2020 (Figure 11 and Table 3).

The estimated mature male biomass trend was the same, with little difference evident when viewing the entire time series (Figure 12). A detailed view of the last 10 years is provided for the MMB estimates in order to view the small difference in the three model estimates. The trends are all similar, with the only difference being the scale of the MMB estimate in the last 7 years (Figure 13). In reference to the base model the "high" run increased the MMB by a very small amount, where the "low" run decreased the MMB trend by about twice as much. All model estimates were very similar and within the typical range of uncertainty of the base model (Figure 14). Based on this analysis the author does not recommend additional uncertainty in the ABC buffer for SMBKC for the 2020 base model.

Recommendations on uncertainty

The analysis performed in this appendix, including the general retrospective analysis, suggest that no additional uncertainty is neccessary for SMBKC. Any additional variability in the model estimates from not having a survey data point in 2020 would like produce a small change in the calculated 2020 OFL. The current buffer of 20% includes the expected uncertainty in the model output that is observed in the retrospective analysis, adding to this uncertainty does not appear neccessary at this time.

The current status of the stock is still overfished, and the directed fishery is closed. The only harvest for this stock comes from bycatch in the groundfish and other crab fisheries which occurs at very low levels. While increasing the buffer on the ABC would not impact these fisheries, it also does not appear neccessary to keep the bycatch numbers well below the projected ABC.

Figures

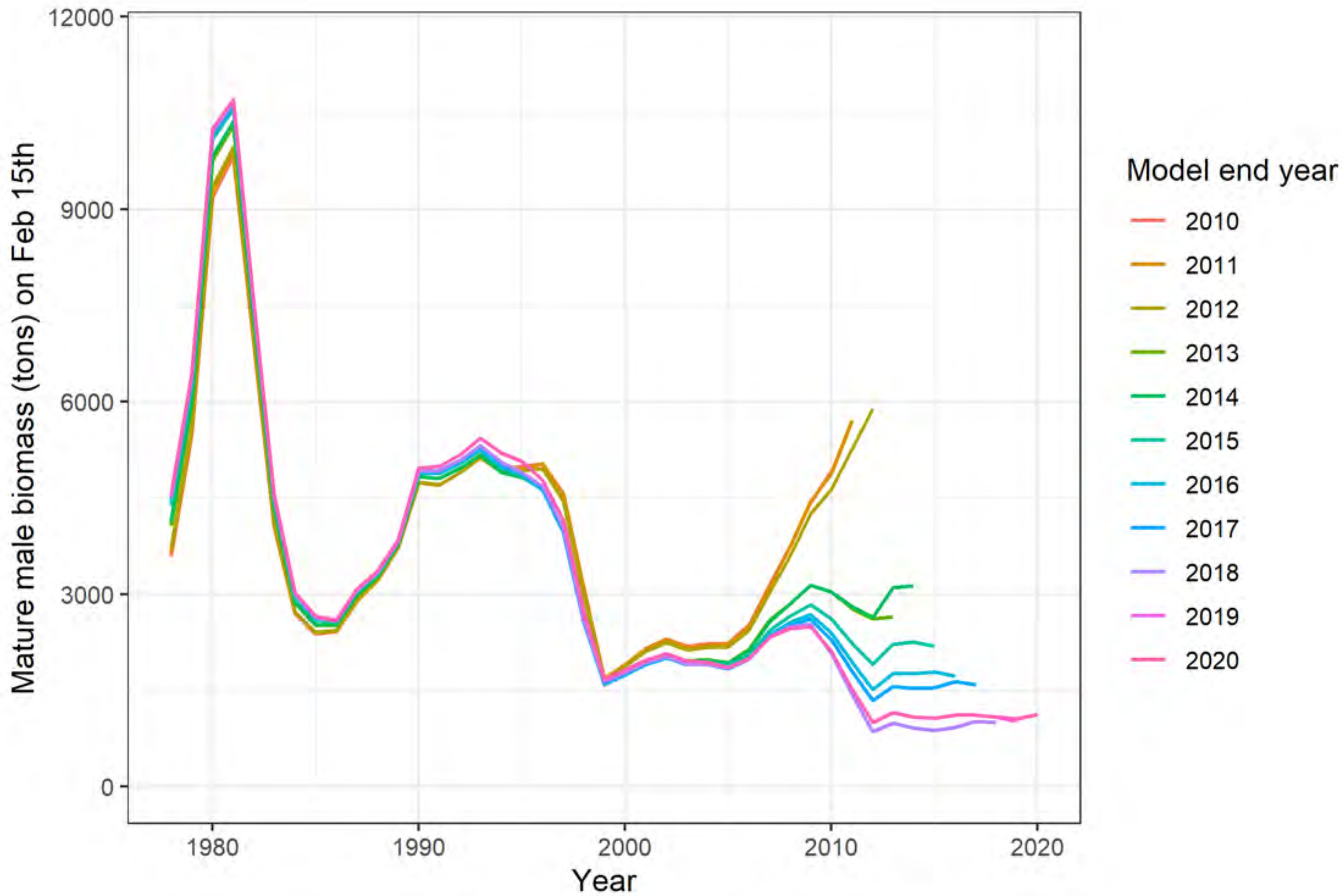


Figure 1: Retrospective run estimates of mature male biomass (mmb) for the SMBKC reference model (16.0) for the last 10 years.

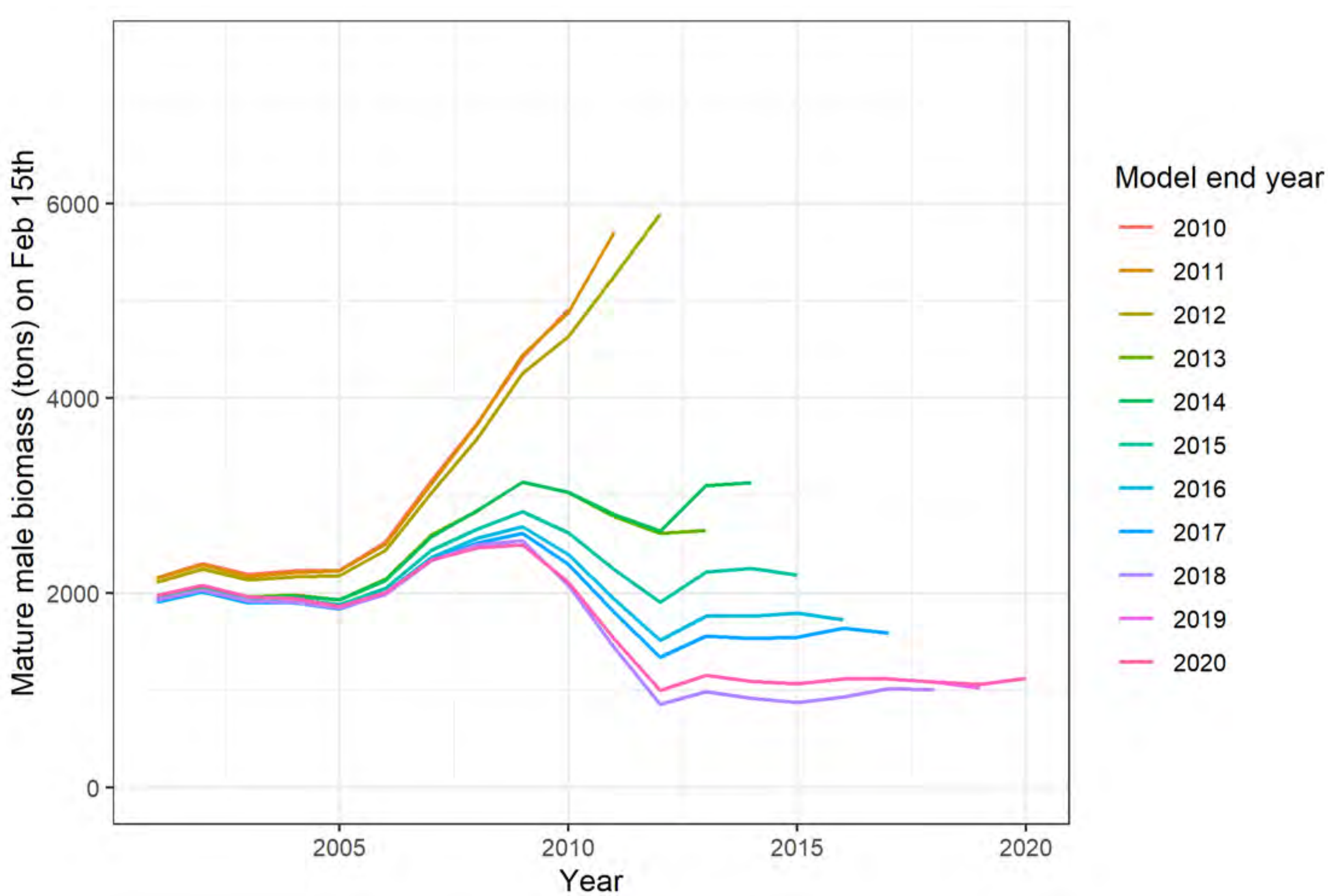


Figure 2: Retrospective run estimates of mature male biomass (mmb) for the SMBKC reference model (16.0) for the last 10 years, only showing the last 20 years for a detailed view.

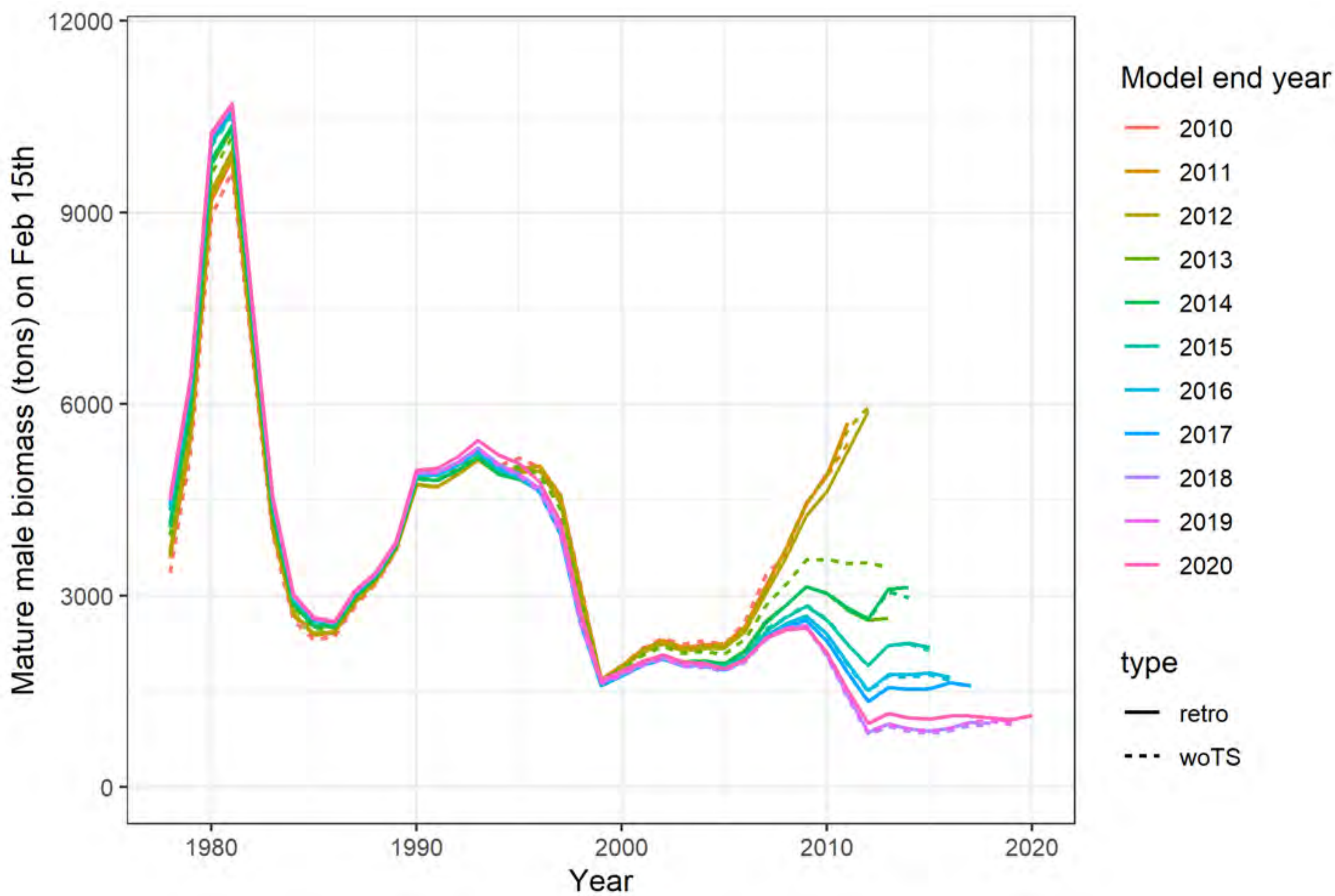


Figure 3: Retrospective run estimates of mature male biomass (mmb) for the SMBKC reference model (16.0) including models that eliminated the terminal year survey data.

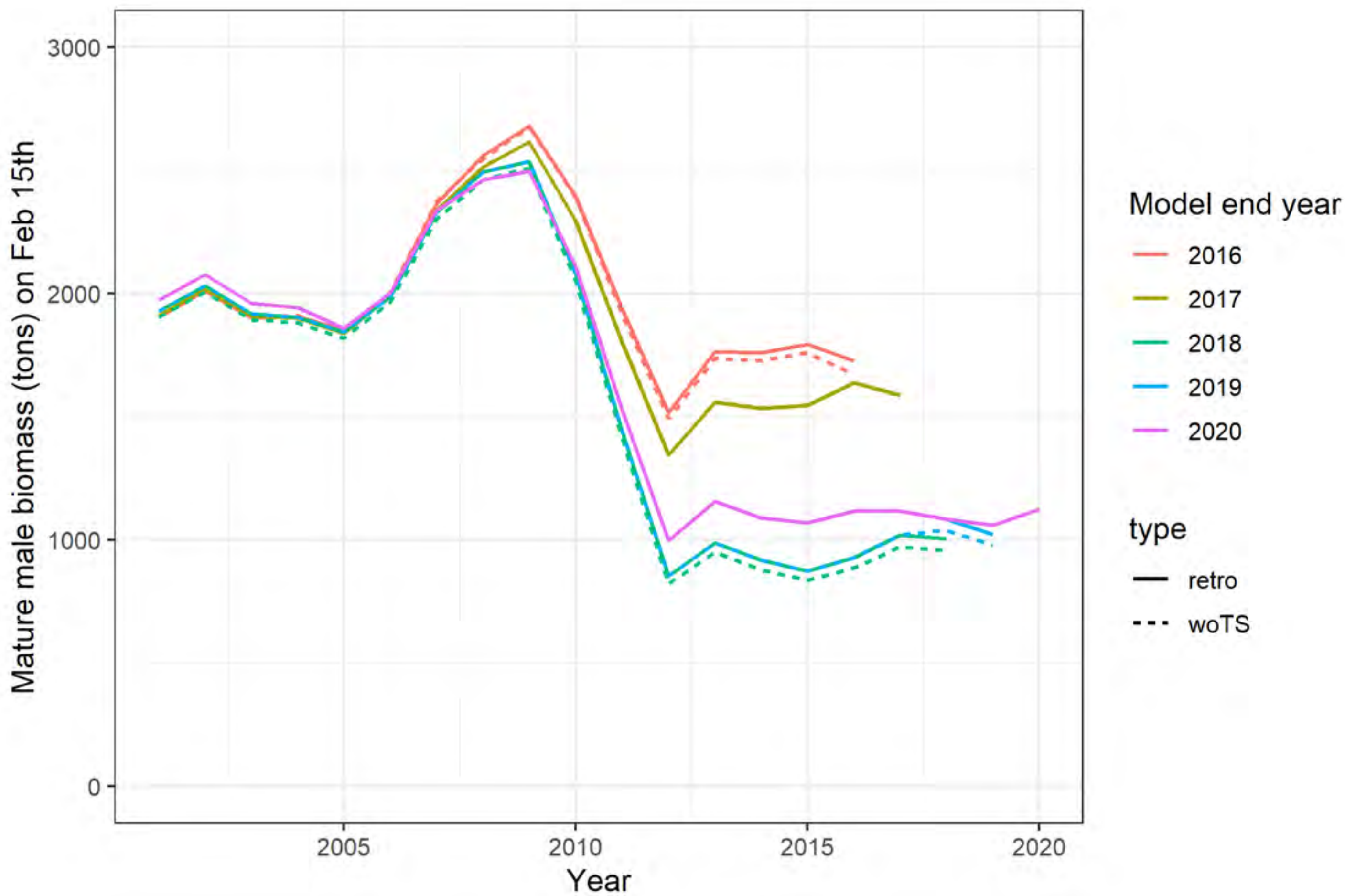


Figure 4: Retrospective run estimates of mature male biomass (mmb) for the SMBKC reference model (16.0) including models that eliminated the terminal year survey data for the last 5 model years. Highlighting the last 20 years for a more detailed view.

Figure 5: Comparison of average recruitment model estimates from 'normal' retrospective runs and those without the terminal year survey data.

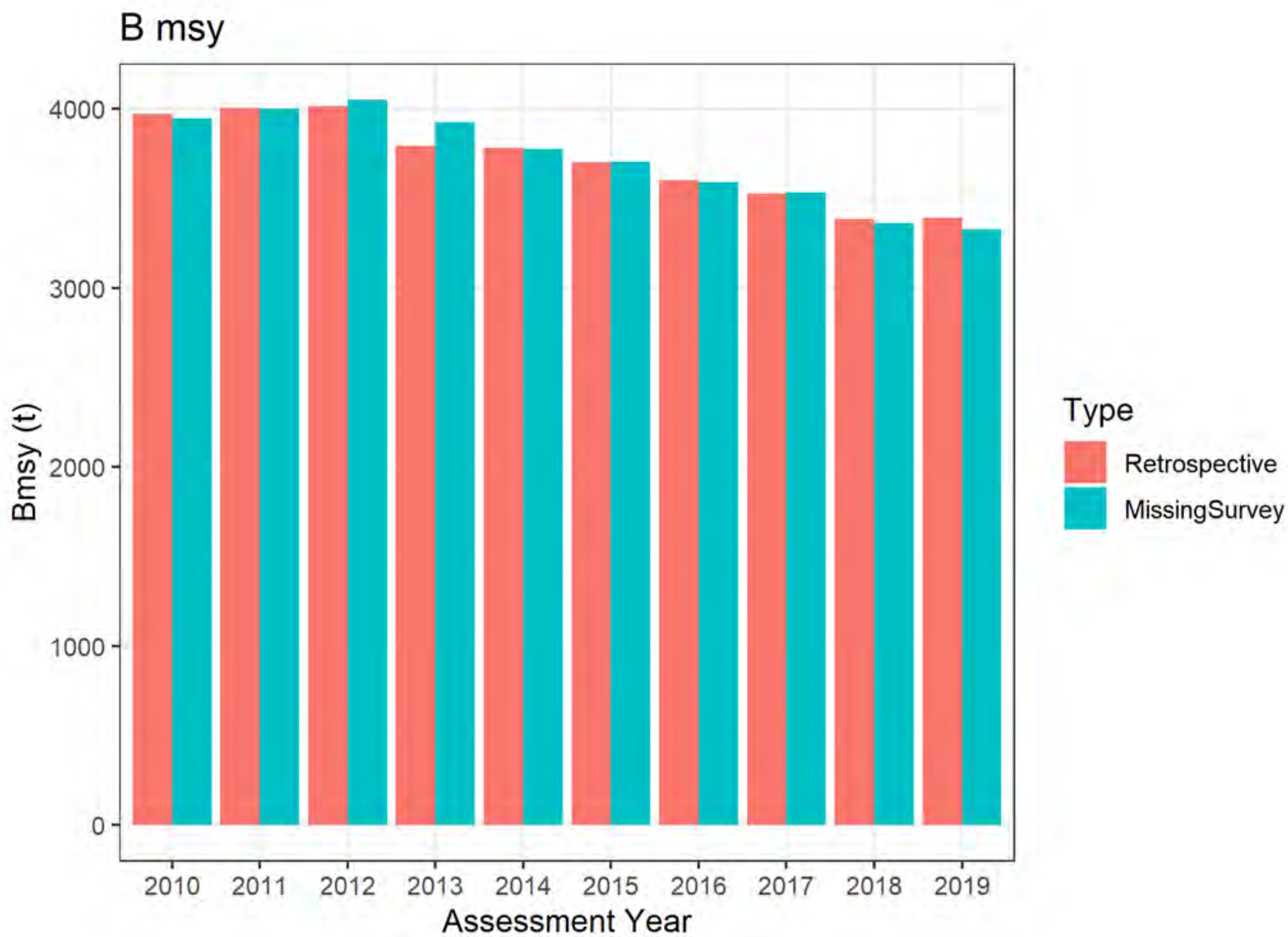


Figure 6: Comparison of Bmsy model estimates from 'normal' retrospective runs and those without the terminal year survey data.

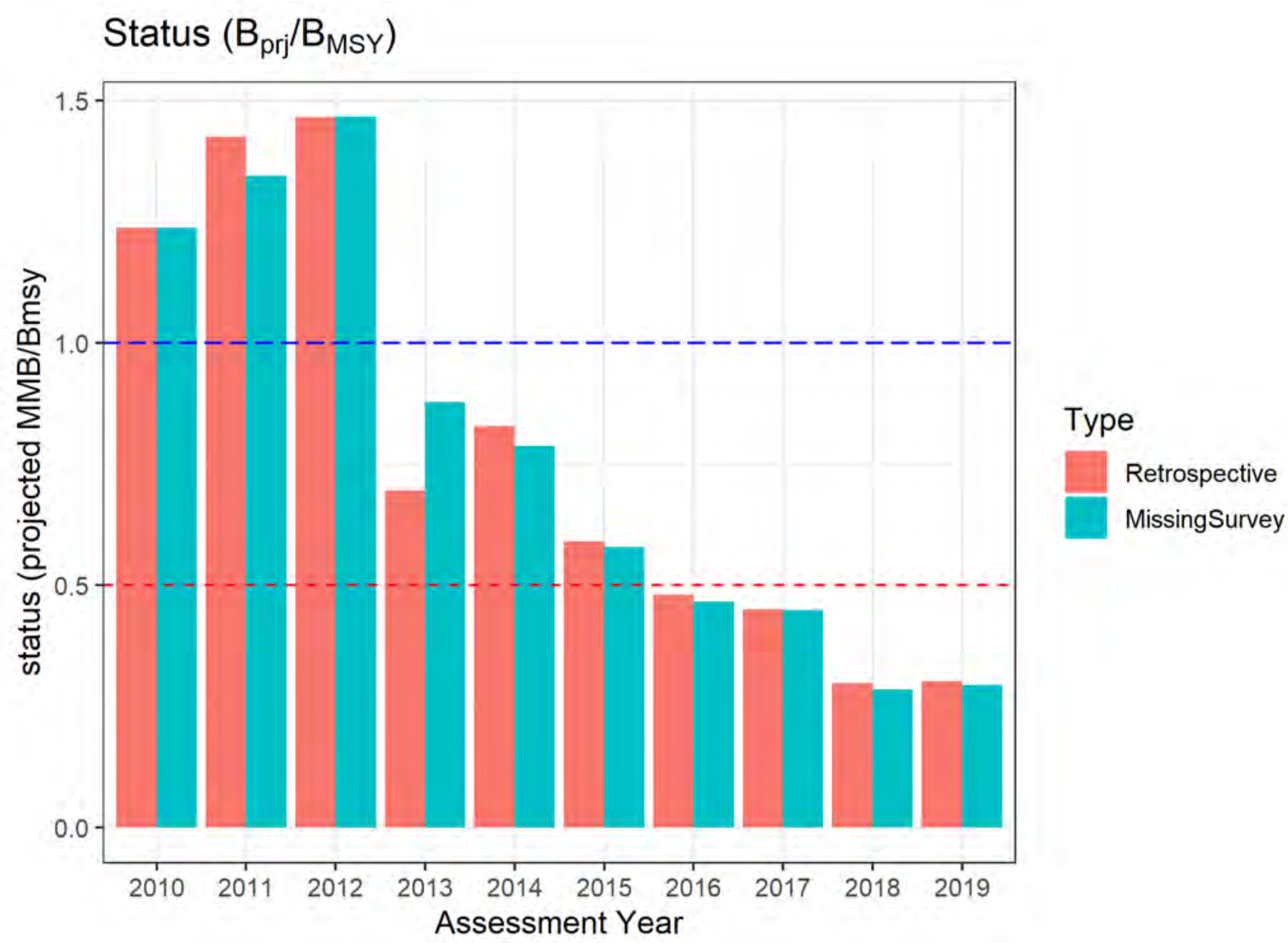


Figure 7: Comparison of the model estimate of 'status' (B/Bmsy) from 'normal' retrospective runs and those without the terminal year survey data.

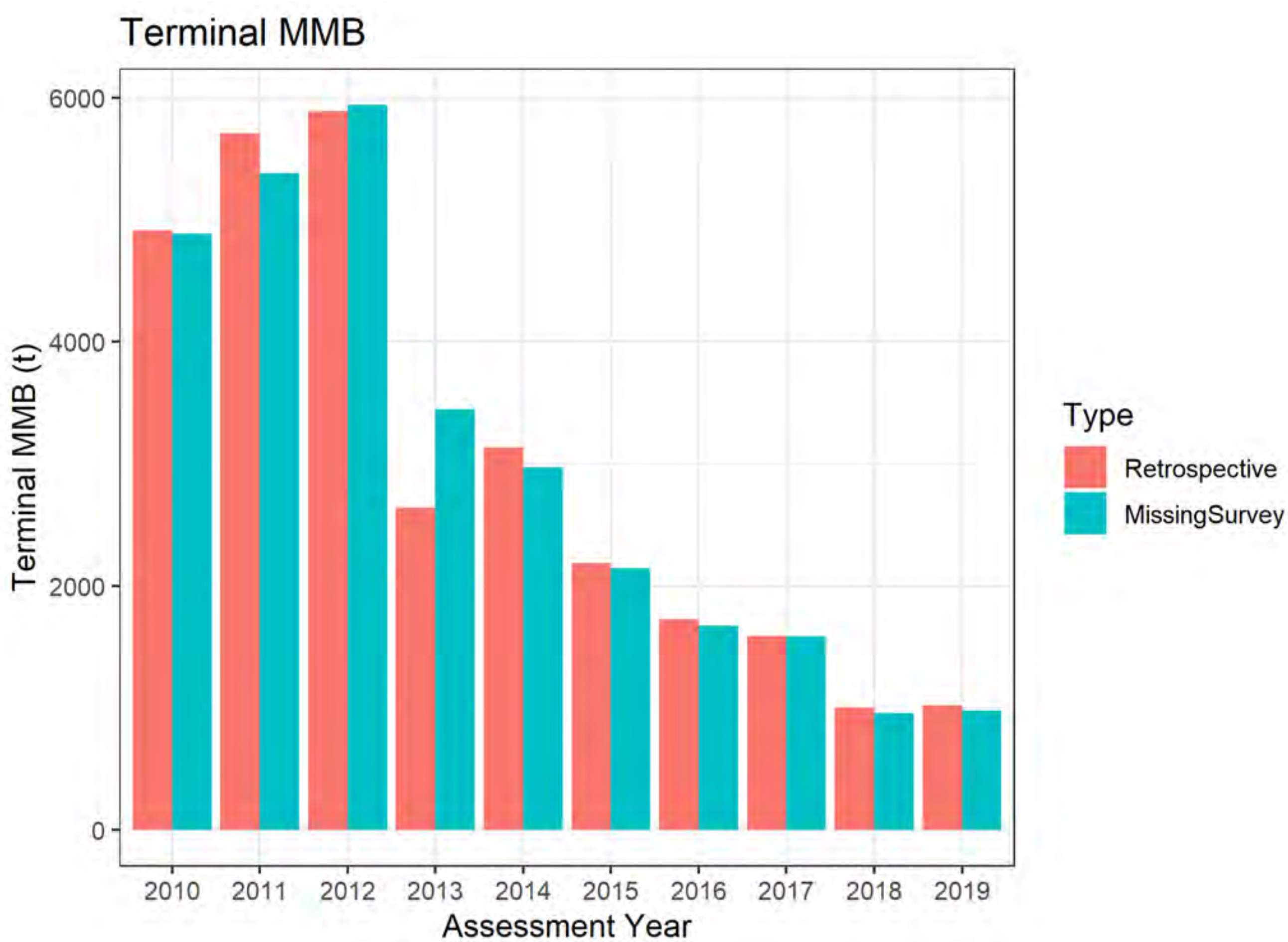


Figure 8: Comparison of the model estimate of terminal year mmb from 'normal' retrospective runs and those without the terminal year survey data.

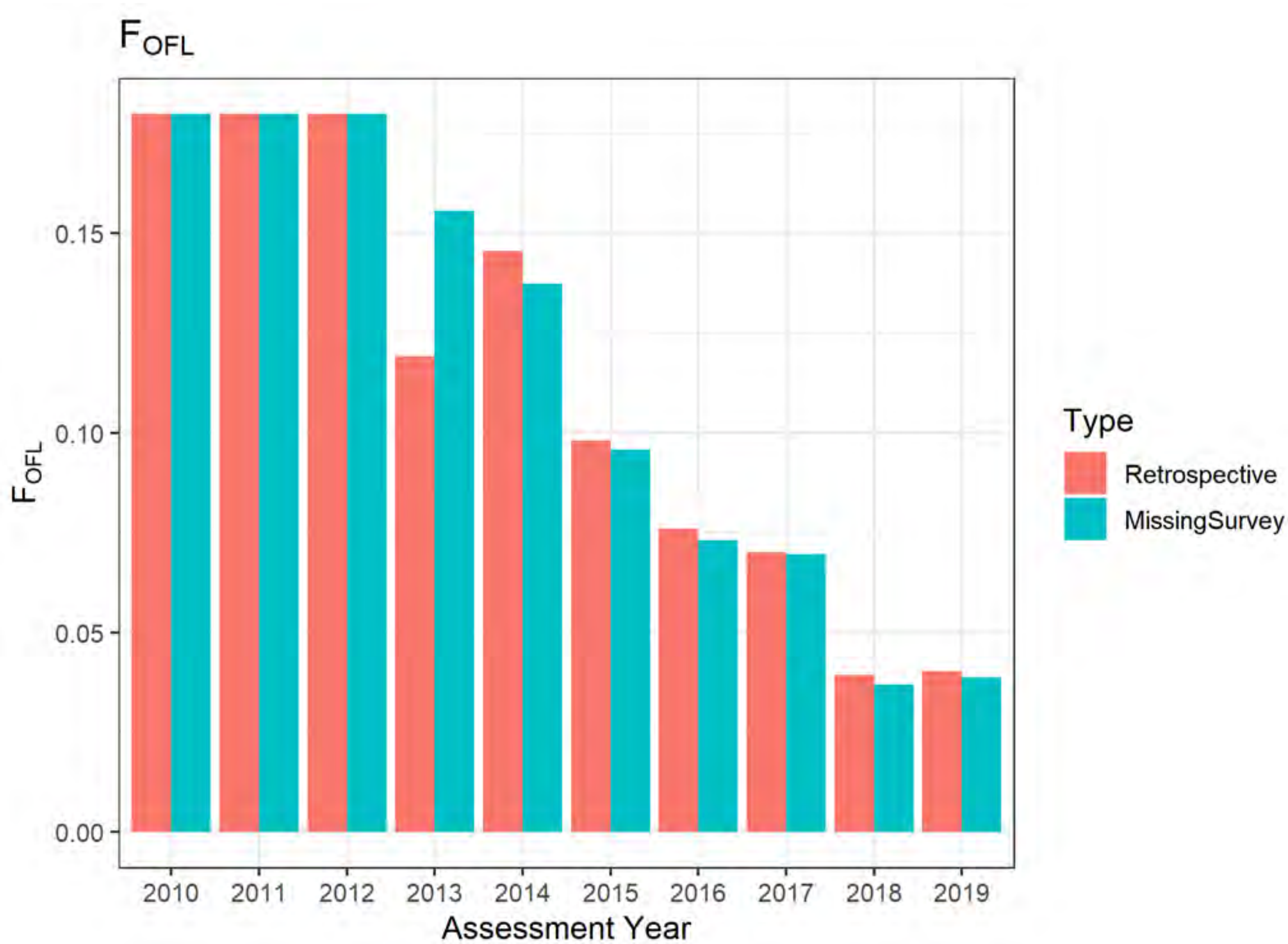


Figure 9: Comparison of the model estimate of fofl from 'normal' retrospective runs and those without the terminal year survey data.

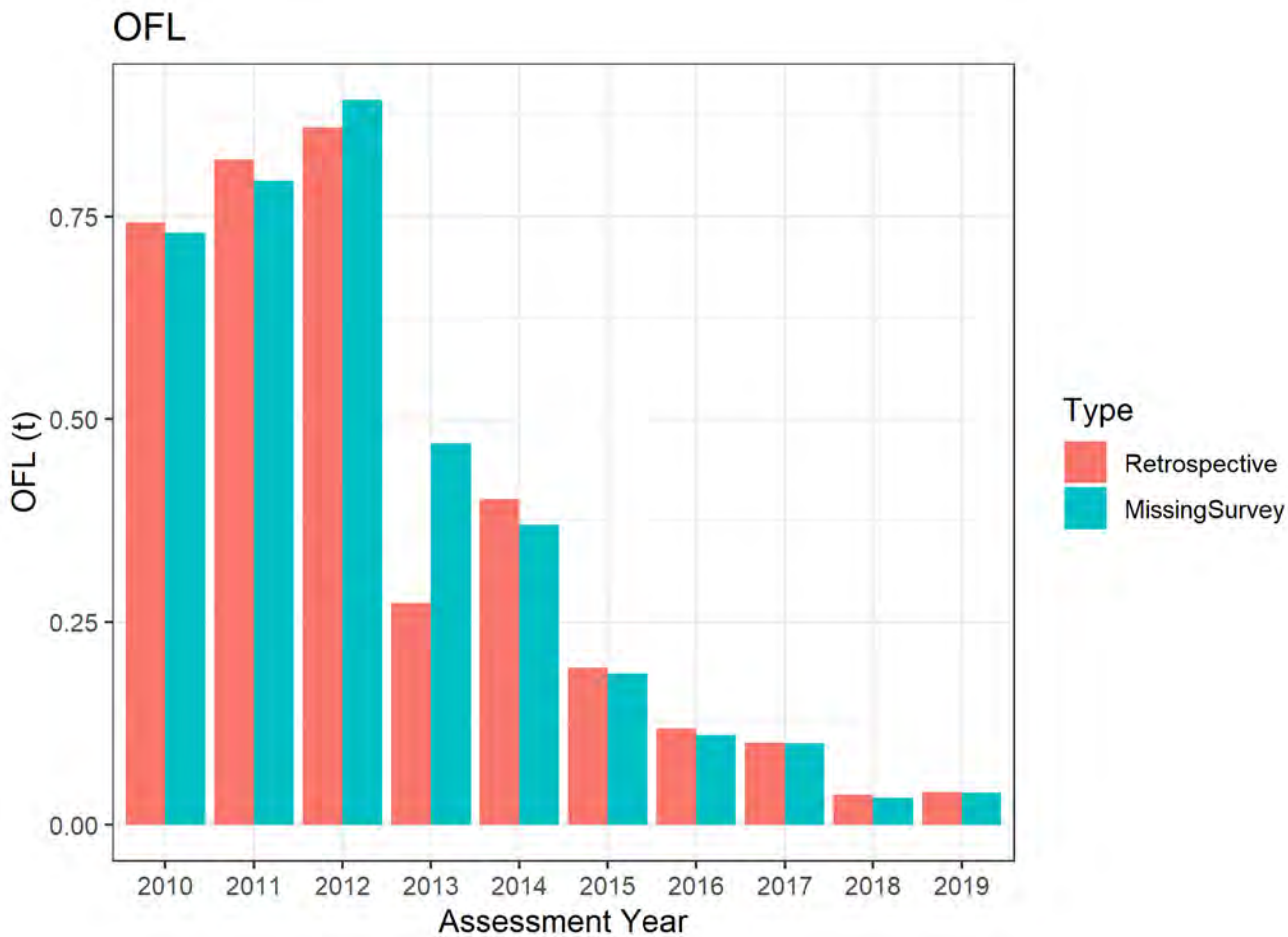


Figure 10: Comparison of the model estimate of OFL from 'normal' retrospective runs and those without the terminal year survey data.

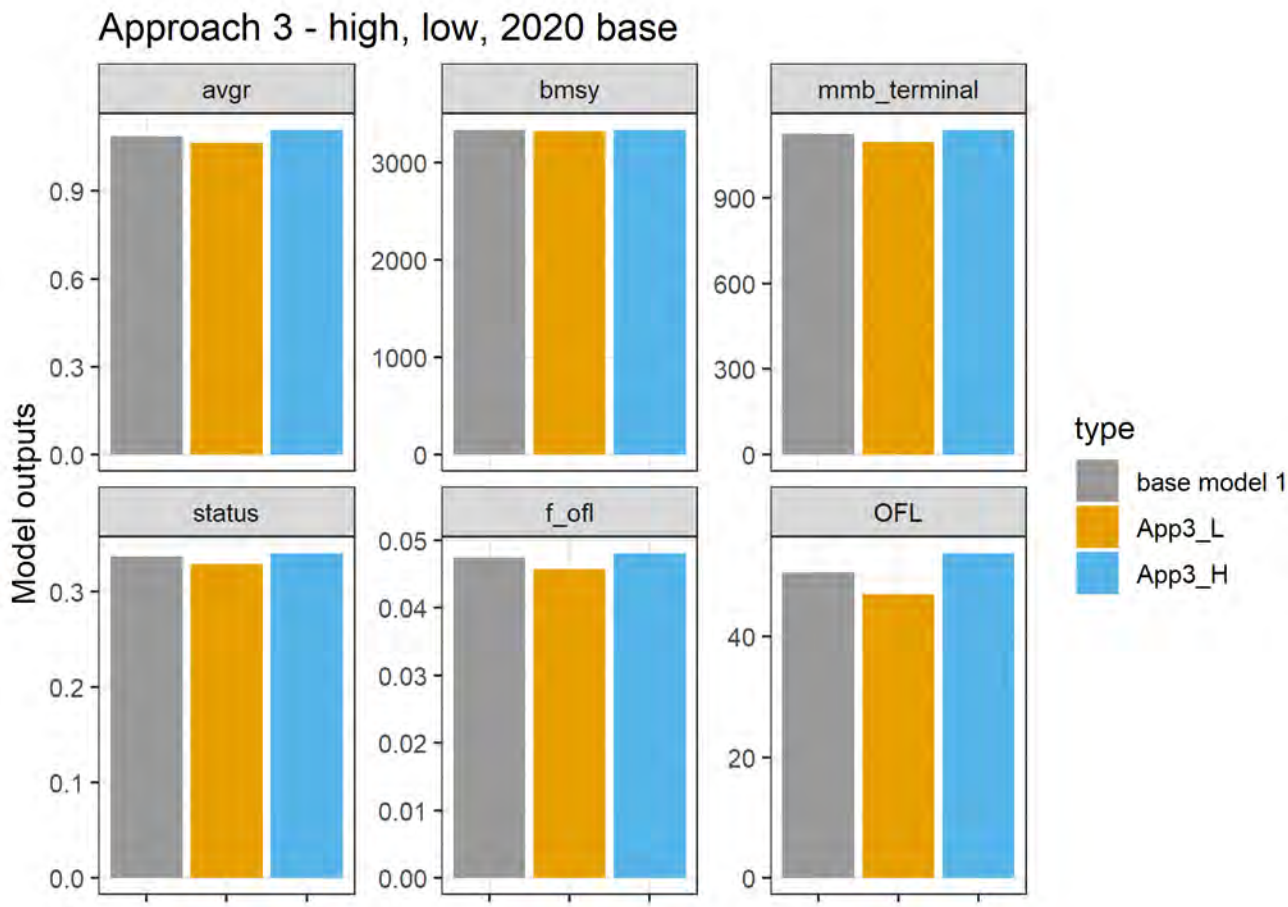


Figure 11: Model output and reference points from approach 3. Comparing the 2020 base model with a model that has a high 'fake' 2020 survey data point and one that has a low 'fake' survey data point.

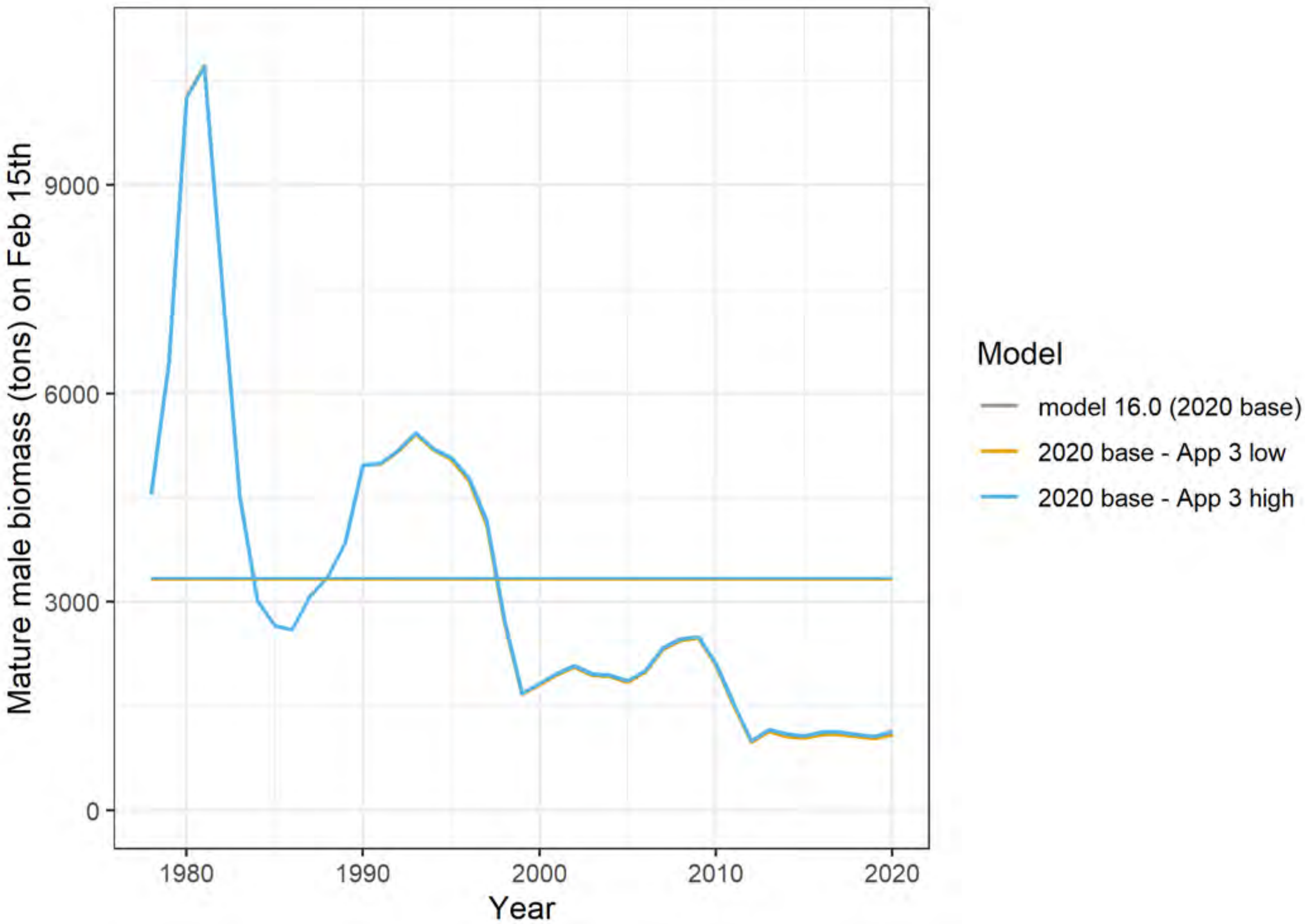


Figure 12: Mature male biomass estimates from approach 3. Comparing the 2020 base model with a model that has a high 'fake' 2020 survey data point and one that has a low 'fake' survey data point.

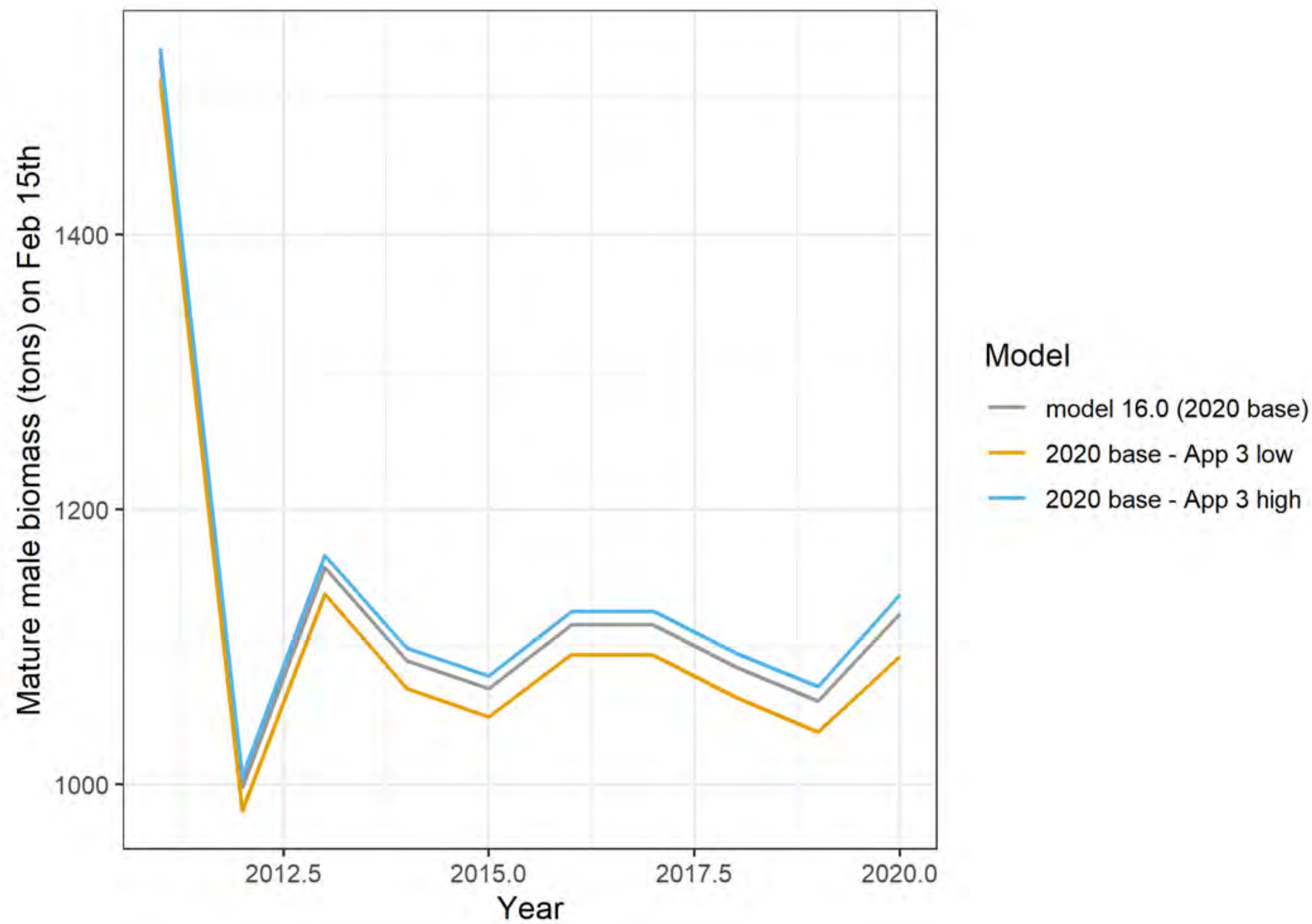


Figure 13: Mature male biomass estimates from approach 3. Comparing the 2020 base model with a model that has a high 'fake' 2020 survey data point and one that has a low 'fake' survey data point, only showing the last 10 years for detail on model differentiation.

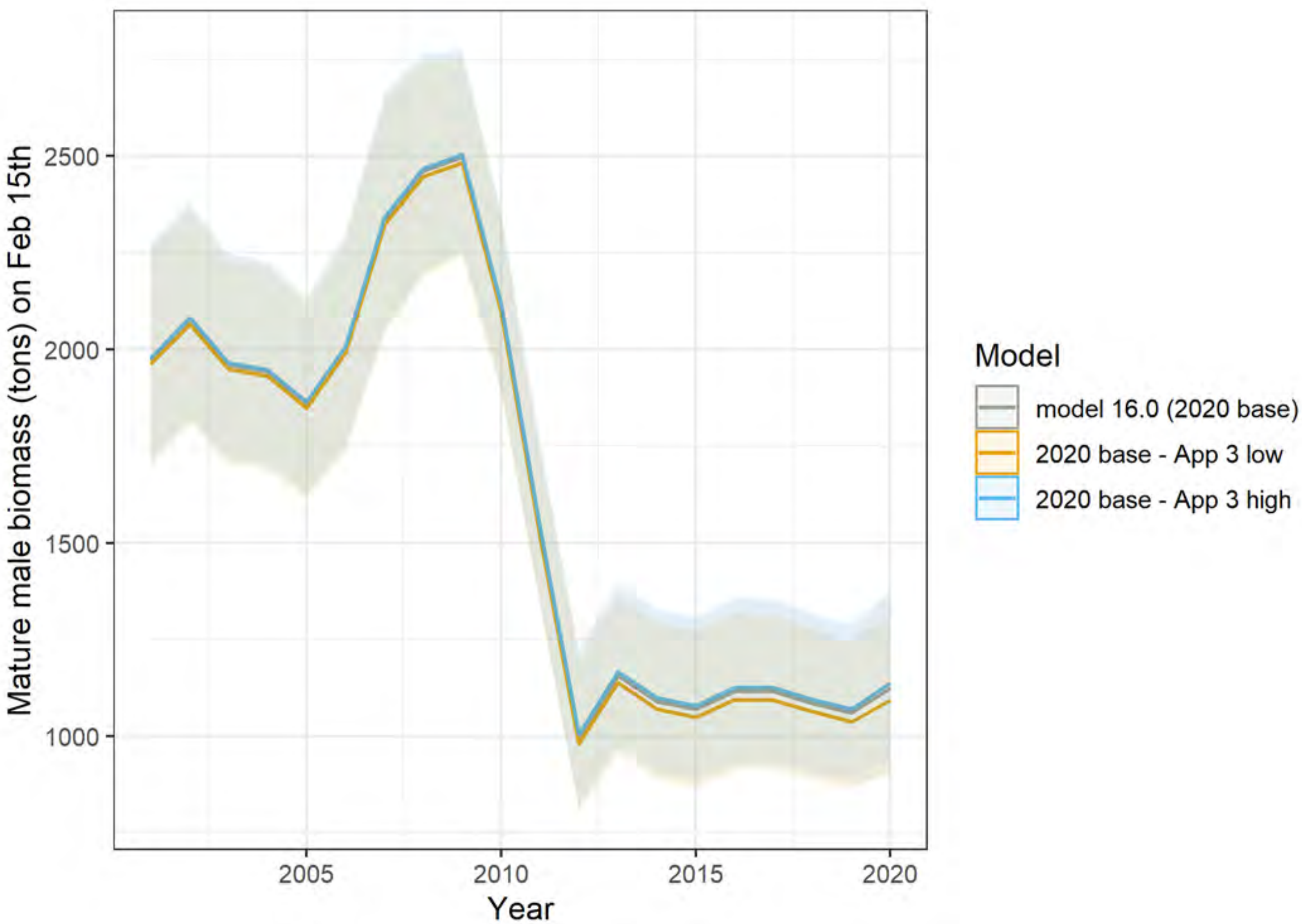


Figure 14: Mature male biomass estimates with associated variability from approach 3. Comparing the 2020 base model with a model that has a high 'fake' 2020 survey data point and one that has a low 'fake' survey data point, only showing the last 20 years for detail on model differentiation.

Tables

Table 1: Comparisons of the percent difference in parameter estimates for the retrospective models with and without the terminal year of survey data.

Year	AvgR	Bmsy	Terminal MMB	Status	Fofl	OFL
2010	-3.921	-0.606	-0.582	0.024	0.000	-1.692
2011	-1.980	-0.117	-5.674	-5.564	0.000	-3.183
2012	1.410	0.835	0.863	0.027	0.000	3.898
2013	9.199	3.471	30.491	26.113	30.537	72.124
2014	-0.399	-0.208	-5.101	-4.903	-5.563	-7.861
2015	-2.176	0.037	-1.912	-1.948	-2.345	-3.588
2016	-2.469	-0.256	-3.270	-3.021	-3.816	-6.579
2017	0.602	0.125	-0.364	-0.488	-0.713	-0.419
2018	-1.882	-0.630	-4.642	-4.038	-6.091	-10.343
2019	0.501	-1.927	-4.270	-2.389	-3.722	-2.330
RMS	3.479	1.318	10.214	8.787	10.173	23.368

Table 2: Average CV over all years (2010-2019) for normal retrospective runs and those missing the terminal year of survey data.

Type	CV-Bmsy	CV-OFL	CV-status	CV-temrinal-SSB
retro	4.32	20.19	11.12	11.77
missing-survey	4.36	21.42	11.71	12.51

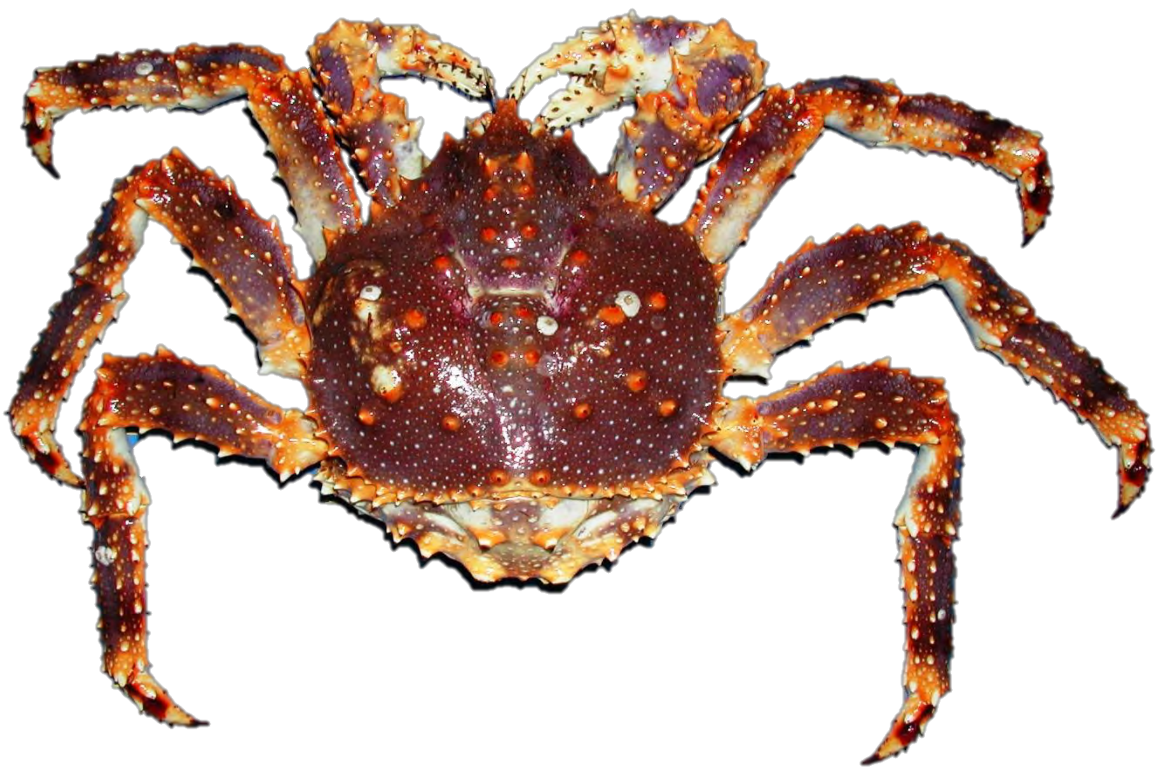
Table 3: Comparisons of the percent difference in parameter estimates for the low and high models in approach 3 compared to the 2020 base model (16.0).

Variable	Diff-Ltobase	Diff-Htobase
avgR	-2.176	2.020
Bmsy	-0.291	0.156
Terminal-MMB	-2.746	1.226
Status	-2.463	1.068
F-ofl	-3.586	1.477
OFL	-7.261	6.303

Appendix D. Ecosystem and Socioeconomic Profile of the Saint Matthew Blue King Crab Stock

Erin Fedewa, Brian Garber-Yonts and Kalei Shotwell

September 2020



With Contributions from:

Curry Cunningham, Kelly Kearny, Jens Nielsen, Katie Palof, Darren Pilcher, Jon Richar, Dale Robinson and Jordan Watson

Executive Summary

National initiative and NPFMC recommendations suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for Saint Matthew blue king crab (SMBKC) due to the stock's current overfished status and poor recruitment in recent years. Scores for stock assessment prioritization, habitat prioritization, climate vulnerability assessment, and data classification analysis were moderate to high. Furthermore, in 2018 when the stock was declared overfished, the Crab Plan Team requested an evaluation of ecosystem factors to inform the stock rebuilding plan.

We follow the standardized template for conducting an ESP and present results of applying the ESP process through a metric and subsequent indicator assessment. We use information from a variety of data streams available for the SMBKC stock. Analysis of the ecosystem and socioeconomic processes for SMBKC by life history stage along with information from the literature identified a suite of indicators for testing and continued monitoring within the ESP. Results of the metric and indicator assessment are summarized below as ecosystem and socioeconomic considerations that can be used for evaluating concerns in the main stock assessment.

Please refer to the last full ESP document for further information regarding the ecosystem and socioeconomic linkages for this stock (Fedewa et al., 2019, available online within the SMBKC SAFE, Appendix E, pp. 99-120 at: https://meetings.npfmc.org/CommentReview/DownloadFile?p=6ffde3ce-67be-4139-b165-cbff9062da06.pdf&fileName=C4%206%20SMBKC%20SAFE%202019.pdf).

Summary of Changes in Assessment Inputs

Changes in the Metric or Indicator Data

The 2020 SMBKC ESP update includes a suite of new ecosystem indicators that were developed from remote sensing data and Bering10K ROMS model output hindcasts. The suite of socioeconomic indicators for SMBKC remain unchanged due to the continued closure of the fishery while the stock rebuilds.

Changes in the Indicator Analysis

We have included the addition of a Stage 2 Importance Test in the Indicator Analysis section of the 2020 SMBKC ESP update. Results from the analysis are outlined below.

Summary of Results

Important ecosystem and socioeconomic processes that may identify dominant pressures on the SMBKC stock were reviewed in the last full ESP document. We updated the suite of ecosystem indicators for SMBKC using these mechanistic linkages or hypothesized relationships. Specifically, the addition of spring bottom temperature, wind stress and chlorophyll *a* indicators likely represent environmental conditions and prey availability for BKC early life stages. Please reference the 2019 full SMBKC ESP document for complete descriptions of indicators that occurred in the last full ESP. Any changes in methodology for indicators developed in 2019 are outlined below, as well as full descriptions for new indicators.

Indicator Suite

Ecosystem Indicators:

1.) Physical Indicators
   - Cold Pool Index: Due to the cancelation of the 2020 EBS summer bottom trawl survey, the cold pool index was calculated from ROMS model output as the fraction of the EBS

survey area with bottom waters less than 2°C on July 1 of each year (Kearney et al., 2020).
- Summer Bottom Temperature: Due to the cancelation of the 2020 EBS summer bottom trawl survey, June-July bottom temperatures were averaged within the SMBKC management area from ROMS model output (Kearney et al., 2020).
- Spring Bottom Temperature: Average of Feb-March bottom temperatures within the SMBKC management boundary from ROMS model output (Kearney et al., 2020).
- Corrosivity Index: Percent of the SMBKC management area containing an average bottom aragonite saturation state of < 1 from Feb-April (D. Pilcher, *pers. commun.*, 2020)
- Chlorophyll *a* Biomass: April-June average chlorophyll-a biomass within the St. Matthew region of the Bering Sea; calculated with 8-day composite data from MODIS satellites (J. Nielsen, *pers. commun.*, 2020)
- Wind Stress: June ocean surface wind stress within the SMBKC management boundary. Product of NOAA blended winds and MetOp ASCAP sensors from multiple satellites (Zhang et al., 2006, NOAA/NESDIS, CoastWatch)

2.) Biological Indicators
- Pacific Cod Biomass: Pacific cod comprise the majority of total biomass in the Benthic Predator Biomass indicator developed for the 2019 full ESP document. As such, we refined a predation indicator to solely include pacific cod biomass within the SMBKC management area.
- Benthic Invert Biomass
- SMBKC Recruit Biomass (Palof, *pers. commun*, 2020)

<u>Socioeconomic Indicators:</u>

1.) Fishery Performance Indicators
- CPUE (mean no. of crabs per potlift): Fishing effort efficiency, as measured by estimated mean number of retained SMBKC per potlift.
- Total Potlifts: Fishing effort, as measured by estimated number of crab pots lifted by vessels during the SMBKC fishery.
- Vessels active in fishery: Annual count of crab vessels that delivered commercial landings of SMBKC to processors.
- SMBKC male bycatch biomass: Incidental bycatch biomass estimates of male BBRKC (tons) in trawl and fixed gear fisheries

2.) Economic Indicators
- TAC Utilization (%): Percentage of the annual SMBKC TAC (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing.
- SMBKC ex-vessel revenue share (% of total exvessel revenue): SMBKC ex-vessel revenue share as percentage of total calendar year ex-vessel revenue from all commercial landings in Alaska fisheries, mean value over all vessels active in SMBKC during the respective year.
- Ex-vessel price per pound: commercial value per unit (pound) of SMBKC landings (as adjusted by CFEC to account for post-season adjustments to ex-vessel settlements), measured as weighted average value over all ex-vessel sales reported.

3.) Community Indicators
- Processors active in fishery: Total number of crab processors that purchased landings of SMBKC from delivering vessels during the calendar year. This provides an indicator of the level of participation of buyers in the market for SMBKC landings.
- Local Quotient of SMBKC landed catch in Saint Paul: Ex-vessel value share of SMBKC landings to communities on St. Paul Island, as percentage of total value of commercial landings to St. Paul processors from all commercial Alaska fisheries, as aggregate

percentage over all landings during the respective year. St Paul represents the principal port of landing for the SMBKC fishery during the post-rationalization period, representing from 78% to 100% of all purchased landings in the fishery. The local quotient (LQ) represents the share of community landings attributed to SMBKC in relation to revenue from all other species landed in the community during years when the fishery was opened.

Indicator Analysis

We provide an update to the list and time-series of ecosystem and socioeconomic indicators (Tables 1-2, Figures 1-2) and then report the results of the first and second stage statistical tests for the indicator analysis with the inclusion of current-year data. The third stage has not yet been completed, and will require more indicator development and review of the ESP modeling applications.

Stage 1: Traffic Light Test

The first stage of the indicator analysis is a simple assessment of the most recent year relative value and a traffic-light evaluation of the most current year where available (Tables 1-2). Details of the analysis can be found in the 2019 full ESP document.

Current year trends suggest relatively average environmental conditions for the SMBKC stock in 2020, although SMBKC recruit biomass is still well below the long-term average (Figure 1). While summer bottom temperatures in the St. Matthew management area were 1-2°C below 2018-2019 temperatures, the region still experienced warmer than average conditions relative to the long-term mean. However, a larger fraction of bottom waters were < 2°C in 2020 compared to previous years. The addition of a corrosivity indicator suggests that SMBKC are exposed to significant interannual variability in the aragonite saturation state of bottom waters. All stations within the SMBKC management area contained under-saturated bottom waters (Ωarag < 1) in spring 2020 which suggests potential consequences for shell formation following the spring molt, as well as reduced condition and survival of embryos and larval stages.

Chlorophyll *a* biomass was above the long-term average in 2020, suggesting a more intense spring bloom and good first-feeding conditions for BKC larvae. Likewise, June wind speeds around St. Matthew Island were near-average in 2020 and on a downward trend since 2015, which may promote increased larval encounter rates with diatom prey. Current-year data for benthic invertebrate and Pacific cod biomass indicators were not available due to the cancellation of the EBS bottom trawl survey. Benthic invertebrate biomass has remained high since the late 1980's (possibly coinciding with a 1989 regime shift in the North Pacific), while Pacific cod biomass has been on a downward trend after reaching an all-time high in 2016.

With the exception of SMBKC male bycatch, all socioeconomic indicators in Table 2 are derived from SMBKC fishery data reported from the most recent open season (2015/16), and thus are not updated in this report. Bycatch of SMBKC in the groundfish fisheries during 2019 was near the lower bound of the historical range, and was slightly reduced from 2018.

Stage 2: Importance Test

Bayesian adaptive sampling (BAS) was used for the second stage statistical test to quantify the association between hypothesized predictors and SMBKC mature male biomass (MMB), and to assess the strength of support for each hypothesis. BAS explores model space, or the full range of candidate combinations of predictor variables, to calculate marginal inclusion probabilities for each predictor, model weights for each combination of predictors, and generate Bayesian model averaged predictions for outcomes (Clyde et al., 2011). In this second test, the full set of indicators is first winnowed to the predictors that could directly relate to MMB, and have consistent temporal data coverage. We then provide the mean relationship between each predictor variable and log MMB over time (Figure 3a), with error bars describing the uncertainty (1 standard deviation) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure 3b). A higher probability indicates that the variable is a better candidate predictor of SMBKC MMB. The highest ranked predictor variables (≥ 0.25 inclusion probability) were: SMBKC recruit biomass, summer bottom temperatures, and benthic invertebrate biomass. Unfortunately, due to the nature of the BAS model only being able to fit years with complete observations for each covariate, the final subset of covariates was quite small and creates a significant data gap. Despite this shortcoming, predictive performance of the BAS model appears to generally capture SMBKC MMB trends across the time series (Figure 3d).

Ecosystem Considerations

- Despite repeated fishery closures, SMBKC mature male biomass and recruitment estimates remain below-average following a 1989 regime shift in the Bering Sea, suggesting that environmental factors may be impeding recruitment success and stock recovery.
- Highly specific thermal optimums and habitat requirements of SMBKC likely limit mobility in response to warmer than average bottom temperatures and shifting predator distributions in the Bering Sea.
- Large catches of Pacific cod in the St. Matthew Island management boundary in 2016 preceded declines in BKC mature male biomass, recruitment, and the overfished declaration in 2018.
- Trend modeling for SMBKC ecosystem indicators revealed near-average conditions for SMBKC in 2020, although persistent, corrosive bottom waters surrounding St. Matthew Island suggest potential impacts on shell formation, growth and survival of BKC.

Socioeconomic Considerations

- Vessel engagement in the SMBKC fishery as measured by annual counts of active vessels during years that the fishery has opened, has declined relative to the pre-rationalization period reflecting consolidation of the crab fleet following rationalization.
- In the most recent open seasons, the active fleet has been reduced to 3-4 vessels, with TAC utilization also declining to 26% during the 2015/16 season.
- Ex-vessel revenue share and the Local Quotient for Saint Paul both reached high values during 2010, concurrent with a peak in ex-vessel price; large declines in both metrics over the subsequent open seasons, despite relatively high ex-vessel prices during the next four open SMBKC seasons indicate that both vessels and processors active during those years have shifted into other fisheries.

Data Gaps and Future Research Priorities

Additional data on BKC life history characteristics (i.e. growth-per-molt data and molting probabilities) as well as estimates for natural mortality would aide in a better understanding of stage-specific vulnerabilities for the metric panel. In addition, process-based studies are necessary in order to identify links between larval survival, recruitment and environmental factors. Examining larval drift patterns and spatial distributions of mature BKC around St. Matthew Island in relation to habitat characteristics will help to inform essential fish habitat models and support the future development of a larval retention indicator. Developing an EFH habitat indicator for SMBKC should also be prioritized, as metric assessment results highlighted several vulnerabilities related to habitat. Furthermore, given the prevalence of corrosive bottom water conditions in the SMBKC management area, continued research efforts should focus on the potential impacts of ocean acidification on BKC physiology and the role pH levels may play in determining habitat use and spatial distributions of the stock.

In most socioeconomic dimensions, SMBKC fishery is relatively data rich in many respects. In the context of the ESP, however, the intermittent nature of the fishery and reliance on fishery-dependent socioeconomic data limits the available socioeconomic information to years when the fishery has opened. This complicates the depiction and/or interpretation of long-term averages for most socioeconomic indicators and suggests the need for development of indicators that are informative of social and economic factors relevant to the purposes of the ESP, but function on a continuous basis, including during years when the fishery is closed. Potential examples include estimation of current value of PSMFC QS assets, calculation of revenue share metrics for SMBKC processors and vessels identified with the SMBKC fishery on the basis of more continuous association than participation in the fishery during a particular year. Substantial improvements over the indicators reported above are feasible, however, are largely dependent on further development of clear objectives for the inclusion of social and economic indicators within the ESP framework.

Responses to SSC and Plan Team Comments on ESPs in General

"Regarding ESPs in general, the SSC recommends development of a method to aggregate indices into a score that could be estimated over time and compared to stock history. One potential pathway forward may be to normalize and use an unweighted sum of all the indicators where all time series overlap, or just assign +1 or -1 to each indicator so that a neutral environment would be zero." (SSC, February 2020, pg. 7)

A presentation on a scoring option for the indicator suite was provided in the ESP Model Workshop in March 2020. The score used a simple +1, 0, and -1 assignment to the indicator based on whether the current year was above, within, or below 1 standard deviation from the mean for the time series. Sablefish and GOA pollock were provided as case studies and scores were calculated historically for the past 15 years. The score timeline trajectory was also evaluated with respect to the general ecosystem and socioeconomic considerations provided in the ESP documents. We plan to provide this score in next year's ESPs for SMBKC and hope for feedback on the method.

Responses to SSC and Plan Team Comments Specific to this ESP

"*The SSC is very pleased to see the Ecosystem and Socioeconomic Profile for SMBKC. The conceptual model was appreciated especially by those that are less familiar with crab life history characteristics. The introduction of some new ecosystem indicators was a good start. It was noted that the stock showed a high vulnerability to ocean acidification (OA), so if there is a way to index OA in the ESP that might be a good addition."* (SSC, Oct, 2019, pg. 12)

In response to this recommendation, we updated the 2020 SMBKC ecosystem indicator suite to include a Corrosivity Index developed from Bering10K ROMS output. This index, representing the percent of SMBKC management area containing low pH bottom waters undersaturated in aragonite, will provide the means to highlight vulnerabilities across BKC life stages to acidified conditions.

"The SMBKC ESP provides a tool to track, for the first time, the socioeconomic context of a fishery that has not successfully provided for the continuous, sustained participation of fishing communities over time. The SSC recommends that the ESP be augmented to track indices of community engagement and dependency, by community or aggregations of communities, across the relevant vessel and processing sectors and, for the years following rationalization, quota share ownership by community by share type. Where data confidentiality constraints dictate, the analysts should consider the use of regional as well as local quotient indicators." (SSC, Oct, 2019, pg. 12)

This recommendation has not been accomplished in this update. AFSC is currently developing a dedicated annual report to accompany the Crab and Groundfish Economic SAFE reports, focused on providing comprehensive analysis and monitoring of community participation and engagement in groundfish and crab fisheries. The Annual Community Engagement and Participation Overview

(ACEPO) will provide detailed, community-level metrics of fishery participation, including income and employment, and ownership of vessel, plant, permit and quota share assets. Development of methods and indices for effectively capturing these and other dimensions of management effects on communities is currently concentrated on producing the ACEPO report. It is expected that this will provide the basis for identifying reduced-form indicators of community effects that will be suitable for incorporation in ESPs in the future.

Acknowledgements

We would like to thank all contributors and stock assessment authors for their timely response to requests and questions regarding data, report summaries, and manuscripts. We also thank all attendees and presenters at ESP Data workshops (May 2019 and March 2020) for their valuable insight on the development of the BBRKC ESP and future indicator development. Lastly, we thank the Crab Plan Team, North Pacific Fisheries Management Council, and AFSC for supporting the development of this report and future reports.

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Table 1. First stage ecosystem indicator analysis for St. Matthew blue king crab (SMBK), including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for SMBKC of the current year conditions relative to 1 standard deviation of the longterm mean (white = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
Cold Pool Index	Fraction of the EBS BT survey area with bottom water less than 2°C on 1 July of each year from Bering10K ROMS model output hindcasts	●
Summer Bottom Temperature	Average of June-July bottom temperatures (° C) within the SMBKC management boundary from the Bering 10K ROMS model output hindcasts	●
Corrosivity Index	Percent of the SMBKC management area containing an average bottom aragonite saturation state of < 1 from Feb-April	+
Spring Bottom Temperature	Average of Feb-March bottom temperatures (° C) within the SMBKC management boundary from the Bering 10K ROMS model output hindcasts	●
Wind Stress	June ocean surface wind stress within the SMBKC management boundary. Product of NOAA blended winds and MetOp ASCAP sensors from multiple satellites	●
Chlorophyll-a Biomass	April-June average chlorophyll-a biomass within the St. Matthew region; calculated with 8-day composite data from MODIS satellites	●
Pacific cod biomass	Biomass (1,000t) of Pacific cod within the SMBKC management boundary on the EBS bottom trawl survey	●
Benthic invertebrate biomass	Combined biomass (1,000t) of benthic invertebrates within the SMBKC management boundary on the EBS bottom trawl survey	+
SMBKC Pre-recruit Biomass	Model estimates for SMBKC recruitment. Includes male crab (90-104 mm CL) that will likely enter the fishery the following year.	●

Table 2. First stage socioeconomic indicator analysis for St. Matthew blue king crab (SMBK), including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for SMBKC of the current year conditions relative to 1 standard deviation of the longterm mean (white = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
Vessels active in fishery	Annual count of crab vessels that delivered commercial landings of SMBKC to processors[1]	•
TAC Utilization	Percentage of the annual SMBKC TAC (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing.	•
Total Potlifts	Fishing effort, as measured by estimated number of crab pots lifted by vessels during the SMBKC fishery	+
CPUE	Fishing effort efficiency, as measured by estimated mean number of retained SMBKC per potlift	•
Ex-vessel price per pound	Commercial value per unit (pound) of SMBKC landings (as adjusted by CFEC to account for post-season adjustments to ex-vessel settlements), measured as weighted average value over all ex-vessel sales reported.	•
SMBKC ex-vessel revenue share	SMBKC ex-vessel revenue share as percentage of total calendar year ex-vessel revenue from all commercial landings in Alaska fisheries, mean value over all vessels active in SMBKC during the respective year.	•
Processors active in fishery	Total number of crab processors that purchased landings of SMBKC from delivering vessels during the calendar year.	-
Local Quotient of SMBKC landed catch in St. Paul	Ex-vessel value share of SMBKC landings to communities on St. Paul Island, as percentage of total value of commercial landings to St. Paul processors from all commercial Alaska fisheries, aggregate percentage over all landings during the respective year.	•
SMBKC Male Bycatch in Groundfish Fishery	Incidental bycatch biomass estimates of male SMBKC (tons) in trawl and fixed gear fisheries	•

[1]Includes crab catcher/processors that harvested and processed SMBKC catch on-board.

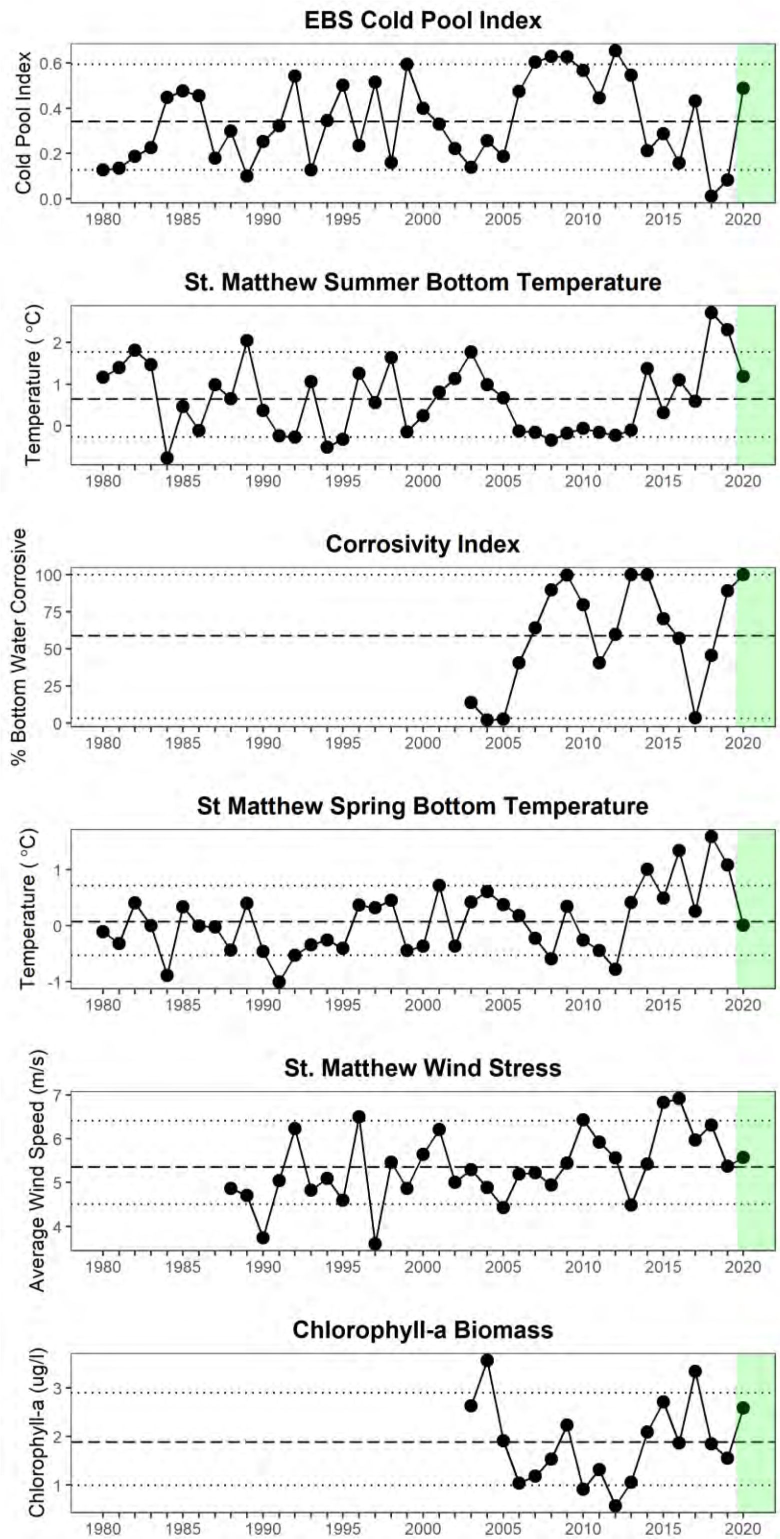

Figure 1. Selected ecosystem indicators for SMBKC with time series ranging from 1980 – 2020. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

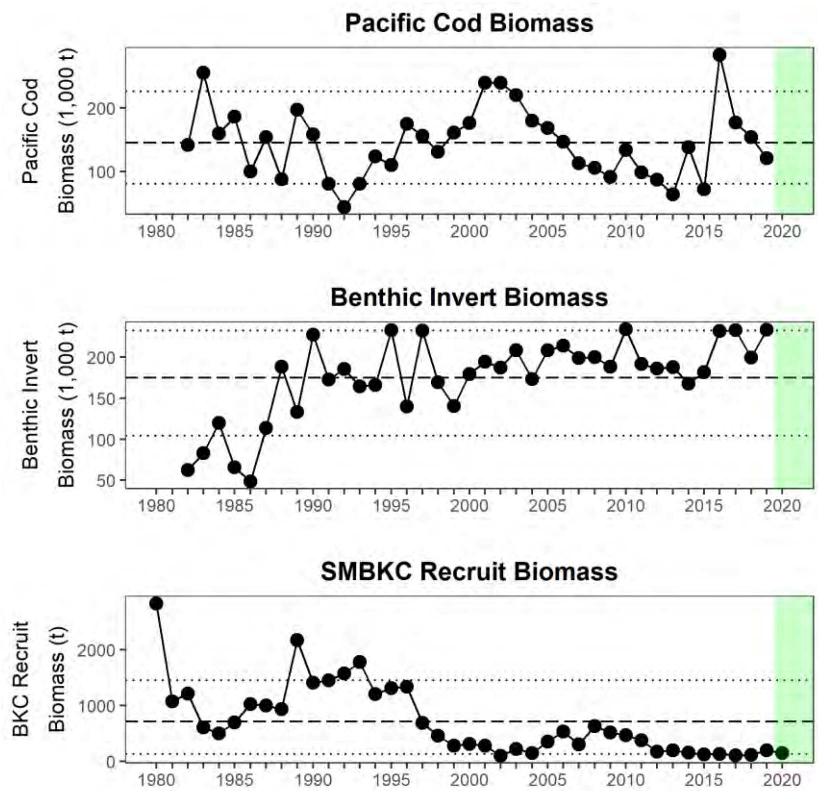

Figure 1. (cont.) Selected ecosystem indicators for SMBKC with time series ranging from 1980 – 2020. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

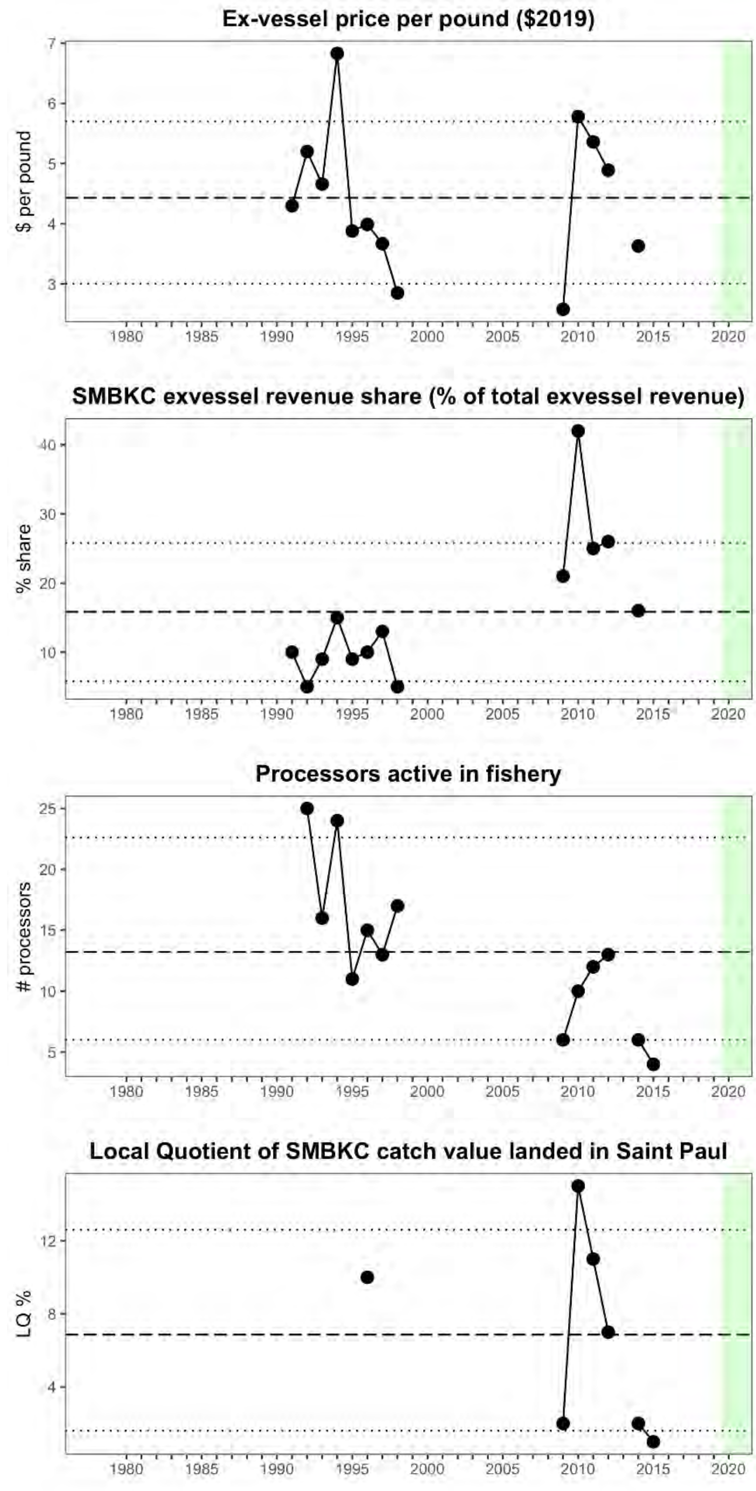

Figure 2. Selected socioeconomic indicators for SMBKC with time series ranging from 1980 – 2019. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

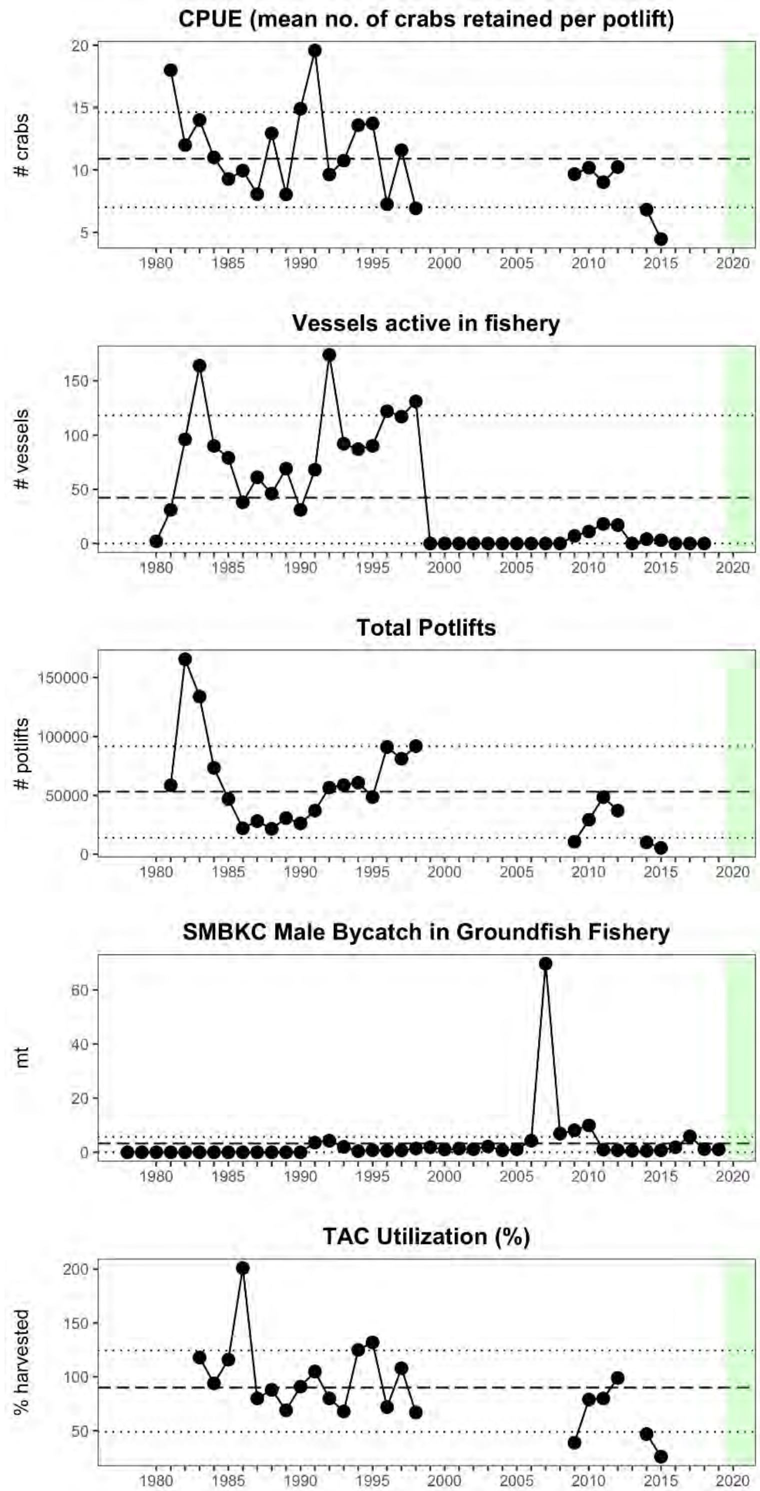

Figure 2. (cont.) Selected socioeconomic indicators for SMBKC with time series ranging from 1980 – 2019. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

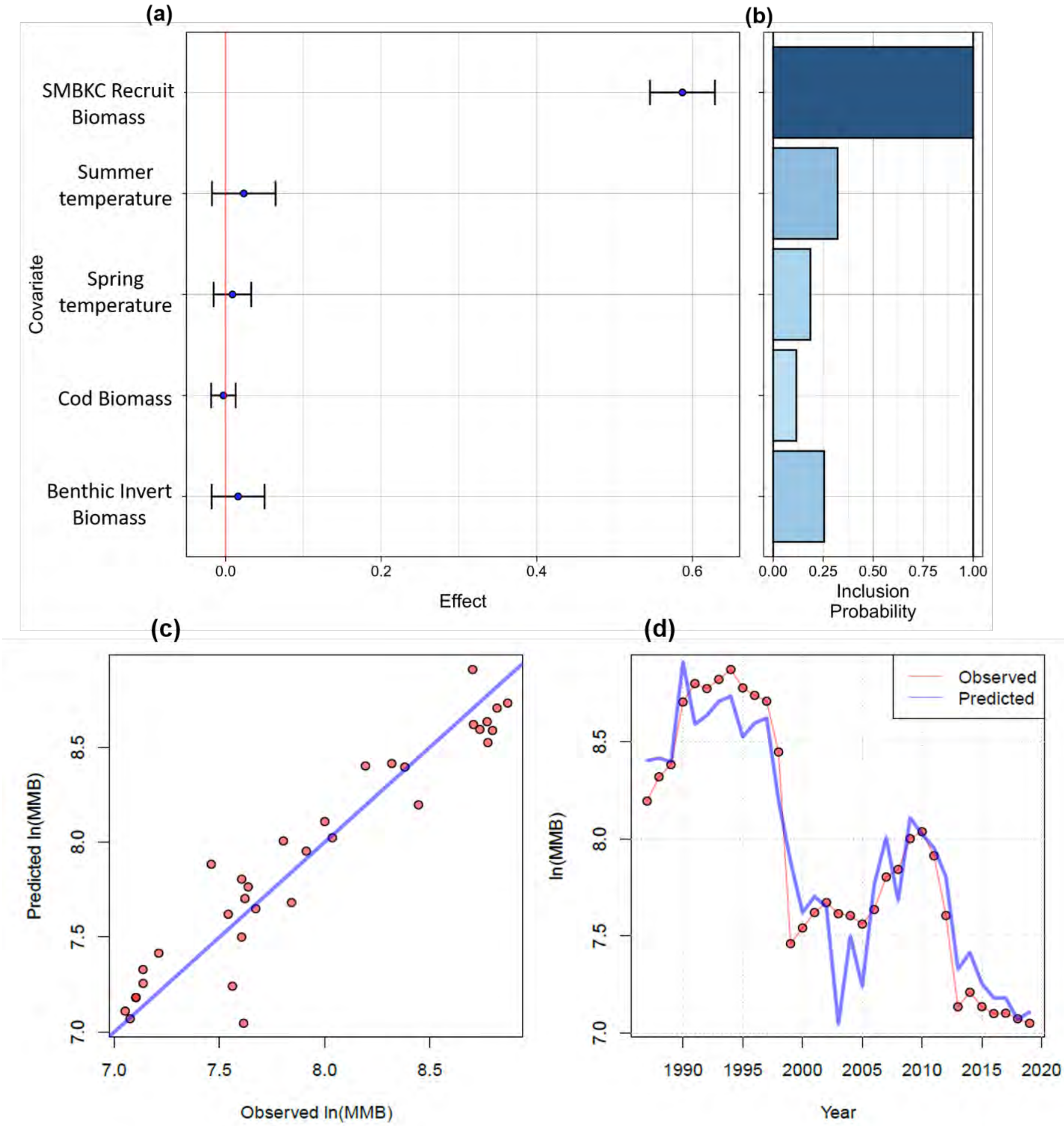

Figure 3. Bayesian adaptive sampling output showing the mean relationship and uncertainty (± 1 SD) with log-transformed St. Matthew blue king crab mature male biomass: a) the estimated effect and b) marginal inclusion probabilities for each predictor variable of the subsetted covariate ecosystem indicator dataset. Output also includes model c) predicted fit (1:1 line) and d) average fit across the MMB time series.

Norton Sound Red King Crab Stock Assessment for the fishing year 2020

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Executive Summary

1. Stock. Red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska.
2. Catches. This stock supports three important fisheries: summer commercial, winter commercial, and winter subsistence fisheries. Of those, the summer commercial fishery accounts for 85% of total harvest. The summer commercial fishery started in 1977. Catch peaked in the late 1970s with retained catch of over 2.9 million pounds. Since 1994, the Norton Sound Crab fishery operated as super exclusive. For the 2019 fishery season, Norton Sound Red King Crab harvest consisted of 1,050 crab (3,295 lb.) by winter commercial, 1,545 crab (3,100 lb) by winter subsistence, and 24,506 crab (75,023 lb) by summer commercial, totaling 27,099 crab (81,418 lb). Total harvests were below ABC of 0.19 million lb. The harvest decline was due to 1) late ice buildup preventing winter fisheries and 2) low catch CPUE and declined summer commercial fishery participation.
3. Stock Biomass. The Norton Sound Red King Crab stock has been monitored by triennial surveys since 1976 by NOAA (1976-1991) and ADF&G (1996-present), with survey catch ranged from 1.41 million to 5.9 million crab. In 2019, abundance by trawl survey by ADF&G was 4.66 million crab with a CV of 0.60, whereas the survey by NMFS was 2.43 million crab with a CV of 0.26. The difference is partially due to 1) ADF&G survey had high crab catch in one station, and 2) high crab catch of NMFS survey occurred outside of the standard survey area.
4. Recruitment. Model estimated recruitment was weak during the late 1970s and high during the early 1980s, with a slightly 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 Commercial Catch	Total Retained Catch	Retained OFL	Retained ABC
2016	2.26[A]	5.87	0.52	0.51	0.52	0.71[A]	0.57
2017	2.31[B]	5.14	0.50	0.49	0.50	0.67[B]	0.54
2018	2.41[C]	4.08	0.30	0.31	0.34	0.43[C]	0.35
2019	2.24[D]	3.12	0.15	0.08	0.08	0.24[D]	0.19
2020	2.28[E]	3.67	TBD	TBD	TBD	0.29[E]	0.22

Status and catch specifications (1000t)

Year	MSST	Biomass (MMB)	GHL	Retained Commercial Catch	Total Retained Catch	Retained OFL	Retained ABC
2016	1.03[A]	2.66	0.24	0.23	0.24	0.32[A]	0.26
2017	1.05[B]	2.33	0.23	0.22	0.24	0.30[B]	0.24
2018	1.09[C]	1.85	0.13	0.14	0.15	0.20[C]	0.16
2019	1.03[D]	1.41	0.07	0.04	0.04	0.11[D]	0.09
2020	1.04[E]	1.66	TBD	TBD	TBD	0.13[E]	0.10

Notes:
MSST was calculated as $B_{MSY}/2$
A-Calculated from the assessment reviewed by the Crab Plan Team in May 2016
B-Calculated from the assessment reviewed by the Crab Plan Team in May 2017
C-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2018
D-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2019
E-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2020

Conversion to Metric ton: 1 Metric ton (t) = 2.2046×1000 lb

Biomass in millions of pounds

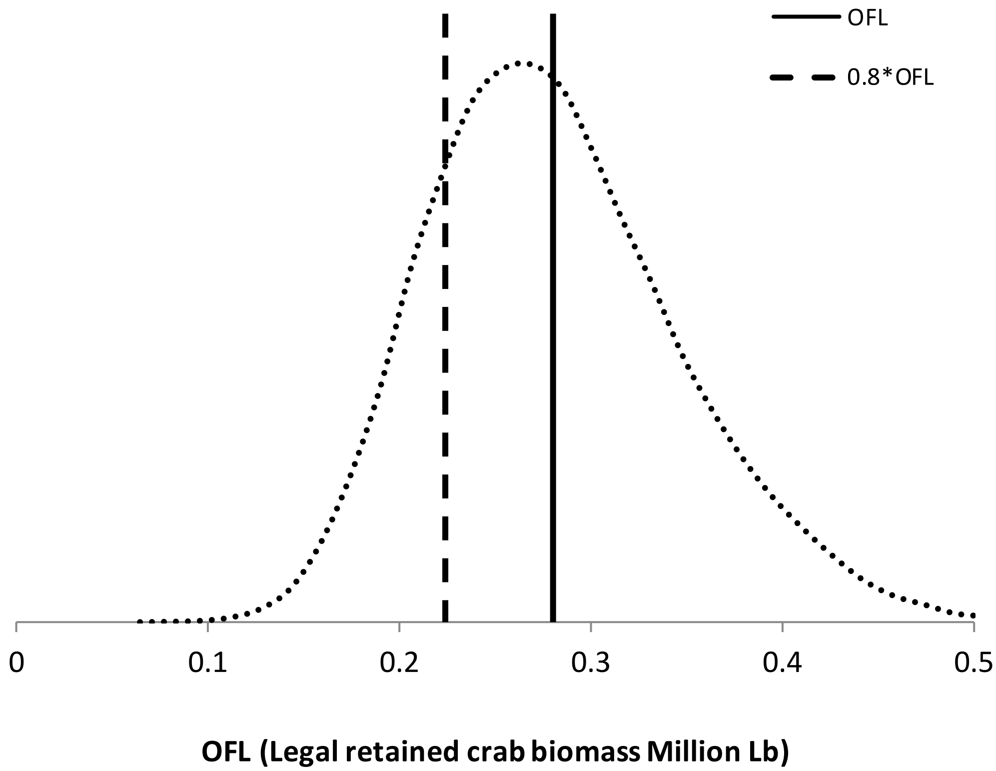
Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	Retained ABC
2016	4a	4.53	5.87	1.3	0.18	1980-2016	0.18	0.8	0.57
2017	4a	4.62	5.14	1.1	0.18	1980-2017	0.18	0.8	0.54
2018	4b	4.82	4.08	0.9	0.15	1980-2018	0.18	0.8	0.35
2019	4b	4.57	3.12	0.7	0.12	1980-2019	0.18	0.8	0.19
2020	4b	4.56	3.66	0.8	0.14	1980-2020	0.18	0.75	0.22

Biomass in 1000t

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define	M	1-Buffer	Retained ABC

				B_{MSY}					
2016	4a	2.06	2.66	1.3	0.18	1980-2016	0.18	0.8	0.26
2017	4a	2.10	2.33	1.1	0.18	1980-2017	0.18	0.8	0.24
2018	4b	2.07	1.85	0.9	0.15	1980-2018	0.18	0.8	0.16
2019	4b	2.06	1.41	0.7	0.12	1980-2019	0.18	0.8	0.09
2020	4b	2.07	1.66	0.8	0.14	1980-2020	0.18	0.75	0.10

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). In 2020, the buffer was increased to 25% (ABC = 75% OFL) over concern for low CPUE of 2018-2019.

8. A summary of the results of any rebuilding analysis

   N/A

A. *Summary of Major Changes in 2019*

1. Changes to the management of the fishery**:**

   None

2. Changes to the input data

   a. Data update:

      i. 1977-2019 standardized commercial catch CPUE and CV. Standardized CPUE was calculated for entire dataset, instead of separating two (1977-1993, 1994-2019) time periods.

      ii. Winter and Summer commercial fishery harvest, discards, and length composition data. Retained size composition data were not collected for 2019 winter commercial due to low harvest.

      iii. Tag recovery data 2019 (14 crab).

      iv. Trawl surveys: abundance, length-shell compositions:

      ADFG and NMFS 2019

3. Changes to the assessment methodology:

   None

4. Changes to the assessment results.

   Model estimated mature male biomass increased from 3.12 million lb. in 2019 to 3.73 million lb. in 2020. Estimated OFL also increased from 0.24 million lb. in 2019 to 0.29 million lb. in 2020.

B. *Response to SSC and CPT Comments*

Crab Plan Team – January 23-25, 2019

- Continue to evaluate methods to improved ADF&G bottom trawl survey biomass estimation, including model based approaches such as VAST.

  Authors' reply: VAST modeling has been applied to historical trawl survey data. However, we were not able to generate estimates. **Authors request experts' instruction and assistance for implementation.**

- Conduct a sensitivity analysis to evaluate the effect of mark-recapture data by fitting the model only marks that are liberty for one year.

  Authors' reply:

  Alternative model: 19.1

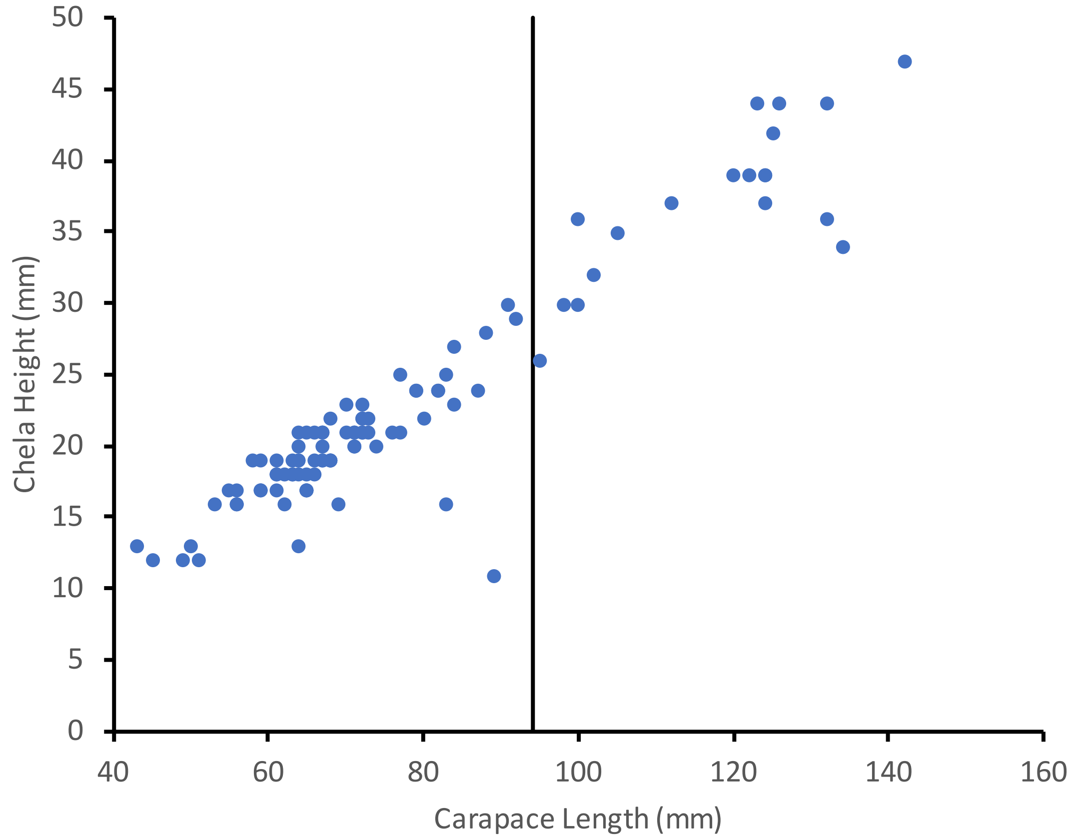
- Evaluate potential differences in survey Q between NOAA and ADFG bottom trawl surveys.

  Authors' reply: Alternative model 19.2 and 19.3

- Collect more chela-carapace data, especially at the small size ranges, to improve the size at maturity estimate.

  Author's reply

  In 2019 97 male samples were collected during the annual bottom trawl survey. No distinctive break point has been present. Solid vertical line shows current cut-off length of 95mm.



SSC – February 4-6 2019

- The model choice does not have much impact on the results, or on the Tier 4 reference points, hence the focus for the stock assessment should be on the input data.

  Authors' reply:

  We fully concur. We are collecting more data as budget allows.

- Bring forward total catch OFLs and ABCs or provide rationale why the retained catch OFL and ABC are still more appropriate at this time.

  Authors' reply:

  Estimating total catch OFL requires estimating the number of discards in summer commercial fisheries. Thus far, no formal estimates of discards have not been established for NSRKC. See Appendix C for 2002-2018 preliminary discards estimates.

- Include options with an estimated constant M across size classes (including the largest class) and a dome-shaped selectivity for the summer commercial fishery and for the summer survey.

  Authors' reply: Alternative model 19.4 and 19.5

- Spatial distribution and modeling. a thorough examination of the spatial distribution of red king crab, in particular spatial differences in size composition, across the northern Bering Sea beyond Norton Sound would be helpful. Available data include the 2010 and 2017-2018 NMFS bottom trawl surveys.

  Authors' reply: We believe that this task is more appropriate for NMFS.

- Spatial modeling: Compare the ADF&G and NMFS surveys using appropriate methods for zero-inflated distributions, such as those offered in various R packages (e.g., pscl, gamlss, INLA, VAST, glmmfields).

  Author's reply:

  We are not familiar with those packages and spatial modeling, including intent of the comparison.

  It should also be noted that ADF&G and NMFS surveys are NOT "paired" (i.e., side-by-side survey). ADF&G and NMFS surveys differ in **survey protocols (e.g., tow distance), trawl gears, survey spatial extent and timing. Itis expected that the two surveys would differ in abundance and spatial distribution.** Changes of distribution and abundances between the two surveys may be due to different survey protocols, movement of crab.

- Survey time series: Explore using two catchability parameters for the differing time blocks of the survey time series shown in Figure 7 which uses a different length range after 1995 to compute the abundance index.

  Author's reply:

  The NMFS survey abundance prior to 1995 were provided by NMFS (NPFMC 2014) when NSRKC model was based on 74mm and above. When this was changed to 64mm and above survey abundances after 1995 were updated by the authors (NPFMC2016), but not for the pre-1995 NMFS surveys. This was because the assessment model was already estimating q (q ~ 0.7) for pre-1995 survey abundance. In this assessment, the pre-1995 survey abundance was updated to 64mm and above. We also included differences in abundance estimation methodologies between pre-1995 NMFS and post 1995 trawl surveys (Table 3). Combining with application of VAST, we will further explore improvement of trawl survey abundance.

- Local and traditional knowledge: Encourage through collaborations at the local level to consider these sources of knowledge

  Author's reply:

  Authors request SSC and experts' instructions how to collaborate and incorporate local and traditional knowledge into assessment.

- Male maturity: new maturity studies are clearly needed to improve the assessment. Explore Russian data on maturity if available. Also, the relationship between maturity and temperature across stocks should be explored for potential predictive capability for Norton Sound.

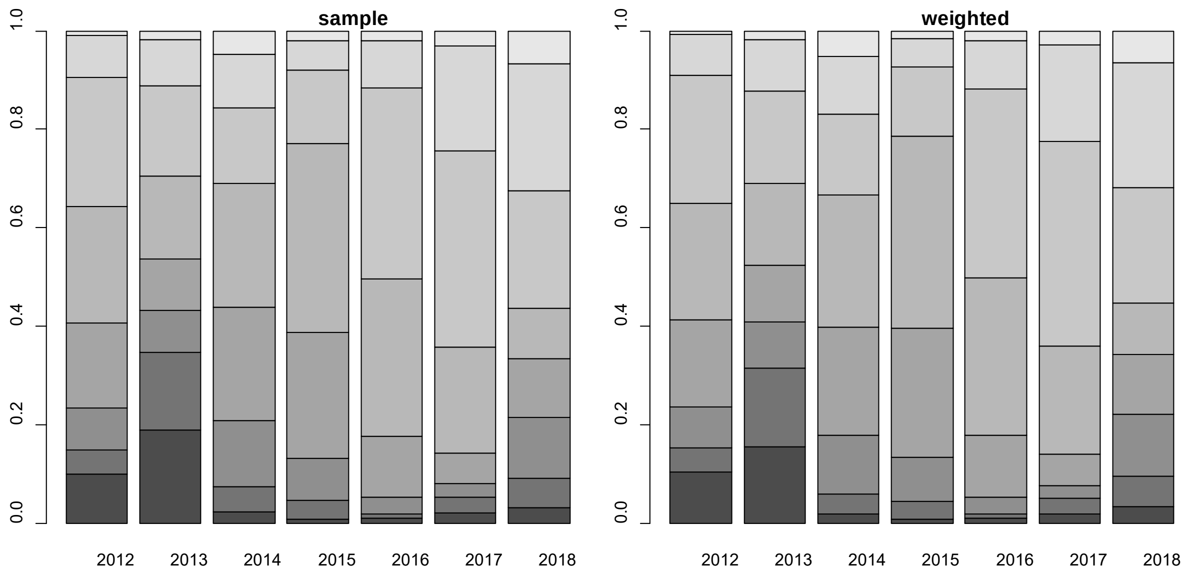
  Authors' reply:

We are eager to incorporate SSC's suggestions on data weighting; however, we are not familiar with the dataset mentioned. **Authors request experts' instruction and assistance for implementation.**

- Consider estimating observer length composition weighted by catch/strata.

  Authors' reply:

  While weighted length composition is considered more accurate than simple unweighted one, there is little difference between the two.



- Consider data weighting based on iterative tuning, number of hauls, or other approaches.

  Authors' reply:

  Francis' (2011, 2017) iterative weighting was applied for size composition and tag recovery data. However, the calculated weights were greater than current model weights, and application of the weights resulted in lower fits trawl survey abundance data. The number of length classes (8) for NSRKC may also be too few to apply Francis' weighting (André Punt, personal communication).

- Include before/after variables in CPUE standardization to account for a change in commercially acceptable size limit. Clarify if the time series of CPUE is showing different measures of CPUE for the time periods prior to and after 1995.

  Authors' reply:

  In the original CPUE standardization, the CPUE data were separated in two periods: 1976-1992 and 1993-present, and two regressions were run. In this revision, we included time stage variables PD, 1976-1992, 1993-2014, 2015-present, and ran a single regression model. The PD variable turned out to be insignificant and was removed from the final regression model. Furthermore, this also increased model sd, so that model estimated additional variance (advar) became 0.

- Use revised Mohn's rho.

Authors' reply:

It was implemented for the final assessment. However, more fundamental note, CPT-SSC has not established standardized criterion for Mohn's rho (e.g., min-max rho value) for selection of the best alternative model, or an adjustment of predicted biomass or determination of OFL/ABC buffer (i.e., what to do when the Mohn's rho of the adopted model exceeded criteria?) The calculated Mohn.Rho of the CPT/SSC recommended model (19.0) based on retrospective analyses of past 4 years was 0.258. This exceeded, guideline range provided by Hurtado-Ferro et al. (2015), of -0.15 to 0.2 for longer lived and -0.22 to 0.30 for shorter lived species. If this is deemed concern, then the model may be rejected or other **Authors appreciate SSC's directive for potential application of revised Mohn's rho for improvement of the NSRKC assessment model.**

- Parameters r_1 and log-phi_{st1} hitting bounds.

Authors' reply:

r_1 is a parameter for normalization for estimating proportion, pi = exp(ri)/[1+sum(exp(r))], (see equation 2 of Appendix A), so that hitting bounds is acceptable. log-phi_{st1} is the trawl survey selectivity curve in log scale (see equation (16) Appendix A). Since trawl selectivity was estimated to be 1.0 across all lengths, hitting bound does not affect results of the assessment model. SSC (NPFMC 2017) suggested setting trawl survey selectivity to 1.0 for all length.

Crab Plan Team – April 29, 2019

- Draft assessment in GMACS will potentially be provided in September 2019.

Authors' reply:

We are eager to incorporate SSC's suggestions on data weighting and are working on implementation.

Crab Plan Team – Sept 16-20, 2019

SSC – Sept 30-Oct 2, 2019

- No additional requests.

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° W. longitude, depths less than 30 m, and summer bottom temperatures above 4°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 investigated possible stock separation within the putative Norton Sound red king crab stock.

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) ºC 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 (Jenefer 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 (Jenefer Bell, ADF&G, personal communication). Molt timing is unknown but likely occurs in late August – September, based on increase catches of newly-molted crab late in the fishing season (August- September) (Joyce Soong, ADF&G personal communication) and evaluation of molting hormone profiles in the hemolymph (Jenefer Bell, ADF&G, personal communication). Recent observations also indicate that mating may be biennial (Robert Foy, NOAA, personal communication). Trawl surveys show that crab distribution is dynamic with recent surveys showing high abundance on the southeast side of Norton 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 harvest occurs offshore during the summer commercial fishery, whereas the winter commercial and subsistence fisheries occur nearshore through ice.

   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 were 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. Changes in regulations and the location of buyers resulted in eastward movement of the harvest distribution 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 (Norton Sound Economic Development Corporation) started accepting only legal crab of ≥ 5 inch CW. This may have increased discards; however, because discards have not been monitored until 2012, impact of this change on discards is unknown. This issue was also examined in assessment model selection, which showed no difference in estimates of selectivity functions before and after 2005 (NPFMC 2016).

Portions of Norton Sound area are closed to commercial fishing for red king crab. Since the beginning of the commercial fisheries in 1977, waters approximately 5-10 miles offshore 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. CDQ harvest share is 7.5% of total projected harvest, which can be prosecuted in both summer and winter fisheries season.

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 crab during 1978-2009. From 2007 to 2015 the winter commercial catch increased from 3,000 crab 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, which became in effect since 2017 season. 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 became in effect since the 2016 season.

Subsistence Fishery

While the winter 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 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. There are no size or sex specific harvest limits; however, the majority of retained catches are males of near legal size.

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.

Note that harvest of both commercial and subsistence winter fisheries is influenced largely by availability of stable ice condition. Regardless of crab abundance, low harvest can occur due to poor ice condition.

6. Brief description of the annual ADF&G harvest strategy

Since 1997 Norton Sound red king crab has 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 the winter commercial fisheries:

1) Revised GHL to include summer and winter commercial fisheries.
2) Set guideline harvest level for the winter commercial fishery (GHL_w) at 8% of the total GHL
3) Dates of the winter red king crab commercial fishing season are from January 15 to April 30.

Year	Notable historical management changes
1976	The abundance survey started
1977	**Large vessel commercial fisheries began (Legal size ≥ 5 inch CW)**
1978	**Legal size changes to ≥ 4.75 inch CW**
1991	Fishery closed due to staff constraints
1994	Super exclusive designation went into effect. The end of large vessel commercial fishery operation.
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 ≥ 5 inch CW**
2006	The Statistical area Q3 section expanded (Figure 1)
2008	Start date of the open access fishery changed from July 1 to after June 15 by emergency order. **Pot configuration requirement: at least 4 escape rings (>4.5 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 > 6.5 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 Tier 4 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 Tier 4a for the 2015-2017 seasons. Since 2018 the stock has been under Tier 4b status.

D. Data

1. Summary of new information:

   Winter commercial and subsistence fisheries:

   The winter commercial fishery catch in 2019 was 9,189 crab (20,118 lb.). Subsistence retained crab catch was 4,424 and unretained was 1,343 crab or 23 % of total catch (Table 2).

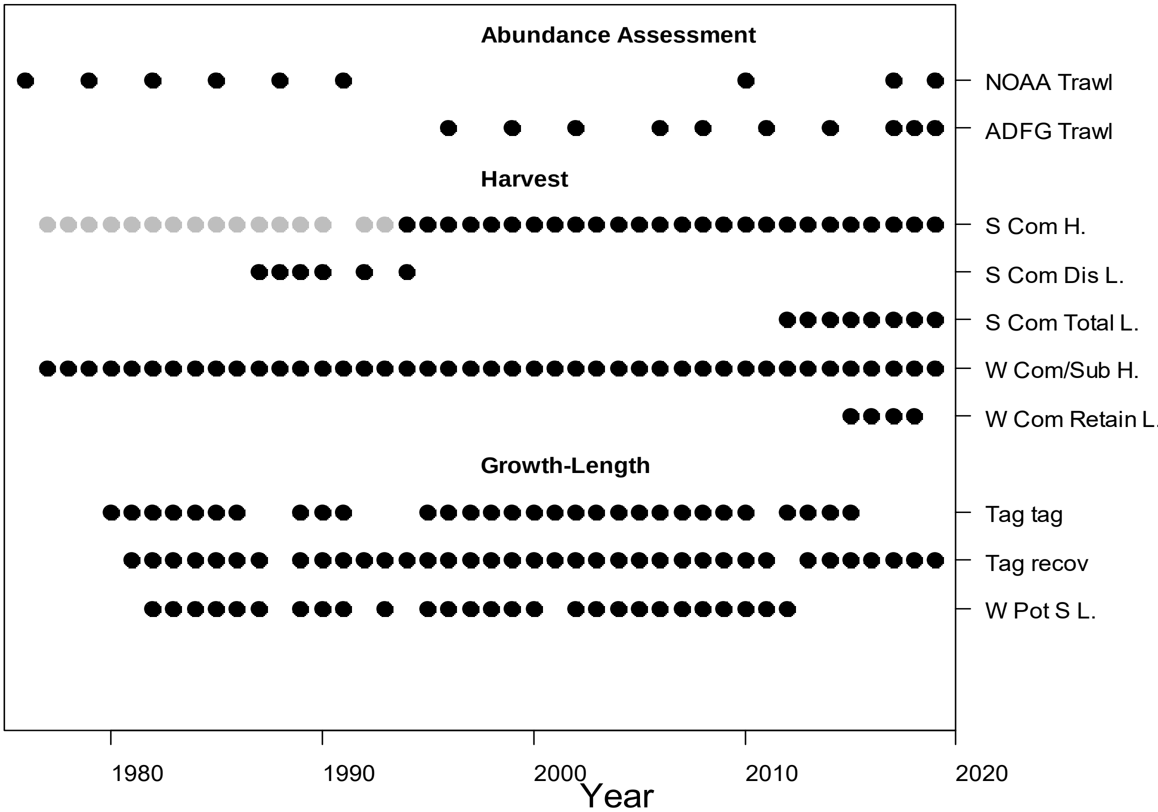
   Summer commercial fishery:

   The summer commercial fishery opened on 6/25/2019 and closed on 9/03/2019. Total of 75,023 crab (24,506 lb.) were harvested (Table 1). This is the lowest harvest since 2000.

   Total retained harvest for 2019 season was 88,646 crab (34,811 lb. or 0.035 million lb) and did not exceed the 2019 ABC of 0.19 million lb.

   Summer Trawl abundance survey by ADFG (7/22-7/29) was estimated to be 4.67 million (CV 60%) and that by NMFS (8/4-8/7) was 2.53 million (CV 26%) (Table 3). These discrepancies were also present in 2017 (Table 3).

2. Available survey, catch, and tagging data



	Years	Data Types	Tables
Summer trawl survey	76,79,82,85,88,91,96, 99, 02,06,08,10,11,14,17, 18,19	Abundance Length-shell comp	3 6
Winter pot survey	81-87, 89-91,93,95-00,02-12	Length-shell comp	7
Summer commercial fishery	77-90,92-19	Retained catch Standardized CPUE, Length-shell comp	1 1 4
Summer Com total catch	12-19	Length-shell comp	9
Summer Com Discards	87-90,92,94	Length-shell comp	8
Winter subsistence fishery	76-19	Total & Retained catch	2
Winter commercial fishery	78-19	Retained catch	2
	15-18	Retained Length-Shell	5
Tag recovery	80-19	Recovered tagged crab	10

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	CPUE data Not reliable due to ice conditions
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, the directed Pacific Cod pot fishery was issued in 2018 under the CDQ permit. From 2015 to 2018 fishery seasons a total of 19 kg (12 ~ 14 crab) of NSRKC were taken from the groundfish fisheries (CPT 2019). This is small enough to ignore.

	Fishery	Data availability
Other crab fisheries	Does not exist	NA
Groundfish pot	Pacific Cod	Y (Confidential)
Groundfish trawl	Does not exist	NA
Scallop fishery	Does not exist	NA

3. Other miscellaneous data:

   Satellite tag migration tracking (NOAA 2016)

   Spring offshore migration distance and direction (2012-2015)

   Monthly blood hormone level (indication of molting timing) (2014-2015)

Data aggregated:

   Proportions of legal size crab, estimated from trawl survey and observer data. (Table 13)

Data estimated outside the model:

   Summer commercial catch standardized CPUE (Table 1, Appendix B)

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 large size class (> 123mm CL) of crab than observed. This problem was further exasperated when natural mortality M was set to 0.18 from previous M = 0.3 in 2011 (NPFMC 2011). This issue has been resolved by assuming (3-4 times) higher M for the length crabs (i.e., M

= 0.18 for length classes ≤ 123mm, and higher M for > 123mm) (NPFMC 2012, 2013, 2014, 2015, 2016, 2017, 2018). Alternative assumptions have been explored, such as changing molting probability (i.e., crab matured quicker or delayed maturation), higher natural mortality, and dorm shaped selectivity (i.e., large crab are not caught, or moved out of fishery/survey grounds). However, those alternative assumptions did not produce better model fits. Model estimated length specific molting probability was similar to inverse logistic curve, and did not improve model fit (NPFMC 2016). Constant *M* across all length classes resulted in higher *M* (0.3-0.45) (NPFMC 2013, 2017). Dome shaped selectivity (i.e., assume large crab were not caught/not surveyed/moved out of survey and fishing area) increased MMB twice higher than other models. A model with gradual increase of *M* across length classes resulted in *M* increase staring at size 94mm. However, this did not improve overall model fit and was rejected for model consideration (NPFMC 2018). With addition of total catch length data in summer and retention length data in winter commercial fisheries, 2019 model specification examined estimation of retention curve for both summer and winter fishery, and evaluation of OFL under Tier 3 formula.

Historical Model configuration progression:

2011 (NPFMC 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 (NPFMC 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 (NPFMC 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 (NPFMC 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 (NPFMC 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.

2016 (NPFMC 2016)

1) Length range extended from 74mm – 124mm above to 64mm – 134mm above.
2) Estimate multiplier for the largest (> 123mm) length classes.

2017 (NPFMC 2017)

1) Change molting probability function from 1 to 2 parameter logistic. Assume molting probability not reaching 1 for the smallest length class.

2018 No model change requests

2019 (NPFMC 2019)

1) Fit total catch length composition and estimate retention probability for summer and winter commercial fishery.
2) Include winter commercial retained length data.

2. Model Description

a. Description of overall modeling approach:

The model is a male-only size structured model that combines multiple sources of survey, catch, and mark-recovery data using a maximum likelihood approach to estimate abundance, recruitment, catchability of the commercial pot gear, and parameters for selectivity and molting probabilities (See Appendix A for full model description).

Unlike other crab assessment models, NSRKC modeling year starts from February 1st to January 31st of the following year. This schedule was selected because Norton Sound winter crab fisheries can start when Norton Sound ice become thick enough to operate fishery safely, which can be as earliest as mid-late January.

b-f. See Appendix A.

g. Critical assumptions of the model:

i. Male crab mature at CL length 94mm.

Size at maturity of NSRKC (CL 94 mm) was determined by adjusting that of BBRKC (CL 120mm) reflect the slower growth and smaller size of NSRKC.

ii. Molting occurs in the fall after the summer fishery.

iii. Instantaneous natural mortality M is 0.18 for all length classes, except for the last length group (>123mm).

iv. Trawl survey selectivity is a logistic function with 1.0 for length classes 7-8. 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 a low proportion of large crab are caught in the nearshore area where winter surveys occur. Causes of this pattern may be that (1) fewer large crab migrate into nearshore waters 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 first explanation is more likely than the second (Jenefer Bell, ADFG, personal communication).

vi. Summer commercial fisheries selectivity is an asymptotic logistic function of 1.0 at the length class CL 134mm. While the fishery changed greatly between the periods (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 the two periods were examined in 2015 and showed no difference between the two models (NPFMC 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 134mm. 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 models were observed (NPFMC 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.

ix. Winter commercial king crab pots can be any dimension (5AAC 34.925(d)). No length composition data exist for crab harvested in the winter commercial and 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.

x. Growth increments are a function of length, constant over time and estimated from tag recovery data.

xi. Molting probability is an inverse logistic function of length for males.

xii. A summer fishing season for the directed fishery is short. All summer commercial harvests occur at the day when 50% of harvest occurred.

xiii. Discards handling mortality rate for all fisheries is 20%.
No empirical estimates are available.

xiv. Annual retained catch is measured without error.

xv. Retained catch of crabs are estimated by retained probability function.
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. However, the model was not sensitive to this change (NPFMC 2013, 2017).

xvi. Length compositions have a multinomial error structure and abundance has a log-normal error structure.

h. Changes of assumptions since last assessment:

None.

3. Model Selection and Evaluation

a. Description of alternative model configurations.

- For 2020 preliminary assessment, we explored all alternative modeling suggestions by CPT and SSC (See Authors' responses). The baseline model (Model 19.0) is Model 18.2b adopted for the 2019 assessment. Model 19.1 explores the effects of tagging data on molting and growth transition matrix. Models 19.2 and 19.3 reexamine validity of assumptions about trawl survey q set in 2013 (NPFMC 2013). Finally, Model 19.4 reexamines the assumption of size dependent mortality (i.e., higher *M* for larger crab) by estimating natural mortality and dome shape selectivity, which was examined in 2017 (NPFMC 2017). In 2017 model assessment, estimating size invariant M resulted in higher *M*, and dome shaped selectivity resulted in assuming large number of crab never observed and caught by the fisheries. Model 19.4-19.5 combines that two alternatives examined previously. The same selectivity for each size class as 2017 was estimated directly with selectivity of one size class assumed to be 1.0. Smoothing penalty was also included in likelihood.

In September 2019 draft assessment, we examined alternative models of
Model 19.0: Baseline: Model 18.2b

Model 19.1: Model 19.0 + Tag recovery data just for 1 year

Model 19.2: Model 19.0 + NOAA trawl survey Q =1.0, Est: ADFG survey Q

Model 19.3: Model 19.0 + Est survey Qs NOAA and ADFG

Model 19.4: Model 19.0 + Est *M* equal for all lengths + Dome shape selectivity for trawl and summer commercial (max sel 94-103 for trawl, 104-113 for com)

Model 19.5: Model 19.0 + Est *M* equal for all lengths + Dome shape selectivity for trawl and summer commercial (max sel 104-113 for trawl, 114-123 for com)

From those, CPT/SSC recommended Model 19.0 with final updated data for assessment in January 2020.

b. Evaluation of negative log-likelihood values with alternative models:

	Jan 2020	Sept 2019					
Model	**Model 19.0**	Model 19.0	Model 19.1	Model 19.2	Model 19.3	Model 19.4	Model 19.5
Additional Parameters					+1	+14	+14
Total	315.9	306.1	254.4	306.2	305.8	296.5	288.6
TSA	10.0	9.8	9.6	9.9	9.7	8.8	9.4
St.CPUE	-24.1	-24.1	-24.1	-24.1	-23.8	-23.2	-23.2
TLP	115.3	110.8	109.7	110.5	110.6	108.4	105.4
WLP	38.5	39.0	39.6	38.6	38.8	41.4	42.5
CLP	49.3	48.4	48.9	48.3	48.3	54.1	50.2
OBS	24.8	20.4	19.9	20.3	20.4	19.4	20.2
REC	2.7	2.6	2.7	2.4	2.5	1.8	1.9
WN	17.8	18.1	18.3	18.1	18.1	18.8	18.8
TAG	81.5	81.2	30.0	81.2	81.2	65.0	61.8
BMSY(mil.lb)	4.58	4.66	4.70	3.40	4.00	6.72	5.13
MMB(mil.lb)	3.73	3.98	3.87	2.86	3.35	5.45	4.66
Legal crab Catchable (mil.lb)	2.43	2.53	2.46	1.78	2.10	2.37	2.18
OFL(mil.lb)	0.29	0.31	0.29	0.22	0.26	0.46	0.60
NOAA q	0.71	0.70	0.68	1	0.81	0.66	0.71
ADFG q	1	1	1	1.40	1.20	1	1
M	0.18/0.58	018/0.58	018/0.64	018/0.52	018/0.55	0.31	0.43

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 retention catch length composition
REC: Recruitment deviation
OBS: Summer commercial catch observer discards (Baseline) or total catch (Alternative models) length composition
TAG: Tagging recovery data composition
WN: Winter Commercial length-shell composition

See Appendix C1-C3 for standard output figures and estimated parameters.

Search for balance:

SSC noted in 2019 that model choice does not have much impact on the results, or on the Tier 4 reference points, which was also true for the 2020 assessment. The only meaningful change occurs when we change assumptions about survey and fishery data selectivity and q, natural mortality, and fate of large crab, in other words, changing assumptions and understandings about biology of the NSRKC that are significantly lacking support.

Using only 1st year molting tagged crab (Model 19.0 vs. 19.1) resulted in slight changes in transition matrix (Table 14), and this did not improve model fit, MMB, and likelihood (Figure 4,8,9,11). Thus, including more than 1 years of recovery data appeared to have little effects on estimation of size transition matrix and the NSRKC assessment model. Estimating ADF&G survey q was greater than 1.0 (Models 19.2, 19.3), indicating that ADFG trawl survey overestimates NSRKC abundance (Figure 7). This lowered MMB and OFL from the baseline model (Figure 5). Assuming domed shape selectivity and estimating *M* (Model 19.4, 19.5) resulted in higher natural mortality and higher MMB (Figure 6), indicating that NSRKC having a greater natural mortality than assumed 0.18 and that larger crab exist in Norton Sound that have never been observed or caught by summer trawl survey or summer commercial fishery. Under the Tier 4 harvest control rule, a higher natural mortality results in a higher OFL (though they are lower than Tier 3 OFL (NPFMC 2019)).

Authors recommended Model 19.0 or 19.1 for final assessment. The question to decide between the two models are whether to include tag-recovery data of 2 and 3 years at liberty, given that the data had little/no influence on assessment model results. CPT recommended and authors concurred Model 19.0 with updated data for the final assessment for January 2020.

4. **Results**

1. List of effective sample sizes and weighting factors (Figure 15)

"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 sizes for length proportions:

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
Tag recovery	0.5× actual sample size

Weighting factor:

Recruitment SD: 0.5.

2. Tables of estimates.
   a. Model parameter estimates (Tables 11, 12).
   b. Abundance and biomass time series (Table 13).
   c. Recruitment time series (Table 13).
   d. Time series of catch/biomass (Tables 14).
3. Graphs of estimates.
   a. Molting probability and trawl/pot selectivity (Figure 3).
   b. Estimated male abundances (recruits, legal, and total) (Figure 4).

c. Estimated mature male biomass (Figure 5).

e. Time series of catch and estimated harvest rate (Figure 6).

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.

b. Model fits to survey numbers.

1. Time series of trawl survey (Figure 7).
2. Time series of standardized cpue for the summer commercial fishery (Figure 8).

c. Model fits to catch and survey proportions by length (Figures 9-13).

d. Marginal distribution for the fits to the composition data.

e. Plots of implied versus input effective sample sizes and time-series of implied effective sample size (Figure 15).

f. RMSEs of trawl survey and standardized CPUE (Figure 17).

QQ plots and histograms of residuals of trawl survey and standardized CPUE (Figure 17).

5. Retrospective analyses (Figure 18).

Retrospective analyses was limited to past 4 years because winter commercial length data that was used to estimate retention curve was limited to 4 years of data.

Year	Predicted MMB (x1000)	Hindcast MMB	Mohn.Rho
2019	3038.92	2826.42	0.2935
2018	3951.35	3190.10	0.4161
2017	5662.02	4762.69	0.2386
2016	6160.35	5164.06	0.0822

Revised Mohn.Rho 0.258

Hurtado-Ferro et al. (2015), provided guideline of Mohn's rho exceeding the range of (-0.15 to 0.2) for longer life-history and (-0.22 to 0.30) for shorter lived species, should cause for concern.

6. Uncertainty and sensitivity analyses.

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.

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	$\beta < B/B_{MSY^{prox}} \leq 1$	$F_{OFL} = \gamma M (B/B_{MSY^{prox}} - \alpha)/(1-\alpha)$
c	$B/B_{MSY^{prox}} \leq \beta$	$F_{OFL} = bycatch\ mortality\ \&\ directed\ fishery\ F = 0$

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 1980-2020.

Estimated B_{MSY} proxy is: 4.561 million lb / 2.07 k ton.

Predicted mature male biomass in 2020 on February 01

Mature male biomass: 3.664 (SE 0.452) million lb. or 2.07 (SE 0.305) k ton

Since projected MMB is less than B_{MSY} proxy,

Norton Sound red king crab stock status is Tier 4b,

Where F_{OFL} is calculated by

$$F_{OFL} = \gamma M (B/B_{MSY^{prox}} - \alpha)/(1-\alpha)$$

F_{OFL} of 0.141 for all length classes.

1. Calculation of OFL.

OFL was calculated for retained (OFL_r), un-retained (OFL_{ur}), and total (OFL_T) for legal sized crab, *Legal_B*, by applying F_{OFL}.

Legal_B is a biomass of legal crab subject to fisheries and is calculated as: projected abundance by length crab × fishery selectivity by length class × proportion of legal crab per length class × average lb per length class.

For the Norton Sound red king crab assessment, *Legal_B* was defined as winter biomass catchable to summer commercial pot fishery gear $Legal\_B_w$, as

$$Legal\_B_w = \sum_l (N_{w,l} + O_{w,l}) S_{s,l} P_{lg,l} wm_l$$

The Norton Sound red king crab fishery consists of two distinct fisheries: winter and summer. The two fisheries are discontinuous with 5 months between the two fisheries during which natural mortalities occur. To incorporate this fishery, the CPT in 2016 recommended the following formula:

$$Legal\_B_s = Legal\_B_w(1-\exp(-x\cdot F_{OFL}))e^{-0.42M}$$
$$OFL_r = (1-\exp(-(1-x)\cdot F_{OFL}))Legal\_B_s$$

And $p = \dfrac{Legal\_B_w(1-\exp(-x\cdot F_{OFL}))}{OFL_r}$

Where p is a specific proportion of winter crab harvest to total (winter + summer) harvest.

Solving x of the above, a revised retained OFL is

$$OFL = Legal\_B_w\left(1-e^{-(F_{OFl}+0.42M)} - (1-e^{-0.42M})\left(\frac{1-p\cdot(1-e^{-(F_{OFL}+0.42M)})}{1-p\cdot(1-e^{-0.42M})}\right)\right)$$

Accounting for difference in length specific natural mortality

$$OFL_r = \sum_l\left[Legal\_B_{w,l}\left(1-e^{-(F_{OF,l}+0.42M_l)} - (1-e^{-0.42M_l})\left(\frac{1-p\cdot(1-e^{-(F_{OFL,l}+0.42M_l)})}{1-p\cdot(1-e^{-0.42M_l})}\right)\right)\right]$$

Unretained OFL (OFL_{ur}) is a sub-legal crab biomass catchable to the summer commercial pot fishery 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 (hm =0.2)

$$OFL_{ur} = \sum_l\left[Sub\_legal\_B_{w,l}\left(1-e^{-(F_{OFL,l}+0.42M_l)} - (1-e^{-0.42M_l})\left(\frac{1-p\cdot(1-e^{-(F_{OFL,l}+0.42M_l)})}{1-p\cdot(1-e^{-0.42M_l})}\right)\right)\right]\cdot hm$$

The total male OFL is

$$OFL_T = OFL_r + OFL_{ur}$$

For calculation of the OFL 2020, we specified p = 0.16.

Legal male biomass catchable to fishery (Feb 01): 2.428 (SE 0.30) million lb or 1.101 k ton
OFL_r = 0.287 million lb. or 0.104 k ton

G. Calculation of the ABC

1. Specification of the probability distribution of the OFL.

Probability distribution of the OFL was derived using ADMB's 1 million MCMC.

In 2015 of ABC buffer of Norton Sound Red King Crab was set to 20%, and ABC is calculated as (1-ABC buffer)·OFL

In 2020, CPT recommended the buffer to 25% due to declined CPUE.

Retained ABC for legal male crab is 75% of OFL

ABC = 0.215 million lb. or 0.098 k ton

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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Tables

Table 1. Historical summer commercial red king crab fishery economic performance, Norton Sound Section, eastern Bering Sea. Bold type shows data that are used for the assessment model.

	Guideline Harvest Level	Commercial Harvest (lb) [a, b]								ST CPUE		Season Length		Mid-day from July
				Number	Total Number (Open Access)			Total Pots						
Year	(lb) [b]	Open Access	CDQ	**Harvest**	Vessels	Permits	Landings	Registered	Pulls	**CPUE**	**SD**	Days	Dates	
1977	[c]	517.787		**195,877**	7	7	13		5,457	**3.29**	**0.68**	60	[c]	**0.049**
1978	3,000.000	2,091.961		**660,829**	8	8	54		10,817	**4.68**	**0.65**	60	6/07-8/15	**0.142**
1979	3,000.000	2,931.672		**970,962**	34	34	76		34,773	**2.87**	**0.64**	16	7/15-7/31	**0.088**
1980	1,000.000	1,186.596		**329,778**	9	9	50		11,199	**3.07**	**0.65**	16	7/15-7/31	**0.066**
1981	2,500.000	1,379.014		**376,313**	36	36	108		33,745	**0.86**	**0.64**	38	7/15-8/22	**0.096**
1982	500.000	228.921		**63,949**	11	11	33		11,230	**0.2**	**0.62**	23	8/09-9/01	**0.151**
1983	300.000	368.032		**132,205**	23	23	26	3,583	11,195	**0.9**	**0.65**	3.8	8/01-8/05	**0.096**
\1984	400.000	387.427		**139,759**	8	8	21	1,245	9,706	**1.59**	**0.65**	13.6	8/01-8/15	**0.110**
1985	450.000	427.011		**146,669**	6	6	72	1,116	13,209	**0.5**	**0.66**	21.7	8/01-8/23	**0.118**
1986	420.000	479.463		**162,438**	3	3		578	4,284	**1.74**	**0.7**	13	8/01-8/25	**0.153**
1987	400.000	327.121		**103,338**	9	9		1,430	10,258	**0.61**	**0.64**	11	8/01-8/12	**0.107**
1988	200.000	236.688		**76,148**	2	2		360	2,350	**2.36**	**0.86**	9.9	8/01-8/11	**0.110**
1989	200.000	246.487		**79,116**	10	10		2,555	5,149	**1.21**	**0.61**	3	8/01-8/04	**0.096**
1990	200.000	192.831		**59,132**	4	4		1,388	3,172	**1.08**	**0.68**	4	8/01-8/05	**0.099**
1991	340.000			**0**	No Summer Fishery									
1992	340.000	74.029		**24,902**	27	27		2,635	5,746	**0.17**	**0.6**	2	8/01-8/03	**0.093**
1993	340.000	335.790		**115,913**	14	20	208	560	7,063	**0.9**	**0.35**	52	7/01-8/28	**0.093**
1994	340.000	327.858		**108,824**	34	52	407	1,360	11,729	**0.81**	**0.34**	31	7/01-7/31	**0.044**
1995	340.000	322.676		**105,967**	48	81	665	1,900	18,782	**0.42**	**0.34**	67	7/01-9/05	**0.093**
1996	340.000	224.231		**74,752**	41	50	264	1,640	10,453	**0.51**	**0.34**	57	7/01-9/03	**0.101**
1997	80.000	92.988		**32,606**	13	15	100	520	2,982	**0.84**	**0.35**	44	7/01-8/13	**0.074**
1998	80.000	29.684	0.00	**10,661**	8	11	50	360	1,639	**0.79**	**0.36**	65	7/01-9/03	**0.110**
1999	80.000	23.553	0.00	**8,734**	10	9	53	360	1,630	**0.92**	**0.36**	66	7/01-9/04	**0.104**
2000	336.000	297.654	14.87	**111,728**	15	22	201	560	6,345	**1.24**	**0.34**	91	7/01- 9/29	**0.126**
2001	303.000	288.199	0	**98,321**	30	37	319	1,200	11,918	**0.64**	**0.34**	97	7/01- 9/09	**0.104**
2002	248.000	244.376	15.226	**86,666**	32	49	201	1,120	6,491	**1.23**	**0.34**	77	6/15-9/03	**0.060**
2003	253.000	253.284	13.923	**93,638**	25	43	236	960	8,494	**0.85**	**0.34**	68	6/15-8/24	**0.058**
2004	326.500	314.472	26.274	**120,289**	26	39	227	1,120	8,066	**1.27**	**0.34**	51	6/15-8/08	**0.033**
2005	370.000	370.744	30.06	**138,926**	31	42	255	1,320	8,867	**1.19**	**0.34**	73	6/15-8/27	**0.058**
2006	454.000	419.191	32.557	**150,358**	28	40	249	1,120	8,867	**1.31**	**0.34**	68	6/15-8/22	**0.052**
2007	315.000	289.264	23.611	**110,344**	38	30	251	1,200	9,118	**1.02**	**0.34**	52	6/15-8/17	**0.036**
2008	412.000	364.235	30.9	**143,337**	23	30	248	920	8,721	**1.32**	**0.34**	73	6/23-9/03	**0.079**
2009	375.000	369.462	28.125	**143,485**	22	27	359	920	11,934	**0.84**	**0.34**	98	6/15-9/20	**0.090**
2010	400.000	387.304	30	**149,822**	23	32	286	1,040	9,698	**1.22**	**0.34**	58	6/28-8/24	**0.074**
2011	358.000	373.990	26.851	**141,626**	24	25	173	1,040	6,808	**1.58**	**0.34**	33	6/28-7/30	**0.038**
2012	465.450	441.080	34.91	**161,113**	40	29	312	1,200	10,041	**1.29**	**0.34**	72	6/29-9/08	**0.093**
2013	495.600	373.278	18.585	**130,603**	37	33	460	1,420	15,058	**0.67**	**0.33**	74	7/3-9/14	**0.110**
2014	382.800	360.860	28.148	**129,657**	52	33	309	1,560	10,127	**1.12**	**0.34**	52	6/25-8/15	**0.052**
2015	394.600	371.520	29.595	**144,255**	42	36	251	1,480	8,356	**1.45**	**0.34**	26	6/29-7/24	**0.033**
2016	517.200	416.576	3,583	**138,997**	36	37	220	1,520	8,009	**1.27**	**0.34**	25	6/27-7/21	**0.025**
2017	496,800	411,736	0	**135,322**	36	36	270	1,640	9,401	**1.1**	**0.34**	30	6/26-7/25	**0.027**
2018	319,400	298,396	0	**89,613**	34	34	256	1,400	8,797	**0.64**	**0.34**	35	6/24-7/29	**0.030**
2019	150,600	73,784	1,239	**24,506**	24	26	146	1,096	5,438	**0.26**	**0.34**	62	6/25-9/03	**0.068**

[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. 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	**41,062**	2014/15	155	153	107	**9,840**	**7,651**
2016	2015/16	25	**29,792**	2015/16	139	97	64	**6,468**	**5,340**
2017	2017	43	**26,008**	2017	163	163	109	**7,185**	**6,039**
2018	2018	28	**9,180**	2018	123	120	82	**5,767**	**4,424**
2019	2019	6	**1,050**	2019	101	101	60	**2,080**	**1,545**

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 (CL ≥ 64mm) . Trawl survey abundance estimate is based on 10×10 nm^2 grid, except for 2010 and 2017 (20×20 nm^2). Bold typed data are used for the assessment model.

				Survey coverage			Abundance ≥64 mm	
Year	Dates	Survey Agency	Survey method	Total surveyed hauls	Stations w/ NSRKC	n mile^2 expaned		CV
1976	9/02 – 9/25	NMFS	Trawl	117	61	7600	**4301.8**	**0.31**
1979	7/26 - 8/05	NMFS	Trawl	115	33	7600	**1457.4**	**0.22**
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	57	46	7600	**3548.9**	**0.25**
1985	7/01 - 7/14	ADFG	Pots				2320.4	0.083
1985	9/16 -10/01	NMFS	Trawl	78	58	7600	**2424.9**	**0.26**
1988	8/16 - 8/30	NMFS	Trawl	82	45	7600	**2702.3**	**0.29**
1991	8/22 - 8/30	NMFS	Trawl	51	38	7600	**4049.1**	**0.40**
1996	8/07 - 8/18	ADFG	Trawl	50	30	4938	**1283.0**	**0.25**
1999	7/28 - 8/07	ADFG	Trawl	52	31	5221	**2608.0**	**0.24**
2002	7/27 - 8/06	ADFG	Trawl	57	37	5621	**2056.0**	**0.36**
2006	7/25 - 8/08	ADFG	Trawl	114	45	6000	**3336.0**	**0.39**
2008	7/24 - 8/11	ADFG	Trawl	86	44	7330	**2894.2**	**0.31**
2010[a]	7/27 - 8/09	NMFS	Trawl	16	14	5841	**1980.1**	**0.44**
2011	7/18 - 8/15	ADFG	Trawl	65	34	6447	**3209.3**	**0.29**
2014	7/18 - 7/30	ADFG	Trawl	47	34	4700	**5934.6**	**0.47**
2017	7/28 - 8/08	ADFG	Trawl	60	41	6000	**1762.1**	**0.22**
2017	8/18 - 8/29	NMFS	Trawl	16	8	5841	**1035.8**	**0.40**
2018	7/22 - 7/29	ADFG	Trawl	60	34	6000	**1108.9**	**0.25**
2019	7/17-7/29	ADFG	Trawl	52	27	5221	**4660.8**	**0.60**
2019	8/04-8/07	NMFS	Trawl	16	10	5841	**2532.4**	**0.30**

Abundance of NMFS survey (1976-1991) was estimated by NMFS, multiplying the mean CPUE (# NRKC/NM^2) across all hauls (including re-tows) to a standard survey area (7600NM^2).

In contrast, abundance of ADFG (1996-2019) and NMFS (2010,2017) survey were estimated by ADFG by multiplying CPUE (# NRKC/NM^2) of each station to an area represented by the station (~100NM^2) and summing across all surveyed station (ADFG: 4700 – 5200NM^2. NOAA 5841 NM^2).

Table 4. Summer commercial retained catch length-shell compositions.

		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
2016	1543	0	0	0	0.00	0.25	0.47	0.16	0.03	0	0	0	0.00	0.02	0.02	0.03	0.01
2017	3412	0	0	0	0.00	0.18	0.39	0.21	0.03	0	0	0	0.01	0.03	0.12	0.05	0.01
2018	2609	0	0	0	0.00	0.11	0.32	0.32	0.08	0	0	0	0	0.01	0.08	0.08	0.02
2019	1136	0	0	0	0.01	0.32	0.23	0.13	0.03	0	0	0	0	0.02	0.10	0.14	0.03

Table 5. Winter commercial catch length-shell compositions.

		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+
2015	576	0	0	0	0.07	0.50	024	0.06	0.01	0	0	0	0.01	0.04	0.03	0.03	0.01
2016	1016	0	0	0	0.03	0.45	0.31	0.03	0.00	0	0	0	0.01	0.09	0.04	0.02	0.01
2017	540	0	0	0	0.00	0.20	0.30	0.13	0.02	0	0	0	0.00	0.08	0.19	0.06	0.02
2018	401	0	0	0	0.00	0.11	0.25	0.27	0.05	0	0	0	0	0.04	0.16	0.10	0.02

Table 6. Summer Trawl Survey length-shell compositions.

			New Shell								Old Shell							
Year	Survey	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	NMFS	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	NMFS	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	NMFS	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	NMFS	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	NMFS	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	NMFS	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	ADFG	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	ADFG	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	ADFG	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	ADFG	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	ADFG	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	NMFS	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	ADFG	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	ADFG	387	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
2017	ADFG	116	0.14	0.12	0.05	0.09	0.10	0.04	0.00	0.00	0.01	0.02	0.02	0.02	0.07	0.18	0.04	0.00
2017	NMFS	58	0.09	0.10	0.14	0.05	0.05	0.05	0.05	0.03	0.03	0.00	0.03	0.05	0.03	0.19	0.05	0.03
2018	ADFG	73	0.37	0.10	0.11	0.03	0.01	0.03	0.04	0.01	0	0.07	0.01	0.04	0.03	0.03	0.10	0.03
2019	ADFG	307	0.55	0.30	0.03	0	0.00	0.00	0.00	0	0.00	0.00	0.01	0.02	0.01	0.02	0.03	0.01
2019	NMFS	135	0.36	0.30	0.08	0.04	0.01	0	0.01	0.01	0.04	0.01	0.04	0.02	0.01	0.01	0.04	0.01

Table 7. Winter pot survey length-shell compositions.

			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

Table 8. Summer commercial 1987-1994 observer discards length-shell compositions.

		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

Table 9. Summer commercial observer total catch length-shell compositions.

		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+
2012	3055	0.10	0.05	0.08	0.15	0.15	0.17	0.06	0.01	0.00	0.00	0.00	0.03	0.08	0.09	0.03	0.00
2013	4762	0.19	0.16	0.09	0.10	0.16	0.16	0.09	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00
2014	3506	0.02	0.05	0.13	0.22	0.22	0.12	0.08	0.03	0.00	0.00	0.00	0.02	0.03	0.03	0.02	0.01
2015	1671	0.01	0.04	0.09	0.23	0.37	0.14	0.05	0.01	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.00
2016	2114	0.01	0.01	0.03	0.12	0.29	0.36	0.08	0.02	0.00	0.00	0.00	0.01	0.03	0.03	0.02	0.00
2017	2748	0.02	0.03	0.03	0.06	0.19	0.33	0.18	0.02	0.00	0.00	0.00	0.00	0.02	0.07	0.03	0.01
2018	1628	0.03	0.06	0.12	0.11	0.09	0.17	0.18	0.04	0.00	0.00	0.01	0.01	0.15	0.07	0.08	0.02
2019	236	0.13	0.06	0.06	0.13	0.08	0.05	0.01	0.01	0	0	0.00	0.04	0.11	0.14	0.14	0.05

Table 10. The number of tagged data released and recovered after 1 year (Y1) – 3 year (Y3) during 1980-1992 and 1993-2019 periods.

Release Length Class	Recap Length Class	1980-1992					1993-2019					
		Y1	Y2	Y3	Y4	Y5	Y1	Y2	Y3	Y4	Y5	Y6
64 – 73	64 – 73											
64 – 73	74 - 83	1										
64 – 73	84 - 93	1	1				3					
64 – 73	94 - 103							5				
64 – 73	104 – 113				1			4	11	3	1	1
64 – 73	114 – 123				1				11	5	1	
64 – 73	124 – 133									1		1
64 – 73	134+										2	
74 - 83	74 - 83											
74 - 83	84 - 93						21					
74 - 83	94 - 103						22	12				
74 - 83	104 – 113		2				4	94	19	4	1	
74 - 83	114 – 123			2		2		5	46	17	2	1
74 - 83	124 – 133								6	11	3	2
74 - 83	134+									1		
84 - 93	84 - 93											
84 - 93	94 - 103	5					42	5	2			
84 - 93	104 – 113	10	2		1		81	34	14	1		
84 - 93	114 – 123		1	1	1		7	69	27	9	3	
84 - 93	124 – 133				1	1	1	3	9	12	4	
84 - 93	134+									2	1	
94 - 103	94 - 103	3	1	1			7	2				
94 - 103	104 – 113	31	1	3			165	33	2			
94 - 103	114 – 123	26		1	1		82	38	32	3		
94 - 103	124 – 133	2						19	13	5	1	
94 - 103	134+					1	1			1	1	1
104 – 113	104 – 113	16					59	7				
104 – 113	114 – 123	34	13				109	64	9	3	1	
104 – 113	124 – 133	7	6	3	1		15	18	18	9	1	
104 – 113	134+				1				4	1	1	1
114 – 123	114 – 123	16	2				72	9				
114 – 123	124 – 133	26	9	1			72	38	10	1	1	
114 – 123	134+	5	1		1		19	6	3	4		
124 – 133	124 – 133	15					41	9	1			
124 – 133	134+	10	4	2			15	12	7	1		
134+	134+	15	6	1			11	2				

Table 11. 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	Est	sd	Lower	Upper
log_$q_{1,2}$	Commercial fishery catchability (1977-92, 1993-2017)	-6.768	0.110	-20.5	20
log_N_{76}	Initial abundance	9.113	0.108	2.0	15.0
R_0	Mean Recruit	6.462	0.081	2.0	12.0
log_σ_R^2	Recruit standard deviation			-40.0	40.0
a_{1-7}	Intimal length proportion			0	10.0
r_1	Proportion of length class 1 for recruit			0	10.0
log_α	Inverse logistic molting parameter	-2.682	0.089	-5.0	-1.0
log_β	Inverse logistic molting parameter	4.831	0.015	1.0	5.5
log_ϕ_{st1}	Logistic trawl selectivity parameter	-5.000	0.048	-5.0	1.0
log_ϕ_{wa}	Inverse logistic winter pot selectivity parameter	-2.220	0.269	-5.0	1.0
log_ϕ_{wb}	Inverse logistic winter pot selectivity parameter	4.795	0.029	0.0	6.0
$Sw_{1,2}$	Winter pot selectivity of length class 1,2			0.1	1.0
log_ϕ_l	Logistic commercial catch selectivity parameter	-2.067	0.052	-5.0	1.0
log_acr	Logistic summer commercial retention selectivity parameter	-0.787	0.129	-5.0	1.0
log_bcr	Logistic summer commercial retention selectivity parameter	4.646	0.008	0.0	6.0
log_awr	Logistic winter commercial retention selectivity parameter	-0.954	0.536	-5.0	1.0
log_bwr	Logistic winter commercial retention selectivity parameter	4.656	0.037	0.0	6.0
w^2_t	Additional variance for standard CPUE	0.000	0.000	0.0	6.0
ms	Natural mortality multipliers	3.226	0.252	0.5	5.0
q	Survey q for NMFS trawl 1976-91	0.710	0.114	0.1	1.0
σ	Growth transition sigma	3.853	0.209	0.0	30.0
β_1	Growth transition mean	12.196	0.704	0.0	20.0
β_2	Growth transition increment	7.713	0.173	0.0	20.0

Table 12. Estimated molting probability incorporated transition matrix.

Pre-molt	Post-molt Length Class							
Length Class	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
64 - 73	0.02	0.10	0.79	0.09	0.00	0.00	0.00	0.00
74 - 83		0.04	0.24	0.70	0.03	0.00	0.00	0.00
84 - 93			0.08	0.43	0.49	0.01	0.00	0.00
94 - 103				0.15	0.58	0.26	0.00	0.00
104 - 113					0.29	0.61	0.10	0.00
114 - 123						0.50	0.47	0.03
124 - 133							0.72	0.28
134+								1.00

Table 13. Annual abundance estimates (million crab) and mature male biomass (Feb 01) (MMB, million lb) for Norton Sound red king crab estimated by a length-based analysis.

	Abundance			Legal (≥ 104mm)		MMB
Year	Recruits (<94mm)	Total	Mature (≥ 94mm)	Abundance	Biomass	Biomass
1976	2.61	9.07	6.46	4.14	11.03	15.39
1977	1.07	7.97	6.90	5.43	15.54	18.35
1978	0.77	6.41	5.64	5.01	15.51	16.74
1979	0.55	4.50	3.95	3.58	11.72	12.42
1980	1.10	3.33	2.23	1.99	6.68	7.13
1981	1.59	3.25	1.66	1.31	4.43	5.07
1982	1.69	3.21	1.52	0.99	3.07	4.04
1983	1.66	3.51	1.85	1.23	3.63	4.78
1984	1.71	3.76	2.05	1.43	4.17	5.34
1985	1.38	3.59	2.20	1.57	4.63	5.81
1986	1.34	3.58	2.23	1.67	4.99	6.05
1987	1.15	3.28	2.13	1.62	4.94	5.89
1988	1.06	3.13	2.07	1.60	4.93	5.80
1989	1.10	3.05	1.95	1.54	4.79	5.57
1990	0.92	2.78	1.86	1.45	4.54	5.32
1991	0.82	2.58	1.76	1.39	4.36	5.06
1992	0.72	2.38	1.66	1.33	4.21	4.83
1993	0.58	2.10	1.52	1.23	3.93	4.47
1994	0.55	1.84	1.29	1.05	3.35	3.79
1995	0.65	1.73	1.08	0.87	2.77	3.17
1996	0.85	1.81	0.96	0.73	2.30	2.73
1997	1.52	2.51	1.00	0.70	2.16	2.71
1998	1.30	2.61	1.31	0.82	2.43	3.34
1999	0.75	2.42	1.66	1.15	3.32	4.29
2000	0.81	2.49	1.67	1.32	3.94	4.61
2001	1.17	2.66	1.49	1.19	3.69	4.26
2002	1.35	2.85	1.50	1.10	3.43	4.18
2003	1.11	2.74	1.64	1.15	3.50	4.40
2004	0.83	2.52	1.69	1.24	3.73	4.56
2005	1.13	2.70	1.57	1.22	3.72	4.37
2006	1.45	2.94	1.50	1.11	3.41	4.14
2007	1.60	3.21	1.61	1.10	3.33	4.26
2008	1.63	3.45	1.82	1.24	3.66	4.73
2009	1.28	3.27	1.98	1.38	4.05	5.18
2010	0.85	2.87	2.02	1.50	4.44	5.42
2011	0.92	2.75	1.83	1.45	4.42	5.12
2012	1.17	2.79	1.62	1.27	3.97	4.61
2013	1.98	3.52	1.54	1.13	3.50	4.26
2014	1.40	3.17	1.77	1.13	3.41	4.59
2015	0.67	2.67	2.00	1.41	4.08	5.19
2016	0.48	2.20	1.72	1.39	4.16	4.79
2017	0.55	1.91	1.36	1.15	3.61	4.01
2018	0.74	1.83	1.08	0.88	2.84	3.21
2019	2.31	3.32	1.00	0.75	2.38	2.85

Table 14. Summary of catch and estimated discards (million lb) for Norton Sound red king crab. Assumed average crab weight is 2.0 lb for winter subsistence catch and 1.0 lb for Winter subsistence discards. Summer and winter commercial discards were estimated from the model.

Year	Summer Com	Winter Com	Winter Sub	Modeled Discards Summer	Discards Winter Sub	Modeled Discards Winter Com	Total	Catch/ MMB
1977	0.52	0.000	0.000	0.022	0	0.000	0.542	0.035
1978	2.09	0.024	0.025	0.040	0.008	0.001	2.188	0.141
1979	2.93	0.001	0.000	0.049	0	0.000	2.98	0.254
1980	1.19	0.000	0.000	0.024	0	0.000	1.214	0.182
1981	1.38	0.000	0.001	0.067	0	0.000	1.448	0.327
1982	0.23	0.000	0.003	0.020	0.001	0.000	0.254	0.083
1983	0.37	0.001	0.021	0.036	0.006	0.000	0.434	0.119
1984	0.39	0.002	0.022	0.033	0.005	0.000	0.452	0.108
1985	0.43	0.003	0.017	0.032	0.002	0.000	0.484	0.105
1986	0.48	0.005	0.014	0.028	0.004	0.001	0.532	0.107
1987	0.33	0.003	0.012	0.018	0.002	0.000	0.365	0.074
1988	0.24	0.001	0.005	0.012	0.001	0.000	0.259	0.053
1989	0.25	0.000	0.012	0.012	0.002	0.000	0.276	0.058
1990	0.19	0.010	0.024	0.009	0.004	0.001	0.238	0.052
1991	0	0.010	0.015	0.000	0.002	0.001	0.028	0.006
1992	0.07	0.021	0.023	0.003	0.003	0.002	0.122	0.029
1993	0.33	0.005	0.002	0.014	0	0.000	0.351	0.089
1994	0.32	0.017	0.008	0.013	0.001	0.001	0.36	0.108
1995	0.32	0.022	0.011	0.015	0.002	0.002	0.372	0.134
1996	0.22	0.005	0.003	0.014	0.001	0.001	0.244	0.106
1997	0.09	0.000	0.001	0.009	0.001	0.000	0.101	0.047
1998	0.03	0.002	0.017	0.004	0.012	0.001	0.066	0.027
1999	0.02	0.007	0.015	0.002	0.003	0.001	0.048	0.014
2000	0.3	0.008	0.011	0.015	0.004	0.001	0.339	0.086
2001	0.28	0.003	0.001	0.015	0	0.000	0.299	0.081
2002	0.25	0.007	0.004	0.019	0.003	0.001	0.284	0.083
2003	0.26	0.017	0.008	0.021	0.005	0.002	0.313	0.090
2004	0.34	0.001	0.002	0.022	0.001	0.000	0.366	0.098
2005	0.4	0.006	0.008	0.022	0.003	0.001	0.44	0.118
2006	0.45	0.000	0.002	0.032	0.001	0.000	0.485	0.142
2007	0.31	0.008	0.021	0.029	0.011	0.001	0.38	0.114
2008	0.39	0.015	0.019	0.037	0.009	0.002	0.472	0.129
2009	0.4	0.012	0.010	0.033	0.002	0.002	0.459	0.113
2010	0.42	0.012	0.014	0.026	0.002	0.001	0.475	0.107
2011	0.4	0.009	0.013	0.019	0.003	0.001	0.445	0.101
2012	0.47	0.025	0.015	0.026	0.004	0.002	0.542	0.137
2013	0.35	0.061	0.015	0.031	0.014	0.009	0.48	0.137
2014	0.39	0.035	0.007	0.042	0.002	0.007	0.483	0.142
2015	0.40	0.099	0.019	0.028	0.005	0.010	0.561	0.138
2016	0.42	0.080	0.011	0.016	0.001	0.005	0.533	0.128
2017	0.41	0.078	0.012	0.013	0.001	0.004	0.518	0.143
2018	0.30	0.029	0.008	0.012	0.001	0.002	0.352	0.124
2019	0.08	0.032	0.003	0.006	0.001	0.006	0.128	0.054

Figures

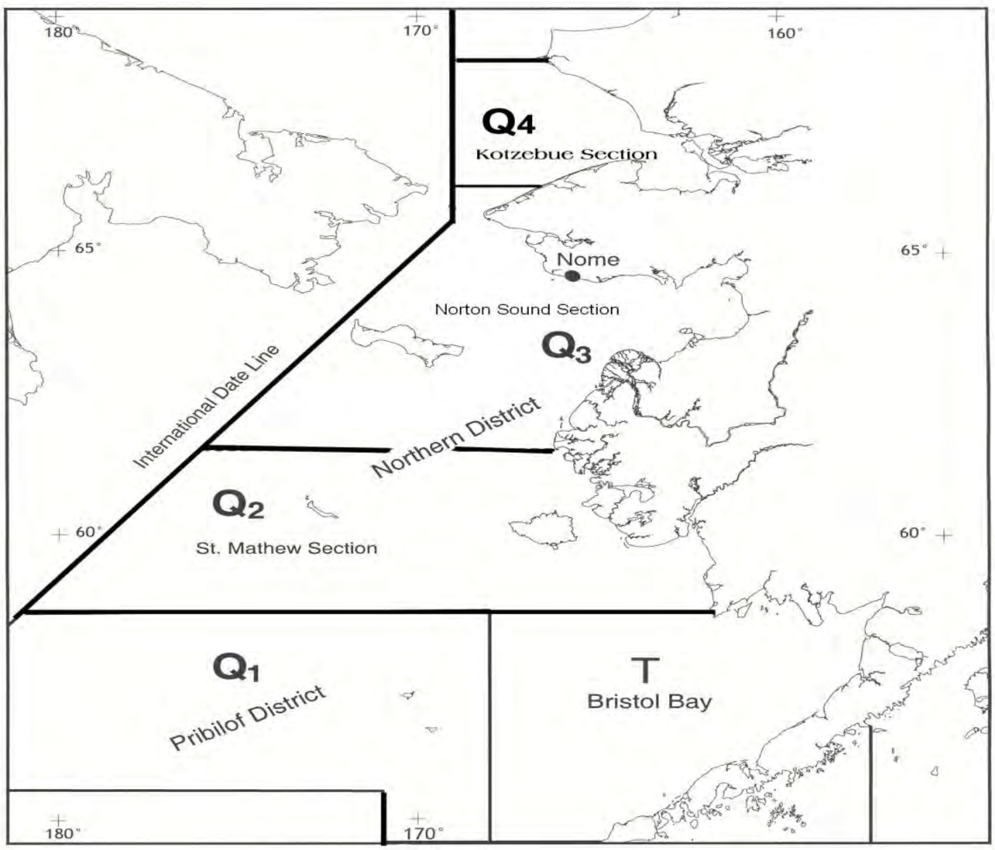


Figure 1. King crab fishing districts and sections of Statistical Area Q.

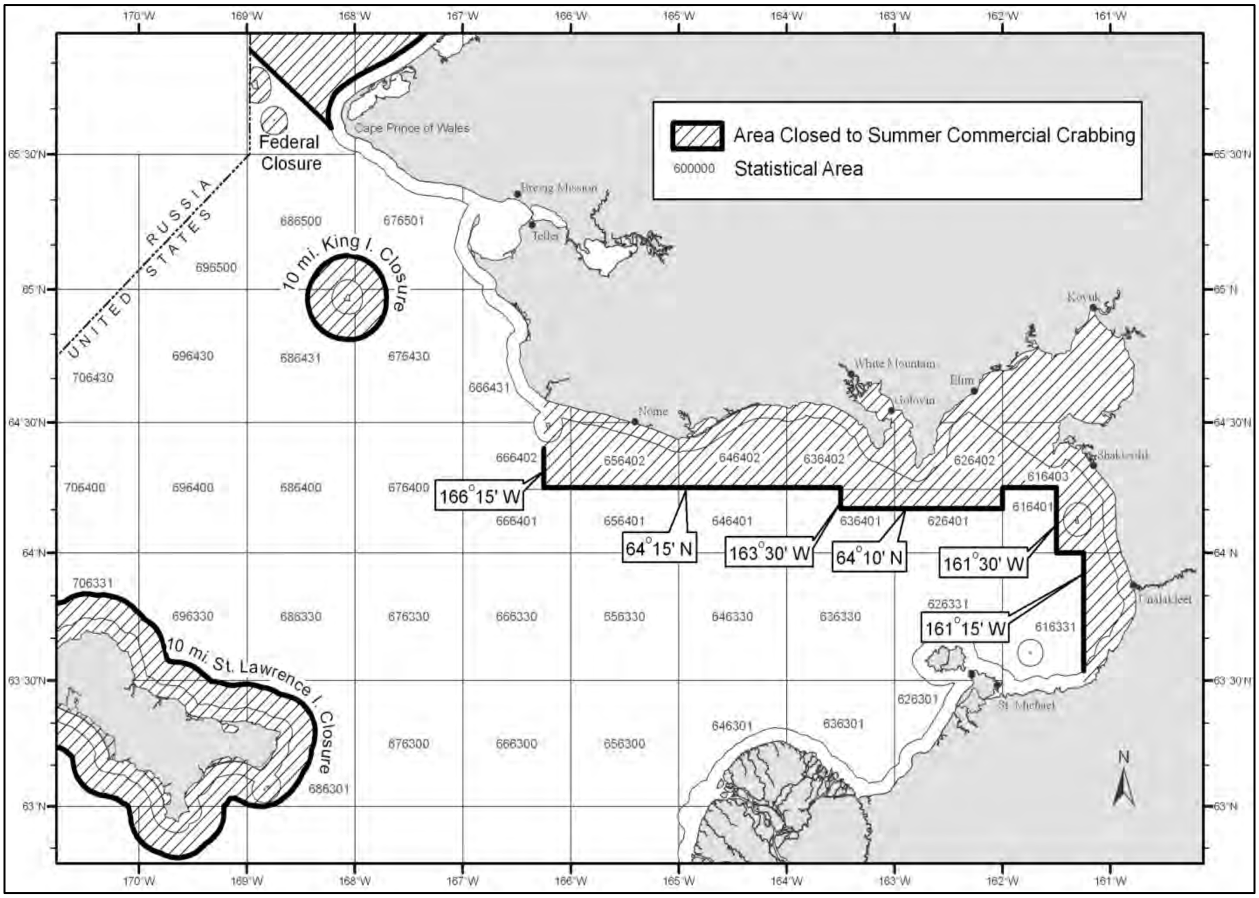


Figure 2. Closed water regulations in effect for the Norton Sound commercial crab fishery. Line around the coastline delineates the 3-mil3 state waters zone.

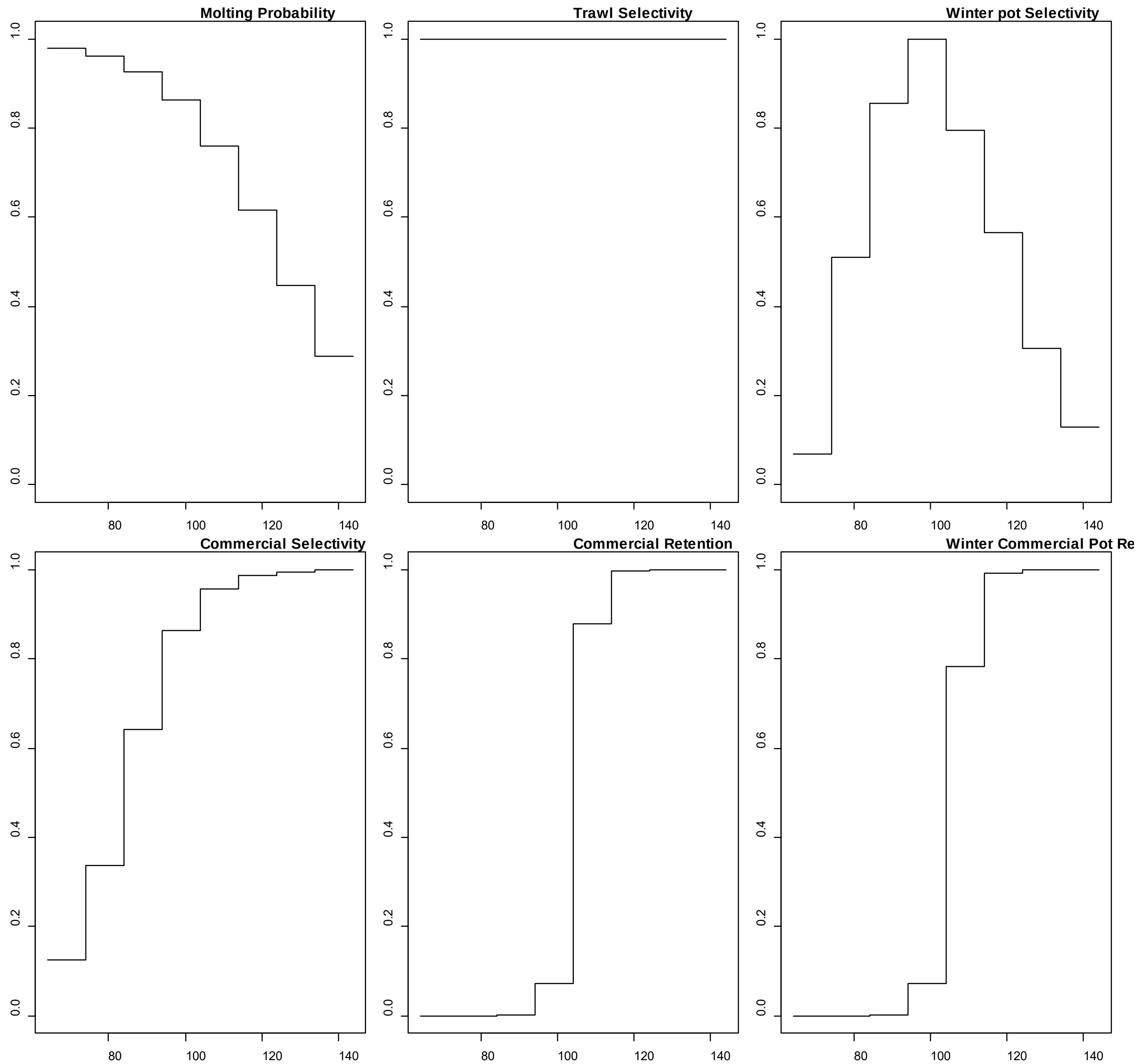


Figure 3. Model estimated annual molting probability, and selectivity for trawl survey, winter pot survey, summer commercial fishery, and summer and winter commercial retention. X-axis is carapace length (mm).

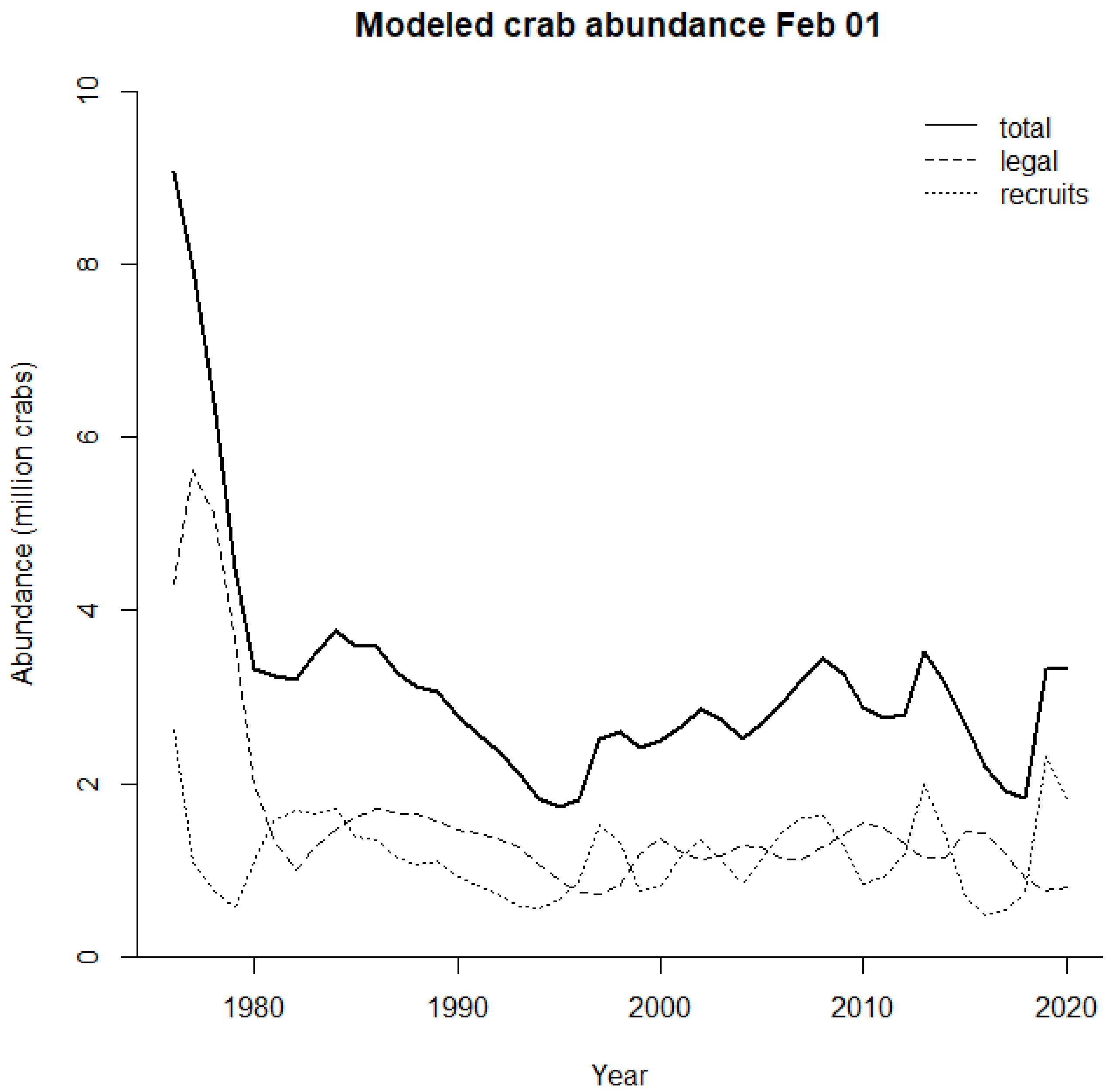


Figure 4. Model estimated abundances of total, legal (CL>104mm) and recruit (CL 64-94nn) males during1976-2019.

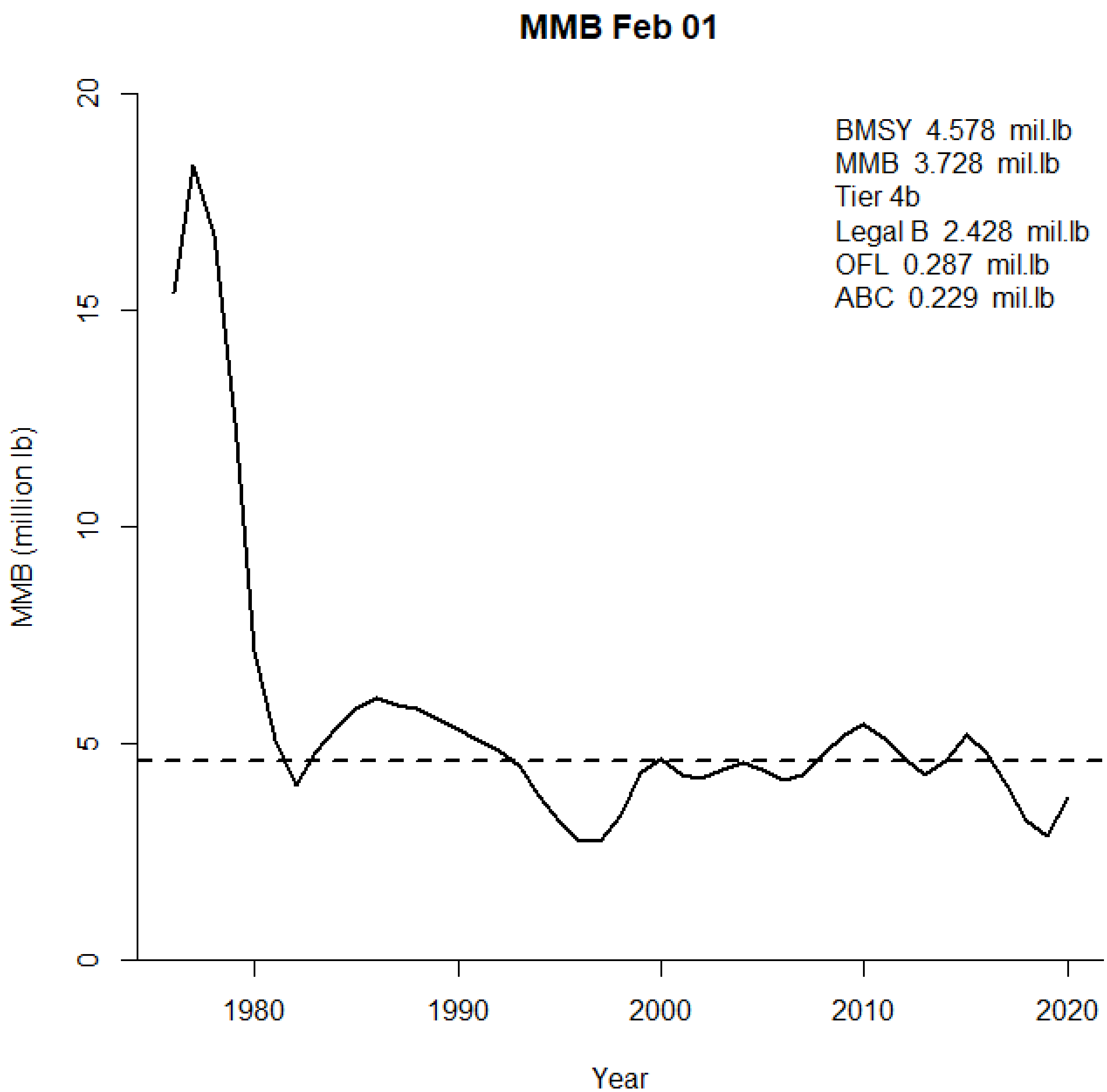


Figure 5. Estimated MMB during 1976-2019. Dash line shows Bmsy (Average MMB of 1980-2020). Dot indicate projected MMB of 2020.

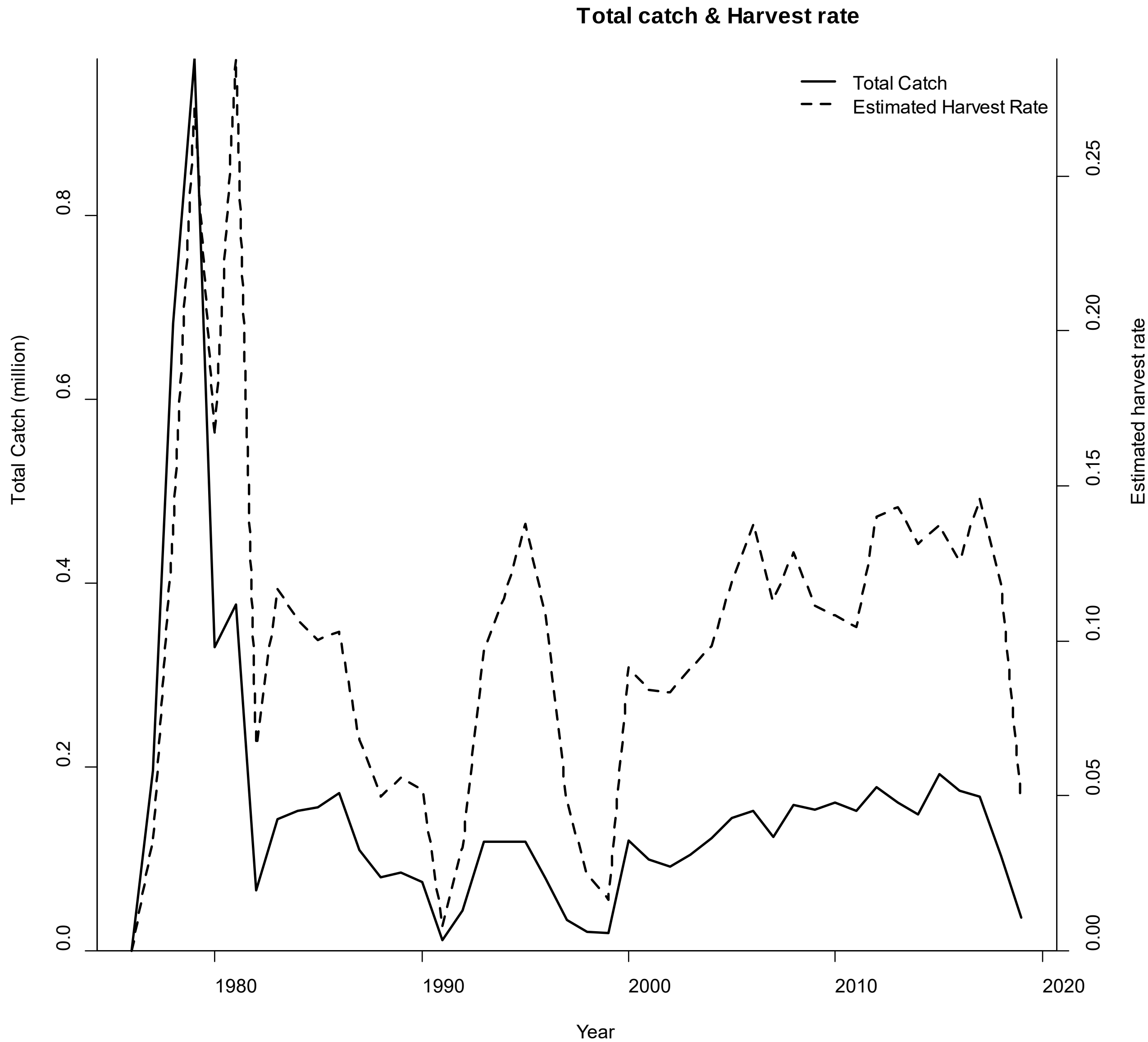


Figure 6. Commercial catch and estimated harvest rates of legal males over time.

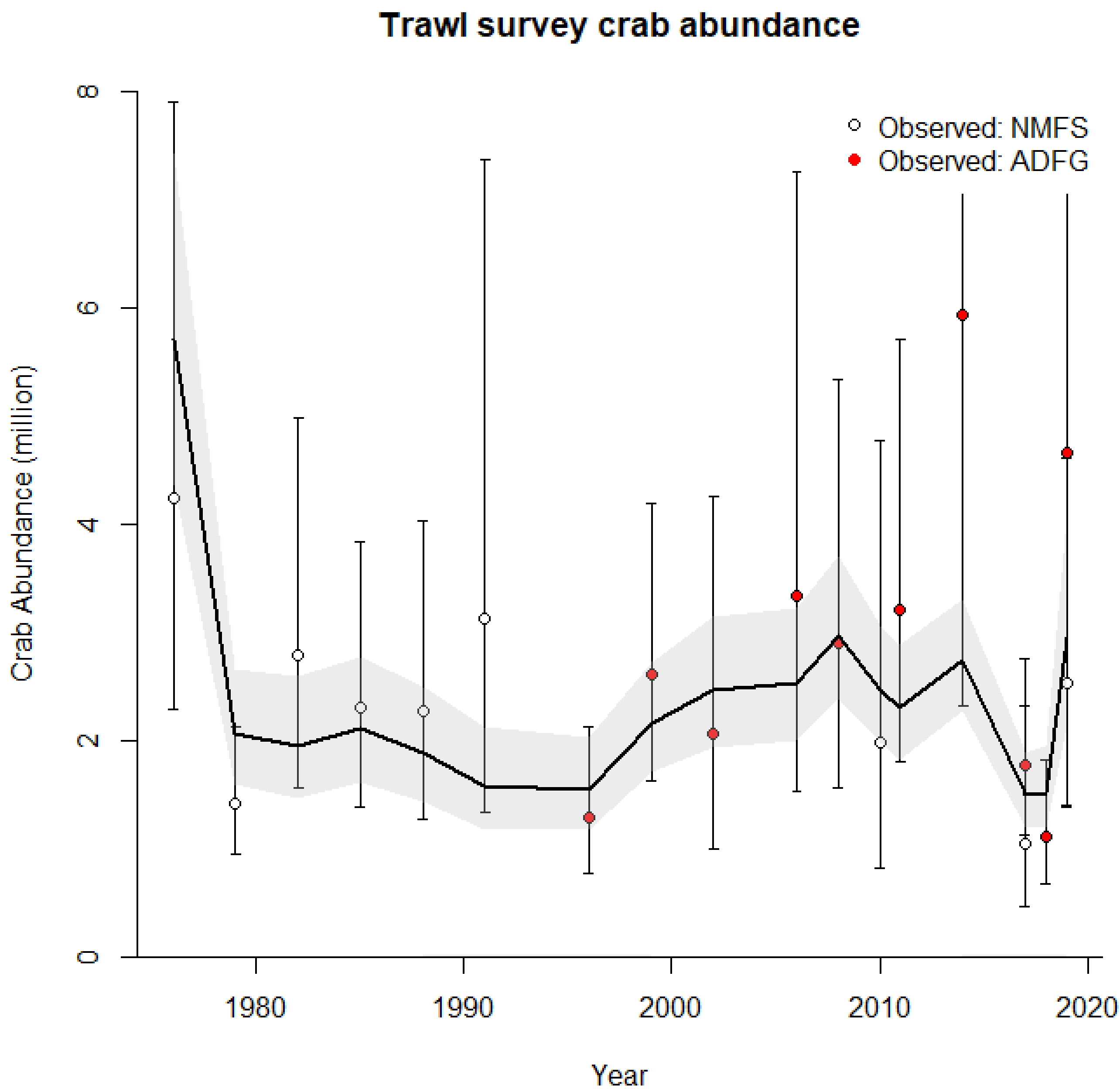


Figure 7. Observed (open circle) (White: NMFS, Red ADF&G) and model estimated (line) trawl survey male abundances with 95% lognormal Confidence Intervals (crab ≥ 64 mm CL). Shaded area indicate 95%CI lognormal CI of the model estimate.

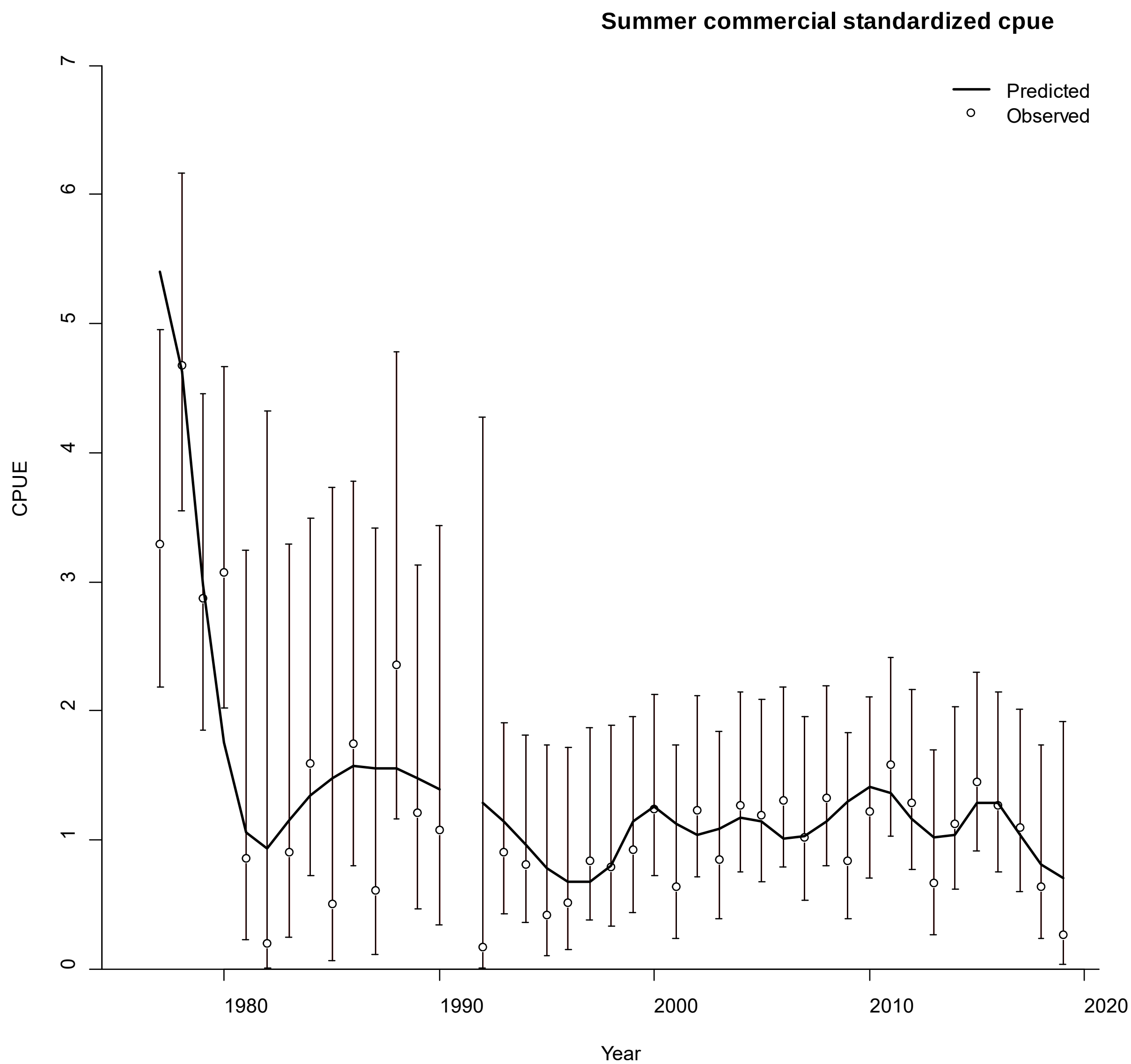


Figure 8. Observed (open circle) with 95% lognormal Confidence Intervals and model estimated (lines) standardized CPUE.

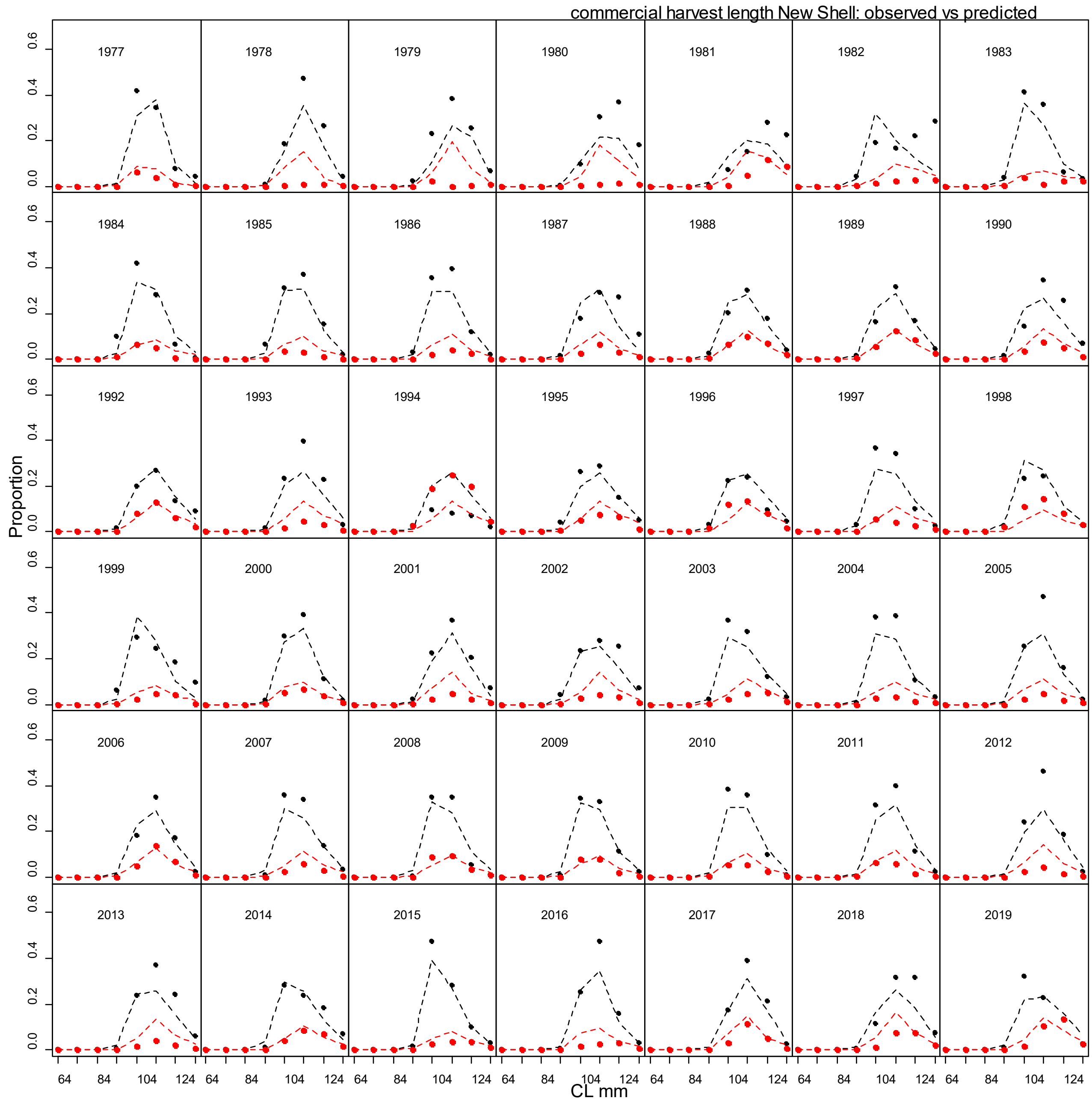


Figure 9. Predicted (line) vs. observed (dots: black New Shell, red Old Shell) length class proportions for the summer commercial harvest 1977-2019.

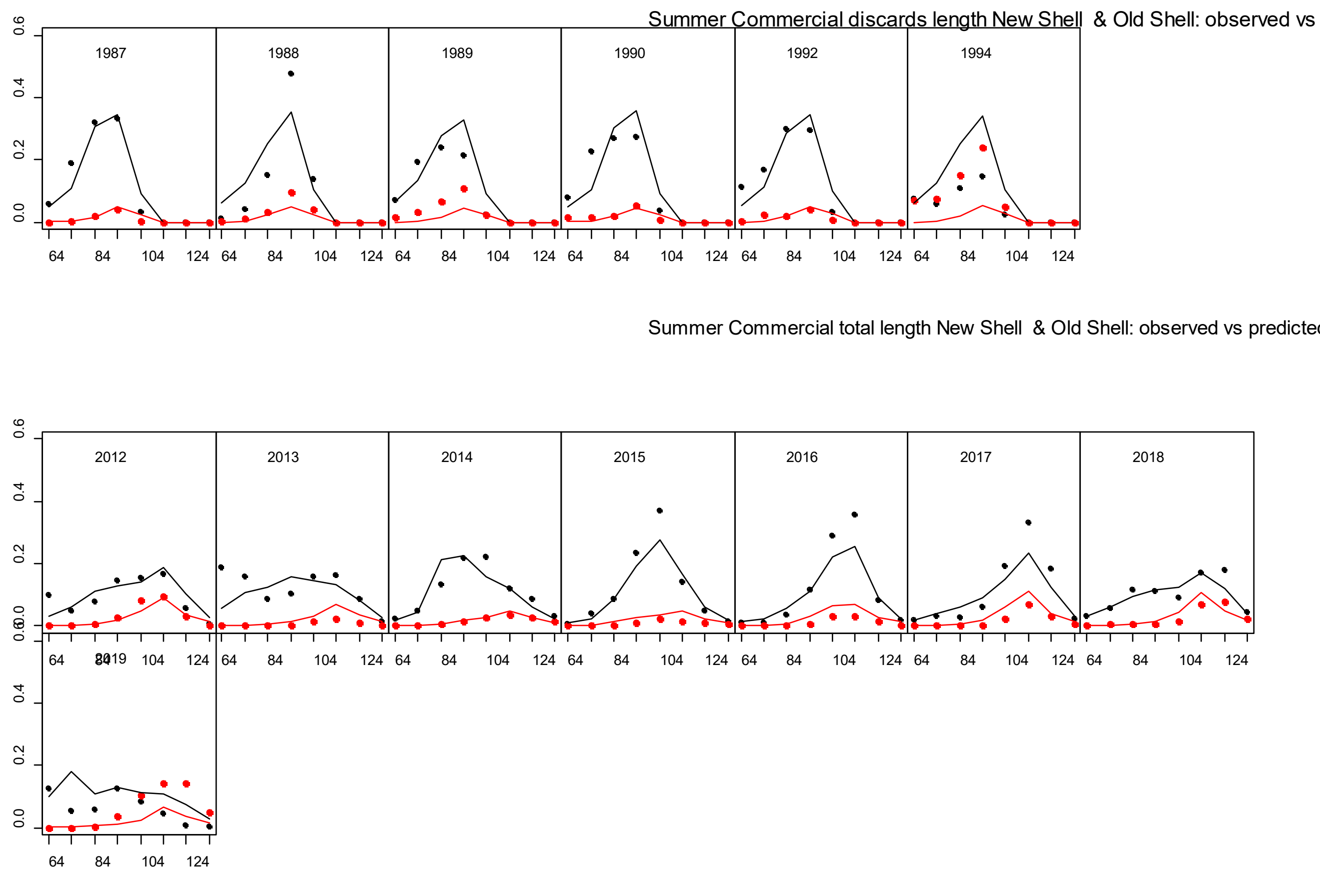


Figure 10. Predicted (line) vs. observed (dots: black New Shell, red Old Shell) length class proportions for summer commercial discards (1987-94) and total catch (2012-2019).

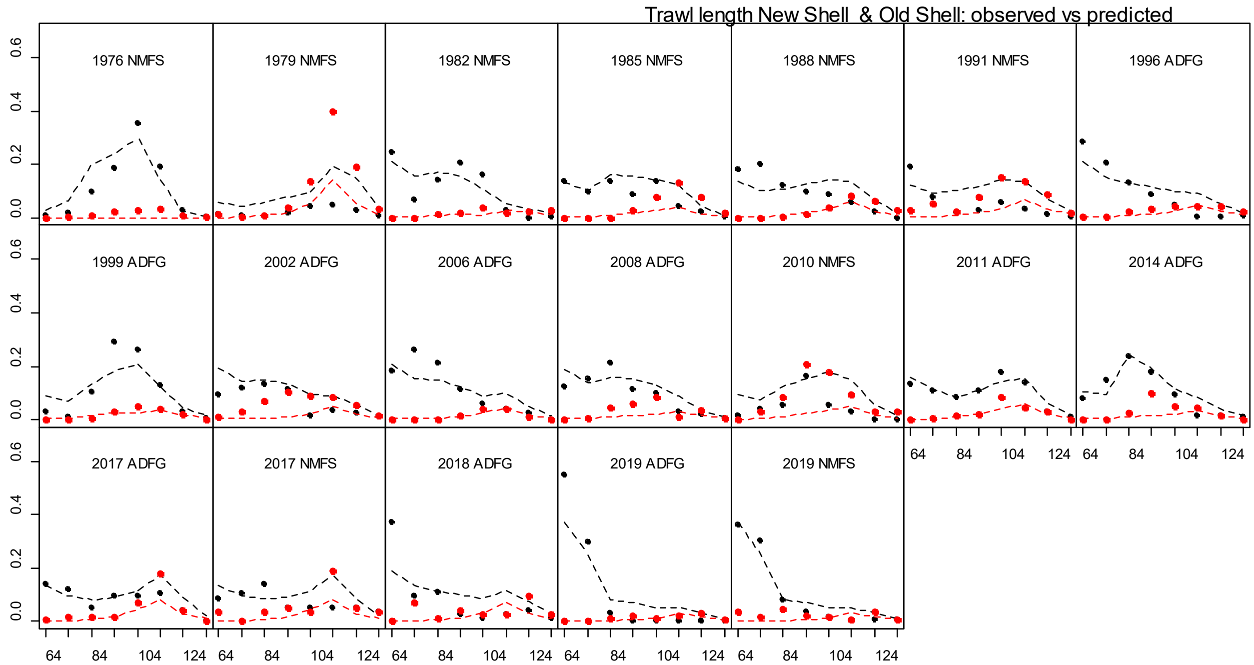


Figure 11. Predicted (line) vs. observed (dots: black New Shell, red Old Shell) length class proportions for summer trawl survey 1976 – 2019

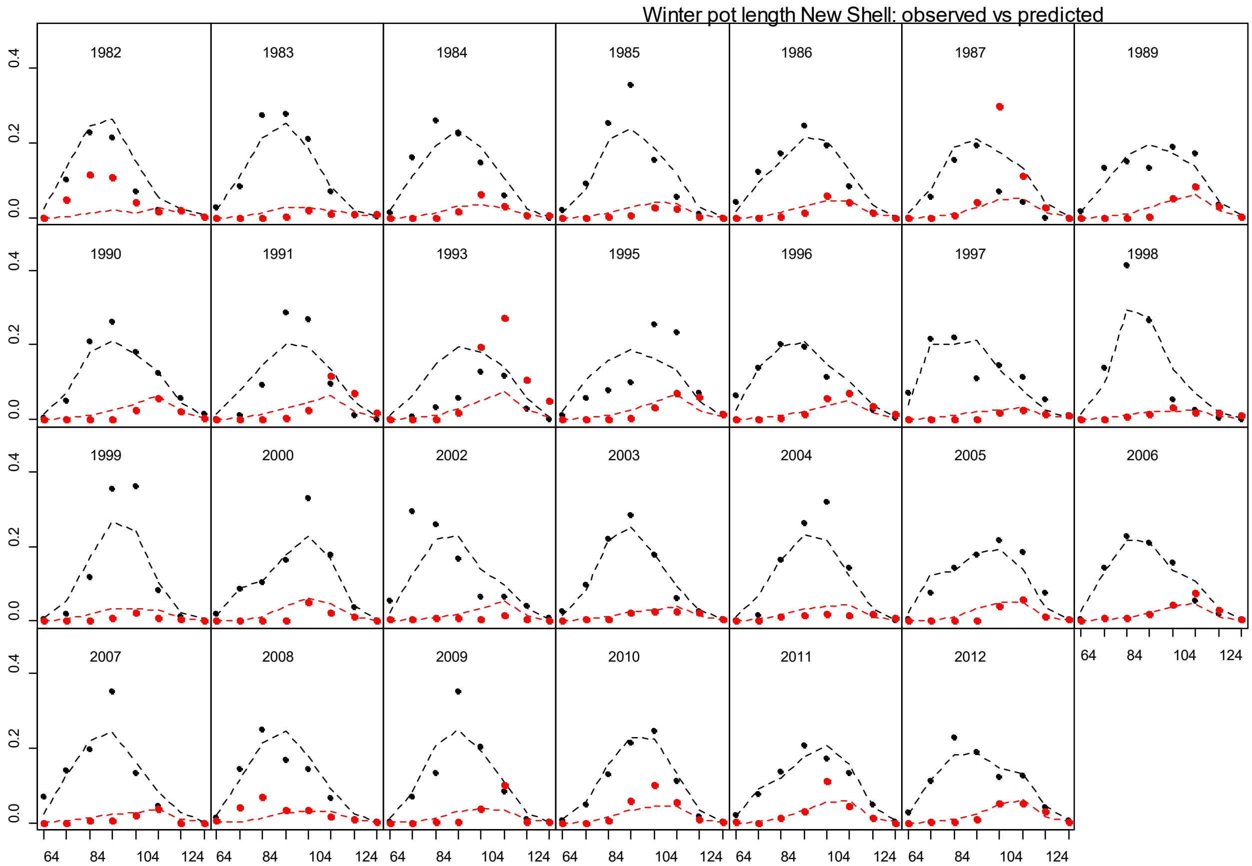


Figure 12. Predicted (line) vs. observed (dots: black New Shell, red Old Shell) length class proportions for winter pot survey 1982 – 2012

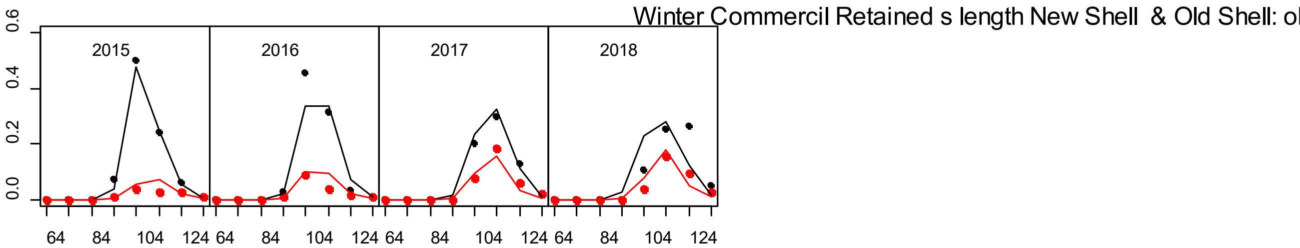


Figure 13. Predicted (line) vs. observed (dots: black New Shell, red Old Shell) length class proportions for winter commercial fishery 2015-2018

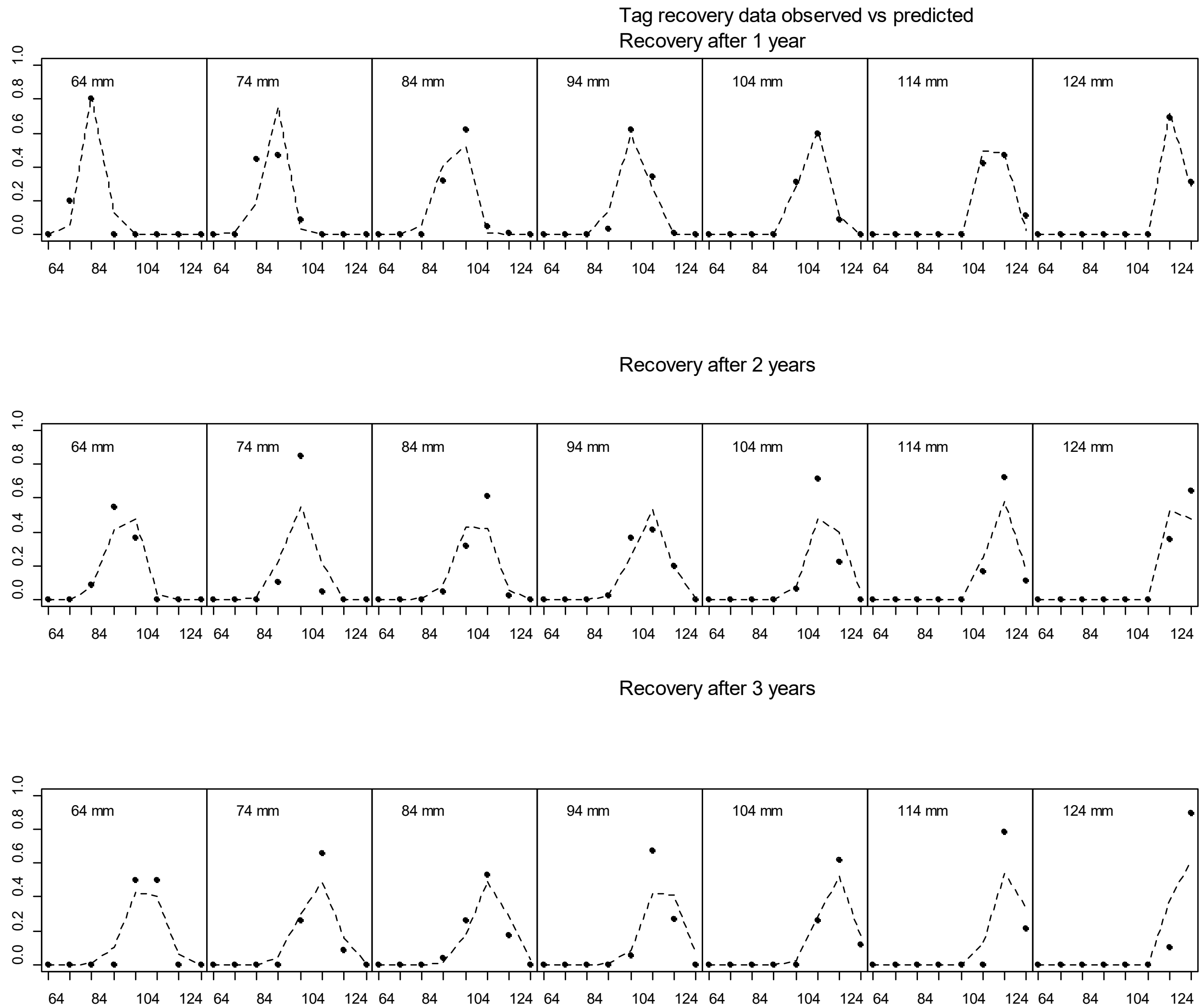


Figure 14. Predicted (line) vs. observed (dots: black New Shell, red Old Shell) length class proportions tag recovery data.

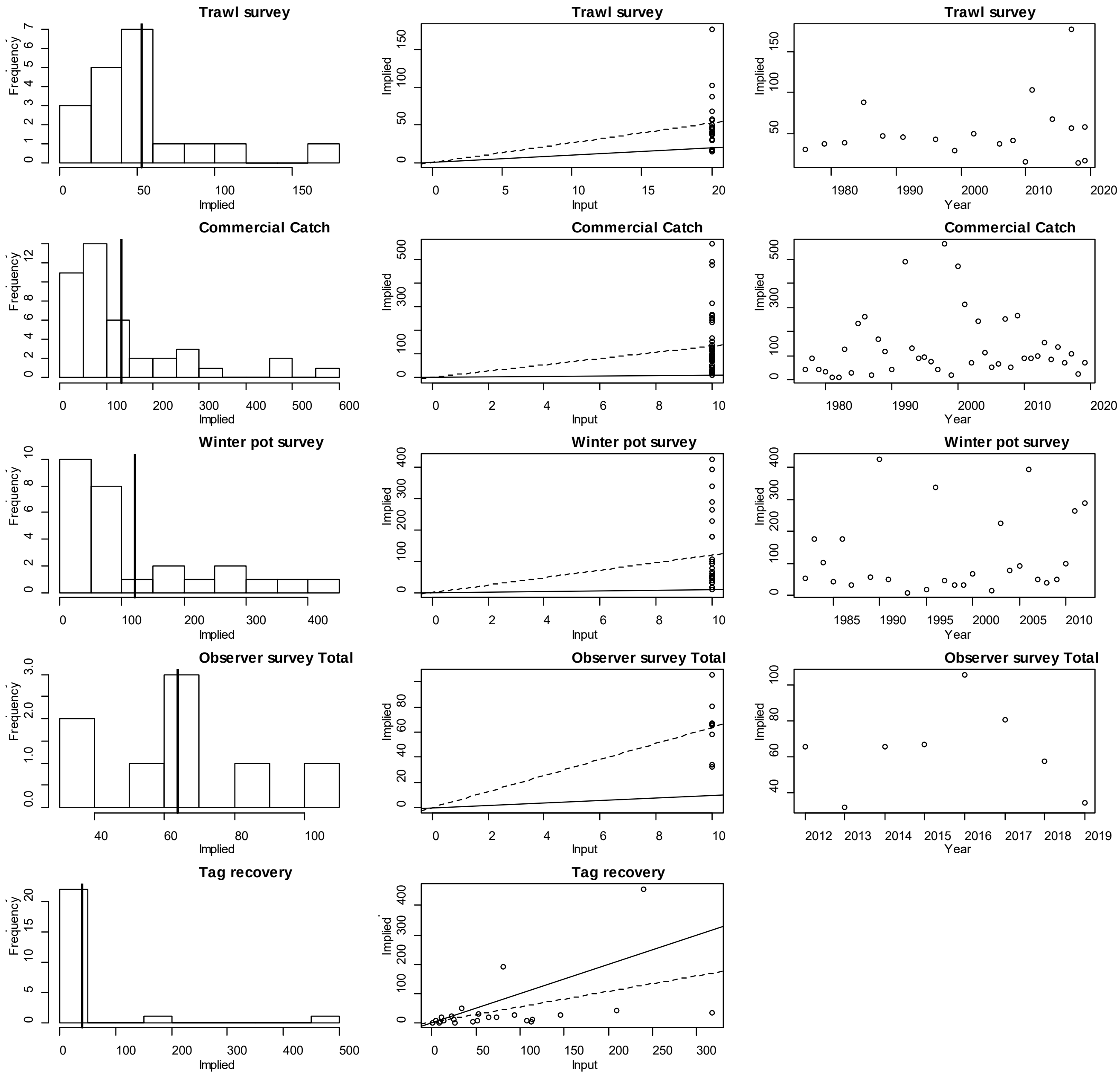


Figure 15. Input vs. model implied effective sample size. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis). Vertical solid line is the implied sample size. Figures in the second column show input sample sizes (x-axis) vs. implied effective sample sizes (y-axis). Dashed line indicates the linear regression slope, and solid line is 1:1 line. Figures in the third column show years (x-axis) vs. implied effective sample sizes (y-axis).

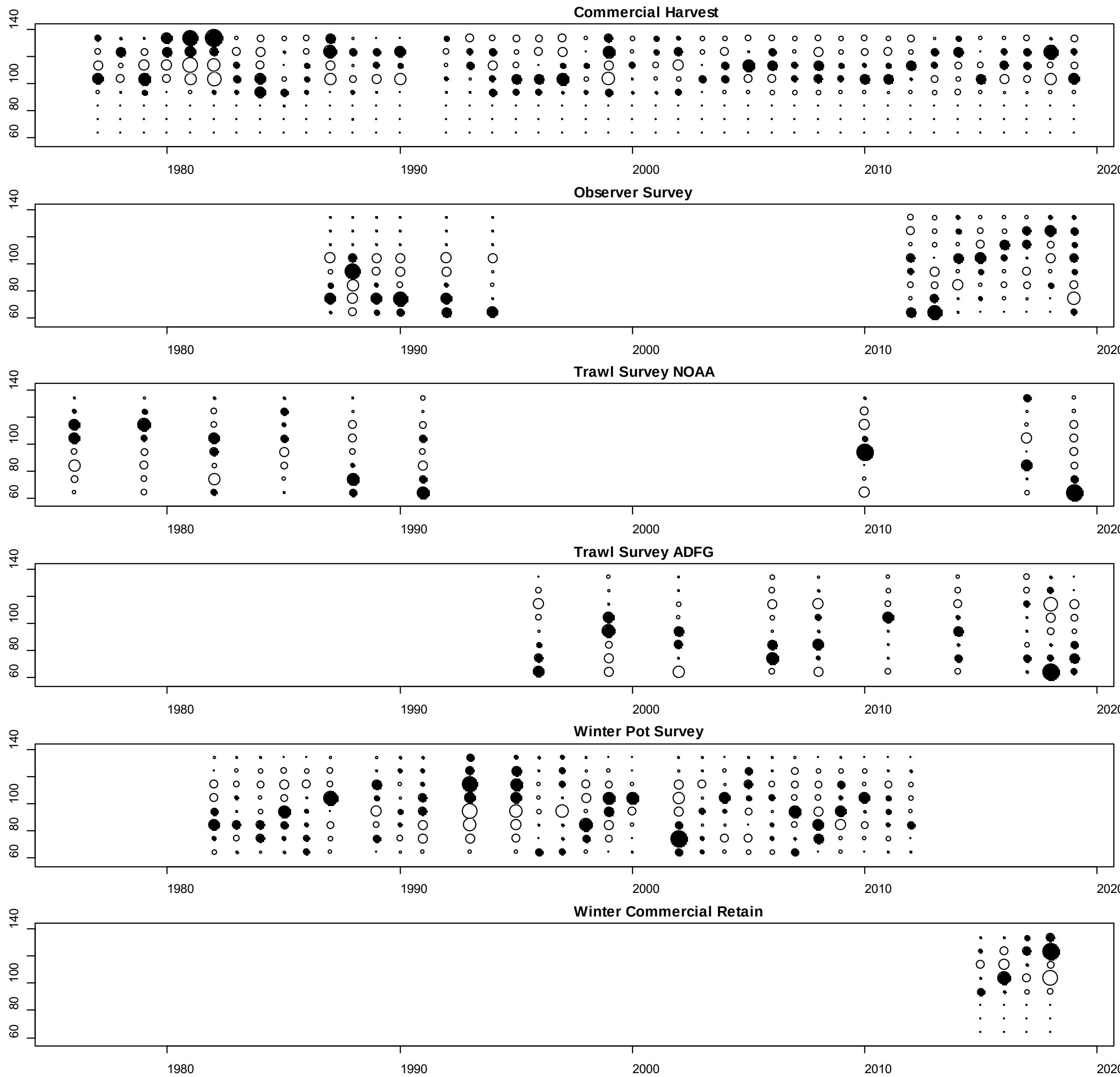


Figure 16. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

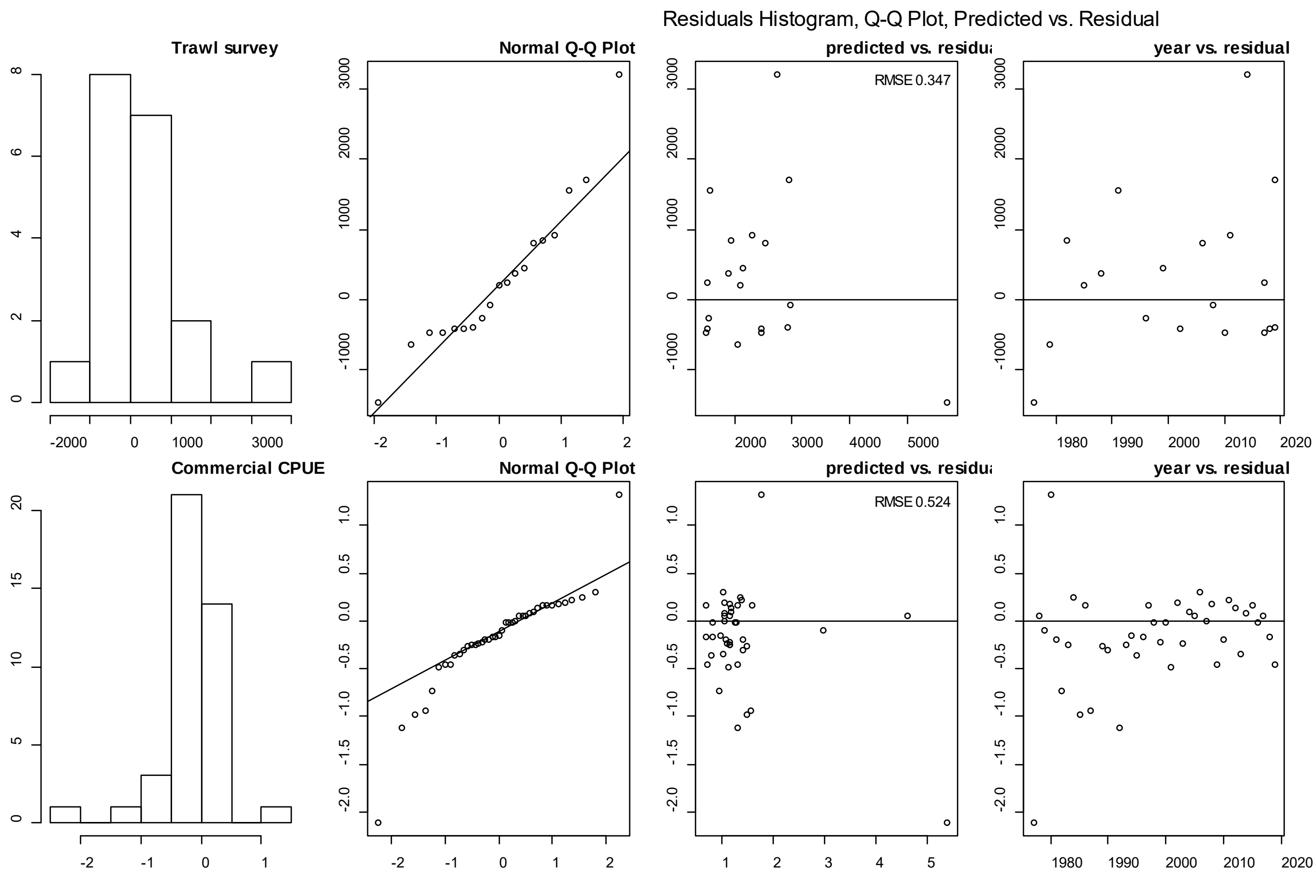


Figure 17. QQ Plot of Trawl survey and Commercial CPUE

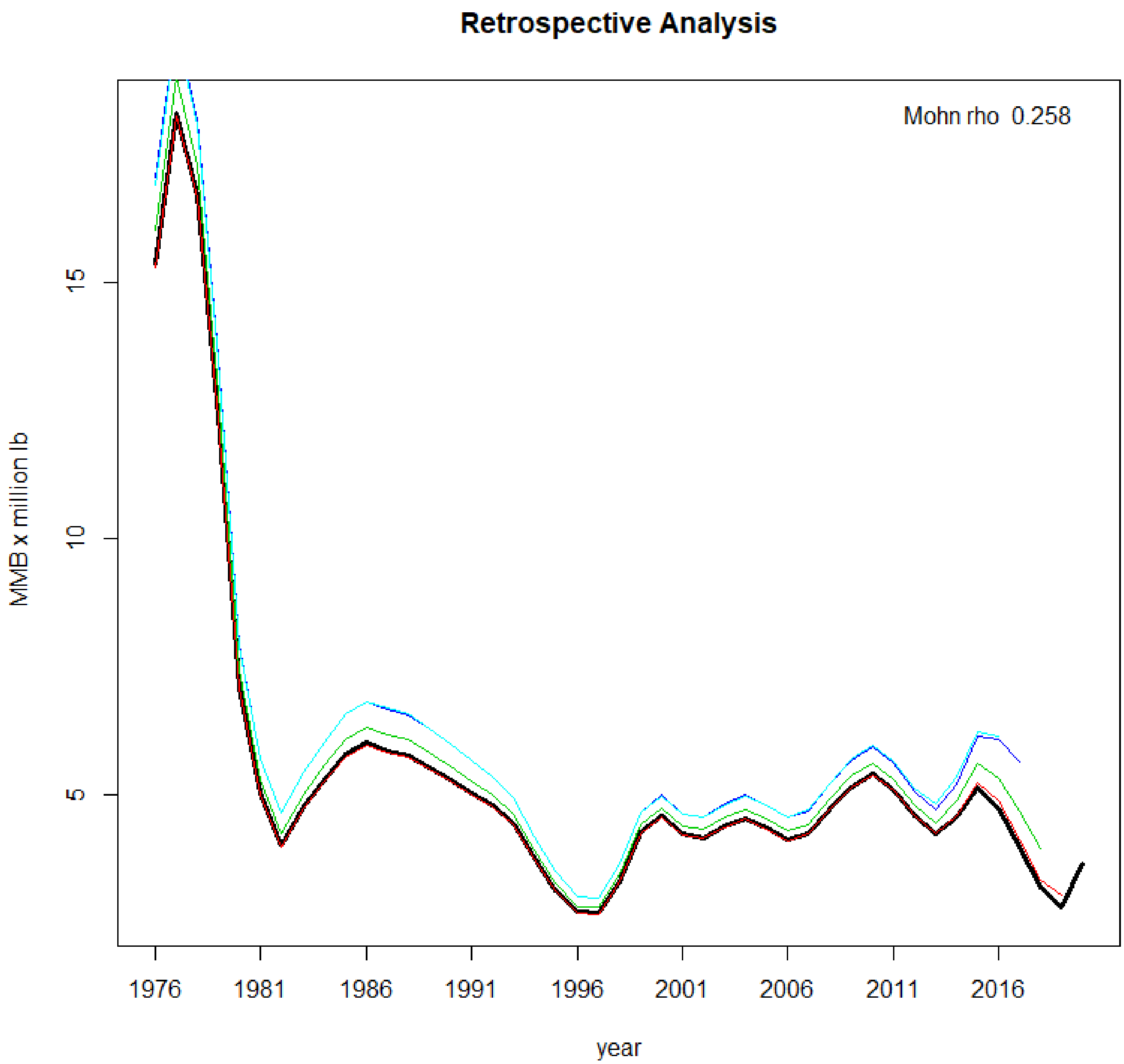
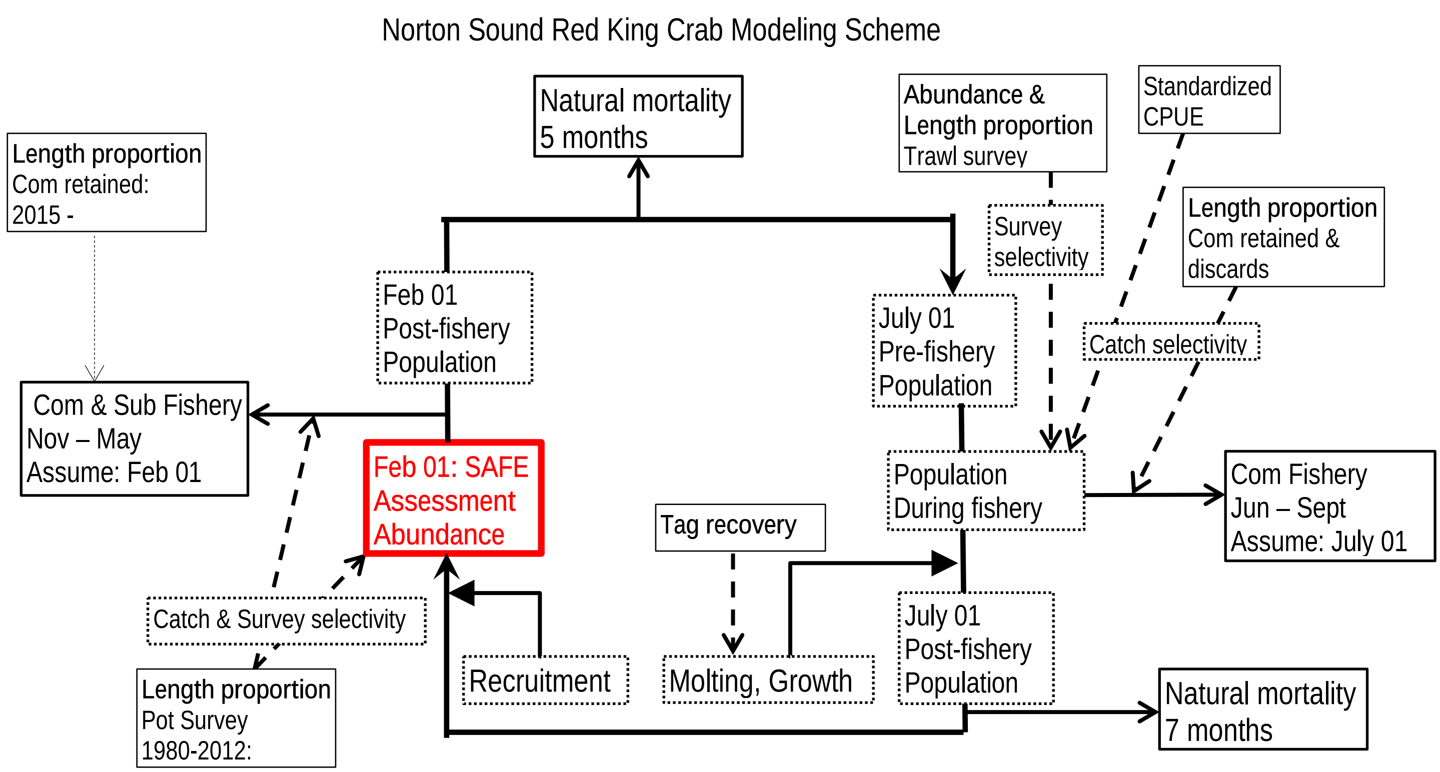


Figure 18. Retrospective Analyses of Norton Sound Red King Crab MMB from 2016 to 2019.

Appendix A. Description of the Norton Sound Red King Crab Model

a. Model description.

The model is an extension of the length-based model developed by Zheng et al. (1998) for Norton Sound red king crab. The model has 8 male length classes with model parameters estimated by the maximum likelihood method. The model estimates abundances of crab with CL ≥64 mm and with 10-mm length intervals (8 length classes, ≥134mm) because few crab measuring less than 64 mm CL were caught during surveys or fisheries and there were relatively small sample sizes for trawl and winter pot surveys. The model treats newshell and oldshell male crab separately but assumes they have the same molting probability and natural mortality.



Timeline of calendar events and crab modeling events:

- **Model year starts February 1st to January 31st of the following year.**
- **All winter fishery harvest occurs on February 1st**
- **Molting and recruitment occur on July 1st**
- **Initial Population Date: February 1st 1976**

Initial pre-fishery summer crab abundance on February 1st 1976

Abundance of the initial pre-fishery population was assumed to consist of newshell crab to reduce the number of parameters, and estimated as

$$N_{l,1} = p_l e^{\log\_N_{76}} \tag{1}$$

where, length proportion of the first year (p_l) was calculated as

$$p_l = \frac{\exp(a_l)}{1+\sum_{l=1}^{n-1}\exp(a_l)} \text{ for } l = 1,..,n\text{-}1$$
$$p_n = 1 - \frac{\sum_{l=1}^{n-1}\exp(a_l)}{1+\sum_{l=1}^{n-1}\exp(a_l)} \tag{2}$$

for model estimated parameters a_l.

Crab abundance on July 1st

Summer (01 July) crab abundance of new and oldshells consists of survivors of winter commercial and subsistence crab fisheries and natural mortality from 01Feb to 01July:

$$N_{s,l,t} = (N_{w,l,t} - C_{w,t}P_{w,n,l,t} - C_{p,t}P_{p,n,l,t} - D_{w,n,l,t} - D_{p,n,l,t})e^{-0.42M_l}$$
$$O_{s,l,t} = (O_{w,l,t} - C_{w,t-1}P_{w,o,l,t} - C_{p,t}P_{p,o,l,t} - D_{w,o,l,t} - D_{p,o,l,t})e^{-0.42M_l} \tag{3}$$

where

$N_{s,l,t}$, $O_{s,l,t}$: summer abundances of newshell and oldshell crab in length class l in year t ,
$N_{w,l,t}$, $O_{w,l,t}$: winter abundances of newshell and oldshell crab in length class l in year t,
$C_{w,t}$, $C_{p,t}$: total winter commercial and subsistence catches in year t,
$P_{w,n,l,t}$, $P_{w,o,l,t}$: Proportion of newshell and oldshell length class l crab in year t, harvested by winter commercial fishery,
$P_{p,n,l,t}$, $P_{p,o,l,t}$: Proportion of newshell and oldshell length class l crab in year t, harvested by winter subsistence fishery,
$D_{w,n,l,t}$, $D_{w,o,l,t}$: Discard mortality of newshell and oldshell length class l crab in winter commercial

fishery in year t ,
$D_{p,n,l,t}$, $D_{p,o,l,t}$: Discard mortality of newshell and oldshell length class l crab in winter subsistence fishery in year t,
M_l : instantaneous natural mortality in length class l,
0.42 : proportion of the year from Feb 1 to July 1 is 5 months.

Length proportion compositions of winter commercial catch ($P_{w,n,l,t}$, $P_{w,o,l,t}$) in year t were estimated as:

$$\begin{aligned} P_{w,n,l,t} &= N_{w,l,t} S_{w,l} P_{lg,l} / \sum_{l=1} [(N_{w,l,t} + O_{w,l,t}) S_{w,l} P_{lg,l}] \\ P_{w,o,l,t} &= O_{w,l,t} S_{w,l} P_{lg,l} / \sum_{l=1} [(N_{w,l,t} + O_{w,l,t}) S_{w,l} P_{lg,l}] \end{aligned} \quad (4)$$

where
$P_{lg,l}$: the proportion of legal males in length class l ,
$S_{w,l}$: Selectivity of winter fishery pot.

Subsistence fishery does not have a size limit; however, crab of size smaller than length class 3 are generally not retained. Hence, we assumed proportion of length composition l = 1 and 2 as 0, and estimated length compositions ($l \geq 3$) as follows

$$\begin{aligned} P_{p,n,l,t} &= N_{w,l,t} S_{w,l} / \sum_{l=3} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \\ P_{p,o,l,t} &= O_{w,l,t} S_{w,l} / \sum_{l=3} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \end{aligned} \quad (5)$$

Crab abundance on Feb 1st

Newshell Crab: Abundance of newshell crab of year t and length-class l ($N_{w,l,t}$) year-t consist of: (1) new and oldshell crab that survived the summer commercial fishery and molted, and (2) recruitment ($R_{l,t}$) .

$$N_{w,l,t} = \sum_{l'=1}^{l'=l} G_{l',l} [(N_{s,l',t-1} + O_{s,l',t-1}) e^{-y_c M_l} - C_{s,t}(P_{s,n,l',t-1} + P_{s,o,l',t-1}) - D_{l',t-1}] m_{l'} e^{-(0.58-y_c)M_l} + R_{l,t-1} \quad (6)$$

Oldshell Crab: Abundance of oldshell crabs of year t and length-class l ($O_{w,l,t}$) consists of the non-molting portion of survivors from the summer fishery:

$$O_{w,l,t} = [(N_{s,l,t-1} + O_{s,l,t-1}) e^{-y_c M_l} - C_{s,t}(P_{s,n,l,t-1} + P_{s,o,l,t-1}) - D_{l,t-1}] (1 - m_l) e^{-(0.58-y_c)M_l} \quad (7)$$

where

$G_{l',l}$: a growth matrix representing the expected proportion of crabs growing from length class l' to length class l
$C_{s,t}$: total summer catch in year t
$P_{s,n,l,t-1}$, $P_{s,o,l,t-1}$: proportion of summer catch for newshell and oldshell crabs of length class l in year $t-1$,
$D_{l,t-1}$: summer discard mortality of length class l in year $t-1$,
m_l : molting probability of length class l,
y_c : the time in year from July 1 to the mid-point of the summer fishery,
0.58: Proportion of the year from July 1st to Feb 1st is 7 months is 0.58 year,
$R_{l,t-1}$: recruitment into length class l in year $t-1$.

Discards

Discards are crabs that were caught by fisheries but were not retained, which consists of summer commercial, winter commercial and winter subsistence.

Summer and winter commercial discards

In summer ($D_{l,t}$) and winter ($D_{w,n,l,t}$, $D_{w,o,l,t}$) commercial fisheries, sublegal males (<4.75 inch CW and <5.0 inch CW since 2005) are discarded. Those discarded crabs are subject to handling mortality. The number of discards was not directly observed, and thus was estimated from the model as: Observed Catch x (estimated abundance of crab that are not caught by commercial pot)/(estimated abundance of crab that are caught by commercial pot)

Model discard mortality in length-class l in year t from the summer and winter commercial pot fisheries is given by

$$D_{l,t} = C_{s,t} \frac{(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - P_{r,l})}{\sum_l (N_{s,l,t} + O_{s,l,t}) S_{s,l} P_{r,l}} hm_s \tag{8}$$

$$D_{w,n,l,t} = C_{w,t} \frac{N_{w,l,t} \, S_{w,l} (1 - P_{lg,l})}{\sum_l (N_{w,l,t} + O_{w,l,t}) \, S_{w,l} \, P_{lg,l}} hm_w \tag{9}$$

$$D_{w,o,l,t} = C_{w,t} \frac{O_{w,l,t} \, S_{w,l} (1 - P_{lg,l})}{\sum_l (N_{w,l,t} + O_{w,l,t}) \, S_{w,l} \, P_{lg,l}} hm_w \tag{10}$$

where

hm_s: summer commercial handling mortality rate assumed to be 0.2,
hm_w: winter commercial handling mortality rate assumed to be 0.2,
$S_{s,l}$: Selectivity of the summer commercial fishery,
$S_{w,l}$: Selectivity of the winter commercial fishery,
$S_{r,l}$: Retention selectivity of the summer commercial fishery,

Winter subsistence Discards

Discards (unretained) of winter subsistence fishery is reported in a permit survey ($C_{d,t}$), though its size composition is unknown. We assumed that subsistence fishers discarded all crabs of length classes 1 -2.

$$D_{p,n,l,t} = C_{d,t} \frac{N_{w,l,t}\, S_{w,l}}{\sum_{l=1}^{2}(N_{w,l,t} + O_{w,l,t})\, S_{w,l}} hm_w \tag{11}$$

$$D_{p,o,l,t} = C_{d,t} \frac{O_{w,l,t}\, S_{w,l}}{\sum_{l=1}^{2}(N_{w,l,t} + O_{w,l,t})\, S_{w,l}} hm_w \tag{12}$$

$C_{d,t}$: Winter subsistence discards catch,

Recruitment

Recruitment of year t, R_t, is a stochastic process around the geometric mean, R_0:

$$R_t = R_0 e^{\tau_t}, \tau_t \sim N(0, \sigma_R^2) \tag{13}$$

R_t of the last year was assumed to be an average of previous 5 years: $R_t = (R_{t-1} + R_{t-2} + R_{t-3} + R_{t-4} + R_{t-5})/5$.

R_t was assumed to be newshell crab of immature (< 94mm) length classes 1 to r:

$$R_{r,t} = p_r\, R_t \tag{14}$$

where r takes multinomial distribution, same as the equation (2)

Molting Probability

Molting probability for length class l, m_l, was estimated as an inverse logistic function of length-class mid carapace length (L) and parameters (α, β) where β corresponds to L_{50}.

$$m_l = \frac{1}{1+e^{\alpha(L-\beta)}} \tag{15}$$

Trawl net, summer commercial pot,

Trawl and summer commercial pot selectivity was assumed to be a logistic function of mid-length-class, constrained to be 0.999 at the largest length-class (L_{max}):

$$S_l = \frac{1}{1+e^{(\alpha(L_{\max}-L)+\ln(1/0.999-1))}} \tag{16}$$

Winter pot selectivity

Winter pot selectivity was assumed to be a dome-shaped with inverse logistic function of length-class mid carapace length (L) and parameters (α, β) where β corresponds to L_{50}.

$$S_{w,l} = \frac{1}{1+e^{\alpha(L-\beta)}} \tag{17}$$

Selectivity of the length classes $S_{w,s}$ (S= l_1, l_2) were individually estimated.

Growth transition matrix

The growth matrix $G_{l',l}$ (the expected proportion of crab molting from length class l' to length class l) was

assumed to be normally distributed:

$$G_{l',l} = \begin{cases} \dfrac{\int_{lm_l-h}^{lm_l+h} N(L \mid \mu_{l'},\sigma^2)dL}{\sum_{l=1}^{n}\int_{lm_l-h}^{lm_l+h} N(L \mid \mu_{l'},\sigma^2)dL} & \text{when } l \geq l' \\ 0 & \text{when } l < l' \end{cases} \tag{18}$$

Where

$$N(x \mid \mu_{l'},\sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}}\exp\left(-\frac{(L-\mu_{l'})^2}{\sigma^2}\right)$$
$$lm_l = L_1 + st \cdot l$$
$$\mu_l = L_1 + \beta_0 + \beta_1 \cdot l$$

Observation model

Summer trawl survey abundance

Modeled trawl survey abundance of year t ($B_{st,t}$) is July 1st abundance subtracted by summer commercial fishery harvest occurring from July 1st to the mid-point of summer trawl survey, multiplied by natural mortality occurring between the mid-point of commercial fishery date and trawl survey date, and multiplied by trawl survey selectivity. For the first year (1976) trawl survey, the commercial fishery did not occur.

$$\hat{B}_{st,t} = \sum_{l}[(N_{s,l,t} + O_{s,l,t})e^{-y_c M_l} - C_{s,t}P_{c,t}(P_{s,n,l,t} + P_{s,o,l,t})]e^{-(y_{st}-y_c)M_l}S_{st,l} \tag{19}$$

where
y_{st} : the time in year from July 1 to the mid-point of the summer trawl survey,
y_c: the time in year from July 1 to the mid-point for the catch before the survey, ($y_{st} > y_c$: Trawl survey starts after opening of commercial fisheries),
$P_{c,t}$: the proportion of summer commercial crab harvested before the mid-point of trawl survey date.
$S_{st,l}$: Selectivity of the trawl survey.

Winter pot survey CPUE

Winter pot survey cpue (f_{wt}) was calculated with catchability coefficient q and exploitable abundance:

$$\hat{f}_{wt} = q_w \sum_{l}[(N_{w,l,t} + O_{w,l,t})S_{w,l}] \tag{20}$$

Summer commercial CPUE

Summer commercial fishing CPUE (f_t) was calculated as a product of catchability coefficient q and mean exploitable abundance minus one half of summer catch, A_t:

$$\hat{f}_t = q_i(A_t - 0.5C_t) \tag{21}$$

Because the fishing fleet and pot limit configuration changed in 1993, q_1 is for fishing efforts before 1993, q_2 is from 1994 to present.

Where A_t is exploitable legal abundance in year t, estimated as

$$A_t = \sum_{l}[(N_{s,l,t} + O_{s,l,t})S_{s,l}S_{r,l}] \tag{22}$$

Summer pot survey abundance (Removed from likelihood components)
Abundance of t-th year pot survey was estimated as

$$\hat{B}_{p,t} = \sum_{l} [(N_{s,l,t} + O_{s,l,t})\, e^{-y_p M_l}] S_{p,l} \tag{23}$$

Where
y_p : the time in year from July 1 to the mid-point of the summer pot survey.
Length composition

Summer commercial catch

Length compositions of the summer commercial catch for new and old shell crabs $P_{s,n,l,t}$ and $P_{s,o,l,t}$, were modeled based on the summer population, selectivity, and legal abundance:

$$\begin{aligned} \hat{P}_{s,n,l,t} &= N_{s,l,t} S_{s,l} S_{r,l} / A_t \\ \hat{P}_{s,o,l,t} &= O_{s,l,t} S_{s,l} S_{r,l} / A_t \end{aligned} \quad \text{(Alternative model)} \tag{24}$$

Summer commercial fishery discards (1977-1995)

Length/shell compositions of observer discards were modeled as

$$\begin{aligned} \hat{P}_{b,n,l,t} &= N_{s,l,t} S_{s,l} (1 - P_{lg,l}) / \sum_{l} [(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - P_{lg,l})] \\ \hat{P}_{b,o,l,t} &= O_{s,l,t} S_{s,l} (1 - P_{lg,l}) / \sum_{l} [(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - P_{lg,l})] \end{aligned} \tag{25}$$

Summer commercial fishery total catch (2012-present)

Length/shell compositions of observer discards were modeled as

$$\begin{aligned} \hat{P}_{t,n,l,t} &= N_{s,l,t} S_{s,l} / \sum_{l} [(N_{s,l,t} + O_{s,l,t}) S_{s,l}] \\ \hat{P}_{t,o,l,t} &= O_{s,l,t} S_{s,l} / \sum_{l} [(N_{s,l,t} + O_{s,l,t}) S_{s,l}] \end{aligned} \tag{26}$$

Summer trawl survey

Proportions of newshell and oldshell crab, $P_{st,n,l,t}$ and $P_{st,o,l,t}$ were given by

$$
\begin{aligned}
\hat{P}_{st,n,l,t} &= \frac{[N_{s,l,t}\, e^{-y_c M_l} - C_{s,t}\, P_{c,t}\, \hat{P}_{s,n,l',t}] e^{-(y_{st}-y_c)M_l} S_{st,l}}{\sum_l [(N_{s,l,t}+O_{s,l,t}) e^{-y_c M_l} - C_{s,t} P_{c,t} (\hat{P}_{s,n,l',t}+\hat{P}_{s,o,l',t})] e^{-(y_{st}-y_c)M_l} S_{st,l}} \\
\hat{P}_{st,o,l,t} &= \frac{[O_{s,l,t}\, e^{-y_c M_l} - C_{s,t}\, \hat{P}_{s,o,l',t}\, P_{c,t}] e^{-(y_{st}-y_c)M_l} S_{st,l}}{\sum_l [(N_{s,l,t}+O_{s,l,t}) e^{-y_c M_l} - C_{s,t} P_{c,t} (\hat{P}_{s,n,l,t}+\hat{P}_{s,o,l,t})] e^{-(y_{st}-y_c)M_l} S_{st,l}}
\end{aligned}
\tag{27}
$$

Winter pot survey

Winter pot survey length compositions for newshell and oldshell crab, $P_{sw,n,l,t}$ and $P_{sw,o,l,t}$ ($l \geq 1$) were calculated as

$$
\begin{aligned}
\hat{P}_{sw,n,l,t} &= N_{w,l,t} S_{w,l} / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \\
\hat{P}_{sw,o,l,t} &= O_{w,l,t} S_{w,l} / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}]
\end{aligned}
\tag{28}
$$

Spring Pot survey 2012-2015

Winter pot survey length compositions for newshell and oldshell crab, $P_{sw,n,l,t}$ and $P_{sw,o,l,t}$ ($l \geq 1$) were assumed to be supper crab population caught by winter pot survey gears

$$
\begin{aligned}
\hat{P}_{sp,n,l,t} &= N_{s,l,t} S_{w,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{w,l}] \\
\hat{P}_{sp,o,l,t} &= O_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{w,l}]
\end{aligned}
\tag{29}
$$

Estimates of tag recovery

The proportion of released tagged length class *l'* crab recovered after *t-th* year with length class of *l* by a fishery of *s-th* selectivity (S_l) was assumed to be proportional to the growth matrix, catch selectivity, and molting probability (m_l) as

$$
\hat{P}_{l',l,t,s} = \frac{S_l \cdot [X^t]_{l',l}}{\sum_{l=1}^{n} S_l \cdot [X^t]_{l',l}}
\tag{30}
$$

where X is a molting probability adjusted growth matrix with each component consisting of

$$X_{l',l} = \begin{cases} m_{l'} \cdot G_{l',l} \quad \text{when } l' \neq l \\ m_l \cdot G_{l',l} + (1\text{-}m_i) \text{ when } l' = l \end{cases} \tag{31}$$

c. Likelihood components.

Under assumptions that measurement errors of annual total survey abundances and summer commercial fishing efforts follow lognormal distributions and each type of length composition has a multinomial error structure (Fournier and Archibald 1982; Methot 1989), the log-likelihood function is

$$\begin{aligned}
&\sum_{i=1}^{i=4}\sum_{t=1}^{t=n_i} K_{i,t}\left[\sum_{l=1}^{l=n} P_{i,l,t}\ln(\hat{P}_{i,l,t}+\kappa) - \sum_{l=1}^{l=n} P_{i,l,t}\ln(P_{i,l,t}+\kappa)\right] \\
&-\sum_{t=1}^{t=n_i}\frac{[\ln(q\cdot\hat{B}_{i,t}+\kappa) - \ln(B_{i,t}+\kappa)]^2}{2\cdot ln(CV_{i,t}^2+1)} \\
&-\sum_{t=1}^{t=n_i}\left[\frac{\ln\left[\ln(CV_t^2+1)+w_t\right]}{2} + \frac{[\ln(\hat{f}_t+\kappa) - \ln(f_t+\kappa)]^2}{2\cdot\left[\ln(CV_t^2+1)+w_t\right]}\right] \qquad (32) \\
&-\sum_{t=1}\frac{\tau_t^2}{2\cdot SDR^2} \\
&+W\sum_{s=1}^{s=2}\sum_{t=1}^{t=3}\sum_{l'=1}^{l'=n} K_{l',t,s}\left[\sum_{l=1}^{l=n} P_{l',l,t}\ln(\hat{P}_{l',l,t,s}+\kappa) - \sum_{l=1}^{l=n} P_{l',l,t}\ln(P_{l',l,t,s}+\kappa)\right]
\end{aligned}$$

where

i: length/shell compositions of :

1 triennial summer trawl survey,
2 annual winter pot survey,
3 summer commercial fishery retained catch,
4 observer discards or total catch during the summer fishery
5 spring pot survey.

$K_{i,t}$: the effective sample size of length/shell compositions for data set *i* in year *t,*
$P_{i,l,t}$: observed and estimated length compositions for data set *i*, length class *l*, and year *t.*
κ : a constant equal to 0.0001,
CV : coefficient of variation for the survey abundance,
$B_{i,k,t}$: observed and estimated annual total abundances for data set *i* and year *t,*
f_t : observed and estimated summer fishing CPUE,
w^2_t: extra variance factor,
SDR : Standard deviation of recruitment = 0.5,
$K_{l',t}$: sample size of length class *l'* released and recovered after *t-th* in year,
$P_{l',l,t,s}$: observed and estimated proportion of tagged crab released at length *l'* and recaptured at length *l*, after *t-th* year by commercial fishy pot selectivity *s*,
W: weighting for the tagging survey likelihood

It is generally believed that total annual commercial crab catches in Alaska are fairly accurately reported. Thus, total annual catch was assumed known.

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

d. Parameter estimation framework:

i. Parameters Estimated Independently

The following parameters were estimated independently: natural mortality (M =0.18), proportions of legal males by length group.

Natural mortality was based on an assumed maximum age, t_{max}, and the 1% rule (Zheng 2005):

$$M = -\ln(p)/t_{\max},$$

where p is the proportion of animals that reach the maximum age and is assumed to be 0.01 for the 1% rule (Shepherd and Breen 1992, Clarke et al. 2003). The maximum age of 25, which was used to estimate M for U.S. federal overfishing limits for red king crab stocks results in an estimated M of 0.18. Among the 199 recovered crabs from the tagging returns during 1991-2007 in Norton Sound, the longest time at liberty was 6 years and 4 months from a crab tagged at 85 mm CL. The crab was below the mature size and was likely less than 6 years old when tagged. Therefore, the maximum age from tagging data is about 12, which does not support the maximum age of 25 chosen by the CPT.

Proportions of legal males (CW > 4.75 inches) by length group were estimated from the ADF&G trawl data 1996-2011 (Table 11).

ii. Parameters Estimated Conditionally

Estimated parameters are listed in Table 10. Selectivity and molting probabilities based on these estimated parameters are summarized in Tables 11.

A likelihood approach was used to estimate parameters

e. Definition of model outputs.

i. Estimate of mature male biomass (MMB) is on **February 1st** and is consisting of the biomass of male crab in length classes 4 to 8

$$MMB = \sum_{l=4}(N_{w,l,} + O_{w,l,})wm_l$$

wm_l: mean weight of each length class (Table 11).

ii. Projected legal male biomass for winter and summer fishery OFL was calculated as

$$Legal\_B = \sum_{l}(N_{w,l,} + O_{w,l,})S_{s,l}P_{lg,l}wm_l \text{ Baseline model}$$

$$Legal\_B = \sum_{l}(N_{w,l,} + O_{w,l,})S_{s,l}S_{r,l}wm_l \text{ Alternative model}$$

iii. Recruitment: the number of males in length classes 1, 2, and 3.

iv.

f. OFL

The Norton Sound red king crab fishery consists of two distinct fisheries: winter and summer. The two fisheries are discontinuous with 5 months between the two fisheries during which natural mortalities occur. To incorporate this fishery, the CPT in 2016 recommended the following formula:

$$OFL_r = \text{Winter harvest (Hw)} + \text{Summer harvest (Hs)} \quad (1)$$

And

$$p = \frac{Hw}{OFL_r} \quad (2)$$

Where p is a specific proportion of winter crab harvest to total (winter + summer) harvest

At given fishery mortality (F_{OFL}), Winter harvest is a fishing mortality

$$Hw = (1 - e^{-x \cdot F})B_w \quad (3)$$

$$Hs = (1 - e^{-(1-x) \cdot F})B_s \quad (4)$$

where B_s is a summer crab biomass after winter fishery and x ($0 \leq x \leq 1$) is a fraction that satisfies equation (2)

Since B_s is a summer crab biomass after winter fishery and 5 months of natural morality ($e^{-0.42M}$)

$$\begin{aligned} B_s &= (B_w - Hw)e^{-0.42M} \quad (5) \\ &= (B_w - (1 - e^{-x \cdot F})B_w)e^{-0.42M} \\ &= B_w e^{-x \cdot F - 0.42M} \end{aligned}$$

Substituting *0.42M* to *m*, summer harvest is

$$\begin{aligned} Hs &= (1 - e^{-(1-x) \cdot F})B_s \quad (6) \\ &= (1 - e^{-(1-x) \cdot F})B_w e^{-x \cdot F - m} = (e^{-(x \cdot F + m)} - e^{-(F+m)})B_w \end{aligned}$$

Thus, OFL is

$$\begin{aligned} OFL &= Hw + Hs = (1 - e^{-xF})B_w + (e^{-(x \cdot F + m)} - e^{-(F+m)})B_w \quad (7) \\ &= (1 - e^{-xF} + e^{-(xF+m) \cdot} - e^{-(F+m) \cdot})B_w \\ &= [1 - e^{-(F+m) \cdot} - (1 - e^{-m \cdot})e^{-xF \cdot}]B_w \end{aligned}$$

Combining (2) and (7),

$$p = \frac{Hw}{OFL_r} = \frac{(1-e^{-xF})B_w}{[1-e^{-(F+m)\cdot} - (1-e^{-m\cdot})e^{-xF\cdot}]B_w} \quad (8)$$

Solving (8) for x

$$(1-e^{-xF}) = p[1-e^{-(F+m)\cdot} - (1-e^{-m\cdot})e^{-xF\cdot}] \quad (9)$$
$$e^{-xF} - p(1-e^{-m\cdot})e^{-xF\cdot} = 1 - p[1-e^{-(F+m)\cdot}]$$
$$[1-p(1-e^{-m\cdot})]e^{-xF\cdot} = 1 - p[1-e^{-(F+m)\cdot}]$$
$$e^{-xF\cdot} = \frac{1-p[1-e^{-(F+m)\cdot}]}{1-p(1-e^{-m\cdot})}$$

Combining (7) and (9), and substituting back,

revised retained OFL is

$$OFL = Legal\_B_w\left(1-e^{-(F_{OFL}+0,42M)} - (1-e^{-0.42M})\left(\frac{1-p(1-e^{-(F_{OFL}+0.42M)})}{1-p(1-e^{-0.42M})}\right)\right)$$

Further combining (3) and (9), Winter fishery harvest rate (Fw) i

$$Fw = (1-e^{-x\cdot F}) = 1 - \frac{1-p[1-e^{-(F+m)\cdot}]}{1-p(1-e^{-m\cdot})} = \frac{1-p(1-e^{-m\cdot}) - 1 + p[1-e^{-(F+m)\cdot}]}{1-p(1-e^{-m\cdot})} \quad (10)$$
$$= \frac{p(e^{-m\cdot} - e^{-(F+m)\cdot})}{1-p(1-e^{-m\cdot})} = \frac{p(1-e^{-F\cdot})e^{-0.42M\cdot}}{1-p(1-e^{-0.42M\cdot})}$$

Summer fishery harvest rate (Fs) is

$$Fs = (e^{-(x\cdot F+m)} - e^{-(F+m)}) = (e^{-x\cdot F} - e^{-F})e^{-m} \quad (11)$$
$$= \left(\frac{1-p[1-e^{-(F+m)\cdot}]}{1-p(1-e^{-m\cdot})} - e^{-F}\right)e^{-m}$$
$$= \left(\frac{1-p[1-e^{-(F+m)\cdot}] - e^{-F} + p(e^{-F} - e^{-(F+m\cdot)})}{1-p(1-e^{-m\cdot})}\right)e^{-m}$$
$$= \left(\frac{1-p+pe^{-(F+m)\cdot} - e^{-F} + pe^{-F} - pe^{-(F+m\cdot)}}{1-p(1-e^{-m\cdot})}\right)e^{-m}$$
$$= \frac{(1-p)(1-e^{-F})e^{-m}}{1-p(1-e^{-m\cdot})} = \frac{(1-p)(1-e^{-F})e^{-0.24M}}{1-p(1-e^{-0.24M\cdot})}$$

Appendix B. Norton Sound Red King Crab CPUE Standardization

Note: This is an update of model by G. Bishop (SAFE 2013).

Methods

Data Source & Cleaning

Commercial fishery harvest data were obtained from ADF&G fish ticket database, which included: Landing Date, Fish Ticket Number, Vessel Number, Permit Fishery ID, Statistical Area(s) fished, Effort, and Number and Pounds of Crab harvested (Table A2-1,2,3, Figure A2-1). Fish ticket database may have multiple entries of identical Fish Ticket Number, Vessel Number, Permit Fishery ID, and Statistical Area. In those cases, at least one Effort data are missing or zero with the Number and Pounds of Crab harvested. These entries indicate that crab were either retained from the commercial fishery (i.e., not sold), or dead loss.

Following data cleaning and combining methods were conducted.

1. Sum crab number and efforts by Fish Ticket Number, Vessel Number, Permit Fishery ID, Statistical Area.
2. Remove data of missing or zero Efforts, Number of Crab, Pounds of Crab (Those are considered as true missing data).
3. Calculate CPUE as Number of Crab/Effort.

Data Censoring

During 1977-92 period, vessels of 1 year of operation and/or 1 delivery per year harvested 20-90% of crab (Table A2-5, Figure A2-2). For instance, all vessels did only 1 delivery in 1989, and in 1988 64% of crab were harvested by 1 vessel that did only 1 delivery. On the other hand, during the 1993-2017 period of post super-exclusive fishery status, the majority of commercial crab fishery and harvest was done by vessels with more than 5 years of operations and more than 5 deliveries per year. For 1977 – 1992, censoring was made for vessels of more than 2 years of operations. Increasing deliveries to more than one would result in no estimates for some years. For 1993 – 2018, censoring was made for vessels of more than 5 years of operations and 5 deliveries per year.

Analyses

A GLM was constructed as

$$\ln(CPUE) = YR + PD + VSL + MSA + WOY + PF$$

Where YR: Year, PD: Fishery periods (1977-1992, 1993-2004,2005-2018), VSL: Vessel, MSA: Statistical Area, WOY: Week of Year, and PF: Permit vs open fishery (Table 1). All variables were treated as categorical. Inclusion of interaction terms was not considered because they were absent (SAFE 2013).

For selection of the best model, forward and backward stepwise selection was conducted. (R step function)

```
fit <- glm(L.CPUE.NO ~ factor(YR) + factor(VSL) + factor(WOY) +
factor(MSA) + factor(PF) + factor(PD),,data=NSdata.C)
step <- step(fit, direction='both', trace = 10)
best.glm<-glm(formula(step), data=NSdata.C)
```

Table B-13. List of variables in the fish ticket database. Variables in bold face were used for generalized linear modeling.

Variable	Description
YR	Year of commercial fishery
VSL	Unique vessel identification number
Fish Ticket Number	Unique delivery to a processor by a vessel
PF	Unique Permit Fishery categories
PD	Fishery period: 1977-1992, 1993-2004,2005-2018
Statistical Area	Unique fishery area.
MOA	Modified statistical area, combining each statistical area into 4 larger areas: Inner, Mid, Outer, Outer North
Fishing Beginning Date	Date of pots set
Landing Date	Date of crab landed to processor
WOY	Week of Landing Date **(calculated)**
Effort	The number of pot lift
Crab Numbers	Total number of crabs harvested from pots
Crab Pounds	Total pounds of crab harvested from pots
ln(CPUE)	ln(Crab Numbers/Effort) **(calculated)**

Table B-2. Permit fisheries, descriptions, and years with deliveries for Norton Sound summer commercial red king crab harvest data.

Permit fishery	Type	Description	Years
K09Q	Open access	KING CRAB , POT GEAR VESSEL UNDER 60', BERING SEA	1994–2002
K09Z	Open access	KING CRAB , POT GEAR VESSEL UNDER 60', NORTON SOUND	1992–2017
K09ZE	CDQ	KING CRAB , POT GEAR VESSEL UNDER 60', NORTON SOUND CDQ, NSEDC	2000–2017
K09ZF	CDQ	KING CRAB , POT GEAR VESSEL UNDER 60', NORTON SOUND CDQ, YDFDA	2002–2004
K91Q	Open access	KING CRAB , POT GEAR VESSEL 60' OR OVER, BERING SEA	1978–1989
K91Z	Open access	KING CRAB , POT GEAR VESSEL 60' OR OVER, NORTON SOUND	1982–1994

Table B-3. Modified statistical area definitions used for analysis of Norton Sound summer commercial red king crab harvest data.

Modified statistical area	Statistical areas included
Inner	616331, 616401, 626331, 626401, 626402
Mid	636330, 636401, 636402, 646301, 646330, 646401, 646402
Outer	656300, 656330, 656401, 656402, 666230, 666300, 666330, 666401
Outer North	666402, 666431, 676300, 676330 ,676400, 676430, 676501, 686330

Table B-4. Final generalized linear model formulae and AIC selected for Norton Sound summer commercial red king crab fishery. The dependent variable is ln(CPUE) in numbers.

Var	Df	Deviance	Resid DF	Resid Dev	AIC
YR	41	1312.43	6274	5082.7	
VSL	90	574.57	6143	3770.3	
WOY	15	82.89	6129	3195.7	
MSA	3	65.83	6125	3047.0	
PF	6	20.14	6119	3026.9	13547
+PD+MOY	3				13547.67

Table B-5. Standardized (censored/full data), and scaled arithmetic observed CPUE indices.

Year	Censored	
	CPUE	SE
1977	3.29	0.68
1978	4.68	0.65
1979	2.87	0.64
1980	3.07	0.65
1981	0.86	0.64
1982	0.20	0.62
1983	0.90	0.65
1984	1.59	0.65
1985	0.50	0.66
1986	1.74	0.70
1987	0.61	0.64
1988	2.36	0.86
1989	1.21	0.61
1990	1.08	0.68
1991		
1992	0.17	0.60
1993	0.90	0.35
1994	0.81	0.34
1995	0.42	0.34
1996	0.51	0.34
1997	0.84	0.35
1998	0.79	0.36
1999	0.92	0.36
2000	1.24	0.34
2001	0.64	0.34
2002	1.23	0.34
2003	0.85	0.34
2004	1.27	0.34
2005	1.19	0.34
2006	1.31	0.34
2007	1.02	0.34
2008	1.32	0.34
2009	0.84	0.34
2010	1.22	0.34
2011	1.58	0.34
2012	1.29	0.34
2013	0.67	0.33
2014	1.12	0.34
2015	1.45	0.34
2016	1.27	0.34
2017	1.10	0.34
2018	0.64	0.34

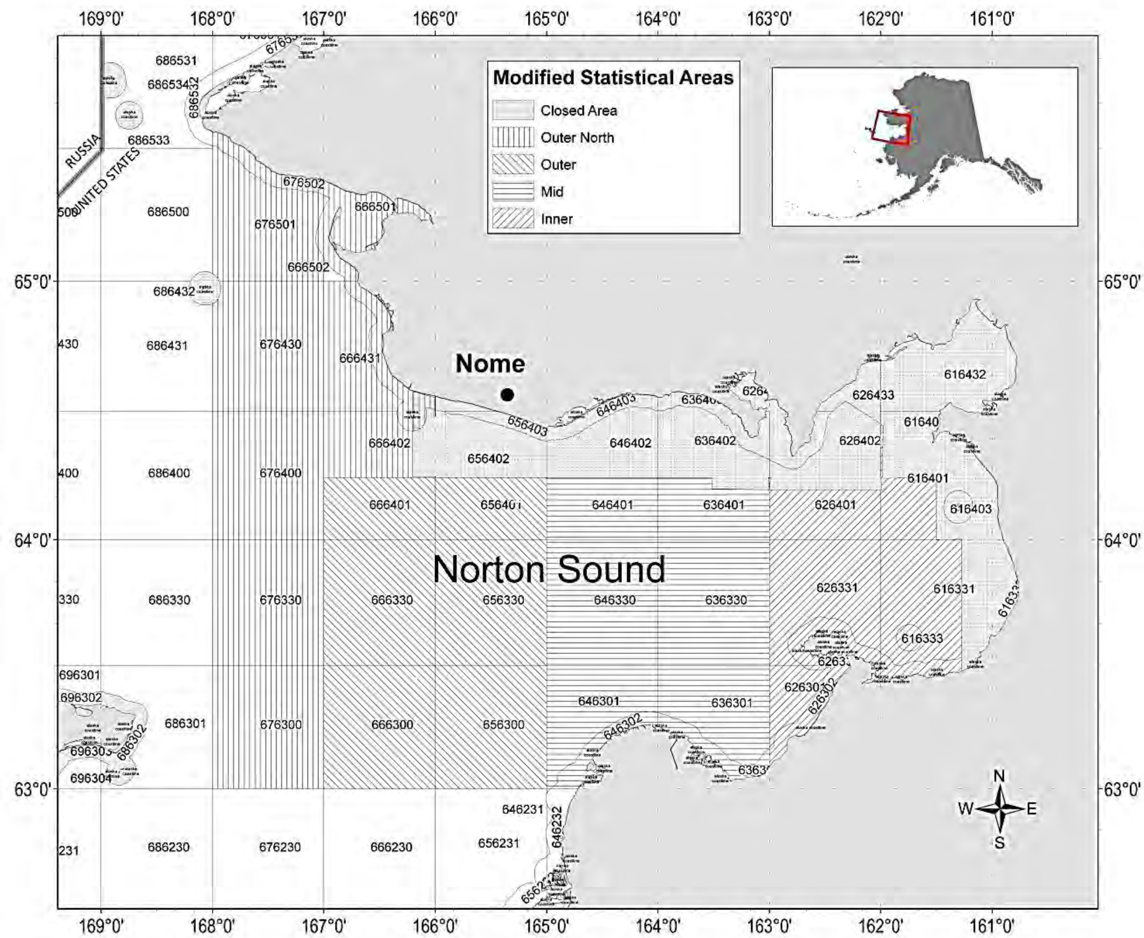


Figure A2-1. Closed area and statistical area boundaries used for reporting commercial harvest information for red king crab in Registration Area Q, Northern District, Norton Sound Section and boundaries of the new *Modified Statistical Areas* used in this analysis.

Appendix C. Norton Sound Red King Crab Summer Commercial fishery Discards Estimation

Formal methodologies have not been established for estimating Red King Crab discards by Norton Sounds Summer commercial fishery from observer data. Here, I describe a few methods and discuss pros and cons of each method.

Data source and description of survey protocols

Norton Sound Summer Commercial fishery observer survey started in 2009 as a potential feasibility project, and formal data collection started since 2012. The observer survey in Norton Sound is voluntary. Due to small boat size, the boat that can take a fishery observer is limited. Fishery observer often work as a crew member. During the fishery, an observe inspect every pots. All lengths/shell condition/sex of red king crab in the pots were measured, and the fisherman sorts out discards that are noted. **Observed discarded crabs are deemed accurate.** However, it is uncertain whether fishing behaviors of the volunteer fishermen are the same as other unobserved fishermen. Observed fishermen tend to have large boat and catcher and sellers. Here are possible concerns:

1. The observed fishermen may go to better fishing grounds with more legal crab and less sub-legals: **higher legal retain CPUE and lower discards CPUE than unobserved (lower discards proportion)**
2. The observed fishermen may not mind sorting out crabs and may choose areas: **higher legal retain CPUE and higher discards CPUE than unobserved (higher discards proportion)**
3. The observed fishermen may keep more legal crabs that are not accepted by NSEDC: **lower discards CPUE than unobserved (lower discards proportion)**

Data Source & Cleaning
From 2012 to 2018, crab catches of 3-4 volunteer crab fishing vessels were observed. Annual observed pots ranged 69 to 199 and total observed crabs ranging from 2200 to 5300 (Table 1). All observed data were combined.

Estimation Methods

Two methods were considered: CPUE and Proportion method. CPUE method expands observed CPUE (Observed number of crab)/(observed pots) to all fisheries pot lifts, whereas proportional method expands observed proportion of discards to retained: (observed number of discards)/(observed number of retained) to all fisheries retained catch.

CPUE has two methods: LNR and Subtraction. LNR simply expands CPUE of discards, whereas Subtraction expands CPUE of total catch and subtract total retained catch.

LNR method

LNR method simply expands CPUE of discards to total pot lifts

$$CPUE_{obs} = \frac{(N_{obs,sub} + N_{obs,ld})}{P_{obs}}$$

Where $N_{obs, sub}$ and $N_{obs, ld}$ are observed number of sublegal and legal crabs discarded, and P_{obs} is the number of pot-lifts by the observed fishermen during the observed period.

$$D_{LNR} = CPUE_{obs} \cdot P_{FT.total}$$

Where $P_{FT.total}$, is total number of pot lifts of all fishermen recorded in fish tickets.

Observer bias corrected LNR method adds correction to CPUE of the observed fishermen by multiplying the CPUE ratio between observed fishermen ($CPUE_{FT.obs}$) and unobserved fishermen ($CPUE_{FT.unobs}$) derived from fish tickets.

$$CPUE_{FT.obs} = \frac{(N_{FT.obs})}{P_{FT.obs}} \qquad CPUE_{FT.unobs} = \frac{(N_{FT.unobs})}{P_{FT.unobs}}$$

Where $N_{FT.obs}$ and $N_{FT.unobs}$ are total number of crab delivered (thorough out season) by observed and unobserved fishermen, and $P_{FT.obs}$ and $P_{FT.unobs}$ total number of pot lifts by observed and unobserved fishermen.

$$D_{LNR2} = \left(\frac{CPUE_{FT.unobs}}{CPUE_{FT.obs}} \right) \cdot D_{LNR}$$

Subtraction method

Subtraction method expands total catch CPUE and subtract total retained catch

$$CPUE_{T.obs} = \frac{(N_{obs})}{P_{obs}}$$

Where N_{obs} is a total number of crab caught by the observed fishermen during the observed period.

$$D_{Sub} = CPUE_{T.obs} \cdot P_{FT.total} - N_{FT.total}$$

Where $N_{FT.total}$ is the total number of retained crab during the season.

Bias corrected Subtraction method is simply bias corrected total catch minus retained catch

$$D_{Sub2} = \left(\frac{CPUE_{FT.unobs}}{CPUE_{FT.obs}} \right) CPUE_{T.obs} P_{FT.total} - N_{FT.total}$$

Finally, the proportion method that expands ratio of discards to retained.

$$D_{prop} = \frac{(N_{obs,sub} + N_{obs,ld})}{N_{obs,lr}} N_{FT.total}$$

Where $N_{obs.lr}$ is observed number of retained legal crabs by observed fishermen during the observed periods.

In assessment model, total number of crabs discarded by summer commercial fishery is modeled as

$$D_{l,t} = \frac{\widehat{N}_{F.D}}{\widehat{N}_{F.R}} N_{FT.total}$$

where $N_{F.R}$ and $N_{F.D}$ are model estimated number of crab retained and discarded, which is essentially the same ss proportional method.

Results

While general annual discards trends were similar among the 3 methods, the number of discards differed (Table 2). Overall, the Subtraction method estimated the highest and the Proportional method estimated the lowest. Bias correction method (LNR2, Sub2) reduced high by discards estimates of 2013 and 2015.

Discussion

The CPUE method assumes that observed CPUE would represent total CPUE or that there is no difference in CPUE between observed and unobserved fishermen. Difference between LNR and Subtraction method is that LNR method assumes that observed discards are accurate whereas subtraction method assumes that observed discards are biased but observed total catches are accurate. On the other hand, the proportional method assumes that observed discards proportions would represent total proportion or that every fisherman has similar crab composition.

In Norton Sound observer survey, discarded crabs are more likely accurate because separation of retained vs discards are often done in corporation with the fishermen. However, fishermen and timing of observation are limited to convenience of volunteer fishermen who have larger boat (so that observer can be on board) and are high also catchers. They would be more efficient in catching legal crabs with fewer discards than those with small boats. They would also take observers when they expect higher catch.

In fact, season total retained legal crab CPUE by observed fishermen were generally higher than other unobserved fishermen (Table 2). Furthermore, their CPUE was generally higher during the periods when observers were on board. Observed fishermen appeared to go different fishing area from those of all fishermen (Table 4). Those suggest that subtraction method would probably overestimate discards. Direction of bias for LNR and proportional methods are difficult to evaluate. If the observed fishermen tend to better avoid catching sublegal crabs (e.g., lower sublegal proportion), the proportional method would underestimate discard catch. But, as they have higher catch CPUE, their discards catch CPUE could still be higher than those of unobserved fishermen. Then, discards catch estimate by LNR method could overestimate as well as underestimate.

Table 14. Observed pot lifts, catch, and total pot lifts and catch from 2012 to 2018

	Observer Survey					Fish Tickets	
	Pot lifts	Sublegal	Legal retained	Legal discards		pot lifts	Retained
Year	P_{obs}	$N_{obs.sub}$	$N_{obs.lr}$	$N_{obs.ld}$	Female	$P_{FT.total}$	$N_{FT.total}$
2012	78	898	1055	177	152	10041	161113
2013	199	2775	2166	258	123	15058	130603
2014	147	1504	1838	341	104	10127	129656
2015	69	969	1676	577	224	8356	144224
2016	67	264	1700	169	878	8,009	138997
2017	110	432	2174	122	373	9440	135322
2018	78	547	1096	10	574	8797	89613
2019	28	123	142	1	89	5436	24913

Table 2. Retained Crab CPUE between observed (CPUE.ob) during the observer survey, and season total CPUE between observed and unobserved fishermen derived from fish ticket data.

Year	CPUEobs	$CPUE_{FT.obs}$	$CPUE_{FT.unobs}$
2012	13.53	16.05	16.57
2013	10.88	8.67	7.47
2014	12.50	12.80	11.87
2015	24.29	17.26	15.62
2016	25.37	17.36	15.30
2017	19.76	14.33	13.33
2018	14.05	10.19	10.09

2019	5.07	4.58	4.56

Table 3. The number of discarded crab estimated by 5 methods.

Year	LNR	LNR2	Sub	Sub2	Prop	Model
2012	138386	150043	113084	136182	164167	94564
2013	229502	173750	262797	167229	182880	120486
2014	127104	104697	124070	79340	130150	147066
2015	187223	135910	245965	139023	133037	88430
2016	51760	32965	115976	23394	35403	50228
2017	47543	34870	98790	36384	34484	46441
2018	62820	60714	96816	90566	45542	45848
2019	24074	23362	26729	24203	21755	28887

Table 4. Average legal crab proportion caught by 2012-2018 trawl survey and Summer commercial harvest proportion in major fishing stat area

	Catch proportion	
STAT Area	All fishermen	Observed Fishermen
666401	15%	7%
656401	21%	18%
646401	19%	46%
636401	33%	19%
626401	15%	2%

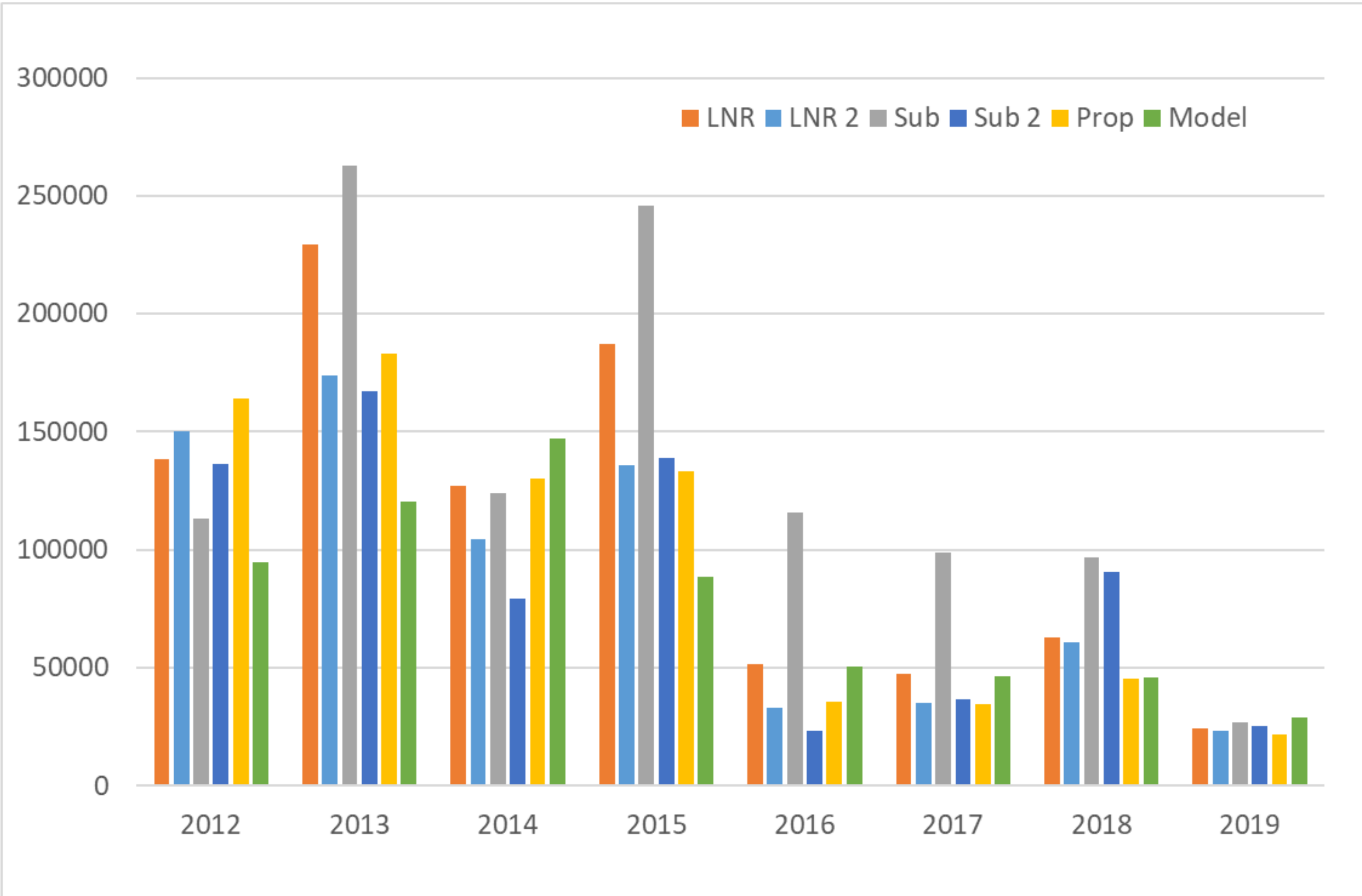


Figure 1. The number of discarded crab estimated by 3 methods.

Appendix D – Model 19.0

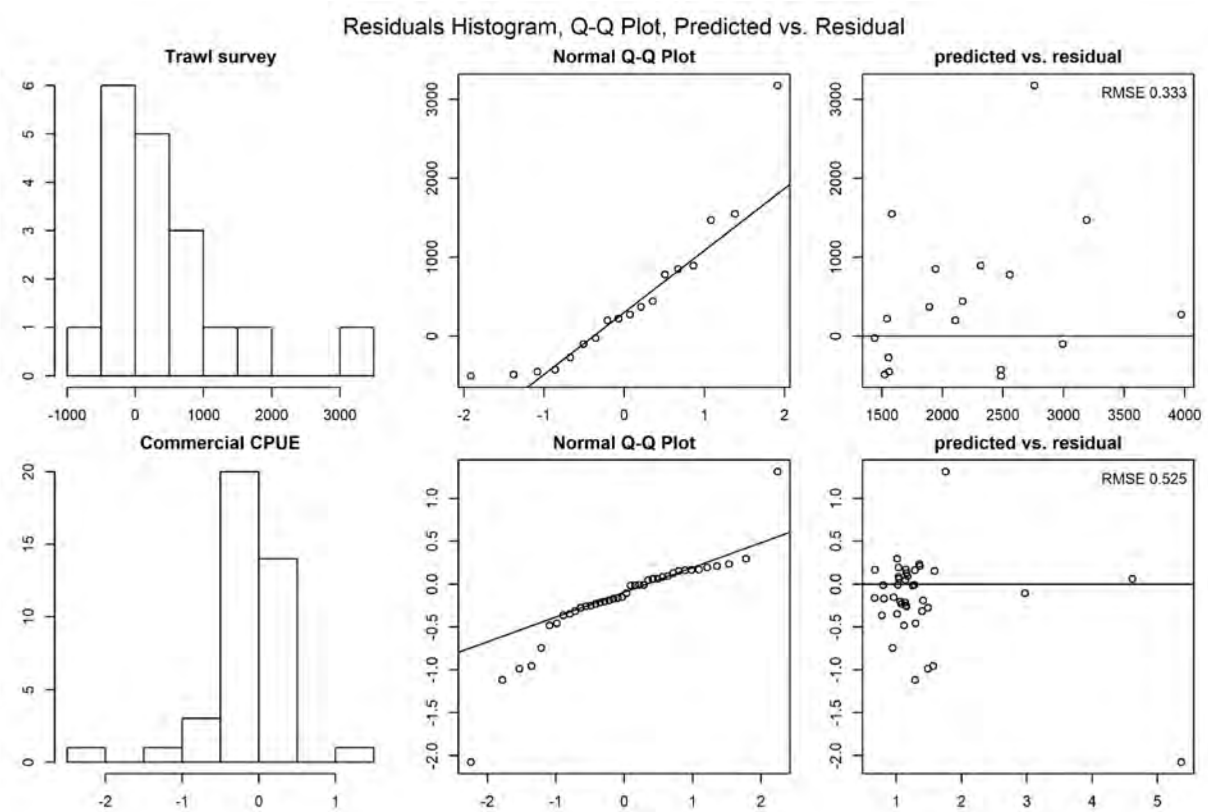


Figure D1-1. QQ plot of trawl survey and commercial CPUE.

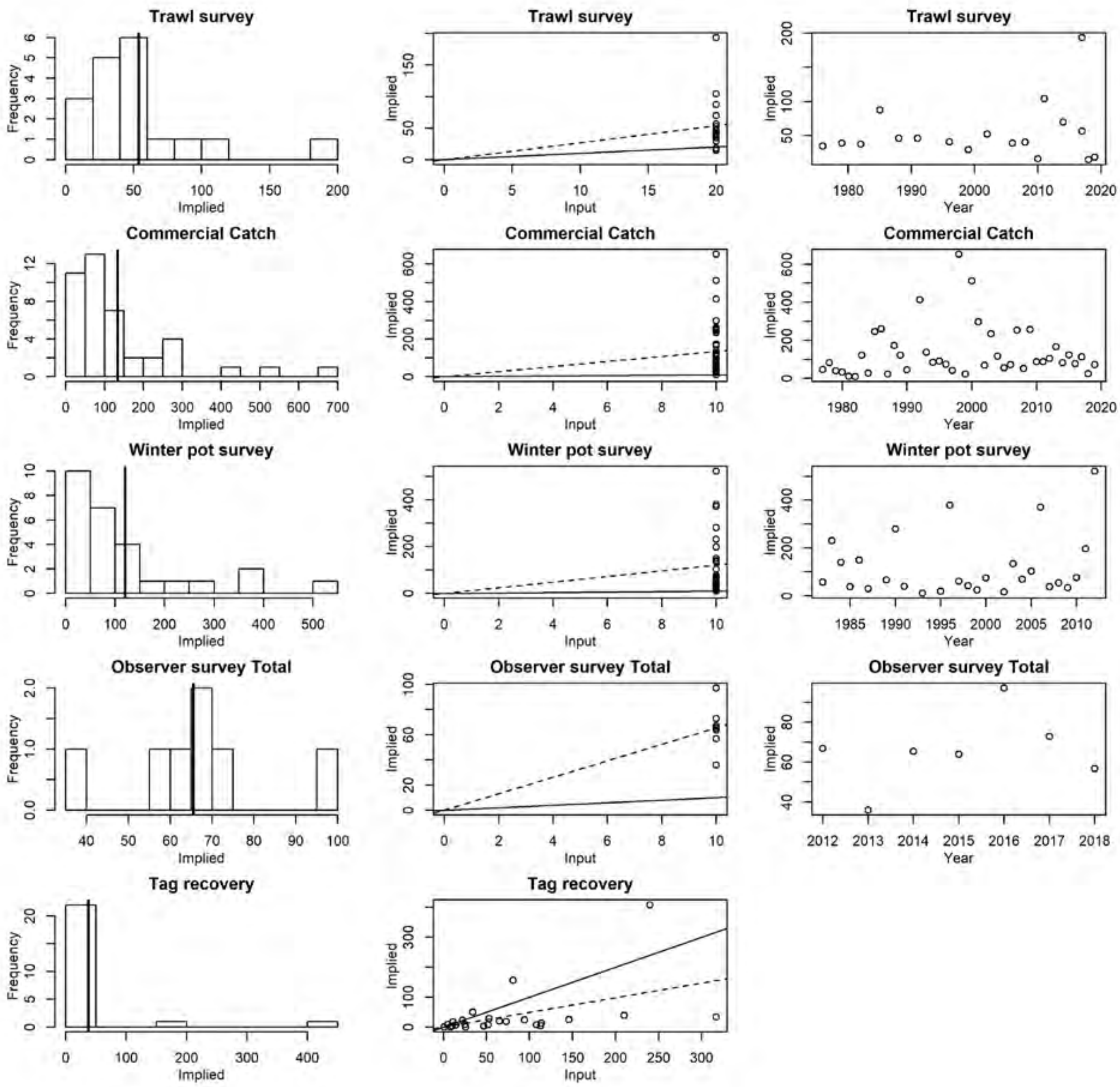


Figure D1-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column shows input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

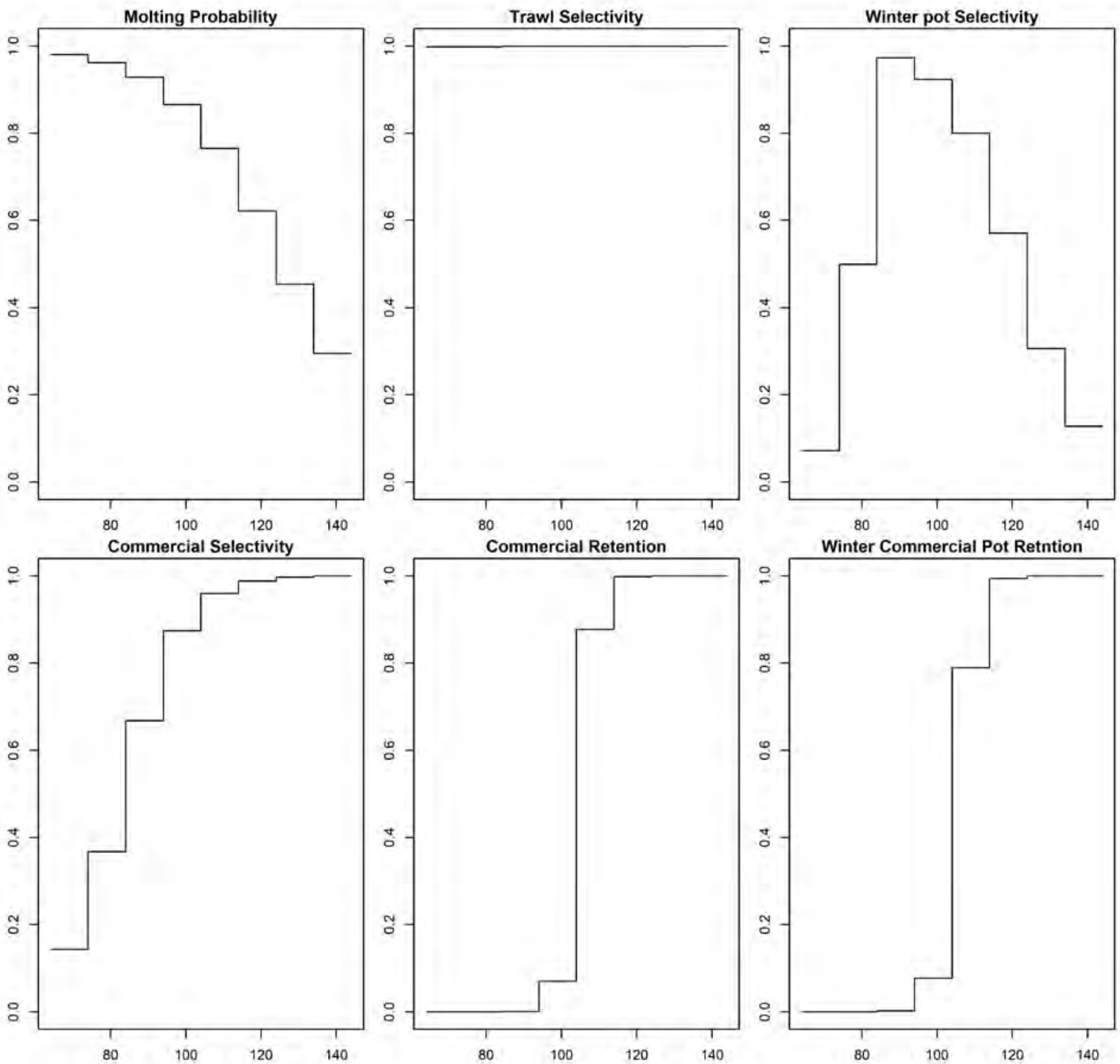


Figure D1-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

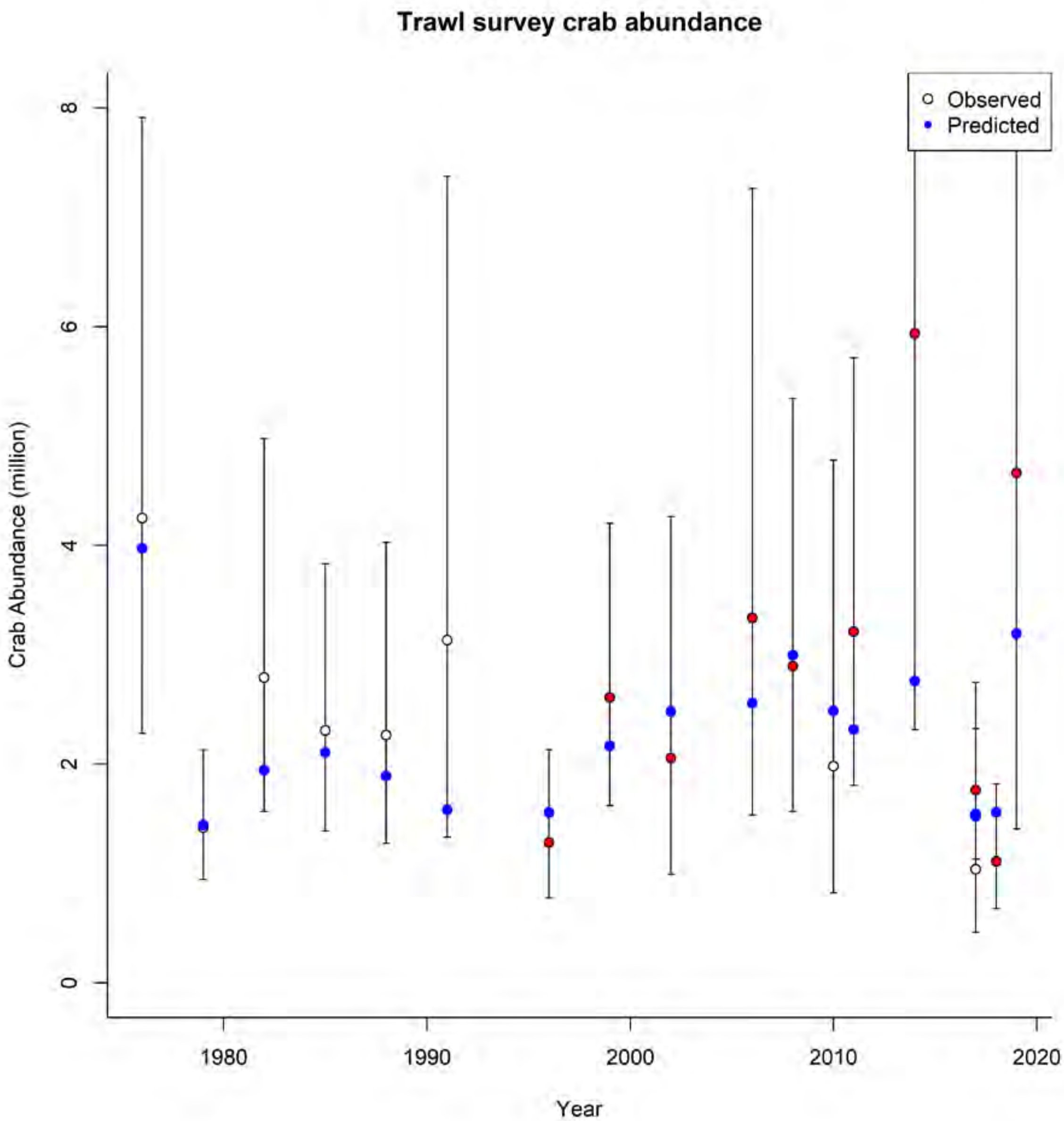


Figure D1-4. Estimated trawl survey male abundance (blue). Observed: white: NOAA trawl Survey, red: ADG&G trawl survey

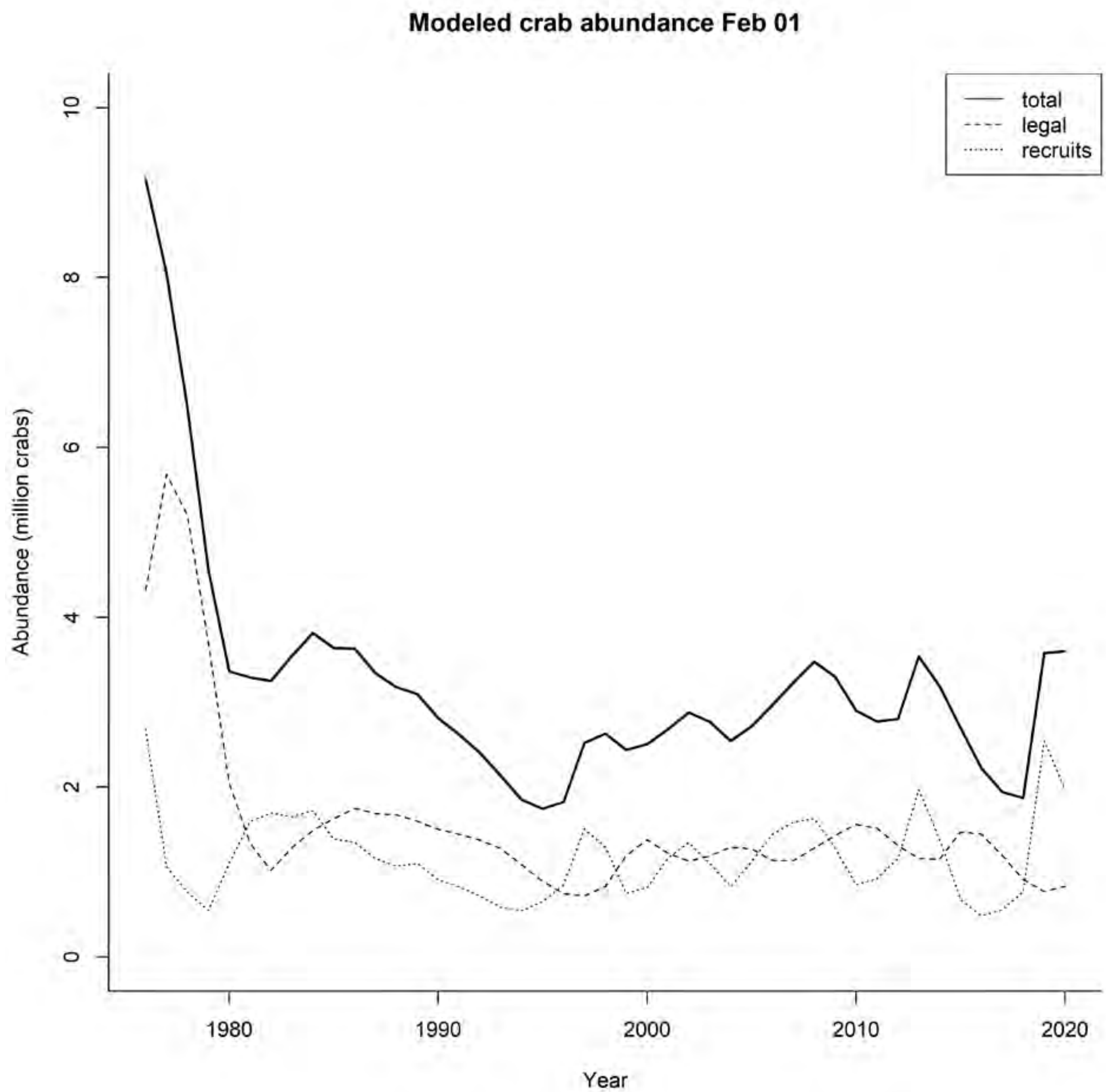


Figure D1-5. Estimated abundance of legal males.

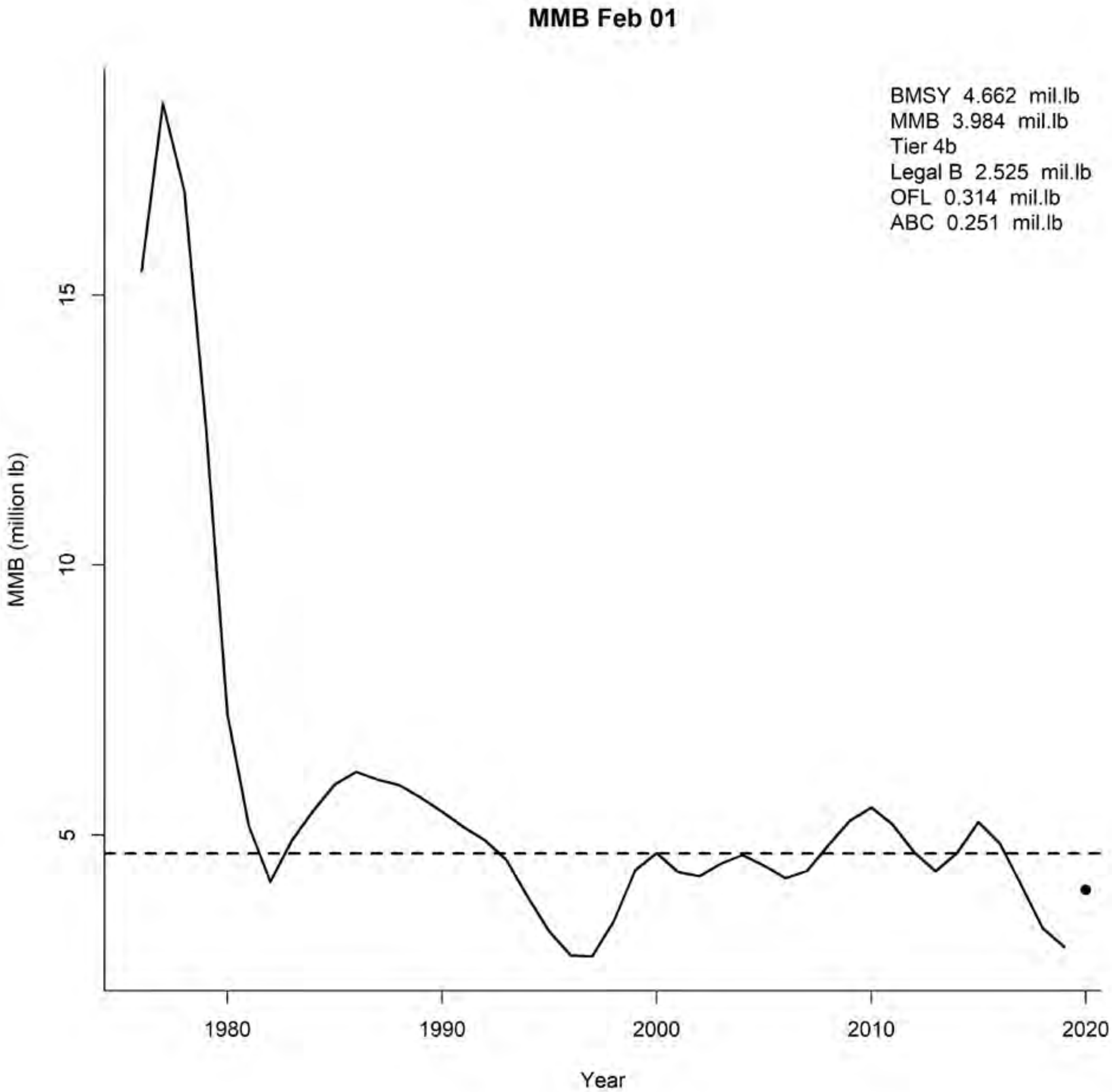


Figure D1-6. Estimated mature male biomass. Dash line shows Bmsy.

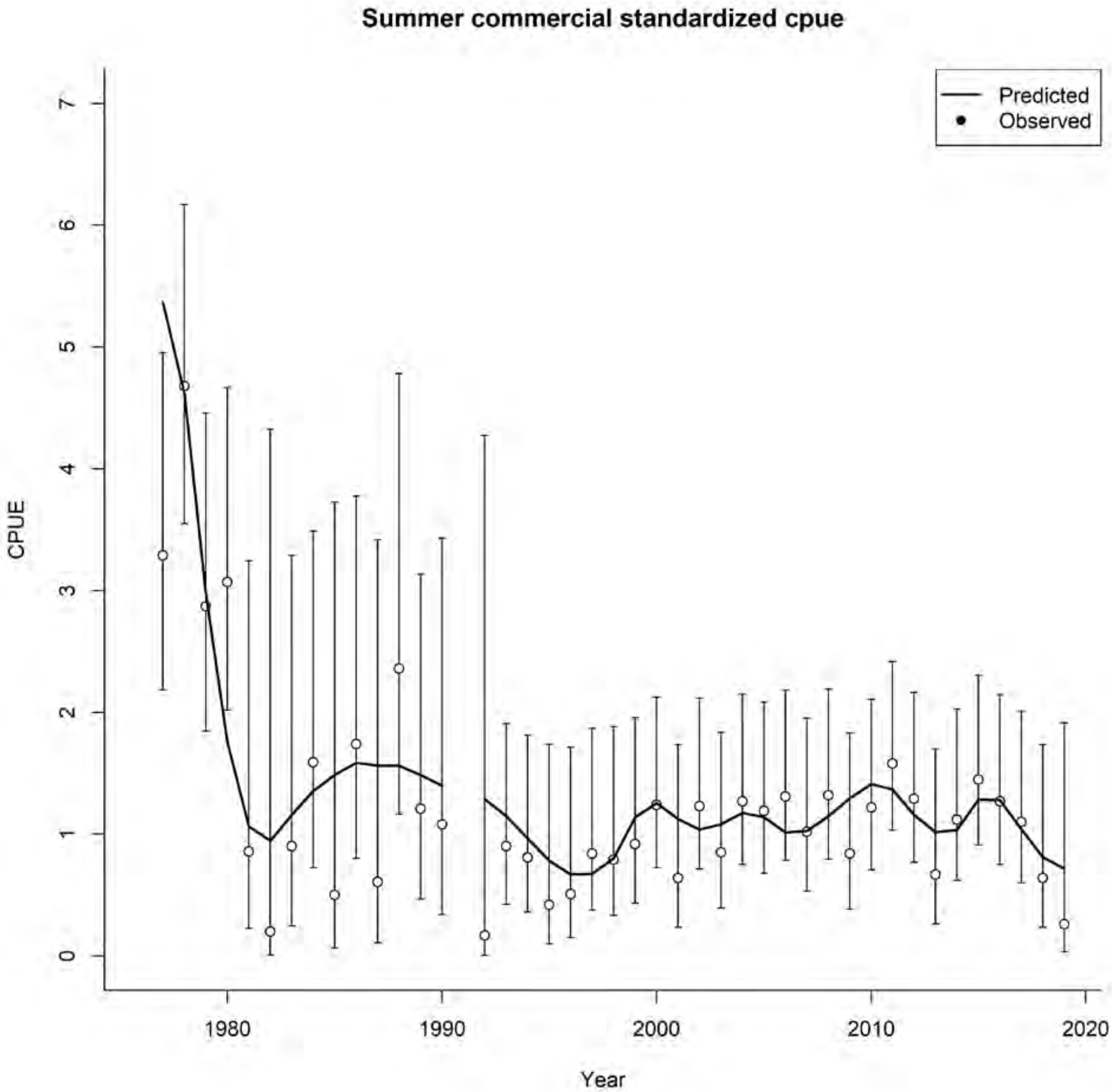


Figure D1-7. Summer commercial standardized cpue. Vertical line incicates lognormal 95%CI

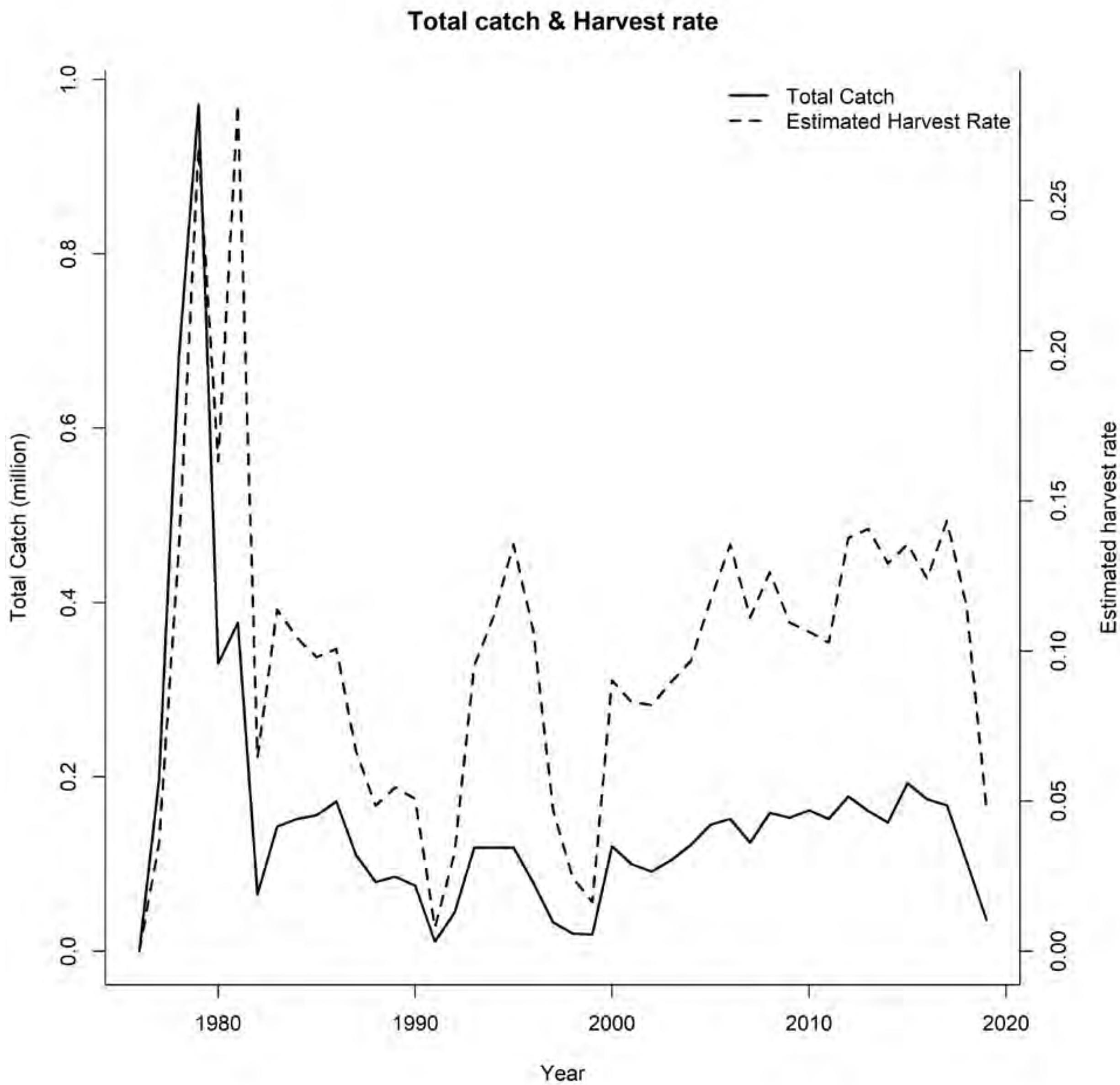


Figure D1-8. Total catch and estimated harvest rate 1976-2019.

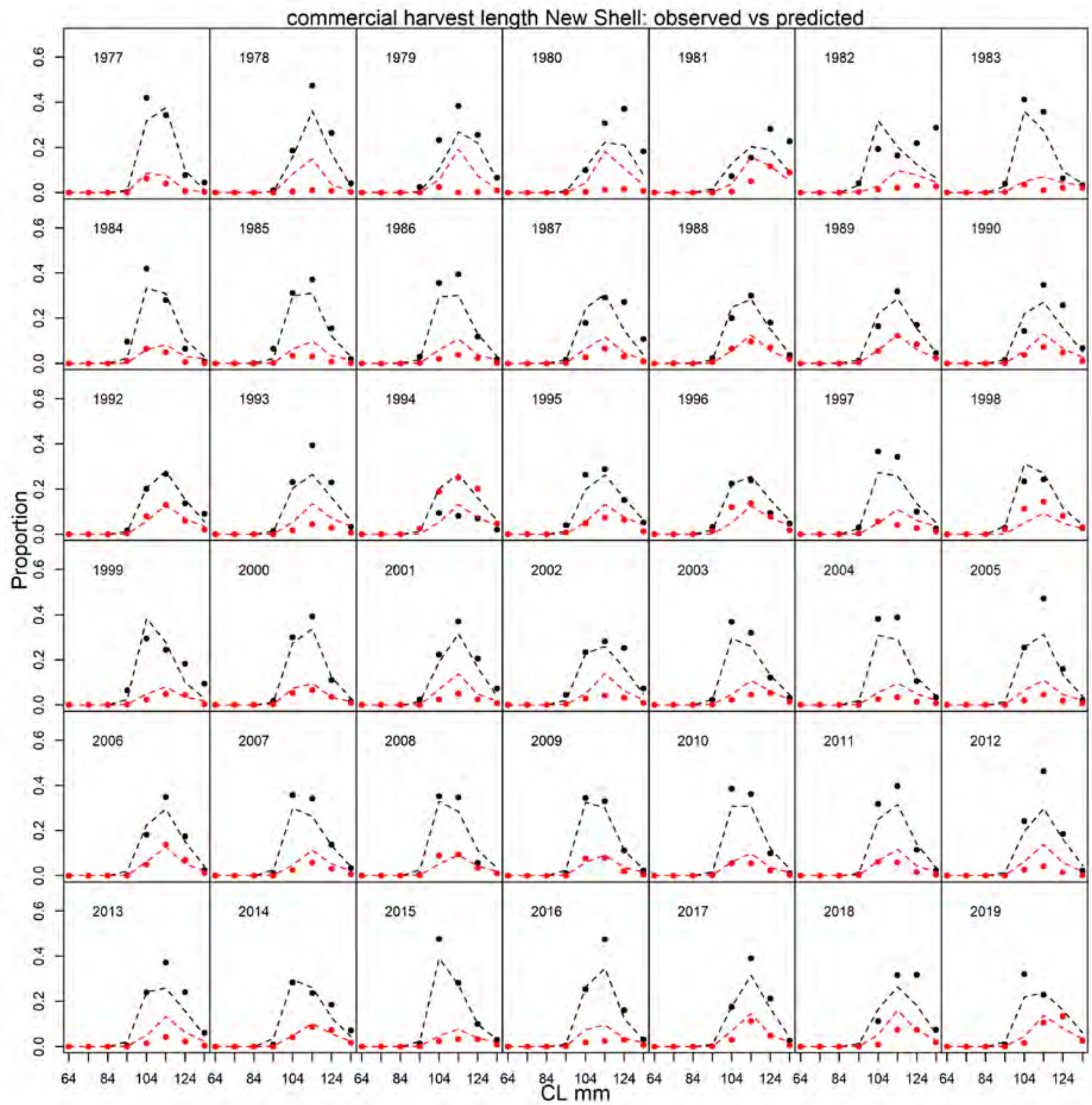


Figure D1-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Black: newshell, Red: oldshell

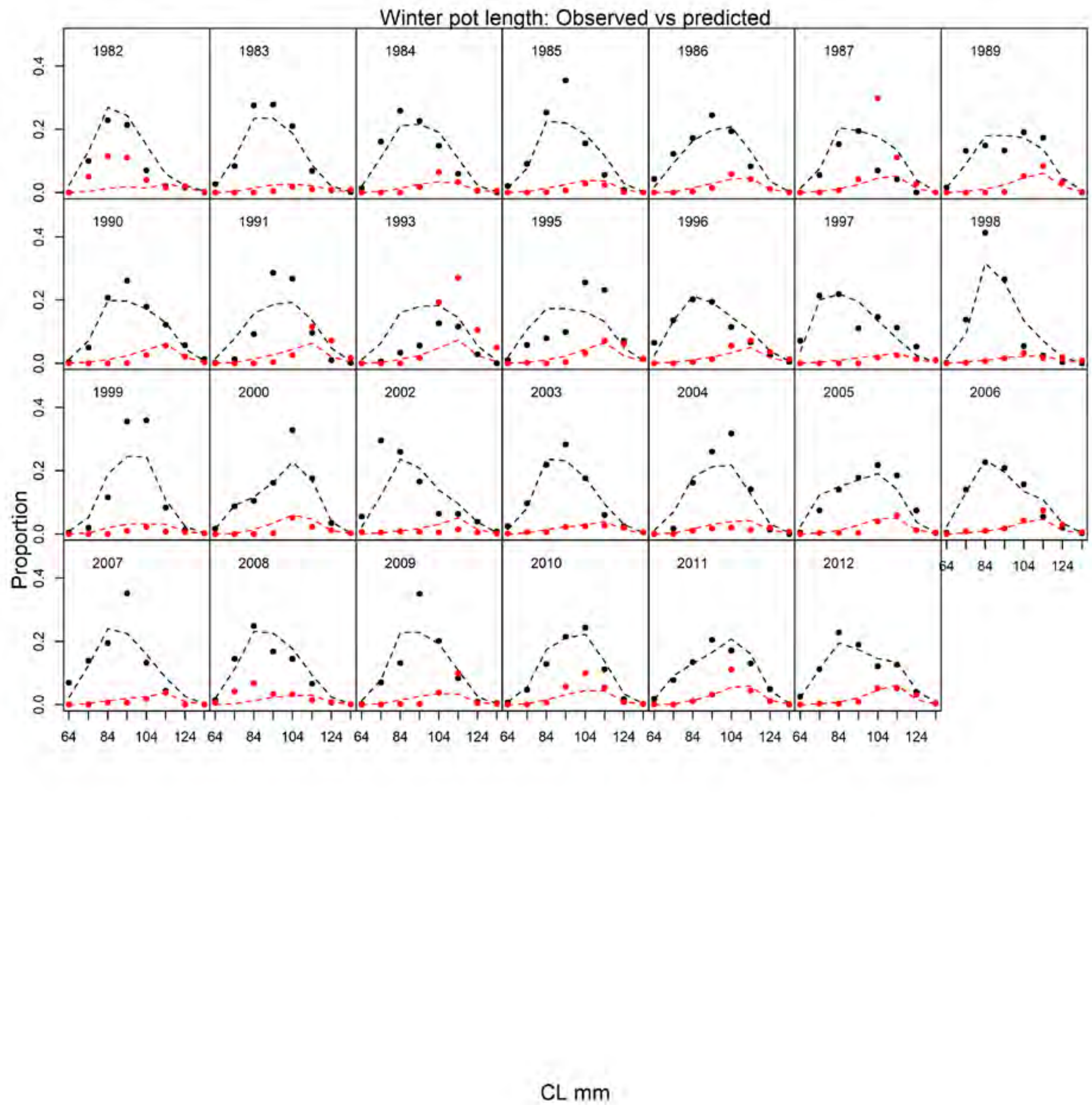


Figure D1-10. Predicted (dashed line) vs. observed (dots) length class proportions for the winter and spring pot survey. Black: newshell, Red: oldshell

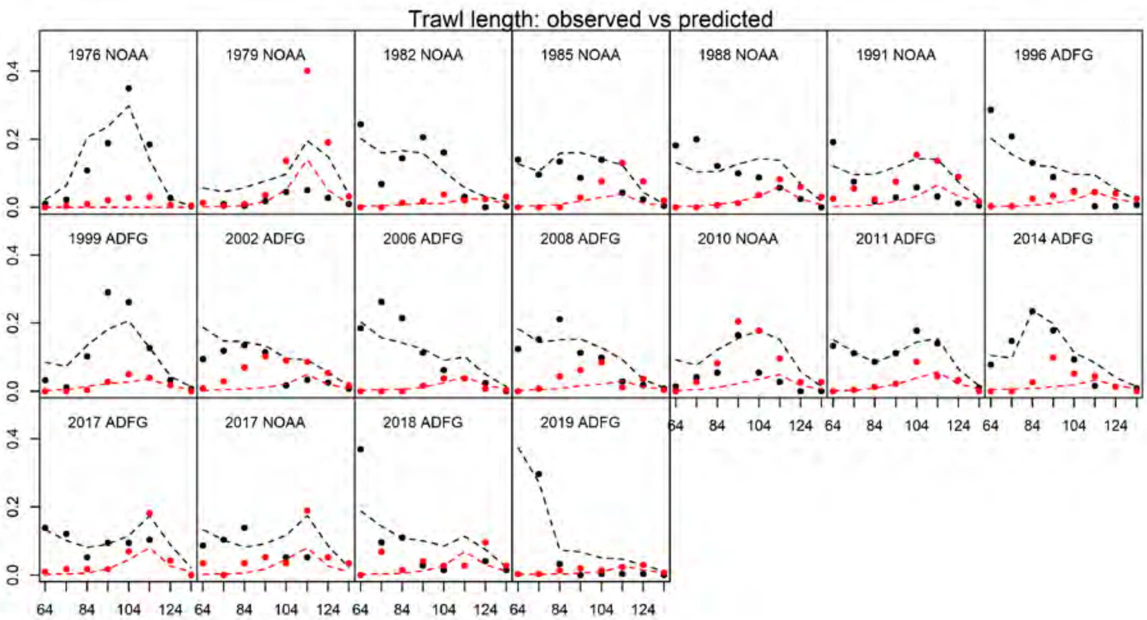


Figure D1-11. Predicted (dashed) vs. observed (dots) length class proportions for Trawl survey. Black: newshell, Red: oldshell

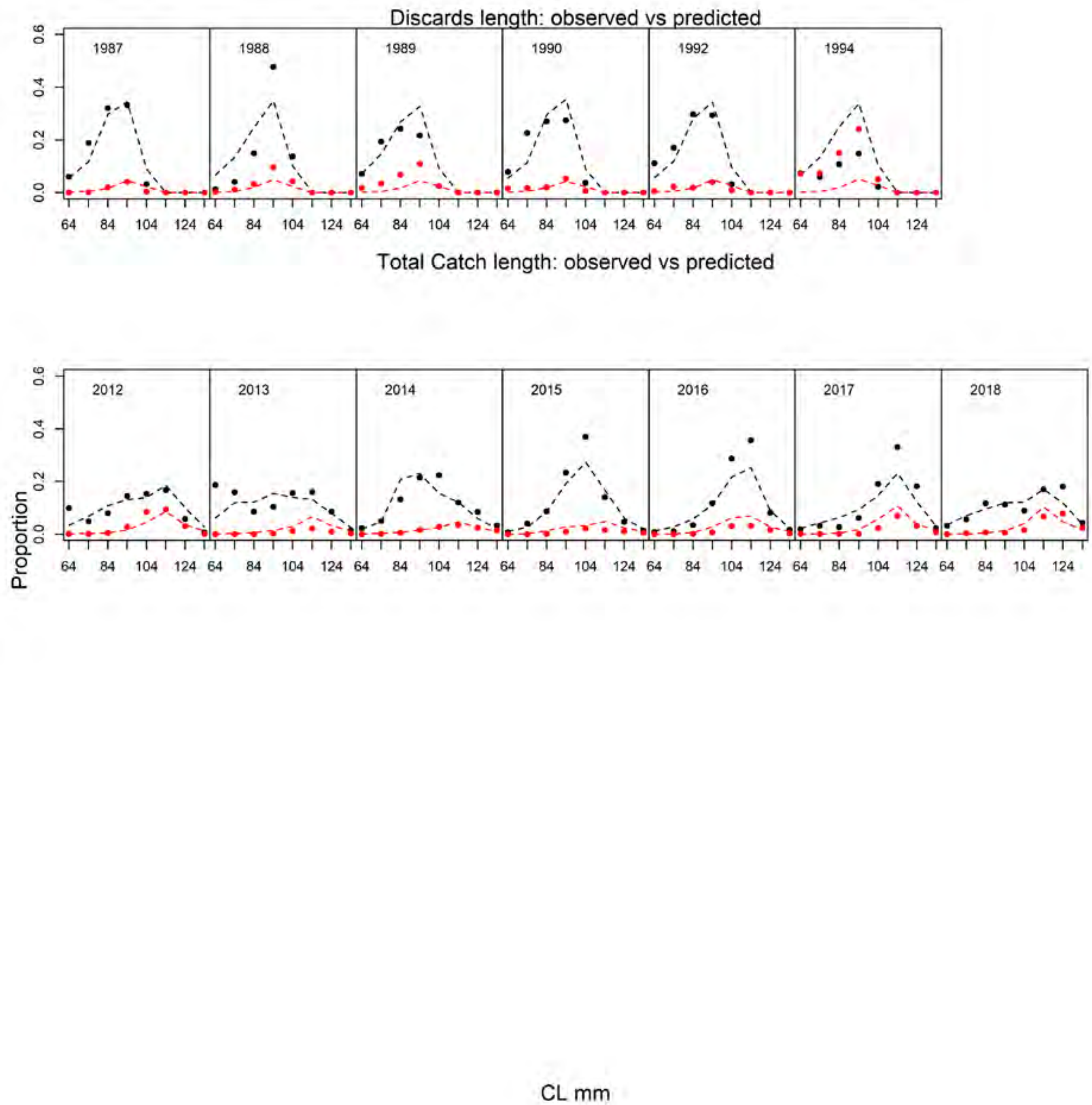


Figure D1-13. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

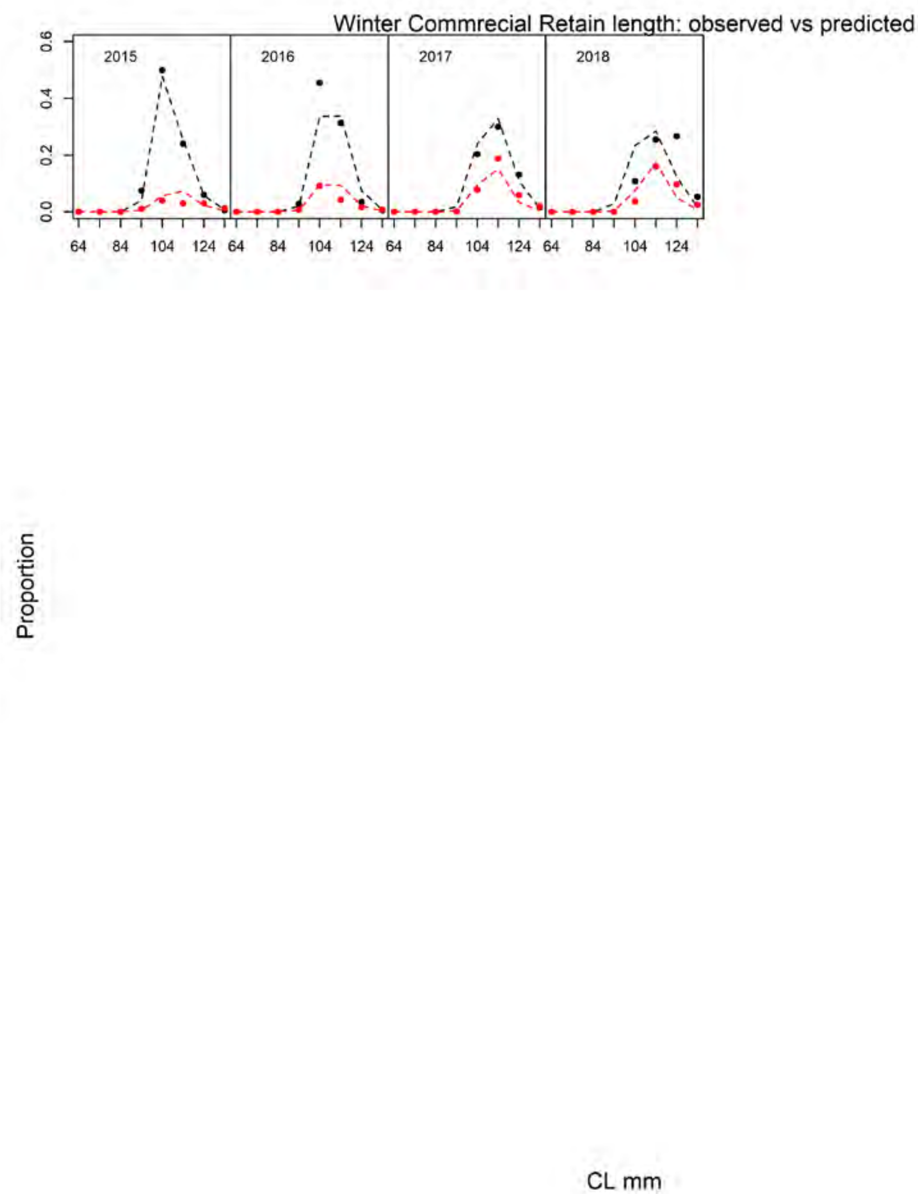


Figure D1-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

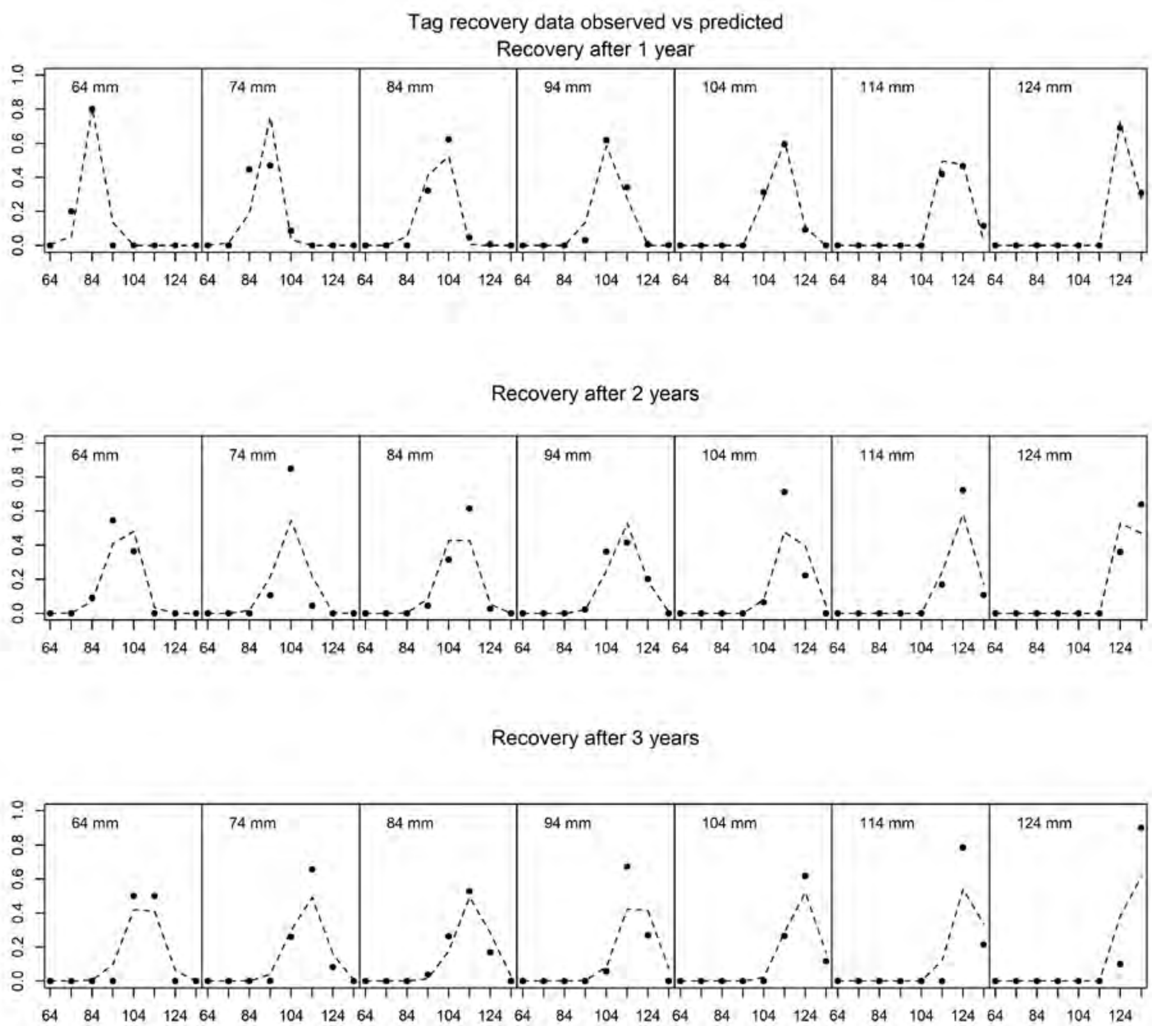


Figure D1-13. Predicted vs. observed length class proportions for tag recovery data.

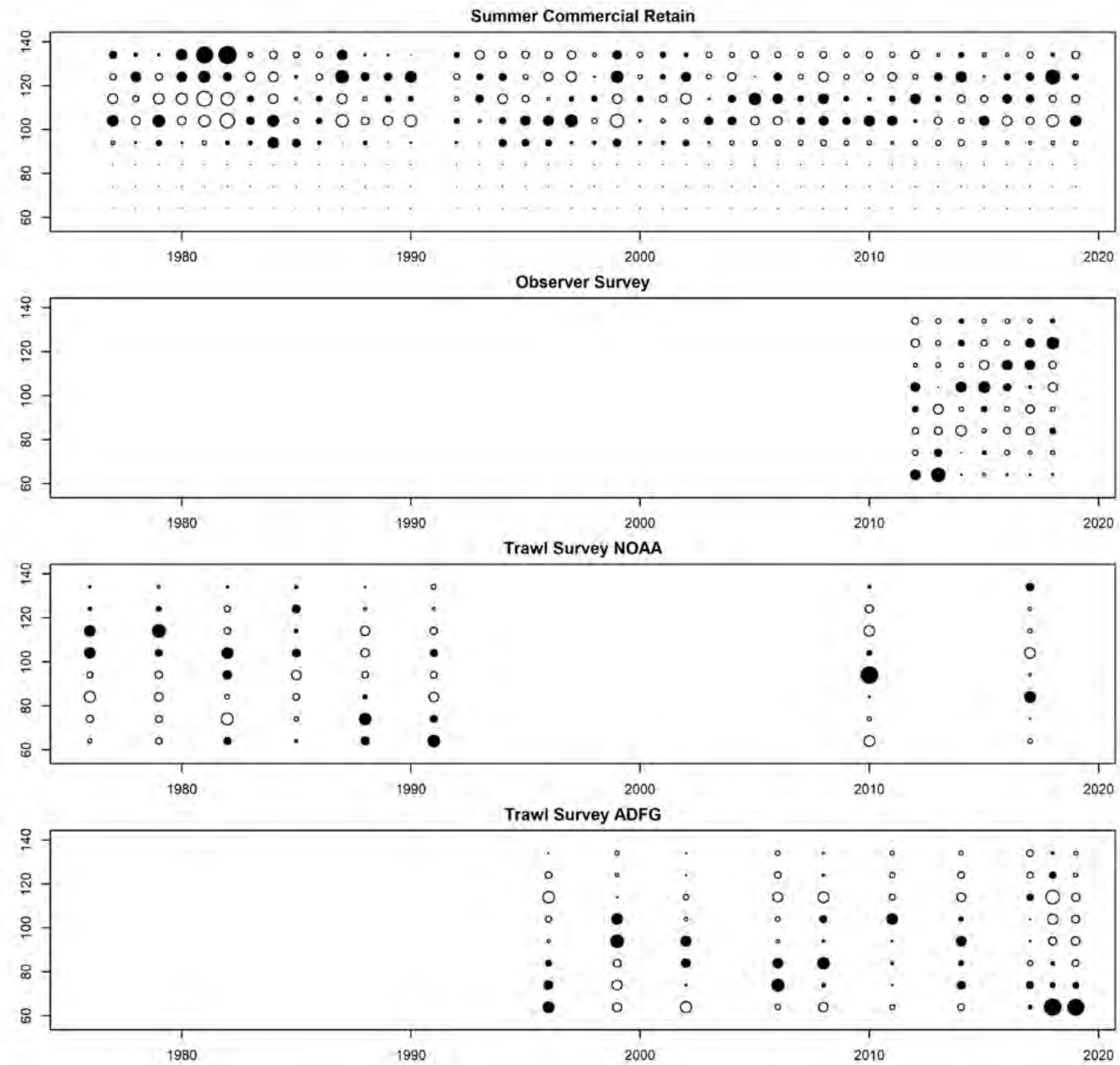


Figure D1-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

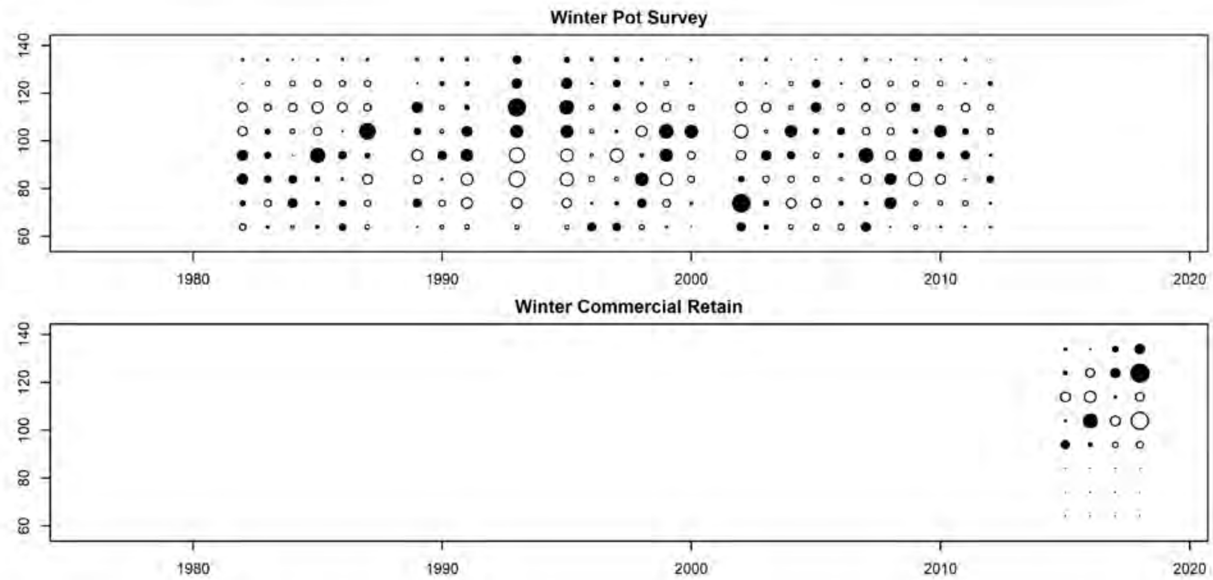


Figure D1-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table D1. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.783	0.111
log_q_2		
log_N_{76}	9.122	0.109
R_0	6.478	0.083
a_1	1.752	4.587
a_2	2.769	4.260
a_3	3.934	4.107
a_4	4.072	4.094
a_5	4.300	4.085
a_6	3.537	4.114
a_7	2.101	4.383
r1	10.000	0.283
r2	9.655	0.332
log_a	-2.682	0.090
log_b	4.835	0.015
log_ϕ_{st1}	-5.000	0.051
log_ϕ_{wa}	-2.206	0.301
log_ϕ_{wb}	4.796	0.032
Sw1	0.072	0.035
Sw2	0.499	0.126
log_ϕ_{l}	-2.086	0.057
$log\_\phi ra$	-0.787	0.129
$log\_\phi rb$	4.646	0.008
$log\_\phi wra$	-0.965	0.553
$log\_\phi wrb$	4.654	0.038
w^2_t	0.000	0.000
q	0.700	0.113
σ	3.886	0.208
β_1	12.393	0.700
β_2	7.661	0.171
ms78	3.248	0.255

Appendix D - Model 19.0 Update

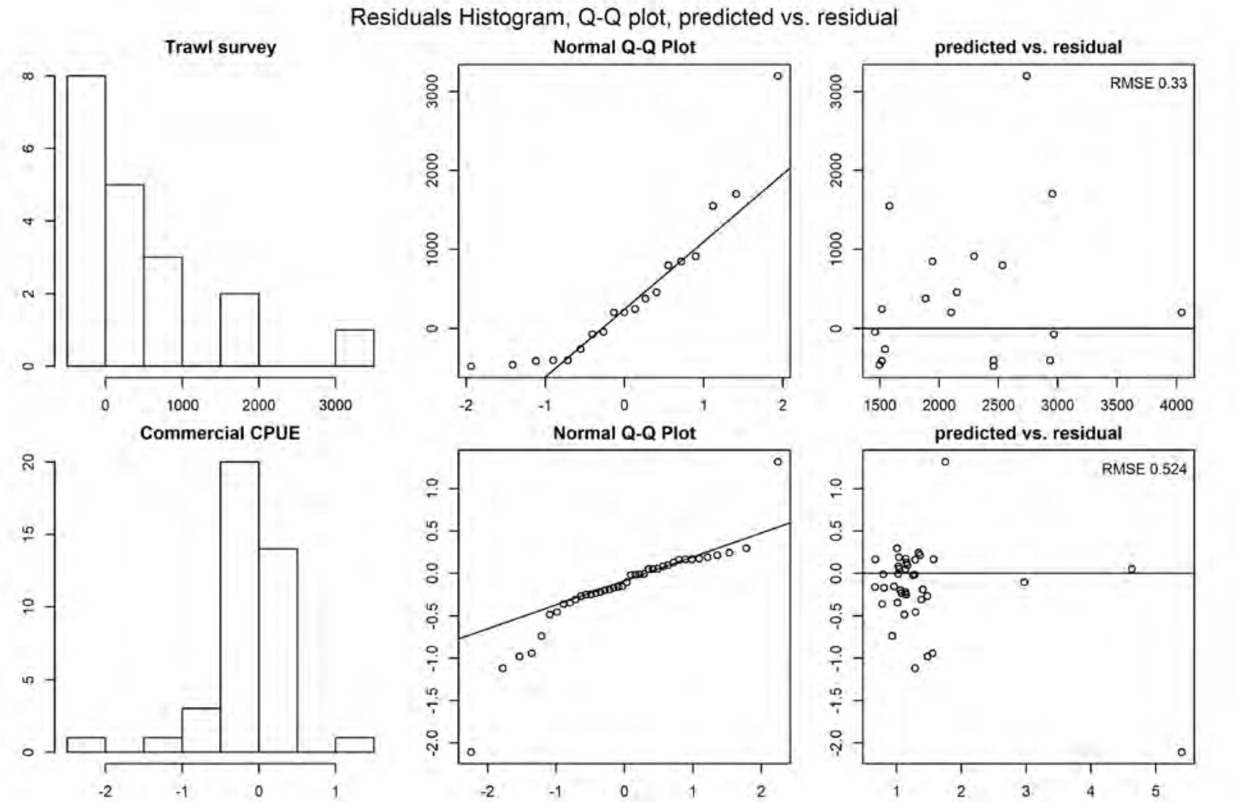


Figure C8-1. QQ plot of trawl survey and commercial CPUE.

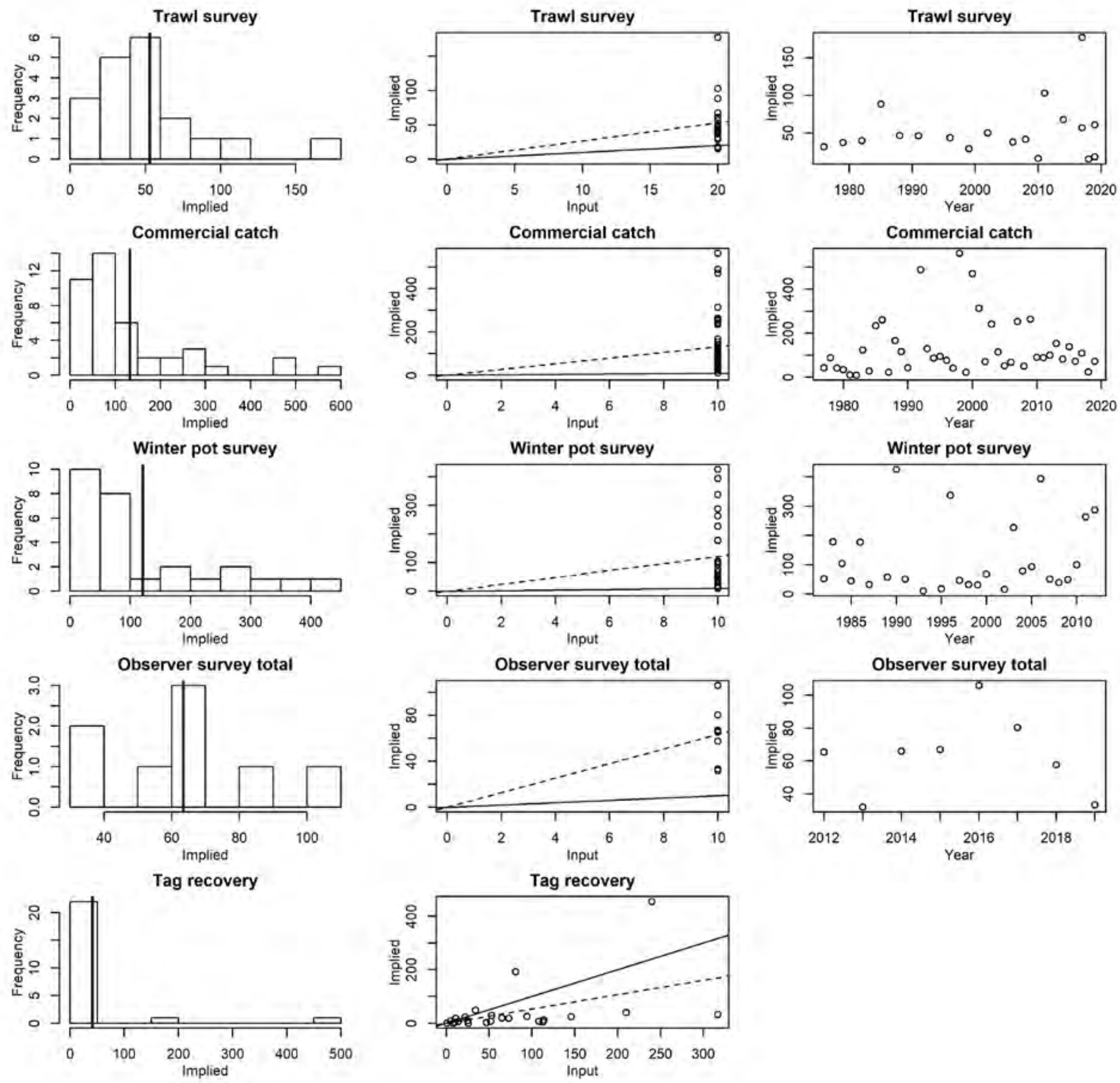


Figure C8-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column shows input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

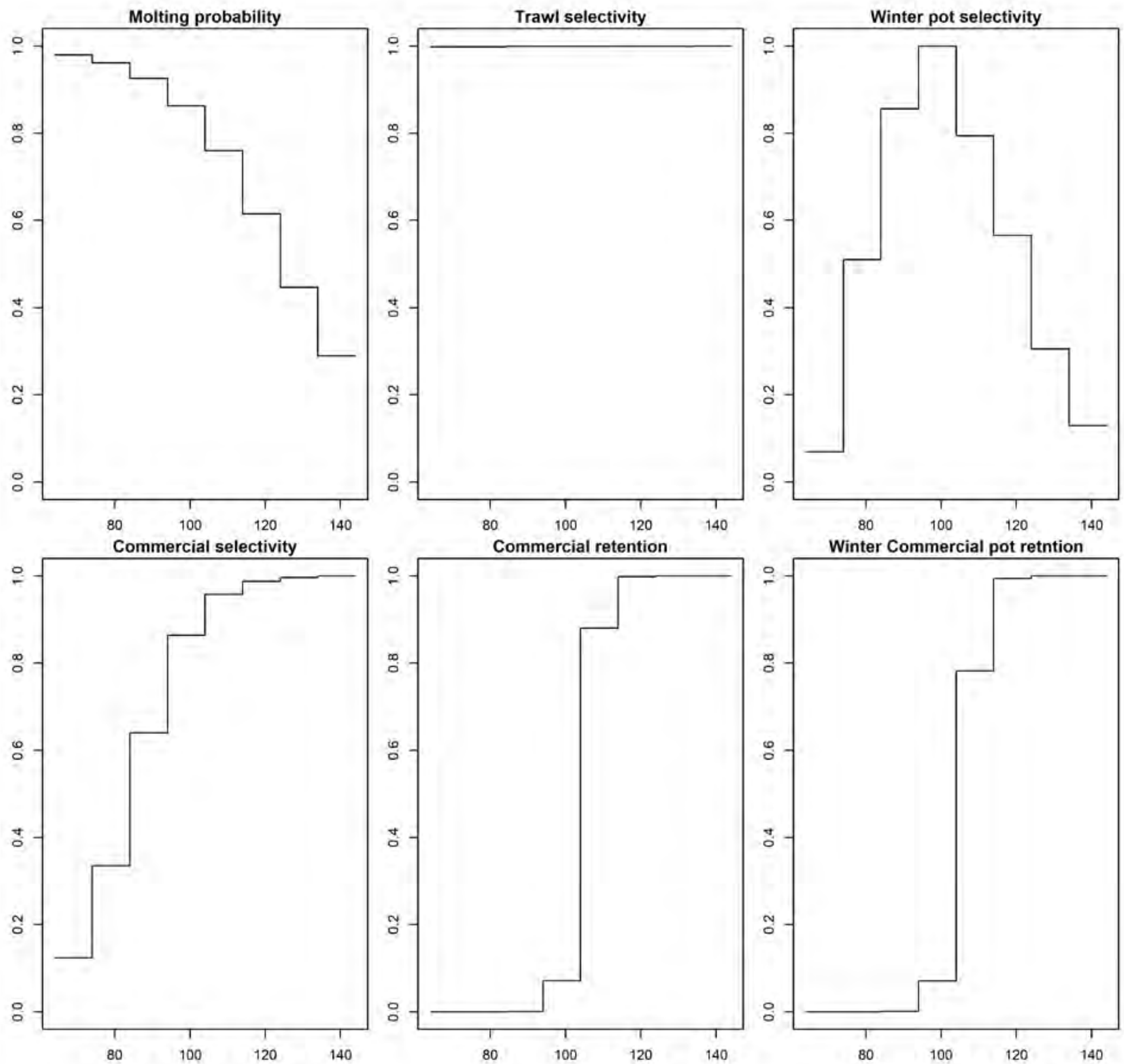


Figure C8-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

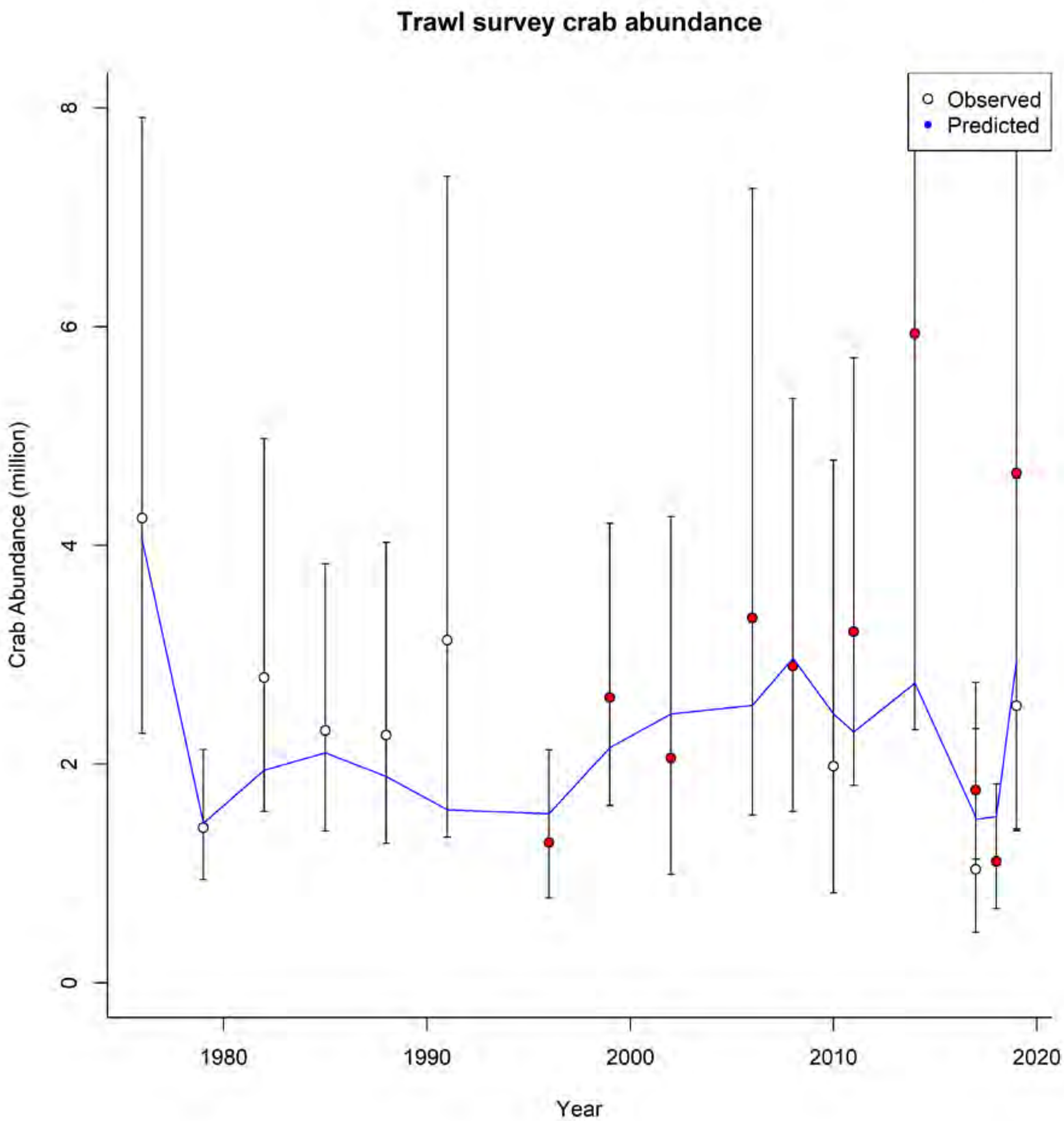


Figure C8-4. Estimated trawl survey male abundance (blue line). Observed: white: NOAA trawl Survey, red: ADG&G trawl survey

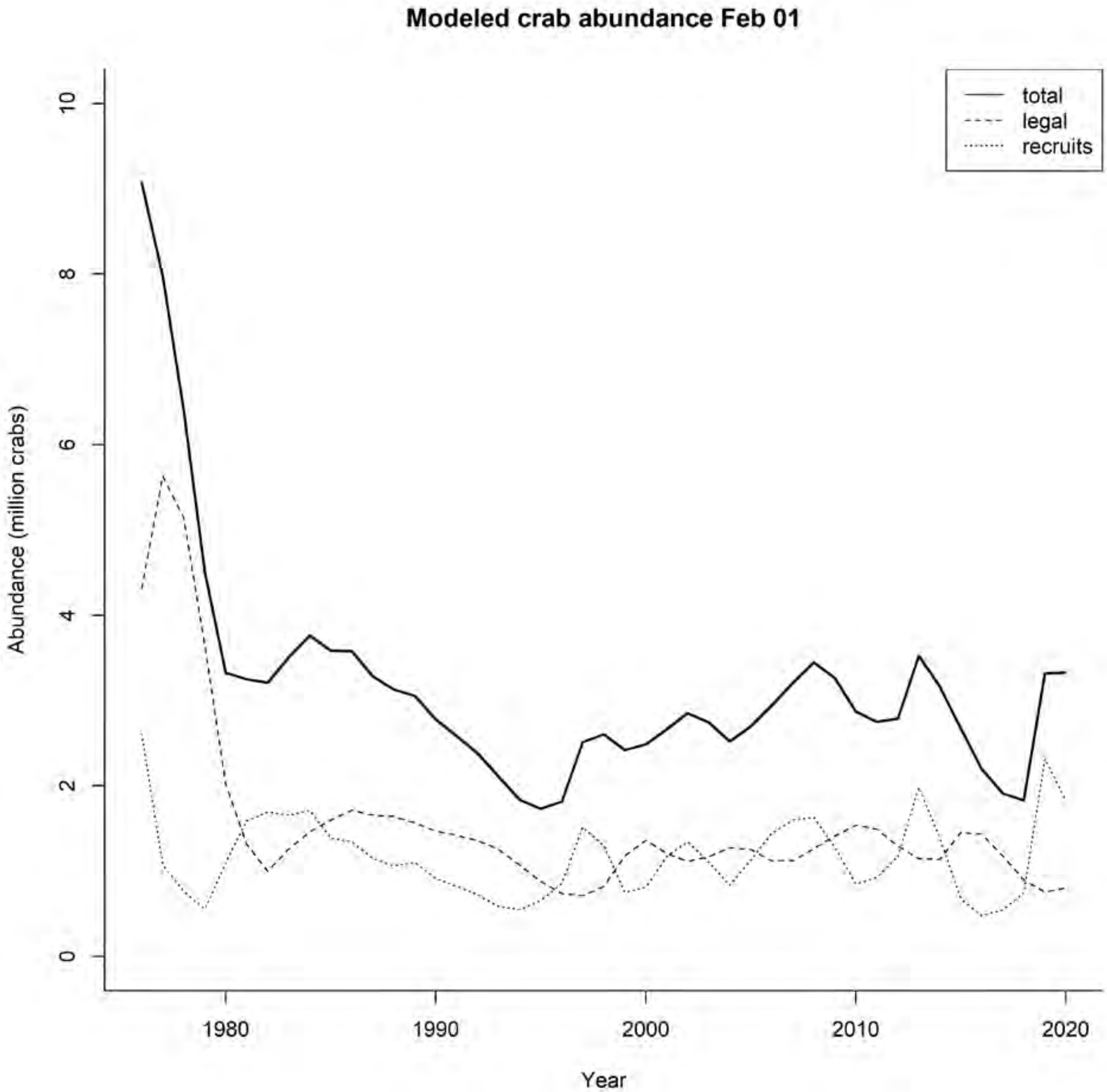


Figure C8-5. Estimated abundance of legal males.

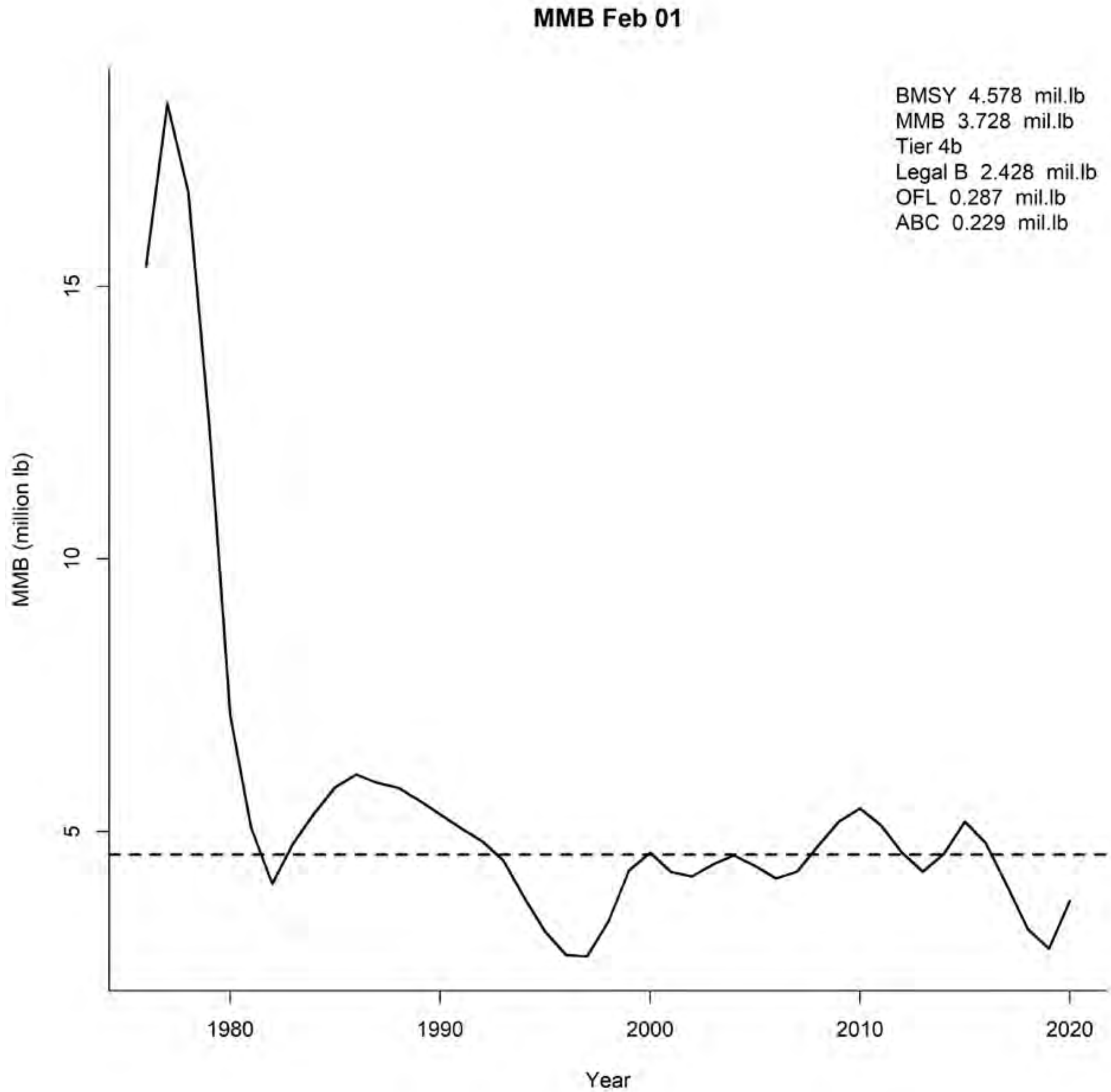


Figure C8-6. Estimated mature male biomass. Dash line shows Bmsy.

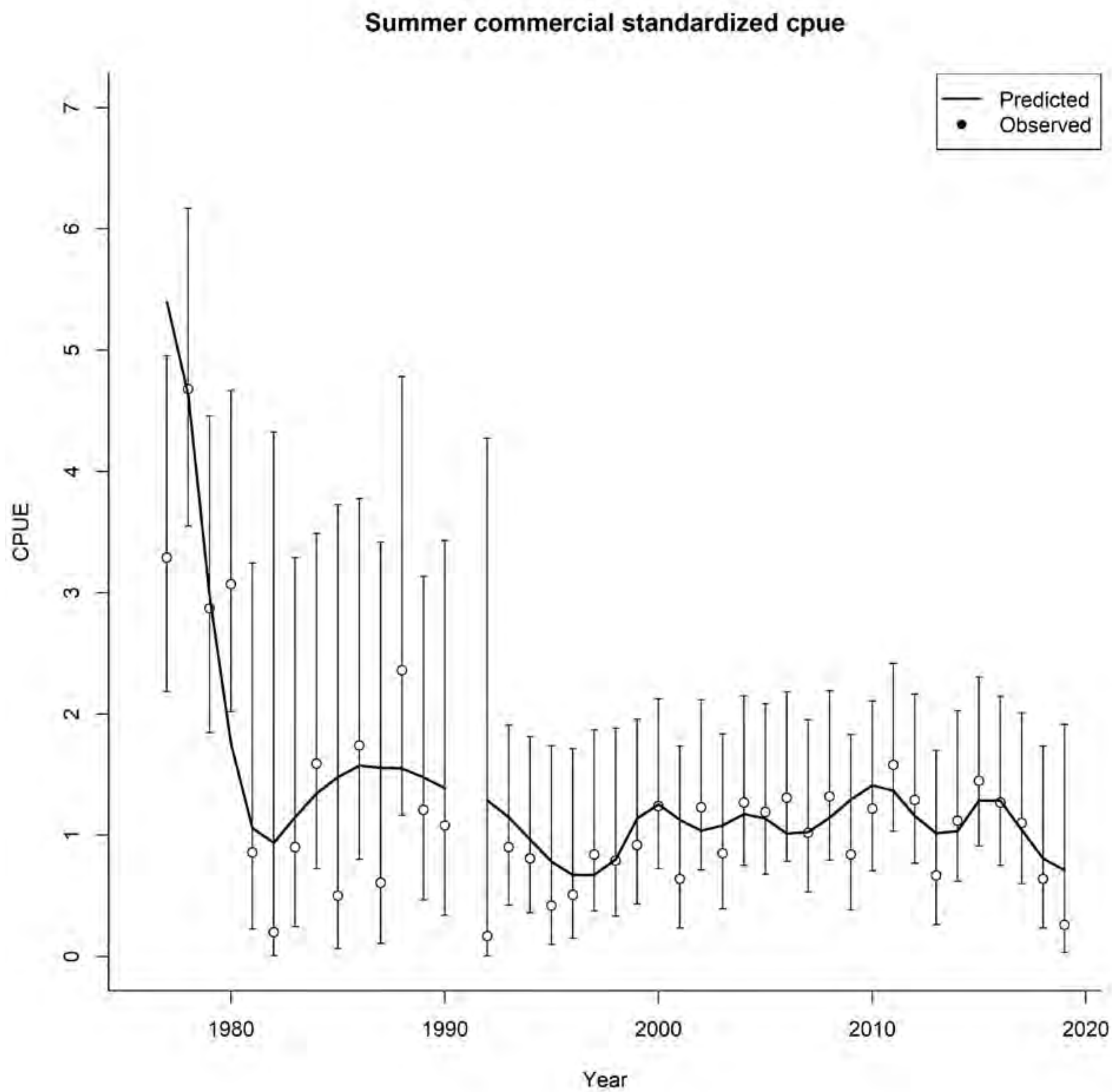


Figure C8-7. Summer commercial standardized cpue. Vertical line incicates lognormal 95%CI

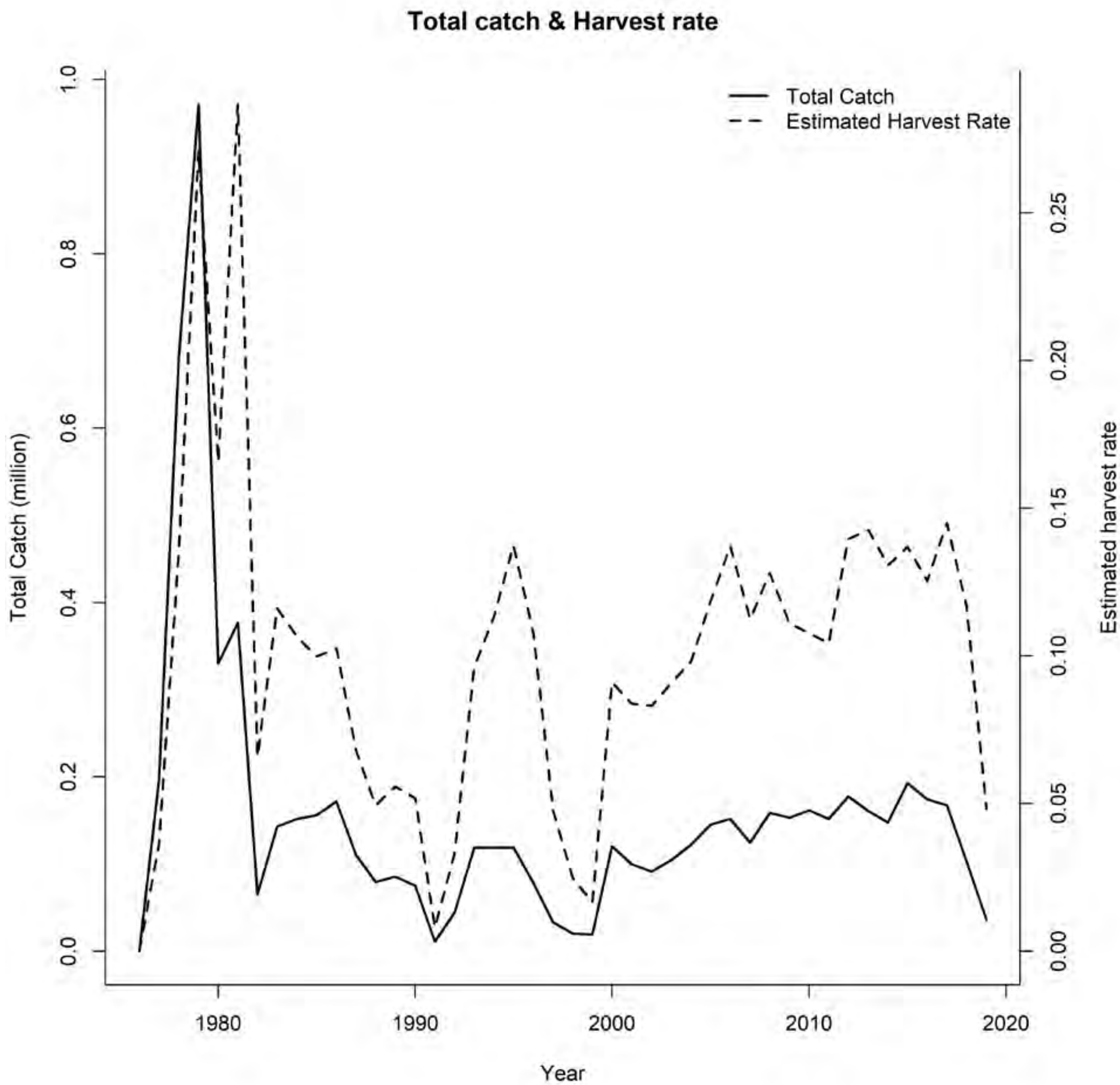


Figure C8-8. Total catch and estimated harvest rate.

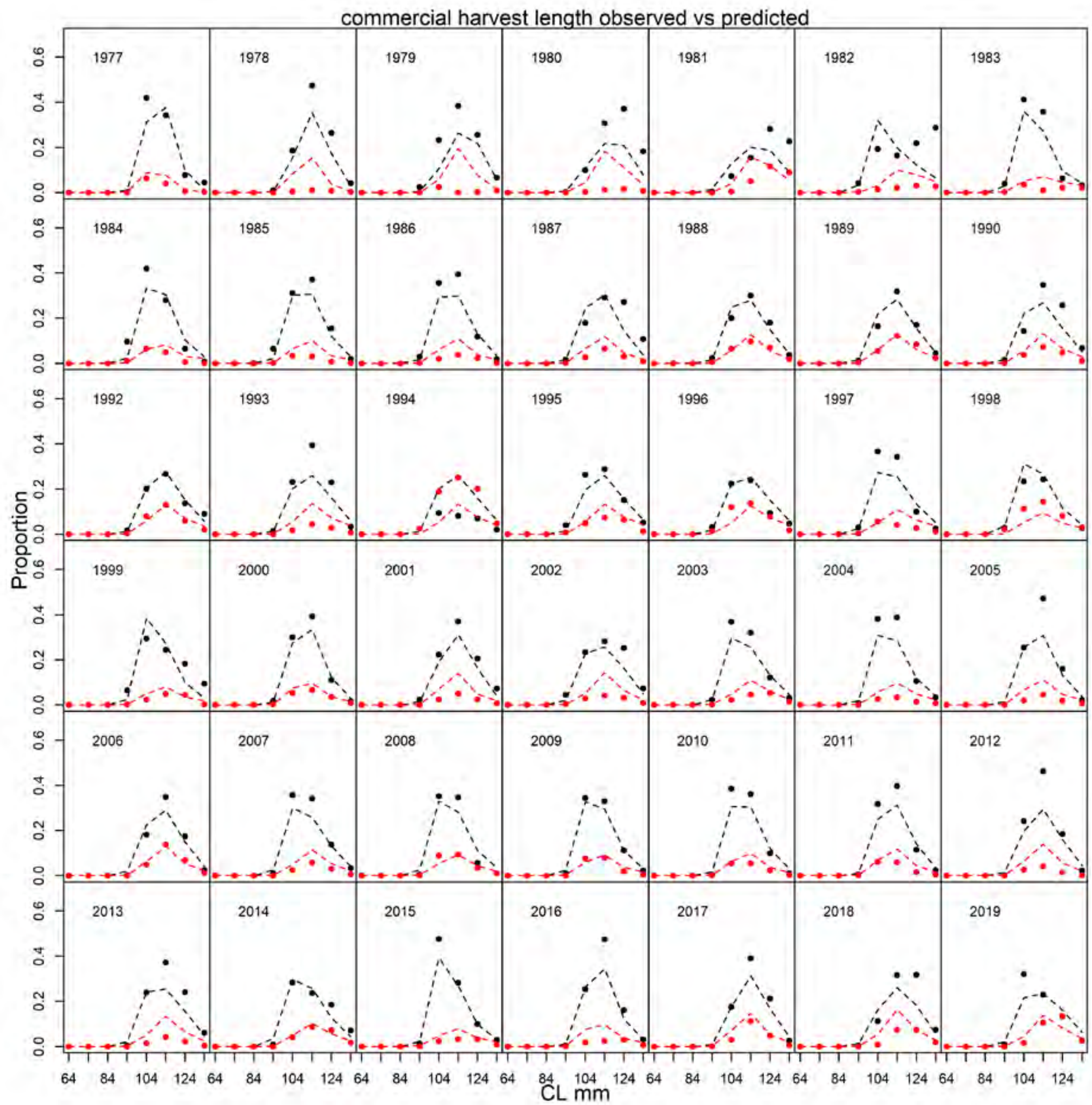


Figure C8-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Bladk: newshell, Red: oldshell

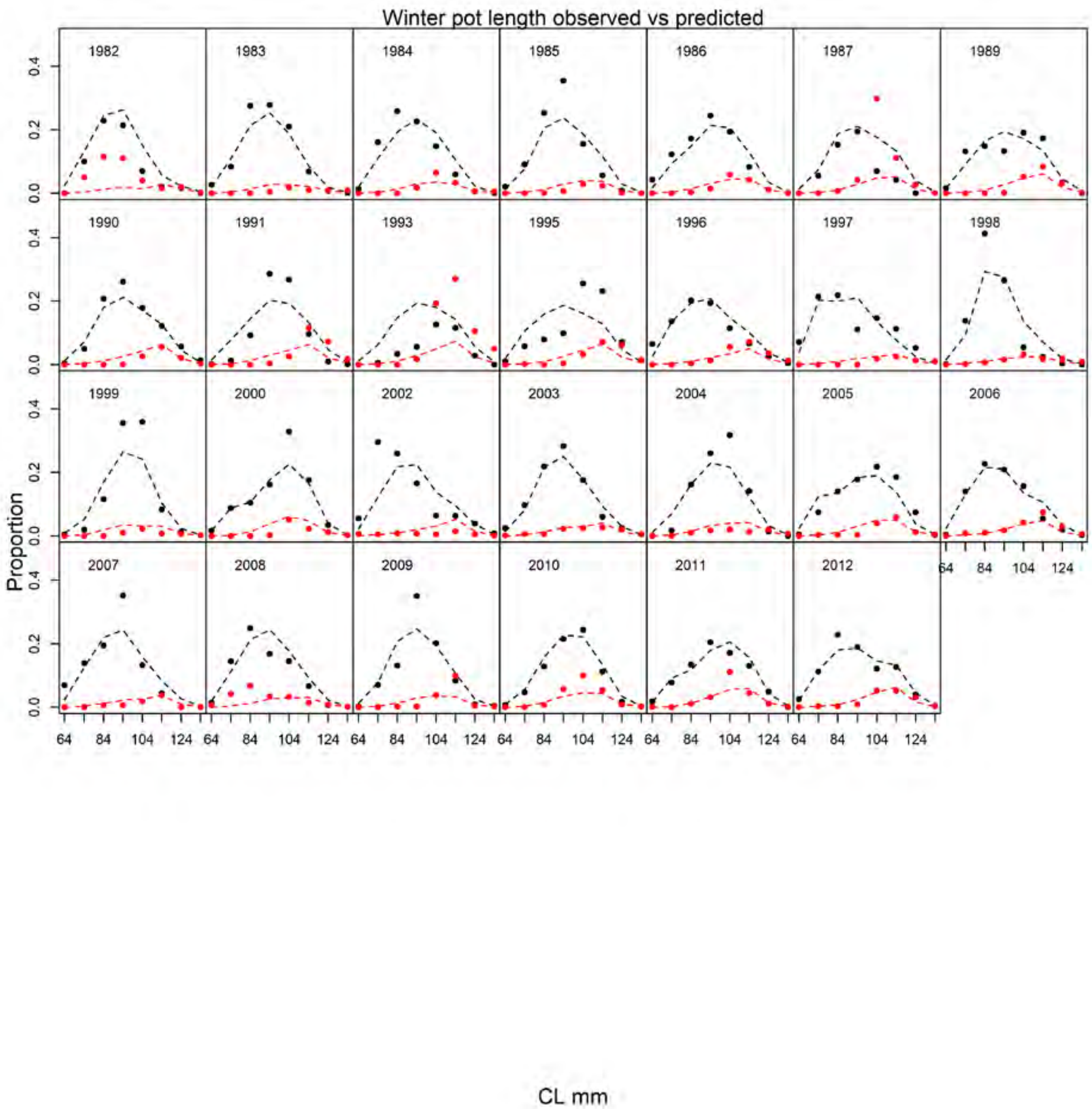


Figure C8-10. Predicted (dashed) vs. observed (dots) length class proportions for the winter pot survey. Black: newsehll, Red: oldshell

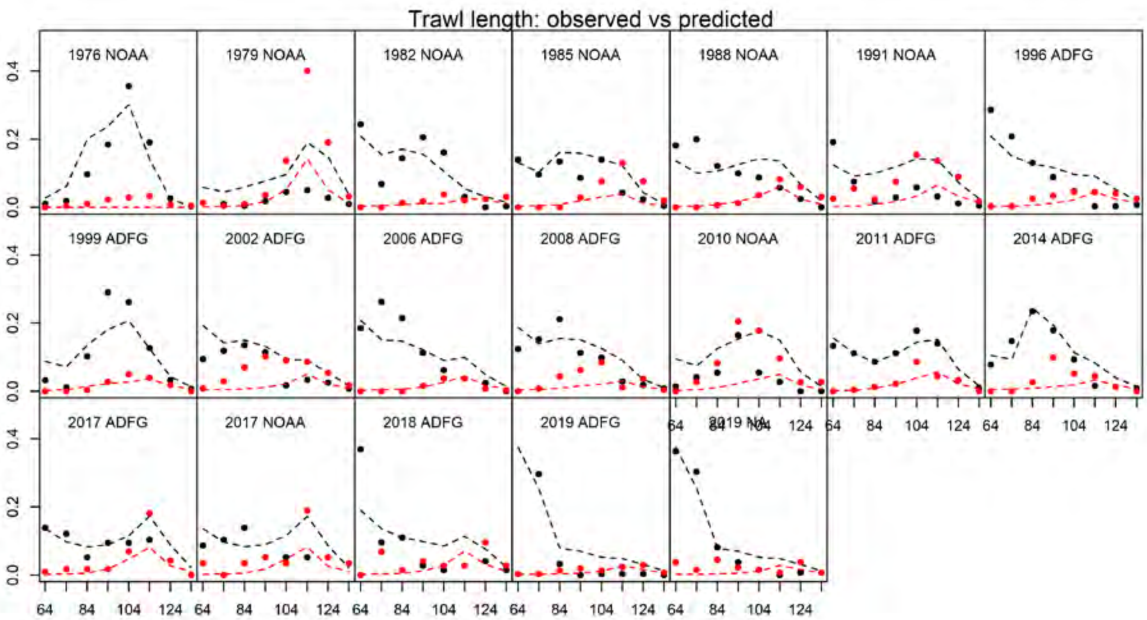


Figure C8-11. Predicted (dashed) vs. observed (dots) length class proportions for trawl survey. Black: newshell, Red: oldshell

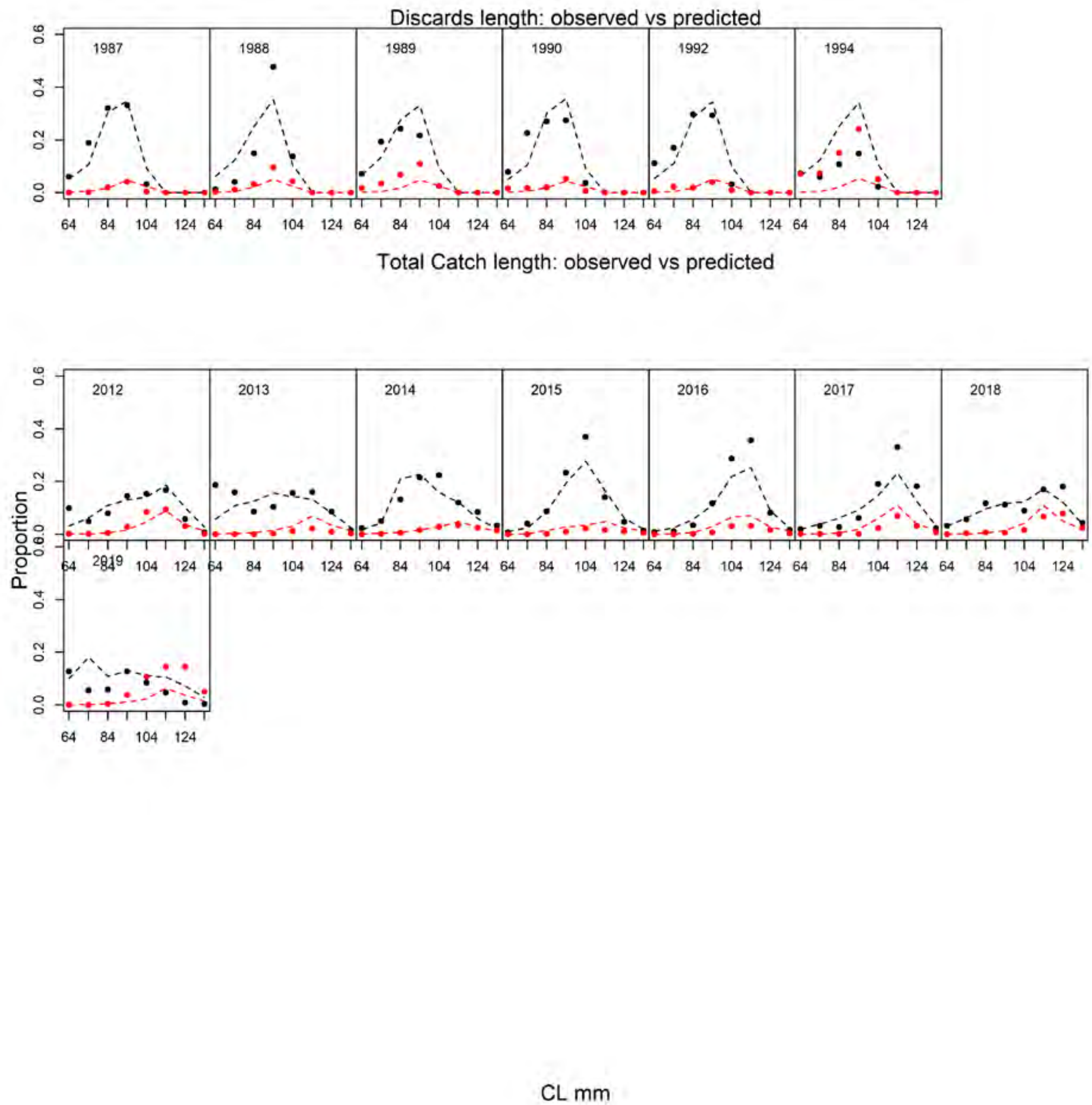


Figure C8-13. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newsehll, Red: oldshell

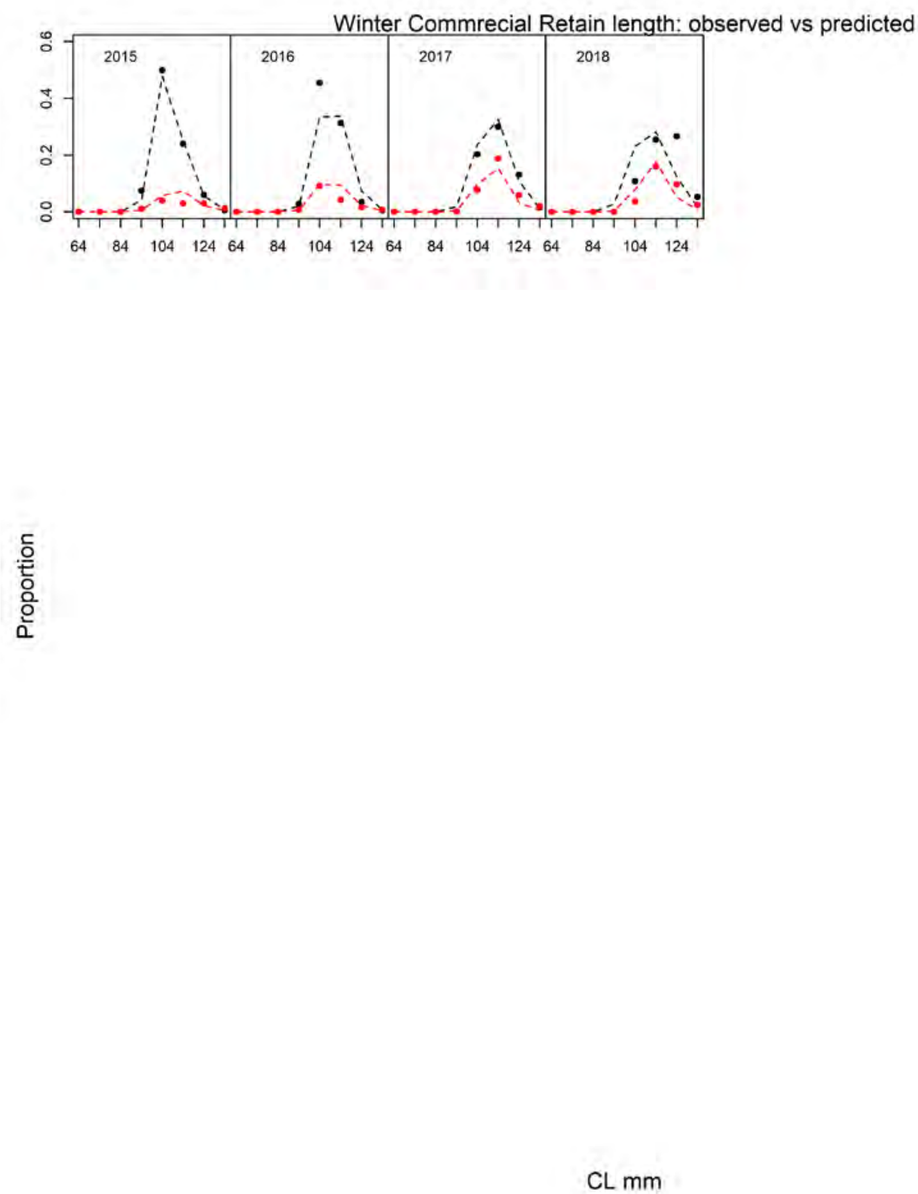


Figure C8-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

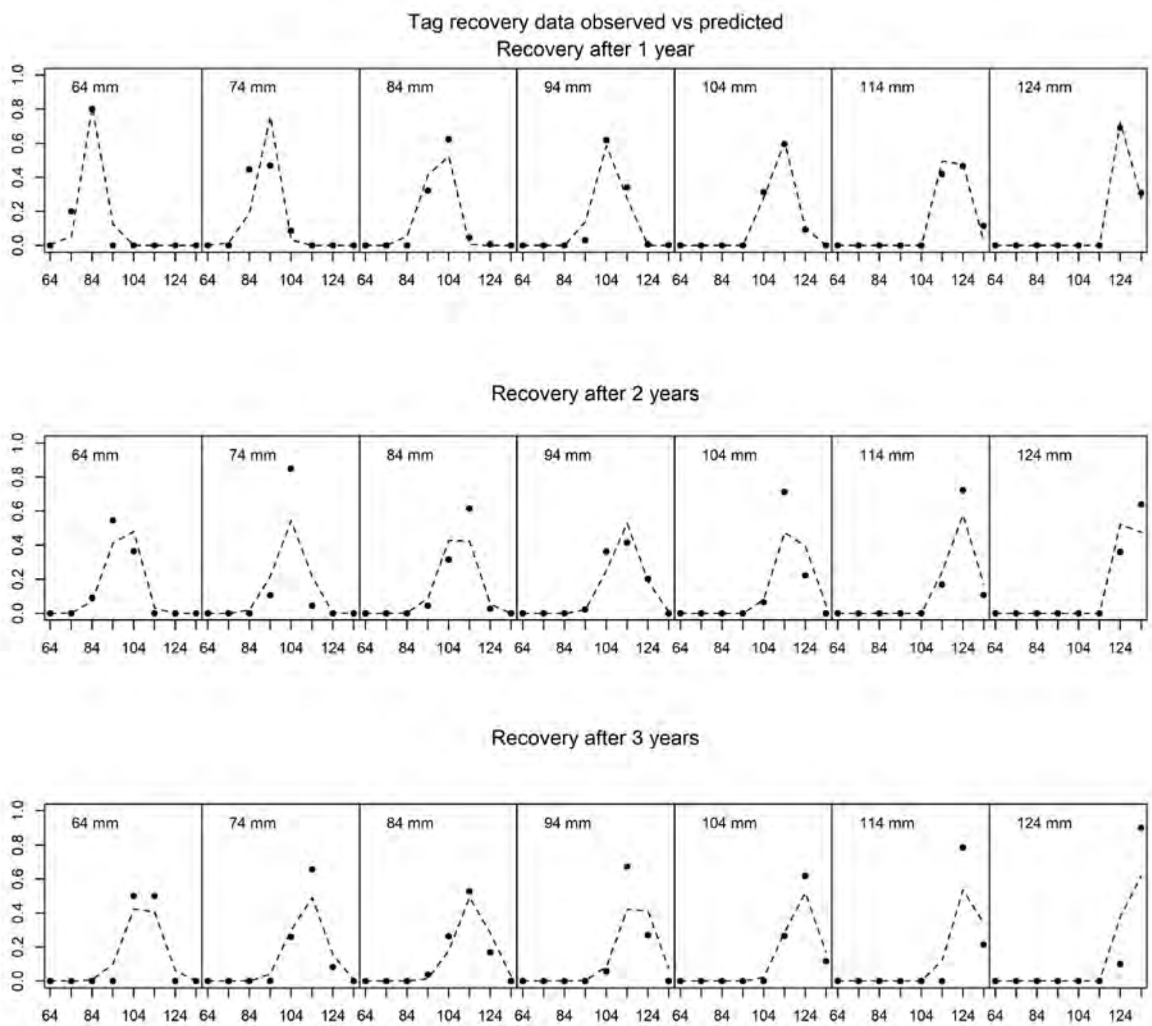


Figure C8-13. Predicted vs. observed length class proportions for tag recovery data.

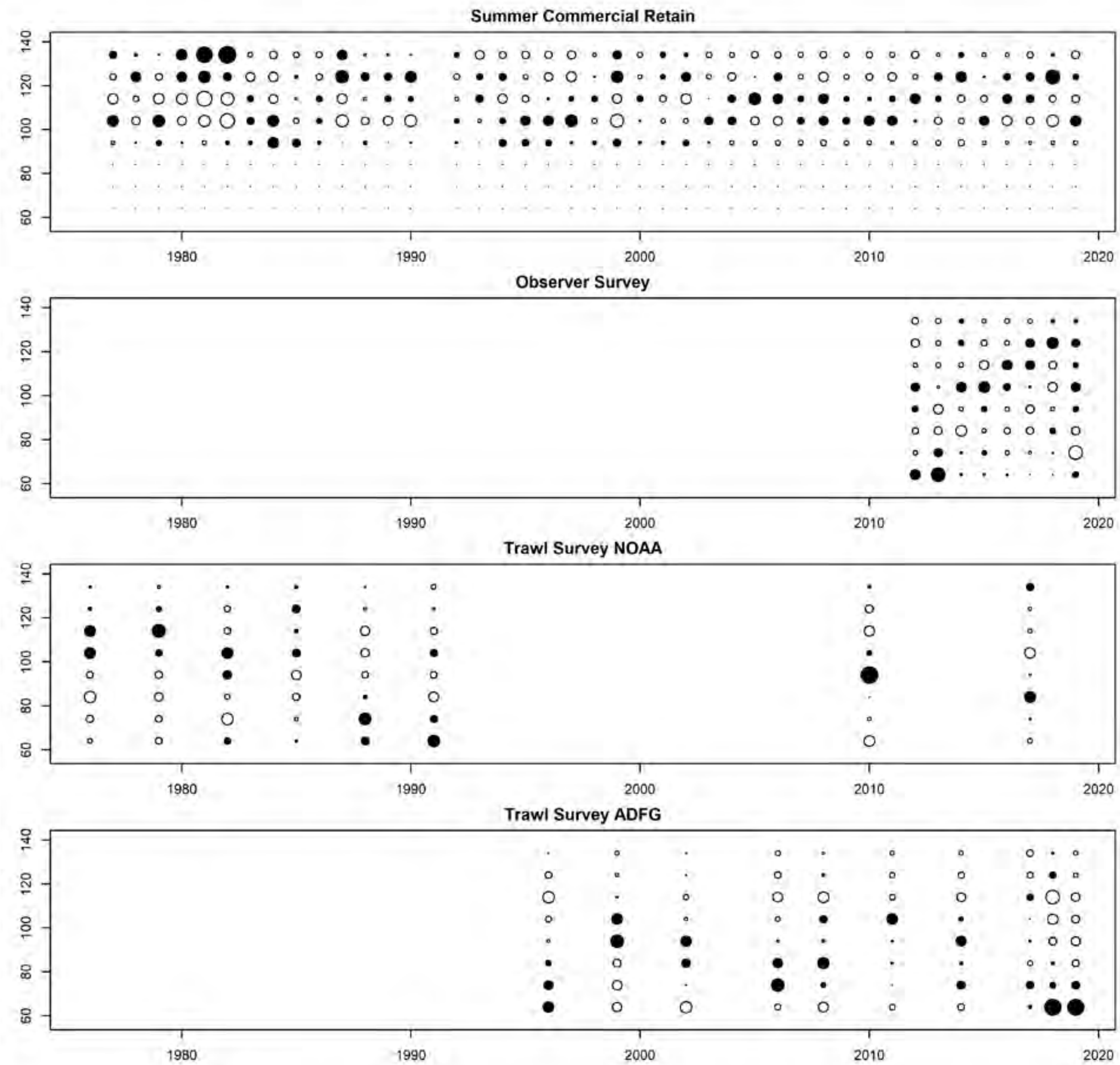


Figure C8-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

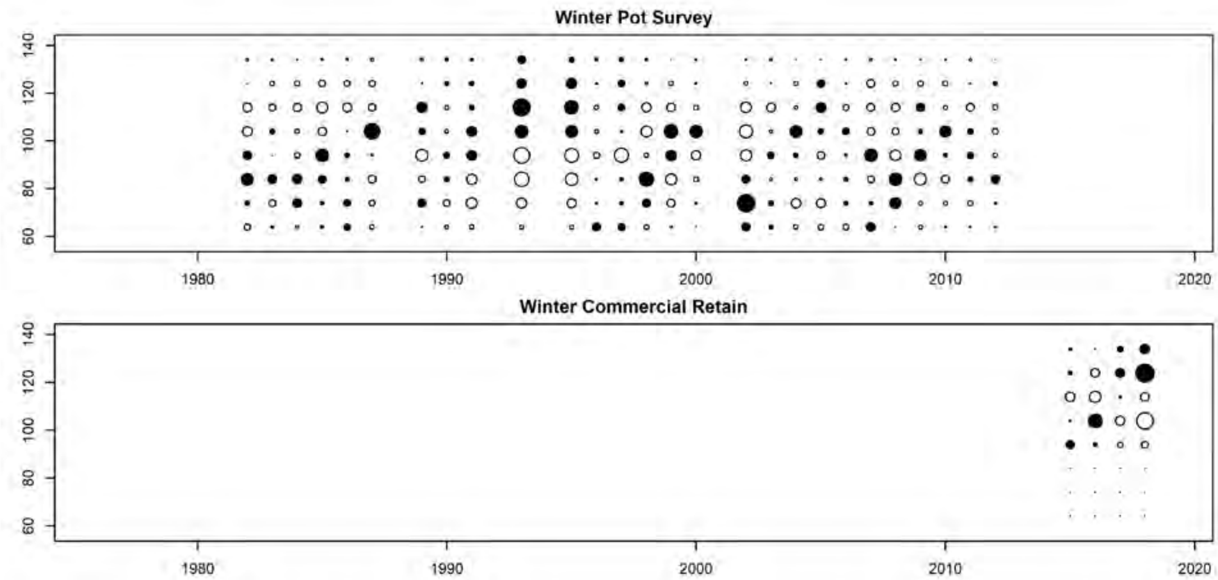


Figure C8-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table C8. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.768	0.110
log_q_2		
log_N_{76}	9.113	0.108
R_0	6.462	0.081
a_1	1.903	4.455
a_2	2.722	4.207
a_3	3.896	4.024
a_4	4.071	4.008
a_5	4.305	3.997
a_6	3.545	4.026
a_7	2.060	4.297
r1	10.000	0.270
r2	9.578	0.322
log_a	-2.682	0.089
log_b	4.831	0.015
log_ϕ_{st1}	-5.000	0.048
log_ϕ_{wa}	-2.220	0.269
log_ϕ_{wb}	4.795	0.029
Sw1	0.069	0.034
Sw2	0.510	0.121
log_ϕ_l	-2.067	0.052
$log\_\phi ra$	-0.787	0.129
$log\_\phi rb$	4.646	0.008
$log\_\phi wra$	-0.954	0.536
$log\_\phi wrb$	4.656	0.037
w^2_t	0.000	0.000
q	0.710	0.114
σ	3.853	0.209
β_1	12.196	0.704
β_2	7.713	0.173
ms78	3.226	0.252

Appendix D - Model 19.1

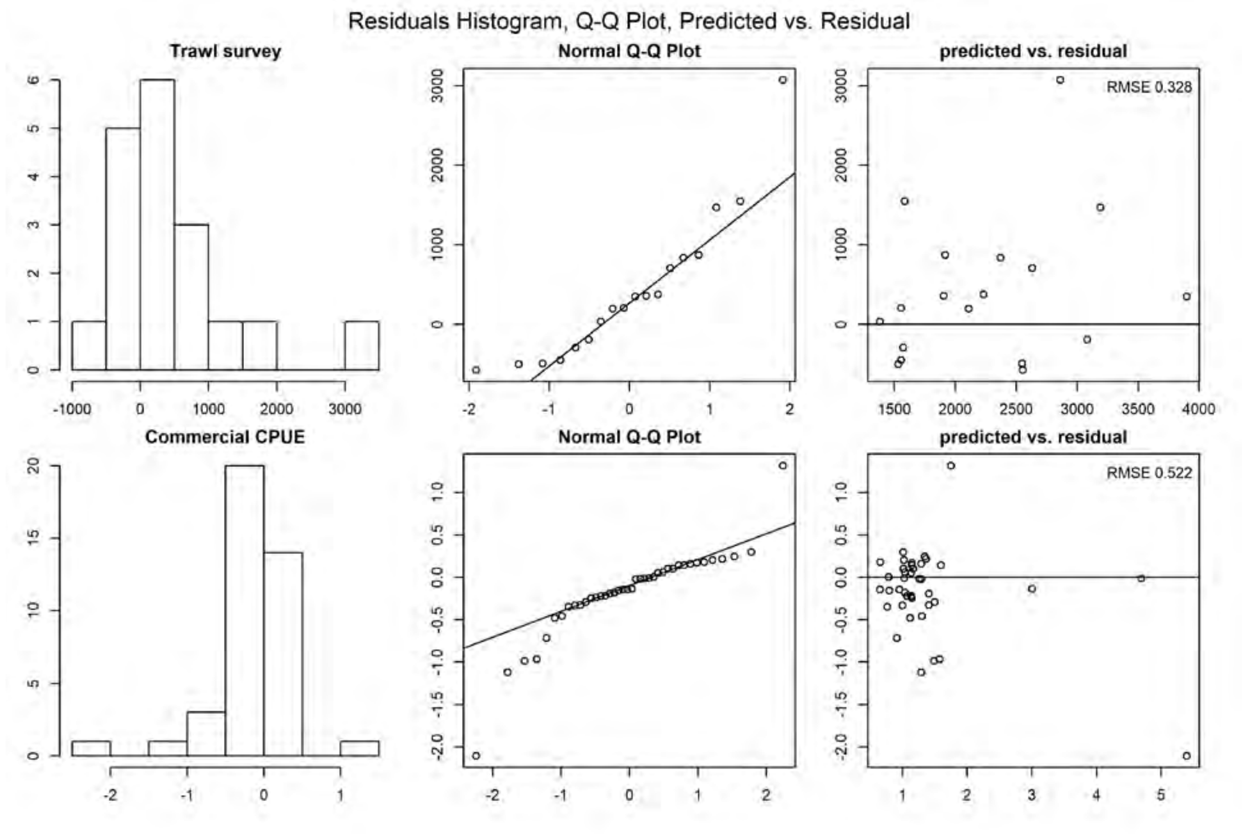


Figure D2-1. QQ Plot of Trawl survey and commercial CPUE.

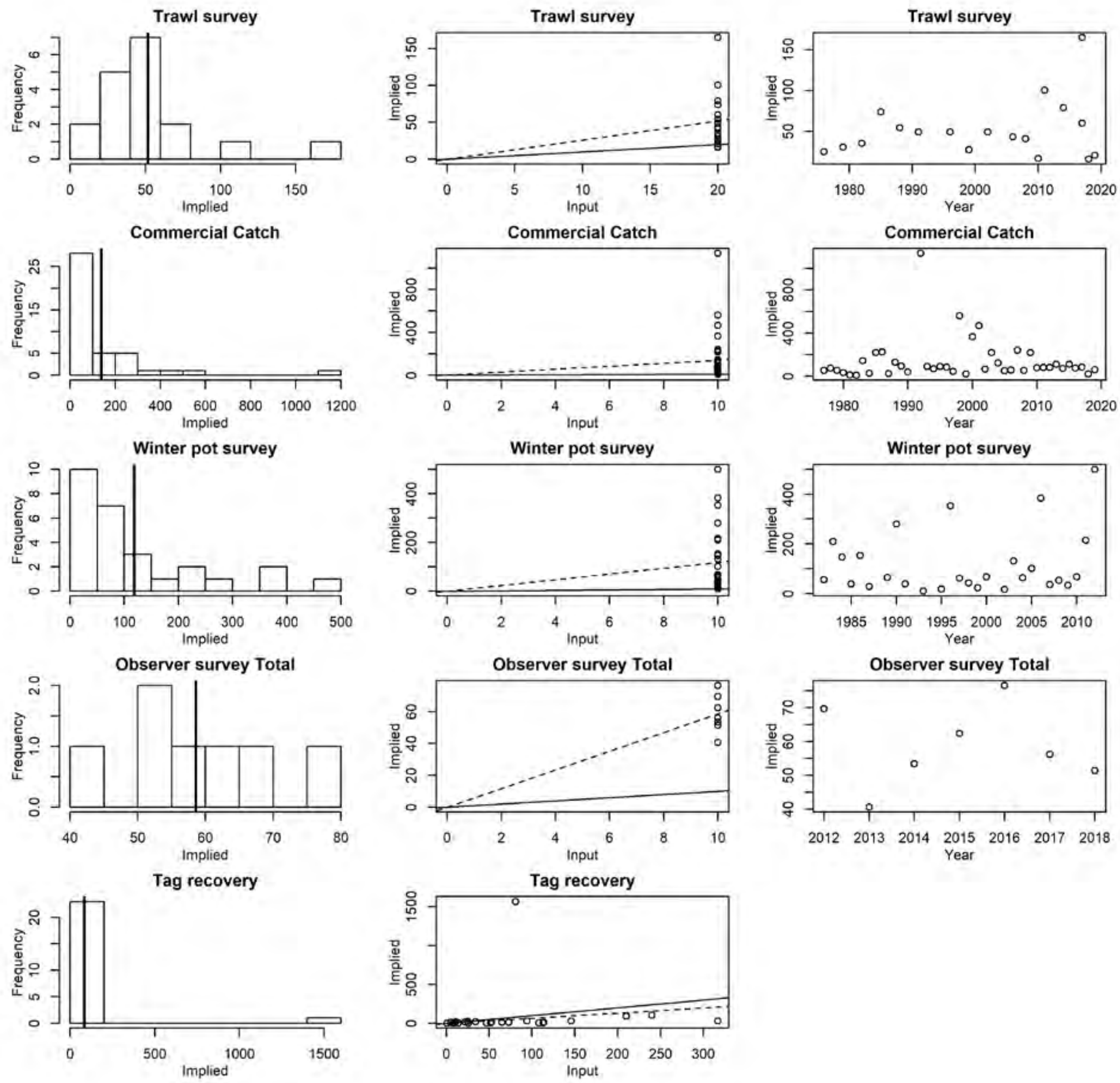


Figure D2-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column shows input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

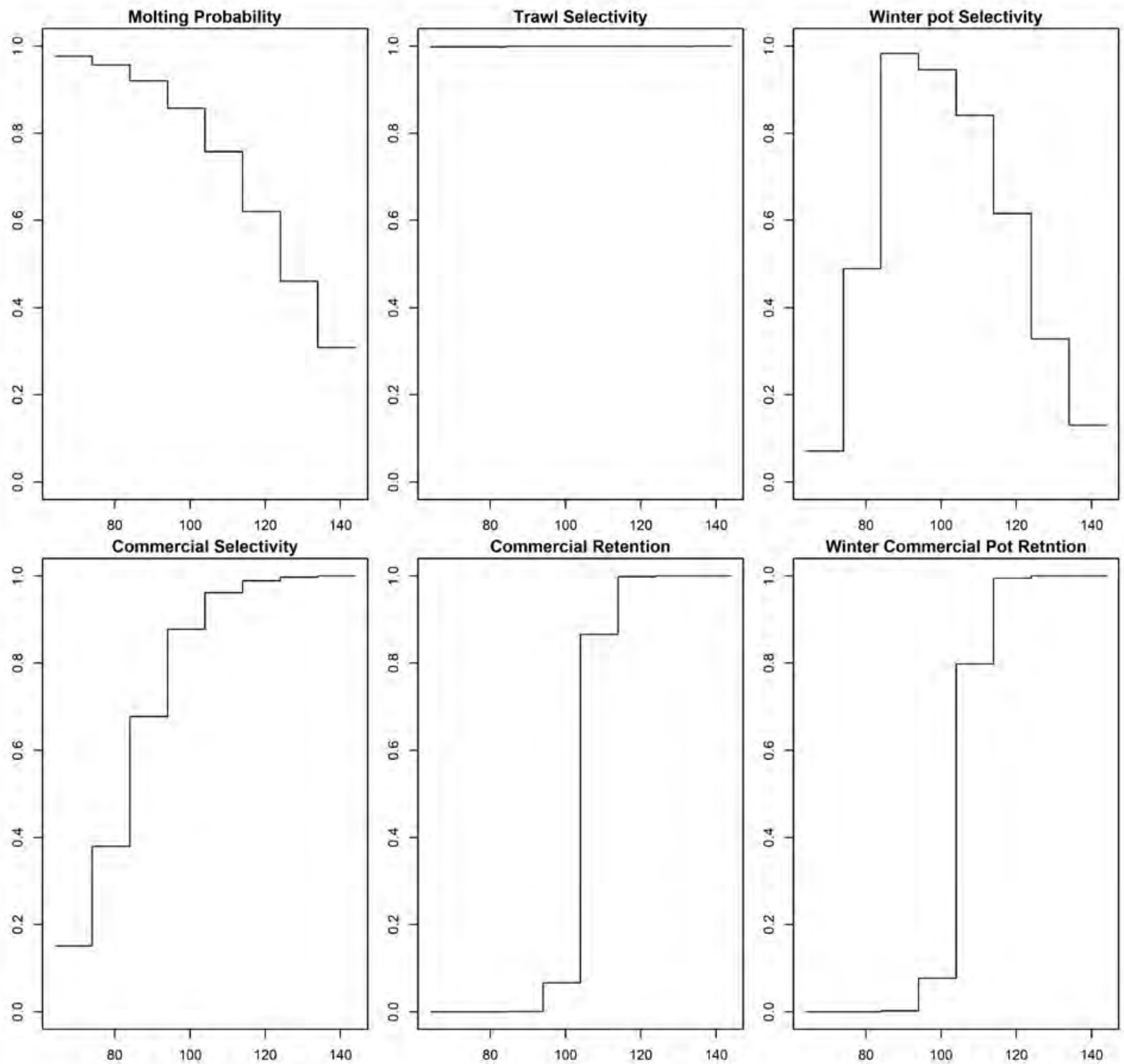


Figure D2-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

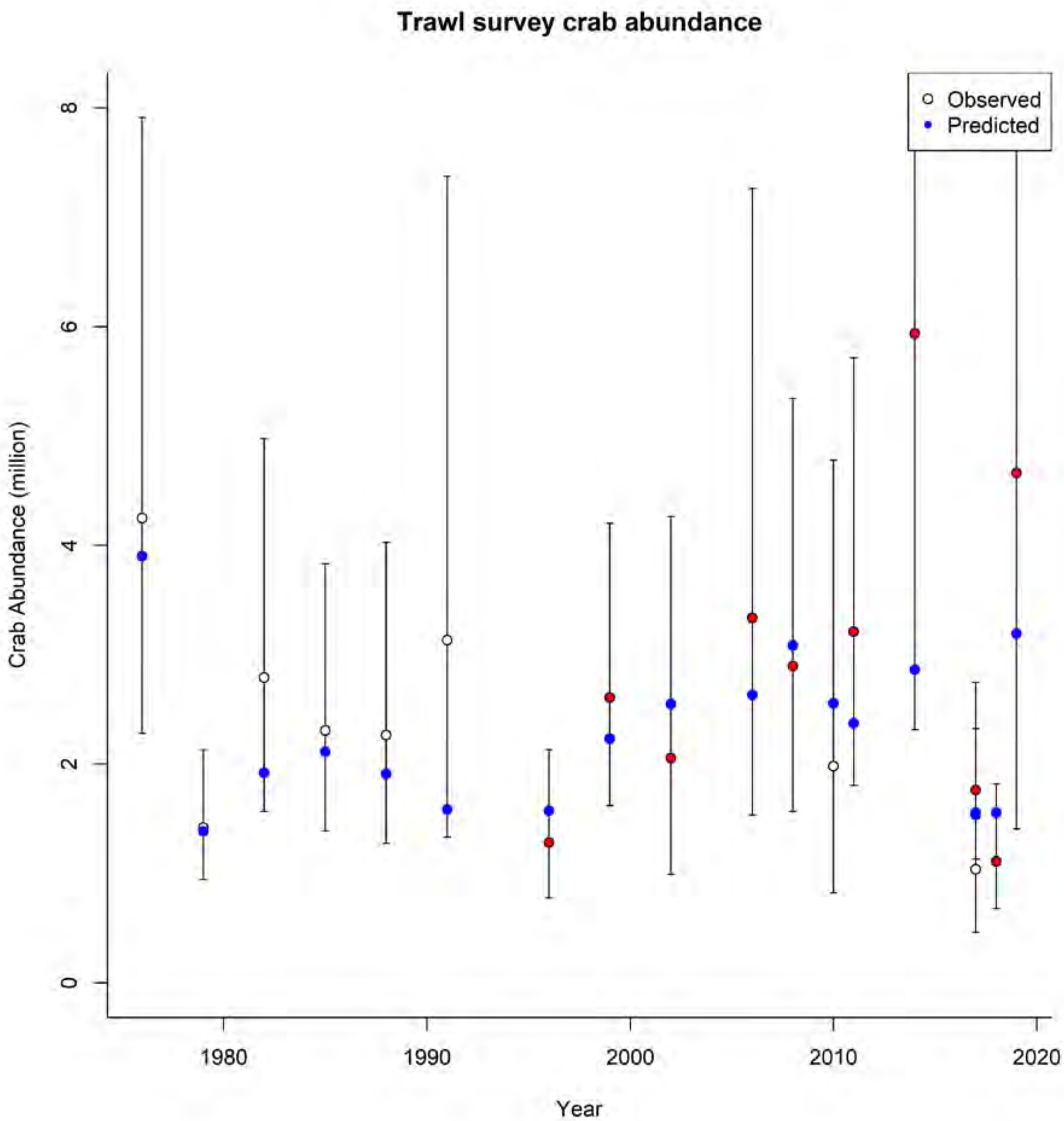


Figure D2-4. Estimated trawl survey male abundance (blue) (crab >= 64 mm CL). Observed: White: NOAA trawl survey, Red: ADG&G trawl survey

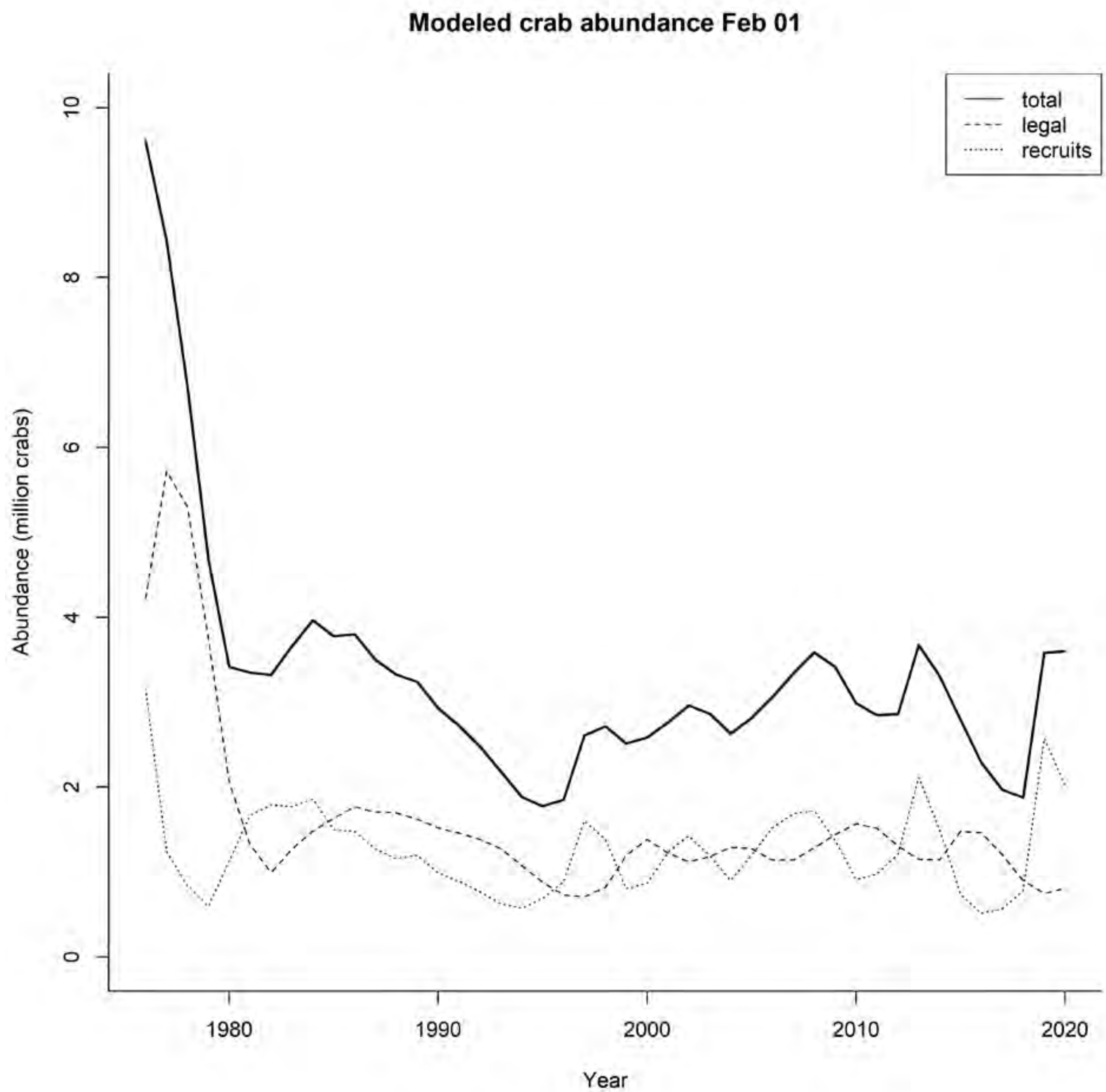


Figure D2-5. Estimated abundance of legal males.

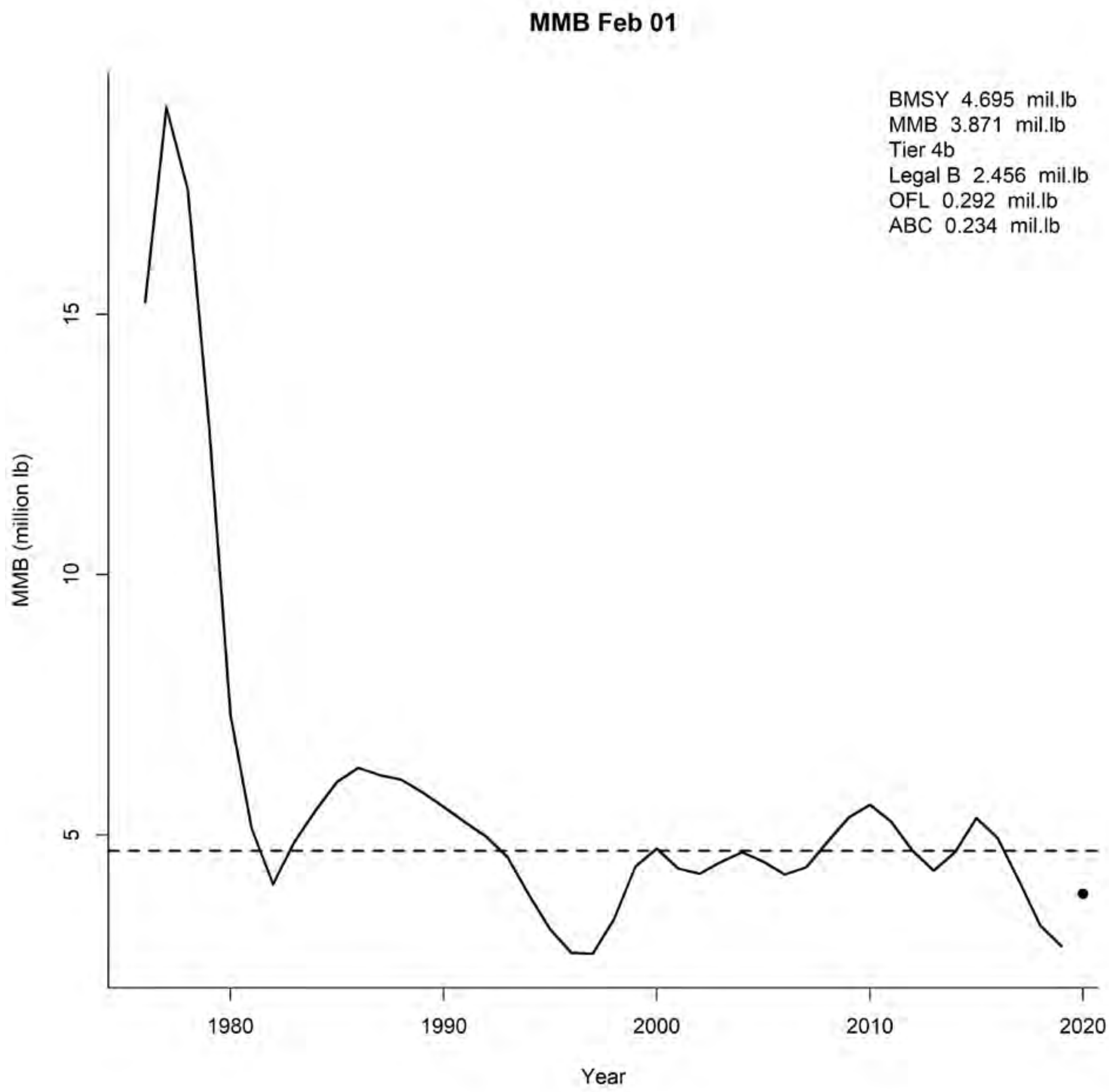


Figure D2-6. Estimated abundance of Mature Male Biomass. Dash line shows Bmsy.

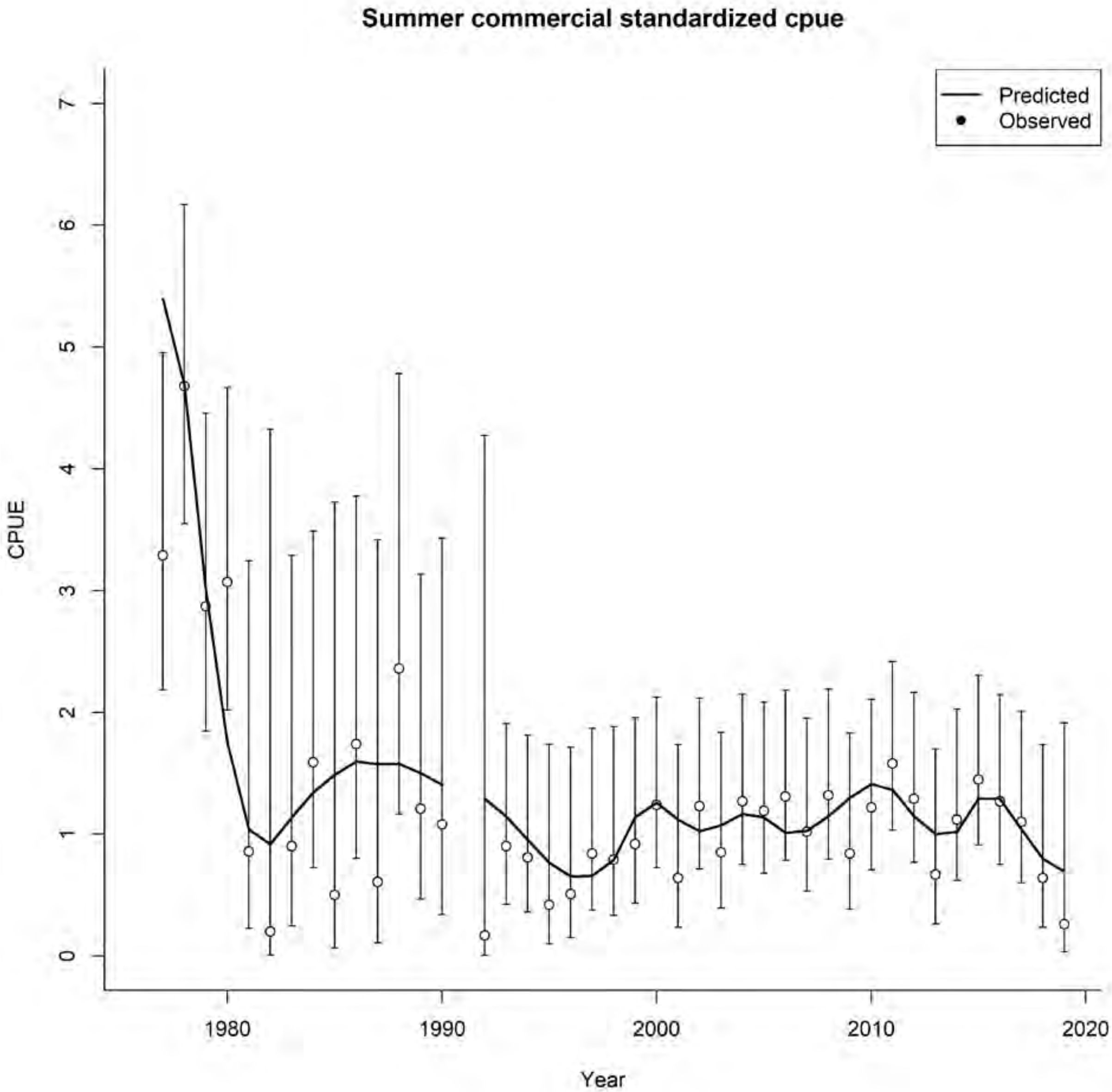


Figure D2-7. Summer commercial standardized cpue.

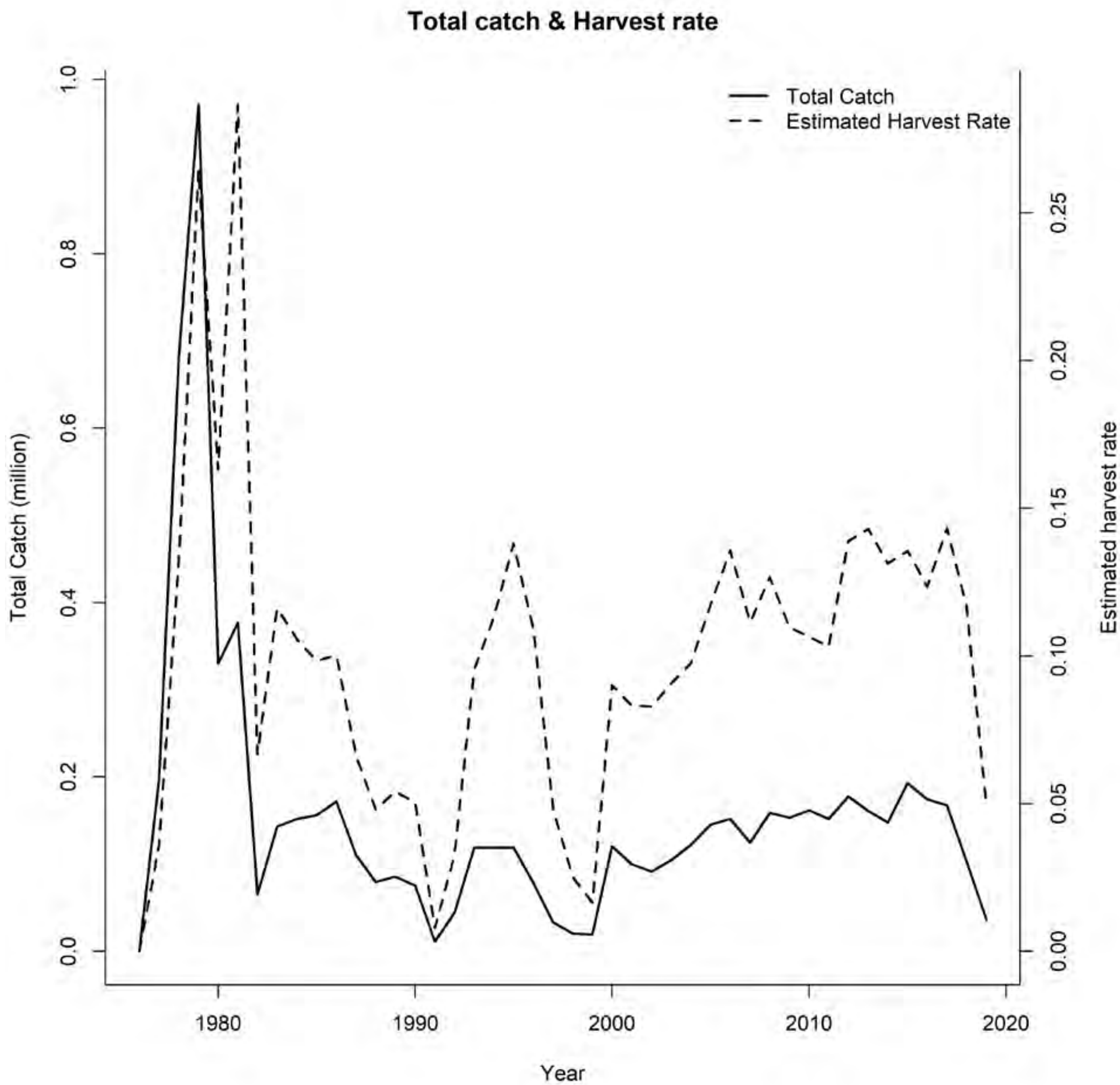


Figure D2-8. Total catch and estimated harvest rate.

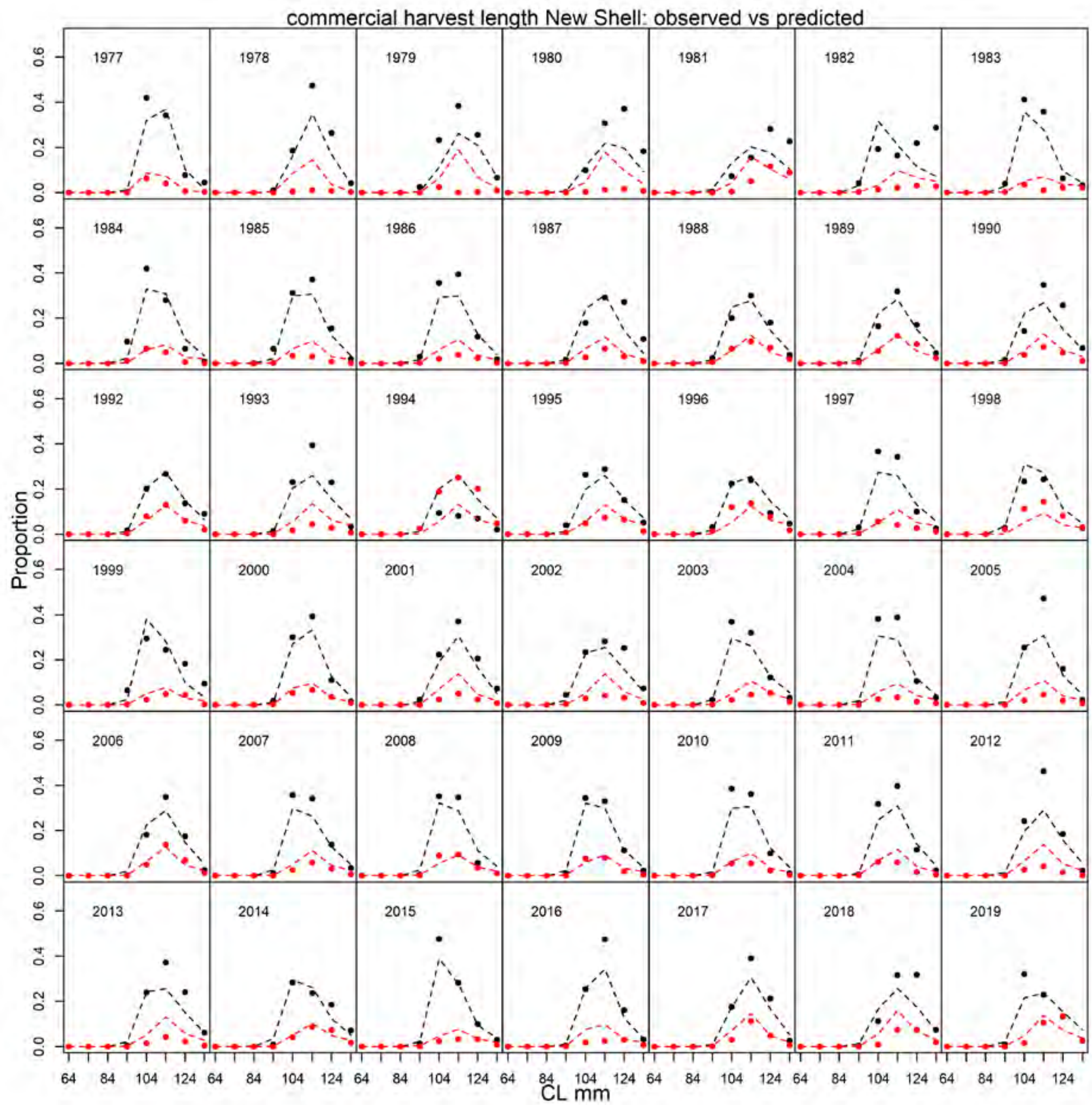


Figure D2-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Black: newshell, Red: oldshell

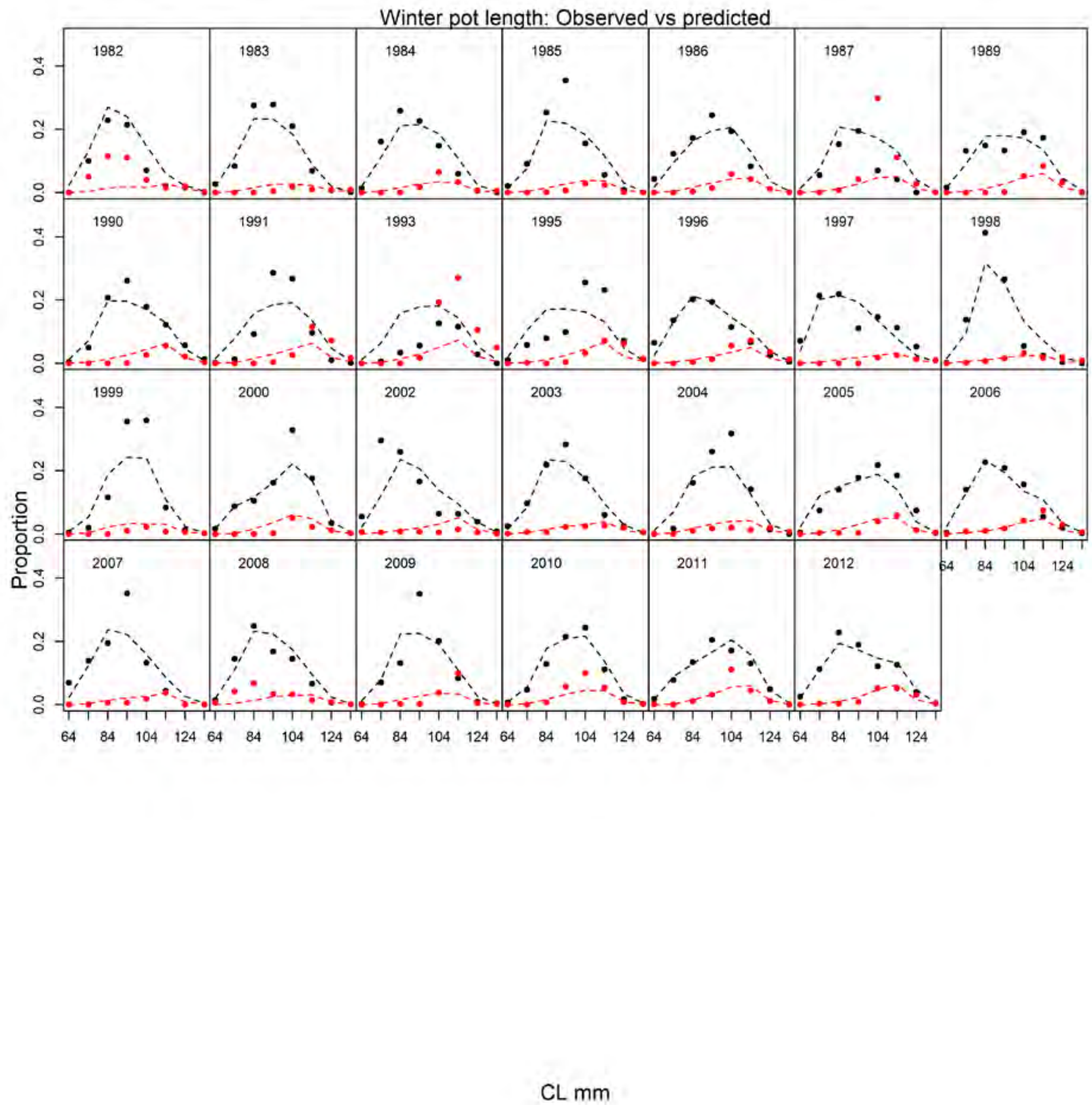


Figure D2-10. Predicted (dashed line) vs. observed (dots) length class proportions for the winter and spring pot survey. Black: newshell, Red: oldshell

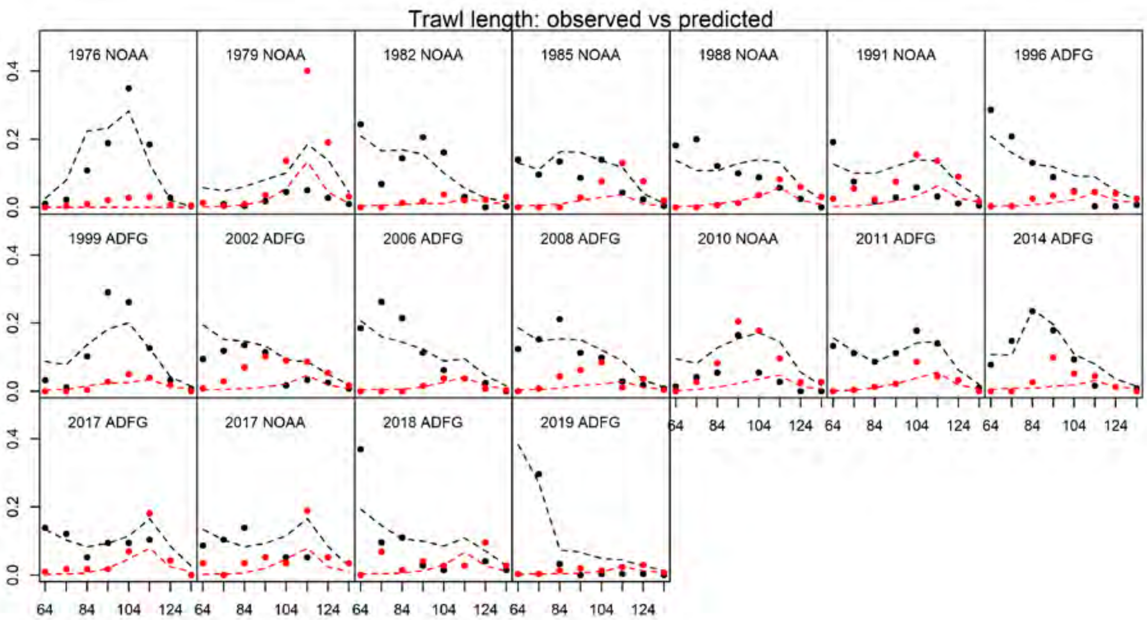


Figure D2-11. Predicted (dashed) vs. observed (dots) length class proportions for trawl survey.
Black: newshell, Red: oldshell

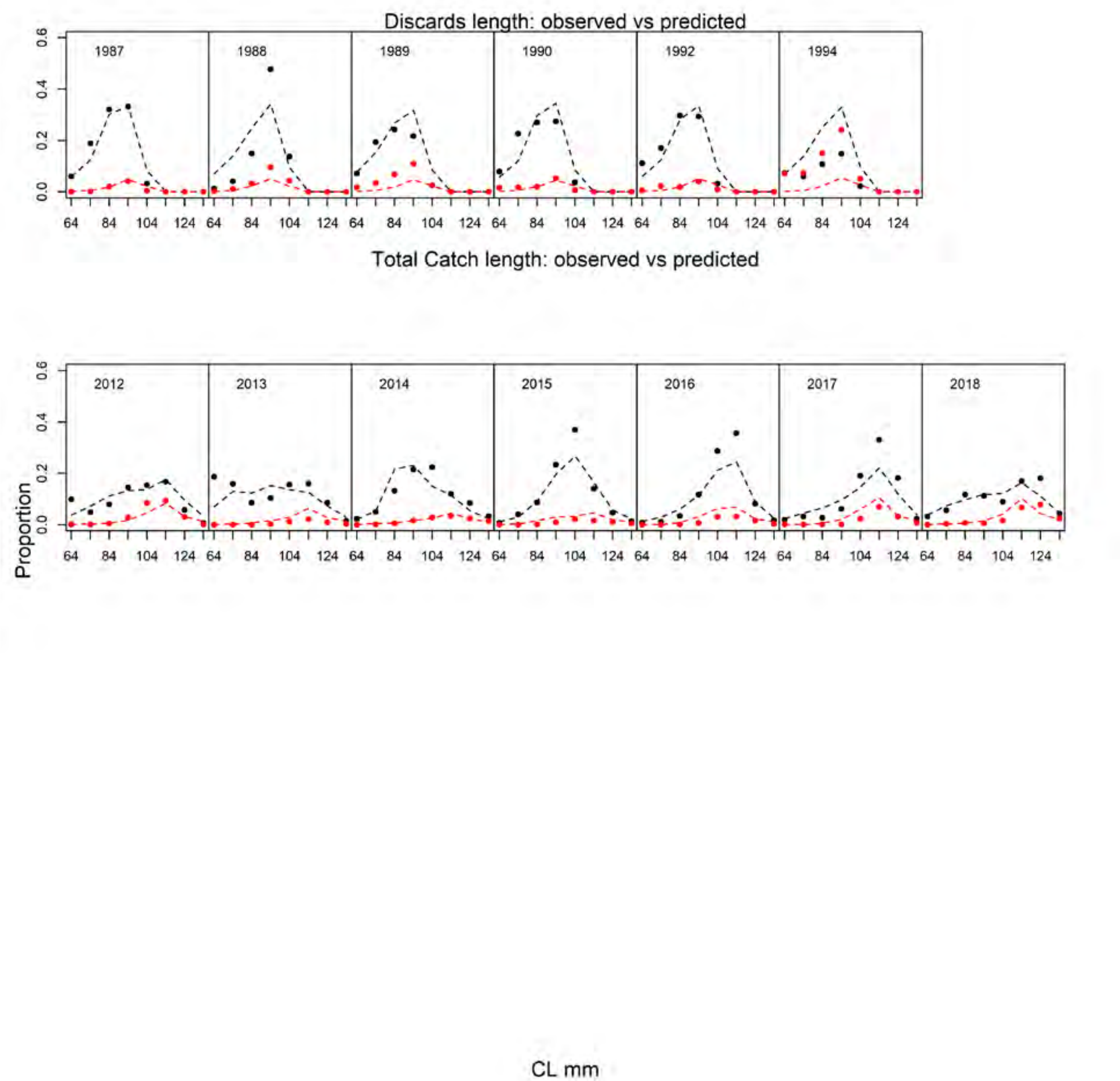


Figure D2-13. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

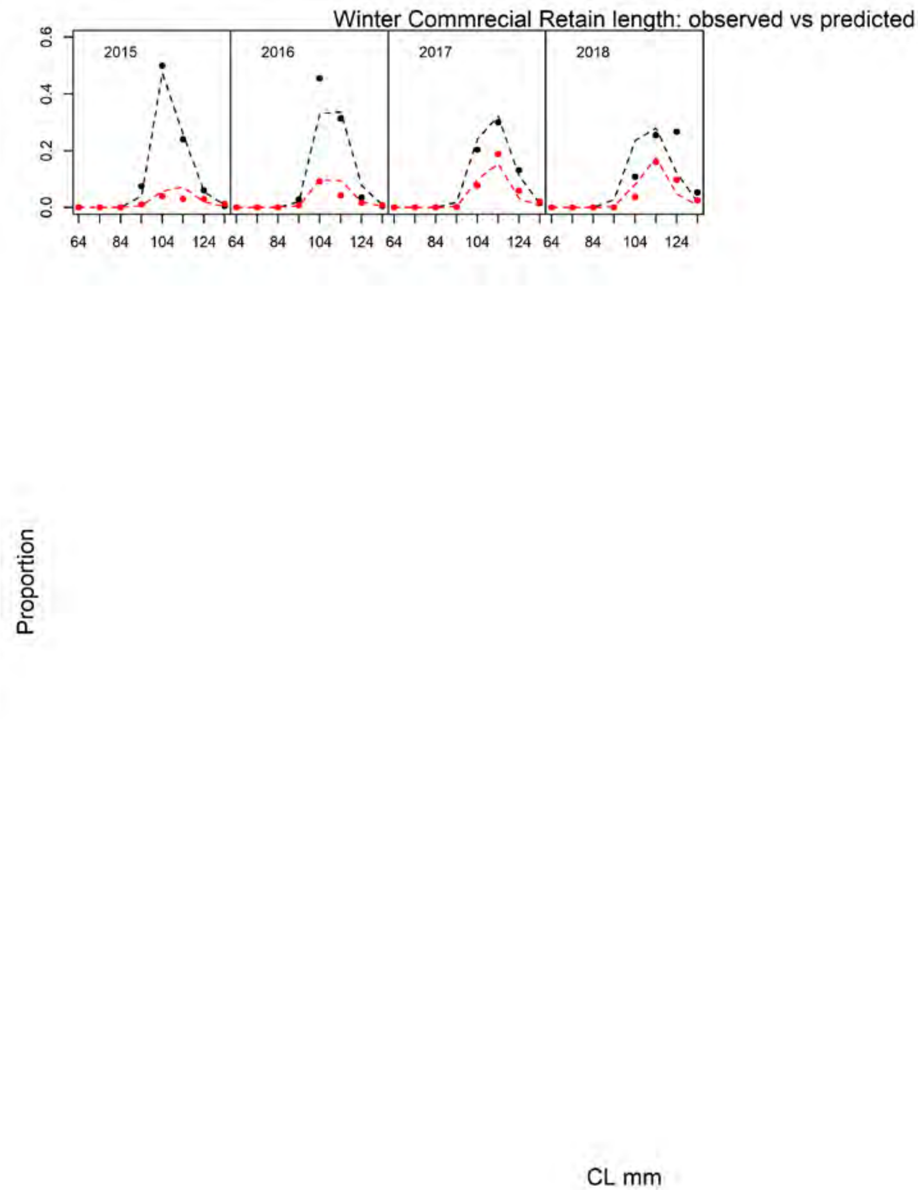


Figure D2-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

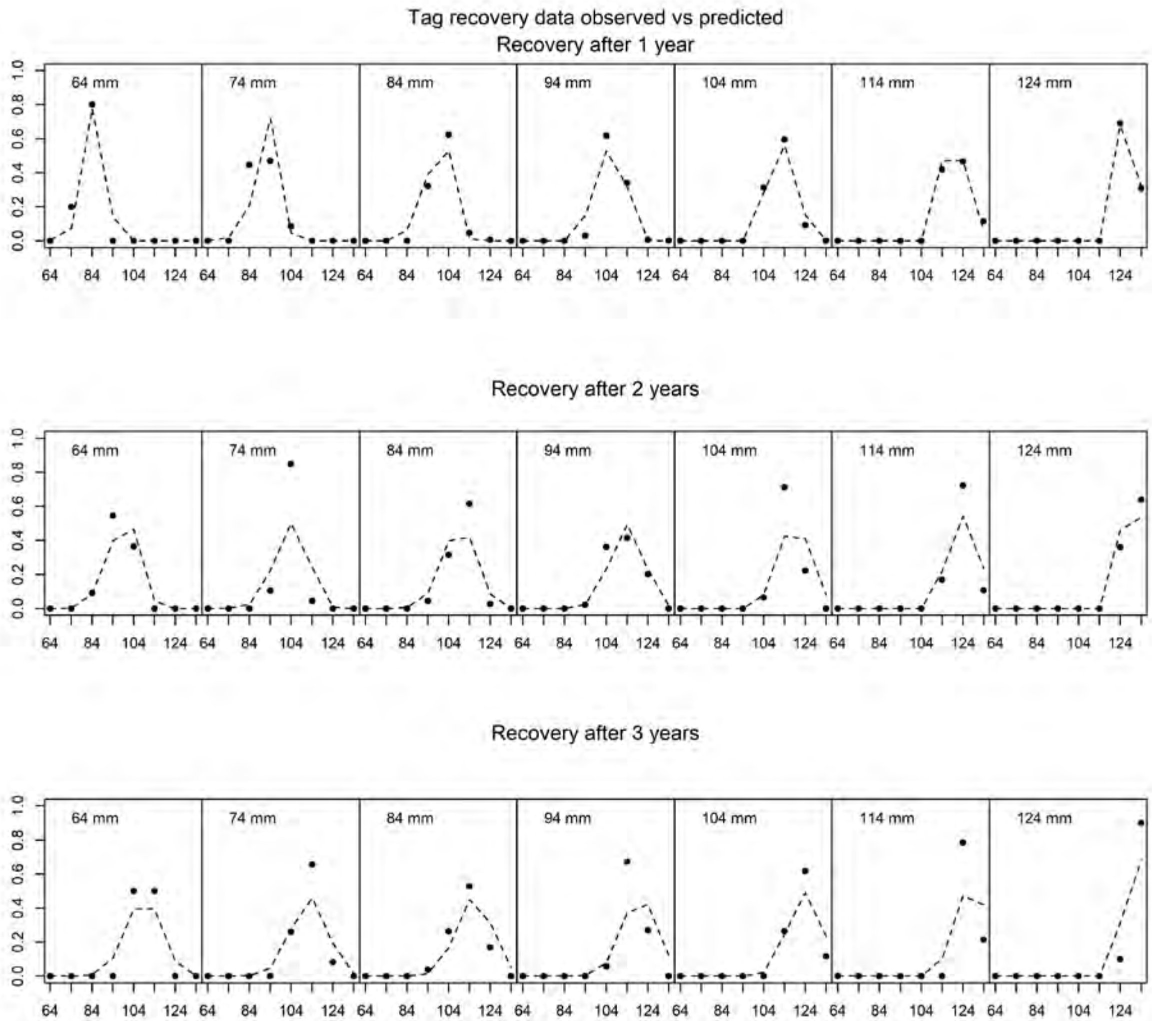


Figure D2-13. Predicted vs. observed length class proportions for tag recovery data.

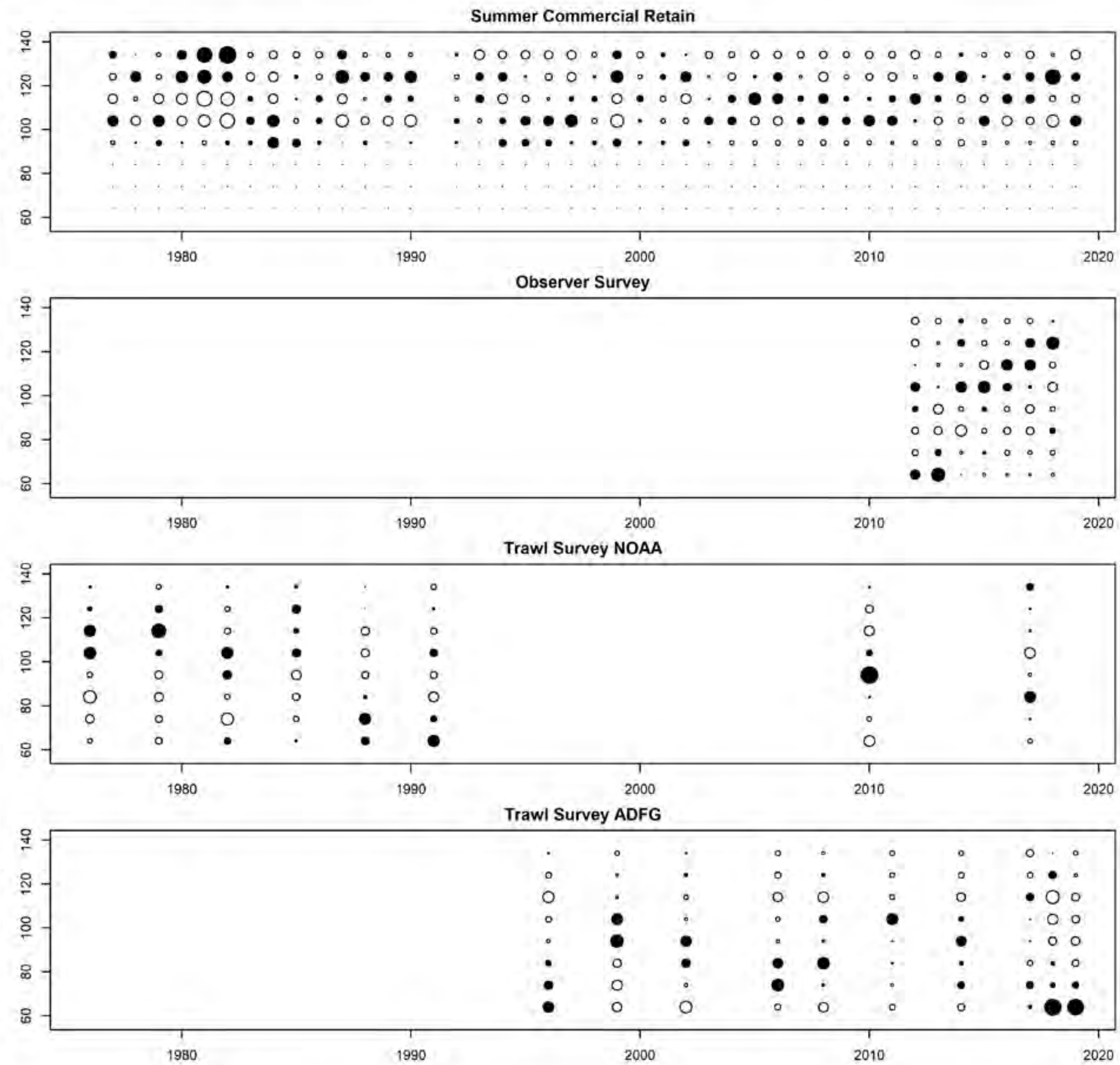


Figure D2-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

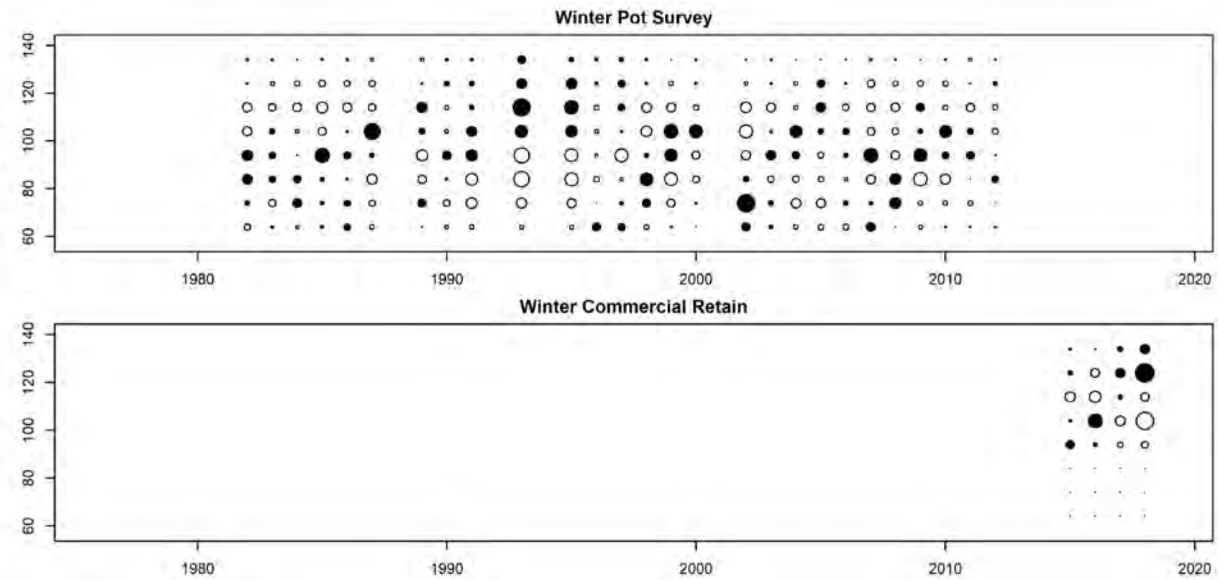


Figure D2-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table D2. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.775	0.112
log_q_2		
log_N_{76}	9.171	0.112
R_0	6.526	0.084
a_1	2.214	5.073
a_2	3.308	4.774
a_3	4.334	4.654
a_4	4.373	4.646
a_5	4.566	4.637
a_6	3.777	4.663
a_7	2.265	4.871
r1	10.000	0.312
r2	9.616	0.362
log_a	-2.733	0.099
log_b	4.837	0.016
log_ϕ_{st1}	-5.000	0.080
log_ϕ_{wa}	-2.130	0.297
log_ϕ_{wb}	4.808	0.030
Sw1	0.071	0.034
Sw2	0.490	0.120
log_ϕ_{I}	-2.093	0.055
$log\_\phi ra$	-0.798	0.128
$log\_\phi rb$	4.648	0.008
$log\_\phi wra$	-0.953	0.561
$log\_\phi wrb$	4.653	0.038
w^2_t	0.000	0.000
q	0.677	0.109
σ	4.232	0.255
β_1	11.829	0.926
β_2	7.919	0.221
ms78	3.554	0.280

Appendix D - Model 19.2

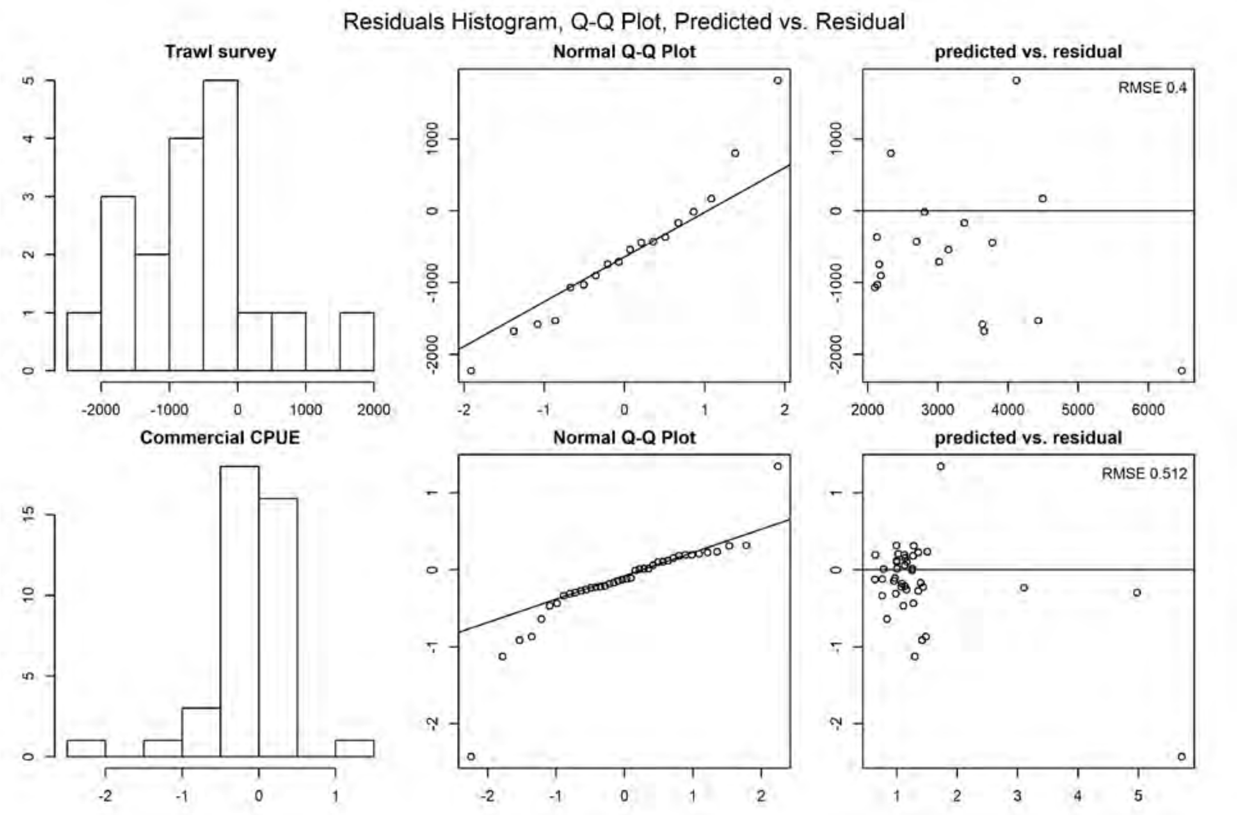


Figure D3-1. QQ Plot of Trawl survey and commercial CPUE.

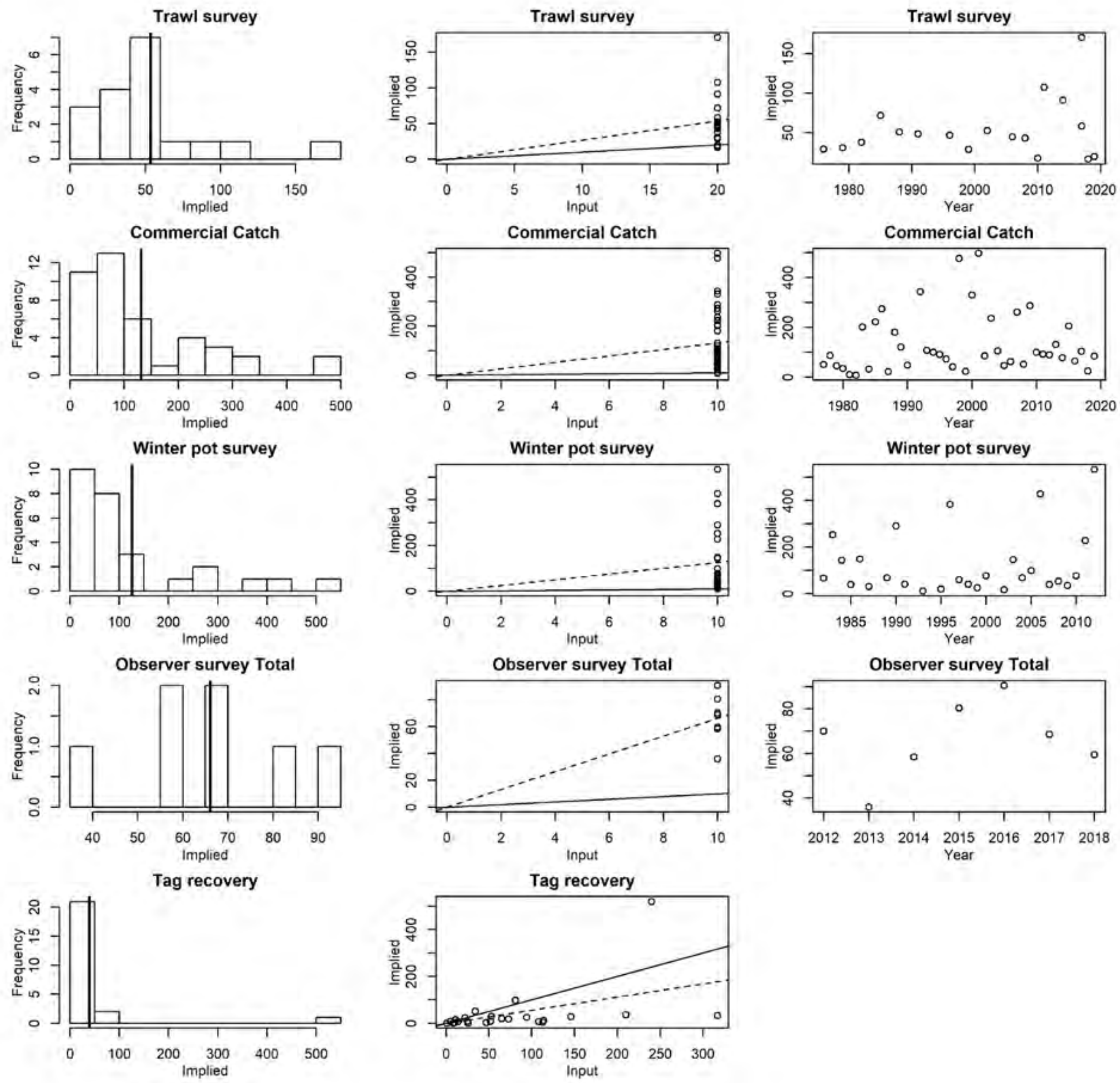


Figure D3-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column shows input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

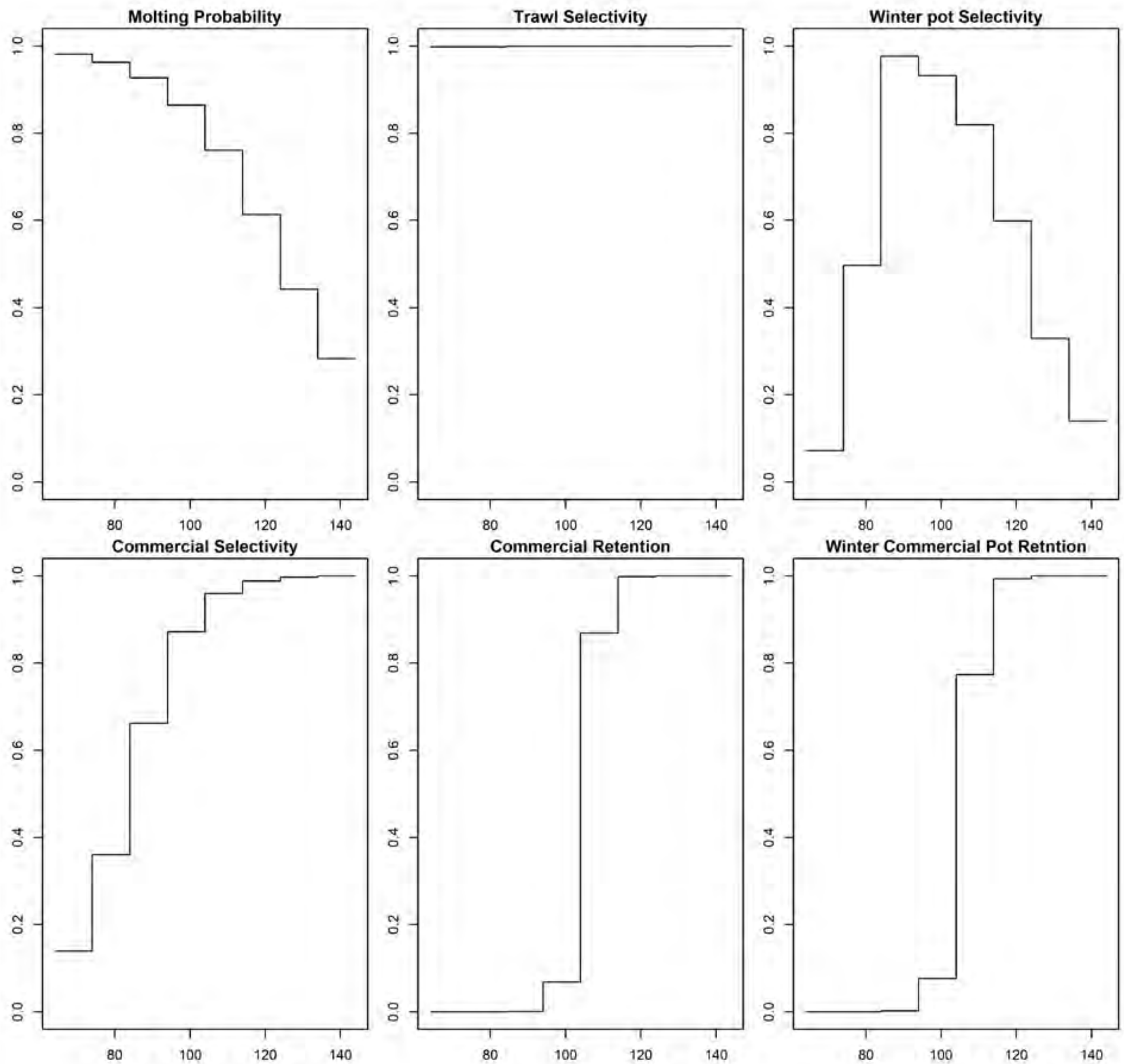


Figure D3-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

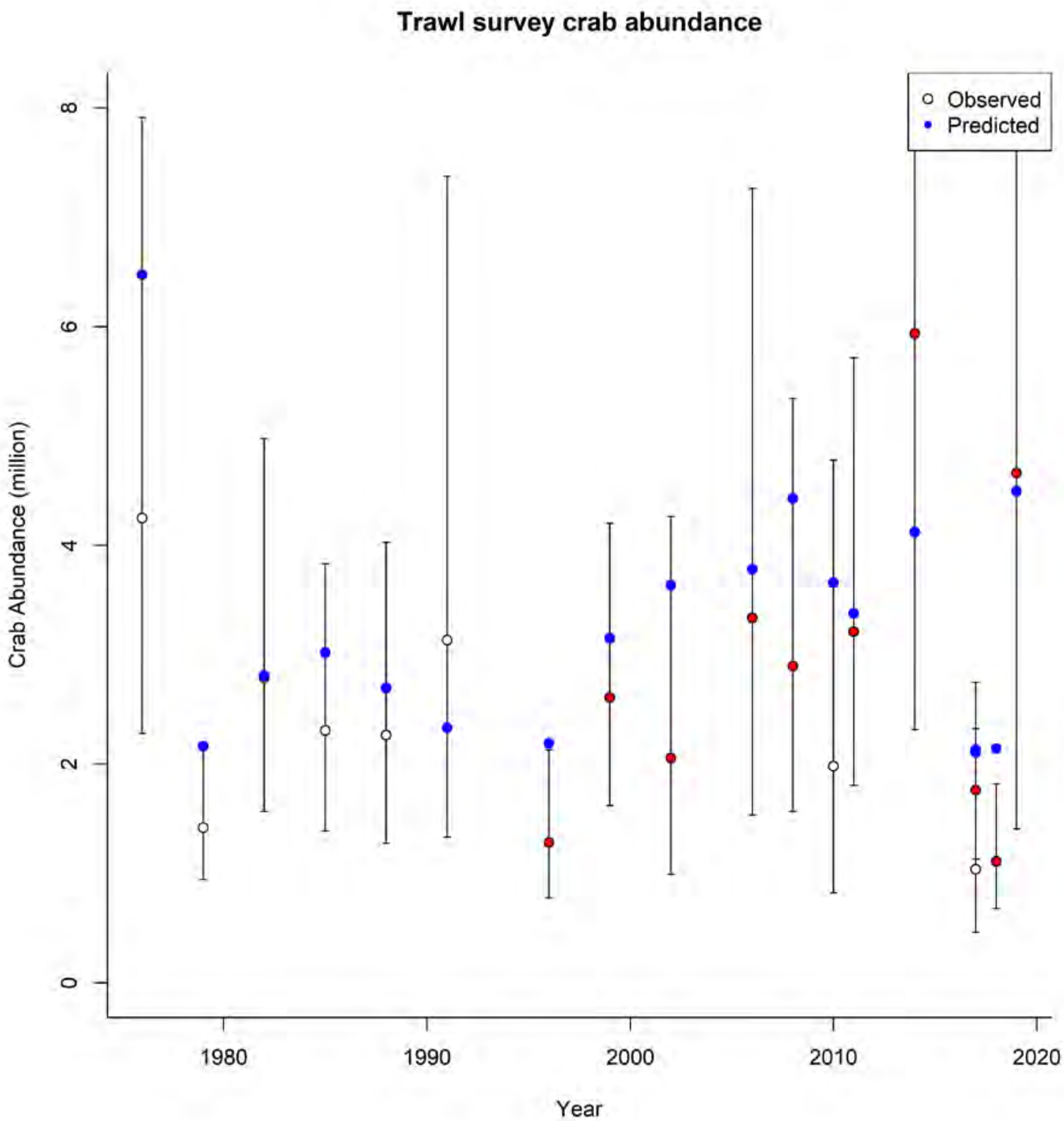


Figure D3-4. Estimated trawl survey male abundance (blue) (crab >= 64 mm CL). Observed: White: NOAA trawl survey, Red: ADG&G trawl survey

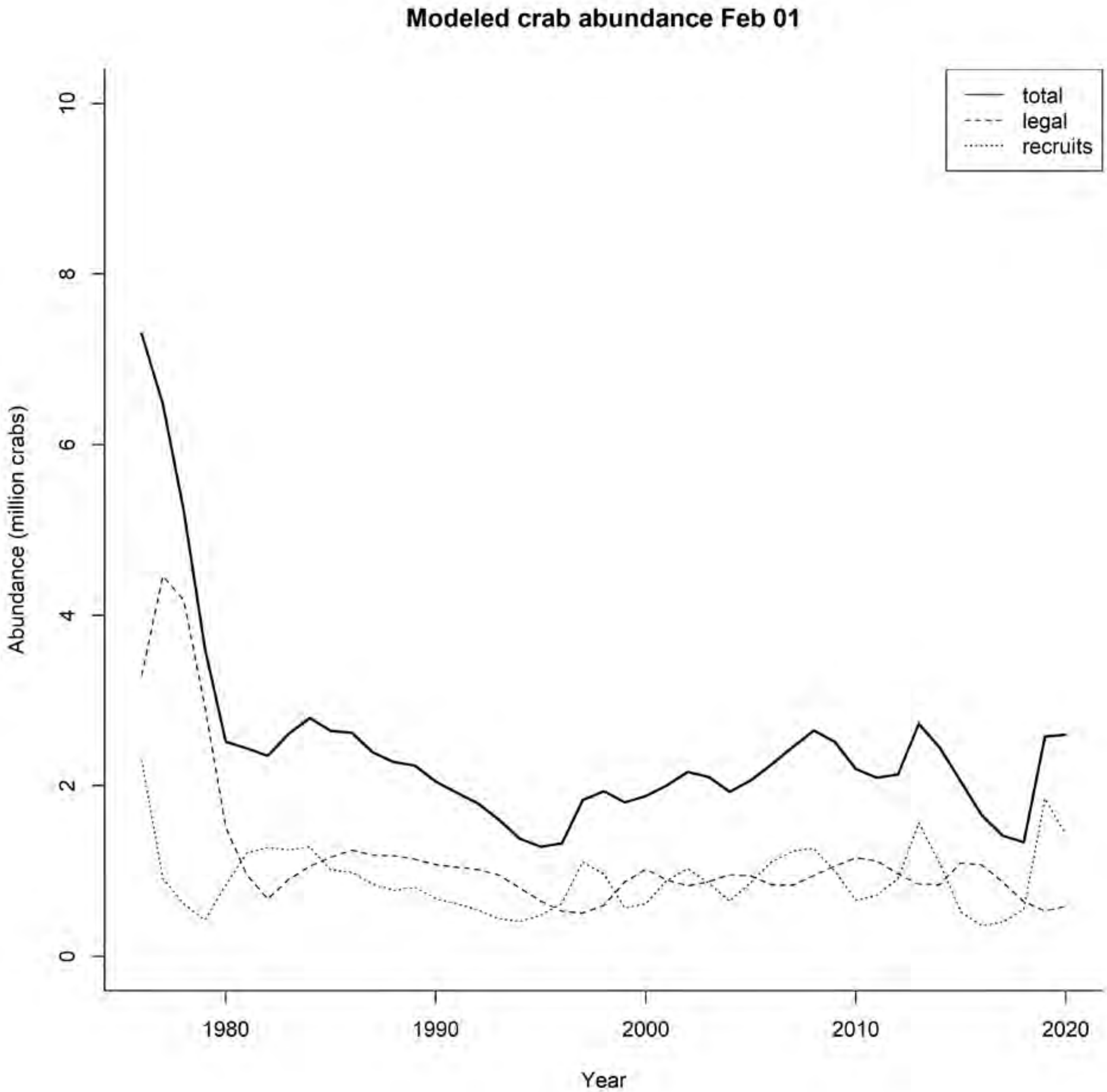


Figure D3-5. Estimated abundance of legal males.

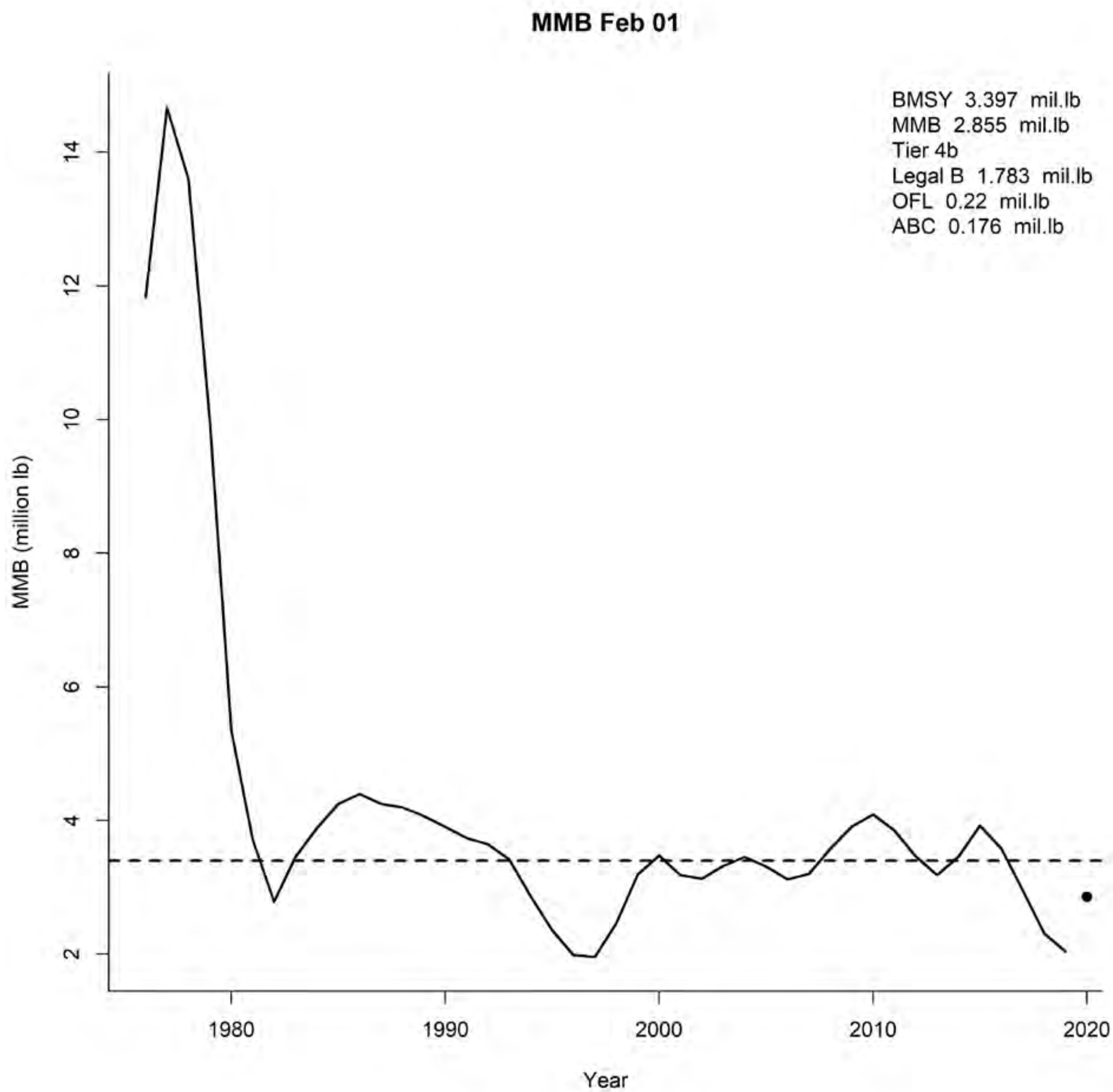


Figure D3-6. Estimated abundance of Mature Male Biomass. Dash line shows Bmsy.

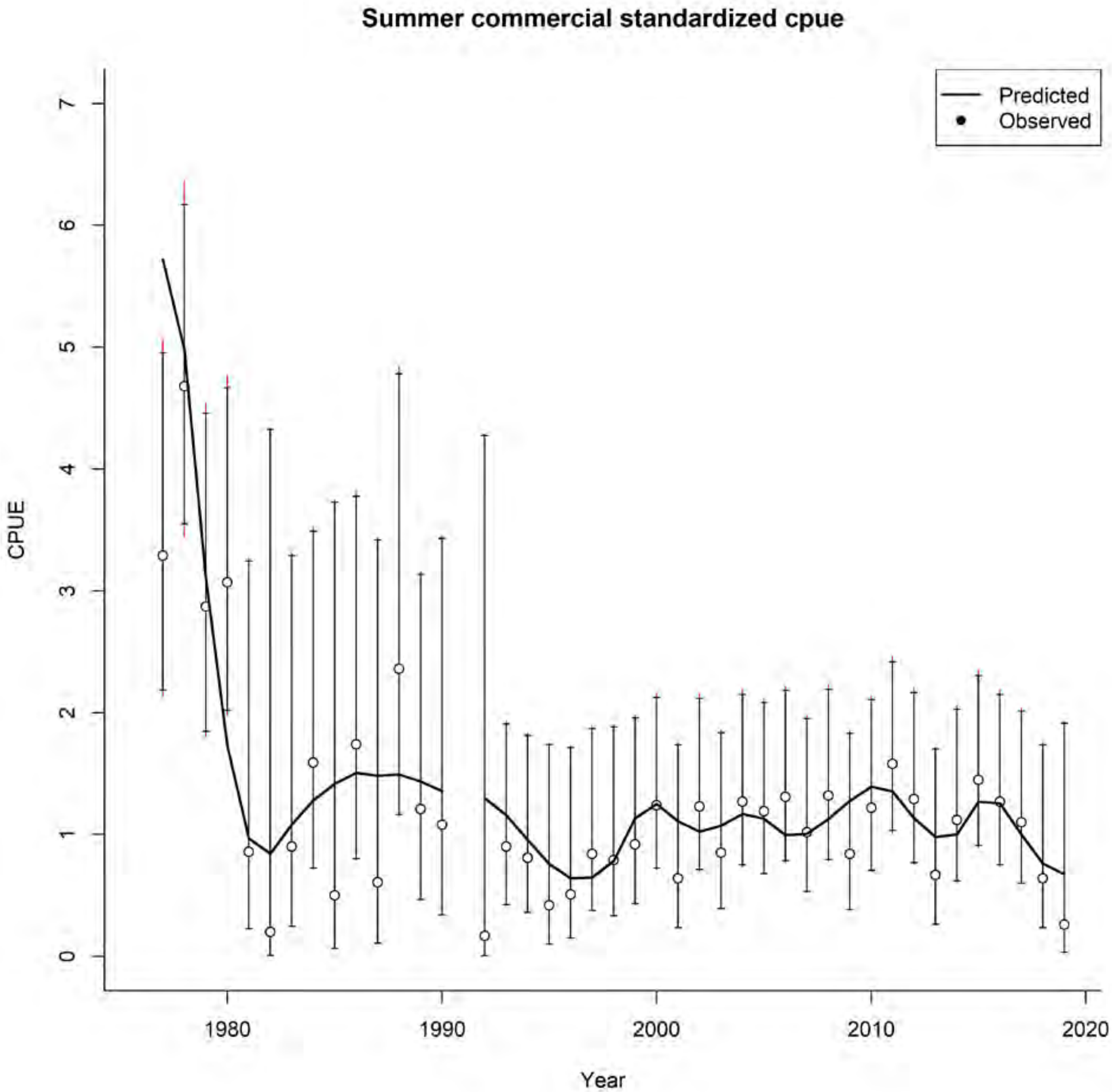


Figure D3-7. Summer commercial standardized cpue.

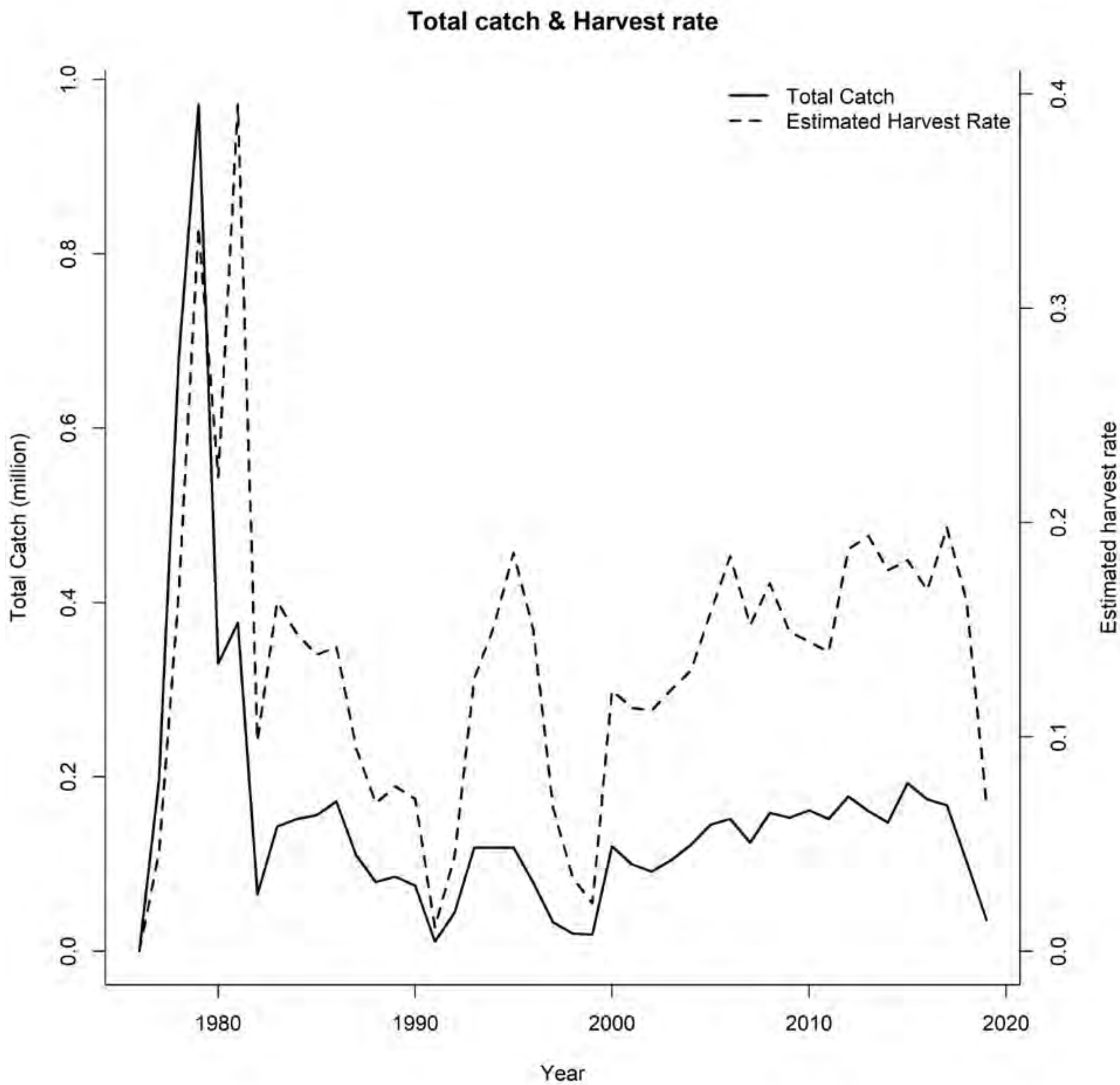


Figure D3-8. Total catch and estimated harvest rate.

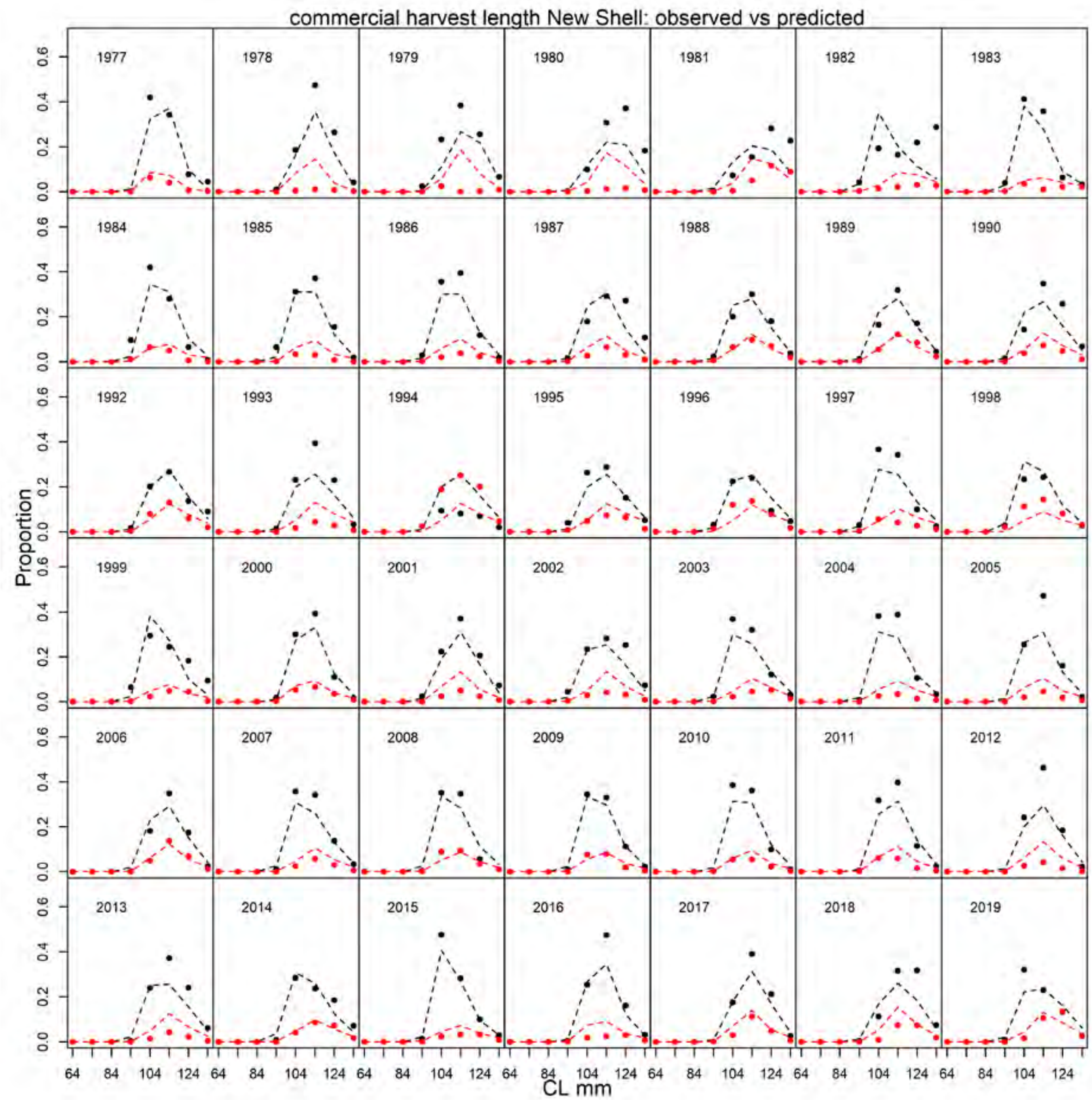


Figure D3-9. Predicted (dashed) vs. observed (dots) length class proportions for commercial catch. Black: newshell, Red: oldshell

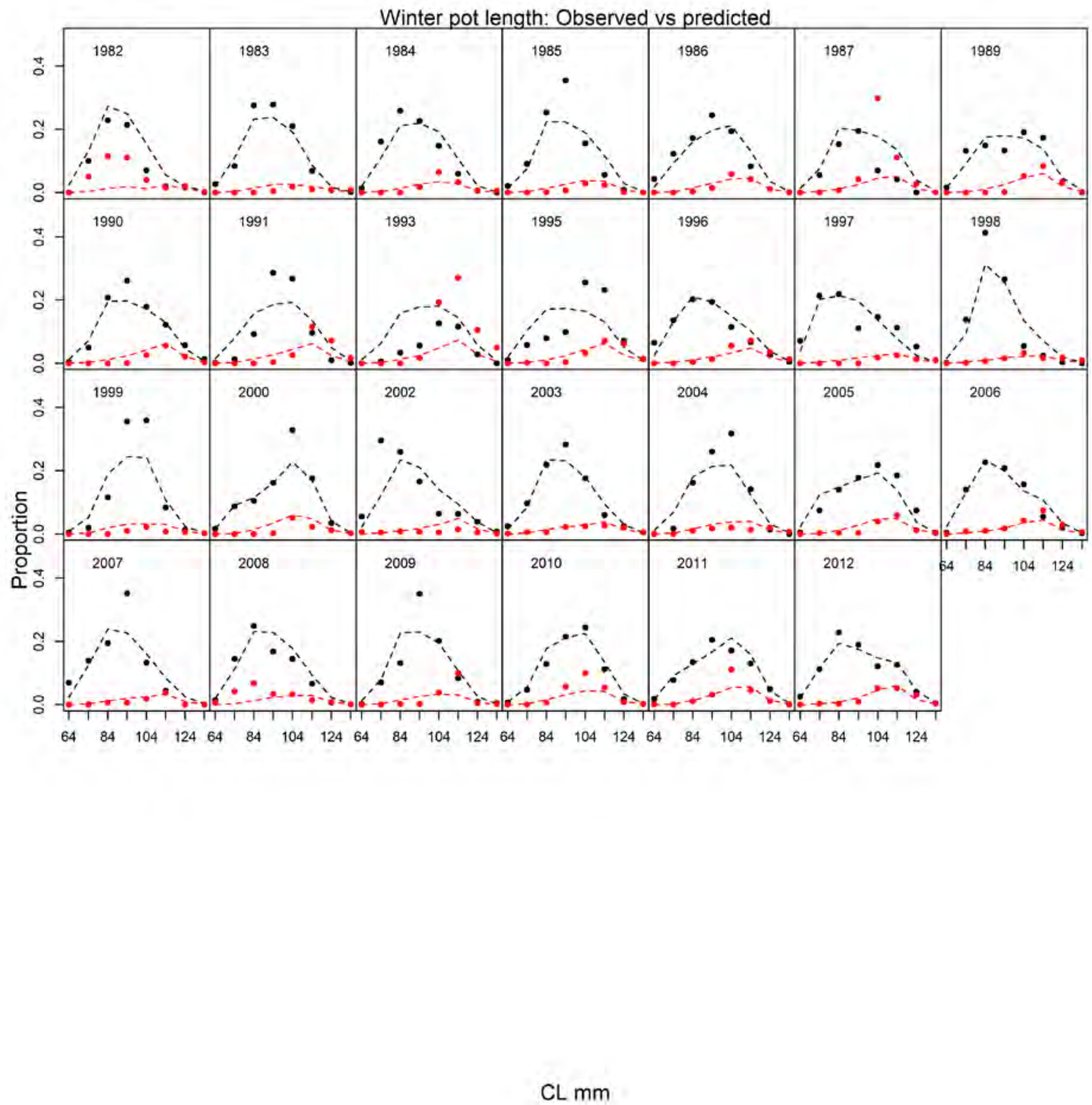


Figure D3-10. Predicted (dashed line) vs. observed (dots) length class proportions for the winter and spring pot survey. Black: newshell, Red: oldshell

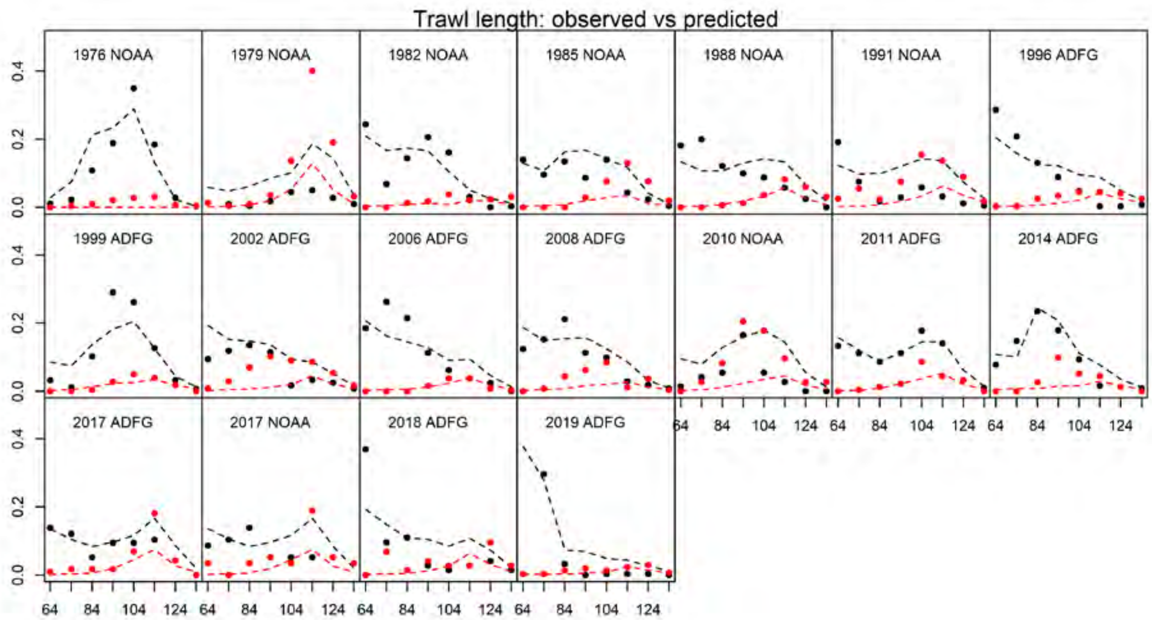


Figure D3-11. Predicted (dashed) vs. observed (dots) length class proportions for trawl survey. Black: newshell, Red: oldshell

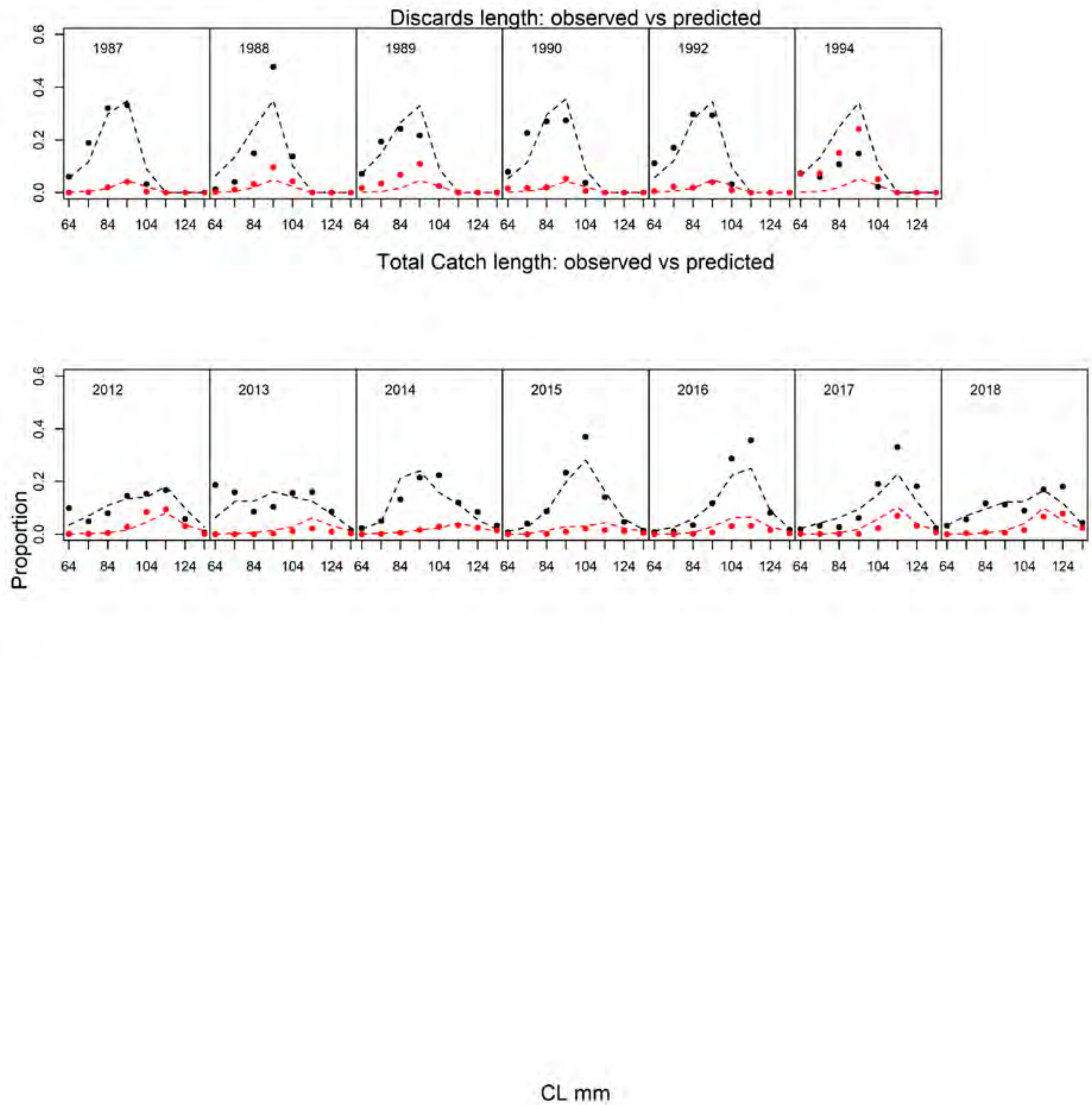


Figure D3-13. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

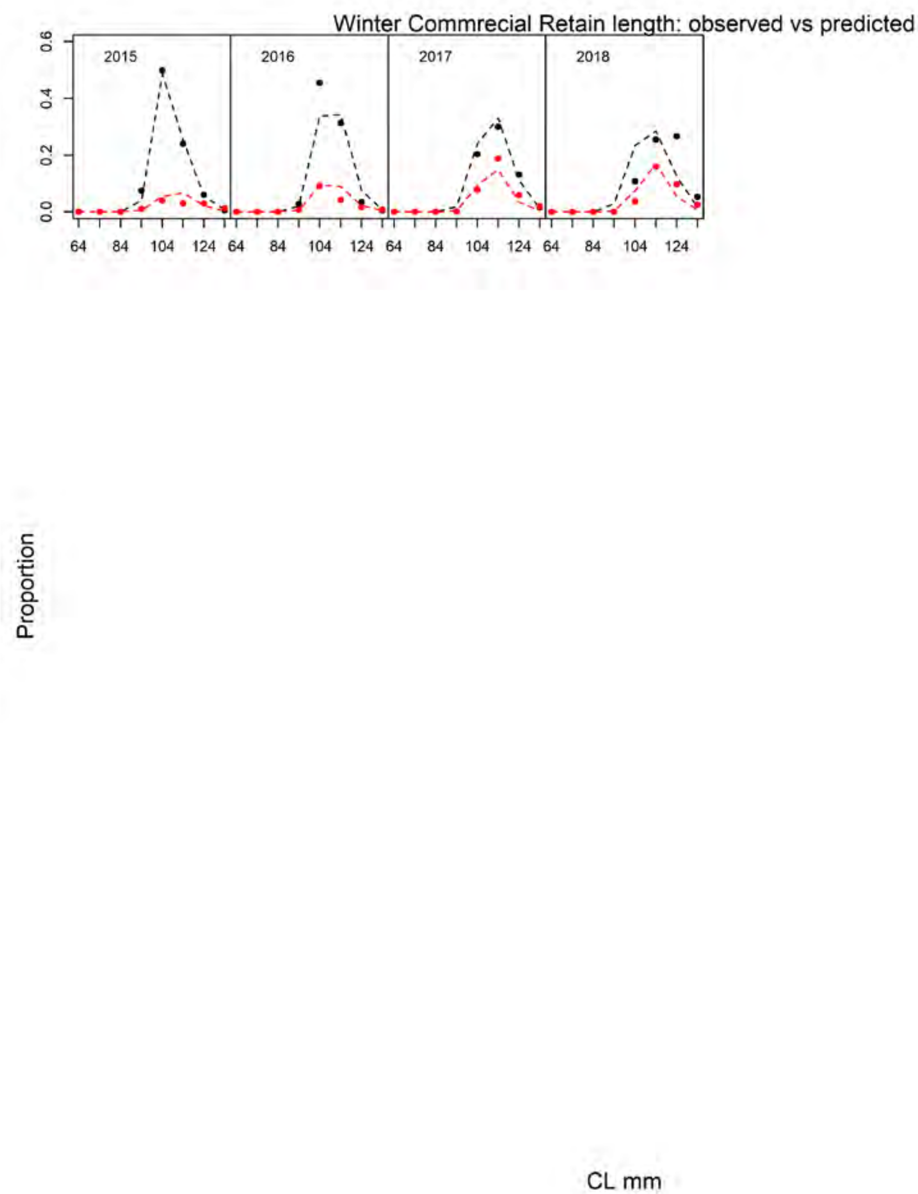


Figure D3-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

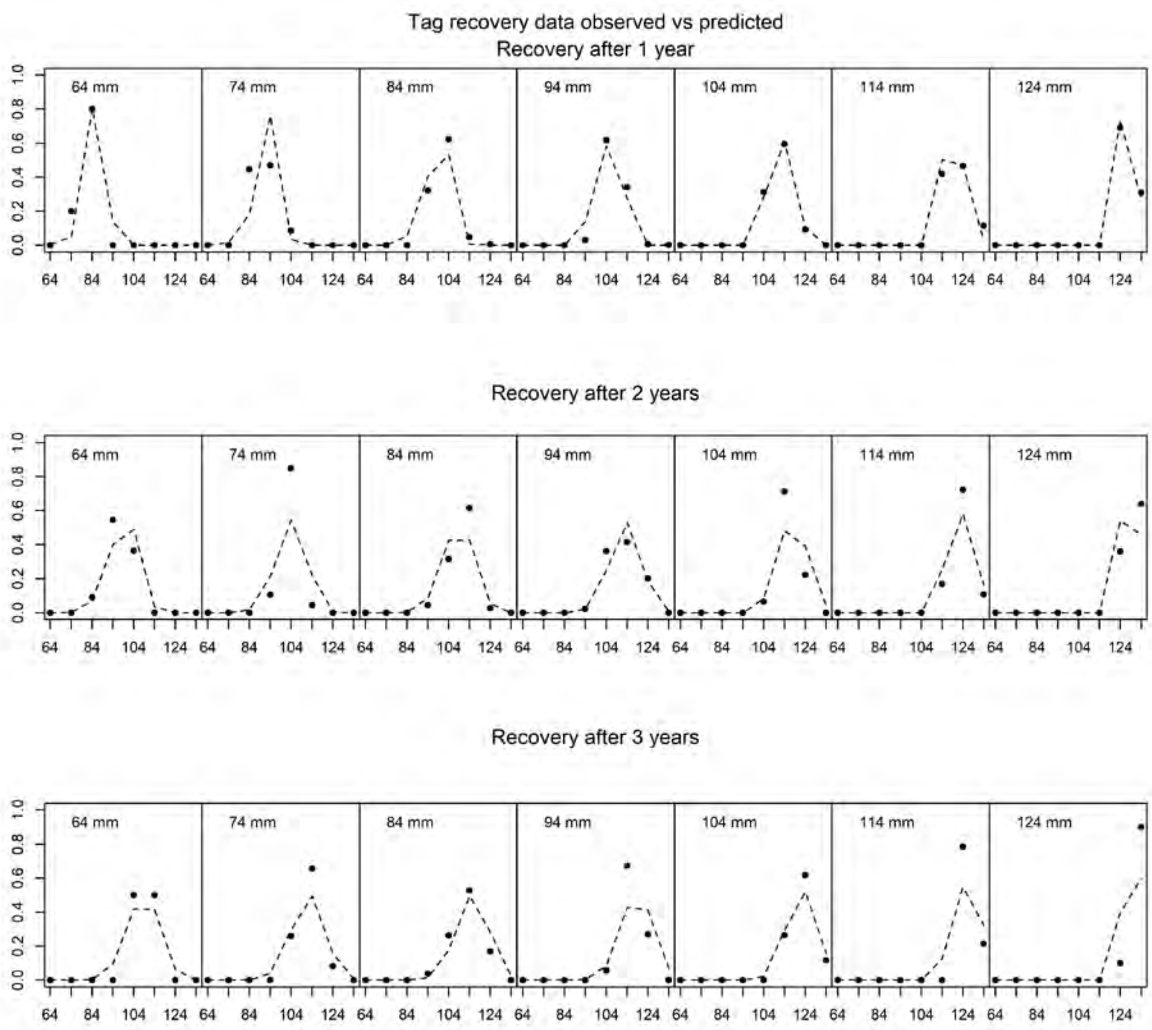


Figure D3-13. Predicted vs. observed length class proportions for tag recovery data.

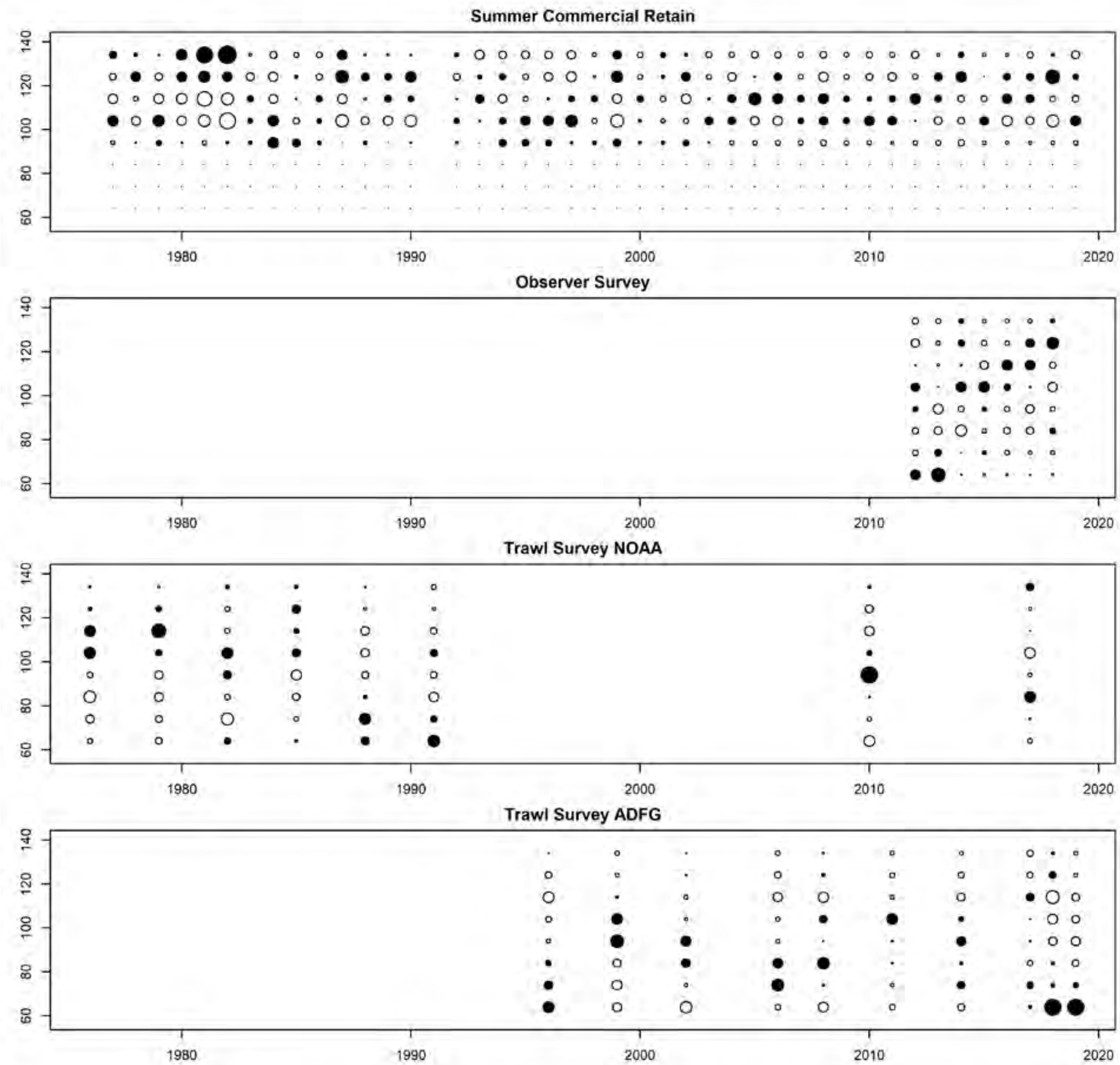


Figure D3-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

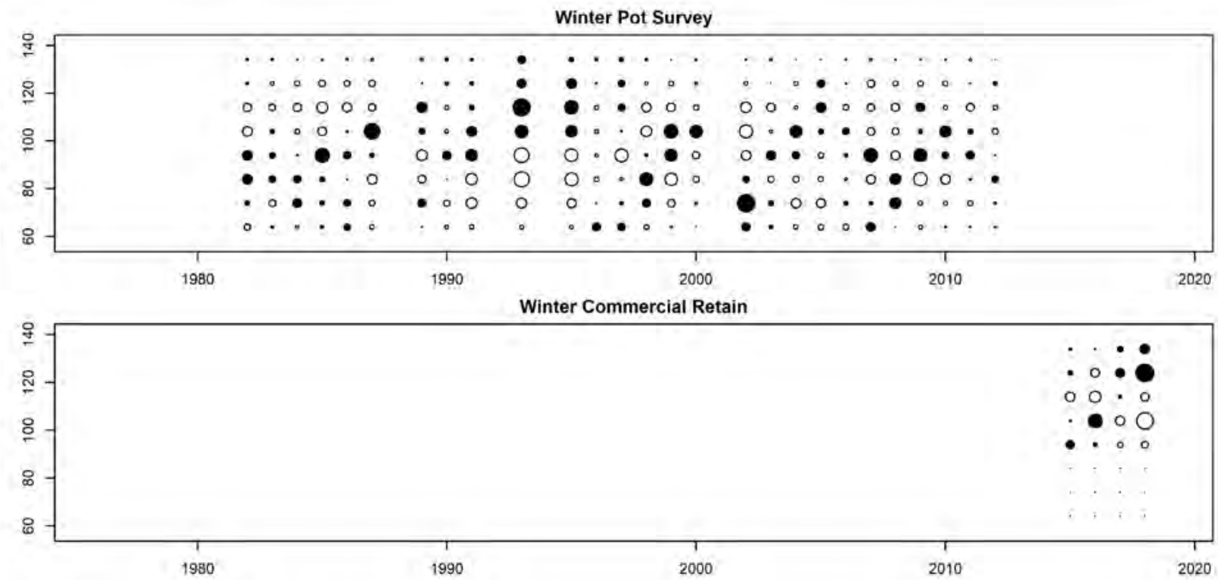


Figure D3-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table D3. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.471	0.123
log_q_2		
log_N_{76}	8.895	0.091
R_0	6.206	0.095
a_1	2.091	4.628
a_2	3.055	4.325
a_3	4.093	4.166
a_4	4.189	4.152
a_5	4.400	4.142
a_6	3.609	4.172
a_7	2.110	4.440
r1	10.000	0.335
r2	9.671	0.376
log_a	-2.665	0.089
log_b	4.829	0.015
log_ϕ_{st1}	-5.000	0.113
log_ϕ_{wa}	-2.198	0.316
log_ϕ_{wb}	4.805	0.032
Sw1	0.072	0.035
Sw2	0.497	0.124
log_ϕ_{I}	-2.082	0.056
log_ϕra	-0.796	0.128
log_ϕrb	4.647	0.008
log_ϕwra	-0.988	0.536
log_ϕwrb	4.656	0.037
w^2_t	0.004	0.019
q ADFG	1.400	0.217
σ	3.870	0.209
β_1	12.524	0.705
β_2	7.636	0.173
ms78	2.883	0.259

Appendix D - Model 19.3

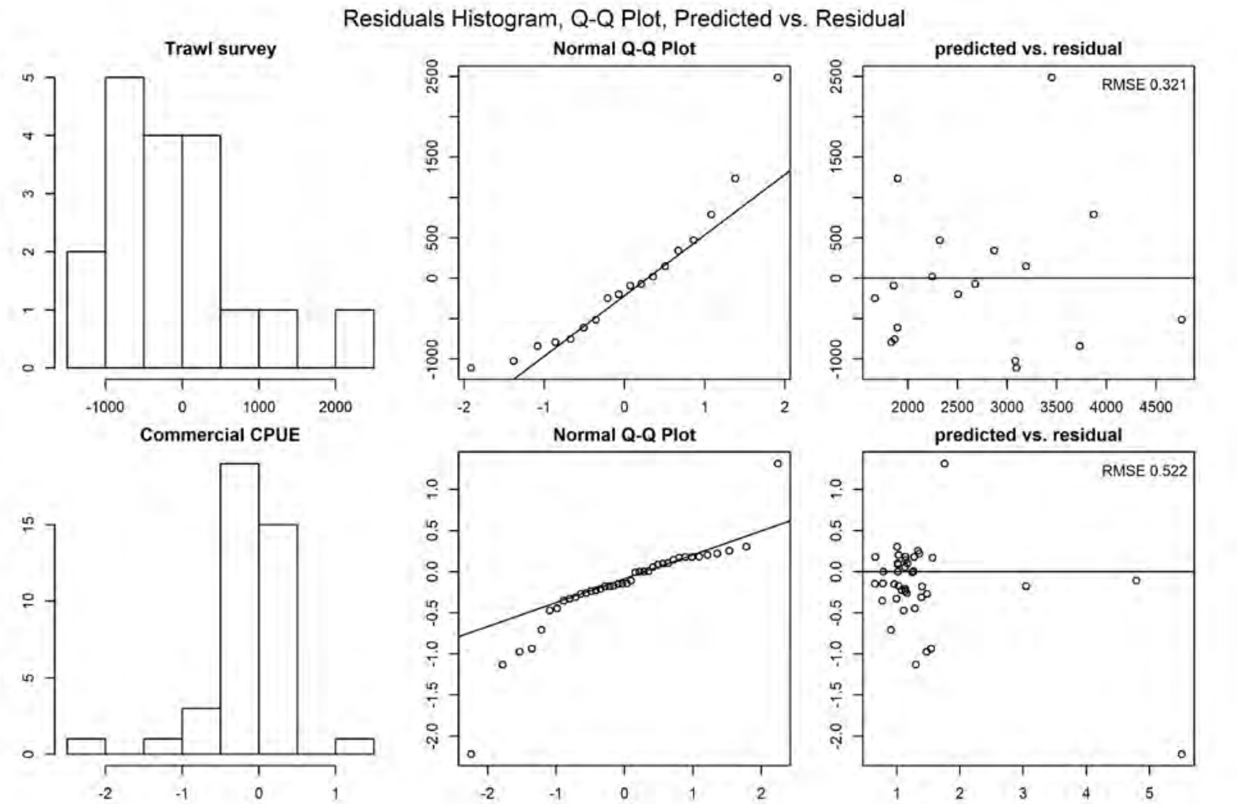


Figure D4-1. QQ Plot of trawl survey and commercial CPUE.

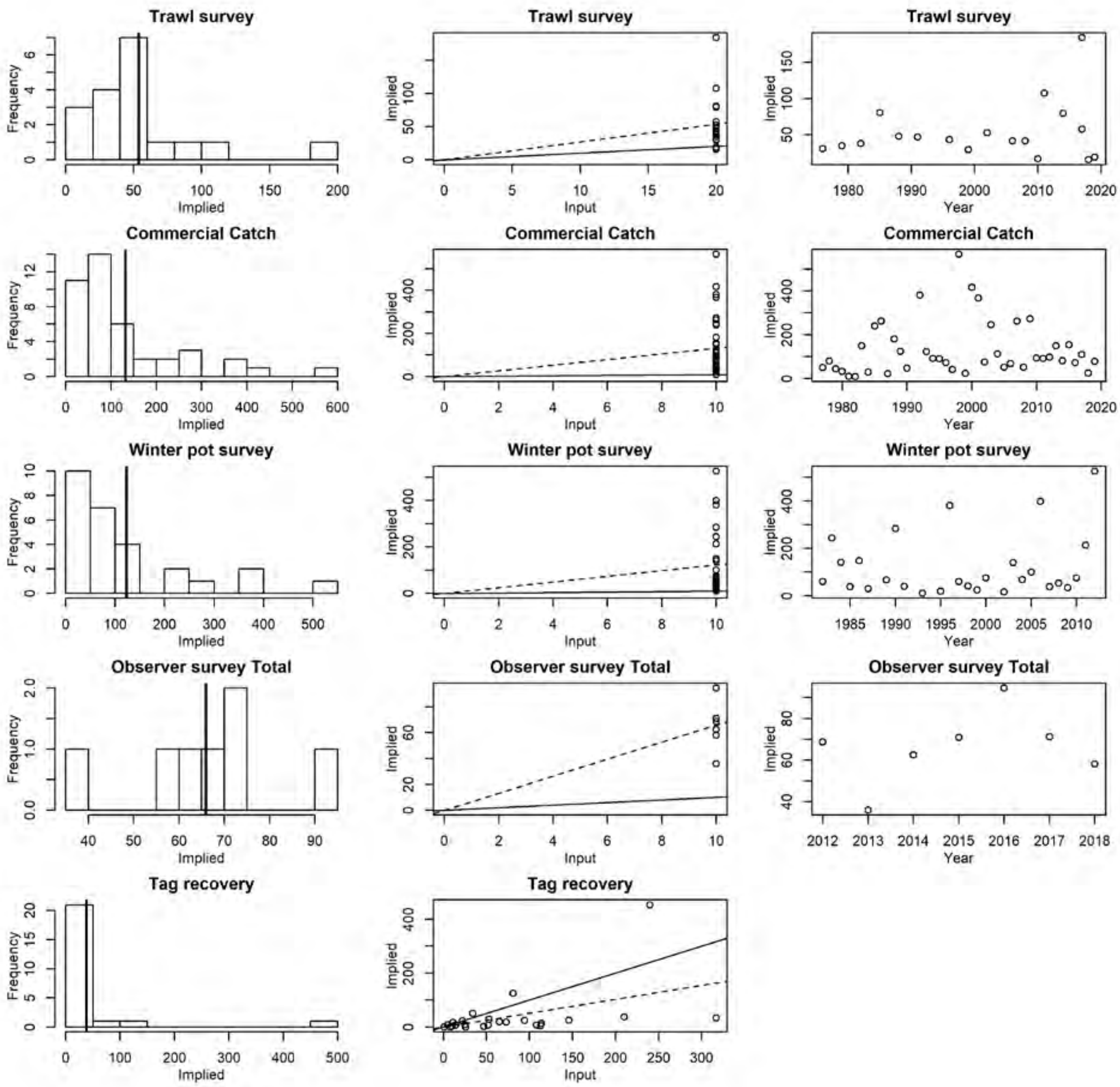


Figure D4-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column shows input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

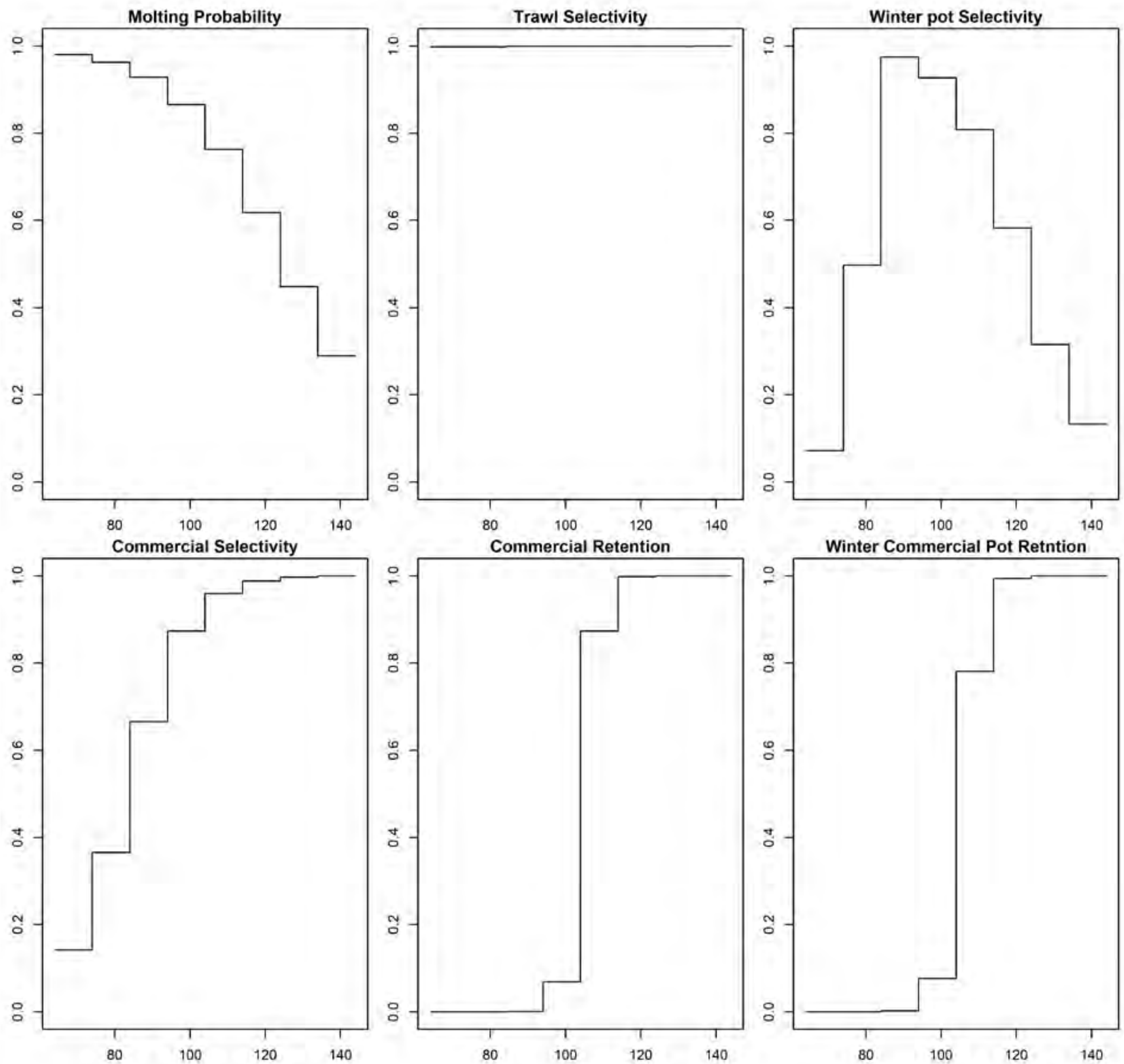


Figure D4-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

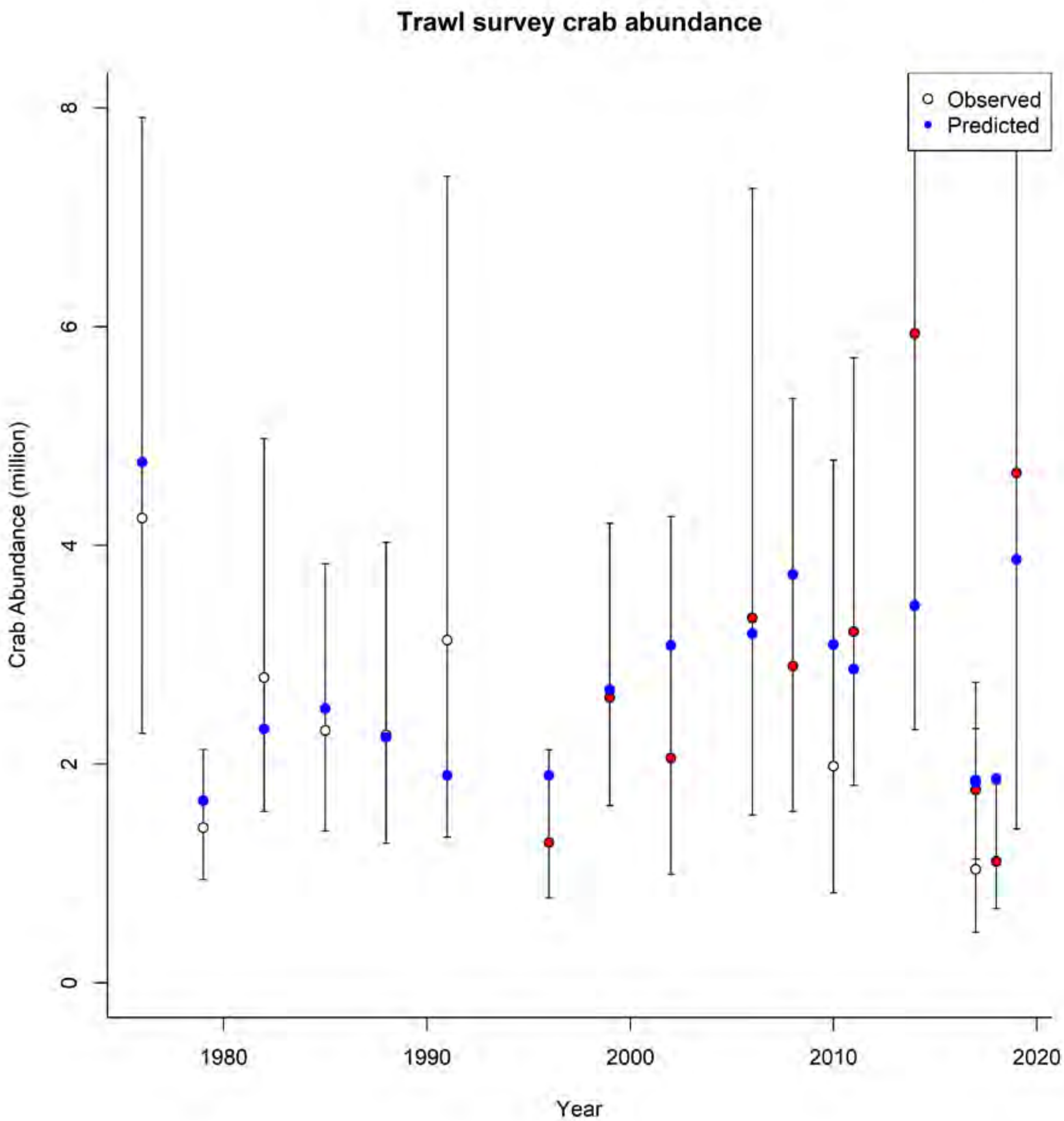


Figure D4-4. Estimated trawl survey male abundance (blue) (crab >= 64 mm CL). Observed: White: NOAA trawl survey, Red: ADG&G trawl survey

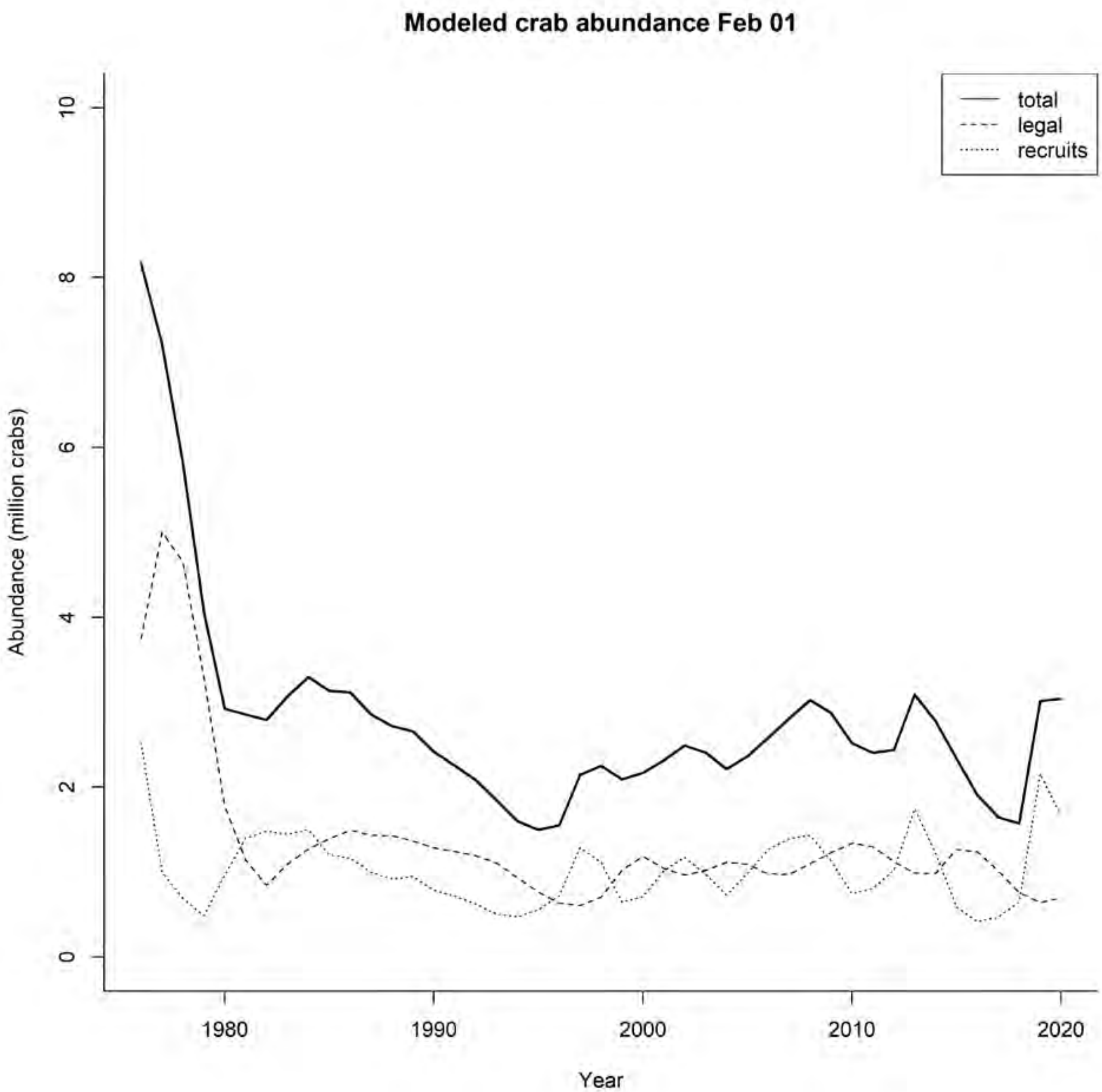


Figure D4-5. Estimated abundance of legal males.

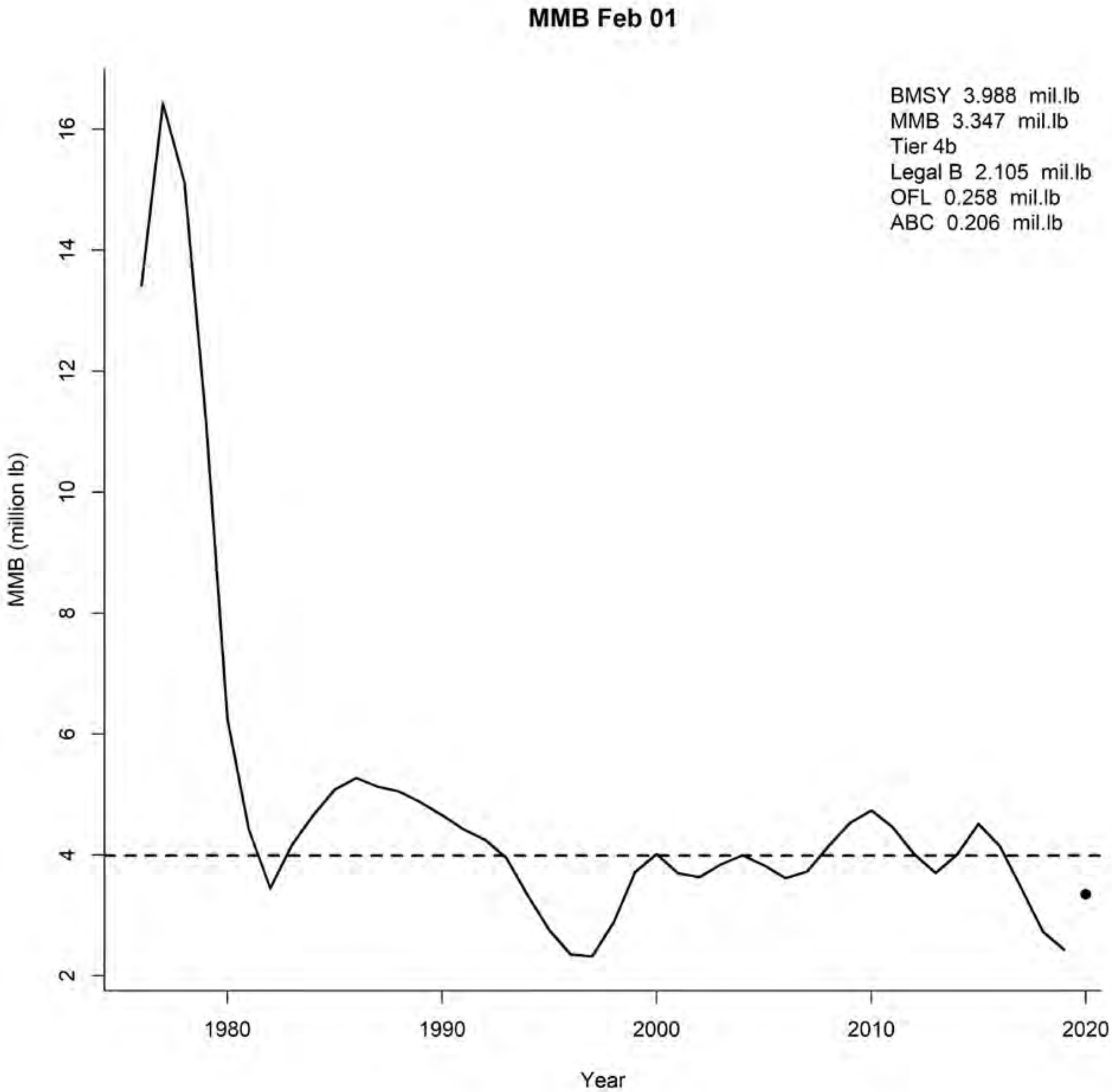


Figure D4-6. Estimated abundance of Mature Male Biomass. Dash line shows Bmsy.

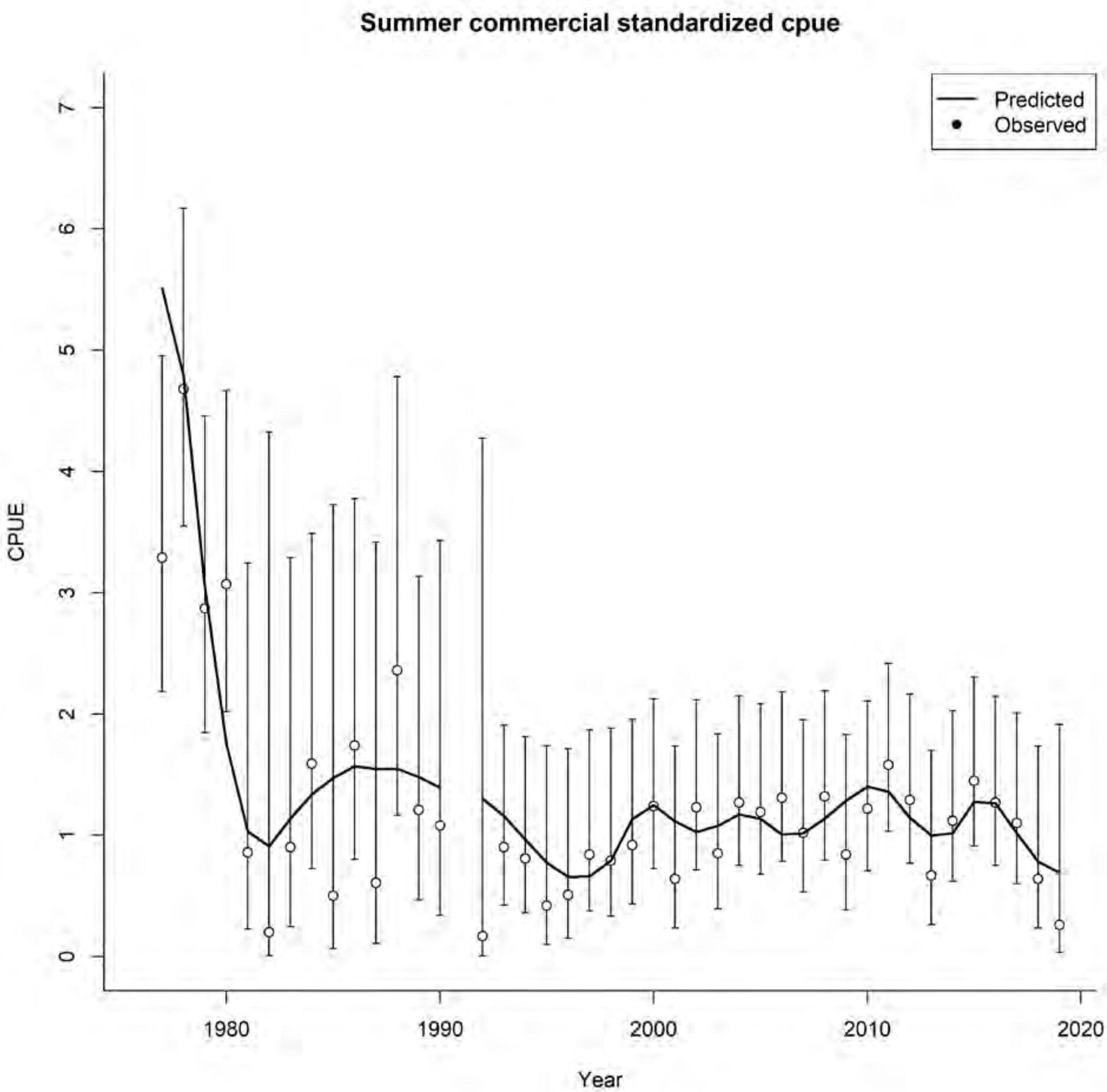


Figure D4-7. Summer commercial standardized cpue.

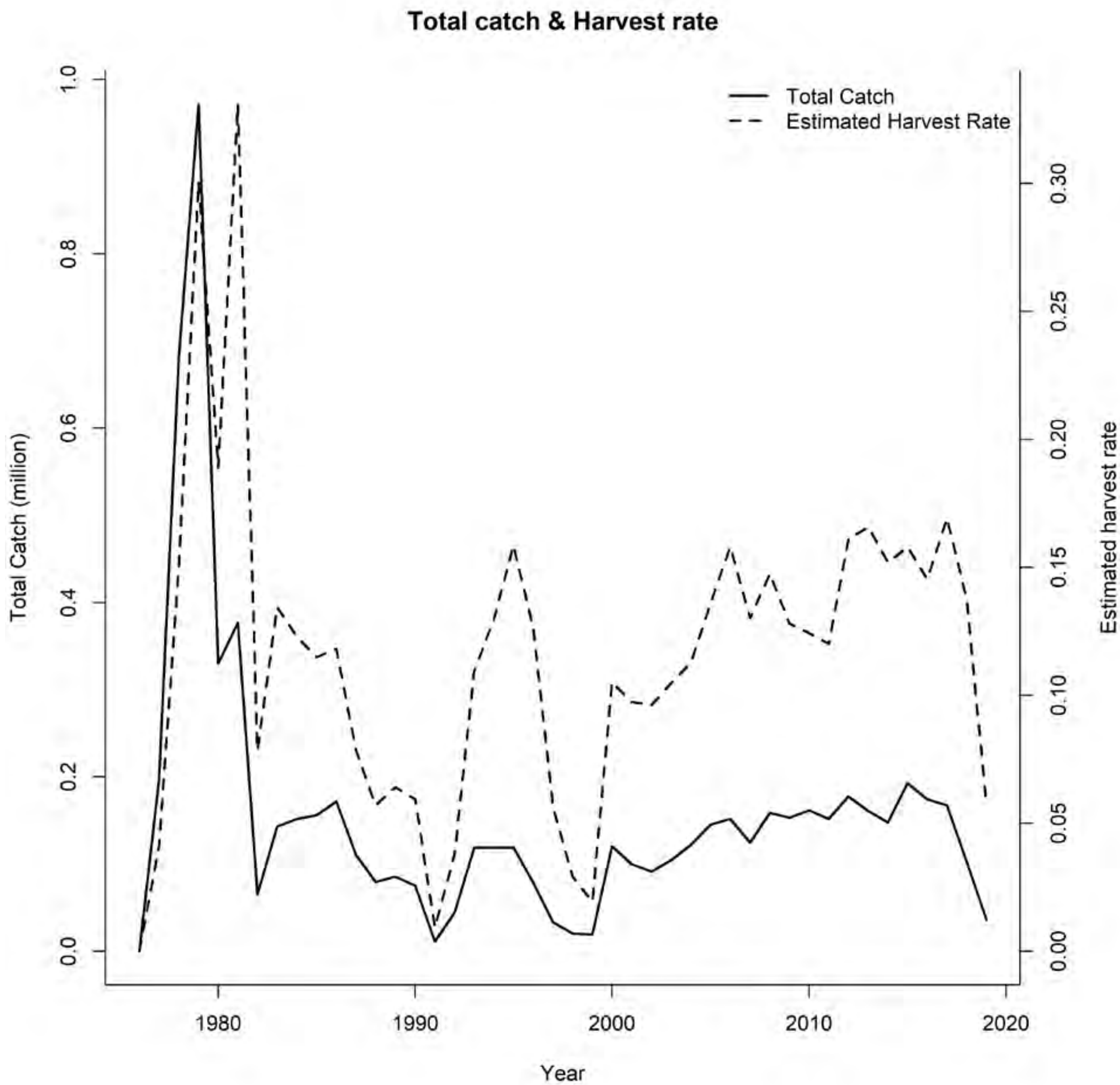


Figure D4-8. Total catch and estimated harvest rate.

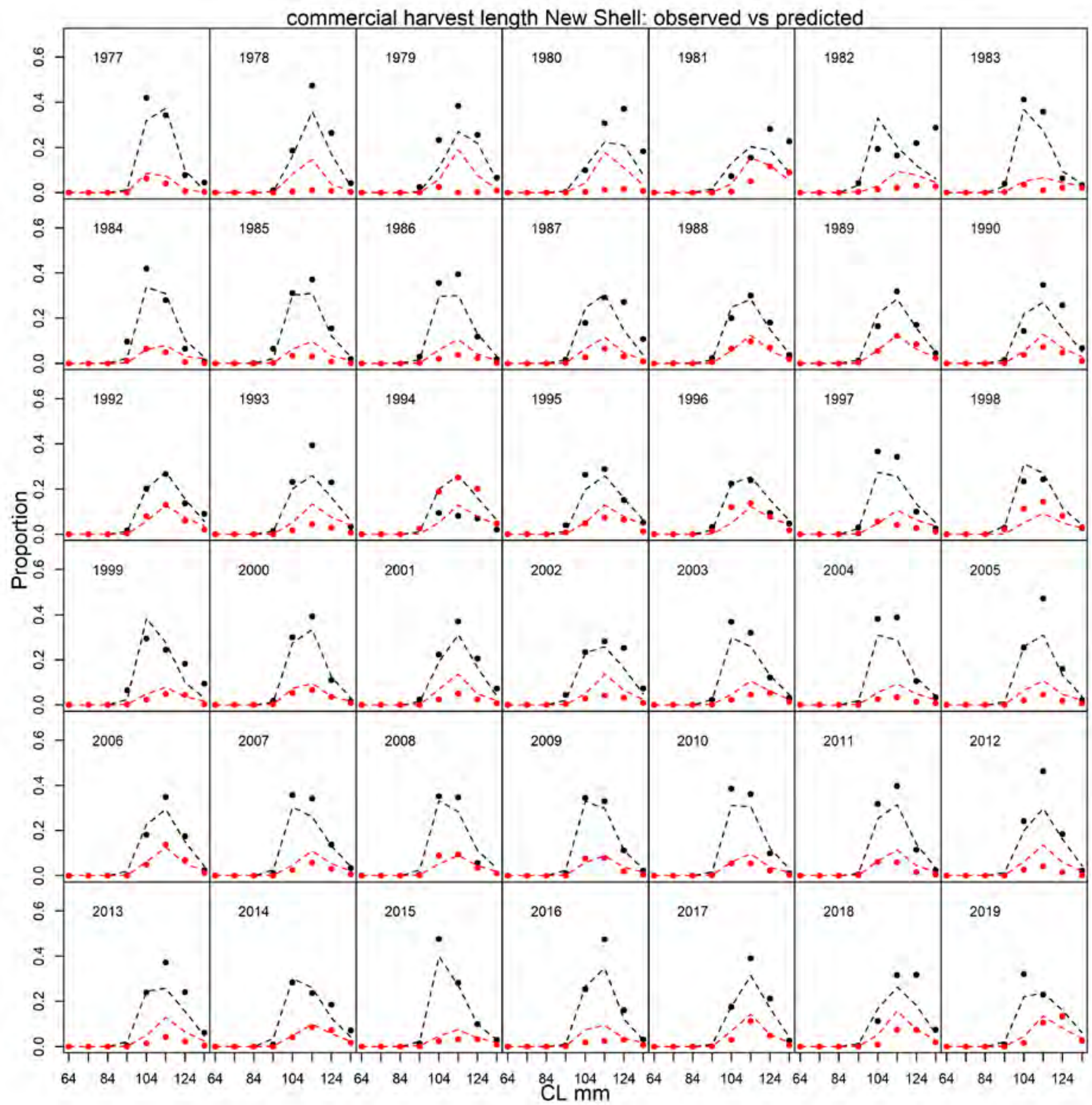


Figure D4-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Black: newshell, Red: oldshell

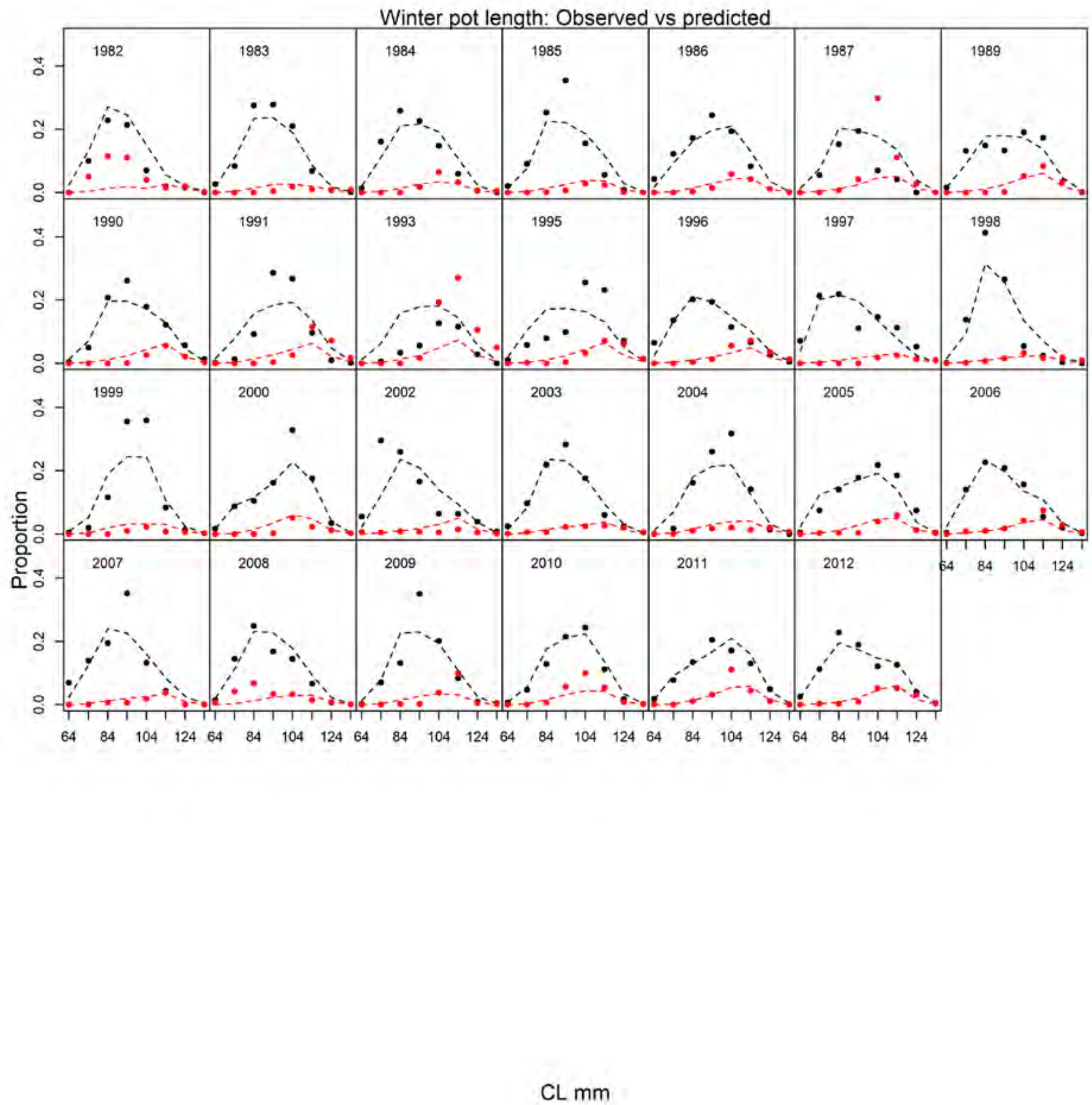


Figure D4-10. Predicted (dashed line) vs. observed (dots) length class proportions for the winter and spring pot survey. Black: newshell, Red: oldshell

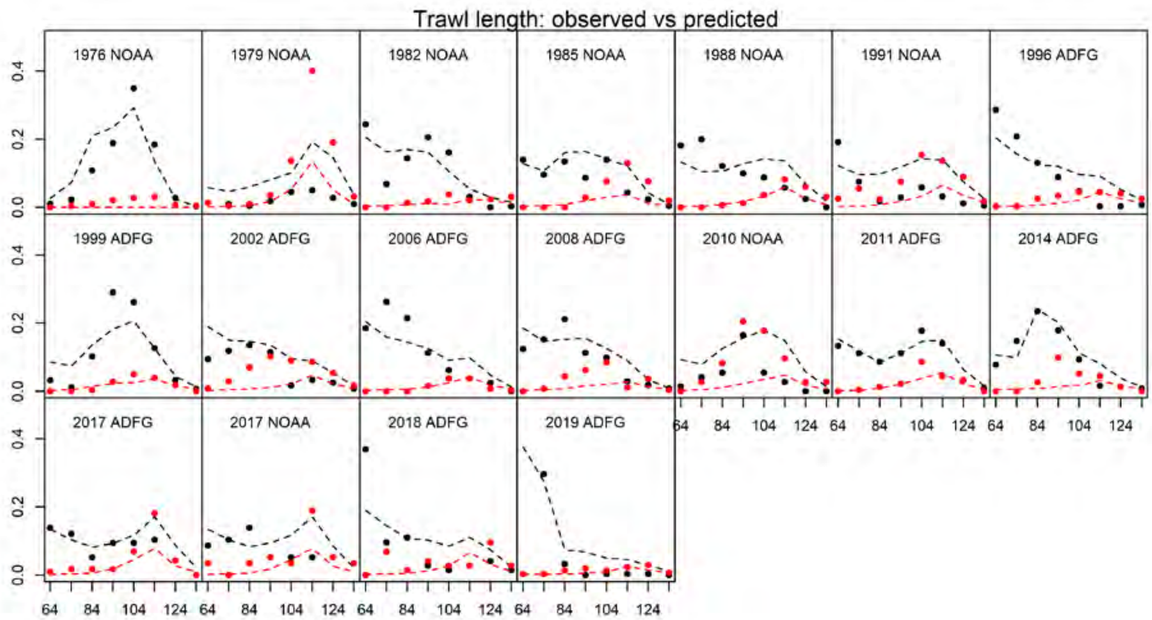


Figure D4-11. Predicted (dashed) vs. observed (dots) length class proportions for trawl survey. Black: newshell, Red: oldshell

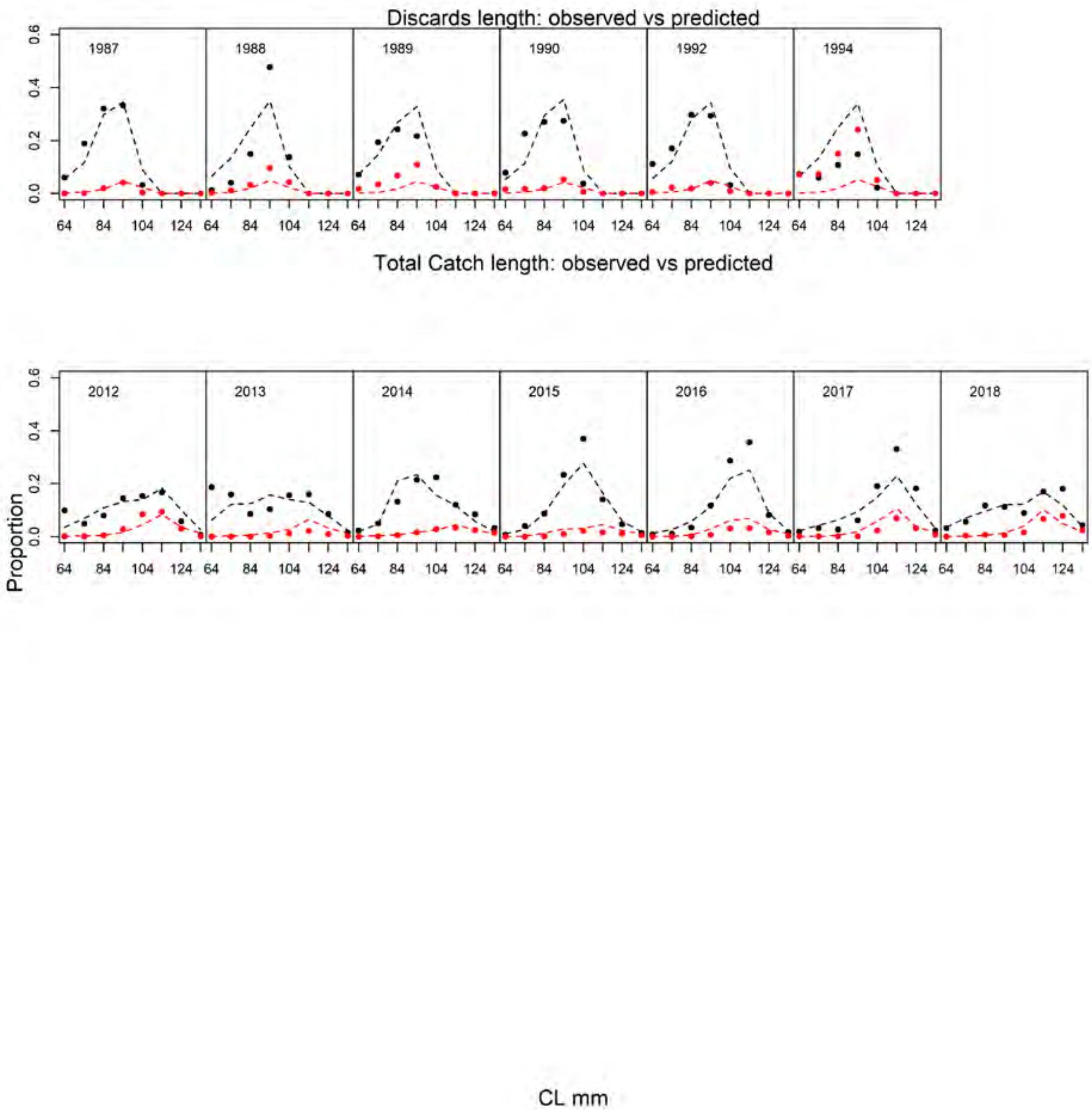


Figure D4-13. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

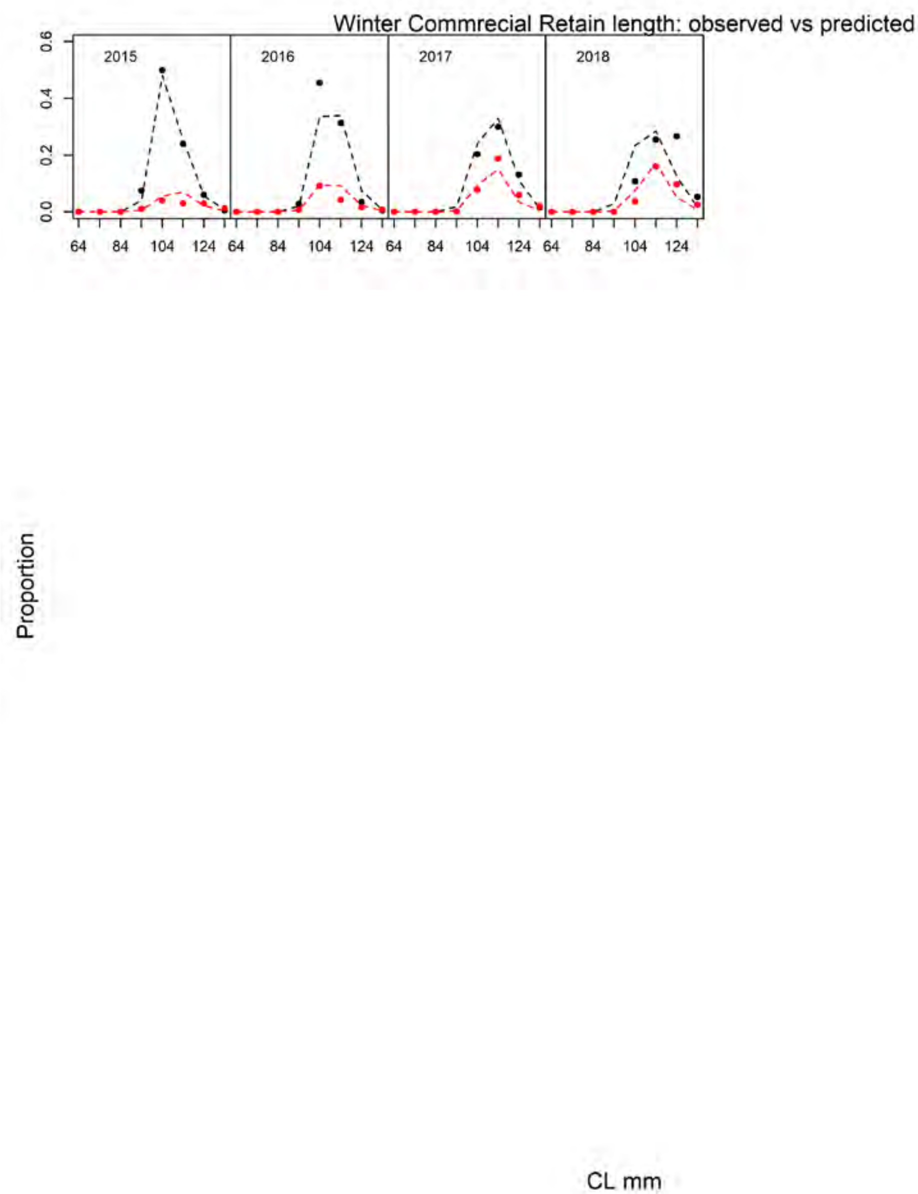


Figure D4-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

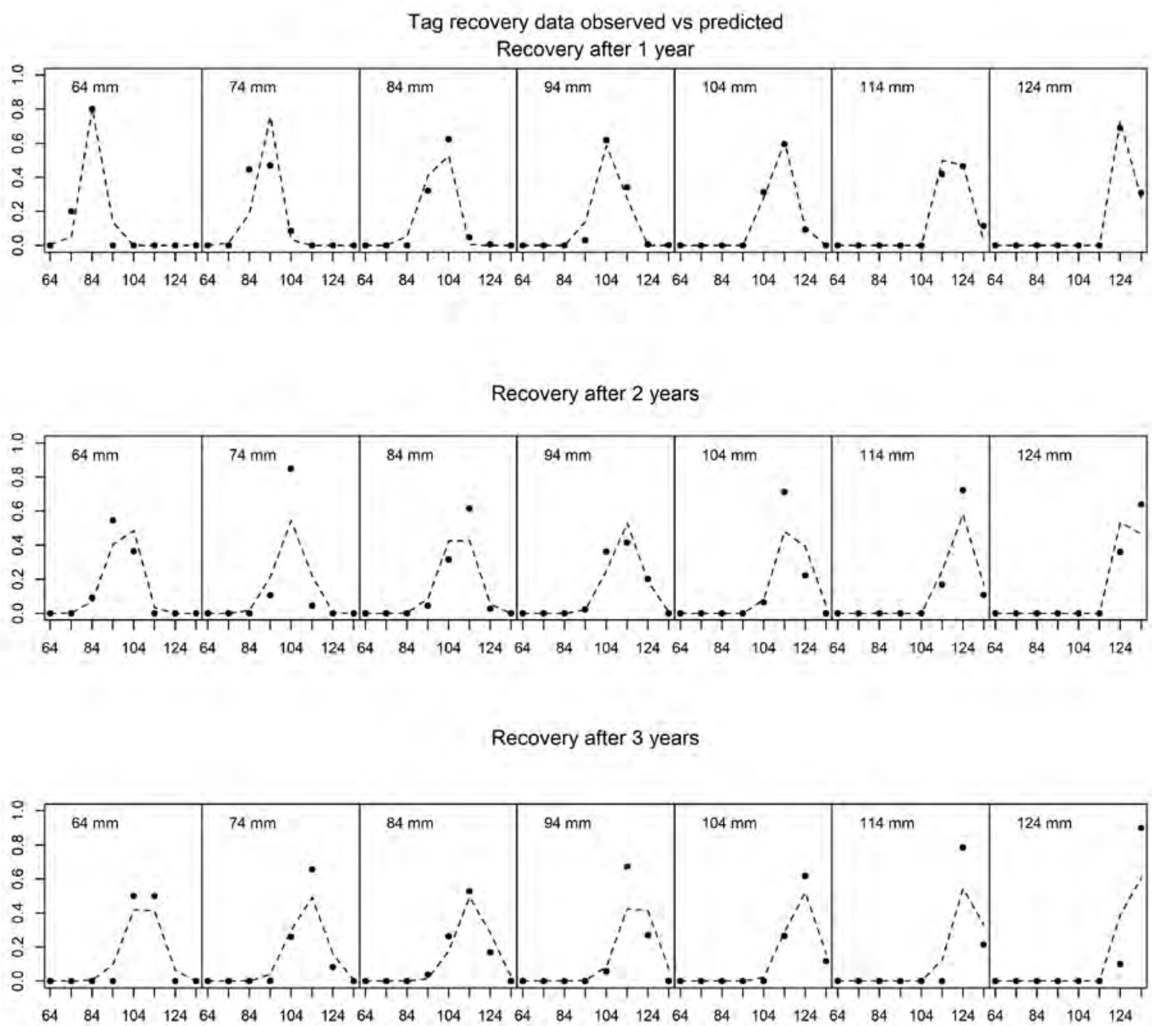


Figure D4-13. Predicted vs. observed length class proportions for tag recovery data.

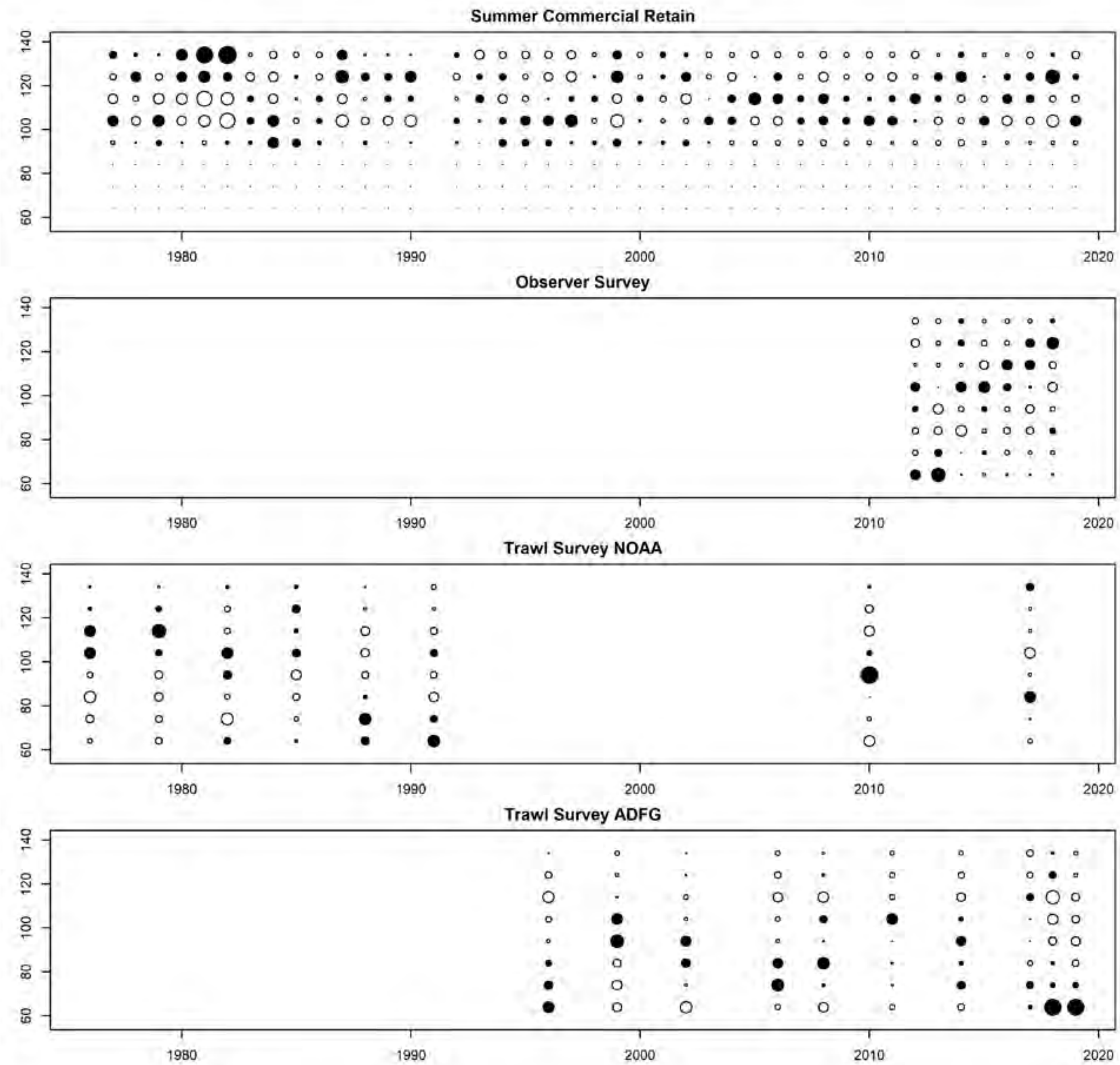


Figure D4-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

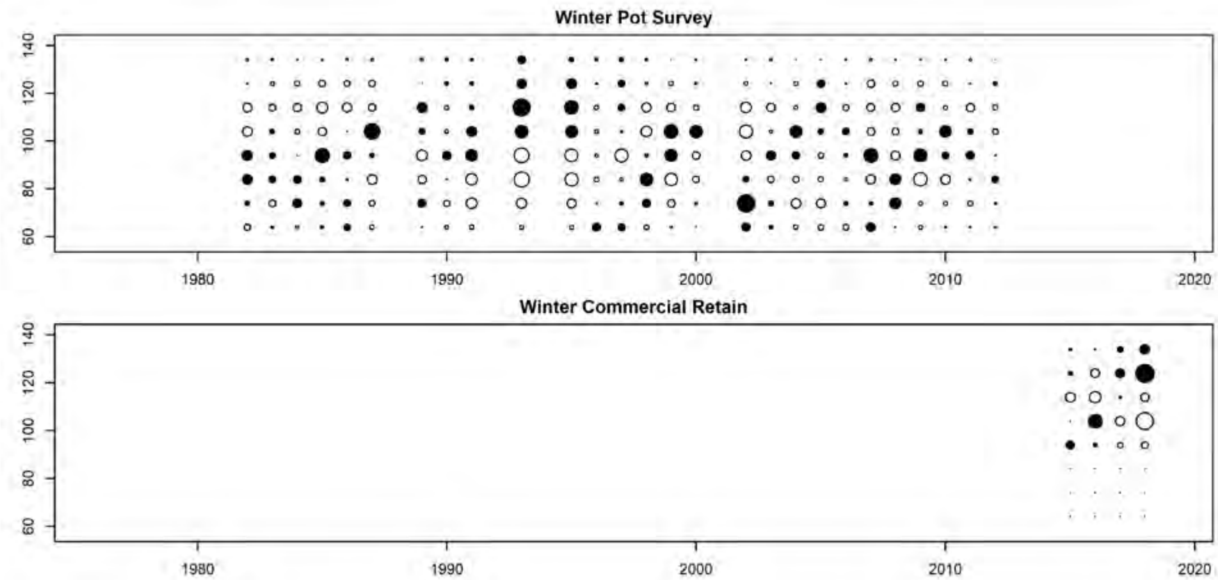


Figure D4-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table D4. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.627	0.227
log_q_2		
log_N_{76}	9.008	0.174
R_0	6.341	0.191
a_1	1.968	4.606
a_2	2.959	4.289
a_3	4.020	4.140
a_4	4.124	4.127
a_5	4.344	4.117
a_6	3.570	4.146
a_7	2.106	4.414
r1	10.000	0.305
r2	9.663	0.351
log_a	-2.674	0.090
log_b	4.832	0.016
log_ϕ_{st1}	-5.000	0.067
log_ϕ_{wa}	-2.203	0.307
log_ϕ_{wb}	4.800	0.032
Sw1	0.072	0.035
Sw2	0.498	0.125
log_ϕ_{l}	-2.085	0.056
$log\_\phi ra$	-0.791	0.129
$log\_\phi rb$	4.647	0.008
$log\_\phi wra$	-0.977	0.543
$log\_\phi wrb$	4.655	0.037
w^2_t	0.000	0.000
q NOAA	0.811	0.197
q ADFG	1.200	0.290
σ	3.878	0.209
β_1	12.453	0.707
β_2	7.649	0.173
ms78	3.083	0.342

Appendix D - Model 19.4

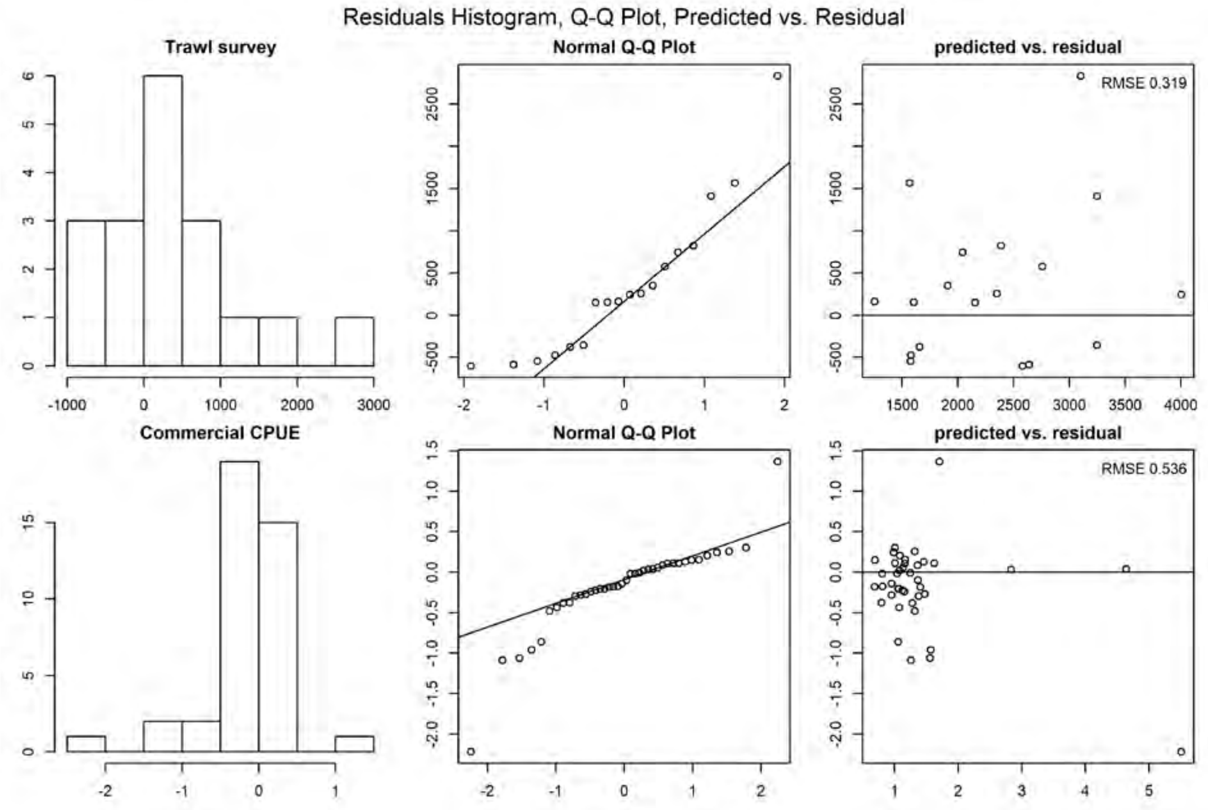


Figure D5-1. QQ Plot of trawl survey and commercial CPUE.

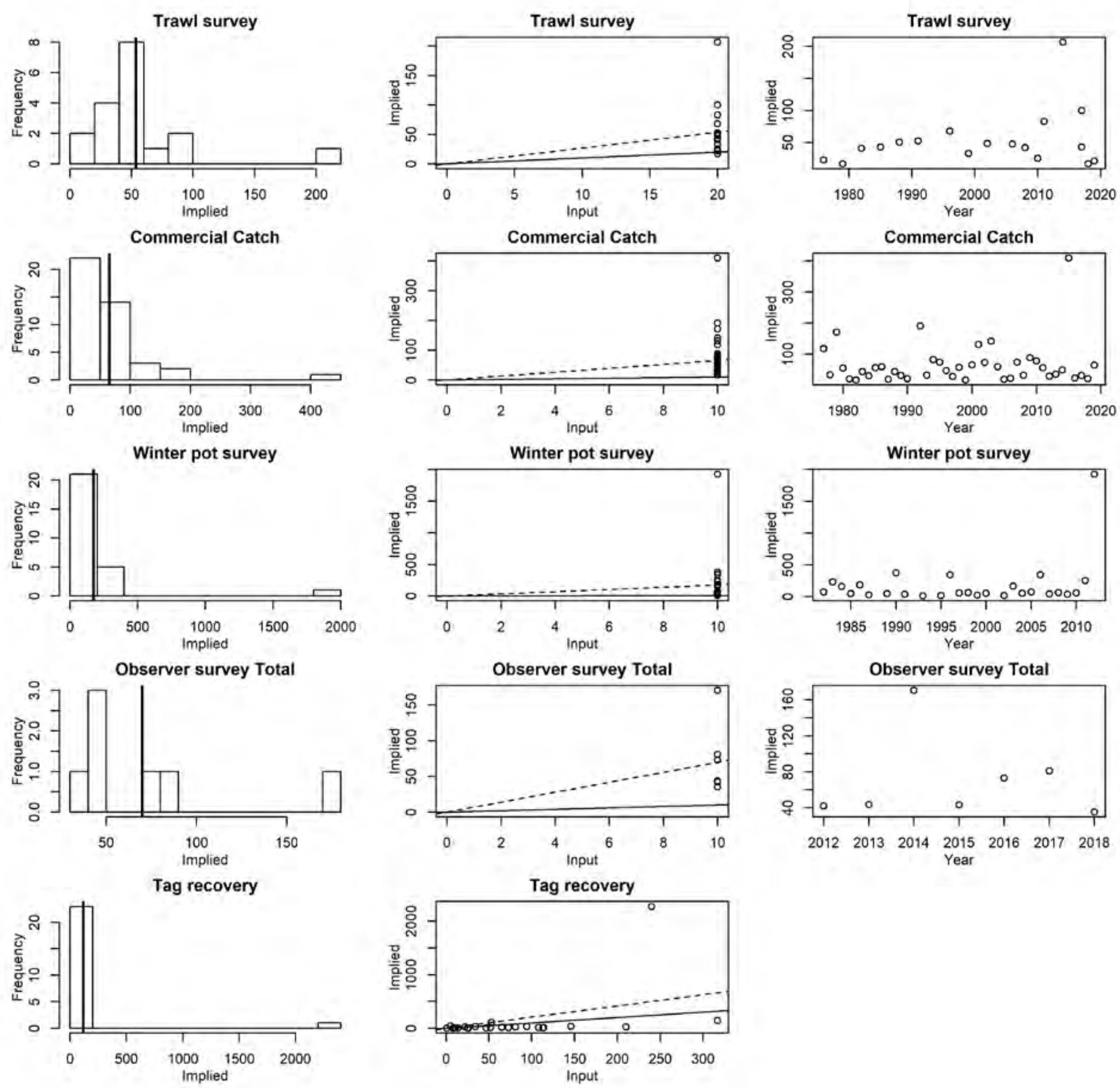


Figure D5-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column shows input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

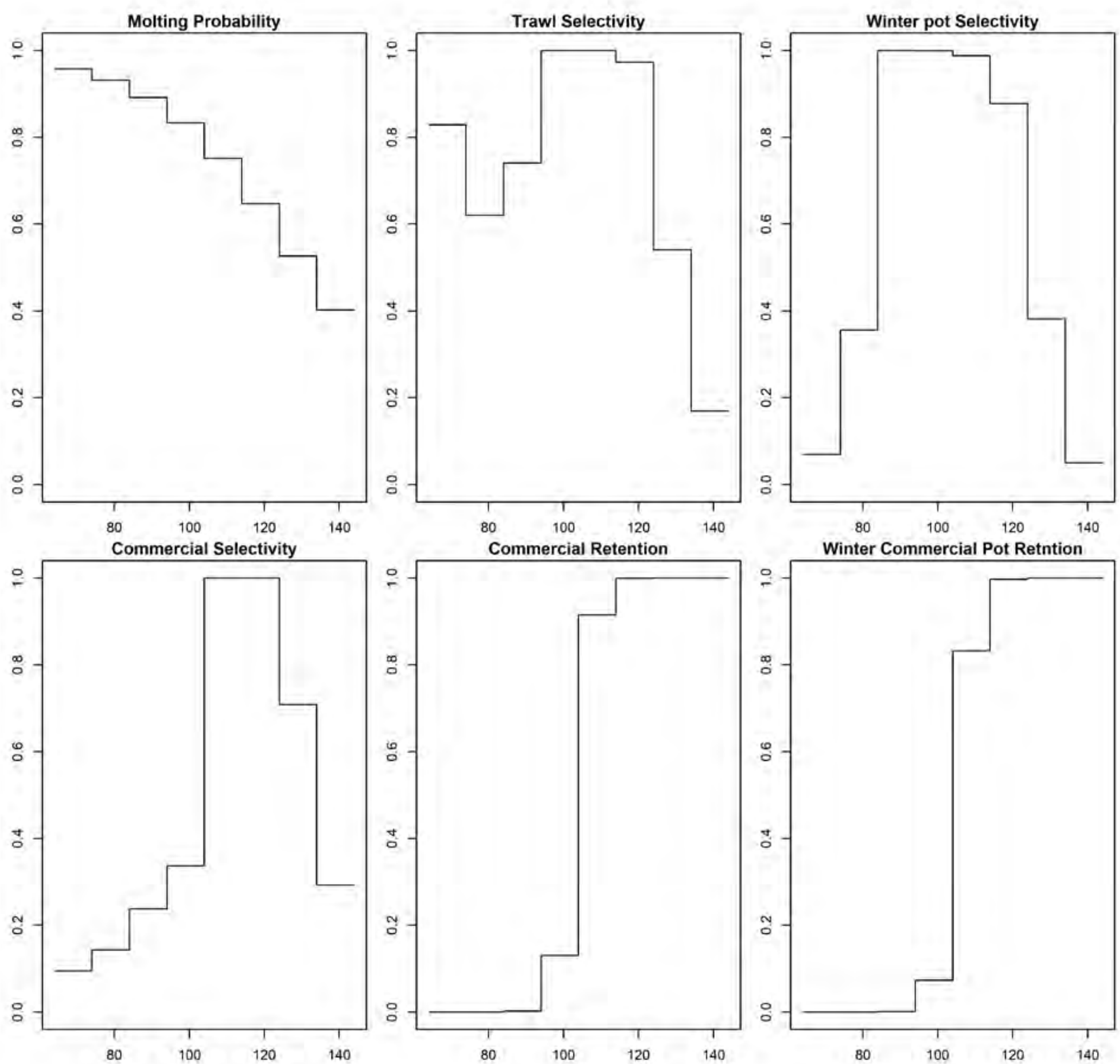


Figure D5-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

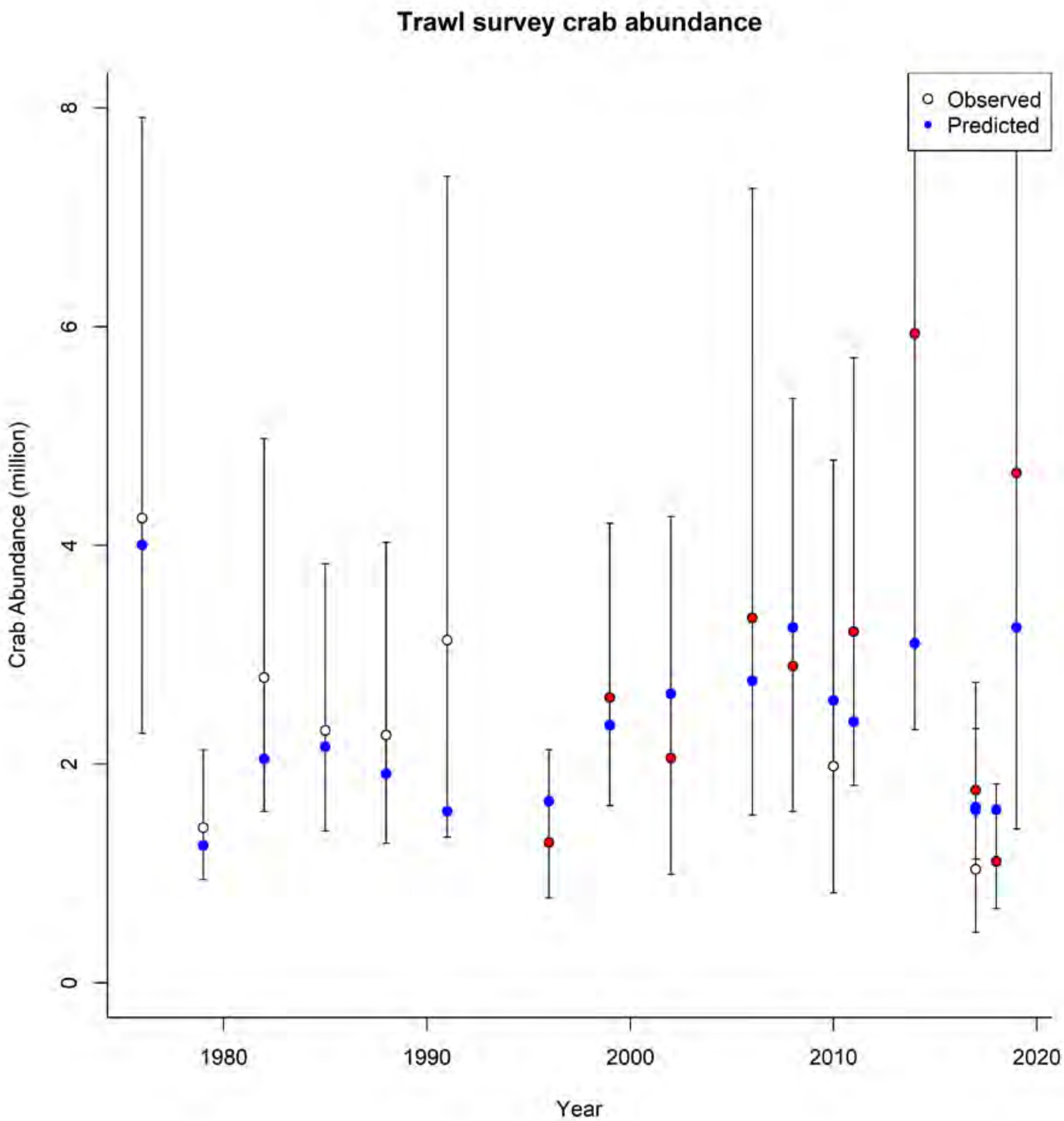


Figure D5-4. Estimated trawl survey male abundance (blue) (crab >= 64 mm CL). Observed: White: NOAA trawl survey, Red: ADG&G trawl survey

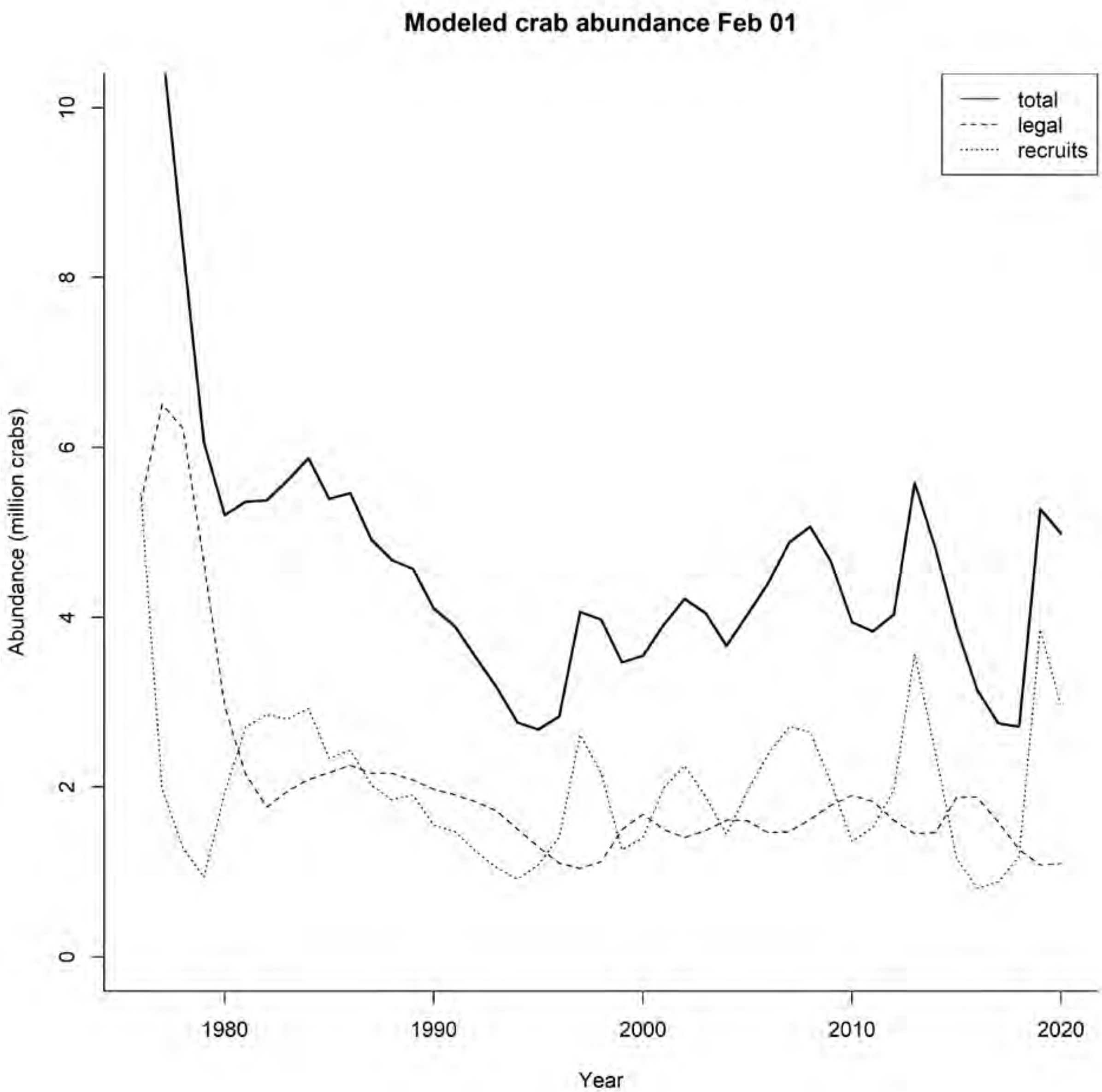


Figure D5-5. Estimated abundance of legal males.

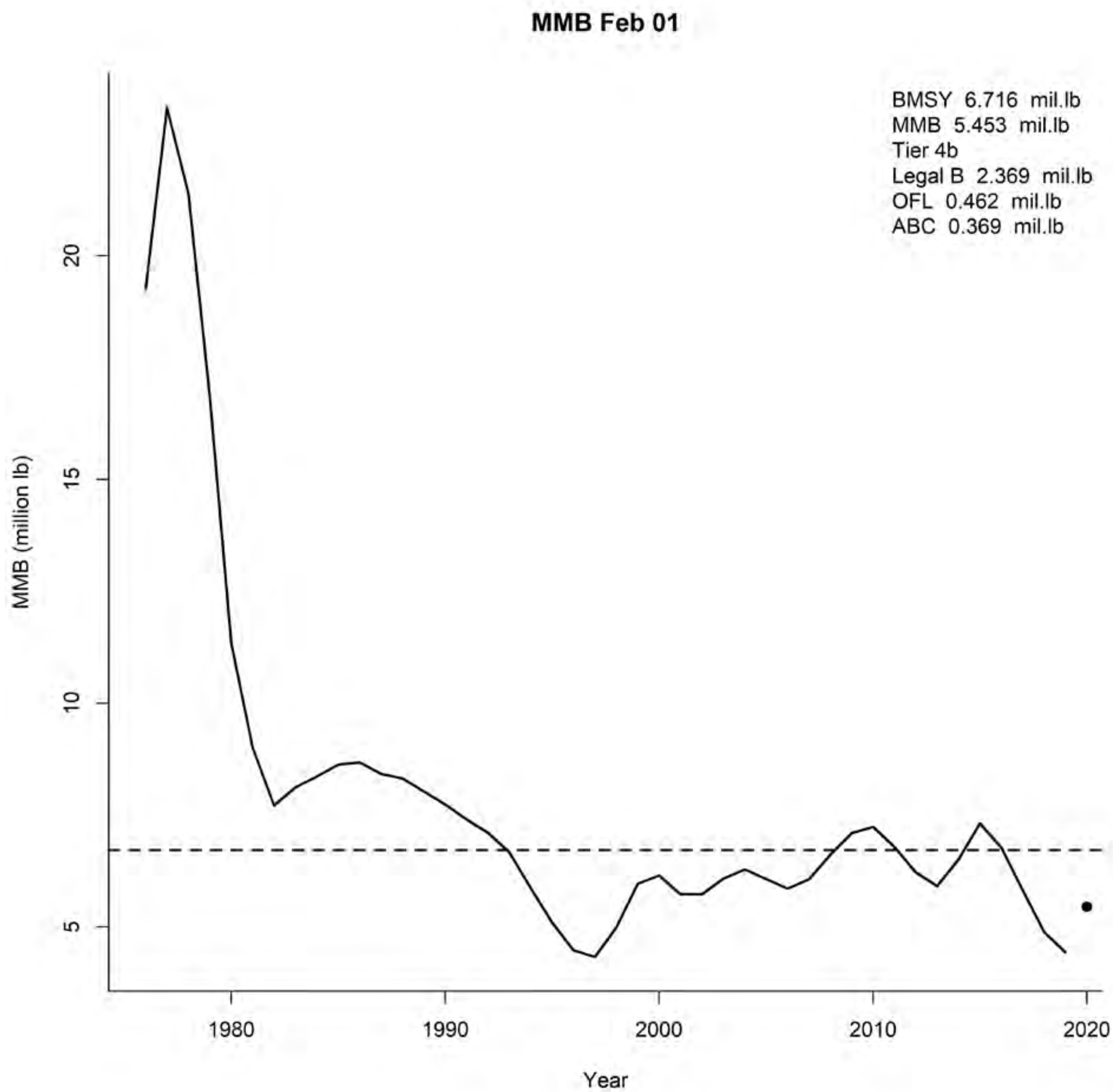


Figure D5-6. Estimated abundance of Mature Male Biomass. Dash line shows Bmsy.

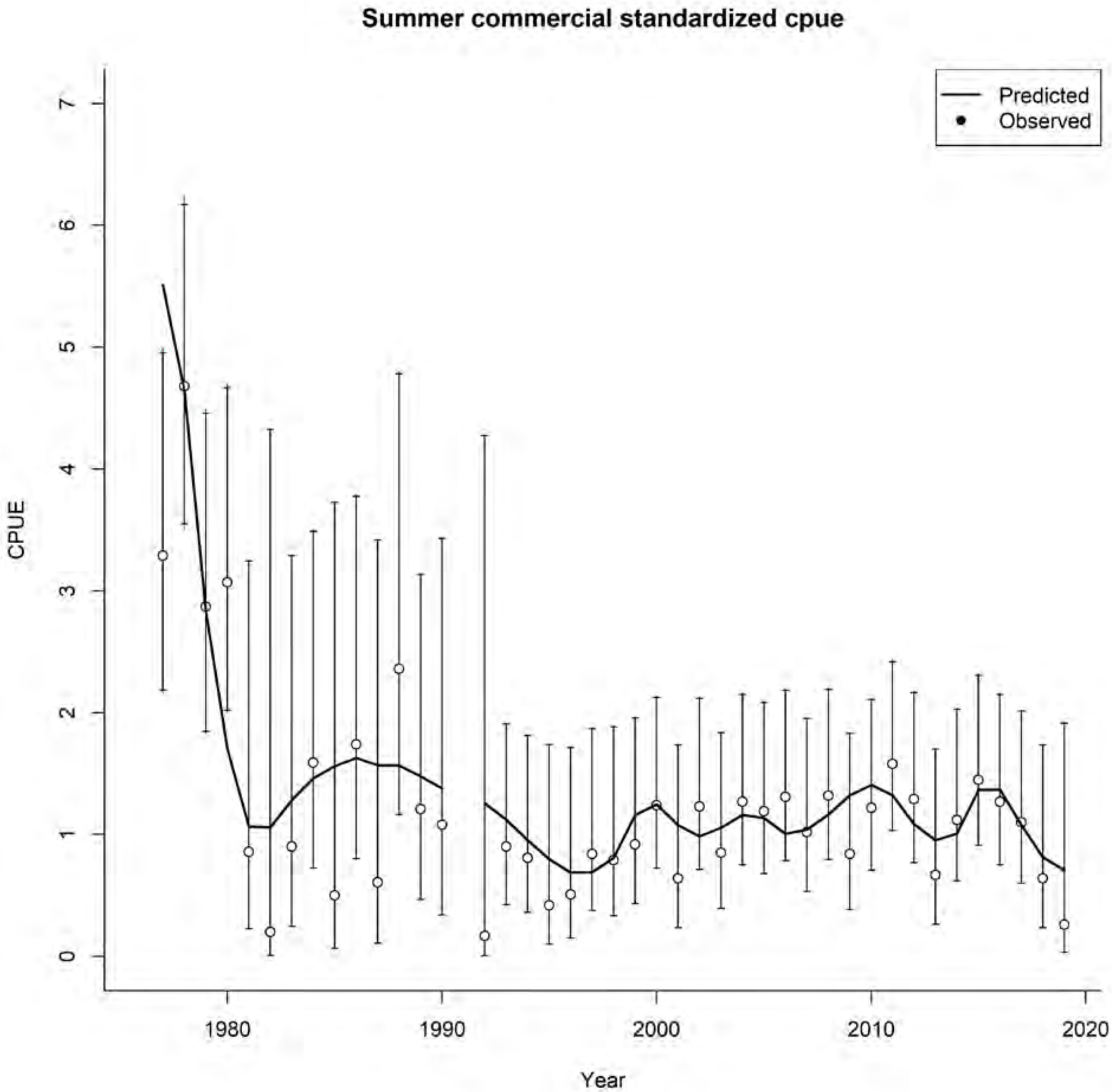


Figure D5-7. Summer commercial standardized cpue.

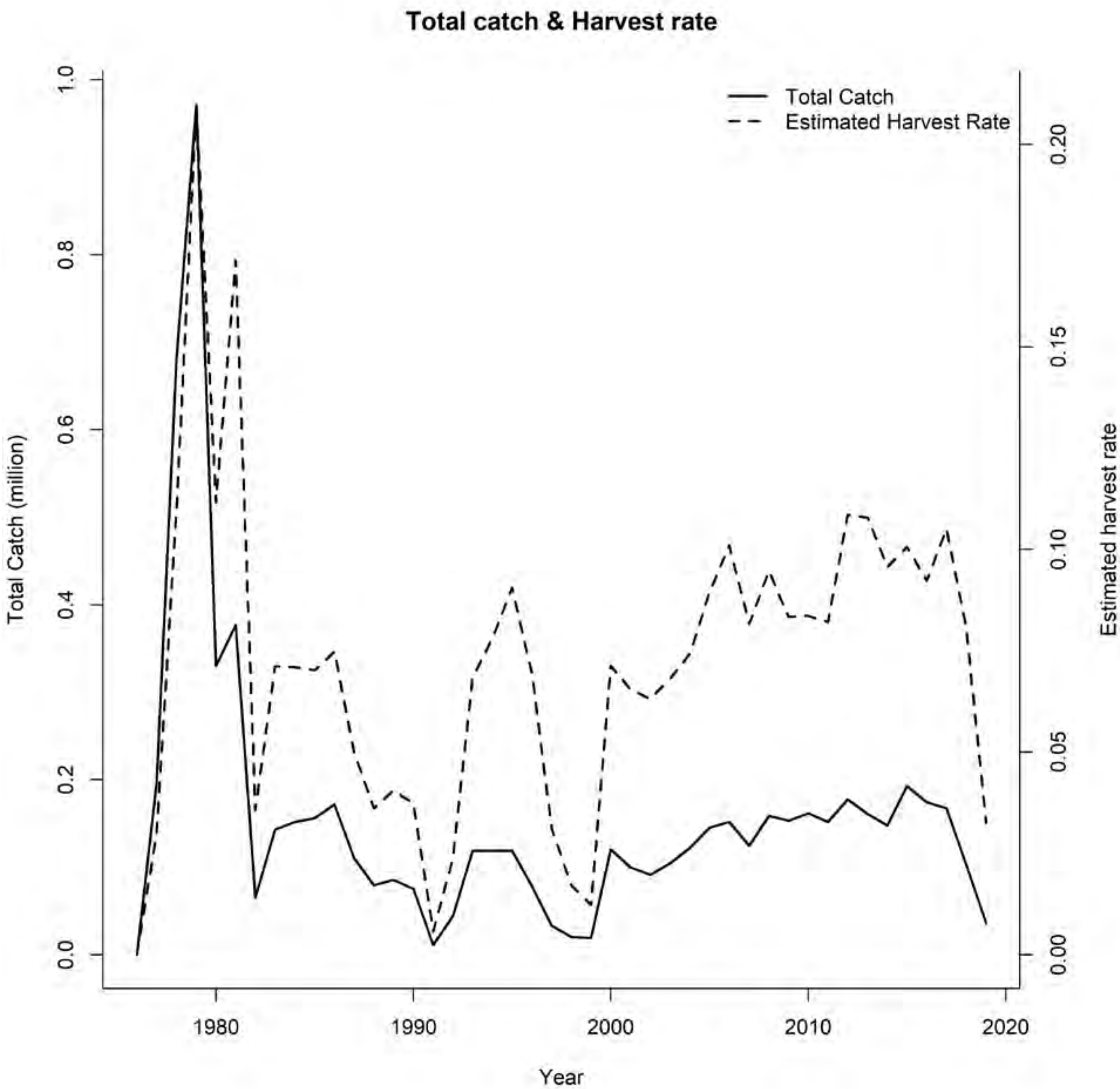


Figure D5-8. Total catch and estimated harvest rate.

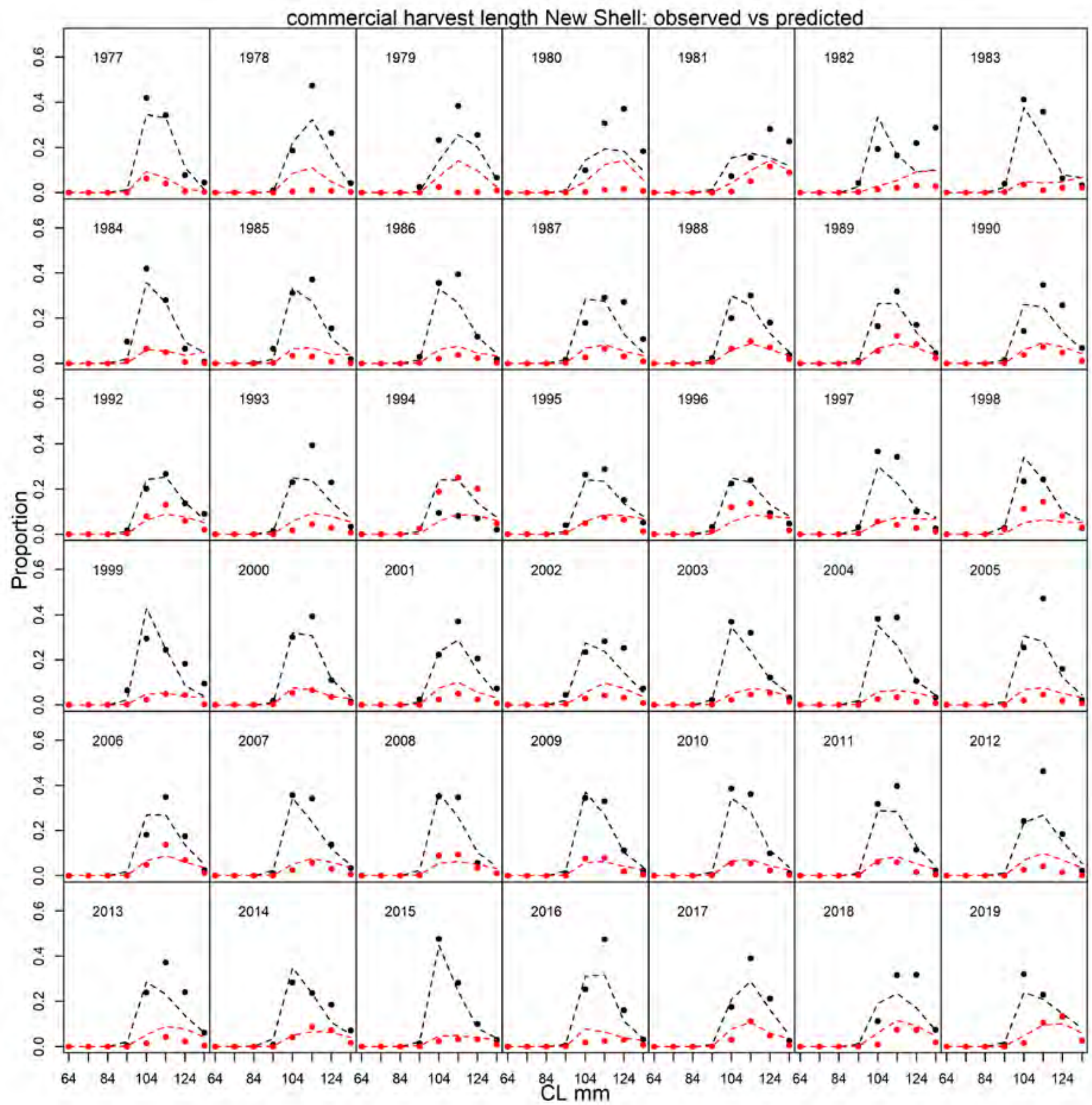


Figure D5-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Black: newshell, Red: oldshell

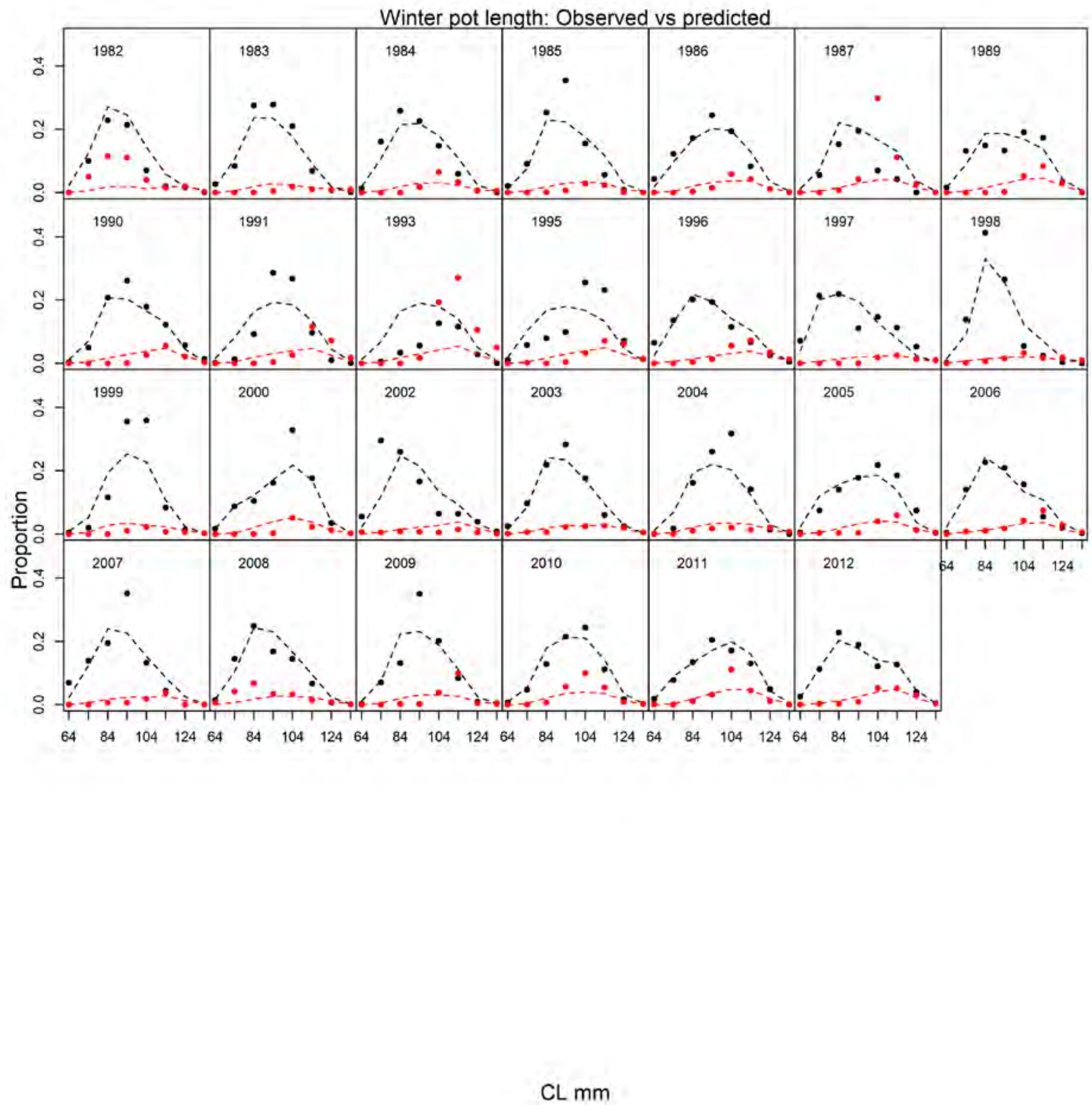


Figure D5-10. Predicted (dashed line) vs. observed (dots) length class proportions for the winter and spring pot survey. Black: newshell, Red: oldshell

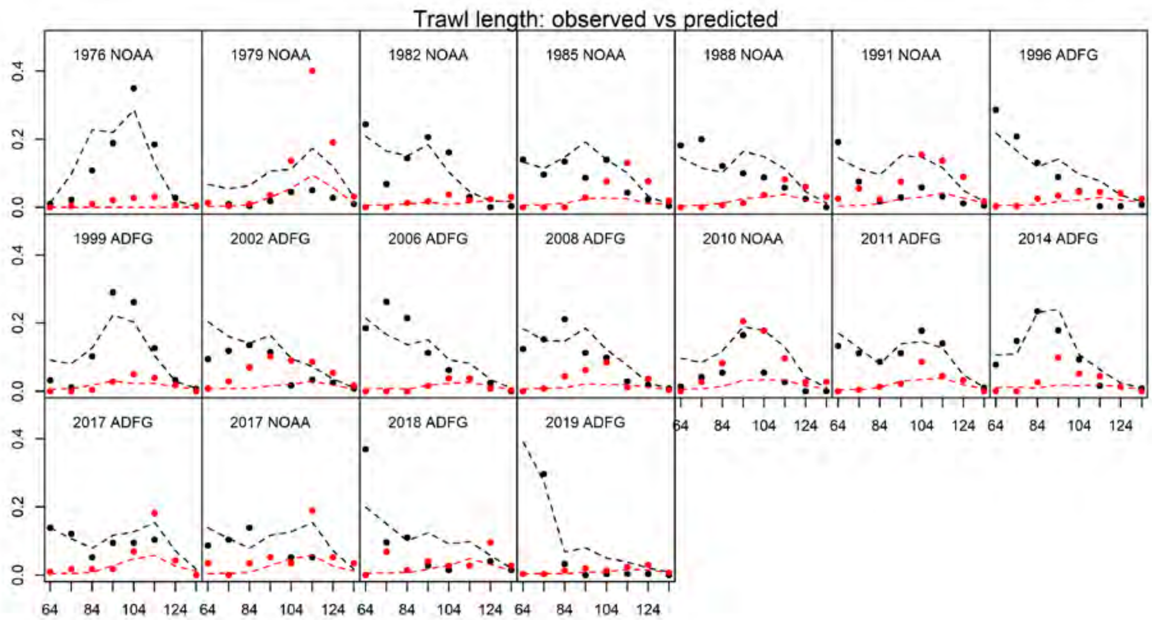


Figure D5-11. Predicted (dashed) vs. observed (dots) length class proportions for trawl survey. Black: newshell, Red: oldshell

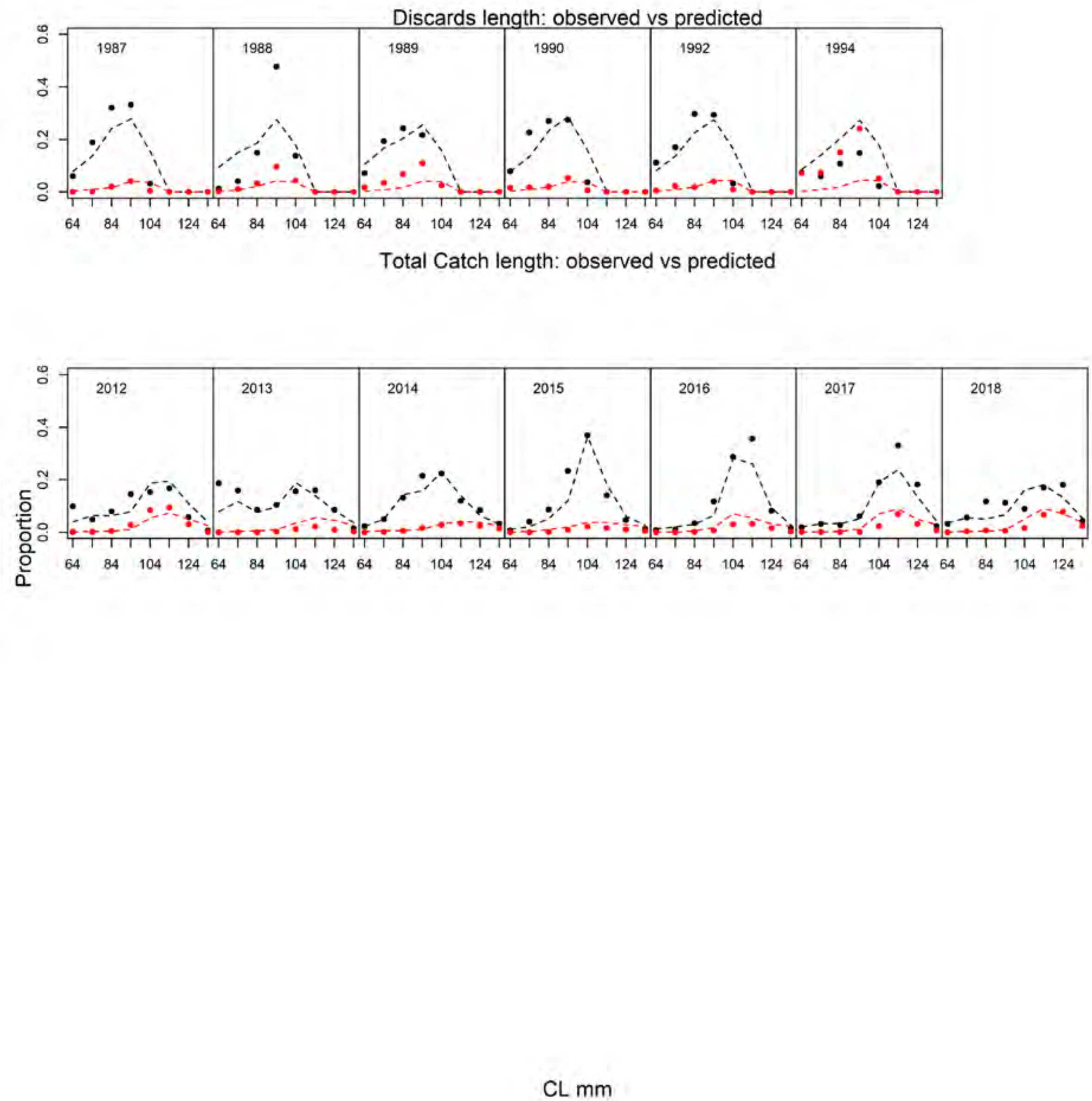


Figure D5-13. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

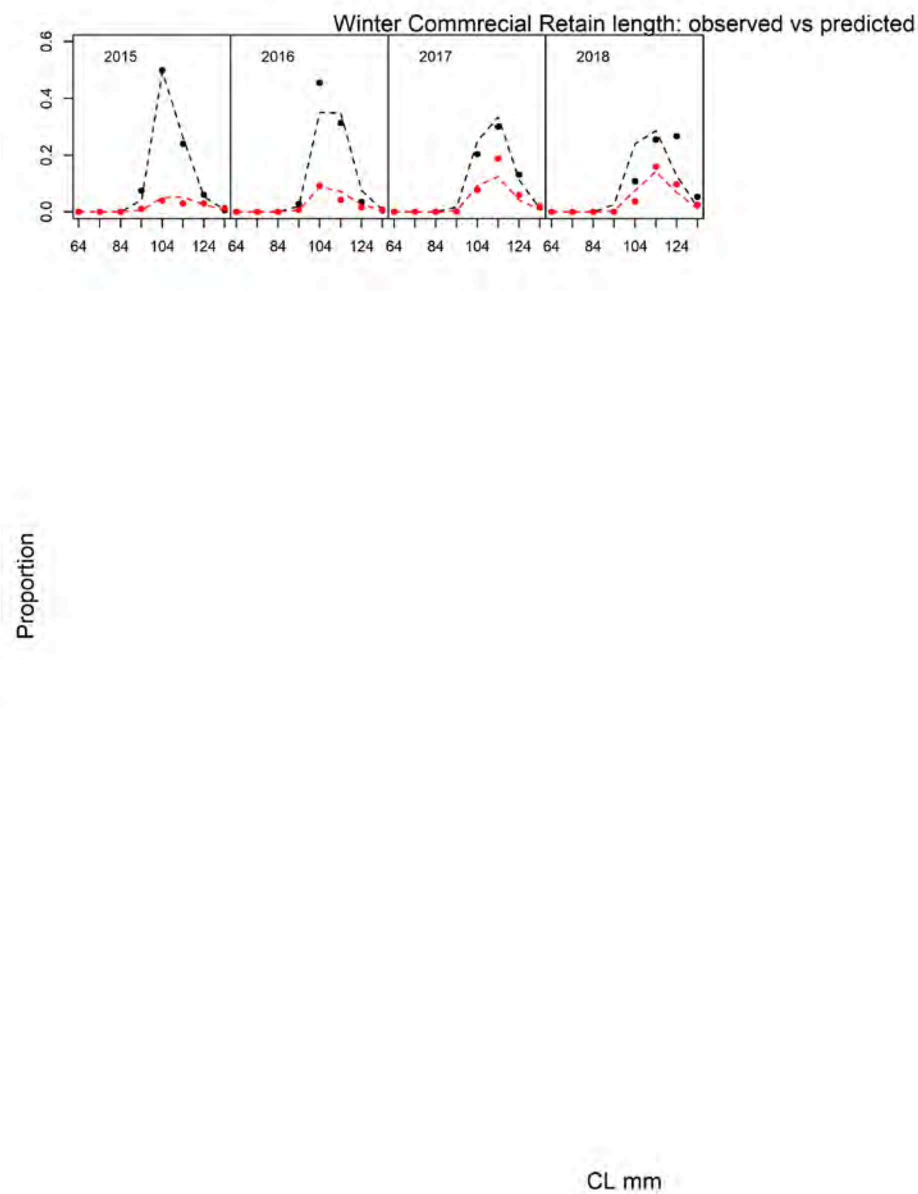


Figure D5-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

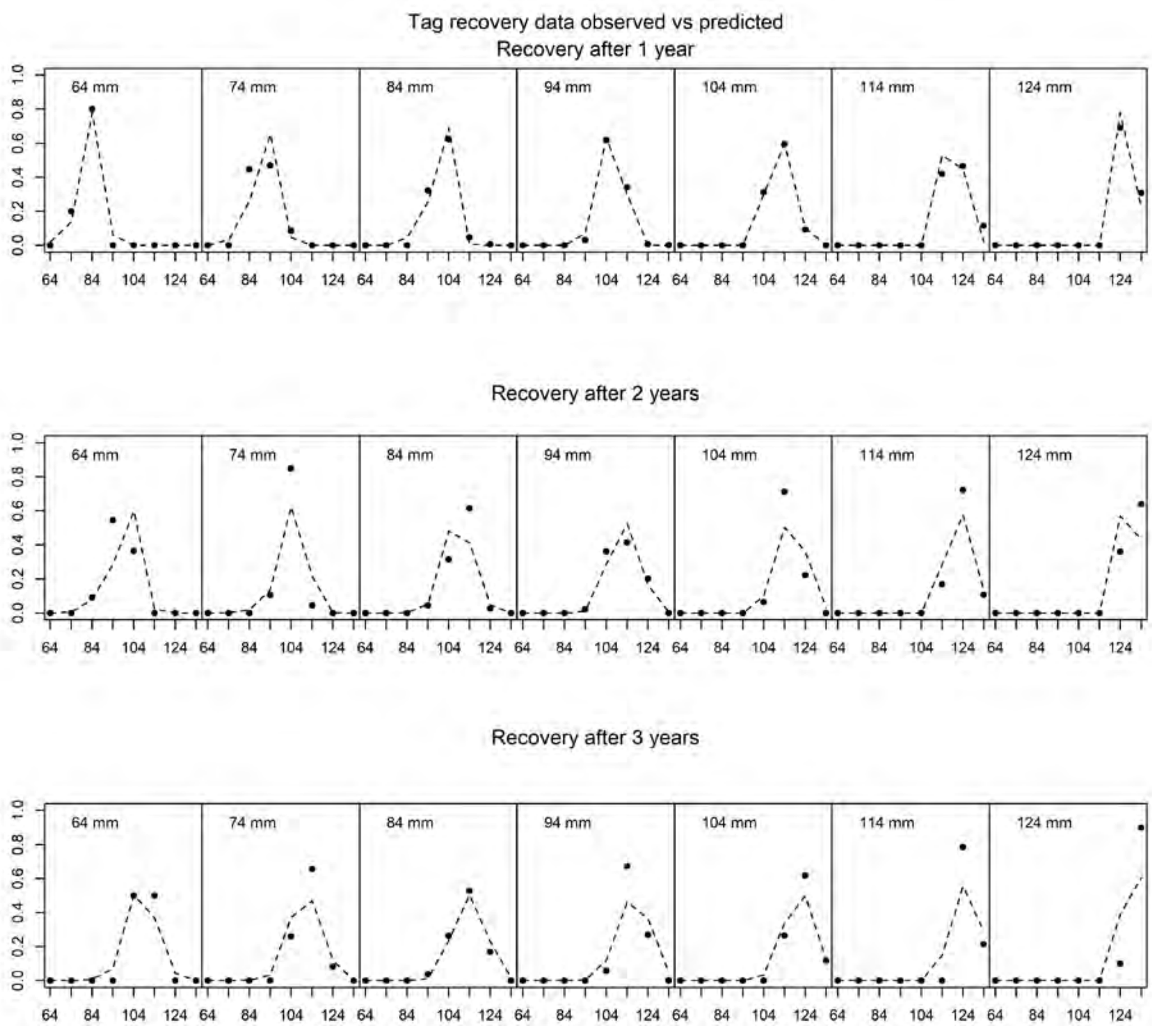


Figure D5-13. Predicted vs. observed length class proportions for tag recovery data.

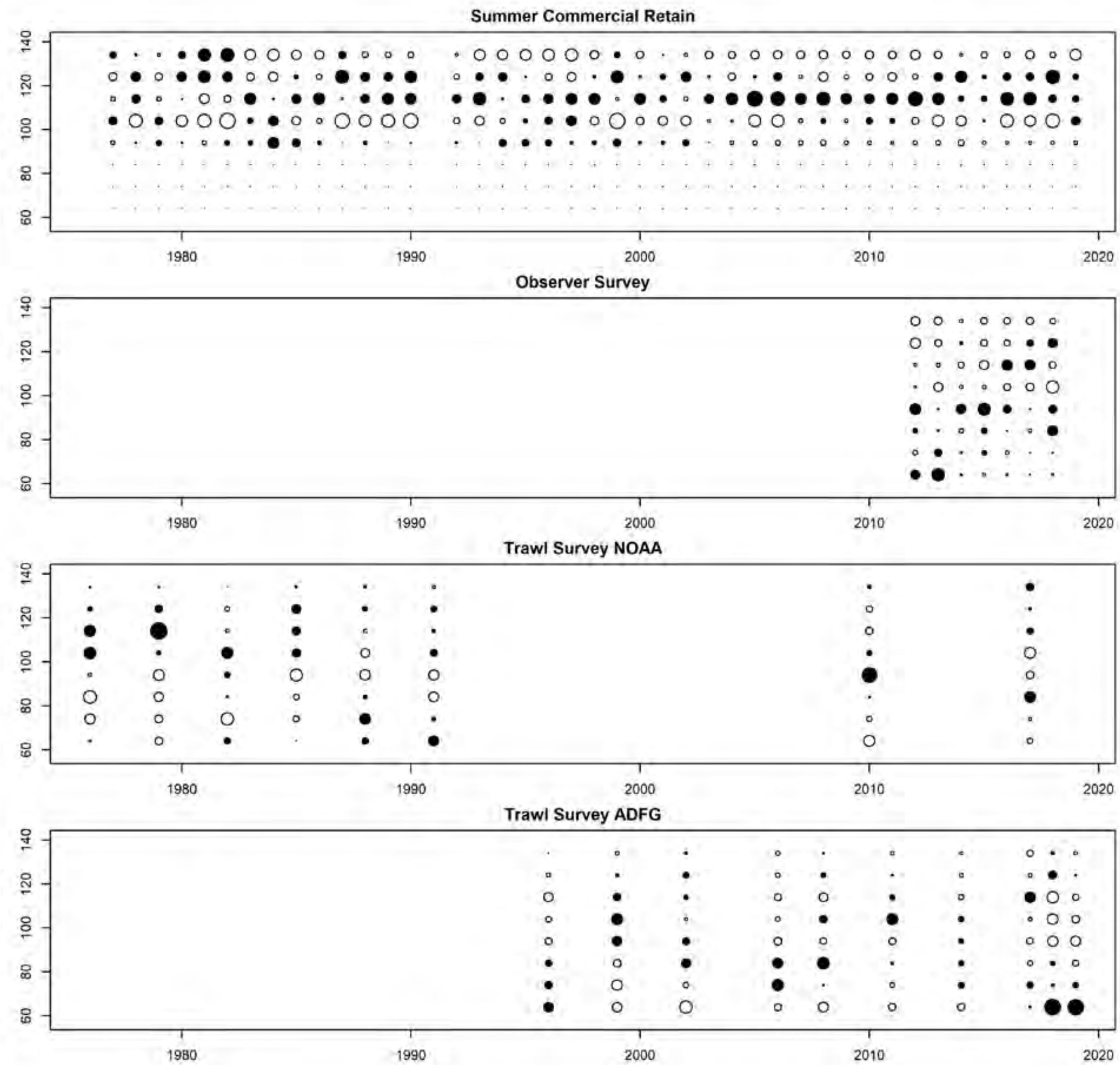


Figure D5-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

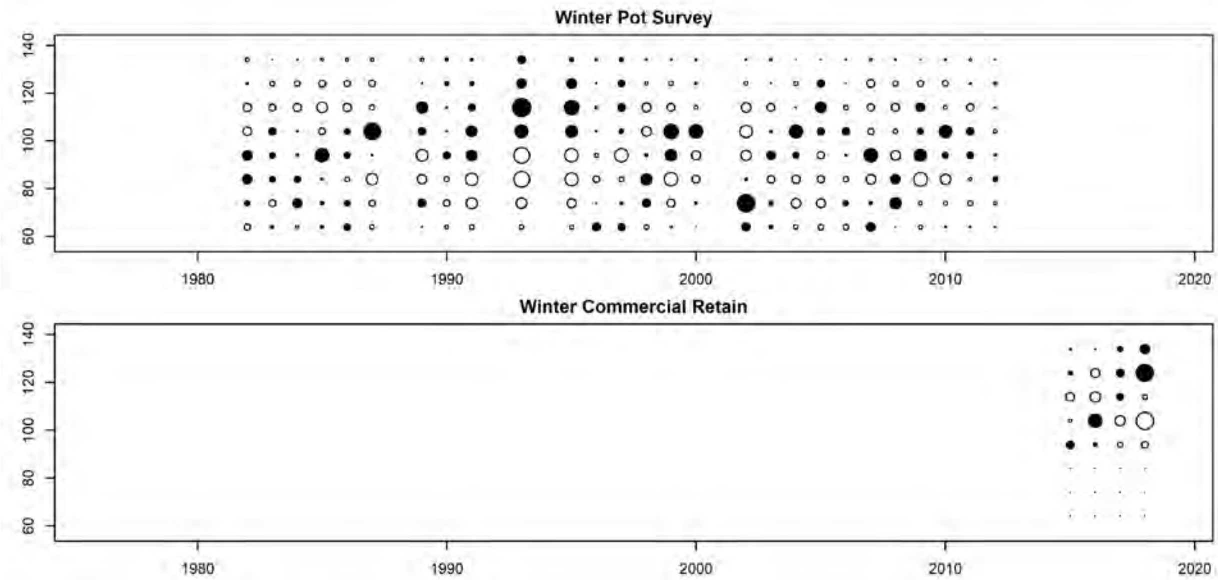


Figure D5-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table D5. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.808	0.138
log_q_2		
log_N_{76}	9.495	0.152
R_0	6.992	0.160
a_1	-0.371	3.653
a_2	1.857	2.993
a_3	2.514	2.818
a_4	2.178	2.818
a_5	2.439	2.803
a_6	1.663	2.856
a_7	0.349	3.350
r1	10.000	0.574
r2	9.895	0.660
log_a	-2.994	0.123
log_b	4.872	0.028
log_ϕ_{st1}		
log_ϕ_{wa}	-1.405	0.272
log_ϕ_{wb}	4.840	0.018
Sw1	0.069	0.034
Sw2	0.356	0.090
log_ϕ_I		
$log\_\phi ra$	-0.852	0.146
$log\_\phi rb$	4.634	0.010
$log\_\phi wra$	-0.883	0.607
$log\_\phi wrb$	4.650	0.040
w^2_t	0.002	0.020
q	0.658	0.109
σ	0.310	0.041
β_1	3.978	0.240
β_2	9.764	1.053

name	Estimate	std.dev
selc 1	0.094	0.039
selc 2	0.143	0.044
selc 3	0.237	0.060
selc 4	0.337	0.055
selc 5	0.653	0.198
selc 6	1.000	0.000
selc 7	0.708	0.099
selc 8	0.292	0.121
selt 1	0.829	0.212
selt 2	0.620	0.129
selt 3	0.741	0.144
selt 4	0.890	0.281
selt 5	1.000	0.000
selt 6	0.973	0.170
selt 7	0.540	0.148
selt 8	0.169	0.092

Appendix D - Model 19.5

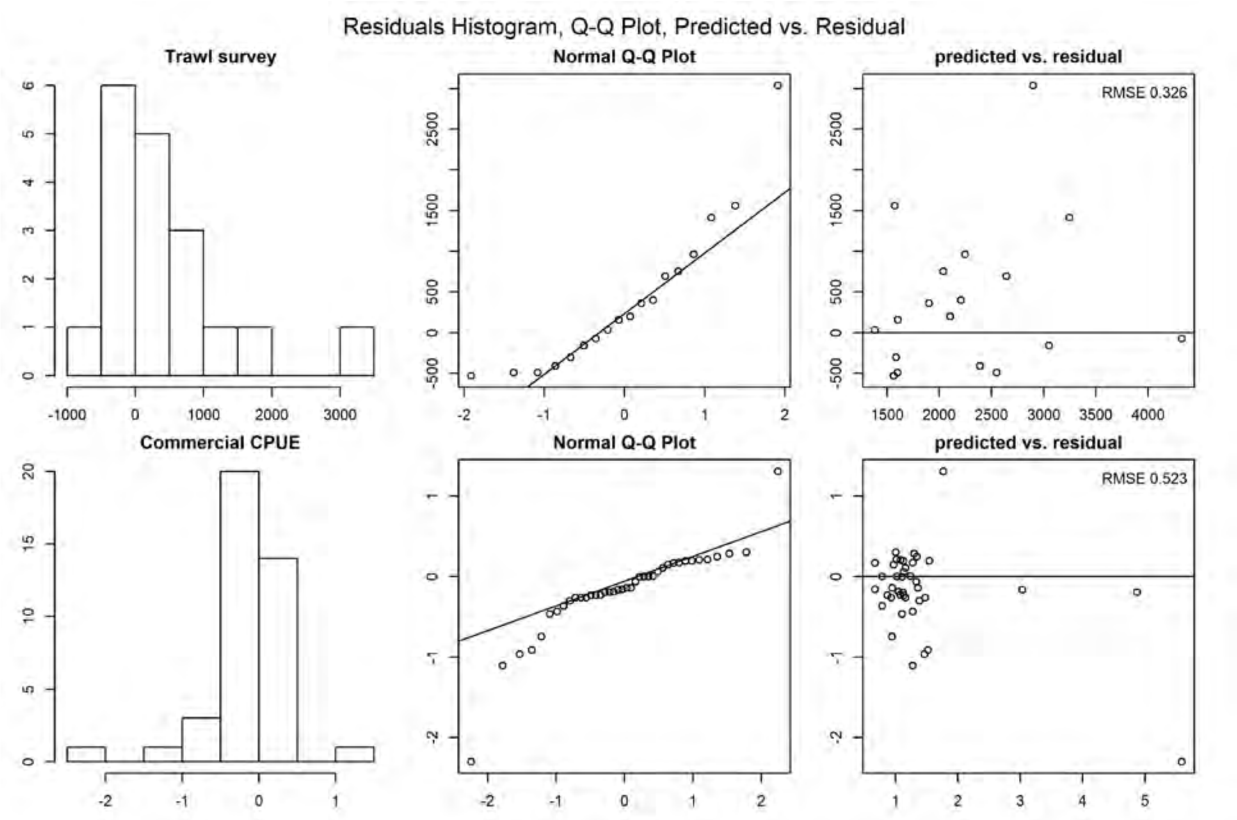


Figure D6-1. QQ Plot of Trawl survey and commercial CPUE.

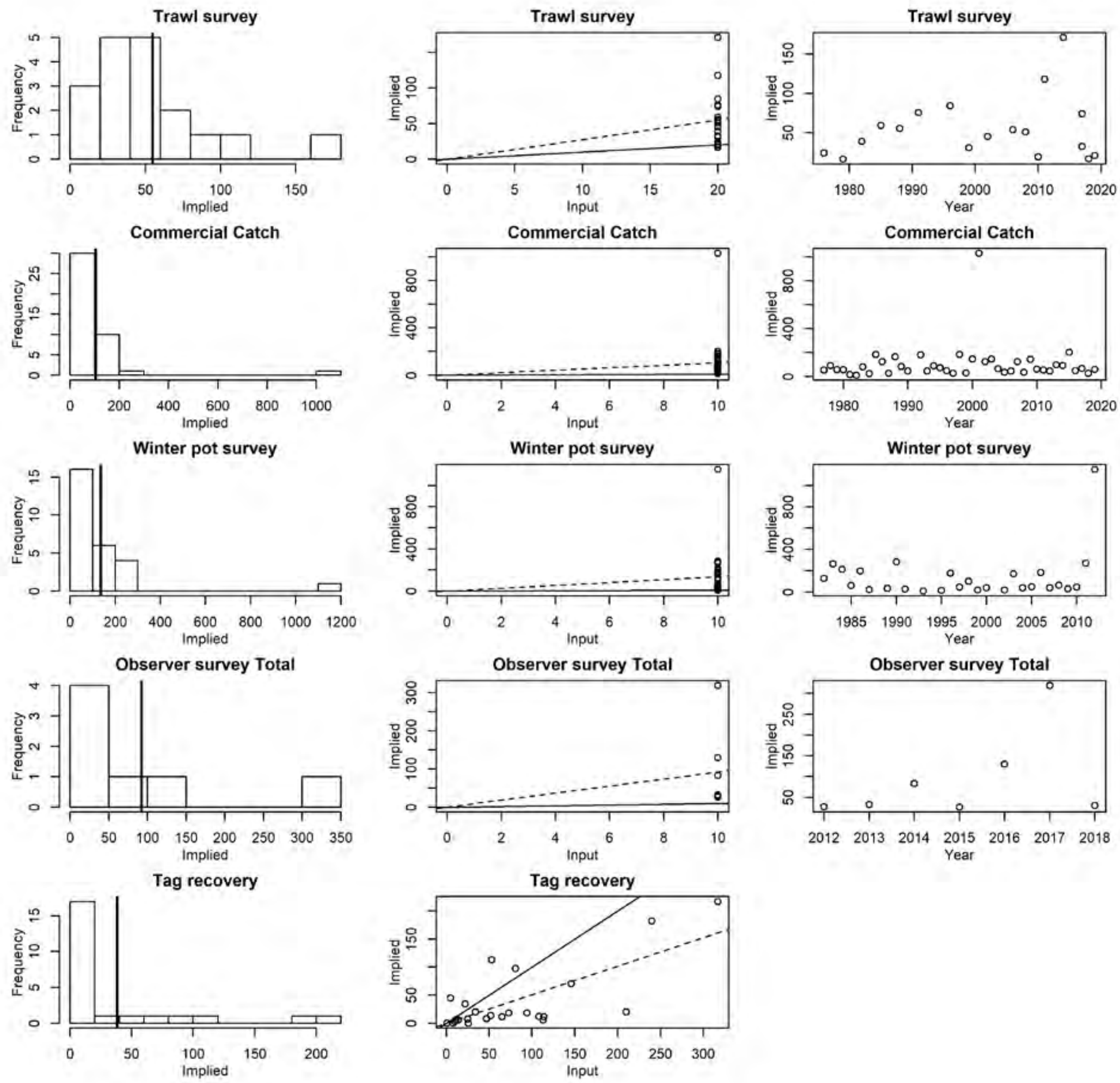


Figure D6-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column shows input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

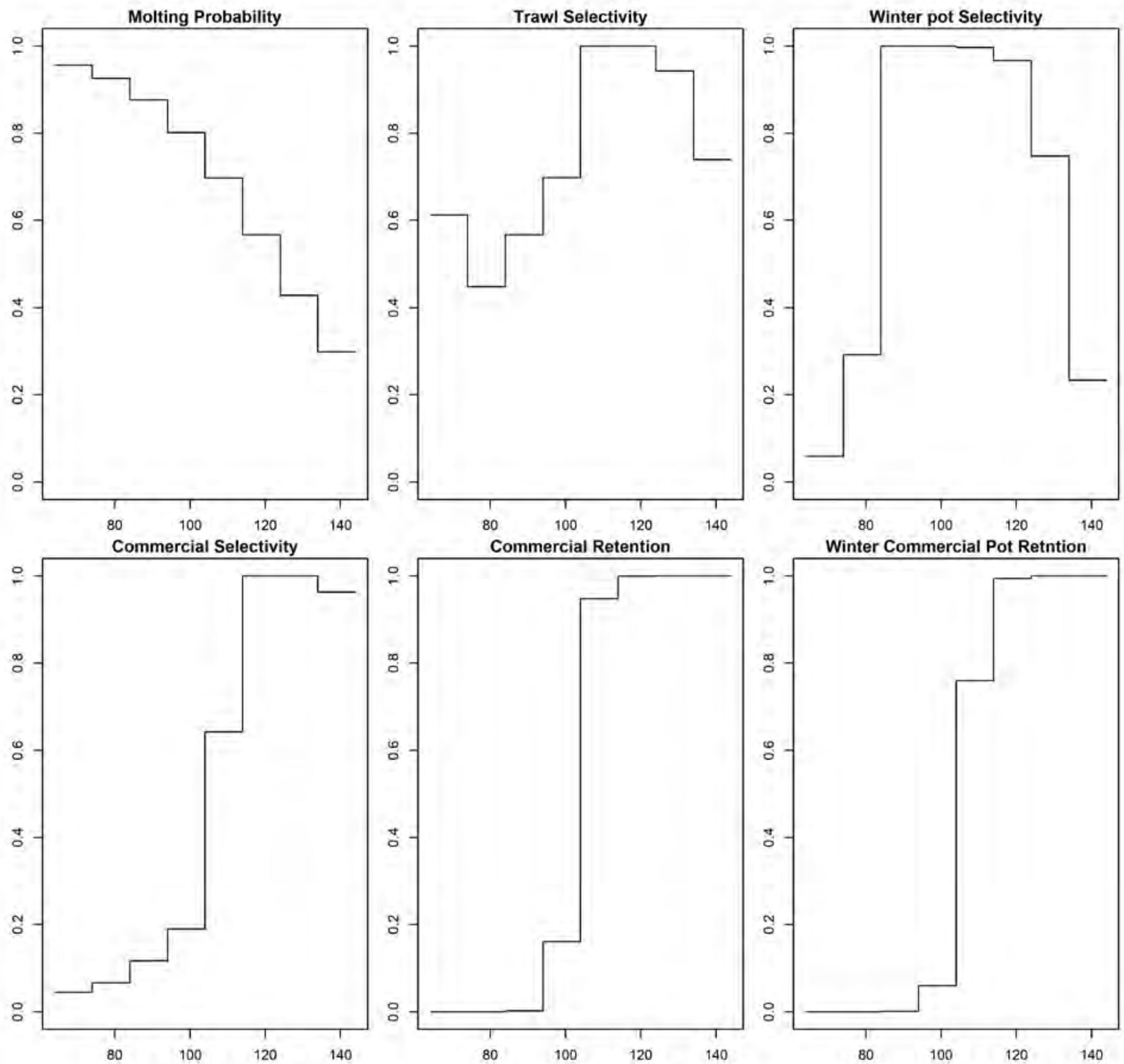


Figure D6-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

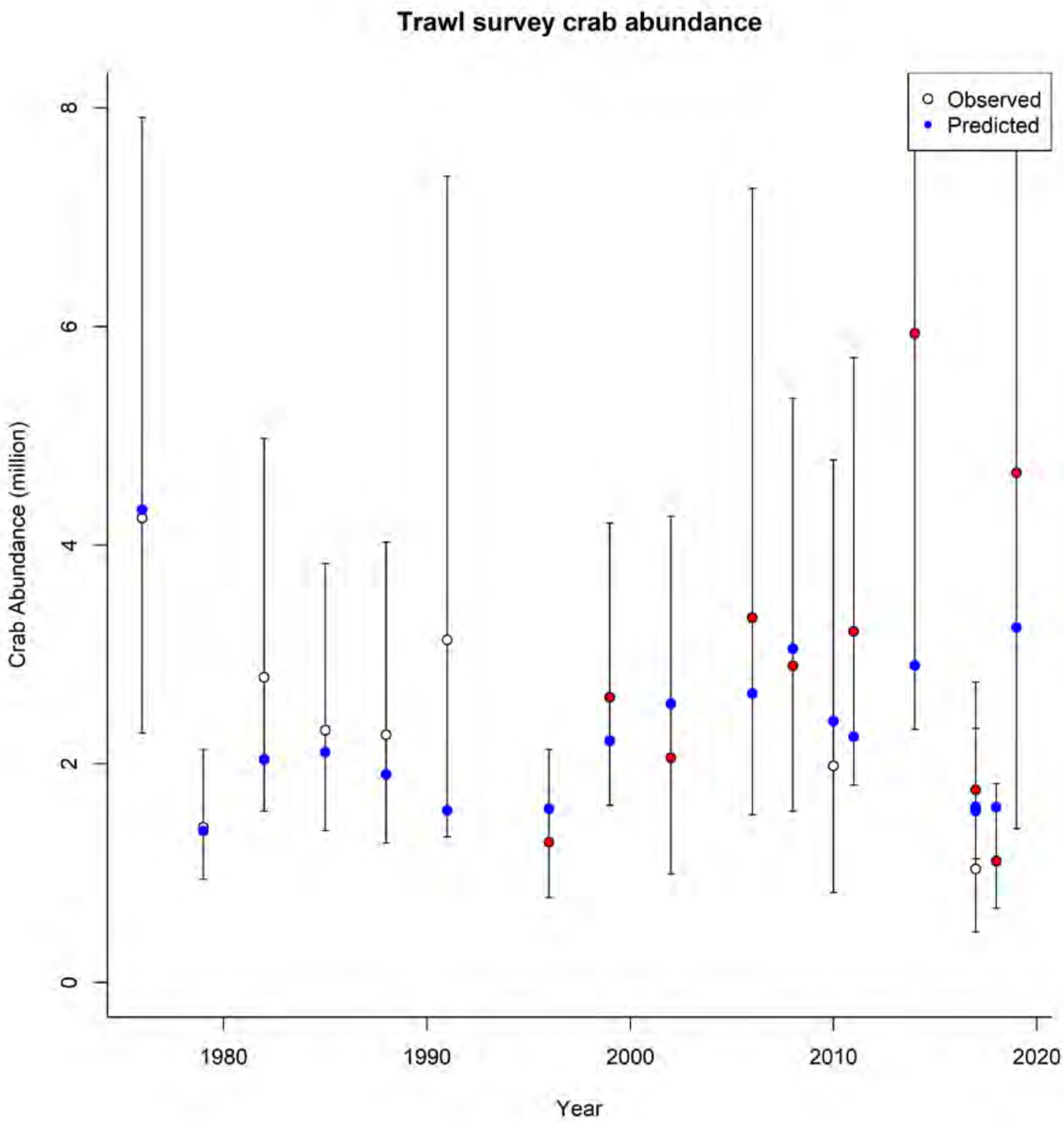


Figure D6-4. Estimated trawl survey male abundance (blue) (crab >= 64 mm CL). Observed: White: NOAA trawl survey, Red: ADG&G trawl survey

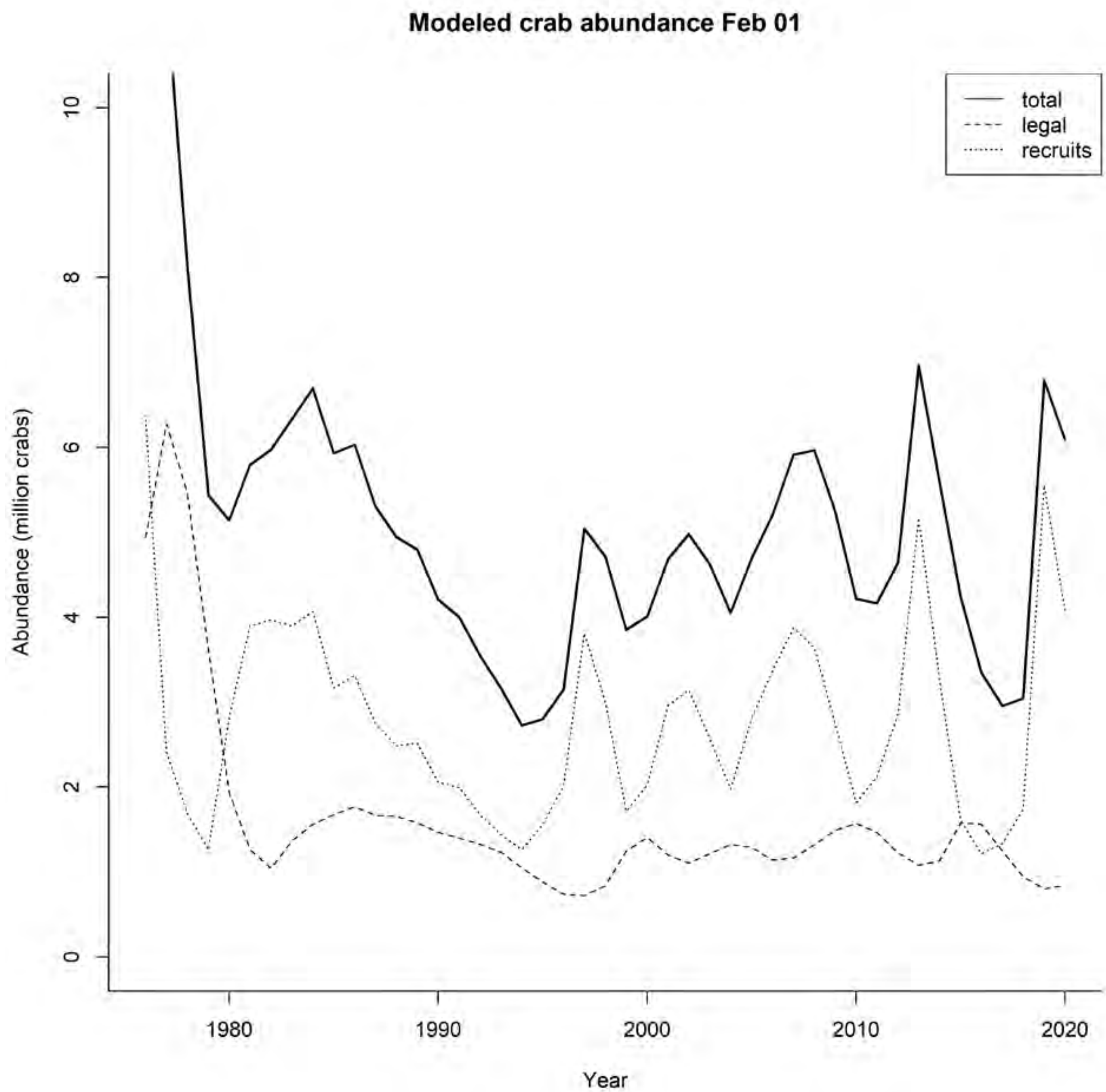


Figure D6-5. Estimated abundance of legal males.

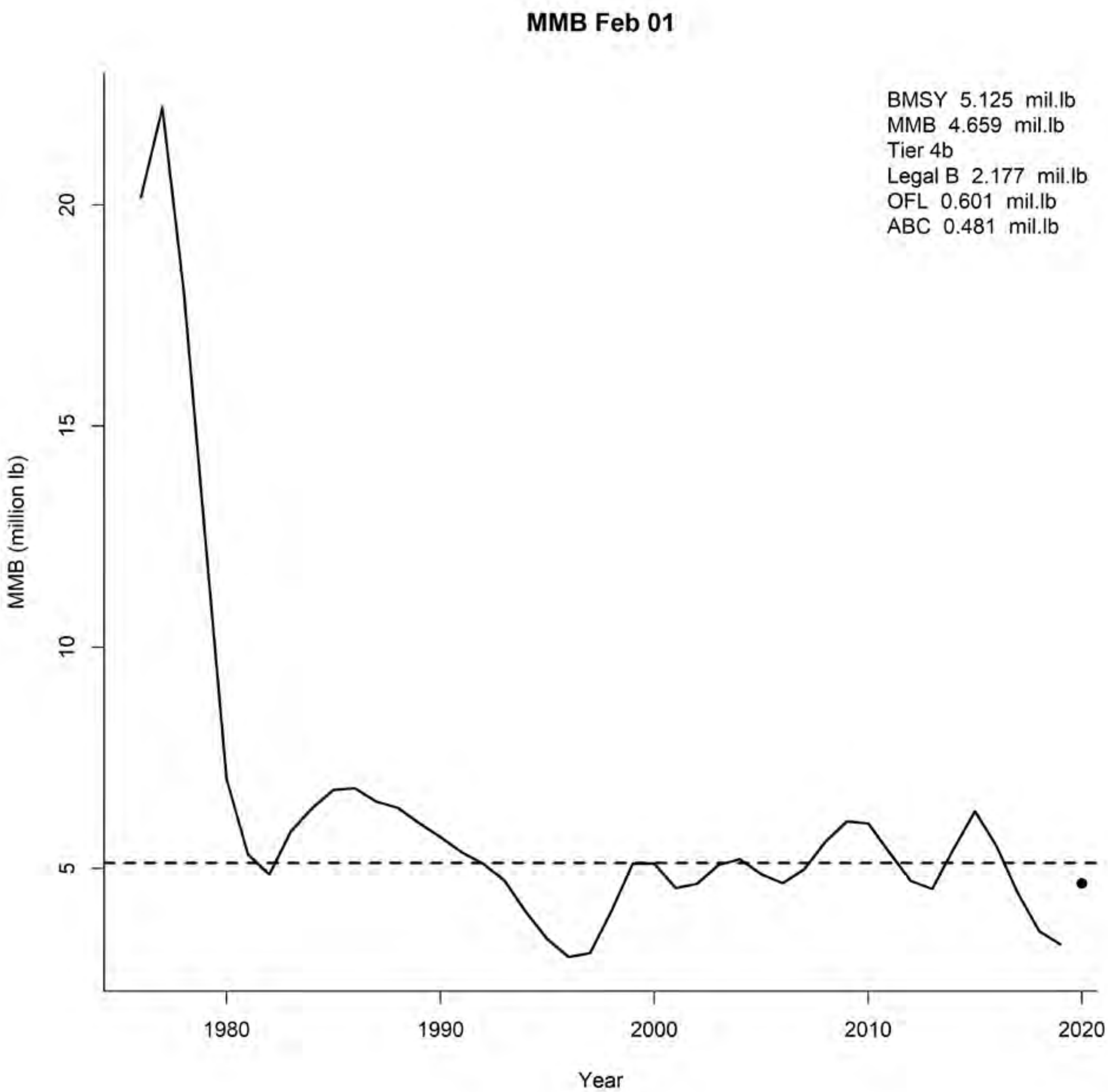


Figure D6-6. Estimated abundance of Mature Male Biomass. Dash line shows Bmsy.

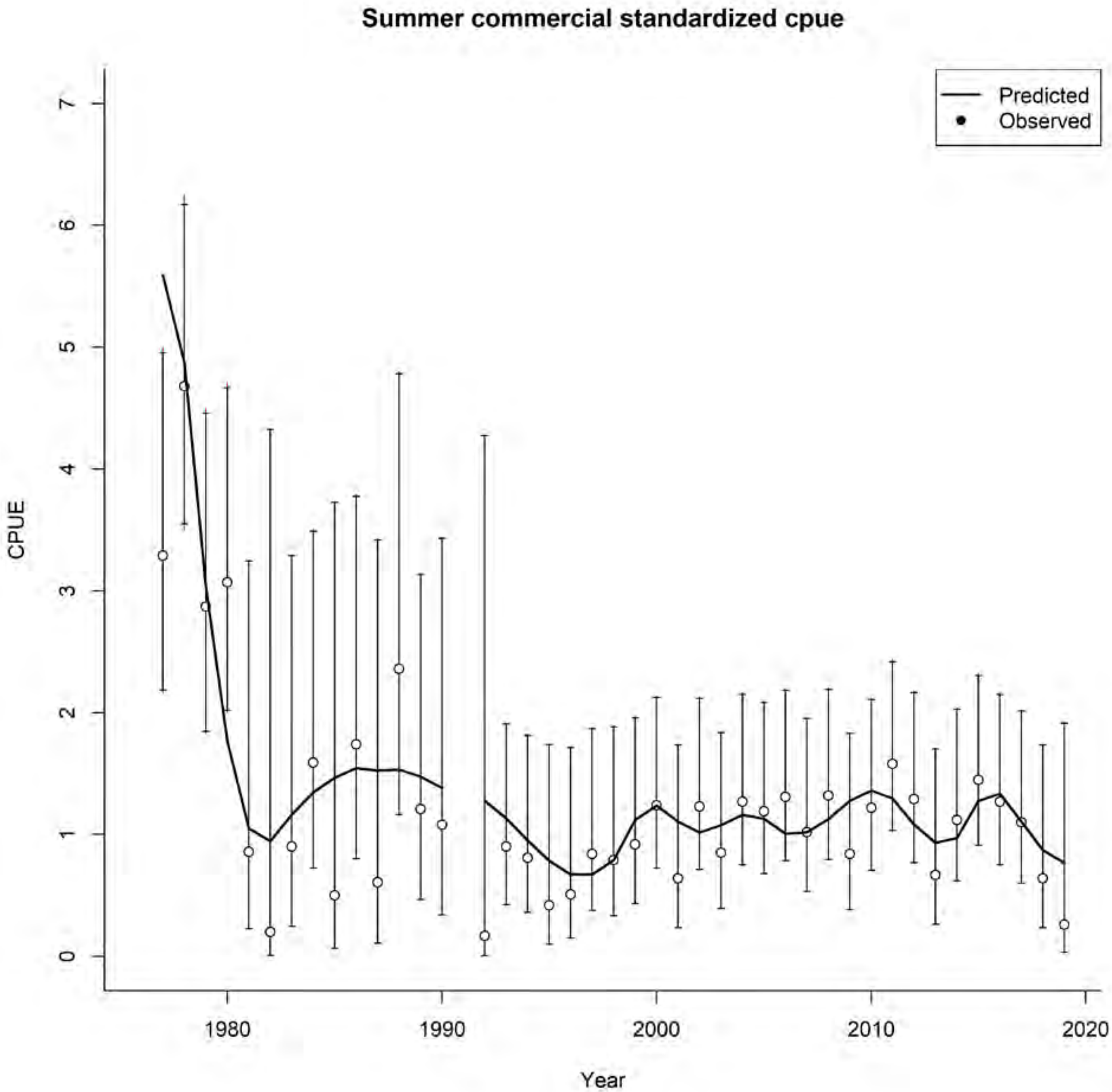


Figure D6-7. Summer commercial standardized cpue.

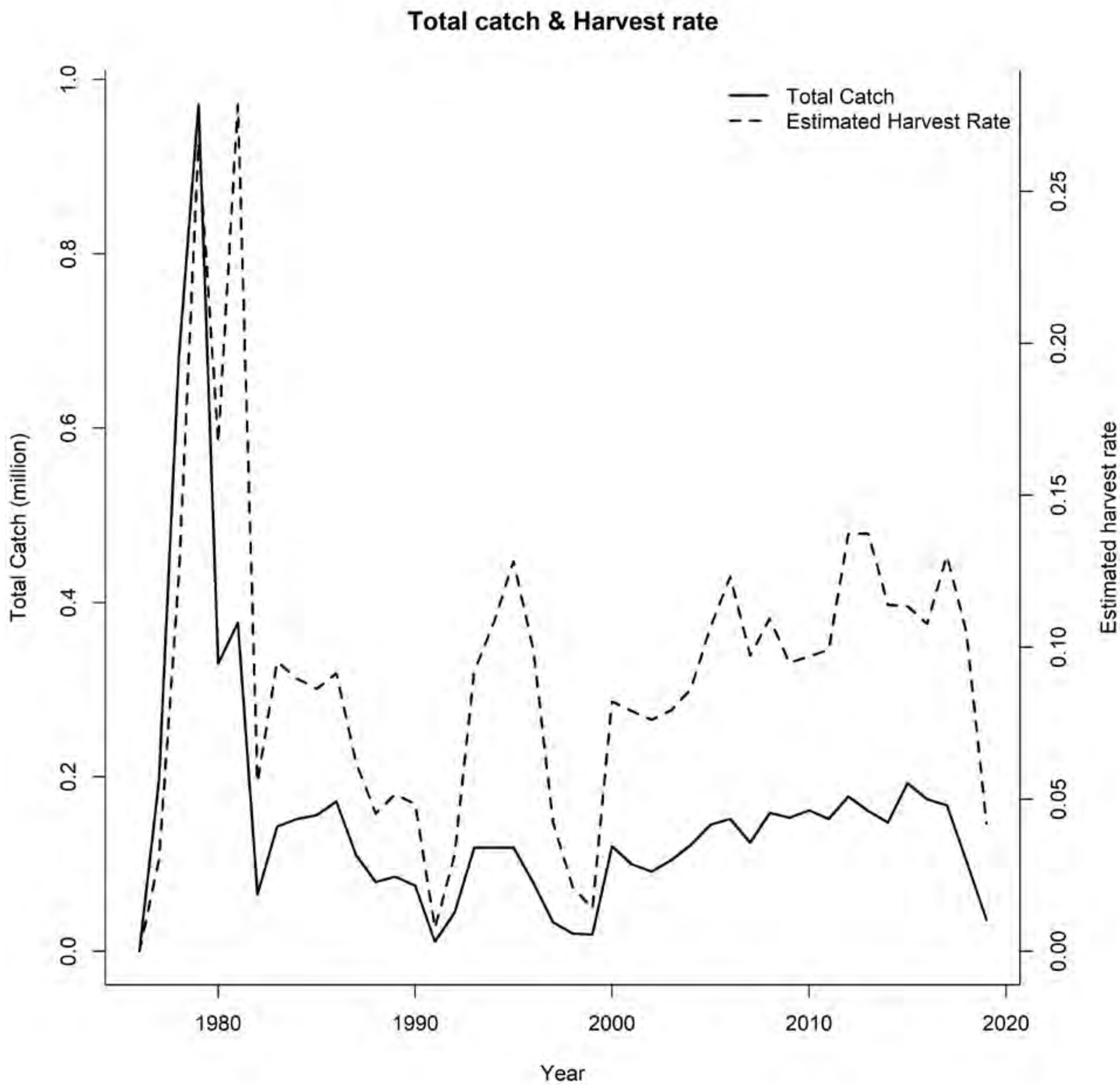


Figure D6-8. Total catch and estimated harvest rate.

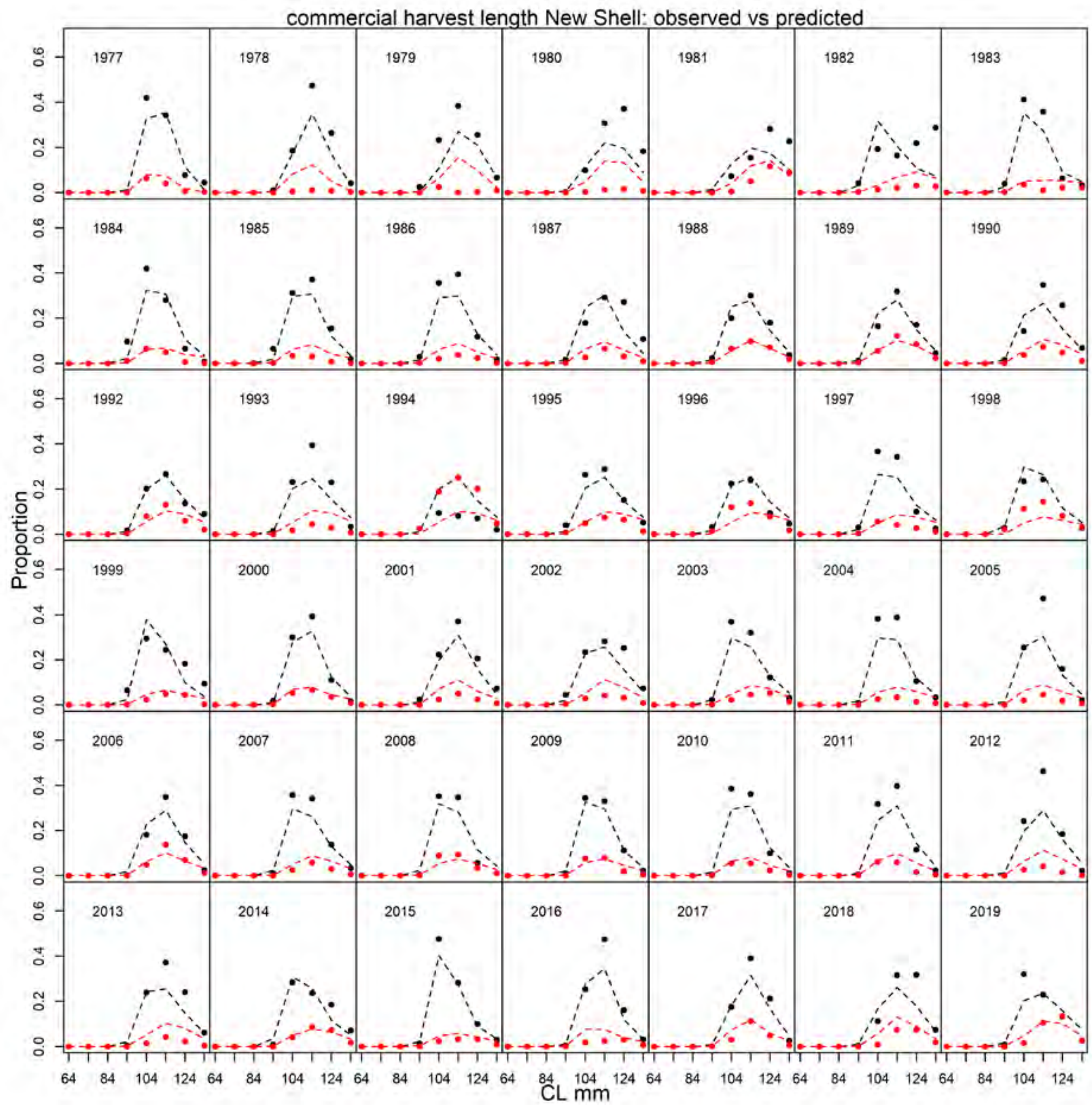


Figure D6-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Black: newshell, Red: oldshell

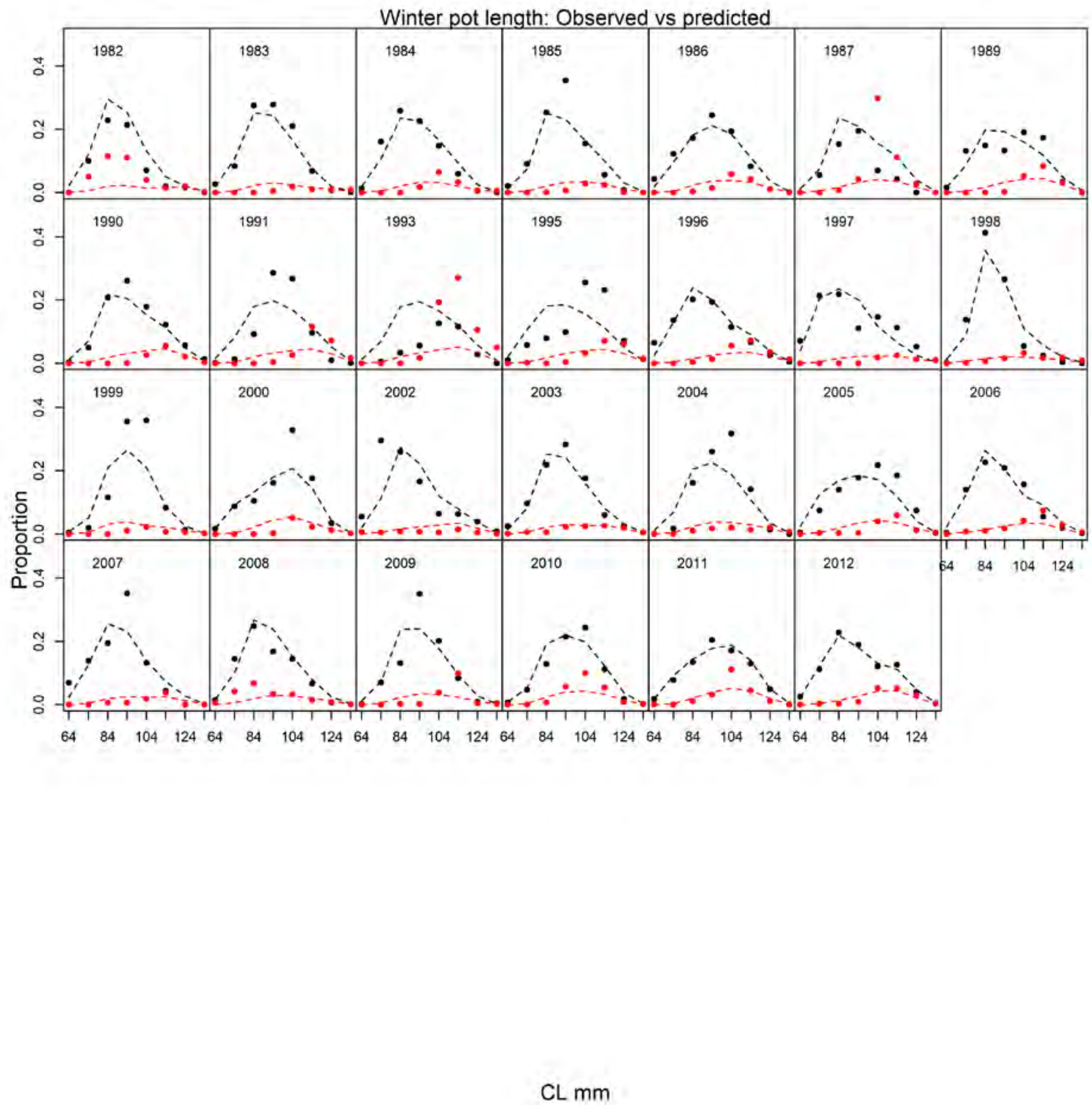


Figure D6-10. Predicted (dashed line) vs. observed (dots) length class proportions for the winter and spring pot survey. Black: newshell, Red: oldshell

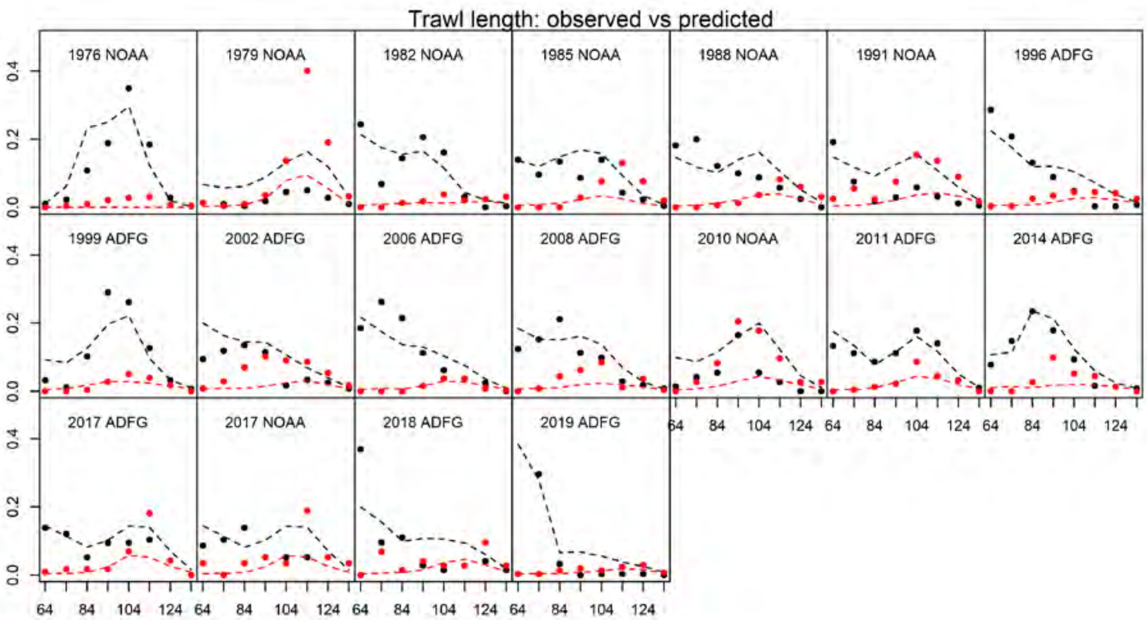


Figure D6-11. Predicted (dashed) vs. observed (dots) length class proportions fo Black: newshell, Red: oldshell r trawl survey.

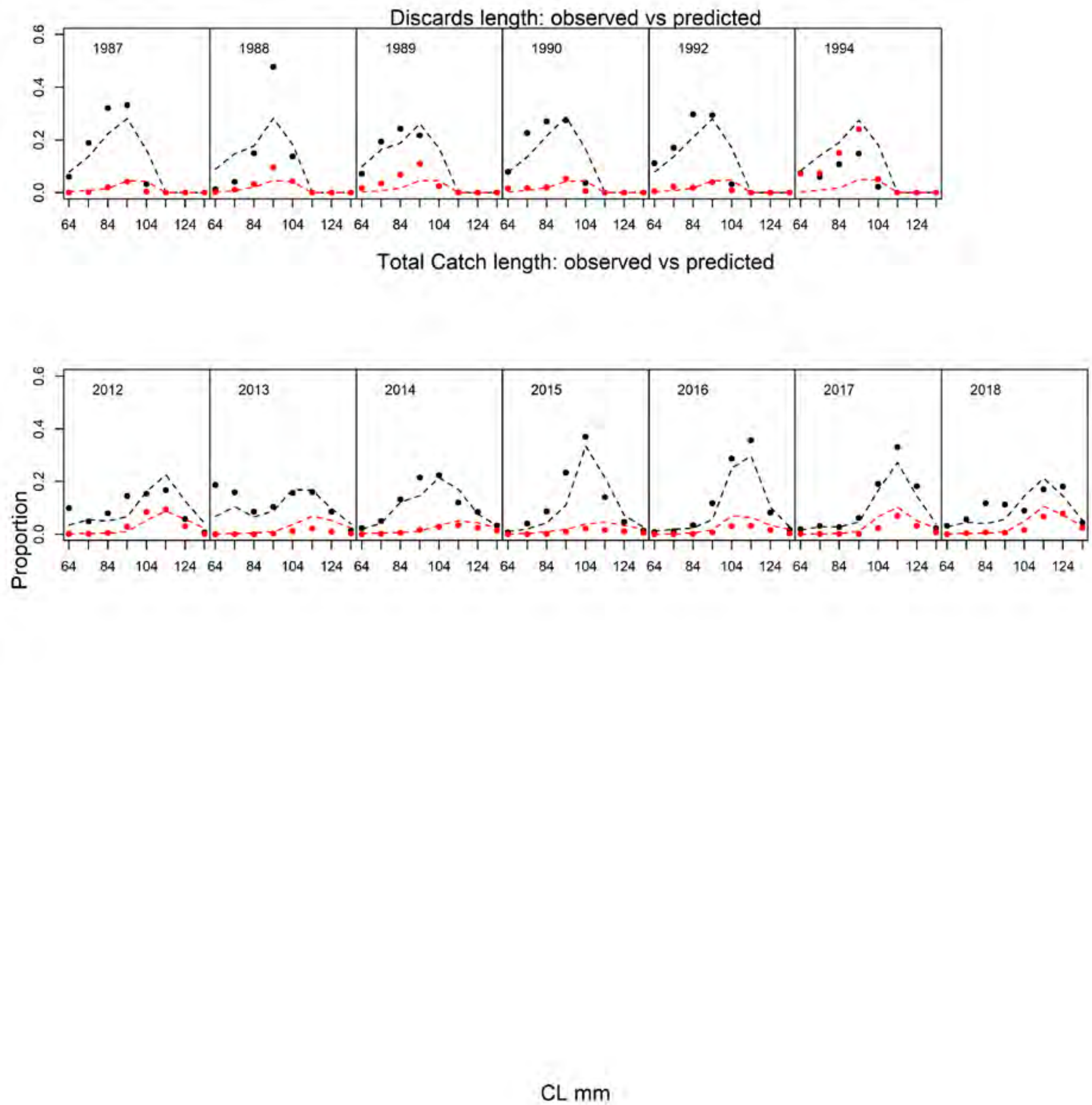


Figure D6-13. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

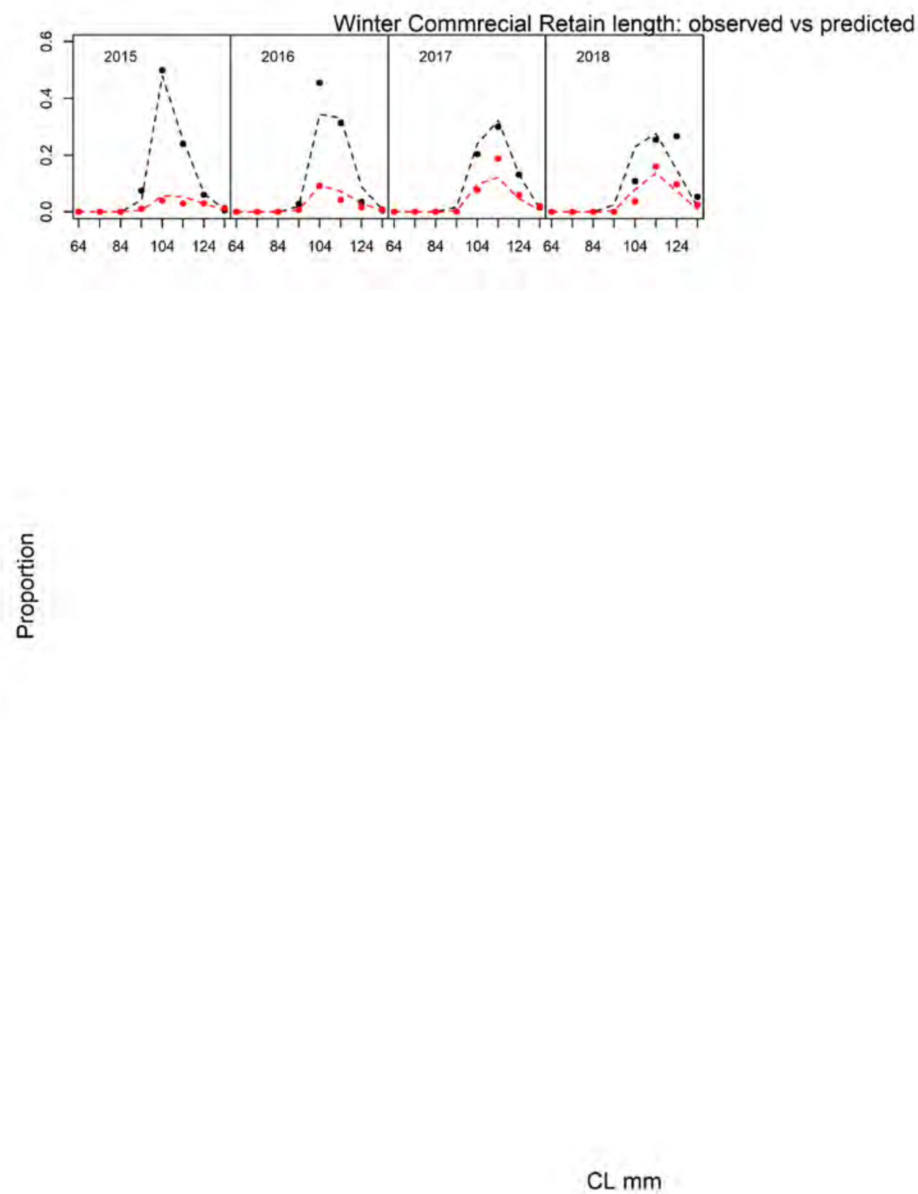


Figure D6-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey. Black: newshell, Red: oldshell

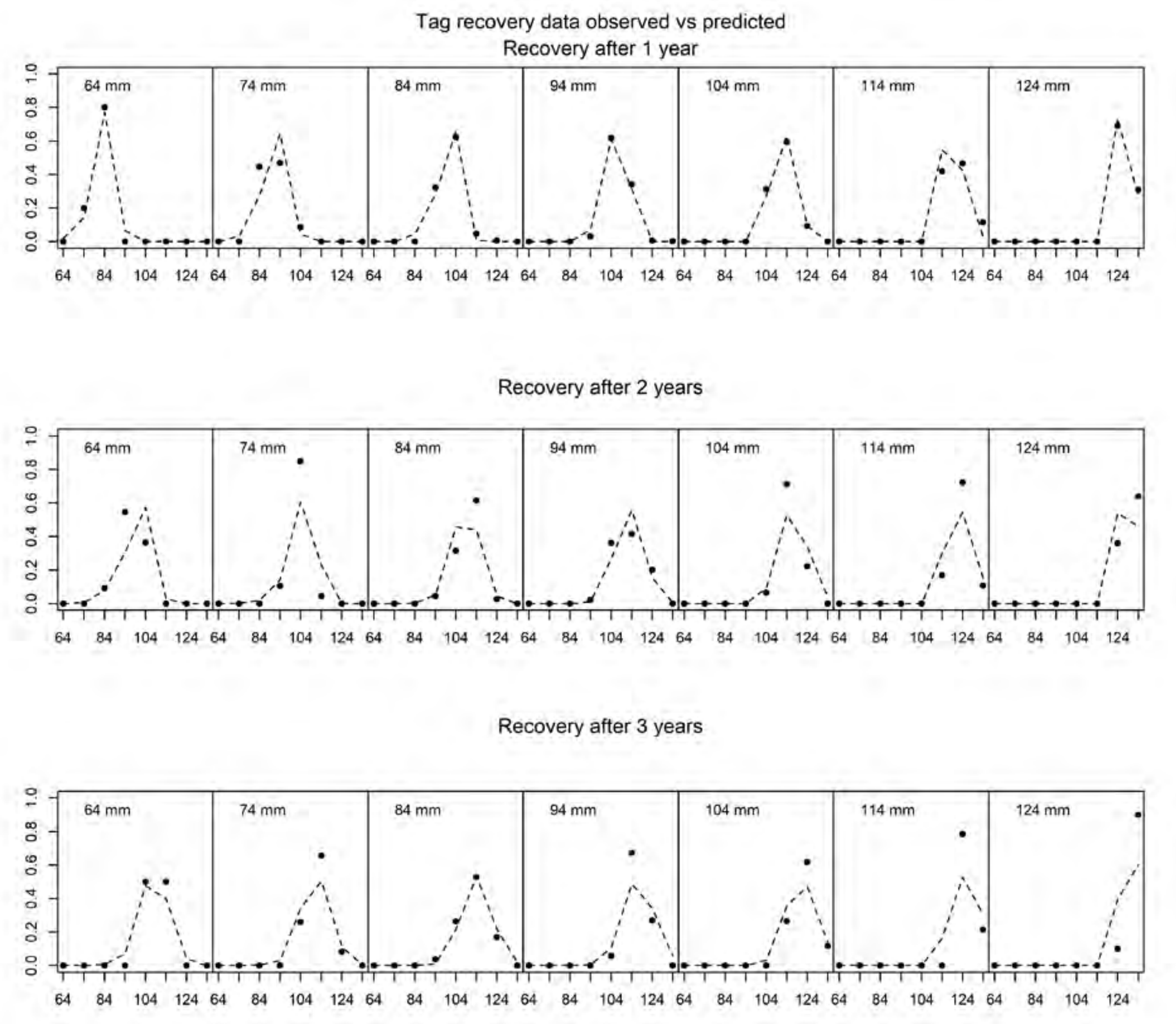


Figure D6-13. Predicted vs. observed length class proportions for tag recovery data.

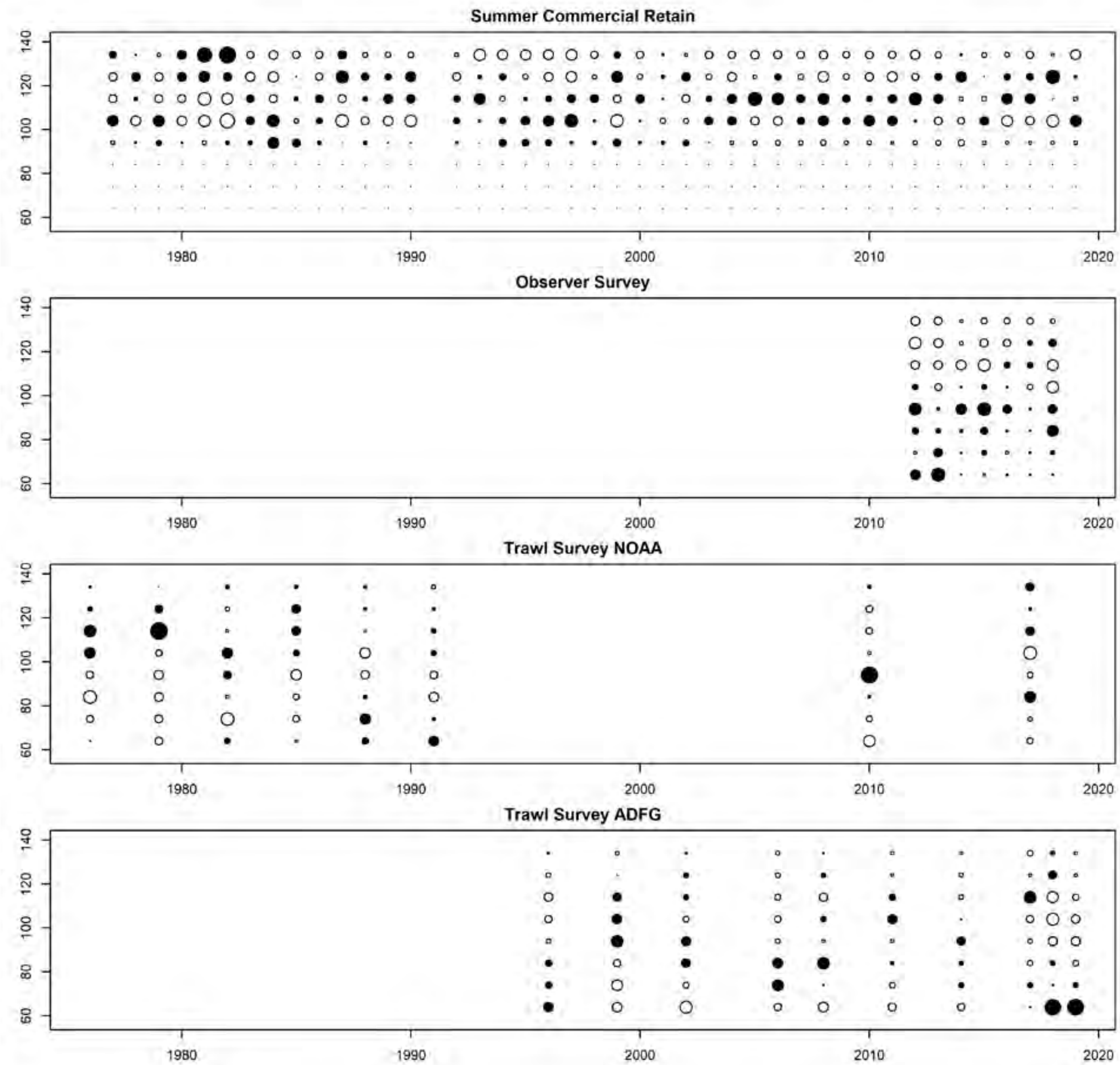


Figure D6-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

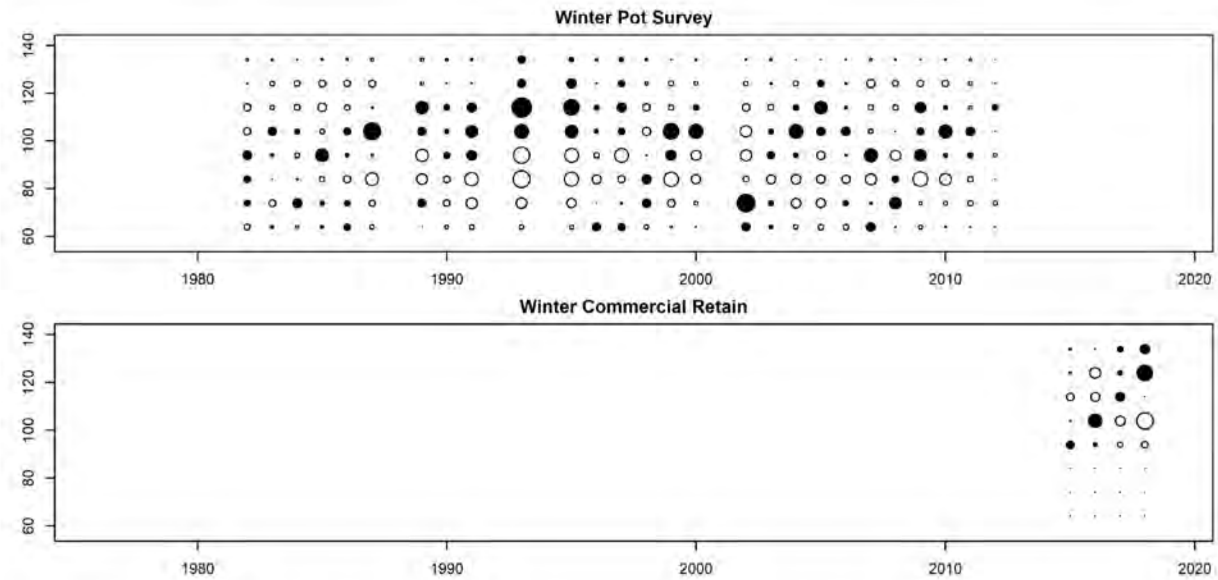


Figure D6-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table D6. Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.600	0.133
log_q_2		
log_N_{76}	9.637	0.169
R_0	7.359	0.202
a_1	1.858	4.830
a_2	3.838	4.409
a_3	4.907	4.227
a_4	4.770	4.211
a_5	4.580	4.201
a_6	3.691	4.233
a_7	1.937	4.514
r1	10.000	0.531
r2	9.951	0.630
log_a	-2.879	0.115
log_b	4.815	0.020
log_ϕ_{st1}		
log_ϕ_{wa}	-1.481	0.434
log_ϕ_{wb}	4.892	0.028
Sw1	0.059	0.030
Sw2	0.292	0.075
log_ϕ_l		
log_ϕra	-0.791	0.138
log_ϕrb	4.626	0.009
log_ϕwra	-0.940	0.470
log_ϕwrb	4.659	0.033
w^2_t	0.002	0.019
q	0.712	0.117
σ	0.433	0.034
β_1	4.010	0.230
β_2	9.762	0.964

name	Estimate	std.dev
selc 1	0.045	0.020
selc 2	0.067	0.023
selc 3	0.117	0.035
selc 4	0.190	0.039
selc 5	0.642	0.062
selc 6	0.988	0.295
selc 7	1.000	0.000
selc 8	0.963	0.252
selt 1	0.613	0.168
selt 2	0.448	0.108
selt 3	0.567	0.118
selt 4	0.698	0.125
selt 5	0.874	0.271
selt 6	1.000	0.000
selt 7	0.943	0.209
selt 8	0.739	0.348

8. Aleutian Islands Golden King Crab Stock Assessment

May 2020 Crab SAFE Draft Report

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Executive Summary

1. Stock

Golden king crab, *Lithodes aequispinus,* Aleutian Islands, east of 174° W longitude (EAG) and west of 174° W longitude (WAG).

2. Catches

The Aleutian Islands golden king crab (AIGKC) commercial fishery has been prosecuted every year since 1981/82. Retained catch peaked in 1986/87 at 2,686 t (5,922,425 lb) and 3,999 t (8,816,319 lb), respectively, for EAG and WAG, but the retained catch dropped sharply from 1989/90 to 1990/91. The fishery has been managed separately east (EAG) and west (WAG) of 174° W longitude since 1996/97, and Guideline Harvest Levels (GHLs) of 1,452 t (3,200,000 lb) for EAG and 1,225 t (2,700,000 lb) for WAG were introduced into management for the first time in 1996/97. The GHL was subsequently reduced to 1,361 t (3,000,000 lb) beginning in 1998/99 for EAG. The reduced GHLs remained at 1,361 t (3,000,000 lb) for EAG and 1,225t (2,700,000 lb) for WAG through 2007/08, but were increased to 1,429 t (3,150,000 lb) for EAG and 1,294 t (2,835,000 lb) for WAG beginning with the 2008/09 fishing season following an Alaska Board of Fisheries (BOF) decision. The management specification changed from GHL to TAC (Total Allowable Catch) with adoption of the Crab Rationalization Program in 2005/06 (NPFMC 2007b). The TACs were increased by another BOF decision to 1,501 t (3,310,000 lb) for EAG and 1,352 t (2,980,000 lb) for WAG beginning with the 2012/13 fishing season. The below par fishery performance in WAG in recent years lead to reduction in TAC to 1,014 t (2,235,000 lb), which reflected a 25% reduction in the TAC for WAG, while the TAC for EAG was kept at the same level 1,501 t (3,310,000 lb) for the 2015/16 through 2017/18 fishing seasons. With the improved fishery performance and stock status in 2017/18, the TACs were further increased to 1,134 t (2,500,000 lb) for WAG and 1,749 t (3,856,000lb) for EAG beginning with the 2018/19 fishing season. With the implementation of a revised state harvest strategy in 2019, the TACs were further increased to 1,302 t (2,870,000 lb) for WAG and 1,955 t (4,310,000 lb) for EAG. The EAG fishery achieved 100% of TAC while the WAG fishery is ongoing with 96% of TAC harvested for the 2019/20 fishing season at the time of this assessment.

Catches have been steady under the GHL/TAC and the fishery has harvested close to allowable levels since 1996/97. These TAC levels were set below the ABCs determined under Tier 5 criteria (considering 1991–1995 mean catch for the whole Aleutian Islands region, 3,145 t (6,933,822 lb), as the limit catch) under the most recent crab management plan. A new harvest strategy based on model estimated mature male abundance was accepted by the BOF in March 2019, specifying a 15% maximum harvest rate for EAG and 20% maximum harvest rate for WAG, and implemented during the 2019/20 fishery. In addition to the retained catch allotted as TAC, there was retained catch in a cost-recovery fishery towards a $300,000 goal in 2013/14 and 2014/15 to fund an onboard observer program, and towards a $500,000 goal in 2015/16 to 2019/20 in order to fund an onboard observer program and stock survey.

Total mortality of Aleutian Islands golden king crab includes retained catch in the directed fishery, mortality of discarded catch, and bycatch in fixed-gear and trawl groundfish fisheries, though bycatch in other fisheries is low compared to mortality in the directed fishery. Total retained catch in the post-rationalized fishery (2005/06–2019/20) has ranged from 2,498 t (5,508,100 lb) to 3,274 t (7,218,545 lb). Total mortality ranged from 2,506 t (5,525,000 lb) to 3,693 t (8,141,000 lb) for the same period. Total retained catch in 2019/20 was 3,274 t (7,218,545 lb): 2,031 t (4,476,775 lb) from the EAG fishery (which included cost-recovery catch), and 1,244 t (2,741,770 lb) from the WAG 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, except as surveys for red king crab conducted under an Alaska Department of Fish and Game (ADF&G) Commissioner's Permit (and 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. Total estimated bycatch mortality during crab fisheries in 2019/20 was 275 t (607,000 lb) for EAG and 116 t (256,000 lb) for WAG. Discarded catch also occurs during fixed-gear and trawl groundfish fisheries but is small relative to the directed fishery. Groundfish fisheries are a minor contributor to total fishery discard mortality, 23 t (52,000 lb) for EAG and 3 t (8,000 lb) for WAG in 2019/20.

Catch per unit effort (CPUE, i.e., catch per pot lift) of retained legal males decreased from the 1980s into the mid-1990s, but increased after 1994/95, particularly with the initiation of the Crab Rationalization Program in 2005/06. Although CPUE for the two areas showed similar trends through 2010/11, during 2011/12–2014/15 CPUE trends have diverged (increasing for EAG and decreasing for WAG).

A cooperative golden king crab survey was performed by the Aleutian Islands King Crab Foundation (an industry group) and ADF&G in the EAG and WAG (for the first time in August 2018) fisheries, by vessels that were quota fishing (i.e., each vessel fishing an allotted share of total allowable catch). For the purpose of catch accounting for 2019/20, it was assumed that bycatch mortality that occurred during the survey was accounted for by reported discards for the 2019/20 fishery.

3. Stock biomass

Estimated mature male biomass (MMB) for EAG under all scenarios decreased from the 1980s to the 1990s, then increased during the 2000s and sharply increased since 2014. Estimated MMB for WAG decreased during the late 1980s and 1990s, increased during the 2000s, decreased for several years since 2009 and has increased since 2014. The low levels of MMB for EAG were observed in 1995–1997 and in 1990s for WAG. Stock trends reflected the fishery standardized CPUE trends in both regions.

4. Recruitment

The numbers of recruits to the model size groups under all scenarios have fluctuated in both EAG and WAG. For EAG, model recruitment was high in 2016, highest in 2017; and lowest in 1986. The model recruitment for WAG was high during 1984 to 1986, highest in 1985, and lowest in 2011. A slightly increasing trend in recruitment was observed since 2011 in WAG.

5. Management performance

The size-based assessment model was accepted at the September 2016 CPT and October 2016 SSC meetings for OFL determination for the 2017/18 fishery cycle. In addition, the CPT in January 2017 and SSC in February 2017 recommended using the Tier 3 method to compute OFL and ABC. The assessment model was first used for setting OFL and ABC for the 2017/18 fishing season. This was followed since. The CPT in May 2017 and SSC in June 2017 accepted the authors' recommendation of using scenario 9 (i.e., model using the knife-edge maturity to determine MMB) for OFL and ABC calculation. During the May 2017 meeting, the CPT noted that a single OFL and ABC are defined for Aleutian Islands golden king crab (AIGKC). However, separate models are available by area. Hence, following previous assessments, OFLs and ABCs by area were summed to calculate OFL and ABC for the entire stock.

All models for EAG and WAG considered the previous season's fishery information (i.e., 2019/20 fishery, concluded in EAG and almost 96% of TAC achieved in WAG). We recommend two models from the common four models for EAG and WAG: model 20_1b Ver 2 (re-evaluation of observer CPUE indices after reducing the number of gear codes; selection of a fixed period, 1987–2012, for mean number of recruits calculation for reference points estimation; and standardization of fishery CPUE by the negative binomial generalized linear model); and model 20_2 (consideration of year and area interaction factor for observer CPUE standardization).

Model 20_1 is the base model (accepted model 19_1 in 2019) with the knife-edge male maturity at 111 mm CL, an M of 0.21yr^{-1}, and the addition of 2019/20 data. Models 20_1b, 20_1b Ver 2, 20_1c, 20_1d, 20_2, and 20_2b are modifications from the base model.

The total catch, 3.693 t, did not exceed OFL, 5.249 t, in 2019/20; therefore, overfishing did not occur.

The mature male biomass, 16.323 t, is above MSST, 5.909 t, in 2019/20; hence, the stock was not overfished.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC[b]
2016/17	N/A	N/A	2.515	2.593	2.947	5.69	4.26
2017/18	6.044	14.205	2.515	2.585	2.942	6.048	4.536
2018/19	5.880	17.848	2.883	2.965	3.355	5.514	4.136
2019/20	5.909[c]	16.323[c]	3.257	3.274[d]	3.693[d]	5.249	3.937
2020/21[e]		**14.760**				**4.793**	**3.595**
2020/21[f]		**15.106**				**4.993**	**3.745**
2020/21[g]		**14.774**				**4.798**	**3.599**

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC[b]
2016/17	N/A	N/A	5.545	5.716	6.497	12.53	9.40
2017/18	13.325	31.315	5.545	5.699	6.487	13.333	10.000
2018/19	12.964	39.348	6.356	6.536	7.396	12.157	9.118
2019/20	13.027[c]	35.985[c]	7.180	7.219[d]	8.141[d]	11.572	8.679
2020/21[e]		**32.540**				**10.566**	**7.925**
2020/21[f]		**33.303**				**11.008**	**8.256**
2020/21[g]		**32.571**				**10.579**	**7.934**

a. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.
b. 25% buffer was applied to total catch OFL to determine ABC.
c. MSST and MMB determined by Model 20_1b Ver 2
d. 100% TAC was achieved in EAG, but over 96% TAC was achieved in WAG at the time of this assessment. The WAG fishery is ongoing.
e. Model 20_1b, up to 2019/20 data, mean number of recruit calculation time period for EAG: 1986–2017 and for WAG: 1987–2018.
f. Model 20_2, up to 2019/20 data.
g. Model 20_1b Ver 2, up to 2019/20 data, mean number of recruit calculation time period for EAG and WAG: 1987–2012.

6. Basis for the OFL

The length-based model developed for the Tier 3 analysis estimated mature male biomass (MMB) on February 15 each year for the period 1986 through 2020. The terminal year mature male biomass was projected by an additional year to determine OFL and ABC for the 2020/21 season. The Tier 3 approach uses a constant annual natural mortality (M), knife-edge maturity size, and the mean number of recruits for different time periods for OFL and ABC calculation. Previously derived M of 0.21 yr^{-1} from the combined data and a knife-edge maturity size of 111 mm carapace length (CL) from the EAG and WAG data were used (Siddeek *et al.* 2018).

We provide the OFL and ABC estimates for EAG and WAG separately and combined (i.e., for the entire Aleutian Islands; AI) from seven models, 20_1, 20_1b, 20_1b Ver 2, 20_1c, 20_1d, 20_2, and 20_2b, for EAG; and from four models, 20_1, 20_1b, 20_1b Ver 2, and 20_2, for WAG and for AI in the following six tables. We treat model 20_1 as the base model.

EAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in millions of pounds. Current MMB = MMB on 15 Feb. 2021.

Model	Tier	$MMB_{35\%}$	Current MMB	MMB/ $MMB_{35\%}$	F_{OFL}	Recruitment Years to define $MMB_{35\%}$	$F_{35\%}$	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
EAG20_1	3a	14.553	18.809	1.29	0.61	1987–2012	0.61	6.648	6.609	4.986
EAG20_1b	3a	14.935	18.674	1.25	0.61	1986–2017	0.61	6.583	6.544	4.937
EAG20_1bVer2	3a	14.547	18.694	1.29	0.61	1986–2012	0.61	6.592	6.553	4.944
EAG20_1c	3a	14.481	15.293	1.06	0.61	1986–2017	0.61	4.977	4.939	3.733
EAG20_1d	3a	14.724	17.173	1.17	0.61	1986–2017	0.61	5.850	5.826	4.387
EAG20_2	3a	14.979	19.104	1.28	0.61	1986–2017	0.61	6.908	6.869	5.181
EAG20_2b	3a	14.579	16.177	1.11	0.61	1986–2017	0.61	5.478	5.438	4.109

Biomass in 1000 t; total OFL and ABC for the next fishing season in t.

Model	Tier	$MMB_{35\%}$	Current MMB	MMB/ $MMB_{35\%}$	F_{OFL}	Recruitment Years to Define $MMB_{35\%}$	$F_{35\%}$	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
EAG20_1	3a	6.601	8.532	1.29	0.61	1987–2012	0.61	3,015.592	2,997.858	2,261.694
EAG20_1b	3a	6.774	8.470	1.25	0.61	1986–2017	0.61	2,985.928	2,968.143	2,239.446
EAG20_1bVer2	3a	6.599	8.480	1.29	0.61	1987–2012	0.61	2,990.063	2,972.283	2,242.547
EAG20_1c	3a	6.568	6.937	1.06	0.61	1986–2017	0.61	2,260.998	2,504.178	1,695.748
EAG20_1d	3a	6.679	7.790	1.17	0.61	1986–2017	0.61	2,653.436	2,642.813	1,990.077
EAG20_2	3a	6.794	8.665	1.28	0.61	1986–2017	0.61	3,133.485	3,115.767	2,350.114
EAG20_2b	3a	6.613	7.338	1.11	0.61	1986–2017	0.61	2,484.903	2,466.646	1,863.677

7.

WAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in millions of pounds. Current MMB = MMB on 15 Feb. 2021.

Model	Tier	$MMB_{35\%}$	Current MMB	MMB/ $MMB_{35\%}$	F_{OFL}	Recruitment Years to Define $MMB_{35\%}$	$F_{35\%}$	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
WAG20_1	3a	11.473	13.844	1.21	0.56	1987–2012	0.56	3.974	3.958	2.981
WAG20_1b	3a	11.725	13.867	1.18	0.56	1987–2018	0.56	3.983	3.968	2.988
WAG20_1bVer2	3a	11.507	13.877	1.21	0.56	1987–2012	0.56	3.987	3.971	2.990
WAG20_2	3a	11.778	14.199	1.21	0.56	1987–2018	0.56	4.100	4.084	3.075

8.
9.

Biomass in 1000 t; total OFL and ABC for the next fishing season in t.

Model	Tier	$MMB_{35\%}$	Current MMB	MMB / $MMB_{35\%}$	F_{OFL}	Recruitment Years to Define $MMB_{35\%}$	$F_{35\%}$	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
WAG20_1	3a	5.204	6.279	1.21	0.56	1987–2012	0.56	1,802.747	1,795.486	1,352.060
WAG20_1b	3a	5.319	6.290	1.18	0.56	1987–2018	0.56	1,806.903	1,799.775	1,355.177
WAG20_1bVer2	3a	5.220	6.295	1.21	0.56	1987–2012	0.56	1,808.318	1,801.190	1,356.239
WAG20_2	3a	5.343	6.441	1.21	0.56	1987–2018	0.56	1,859.828	1,852.480	1,394.871

Aleutian Islands (AI)
Total OFL and ABC for the next fishing season in millions of pounds.

Model	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
20_1	10.622	10.567	7.967
20_1b	10.566	10.512	7.925
20_1bVer2	10.579	10.524	7.934
20_2	11.008	10.953	8.256

Aleutian Islands (AI)
Total OFL and ABC for the next fishing season in t.

Model	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
20_1	4,818.34	4,793.34	3,613.75
20_1b	4,792.83	4,767.92	3,594.62
20_1bVer2	4,798.38	4,773.47	3,598.79
20_2	4,993.31	4,968.25	3,744.99

7. Probability density functions of the OFL

Assuming a lognormal distribution of total OFL, we determined the cumulative distributions of OFL and selected the median as the OFL.

8. Basis for the ABC recommendation

An x proportion buffer on the OFL; i.e., ABC = (1.0 - x) *OFL.
The CPT recommended x = 0.25.
See also the section G on ABC.

9. A summary of the results of any rebuilding analysis:

Not applicable.

A. Summary of Major Changes

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

In 2019, a new state harvest strategy was implemented.

2. Changes to input data

Commercial fisheries data were updated with values from the most recent observer and fish ticket data for 2019/20: retained catch for the directed fishery and discarded catch estimates for the directed fishery, non-directed crab fisheries, and groundfish fisheries. Thus, the time series of data used in the model are retained catch (1981/82–2019/20), total catch (1990/91–2019/20), and groundfish bycatch (1989/90–2019/20) biomass and size compositions.

Fish ticket retained CPUE were standardized by the generalized linear model (GLM) with the lognormal and negative binomial link functions for the 1985/86–1998/98 period.

Observer pot sample legal size crab CPUE data were standardized by the GLM with the negative binomial link function with variable selection by CAIC (modified AIC) followed by R square criterion, separately for 1995/96–2004/05 and 2005/06–2019/20 periods. A Year and Area interaction factor was considered in one model to estimate a set of CPUE indices. The habitat areas were determined from observer historical pot locations as fishing footprints (see Appendix B).

3. Changes to assessment methodology

None

4. Changes to assessment results

As expected, the addition of the 2019/20 data changed the OFL and ABC estimates, but changes in parameter or abundance estimates were not dramatic.

B. Response to SSC and CPT comments

<u>**January 2020 CPT Comments**</u>

Comment# 1: The CPT reiterates the SSC request for a brief description of the cooperative survey in the assessment document, including the area sampled, size composition and a summary of results.

Response:
This is an evolving project to collect AIGKC data by active fishing vessels, following a designed two-stage sampling. The data collection covers species, sex, count of crab by size, by pot, by string, and by vessel. Additional data such as depth of fishing, soak time, bait type, mesh size, and pot size are also collected. We use the number of legal-size male crabs at the vessel/string/pot level to estimate the CPUE by a hierarchical random effects model. A brief explanation of the method is provided in Appendix C.

We have completed the cooperative surveys for five fishing seasons (2015/16, 2016/17, 2017/18, 2018/19, and 2019/20) in the EAG region. We also extended the survey for the first time in the

WAG region in 2018/19. The data series is too short to obtain meaningful results. However, we used the EAG CPUE indices in some model scenarios in this analysis to get some feedback.

Comment# 2: *Revised approach to select mean recruitment*: The proposed approach sets mean recruitment to the average over the years for which the standard deviations of the recruitment estimates is 70% of the assumed standard deviation of inter-annual variability in recruitment. The choice of 70% is the lowest percentage at which a contiguous set of years would be selected. The CPT agrees with the general approach, and requests that the authors include the basis for the 70% in the next report.

Response:
The 70% value is an arbitrary choice satisfying the need to remove a few years from the tail end of the recruitment time series. Instead of using 70% of the fixed R_{sigma}, we used the 90th percentile cutoff level based on 1986 to 2020 recruit standard errors estimated by the base model 20_1 to exclude years with high recruit standard deviations. The 90^{th} percentile choice is also an arbitrary level but uses the actual recruitment standard errors to obtain the cutoff level instead of R_{sigma}

Comment# 3: Revised approach for standardizing the fishery catch-rate data for 1995/96 – 2019/20. The CPT notes that basis for the specific blocks chosen for Year and Area interaction needs to be more clearly documented. The weight assigned to each block needs to be the total number of 1^0x1^0 cells ever fished. One potential problem with this approach is that there are blocks x years with no (or very few) data. The CPT made two suggestions:

a. Fit a model of the form $B_{i,j} = A_i + C_j$ where $B_{i,j}$ is the index of biomass for year i and block j, A_i is a year factor, and C_j is a block factor, and use this model to infer the biomass index for blocks x years with no (or very limited) data.

b. The variance of the total biomass index should be computed as:

$$Var\ (B_i) = \sum_j N_{ever,j}{}^2\ var(CPUE_{i,j})$$

where $N_{ever,j}$ is the total number of 1^0x1^0 cells ever fished in block *j*, and $CPUE_{i,j}$ is the expected CPUE index for year *i* and block *j*.

Response:
We followed both *suggestions. We used a GLM procedure to fit the year and area factors to available $B_{i,j}$ indices and used the fitted model to fill the gap for missing year by block values. We also estimated the variance of the biomass index using the suggested formula (Appendix B).*

Comment# 4: *Analysis of the cooperative survey data*. The use of a mixed-effects model is appropriate. However, the choice of covariates needs additional justification. For example, it was not clear that vessel * pot number should be treated as a fixed effect rather than pot number random within vessel. Similarly, a hierarchical structure for strings * block should be considered, such as string random within block, which is itself random. In general, the model for the analysis of the survey data should be more closely aligned with the design of the survey. One possible model would be:

Sumcatch ~ Year + (1|vessel/pot number) + ns(soakdays,ns=9) + ns(Depth,df=6) + (1|block/string).

Response:
We followed the hierarchical random effects model structure suggested by the CPT to analyze the cooperative survey data (Appendix C).

Comment# 5: The CPT recommended the following models for exploration for the May 2020 CPT meeting:

- **Model 19.1b. As for model 19.1 but with revised periods of years for defining mean recruitment (EAG: 1985-2016; WAG: 1987-2016) and the fish ticket CPUE data standardized assuming a negative binomial distribution.**
- **Model 19.1c. As for model 19.1b except that the EAG 2015-2019 cooperative survey CPUE index is included in the assessment.**
- **Model 19.2. As for model 19.1b, except that the 1995/96 – 2018/19 CPUE data are standardized using year*area interactions.**
- **Model. 19.2b. As for model 19.2, except that the EAG 2015-2019 cooperative survey CPUE index is included in the assessment**.

Response:
We considered all suggested models in this report (see Table T1).

January 2020 SSC comments:

Comment# 1: The SSC reiterates for a description of the cooperative survey in the assessment document, including the area sampled and size compositions.

Response:
Please refer to our response to CPT comment#1.

Comment# 2: SSC supports exploration of treating pot as a random effect nested within vessel, or possibly string, and encourages alternative random effects model structures that align with assumptions of the cooperative survey design.

Response:
We followed the random effects approach to analyze the cooperative survey data because of the two-stage sampling design. As per CPT suggestion#3, we used the pot within vessel and string within block structures in the random effects model analysis for this report. The exploration is continuing.

Comment# 3:
The SSC also reiterates the CPT request on the rationale for the 0.7 Sigma_R criterian for recruitments included in the estimation of reference points as this does not seem justified at this point.

Response:
The R_{sigma} value is user enforced, came from an arbitrary weight specified to the recruit likelihood. We made it non-subjective by setting the cutoff recruit deviation value at 90^{th} percentile of the

model-estimated recruitment standard deviations for the whole time series. Recruitments with standard deviations less than the cutoff value are included for reference point estimation.

Comment# 4:
The SSC supports the CPT recommendation to explore the given set of models (CPT comments#5) for the May CPT meeting that explore new recruitment time series, different formulations of CPUE standardization, and the inclusion of cooperative survey CPUE.

Response:
We did in this report.

C. Introduction

1. **Scientific name:**

Golden king crab, *Lithodes aequispinus* J.E. Benedict, 1895.

2. **Distribution:**

General distribution of golden king crab is summarized by NMFS (2004). Golden king crab, also called brown king crab, occur from the Japan Sea to the northern Bering Sea (ca. 61° N latitude), around the Aleutian Islands, generally in high-relief habitat such as inter-island passes, 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. Leon *et al.* (2017) define the boundaries of Aleutian Islands king crab Registration Area O:

The Aleutian Islands king crab management area's eastern boundary is the longitude of Scotch Cap Light (164°44.72'W long), the northern boundary is a line from Cape Sarichef (54°36'N lat) to 171°W long, north to 55°30'N lat, and the western boundary the Maritime Boundary Agreement Line as described in the Maritime Boundary Agreement between the United States and the Union of Soviet Socialist Republics signed in Washington, June 1, 1990 (Figure 1-1 in Leon et al. 2017). Area O encompasses territorial waters of the state of Alaska (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 2). 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 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. Evidence of stock structure:

Given the expansiveness of the Aleutian Islands Area and the existence of deep (>1,000 m) canyons between some islands, at least some weak structuring of the stock within the area would be expected. Data for making inferences on stock structure of golden king crab within the Aleutian Islands 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. Life history characteristics relevant to management:

There is a paucity of information on golden king crab life history characteristics due in part to the deep depth distribution (~200–1000 m) and the asynchronous nature of life history events (Otto and Cummiskey 1985; Somerton and Otto 1986). The reproductive cycle is thought to last approximately 24 months and at any time of year, ovigerous females can be found carrying egg clutches in highly disparate developmental states (Otto and Cummiskey 1985). Females carry large, yolk-rich, eggs, which hatch into lecithotrophic (i.e., the larvae can develop successfully to juvenile crab without eating; Shirley and Zhou 1997) larvae that are negatively phototactic (Adams and Paul 1999). Molting and mating are also asynchronous and protracted (Otto and Cummiskey 1985; Shirley and Zhou 1997) with some indications of seasonality (Hiramoto 1985). Molt increment for large males (adults) in Southeast Alaska is 16.3 mm CL per molt (Koeneman and Buchanan 1985) and was estimated at 14.4 mm CL for legal males in the EAG (Watson *et al.* 2002). Annual molting probability of males decreases with increasing size, which results in a protracted inter-molt period and creates difficulty in determining annual molt probability (Watson *et al.* 2002). Male size-at-maturity varies among stocks (Webb 2014) and declines with increasing latitude from about 130 mm CL in the Aleutian Islands to 90 mm CL in Saint Matthew Island section (Somerton and Otto 1986). Along with a lack of annual survey data, limited stock-specific life history stock information prevents development of the standard length-based assessment model.

5. Brief summary of management history:

A complete summary of the management history through 2015/16 is provided in Leon *et al.* (2017). 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.

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 (ADF&G 2002). Hereafter, the east of 174° W longitude stock segment is referred to as EAG and the west of 174° W longitude stock segment is referred to as WAG. Table 1 provides the historical summary of number of vessels, GHL/TAC, harvest, effort, CPUE and average weight in the Aleutian Islands golden king crab fishery.

The fisheries in 1996/97–1997/98 were managed for GHLs of 1,452 t (3,200,000 lb) in EAG and 1,225 t (2,700,000 lb) in WAG (Table 1). During 1998/99–2004/05 the fisheries were managed with GHLs of 1,361 t (3,000,000 lb) for EAG and 1,225 t (2,700,000 lb) for WAG. During 2005/06–2007/08 the fisheries were managed with a total allowable catch (TAC) of 1,361 t (3,000,000 lb) for EAG and a TAC of 1,225 t (2,700,000 lb) for WAG. By state regulation (*5 AAC 34.612*), TAC for the Aleutian Islands golden king crab fishery during 2008/09–2011/12 was 1,429 t (3,150,000 lb) for EAG and 1,286 t (2,835,000 lb) for WAG. In March 2012 the BOF changed *5 AAC 34.612* so that the TAC beginning in 2012/13 would be 1,501 t (3,310,000 lb) for the EAG and 1,352 t (2,980,000 lb) for WAG. 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 (and 2017/18) was reduced by 25% for WAG to 1,014 t (2,235,000 lb) while keeping the TAC for EAG at the same level as the previous season.

During 1996/97–2019/20 the annual retained catch during commercial fishing (including cost-recovery fishing that occurred during 2013/14–2019/20) has averaged 2% below the annual GHL/TACs. During 1996/97–2019/20, the retained catch has been as much as 13% below (1998/99) and as much as 6% above (2000/01) the GHL/TAC.

A summary of other relevant State of Alaska 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 adoption of crab rationalization program was implementation of a community development quota (CDQ) fishery for golden king crab in the eastern Aleutians (i.e., EAG) and the Adak Community Allocation (ACA) fishery for golden king crab in the western Aleutians (i.e., WAG; 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 individual fisheries quota fishery.

Golden king crab may be commercially fished only with king crab pots (defined in state regulation *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, each pot 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 [5.5 inches]) into their gear or, more rarely, included panels with escape mesh (Beers 1992). Regarding 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, "… 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 was conducted aboard one vessel commercial fishing for golden king crab during the 2012/13 season and found gear and fishing practices used by that vessel were 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 always required on catcher-processor vessels during the fishing season.

In addition, the commercial golden king crab fishery in the Aleutian Islands Area may only retain at least 6.0-inches (152.4 mm) carapace width (CW), including spines (*5 AAC 34.620 (b)*), which is at least one annual molt increment larger than the 50% maturity length of 120.8 mm CL for males estimated by Otto and Cummiskey (1985). 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 the size limit for golden king crab has been 6-inches (152.4 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 (165.1 mm) CW for at least one of the now-defunct Adak or Dutch Harbor Registration Areas.

We re-evaluated the male maturity size using 1991 pot survey measurements of carapace length and chela height in EAG and 1984 NMFS measurements in WAG (Siddeek *et al*. 2018). Bootstrap analysis of chela height and carapace length data provided the median 50% male maturity length estimates of 107.02 mm CL in EAG and 107.85 mm CL in WAG. We used a knife-edge 50% maturity length of 111.0 mm CL, which is the lower limit of the next upper size bin, for mature male biomass (MMB) estimation.

Daily catch and catch-per-unit effort (CPUE) are determined in-season to monitor fishery performance and progress towards the respective TACs. Figures 6 to 8 provide the 1985/86–2018/19 time series of catches, CPUE, and the geographic distribution of catch during the 2018/19 fishing season. Increases in CPUE were observed during the late 1990s through the early 2000s, and with the implementation of crab rationalization in 2005. This is likely due to changes in gear configurations in the late 1990s (crab harvesters, personal communication, 1 July 2008) and, after rationalization, to increased soak time (Siddeek *et al.* 2015), and decreased competition owing to the reduced number of vessels fishing. Decreased competition could allow crab vessels to target only the most productive fishing areas. Trends in fishery CPUE within the areas EAG and WAG generally paralleled each other during 1985/86–2010/11 but diverged during 2011/12–2019/20 (an increasing trend in EAG and a decreasing followed by increasing trends in WAG). Sharp increases in CPUE were observed since 2016/17 in WAG and 2017/18 in EAG, with moderate declines in 2019/20.

6. Brief description of the annual ADF&G harvest strategy:

In March 2019, the BOF adopted a revised harvest strategy (Daly *et al.* 2019). The annual TAC is set by state regulation, *5 AAC 34.612* (Harvest Levels for Golden King Crab in Registration Area O), per:

(a) In that portion of the Registration Area O east of 174° W. long., the total allowable catch level shall be established as follows:
   (1) if MMA_E is less than 25 percent of $MMA_{E,(1985\text{-}2017)}$, the fishery will not open;
   (2) if MMA_E is at least 25 percent but not greater than 100 percent of $MMA_{E,(1985\text{-}2017)}$, the number of legal male golden king crab available for harvest will be computed as $(0.15)\text{x}(MMA_E/MMA_{E,(1985\text{-}2017)})\text{x}(MMA_E)$ or 25 percent of LMA_E, whichever is less; and
   (3) if MMA_E is greater than 100 percent of $MMA_{E,(1985\text{-}2017)}$, the number of legal male golden king crab available for harvest will be computed as $(0.15)\text{x}(MMA_E)$ or 25 percent of LMA_E, whichever is less.

(b) In that portion of the Registration Area O west of 174° W. long., the total allowable catch level shall be established as follows:
   (1) if MMA_W is less than 25 percent of $MMA_{W,(1985\text{-}2017)}$, the fishery will not open
   (2) if MMA_W is at least 25 percent but not greater than 100 percent of $MMA_{W,(1985\text{-}2017)}$, the number of legal male golden king crab available for harvest will be

computed as $(0.20)x(MMA_W/MMA_{W,(1985-2017)})x(MMA_W)$ or 25 percent of LMA_W, whichever is less; and

(3) if MMA_W is greater than 100 percent of $MMA_{W,(1985-2017)}$, the number of legal male golden king crab available for harvest will be computed as $(0.20)x(MMA_W)$ or 25 percent of LMA_W, whichever is less.

(c) In implementing this harvest strategy, the department shall consider the reliability of estimates of golden king crab, the manageability of the fishery, and other factors the department determines necessary to be consistent with sustained yield principles and to use the best scientific information available and consider all sources of uncertainty as necessary to avoid overfishing.

(d) In this section,

(1) MMA_E means the abundance of male golden king crab in the portion of the Aleutian Islands Management Area O east of 174° W. long that are greater than or equal to 111 millimeters in carapace length estimated by the stock assessment model for the time prior to the start of the fishery;

(2) $MMA_{E,(1985-2017)}$ means the mean value of the abundance of male golden king crab in the portion of the Aleutian Islands Management Area O east of 174° W. long that are greater than or equal to 111 millimeters in carapace length estimated by the stock assessment model for the time prior to the start of the fishery for the period 1985 – 2017;

(3) LMA_E means the abundance of male golden king crab in the portion of the Aleutian Islands Management Area O east of 174° W. long that are greater than or equal to 136 millimeters in carapace length estimated by the stock assessment model for the time prior to the start of the fishery;

(4) MMA_W means the abundance of male golden king crab in the portion of the Aleutian Islands Management Area O west of 174° W. long that are greater than or equal to 111 millimeters in carapace length estimated by the stock assessment model for the time prior to the start of the fishery;

(5) $MMA_{W,(1985-2017)}$ means the mean value of the abundance of male golden king crab in the portion of the Aleutian Islands Management Area O west of 174° W. long that are greater than or equal to 111 millimeters in carapace length estimated by the stock assessment model for the time prior to the start of the fishery for the period 1985 – 2017;

(6) LMA_W means the abundance of male golden king crab in the portion of the Aleutian Islands Management Area O west of 174° W. long that are greater than or equal to 136 millimeters in carapace length estimated by the stock assessment model for the time prior to the start of the fishery.

In addition to the retained catch that is limited by the TAC established by ADF&G under *5 AAC 34.612*, ADF&G has authority to annually receive receipts up to $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.

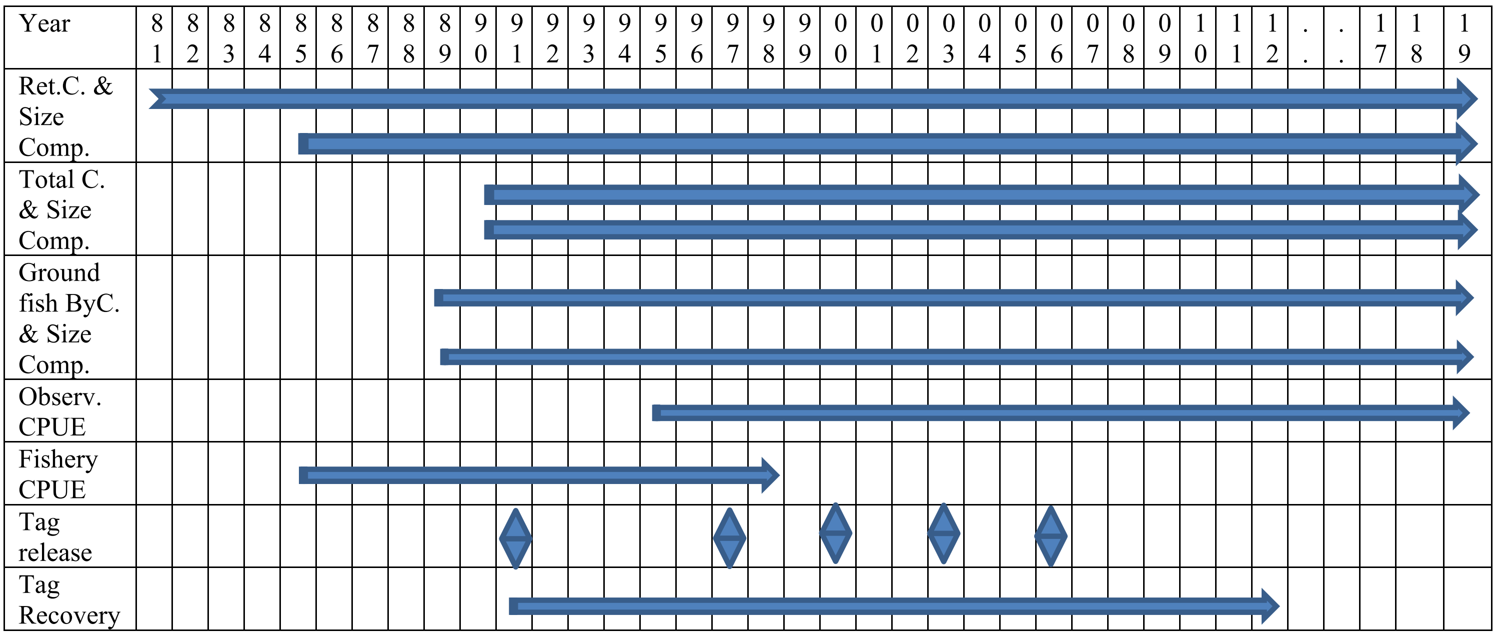
7. Summary of the history of the basis and estimates of MMBMSY or proxy MMBMSY:

We estimated the proxy MMB_{MSY} as $MMB_{35\%}$ using the Tier 3 estimation procedure, which is explained in a subsequent section.

D. Data

1. Summary of new information:

(a) Commercial fishery retained catch by size, estimated total catch by size, groundfish male discard catch by size, observer CPUE index, and commercial fishery CPUE index were updated to include 2019/20 information. Available data by year are shown below



2. Data presented as time series:

a. **Total Catch**:

Fish ticket data on retained catch weight, catch numbers, effort (pot lifts), CPUE, and average weight of retained catch for 1981/82–2019/20 (Table 1). Estimated total catch weight for 1990/91–2019/20 (Table 2a).

b. **Bycatch and discards**:

Retained catch, bycatch mortality (male and female of all sizes) separated by the crab fishery and groundfish fishery, and total fishery mortality for 1981/82–2019/20 (Table 2). Crab fishery discards are available after observer sampling was established in 1988/89. Observer data for the 1988/89–1989/90 seasons are not considered reliable. Table 2 provides crab fishery discards and groundfish fishery bycatch for 1991/92–2019/20 seasons.

c. Catch-per-unit-effort:

Pot fishery and observer nominal retained and total CPUE, pot fishery effort, observer sample size, and estimated observer CPUE index delineated by EAG and WAG for 1985/86–2019/20 (Table 3).

Estimated commercial fishery CPUE index with coefficient of variation (Table 4 for EAG and Table 13 for WAG). The estimation methods, and CPUE fits are described in Appendix B.

d. Catch-at-length:

Information on length compositions are provided (Figures 9 to 11 for EAG; and 27 to 29 for WAG).

e. Survey biomass estimates:

Estimates are not available for the area because no systematic surveys, covering the entire fishing area, have occurred.

f. Survey catch–at–length:

Not available.

g. **Other time series data**: None.

3. Data which may be aggregated over time:

Molt and size transition matrix: Tag release – recapture –time at liberty records from 1991, 1997, 2000, 2003, and 2006 male tag crab releases were aggregated by year at liberty to determine the molt increment and size transition matrix by the integrated model.

Weight-at-length: Male length-weight relationship: $W = aL^b$ where a = 3.7255*10-4, b = 3.0896 (updated estimates).

Natural mortality: A previous model estimated fixed natural mortality value of 0.21 yr-1, was used in the assessment.

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

Data from triennial ADF&G pot surveys for Aleutian Islands golden king crab in a limited area in EAG (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 assessment. However, the tag release and recapture data from these surveys were used.

Data from the cooperative pot surveys conducted during 2015 to 2019 are available but is limited in time span for full usage. The EAG survey covers the full time series but WAG survey started only in 2018. We incorporate the EAG data in a model scenario as a test run in this assessment.

E. Analytic Approach

1. History of modeling approaches for this stock:

A size structured assessment model based on only fisheries data was under development for several years for the EAG and WAG golden king crab stocks and accepted in 2016 for OFL and ABC setting for the 2017/18 season. The CPT in January 2017 and SSC in February 2017 recommended using the Tier 3 procedure to set the OFL and ABC. They also suggested using the maturity data to estimate the male mature biomass (MMB). We followed these suggestions in this report to estimate the model based OFL and ABC.

2. Model Description:

a. Description of overall modeling approach:

The underlying population dynamics model is male-only and length-based (Appendix A). This model combines commercial retained catch, total catch, groundfish fishery discarded catch, standardized observer legal size catch-per-unit-effort (CPUE) indices, fishery retained catch size composition, total catch size composition, and tag recaptures by release-recapture length to estimate stock assessment parameters. The tagging data were used to calculate the size transition matrix. To estimate the MMB, we used the knife-edge 50% maturity based on the chela height and carapace length data analysis. To include a long time series of CPUE indices for stock abundance contrast, we also considered the 1985/86–1998/99 legal size standardized CPUE indices as a separate likelihood component in all scenarios (see Table T1).

There were significant changes in fishing practice associated with changes in management regulations (e.g., constant TAC since 1996/97 and crab rationalization since 2005/06), pot configuration (escape web on the pot door increased to 9-inch since 1999), and improved observer recording in Aleutian Islands golden king crab fisheries since 1998. These changes prompted us to consider two sets of catchability and total selectivity parameters with only one set of retention parameters for the periods 1985/86–2004/05 and 2005/06–2019/20.

We fitted the observer and commercial fishery CPUE indices with estimated (by GLM) standard errors and an additional model estimated constant variance. The assessment model predicted total and retained CPUEs. However, we compared only the predicted retained CPUE with the observer legal size crab CPUE indices in the likelihood function because observer recordings of legal-size crabs are reliable.

The data series ranges used for the WAG are the same as those for EAG.

b. **Software**:

AD Model Builder (Fournier *et al.* 2012).

c.–f. Details are given in Appendix A.

g. **Critical assumptions and consequences of assumption failures**:

Because of the lack of an annual stock survey, we relied heavily on standardized CPUE indices (Appendix B) and catch and size composition information to determine the stock abundance trends in both regions. We assumed that the observer and fish ticket CPUE indices are linearly related to exploitable abundance. We kept M constant at 0.21

yr^{-1} and knife-edge maturity size at 111 mm CL (Siddeek *et a*l. 2018). We assumed directed pot fishery discard mortality at 0.20 yr^{-1}, overall groundfish fishery mortality at 0.65 yr^{-1} (mean of groundfish pot fishery mortality [0.5 yr^{-1}] and groundfish trawl fishery mortality [0.8 yr^{-1}]), groundfish fishery selectivity at full selection for all length classes (selectivity = 1.0). Any discard of legal-size males in the directed pot fishery was not considered in this analysis. These fixed values invariably reduced the number of model parameters to be estimated and helped in convergence. We assumed different *q*'s (scaling parameter for standardized CPUE in the model, Equation A.13) and logistic selectivity patterns (Equation A.9) for different periods for the pot fishery.

h. **Changes to any of the above since the previous assessment:**

None.

i. **Model code has been checked and validated**.

The codes have been checked at various times by independent reviewers and the current codes are available from the first author.

3. Model Selection and Evaluation

a. Description of alternative model configurations:

We considered seven models for EAG and four for WAG (Table T1). We presented OFL and ABC results for all models separately for EAG, WAG, and the entire AI in the executive summary tables. We considered model 20_1 as the base model. It considers:

i) Initial abundance by the equilibrium condition considering the mean number of recruits for 1987–2012: The equilibrium abundance was determined for 1960, projected forward with only *M* and annual recruits until 1980, then retained catches removed during 1981–1984 and projected to obtain the initial abundance in 1985 (see Equations A.4 and A.5).

ii) Observer CPUE indices for 1995/96–2019/20.

iii) Fishery CPUE indices for 1985/86–1998/99.

iv) Initial (Stage-1) weighting of effective sample sizes: number of vessel-days for retained and total catch size compositions, and number of fishing trips for groundfish discard size composition (the groundfish size composition was not used in the model fitting); and (Stage-2) iterative re-weighting of effective sample sizes by the Francis method.

v) Two catchabilities and two sets of logistic total selectivities for the periods 1985/86–2004/05 and 2005/06–2019/20, and a single set of logistic retention curve parameters.

vi) Full selectivity (selectivity =1.0) for groundfish fishery bycatch.

vii) Knife-edge 50% maturity size of 111 mm CL.

viii) Stock dynamics $M = 0.21$ yr^{-1}, pot fishery handling mortality = 0.2 yr^{-1}, and mean groundfish bycatch handling mortality = 0.65 yr^{-1}.

ix) Size transition matrix using tagging data estimated by the normal probability function with the logistic molt probability sub-model. The tag-recaptures were treated as Bernoulli trials (i.e., Stage-1 weighting).

x) The time period, 1987–2012, was used to determine the mean number of recruits for $MMB_{35\%}$ (a proxy for MMB_{MSY}) estimation under Tier 3.

The salient features and variations from the base scenario of all other scenarios are listed in Table T1. The list of fixed and estimable parameters is provided in Table A1 and detail weights with coefficient of variations (CVs) assigned to each type of data are listed in Table A2.

Best estimates of parameter values for models 20_1b and 20_2 were jittered to confirm model global convergence. The results indicated that global convergence was achieved for most runs (Appendix D).

Table T1. Features of all model scenarios: Initial condition was estimated in year 1960 by the equilibrium condition; two catchability and two sets of logistic total selectivity curves were used for the pre- and post-rationalization periods; a single retention curve was used for the whole period; a knife-edge minimum maturity size of 111 mm CL was used for MMB calculation; and a common M of 0.21 yr^{-1} was used. The effective sample sizes for size compositions were estimated in two stages: Stage-1: as the number of vessel days/trips and Stage-2: as the Francis re-iteration method. Changes in model specifications are highlighted by the shaded text.

Model	**CPUE Data Type**	**Time Period for Mean Number of Recruit Calculation for (a) Initial Equilibrium Abundance Composition and (b) Reference Points Estimations**
20_1 (accepted model in May 2019, implemented with up to 2019/20 data)	Observer data from 1995/96–2019/20 Fish ticket data from 1985/86–1998/99. Observer CPUE standardization by negative binomial and Fish ticket CPUE standardization by lognormal models	1987–2012
20_1b	20_1+ Fish ticket CPUE standardization by negative binomial	EAG:1986–2017; WAG:1987–2018
20_1b Ver2	20_1b+	EAG & WAG:1987–2012
20_1c	20_1b+ cooperative survey CPUE indices for 2015–2019.	EAG:1986–2017
20_1d	20_1c+ restrict cooperative survey CPUE indices to 2015–2018	EAG:1986–2017
20_2	20_1b+ Year:Area interaction for observer CPUE standardization.	EAG:1986–2017; WAG:1987–2018
20_2b	20_2+ cooperative survey CPUE indices for 2015–2019	EAG:1986–2017

b. **Progression of results:**

The OFL and ABC estimates are similar to estimates by the 2019 model.

c. **Label the approved model from the previous year as model:**

We used the notation 20_1 for the base model which came from the last year accepted assessment model, 19_1.

d. **Evidence of search for balance between realistic and simpler models**:

Unlike annually surveyed stocks, Aleutian Islands golden king crab stock biomass is difficult to track, and several biological parameters are assumed based on knowledge from red king crab (e.g., handling mortality rate of 0.2 yr^{-1}) due to a lack of species/stock specific information. We fixed several model parameters after initially running the model with free parameters to reduce the number of parameters to be estimated (e.g., groundfish bycatch selectivity parameters were fixed). In CPUE standardization, instead of using the traditional AIC we used the Consistent Akaike Information Criteria (Bozdogan 1987) that considers number of parameters and data points used for fitting when selecting the final model. The models also considered different configuration of parameters to select parsimonious models. The detailed results of all models are provided in tables and figures.

e. **Convergence status and criteria**:

ADMB default convergence criteria were used.

f. Table of the sample sizes assumed for the size compositional data:

We estimated the initial input effective sample sizes (i.e., Stage-1) either as number of vessel-days for retained and total catch compositions or number of fishing trips for groundfish size composition (note: we did not use the groundfish size composition in the model fit) for all model scenarios. Then we estimated the Stage-2 effective sample sizes iteratively from Stage-1 input effective sample sizes using the Francis' (2011, 2017) mean length-based method.

We provide the initial input sample sizes (Stage-1) and Stage-2 effective sample sizes for models 20_1, 20_1b, and 20_2 in Tables 5 to 7 for EAG and Tables 14 to 16 for WAG.

g. **Provide the basis for data weighting, including whether the input effective sample sizes are tuned, and the survey CV adjusted:**

Described previously (f).

h. **Do parameter estimates make sense and are they credible?**

The estimated parameter values are within the bounds and various plots suggest that the parameter values are reasonable for a fixed *M* value for the golden king crab stocks.

i. **Model selection criteria:**

We used several diagnostic criteria to select the appropriate models for our recommendation: CPUE fits, observed vs. predicted tag recapture numbers by time at large and release size, retained and total catch, and groundfish bycatch fits. Figures are provided for all model scenarios in the Results section.

j. **Residual analysis:**

We illustrated residual fits by bubble plots for retained and total catch size composition predictions in various figures in the Results section.

k. **Model evaluation:**

Only one model with several model scenarios is presented and the evaluations are presented in the Results section below.

4. Results

1. List of effective sample sizes and weighting factors:

The Stage-1 and Stage-2 effective sample sizes are listed for various models in Tables 5 to 7 for EAG and Tables 14 to 16 for WAG. The weights, with the corresponding coefficient of variations specifications, for different data sets are provided in Table A2 for various models for both EAG and WAG. These weights (with the corresponding coefficient of variations) adequately fitted the length compositions and no further changes were examined.

We used weighting factors for catch biomass, recruitment deviation, pot fishery F, and groundfish fishery F. We set the retained catch biomass weight to an arbitrarily large value (500.0) because retained catches are more reliable than any other data sets. We scaled the total catch biomass weight in accordance with the observer annual sample sizes (number of pots) with a maximum of 250.0. The total catches were derived from observer nominal total CPUE and effort. In some years, observer sample sizes were low (Tables 3). We chose a small groundfish bycatch weight (0.2) based on the September 2015 CPT suggestion for a lower its weight. We used the best fit criteria to choose the lower weight for the groundfish bycatch. Groundfish bycatch of Aleutian Islands golden king crab is very low (Table 2). We set the CPUE weights to 1.0 for all models. We included a constant (model estimated) variance in addition to input CPUE variance for the CPUE fit. We used the Burnham *et al.* (1987) suggested formula for ln(CPUE) (and ln(MMB)) variance estimation (Equation A.14). However, the estimated additional variance values were small for both observer and fish ticket CPUE indices for the two regions. Nevertheless, the CPUE index variances estimated from the negative binomial and lognormal GLMs were adequate to fit the model, as confirmed by the fit diagnostics (Fox and Weisberg 2011). Parameter estimates are provided in Tables 8 for EAG and 17 for WAG for all models. The numbers of estimable parameters are listed in Table A1.

2. Include tables showing differences in likelihood:

Tables 12 and 21 list the total and component negative log likelihood values for EAG and WAG, respectively.

3. Tables of estimates:

a. The parameter estimates with coefficient of variation for models 20_1, 20_1b, 20_1b Ver 2, and 20_2 are summarized in Tables 8 and 17 for EAG and WAG, respectively. We have also provided the boundaries for parameter searches in those tables. All parameter estimates were within the bounds.

b. All models considered molt probability parameters in addition to the linear growth increment and normally distributed growth variability parameters to determine the size transition matrix.

c. The mature male and legal male abundance time series for selected models (20_1, 20_1b, and 20_2) are summarized in Tables 9 to 11 for EAG and Tables 18 to 20 for WAG.

d. The recruitment estimates for those models are summarized in Tables 9 to 11 for EAG and Tables 18 to 20 for WAG.

e. The negative log-likelihood component values and total negative log-likelihood values for models 20_1, 20_1b, 20_1b Ver 2, and 20_2 are summarized in Table 12 for EAG and Table 21 for WAG. Model 20_2 has the minimum total negative log likelihood for EAG whereas model 20_1 has the minimum for WAG. However, the total negative log likelihood values for the four models for WAG were not very different. We may conclude that the input observer CPUE indices with Year and Area interaction appears to have positively influenced the overall fit.

4. **Graphs of estimates:**

a. **Selectivity**:

Total selectivity and retention curves of the pre- and post-rationalization periods for selected models are illustrated in Figure 12 for EAG and Figure 30 for WAG. Total selectivity for the pre-rationalization period was used in the tagging model. The groundfish bycatch selectivity appeared flat in the preliminary analysis, indicating that all size groups were vulnerable to the gear. This is also shown in the size compositions of groundfish bycatch (Figures 11 and 29 for EAG and WAG, respectively). Thus, we set the groundfish bycatch selectivity to 1.0 for all length-classes in the subsequent analysis.

b. **Mature male biomass**:

The mature male biomass time series for selected models are depicted in Figures 26 for EAG (for seven models) and WAG (for four models). Mature male biomass tracked the CPUE trends well for selected models for EAG and WAG. The biomass variance was estimated using the Burnham *et al.* (1987) suggested formula (Equation A.14). We determined the mature male biomass values on 15 February each year and considered varying time series of recruits (see Table T1) for estimating mean number of recruits for the $MMB_{35\%}$ calculation under a Tier 3 approach.

c. **Fishing mortality**:

The full selection pot fishery F over time for selected models is shown in Figure 25 for EAG (for seven models) and WAG (for four models). The F peaked in late 1980s and early to mid-1990s and systematically declined in the EAG. Slight increases in F were observed from 2014 to 2016, followed by a decline in the EAG. On the other hand, the F in the WAG peaked in late 1980s, 1990s and early 2000s, declined in late 2000s, and slightly increased in 2013–2014 before declining.

d. **F vs. MMB:**

We provide these plots for models 20_1b Ver2 and 20_2 for EAG and WAG in Figure 43. The 2019 F was below the overfishing levels in both regions.

e. **Stock-Recruitment relationship:** None.

f. **Recruitment**:

The temporal changes in total number of recruits to the modeled population are illustrated in Figure 14 for EAG (for six models) and in Figure 32 for WAG (for four models). The recruitment distribution to the model size group (101–185 mm CL) is shown in Figures 15 and 33 for EAG and WAG, respectively for the respective number of models.

5. Evaluation of the fit to the data:

g. **Fits to catches:**

The fishery retained and total catch, and groundfish bycatch (observed vs. estimated) plots are illustrated in Figure 17 for EAG (for six models) and in Figure 35 for WAG (for four models). The 1981/82–1984//85 retained catch plots for respective number of models are depicted in Figures 18 and 36 for EAG and WAG, respectively. All predicted fits were very close to observed values, especially for retained catch and groundfish bycatch mortality. However, pre-1995 total catch data did not fit well.

h. **Survey data plot:**

We provide some cooperative pot survey data plots in Appendix C.

i. **CPUE index data:**

The model predicted CPUE vs. input CPUE indices for six models are shown in Figure 24 for EAG and for four models in Figure 42 for WAG. The CPUE variance was estimated using the Burnham *et al.* (1987) suggested formula (Equation A.14). These figures compare the effects of different CPUE indices input to models.

j. **Tagging data:**

The predicted vs. observed tag recaptures by length-class for years 1 to 6 post tagging are depicted in Figure 13 for EAG and Figure 31 for WAG. The predictions appear reasonable. Note that we used the EAG tagging information for size transition matrix estimation for both stocks (EAG and WAG). The size transition matrices estimated using EAG tagging data in the EAG and WAG models were similar.

k. **Molt probability**:

The predicted molt probabilities vs. CL are depicted for six models in Figures 16 for EAG and for four models in Figure 34 for WAG. The fitted curves appear to be satisfactory.

l. **Fit to catch size compositions:**

Retained, total, and groundfish discard length compositions are shown in Figures 9 to 11 for EAG and 27 to 29 for WAG. The retained and total catch size composition fits appear satisfactory. But, the fits to groundfish bycatch size compositions are bad. Note that we did not use the groundfish size composition in any of the model scenario fits.

We illustrate the standardized residual plots as bubble plots of size composition over time for retained catch (Figures 19 and 21 for EAG, and 37 and 39 for WAG) and for total catch (Figures 20 and 22 for EAG, and 38 and 40 for WAG) for two models (20_1b and 20_2). The retained catch bubble plots do not appear to exhibit major pronounced patterns among residuals for the selected models.

m. **Marginal distributions for the fits to the composition data:**

We did not provide this plot in this report.

n. **Plots of implied versus input effective sample sizes and time series of implied effective sample sizes:**

We did not provide the plots or table values of implied vs. input effective sample sizes in this report. However, we provide the Stage-1 and the re-weighted Stage-2 effective sample sizes in Tables 5 to 7 for EAG and in Tables 14 to 16 for WAG, respectively for models 20_1, 20_1b, and 20_2.

o. **Tables of RMSEs for the indices:**

We did not provide this table in this report.

p. **Quantile-quantile (Q–Q) plots:**

We did not provide these plots for model fits in this report. However, we provide a Q-Q plot for cooperative survey CPUE fit in Appendix C.

6. Retrospective and historical analysis:

The retrospective fits for scenarios 20_1, 20_1b, 20_1b Ver 2, and 20_2 are shown in Figure 23 for EAG and in Figure 41 for WAG. The retrospective fits, prepared for the whole time series 1961 to 2019, did not show severe departure when five terminal years' data were sequentially removed, especially for WAG, and hence the current formulation of the model appears stable. The modified Mohn rho (1999) values are also given in the figures.

Mohn rho (ρ) formula, modified by Deroba (2014), is:

$$Mohn\ \rho = \frac{\sum_{n=1}^{x} \frac{\left[\widehat{MMB}_{y=T-n,T-n} - \widehat{MMB}_{y=T-n,T}\right]}{\widehat{MMB}_{y=T-n,T}}}{x}$$

where, $\widehat{MMB}_{y=T-n,T-n}$ is the MMB estimated for year T-n (left subscript) using data up to T-n years (right subscript), T is the terminal year of the entire data, x is the total number of peels, most recent year's data is "peeled off" recursively n times, where n =1, 2, 3. …x. We used five peels (x=5) and our T =2019.

The low values (<<1.0) of Mohn rho indicate no severe model misspecification, especially for WAG. A severe drop in modeled biomass from the initial MMB occurred when the fishery time series started in 1981.

7. **Uncertainty and sensitivity analysis:**

   The main task was to determine a plausible size transition matrix to project the population over time. In a previous study, we investigated the sensitivity of the model to determining the size transition matrix by using or not using a molt probability function (Siddeek *et al.* 2016a). The model fit improved when molt probability model is included. Therefore, we included a molt probability sub-model for the size transition matrix calculation in all models.

8. **Conduct 'jitter analysis':**

   We conducted jitter analysis on models 20_1b and 20_2 (Appendix D). The results indicated that global convergence was achieved for most runs.

F. Calculation of the OFL

1. Specification of the Tier level:

In the following section, we provide the Tier 3 method to determine OFL and ABC.

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:

The critical assumptions for MMB_{MSY} reference point estimation of Aleutian Islands golden king crab are:

a. Natural mortality is constant.
b. A fixed growth transition matrix is adequately estimated from tagging data and a molt probability sub-model.
c. Total fishery selectivity and retention curves are length-dependent and the 2005/06–2019/20 period selectivity estimates are applicable.
d. Groundfish bycatch fishery selectivity is kept constant at 1.0 for all length groups.
e. Model estimated recruits (in millions of crab) are valid for different time periods considered on chosen given model.
f. Model estimated groundfish bycatch mortality values are appropriately averaged for the period 2010/11–2019/20 (10 years).
g. A knife-edge 50% maturity size of 111 mm CL, as used for MMB estimation, is correct.

Method:

We simulated the population abundance starting from the model estimated terminal year stock size by length, model estimated parameter values, a fishing mortality value (F), and a constant number of annual recruits. Once stock dynamics stabilized (we used the 99th year estimates) for an F, we calculated the MMB/R for that F.

We computed the relative MMB/R in percentage, $\left(\frac{MMB}{R}\right)_{x\%}$ (where x% = $\frac{\frac{MMB_F}{R}}{\frac{MMB_0}{R}} \times 100$ and MMB_0/R is the virgin MMB/R) for different F values.

$F_{35\%}$ is the F value producing an MMB/R value equal to 35% of MMB_0/R.

$MMB_{35\%}$ is estimated using the following formula:

$MMB_{35\%} = \left(\frac{MMB}{R}\right)_{35} \times \bar{R}$, where $\bar{R}$ is the mean number of model estimated recruits for a selected period.

3. Specification of the OFL:

a. Provide the equations (from Amendment 24) on which the OFL is to be based:

F_{OFL} uses Equation A.28. The OFL is estimated by an iterative procedure accounting for intervening total removals (see Appendix A).

b. Basis for projecting MMB to the time of mating:

We followed the NPFMC 2007a guideline.

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:

The 2019/20 fishery data indicated that overfishing did not occur (Total Catch < OFL) and the stock did not reach the overfished status (MMB > MSST). See Management Performance table below. The OFL and ABC values for 2020/21 in the table below are the recommended values. The TACs for 2015/16–2016/17 in the table below do not include landings towards a cost-recovery fishery goal, but the catches towards cost-recovery fishing are included in the retained and total catches.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC[b]
2016/17	N/A	N/A	2.515	2.593	2.947	5.69	4.26
2017/18	6.044	14.205	2.515	2.585	2.942	6.048	4.536
2018/19	5.880	17.848	2.883	2.965	3.355	5.514	4.136
2019/20	5.909[c]	16.323[c]	3.257	3.274[d]	3.693[d]	5.249	3.937
2020/21[e]		**14.760**				**4.793**	**3.595**
2020/21[f]		**15.106**				**4.993**	**3.745**
2020/21[g]		**14.774**				**4.798**	**3.599**

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC[b]
2016/17	N/A	N/A	5.545	5.716	6.497	12.53	9.40
2017/18	13.325	31.315	5.545	5.699	6.487	13.333	10.000
2018/19	12.964	39.348	6.356	6.536	7.396	12.157	9.118
2019/20	13.027[c]	35.985[c]	7.180	7.219[d]	8.141[d]	11.572	8.679
2020/21[e]		**32.540**				**10.566**	**7.925**
2020/21[f]		**33.303**				**11.008**	**8.256**
2020/21[g]		**32.571**				**10.579**	**7.934**

a. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.
b. 25% buffer was applied to total catch OFL to determine ABC.
c. MSST and MMB determined by Model 20_1b Ver 2
d. 100% TAC was achieved in EAG, but over 96% TAC was achieved in WAG at the time of this assessment. The WAG fishery is ongoing.
e. Model 20_1b, up to 2019/20 data, mean number of recruit calculation time period for EAG: 1986–2017 and for WAG: 1987–2018.
f. Model 20_2, up to 2019/20 data.
g. Model 20_1b Ver 2, up to 2019/20 data, mean number of recruit calculation time period for EAG and WAG: 1987–2012.

4. Specification of the retained portion of the total catch OFL:

The retained catch portion of the total-catch OFL for EAG, WAG, and the entire Aleutian Islands (AI = EAG + WAG) stock were calculated for the three models (20_1, 20_1b, and 20_2):

Model 20_1:

EAG: 2,899 t (6.391 million lb)

WAG: 1,693 t (3.732 million lb)

AI: 4,592 t (10.123 million lb).

Model 20_1b:

EAG: 2,870 t (6.327 million lb)

WAG: 1,697 t (3.741 million lb)

AI: 4,567 t (10.068 million lb).

Model 20_2:

EAG: 3,011 t (6.638 million lb)

WAG: 1,748 t (3.853 million lb)

AI: 4,759 t (10.491 million lb).

G. Calculation of ABC

We estimated the cumulative probability distribution of OFL assuming a log normal distribution of OFL. We calculated the OFL at the 0.5 probability and the maximum ABC at the 0.49 probability and considered an additional buffer by setting ABC =0.75*OFL

We provide the ABC estimates with the 25% buffer for EAG, WAG, and AI considering models 20_1, 20_1b, and 20_2:

Model 20_1:

EAG: ABC = 2,262 t (4.986 million lb)

WAG: ABC = 1,352 t (2.981 million lb)

AI: ABC = 3,614 t (7.967 million lb).

Model 20_1b:

EAG: ABC = 2,239 t (4.937 million lb)

WAG: ABC = 1,355 t (2.988 million lb)

AI: ABC = 3,594 t (7.925 million lb).

Model 20_2:

EAG: ABC = 2,350 t (5.181 million lb)

WAG: ABC = 1,395 t (3.075 million lb)

AI: ABC = 3.745 t (8.256 million lb).

1. List of variables related to scientific uncertainty:

- Models rely largely on fisheries data.
- Observer and fisheries CPUE indices played a major role in the assessment model.
- Natural mortality, 0.21 yr^{-1}, was estimated in the previous model and not independently estimated here.
- The time period to compute the average number of recruits relative to the assumption that this represents “a time period determined to be representative of the production potential of the stock.”
- Fixed bycatch mortality rates were used in each fishery (crab fishery and the groundfish fishery) that discarded golden king crab.
- Discarded catch and bycatch mortality for each fishery that bycatch occurred during 1981/82–1989/90 were not available.

2. List of additional uncertainties for alternative sigma-b.

We recommend a buffer of 25% to account for additional uncertainties.

3. Author recommended ABC:

Authors recommend two ABC options based on 25% buffer on the OFL under scenarios 20_1bVer2 and 20_2.

H. Data Gaps and Research Priorities

1. Recruit abundances were tied to commercial catch sampling data. The implicit assumption in the analysis was that the estimated recruits come solely from the same exploited stock through growth and mortality. The current analysis did not consider that additional recruitment may occur through immigration from neighboring areas and possibly separate sub-stocks. The analysis also did not consider emigration from the study area, which would result in an assumption of increased *M* or a reduced estimate of recruits. Extensive tagging experiments or resource surveys are needed to investigate stock distributions.

2. We estimated *M* in the model. However, an independent estimate of *M* is needed for comparison, which could be achieved with tagging experiments.

3. An extensive tagging study may provide independent estimates of molting probability and growth. We used historical tagging data to determine the size transition matrix.

4. An arbitrary 20% handling mortality rate on discarded males was used, which was obtained from the red king crab literature (Kruse *et al.* 2000; Siddeek 2002). An experimental-based independent estimate of handling mortality is needed for Aleutian Islands golden king crab.

5. The Aleutian King Crab Research Foundation recently initiated crab survey programs in the Aleutian Islands. This program needs to be strengthened and continued for golden king crab research to address some of the data gaps and establish a fishery independent data source.

6. We have been using a length-weight relationship established based on late 1990s data for golden king crab. It is unclear how the recent changes in environmental conditions in the Bering Sea will affect golden king crab growth and survival. Length-weight data from the cooperative 2018 survey were used in the current assessment; however, more measurements are needed to increase the sample size to refine the length-weight model.

7. We have recently added male maturity data in the model to determine a maturity curve for MMB estimation. These maturity data were collected in 1984 and 1991 and need to be updated. More data and more recent data are needed. The ADF&G observer sampling, dock side sampling, and independent survey programs collected male maturity data during the 2018/19 fishery. Preliminary analysis on these data was presented at the January 2020 CPT meeting. The CPT recommended to collect additional data on small size crab (sublegal) to evaluate the maturity fit. ADF&G and cooperative survey are continuing to collect additional data.

8. Morphometric measurements provide size at maturity. Ideally, an experimental study under natural environment condition is needed to collect male size at functional maturity data to determine functional maturity size.

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Tables

Table 1. Commercial fishery history for the Aleutian Islands golden king crab fishery 1981/82–2019/20: number of vessels, guideline harvest level (GHL; established in lb, converted to t) for 1996/97 – 2004/05, total allowable catch (TAC; established in lb, converted to t) for 2005/06–2019/20, 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. The values are separated by EAG and WAG beginning in 1996/97.

Crab Fishing Season	Vessels	GHL/TAC	Harvest[a]	Crab[b]	Pot Lifts	CPUE[b]	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	–	5,776	2,816,313	236,601	12	2.1[f]
1986/87	64	–	6,685	3,345,680	433,870	8	2.0[f]
1987/88	66	–	4,199	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	–	3,153	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]

Information for subsequent seasons is presented separately for EAG, WAG in the rows below

Table 1. (continued)

Crab Fishing Season	Vessels		GHL/TAC		Harvest[a]		Crab[b]		Pot Lifts		CPUE[b]		Average Weight[c]	
	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG
1996/97	14	13	1,452	1,225	1,493	1,145	731,909	602,968	113,460	99,267	7	6	2.04[f]	1.91[f]
1997/98	13	9	1,452	1,225	1,588	1,109	780,610	569,550	106,403	86,811	7	7	2.04[f]	1.95[f]
1998/99	14	3	1,361	1,225	1,473	768	740,011	410,018	83,378	35,975	9	11	2.00[f]	1.86[f]
1999/00	15	15	1,361	1,225	1,392	1,256	709,332	676,558	79,129	107,040	9	6	1.95[f]	1.86[f]
2000/01	15	12	1,361	1,225	1,422	1,308	704,702	705,613	71,551	101,239	10	7	2.00[f]	1.86[f]
2001/02	19	9	1,361	1,225	1,442	1,243	730,030	686,738	62,639	105,512	12	7	2.00[f]	1.81[f]
2002/03	19	6	1,361	1,225	1,280	1,198	643,886	664,823	52,042	78,979	12	8	2.00[f]	1.81[f]
2003/04	18	6	1,361	1,225	1,350	1,220	643,074	676,633	58,883	66,236	11	10	2.09[f]	1.81[f]
2004/05	19	6	1,361	1,225	1,309	1,219	637,536	685,465	34,848	56,846	18	12	2.04[f]	1.77[f]
2005/06	7	3	1,361	1,225	1,300	1,204	623,971	639,368	24,569	30,116	25	21	2.09[f]	1.91[f]
2006/07	6	4	1,361	1,225	1,357	1,030	650,587	527,734	26,195	26,870	25	20	2.09[f]	1.95[f]
2007/08	4	3	1,361	1,225	1,356	1,142	633,253	600,595	22,653	29,950	28	20	2.13[f]	1.91[f]
2008/09	3	3	1,361	1,286	1,426	1,150	666,946	587,661	24,466	26,200	27	22	2.13[f]	1.95[f]
2009/10	3	3	1,429	1,286	1,429	1,253	679,886	628,332	29,298	26,489	26	24	2.09[f]	2.00[f]
2010/11	3	3	1,429	1,286	1,428	1,279	670,983	626,246	25,851	29,994	26	21	2.13[f]	2.04[f]
2011/12	3	3	1,429	1,286	1,429	1,276	668,828	616,118	17,915	26,326	37	23	2.13[f]	2.09[f]
2012/13	3	3	1,501	1,352	1,504	1,339	687,666	672,916	20,827	32,716	33	21	2.18[f]	2.00[f]
2013/14	3	3	1,501	1,352	1,546	1,347	720,220	686,883	21,388	41,835	34	16	2.13[f]	1.95[f]
2014/15	3	2	1,501	1,352	1,554	1,217	719,064	635,312	17,002	41,548	42	15	2.18[f]	1.91[f]
2015/16	3	2	1,501	1,352	1,590	1,139	763,604	615,355	19,376	41,108	39	15	2.09[f]	1.85[f]

Crab Fishing Season	Vessels		GHL/TAC		Harvest[a]		Crab[b]		Pot Lifts		CPUE[b]		Average Weight[c]	
	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG
2016/17	3	3	1,501	1,014	1,578	1,015	793,983	543,796	24,470	38,118	32	14	1.99[f]	1.87[f]
2017/18	3	3	1,501	1,014	1,571	1,014	802,610	519,051	25,516	30,885	31	17	1.96[f]	1.95[f]
2018/19	3	3	1,749	1,134	1,830	1,135	940,336	578,221	25,553	29,156	37	20	1.95[f]	1.96[f]
2019/20	3	3	1,955	1,302	2,031	1,244	1,057,464	626,735	30,998	38,733	34	16	1.92[f]	1.98[f]

Note:

a. Includes deadloss.
b. Number of crab per pot lift.
c. Average weight of landed crab, including dead loss.
d. Managed with 6.5" carapace width (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.

Catch and effort data include cost recovery fishery.

Table 2. Annual weight of total fishery mortality to Aleutian Islands golden king crab, 1981/82 – 2019/20, partitioned by source of mortality: retained catch, bycatch mortality during crab fisheries, and bycatch mortality during groundfish fisheries. For bycatch in the federal groundfish fisheries, historical data (1991–2008) are not available for areas east and west of 174W, and are listed for federal groundfish reporting areas 541, 542, and 543 combined. The 2009– present data are available by separate EAG and WAG fisheries and are listed as such. A mortality rate of 20% was applied for crab fisheries bycatch, and a mortality rate of 50% for groundfish pot fisheries and 80% for the trawl fisheries were applied.

Season	Retained Catch (t)		Bycatch Mortality by Fishery Type (t)				Total Fishery Mortality (t)		
			Crab		Groundfish				
	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	Entire AI
1981/82	490	95							585
1982/83	1,260	2,655							3,914
1983/84	1,554	2,991							4,545
1984/85	1,839	424							2,263
1985/86	2,677	1,996							4,673
1986/87	2,798	4,200							6,998
1987/88	1,882	2,496							4,379
1988/89	2,382	2,441							4,823
1989/90	2,738	3,028							5,766
1990/91	1,623	1,621							3,244
1991/92	2,035	1,397	515	344	0				4,291
1992/93	2,112	1,025	1,206	373	0				4,716
1993/94	1,439	686	383	258	4				2,770
1994/95	2,044	1,540	687	823	1				5,095
1995/96	2,259	1,203	725	530	2				4,719
1996/97	1,738	1,259	485	439	5				3,926
1997/98	1,588	1,083	441	343	1				3,455
1998/99	1,473	955	434	285	1				3,149
1999/00	1,392	1,222	313	385	3				3,316
2000/01	1,422	1,342	82	437	2				3,285
2001/02	1,442	1,243	74	387	0				3,146
2002/03	1,280	1,198	52	303	18				2,850
2003/04	1,350	1,220	53	148	20				2,792
2004/05	1,309	1,219	41	143	1				2,715
2005/06	1,300	1,204	22	73	2				2,601
2006/07	1,357	1,022	28	81	18				2,506
2007/08	1,356	1,142	24	114	59				2,695
2008/09	1,426	1,150	61	102	33				2,772
2009/10	1,429	1,253	111	108	18	5	1,558	1,366	2,923
2010/11	1,428	1,279	123	124	49	3	1,600	1,407	3,006
2011/12	1,429	1,276	106	117	25	4	1,560	1,398	2,957
2012/13	1,504	1,339	118	145	9	6	1,631	1,491	3,122

2013/14	1,546	1,347	113	174	5	7	1,665	1,528	3,192
2014/15	1,554	1,217	127	175	9	5	1,691	1,397	3,088
2015/16	1,590	1,139	165	157	23	2	1,778	1,298	3,076
2016/17	1,578	1,015	203	145	3	3	1,785	1,163	2,947
2017/18	1,571	1,014	219	126	10	2	1,801	1,142	2,942
2018/19	1,830	1,135	240	140	8	2	2,078	1,277	3,355
2019/20	2,031	1,244	275	116	23	3	2,239	1,363	3,693

Table 2a. Time series of estimated total male catch (weight of crabs on the deck without applying any handling mortality) for the EAG and WAG golden king crab stocks (1990/91–2019/20). The crab weights are for the size range ≥ 101mm CL and a length-weight formula was used to predict weight at the mid-point of each size bin. NA: no observer sampling to compute catch.

Year	Total Catch Biomass (t) EAG	Total Catch Biomass (t) WAG
1990/91	1,391	3,626
1991/92	5,813	2,537
1992/93	5,484	1,496
1993/94	NA	2,783
1994/95	1,950	4,872
1995/96	3,681	2,099
1996/97	2,037	1,740
1997/98	2,521	1,777
1998/99	2,762	1,070
1999/00	2,260	2,063
2000/01	2,537	2,197
2001/02	2,086	2,107
2002/03	1,796	1,865
2003/04	1,815	1,845
2004/05	1,621	1,859
2005/06	1,731	1,783
2006/07	1,631	1,546
2007/08	1,814	1,602
2008/09	1,811	1,726
2009/10	1,766	1,681
2010/11	1,750	1,592
2011/12	1,765	1,519
2012/13	1,943	1,825
2013/14	1,834	1,910
2014/15	1,962	1,586
2015/16	2,120	1,551
2016/17	2,224	1,544
2017/18	2,031	1,155
2018/19	2,639	1,507
2019/20	2,985	1,714

Table 3. Time series of nominal annual pot fishery retained, observer retained, and observer total catch-per-unit-effort (CPUE, number of crabs per pot lift), total pot fishing effort (number of pot lifts), observer sample size (number of sampled pots), and GLM estimated observer CPUE Index (for Model 20_1) for the EAG and WAG golden king crab stocks, 1985/86–2019/20. Observer retained CPUE includes retained and non-retained legal-size crabs.

Year	Pot Fishery Nominal Retained CPUE		Obs. Nominal Retained CPUE		Obs. Nominal Total CPUE		Pot Fishery Effort (no.pot lifts)		Obs. Sample Size (no.pot lifts)		Obs. CPUE Index	
	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG
1985/86	11.90	11.90					117,718	118,563				
1986/87	8.42	7.32					155,240	277,780				
1987/88	7.03	7.15					146,501	160,229				
1988/89	7.52	7.93					155,518	166,409				
1989/90	8.49	7.83					155,262	202,541				
1990/91	8.90	7.00	6.84	8.34	13.00	26.67	106,281	108,533	138	340		
1991/92	8.20	7.40	9.84	6.14	36.91	19.17	133,428	101,429	377	857		
1992/93	8.40	5.90	10.44	4.26	38.52	16.83	133,778	69,443	199	690		
1993/94	7.80	4.40	5.91	12.75	20.81	17.23	106,890	127,764	31	174		
1994/95	5.90	4.10	4.66	6.62	12.91	19.23	191,455	195,138	127	1,270		
1995/96	5.90	4.70	6.03	6.03	16.98	14.28	177,773	115,248	6,388	5,598	1.00	1.17
1996/97	6.50	6.10	6.02	5.90	13.81	13.54	113,460	99,267	8,360	7,194	0.94	0.98
1997/98	7.30	6.60	7.99	6.72	18.25	15.03	106,403	86,811	4,670	3,985	0.87	0.98
1998/99	8.90	11.40	9.82	9.43	25.77	23.09	83,378	35,975	3,616	1,876	1.00	1.09
1999/00	9.00	6.30	10.28	6.09	20.77	14.49	79,129	107,040	3,851	4,523	0.92	0.91
2000/01	9.90	7.00	10.40	6.46	25.39	16.64	71,551	101,239	5,043	4,740	0.82	0.84
2001/02	11.70	6.50	11.73	6.04	22.48	14.66	62,639	105,512	4,626	4,454	1.04	0.82
2002/03	12.40	8.40	12.70	7.47	22.59	17.37	52,042	78,979	3,980	2,509	1.10	0.91
2003/04	10.90	10.20	11.34	9.33	19.43	18.17	58,883	66,236	3,960	3,334	0.97	1.16
2004/05	18.30	12.10	18.34	11.14	28.48	22.45	34,848	56,846	2,206	2,619	1.44	1.24
2005/06	25.40	21.20	29.52	23.89	38.55	36.23	24,569	30,116	1,193	1,365	0.98	1.16
2006/07	24.80	19.60	25.13	23.93	33.39	33.47	26,195	26,870	1,098	1,183	0.80	1.10
2007/08	28.00	20.00	31.10	21.01	40.38	32.46	22,653	29,950	998	1,082	0.89	1.00
2008/09	27.30	22.40	29.97	24.50	38.23	38.16	24,466	26,200	613	979	0.88	1.15
2009/10	25.90	23.70	26.60	26.54	35.88	34.08	26,298	26,489	408	892	0.73	1.23
2010/11	26.00	20.90	26.40	22.43	37.10	29.05	25,851	29,994	436	867	0.76	1.10
2011/12	37.30	23.40	39.48	23.63	52.04	31.13	17,915	26,326	361	837	1.08	1.10
2012/13	33.02	20.57	37.82	22.88	47.57	30.76	20,827	32,716	438	1,109	1.04	1.07
2013/14	33.67	16.42	35.94	16.89	46.16	25.01	21,388	41,835	499	1,223	1.02	0.81
2014/15	42.29	15.29	47.01	15.25	60.00	22.67	17,002	41,548	376	1,137	1.34	0.73
2015/16	39.41	14.97	43.27	15.81	58.68	22.14	19,376	41,108	478	1,296	1.26	0.74
2016/17	32.45	14.29	36.89	16.65	52.82	24.41	24,470	38,118	617	1,060	1.05	0.86
2017/18	31.46	16.81	35.18	19.30	54.62	25.54	25,516	30,885	585	760	1.00	0.98
2018/19	36.80	19.83	41.57	22.90	62.97	30.61	25,553	29,156	475	688	1.25	1.18
2019/20	34.11	16.18	40.88	19.25	57.46	27.15	30,998	38,733	540	793	1.16	0.96

Table 4. Time series of negative binomial GLM estimated CPUE indices and coefficient of variation (CV) for the fish ticket based retained catch-per-pot lift for the EAG golden king crab stock. The GLM was fitted to the 1985/86 to 1998/99 time series of data.

Year	CPUE Index	CV
1985/86	1.63	0.05
1986/87	1.23	0.05
1987/88	0.96	0.05
1988/89	1.04	0.04
1989/90	1.08	0.03
1990/91	0.99	0.05
1991/92	0.90	0.04
1992/93	0.92	0.04
1993/94	0.91	0.05
1994/95	0.81	0.04
1995/96	0.78	0.04
1996/97	0.78	0.04
1997/98	1.05	0.05
1998/99	1.21	0.05

Table 5. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by the Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for model 20_1 fit to EAG data. NA: not available.

Year	Initial Input Retained Vessel-Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Vessel-Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985/86	57	47				
1986/87	11	9				
1987/88	61	50				
1988/89	352	288				
1989/90	792	649			9	4
1990/91	163	134	22	13	13	6
1991/92	140	115	48	28	NA	NA
1992/93	49	40	41	24	2	1
1993/94	340	279	NA	NA	2	1
1994/95	319	261	34	20	4	2
1995/96	879	720	1,117	654	5	2
1996/97	547	448	509	298	4	2
1997/98	538	441	711	416	8	4
1998/99	541	443	574	336	15	7
1999/00	463	379	607	355	14	7
2000/01	436	357	495	290	16	8
2001/02	488	400	510	298	13	6
2002/03	406	333	438	256	15	7
2003/04	405	332	416	243	17	8
2004/05	280	229	299	175	10	5
2005/06	266	218	232	136	12	6
2006/07	234	192	143	84	14	7
2007/08	199	163	134	78	17	8
2008/09	197	161	113	66	15	7
2009/10	170	139	95	56	16	8
2010/11	183	150	108	63	26	12
2011/12	160	131	107	63	13	6
2012/13	187	153	99	58	18	9
2013/14	193	158	122	71	17	8
2014/15	168	138	99	58	16	8
2015/16	190	156	125	73	10	5
2016/17	223	183	155	91	12	6
2017/18	213	175	133	78	12	6
2018/19	218	179	234	137	9	4
2019/20	208	170	230	135	8	4

Table 6. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by the Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for model 20_1b fit to EAG data. NA: not available.

Year	Initial Input Retained Vessel-Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Vessel-Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985/86	57	47				
1986/87	11	9				
1987/88	61	50				
1988/89	352	289				
1989/90	792	650			9	4
1990/91	163	134	22	13	13	6
1991/92	140	115	48	28	NA	NA
1992/93	49	40	41	24	2	1
1993/94	340	279	NA	NA	2	1
1994/95	319	262	34	20	4	2
1995/96	879	721	1,117	650	5	2
1996/97	547	449	509	296	4	2
1997/98	538	441	711	414	8	4
1998/99	541	444	574	334	15	7
1999/00	463	380	607	353	14	7
2000/01	436	358	495	288	16	8
2001/02	488	400	510	297	13	6
2002/03	406	333	438	255	15	7
2003/04	405	332	416	242	17	8
2004/05	280	230	299	174	10	5
2005/06	266	218	232	135	12	6
2006/07	234	192	143	83	14	7
2007/08	199	163	134	78	17	8
2008/09	197	162	113	66	15	7
2009/10	170	139	95	55	16	8
2010/11	183	150	108	63	26	12
2011/12	160	131	107	62	13	6
2012/13	187	153	99	58	18	9
2013/14	193	158	122	71	17	8
2014/15	168	138	99	58	16	8
2015/16	190	156	125	73	10	5
2016/17	223	183	155	90	12	6
2017/18	213	175	133	77	12	6
2018/19	218	179	234	136	9	4
2019/20	208	171	230	134	8	4

Table 7. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by the Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for model 20_2 fit to EAG data. NA: not available.

Year	Initial Input Retained Vessel-Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Vessel-Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985/86	57	47				
1986/87	11	9				
1987/88	61	50				
1988/89	352	289				
1989/90	792	651			9	4
1990/91	163	134	22	13	13	6
1991/92	140	115	48	28	NA	NA
1992/93	49	40	41	24	2	1
1993/94	340	279	NA	NA	2	1
1994/95	319	262	34	20	4	2
1995/96	879	723	1,117	659	5	2
1996/97	547	450	509	301	4	2
1997/98	538	442	711	420	8	4
1998/99	541	445	574	339	15	7
1999/00	463	381	607	358	14	7
2000/01	436	358	495	292	16	8
2001/02	488	401	510	301	13	6
2002/03	406	334	438	259	15	7
2003/04	405	333	416	246	17	8
2004/05	280	230	299	177	10	5
2005/06	266	219	232	137	12	6
2006/07	234	192	143	84	14	7
2007/08	199	164	134	79	17	8
2008/09	197	162	113	67	15	7
2009/10	170	140	95	56	16	8
2010/11	183	150	108	64	26	12
2011/12	160	132	107	63	13	6
2012/13	187	154	99	58	18	9
2013/14	193	159	122	72	17	8
2014/15	168	138	99	58	16	8
2015/16	190	156	125	74	10	5
2016/17	223	183	155	92	12	6
2017/18	213	175	133	79	12	6
2018/19	218	179	234	138	9	4
2019/20	208	171	230	136	8	4

Table 8. Parameter estimates and coefficient of variations (CV) with the 2019 MMB (MMB estimated on 15 Feb 2020) for models 20_1, 20_1b, 20_1b Ver 2, and 20_2 for the golden king crab data from the EAG, 1985/86–2019/20. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Model 20_1		**Model 20_1b**		**Model 20_1b Ver 2**		**Model 20_2**		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.538	0.01	2.537	0.01	2.537	0.01	2.537	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-8.282	0.21	-8.311	0.21	-8.311	0.21	-8.297	0.21	-12.0-5.0
log_a (molt prob. slope)	-2.509	0.02	-2.508	0.02	-2.508	0.02	-2.502	0.02	-4.61-1.39
log_b (molt prob. L50)	4.949	0.001	4.949	0.001	4.949	0.001	4.949	0.001	3.869,5.05
σ (growth variability std)	3.678	0.03	3.677	0.03	3.677	0.03	3.678	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.387	0.02	3.383	0.02	3.383	0.02	3.388	0.02	0.,4.4
log_ total sel deltaθ, 2005–19	2.951	0.02	2.951	0.02	2.951	0.02	2.938	0.02	0.,4.4
log_ ret. sel deltaθ, 1985–19	1.868	0.02	1.868	0.02	1.868	0.02	1.869	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.835	0.002	4.834	0.002	4.834	0.002	4.836	0.002	4.0,5.0
log_tot sel θ_{50}, 2005–19	4.922	0.002	4.922	0.002	4.922	0.002	4.919	0.002	4.0,5.0
log_ret. sel θ_{50}, 1985–19	4.915	0.0003	4.915	0.0003	4.915	0.0003	4.915	0.0003	4.0,5.0
log_β_r (rec.distribution par.)	-1.079	0.17	-1.080	0.17	-1.080	0.17	-1.076	0.17	-12.0, 12.0
logq2 (catchability 1995–04)	-0.538	0.14	-0.541	0.13	-0.540	0.13	-0.541	0.13	-9.0, 2.25
logq3 (catchability 2005–19)	-0.711	0.17	-0.712	0.17	-0.712	0.17	-0.752	0.15	-9.0, 2.25
log_mean_rec (mean rec.)	0.828	0.05	0.828	0.05	0.828	0.05	0.836	0.05	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.940	0.07	-0.943	0.07	-0.943	0.07	-0.963	0.07	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.155	0.09	-9.156	0.09	-9.156	0.09	-9.172	0.09	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.055	0.36	0.055	0.36	0.055	0.36	0.045	0.37	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.039	0.43	0.033	0.44	0.033	0.44	0.033	0.44	0.0,1.0
2019 MMB	9,765	0.22	9,762	0.22	9,775	0.22	10,099	0.21	

Table 9. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 20_1 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2020 are restricted to 1985–2020. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =22,632			
		$MMB_{35\%}$=6,601			
1985	1.68	9,486	0.04	9,723	0.06
1986	1.01	7,259	0.04	8,234	0.04
1987	4.25	6,645	0.05	6,430	0.04
1988	3.60	6,630	0.05	5,363	0.05
1989	2.02	5,771	0.06	4,793	0.07
1990	2.96	5,882	0.05	4,306	0.07
1991	3.49	5,966	0.04	4,586	0.06
1992	2.25	5,887	0.04	4,425	0.05
1993	2.15	6,044	0.03	4,452	0.05
1994	2.43	5,581	0.03	4,875	0.04
1995	2.30	5,001	0.04	4,435	0.04
1996	2.24	5,111	0.04	3,835	0.04
1997	3.00	5,363	0.05	3,969	0.04
1998	2.76	5,918	0.05	4,076	0.05
1999	2.86	6,571	0.05	4,501	0.05
2000	2.65	7,143	0.06	5,147	0.06
2001	2.00	7,456	0.06	5,746	0.06
2002	2.45	7,689	0.07	6,241	0.06
2003	2.12	7,882	0.07	6,540	0.07
2004	1.87	7,889	0.07	6,718	0.07
2005	2.76	7,902	0.07	6,830	0.07
2006	2.14	8,072	0.07	6,709	0.08
2007	2.06	8,055	0.07	6,798	0.08
2008	2.97	8,131	0.07	6,906	0.08
2009	1.93	8,314	0.06	6,837	0.08
2010	1.79	8,109	0.06	7,026	0.07
2011	2.09	7,817	0.06	7,063	0.06
2012	1.80	7,489	0.06	6,794	0.06
2013	1.55	6,963	0.06	6,465	0.06
2014	2.65	6,610	0.07	6,048	0.06
2015	3.24	6,783	0.08	5,534	0.07
2016	3.71	7,436	0.11	5,321	0.08
2017	4.97	8,770	0.14	5,670	0.11
2018	2.61	9,901	0.19	6,586	0.14
2019	2.25	9,765	0.22	7,893	0.18
2020	2.29				

Table 10. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 20_1b for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2020 are restricted to 1985–2020. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =22,241 $MMB_{35\%}$=6,774			
1985	1.71	9,454	0.04	9,671	0.06
1986	1.02	7,248	0.04	8,189	0.04
1987	4.29	6,655	0.05	6,411	0.04
1988	3.63	6,672	0.05	5,363	0.05
1989	2.02	5,830	0.06	4,820	0.07
1990	2.91	5,926	0.05	4,359	0.07
1991	3.49	5,986	0.04	4,645	0.06
1992	2.25	5,903	0.04	4,459	0.05
1993	2.16	6,057	0.03	4,471	0.05
1994	2.43	5,592	0.04	4,889	0.04
1995	2.31	5,007	0.04	4,448	0.04
1996	2.24	5,117	0.04	3,844	0.04
1997	3.01	5,368	0.05	3,976	0.04
1998	2.76	5,923	0.05	4,082	0.05
1999	2.86	6,576	0.05	4,508	0.05
2000	2.65	7,149	0.06	5,154	0.06
2001	2.00	7,461	0.06	5,753	0.06
2002	2.45	7,693	0.07	6,248	0.06
2003	2.12	7,885	0.07	6,546	0.07
2004	1.87	7,891	0.07	6,723	0.07
2005	2.77	7,904	0.07	6,833	0.07
2006	2.14	8,074	0.07	6,712	0.08
2007	2.06	8,058	0.07	6,802	0.08
2008	2.97	8,134	0.07	6,911	0.08
2009	1.93	8,318	0.06	6,842	0.08
2010	1.79	8,112	0.06	7,031	0.07
2011	2.09	7,820	0.06	7,067	0.06
2012	1.80	7,493	0.06	6,798	0.06
2013	1.55	6,967	0.06	6,470	0.06
2014	2.65	6,613	0.07	6,053	0.06
2015	3.24	6,786	0.08	5,538	0.07
2016	3.71	7,437	0.11	5,326	0.08
2017	4.96	8,770	0.14	5,674	0.11
2018	2.61	9,899	0.19	6,589	0.14
2019	2.25	9,762	0.22	7,895	0.18
2020	2.29				

Table 11. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 20_2 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2020 are restricted to 1985–2020. Equilibrium MMBeq and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =23,445 $MMB_{35\%}$=6,794			
1985	1.71	9,473	0.04	9,704	0.06
1986	1.02	7,262	0.04	8,208	0.04
1987	4.30	6,669	0.05	6,420	0.04
1988	3.62	6,685	0.05	5,370	0.05
1989	2.02	5,840	0.06	4,830	0.07
1990	2.90	5,936	0.05	4,365	0.07
1991	3.49	5,991	0.04	4,651	0.06
1992	2.22	5,899	0.04	4,463	0.05
1993	2.15	6,038	0.03	4,470	0.05
1994	2.44	5,566	0.04	4,875	0.04
1995	2.32	4,990	0.04	4,421	0.04
1996	2.26	5,114	0.04	3,819	0.04
1997	3.05	5,391	0.05	3,962	0.05
1998	2.83	5,985	0.05	4,087	0.05
1999	2.93	6,688	0.05	4,541	0.05
2000	2.72	7,314	0.06	5,229	0.06
2001	2.06	7,676	0.06	5,879	0.06
2002	2.52	7,951	0.06	6,423	0.06
2003	2.13	8,166	0.07	6,764	0.07
2004	1.87	8,160	0.07	6,977	0.07
2005	2.75	8,143	0.07	7,092	0.07
2006	2.16	8,281	0.07	6,948	0.08
2007	2.08	8,249	0.07	7,001	0.07
2008	2.98	8,313	0.07	7,085	0.07
2009	1.95	8,482	0.06	7,004	0.07
2010	1.81	8,267	0.06	7,181	0.07
2011	2.13	7,976	0.06	7,206	0.06
2012	1.82	7,658	0.06	6,932	0.06
2013	1.56	7,133	0.06	6,611	0.06
2014	2.68	6,777	0.07	6,201	0.06
2015	3.30	6,959	0.09	5,685	0.07
2016	3.82	7,648	0.11	5,473	0.09
2017	5.05	9,042	0.14	5,839	0.11
2018	2.66	10,217	0.18	6,804	0.13
2019	2.28	10,099	0.21	8,165	0.18
2020	2.31				

Table 12. Negative log-likelihood values of the fits for models 20_1 (base, last year's accepted model with additional 2019/20 data), 20_1b, 20_1b Ver 2 (21_b but mean recruitment estimation time period modified to 1987–2012), and 20_2 (observer CPUE estimated with Year an Area interaction factor) for golden king crab in the EAG. Likelihood components with zero entry in the entire rows are omitted. RetdcatchB= retained catch biomass.

Likelihood Component	**Model 20_1**	**Model 20_1b**	**Model 20_1b Ver 2**	**Model 20_2**
Number of free parameters	149	149	149	149
Retlencomp	-1286.4300	-1286.6600	-1286.6600	-1286.7800
Totallencomp	-1428.6400	-1427.3300	-1427.3200	-1430.6100
Observer cpue	-0.5240	-0.5376	-0.5493	-2.4792
RetdcatchB	7.7446	7.6845	7.6847	7.9245
TotalcatchB	23.3301	23.3858	23.3859	23.4631
GdiscdcatchB	0.0003	0.0003	0.0003	0.0003
Rec_dev	7.3036	7.3053	7.3061	7.3886
Pot F_dev	0.0126	0.0125	0.0125	0.0128
Gbyc_F_dev	0.0296	0.0296	0.0296	0.0296
Tag	2692.5200	2692.5100	2692.5100	2692.3100
Fishery cpue	-2.3673	-3.5143	-3.5137	-3.4738
RetcatchN	0.0054	0.0055	0.0055	0.0055
Total	12.9831	12.8964	12.8904	7.7967

Table 13. Time series of negative binomial GLM estimated CPUE indices and coefficient of variations (CV) for the fish ticket based retained catch-per-pot lift for the WAG golden king crab stock. The GLM was fitted to the 1985/86 to 1998/99 time series of data. GLM predictor variables were selected by R square criteria.

Year	CPUE Index	CV
1985/86	2.07	0.05
1986/87	1.59	0.04
1987/88	1.22	0.04
1988/89	1.41	0.03
1989/90	1.15	0.03
1990/91	0.87	0.03
1991/92	0.76	0.04
1992/93	0.61	0.04
1993/94	0.76	0.05
1994/95	0.83	0.04
1995/96	0.90	0.04
1996/97	0.84	0.03
1997/98	0.76	0.03
1998/99	1.06	0.03

Table 14. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by the Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for model 20_1 model fit to WAG data. NA: not available.

Year	Initial Input Retained Vessel-Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Vessel-Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985/86	45	22				
1986/87	23	11				
1987/88	8	4				
1988/89	286	139				
1989/90	513	250			7	4
1990/91	205	100	190	99	6	4
1991/92	102	50	104	54	1	1
1992/93	76	37	94	49	3	2
1993/94	378	184	62	32	NA	NA
1994/95	367	179	119	62	2	1
1995/96	705	344	907	474	5	3
1996/97	817	398	1061	554	8	5
1997/98	984	480	1116	583	6	4
1998/99	613	299	638	333	14	9
1999/00	915	446	1155	603	18	11
2000/01	1029	502	1205	629	11	7
2001/02	898	438	975	509	11	7
2002/03	628	306	675	352	16	10
2003/04	688	336	700	365	8	5
2004/05	449	219	488	255	9	6
2005/06	337	164	220	115	6	4
2006/07	337	164	321	168	14	9
2007/08	276	135	257	134	17	11
2008/09	318	155	258	135	19	12
2009/10	362	177	292	152	24	15
2010/11	328	160	222	116	13	8
2011/12	295	144	252	132	14	9
2012/13	288	140	241	126	18	11
2013/14	327	159	236	123	17	11
2014/15	305	149	219	114	18	11
2015/16	287	140	243	127	10	6
2016/17	392	191	253	132	12	8
2017/18	299	146	222	116	10	6
2018/19	328	160	318	166	5	3
2019/20	256	125	320	167	6	4

Table 15. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by the Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for model 20_1b model fit to WAG data. NA: not available.

Year	Initial Input Retained Vessel-Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Vessel-Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985/86	45	22				
1986/87	23	11				
1987/88	8	4				
1988/89	286	142				
1989/90	513	255			7	4
1990/91	205	102	190	98	6	4
1991/92	102	51	104	54	1	1
1992/93	76	38	94	48	3	2
1993/94	378	188	62	32	NA	NA
1994/95	367	182	119	61	2	1
1995/96	705	350	907	467	5	3
1996/97	817	405	1061	546	8	5
1997/98	984	488	1116	574	6	4
1998/99	613	304	638	328	14	9
1999/00	915	454	1155	595	18	11
2000/01	1029	511	1205	620	11	7
2001/02	898	446	975	502	11	7
2002/03	628	312	675	347	16	10
2003/04	688	341	700	360	8	5
2004/05	449	223	488	251	9	6
2005/06	337	167	220	113	6	4
2006/07	337	167	321	165	14	9
2007/08	276	137	257	132	17	11
2008/09	318	158	258	133	19	12
2009/10	362	180	292	150	24	15
2010/11	328	163	222	114	13	8
2011/12	295	146	252	130	14	9
2012/13	288	143	241	124	18	11
2013/14	327	162	236	121	17	11
2014/15	305	151	219	113	18	11
2015/16	287	142	243	125	10	6
2016/17	392	195	253	130	12	8
2017/18	299	148	222	114	10	6
2018/19	328	163	318	164	5	3
2019/20	256	127	320	165	6	4

Table 16. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by the Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for model 20_2 model fit to WAG data. NA: not available.

Year	Initial Input Retained Vessel-Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Vessel-Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985/86	45	22				
1986/87	23	11				
1987/88	8	4				
1988/89	286	142				
1989/90	513	254			7	4
1990/91	205	102	190	99	6	4
1991/92	102	51	104	54	1	1
1992/93	76	38	94	49	3	2
1993/94	378	187	62	32	NA	NA
1994/95	367	182	119	62	2	1
1995/96	705	349	907	475	5	3
1996/97	817	405	1061	555	8	5
1997/98	984	488	1116	584	6	4
1998/99	613	304	638	334	14	9
1999/00	915	453	1155	605	18	11
2000/01	1029	510	1205	631	11	7
2001/02	898	445	975	510	11	7
2002/03	628	311	675	353	16	10
2003/04	688	341	700	366	8	5
2004/05	449	223	488	255	9	6
2005/06	337	167	220	115	6	4
2006/07	337	167	321	168	14	9
2007/08	276	137	257	135	17	11
2008/09	318	158	258	135	19	12
2009/10	362	179	292	153	24	15
2010/11	328	163	222	116	13	8
2011/12	295	146	252	132	14	9
2012/13	288	143	241	126	18	11
2013/14	327	162	236	124	17	11
2014/15	305	151	219	115	18	11
2015/16	287	142	243	127	10	6
2016/17	392	194	253	132	12	8
2017/18	299	148	222	116	10	6
2018/19	328	163	318	166	5	3
2019/20	256	127	320	168	6	4

Table 17. Parameter estimates and coefficient of variations (CV) with the 2019 MMB (MMB estimated on 15 Feb 2020) for models 20_1, 20_1b, 20_1b Ver 2, and 20_2 for the golden king crab data from the WAG, 1985/86–2019/20. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Model 20_1		**Model 20_1b**		**Model 20_1b Ver 2**		**Model 20_2**		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.537	0.01	2.537	0.01	2.537	0.01	2.537	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-7.699	0.22	-7.733	0.22	-7.733	0.22	-7.717	0.22	-12.0-5.0
log_a (molt prob. slope)	-2.625	0.03	-2.626	0.03	-2.626	0.03	-2.626	0.03	-4.61-1.39
log_b (molt prob. L50)	4.947	0.001	4.947	0.001	4.947	0.001	4.947	0.001	3.869,5.05
σ (growth variability std)	3.690	0.03	3.689	0.03	3.689	0.03	3.690	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.411	0.01	3.408	0.01	3.408	0.01	3.410	0.01	0.,4.4
log_ total sel deltaθ, 2005–19	2.838	0.02	2.840	0.02	2.840	0.02	2.840	0.02	0.,4.4
log_ ret. sel deltaθ, 1985–19	1.793	0.02	1.793	0.02	1.793	0.02	1.793	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.868	0.002	4.868	0.002	4.868	0.002	4.868	0.002	4.0,5.0
log_tot sel θ_{50}, 2005–19	4.900	0.001	4.900	0.001	4.900	0.001	4.900	0.001	4.0,5.0
log_ret. sel θ_{50}, 1985–19	4.916	0.0002	4.916	0.0002	4.916	0.0002	4.916	0.0002	4.0,5.0
log_β_r (rec.distribution par.)	-1.039	0.15	-1.040	0.15	-1.040	0.15	-1.037	0.15	-12.0, 12.0
logq2 (catchability 1995–04)	-0.046	1.41	-0.036	1.93	-0.036	1.93	-0.037	1.85	-9.0, 2.25
logq3 (catchability 2005–19)	-0.371	0.22	-0.372	0.22	-0.372	0.22	-0.371	0.23	-9.0, 2.25
log_mean_rec (mean rec.)	0.719	0.06	0.721	0.05	0.721	0.05	0.722	0.05	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.691	0.09	-0.695	0.09	-0.695	0.09	-0.694	0.09	-15.0, -0.01
log_mean_Fground (GF byc. F)	-8.292	0.10	-8.294	0.10	-8.294	0.10	-8.296	0.10	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.020	0.34	0.019	0.35	0.019	0.35	0.019	0.40	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.014	0.65	0.024	0.61	0.024	0.61	0.024	0.60	0.0,1.0
2019 MMB	6,528	0.16	6,542	0.16	6,548	0.16	6,734	0.16	

Table 18. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 20_1 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2020 are restricted to 1985–2020. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =17,953 $MMB_{35\%}$=5,204			
1985	4.00	10,485	0.05	8,930	0.09
1986	3.57	8,072	0.05	8,414	0.07
1987	2.66	7,459	0.04	5,973	0.06
1988	1.76	6,376	0.04	5,631	0.04
1989	2.39	4,316	0.04	5,002	0.04
1990	1.92	3,956	0.05	3,130	0.05
1991	1.67	3,722	0.05	2,792	0.05
1992	2.10	3,895	0.04	2,692	0.05
1993	1.56	4,497	0.03	2,850	0.05
1994	1.97	3,808	0.03	3,469	0.03
1995	1.89	3,810	0.03	2,813	0.03
1996	1.71	3,821	0.04	2,762	0.03
1997	1.86	3,891	0.04	2,808	0.04
1998	1.90	4,214	0.03	2,888	0.04
1999	2.24	4,245	0.04	3,172	0.03
2000	2.50	4,394	0.04	3,114	0.04
2001	2.52	4,818	0.05	3,121	0.04
2002	2.44	5,345	0.05	3,446	0.05
2003	1.71	5,640	0.05	3,955	0.05
2004	2.23	5,715	0.06	4,421	0.05
2005	2.35	5,989	0.06	4,578	0.06
2006	2.47	6,531	0.05	4,720	0.06
2007	1.71	6,732	0.05	5,165	0.06
2008	1.51	6,563	0.05	5,483	0.05
2009	1.91	6,197	0.05	5,552	0.05
2010	1.59	5,916	0.05	5,205	0.05
2011	1.15	5,421	0.04	4,906	0.05
2012	1.84	4,823	0.05	4,564	0.05
2013	2.21	4,570	0.05	3,951	0.05
2014	1.69	4,639	0.06	3,469	0.06
2015	2.01	4,730	0.06	3,511	0.06
2016	2.14	5,101	0.07	3,635	0.07
2017	1.80	5,462	0.09	3,927	0.07
2018	3.28	5,897	0.12	4,313	0.09
2019	2.02	6,528	0.16	4,500	0.11
2020	2.05				

Table 19. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 20_1b for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2020 are restricted to 1985–2020. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =18,343 $MMB_{35\%}$=5,319			
1985	4.05	10,471	0.05	9,006	0.10
1986	3.47	8,040	0.05	8,427	0.08
1987	2.68	7,387	0.04	5,960	0.06
1988	1.86	6,326	0.04	5,580	0.05
1989	2.52	4,339	0.04	4,936	0.04
1990	1.92	4,037	0.05	3,104	0.06
1991	1.64	3,808	0.05	2,836	0.05
1992	2.02	3,950	0.04	2,775	0.05
1993	1.59	4,521	0.03	2,928	0.05
1994	1.96	3,824	0.03	3,509	0.03
1995	1.89	3,817	0.04	2,830	0.03
1996	1.71	3,827	0.04	2,771	0.04
1997	1.86	3,892	0.04	2,814	0.04
1998	1.89	4,211	0.04	2,891	0.04
1999	2.24	4,238	0.04	3,172	0.04
2000	2.49	4,384	0.04	3,111	0.04
2001	2.52	4,805	0.05	3,114	0.04
2002	2.45	5,333	0.05	3,436	0.05
2003	1.71	5,631	0.05	3,943	0.05
2004	2.23	5,712	0.06	4,411	0.05
2005	2.35	5,988	0.06	4,572	0.06
2006	2.46	6,529	0.05	4,719	0.06
2007	1.71	6,731	0.05	5,165	0.06
2008	1.51	6,562	0.05	5,482	0.06
2009	1.91	6,197	0.05	5,551	0.05
2010	1.59	5,917	0.05	5,205	0.05
2011	1.15	5,423	0.04	4,907	0.05
2012	1.84	4,824	0.05	4,566	0.05
2013	2.21	4,574	0.05	3,952	0.05
2014	1.69	4,648	0.06	3,472	0.06
2015	2.01	4,742	0.06	3,517	0.06
2016	2.14	5,113	0.07	3,646	0.07
2017	1.81	5,475	0.09	3,940	0.07
2018	3.28	5,910	0.12	4,326	0.09
2019	2.02	6,542	0.16	4,513	0.11
2020	2.06				

Table 20. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for model 20_2 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year y+1, after the year y fishery total catch removal. Recruits estimates for 1961 to 2020 are restricted to 1985–2020. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model (≥ 101 mm CL)	Mature Male Biomass (≥ 111 mm CL)	CV	Legal Size Male Biomass (≥ 136 mm CL)	CV
		MMB_{eq} =18,413 $MMB_{35\%}$=5,343			
1985	4.04	10,474	0.05	9,012	0.10
1986	3.47	8,041	0.05	8,432	0.08
1987	2.68	7,389	0.04	5,961	0.06
1988	1.86	6,328	0.04	5,582	0.05
1989	2.52	4,338	0.04	4,938	0.04
1990	1.91	4,035	0.05	3,105	0.05
1991	1.64	3,805	0.05	2,835	0.05
1992	2.01	3,943	0.04	2,772	0.05
1993	1.58	4,507	0.03	2,924	0.05
1994	1.97	3,809	0.03	3,500	0.03
1995	1.89	3,807	0.04	2,816	0.03
1996	1.70	3,817	0.04	2,760	0.04
1997	1.87	3,884	0.04	2,806	0.04
1998	1.90	4,210	0.03	2,882	0.04
1999	2.24	4,240	0.04	3,168	0.03
2000	2.49	4,384	0.04	3,111	0.04
2001	2.50	4,796	0.05	3,116	0.04
2002	2.42	5,307	0.05	3,433	0.05
2003	1.70	5,589	0.05	3,929	0.05
2004	2.26	5,667	0.06	4,379	0.05
2005	2.42	5,973	0.06	4,528	0.06
2006	2.51	6,566	0.05	4,682	0.06
2007	1.69	6,794	0.05	5,168	0.06
2008	1.46	6,612	0.05	5,531	0.05
2009	1.89	6,217	0.05	5,612	0.05
2010	1.57	5,912	0.04	5,243	0.05
2011	1.14	5,397	0.04	4,917	0.05
2012	1.86	4,792	0.05	4,551	0.05
2013	2.22	4,549	0.05	3,921	0.05
2014	1.72	4,638	0.06	3,442	0.06
2015	2.07	4,765	0.07	3,497	0.06
2016	2.18	5,177	0.07	3,647	0.07
2017	1.83	5,571	0.09	3,976	0.07
2018	3.39	6,050	0.12	4,400	0.09
2019	2.03	6,734	0.16	4,616	0.11
2020	2.06				

Table 21. Negative log-likelihood values of the fits for models 20_1 (base, last year's accepted model with additional 2019/20 data), 20_1b, 20_1b Ver 2 (21_b but mean recruitment estimation time period modified to 1987–2012), and 20_2 (observer CPUE estimated with Year an Area interaction factor) for golden king crab in the WAG. Likelihood components with zero entry in the entire rows are omitted. RetdcatchB= retained catch biomass.

Likelihood Component	**Model 20_1**	**Model 20_1b**	**Model 20_1b Ver 2**	**Model 20_2**
Number of free parameters	149	149	149	149
Retlencomp	-1240.2800	-1244.3900	-1244.3900	-1243.7800
Totallencomp	-1564.8500	-1561.8900	-1561.8800	-1565.1200
Observer cpue	-13.0279	-13.7535	-13.7556	-11.6569
RetdcatchB	5.1206	5.2357	5.2357	5.3112
TotalcatchB	45.6044	45.7246	45.7252	45.7664
GdiscdcatchB	0.0014	0.0015	0.0015	0.0014
Rec_dev	5.0374	4.9326	4.9342	5.1016
Pot F_dev	0.0264	0.0265	0.0265	0.0266
Gbyc_F_dev	0.0384	0.0385	0.0385	0.0384
Tag	2694.2000	2694.1900	2694.1900	2694.2400
Fishery cpue	-9.3432	-5.6807	-5.6811	-5.7031
RetcatchN	0.0019	0.0019	0.0018	0.0019
Total	-77.4698	-75.5594	-75.5643	-75.7768

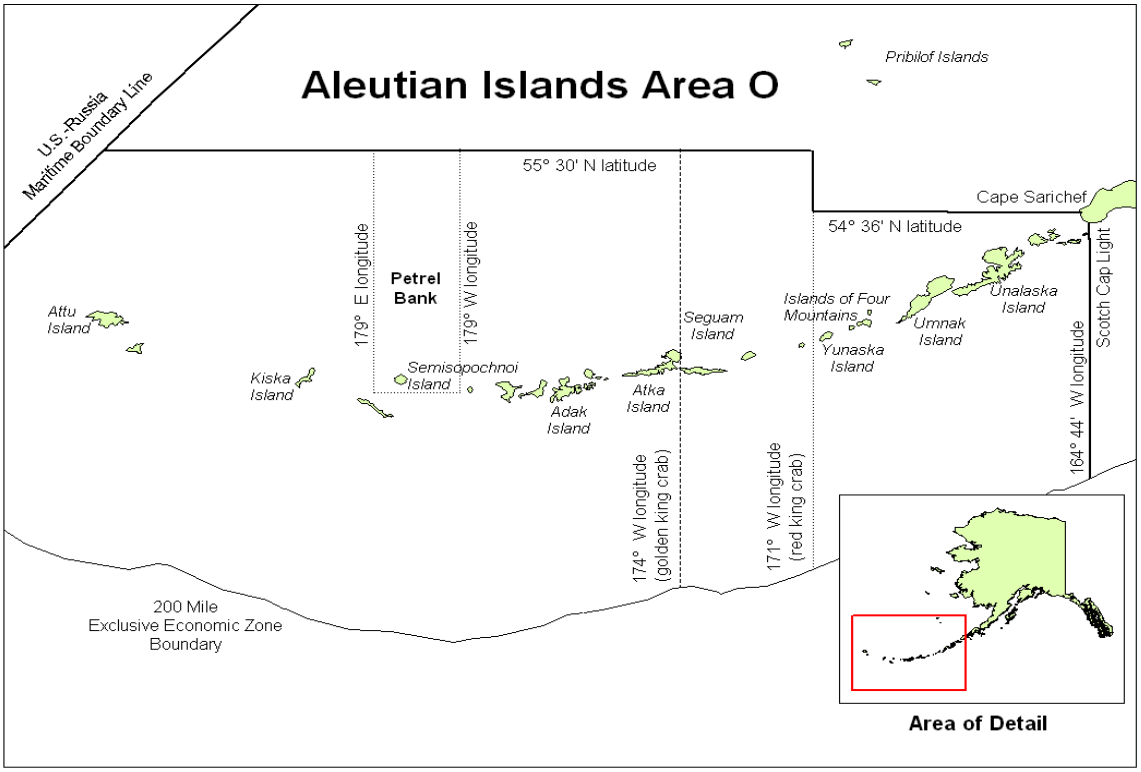

Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Leon *et al.* 2017).

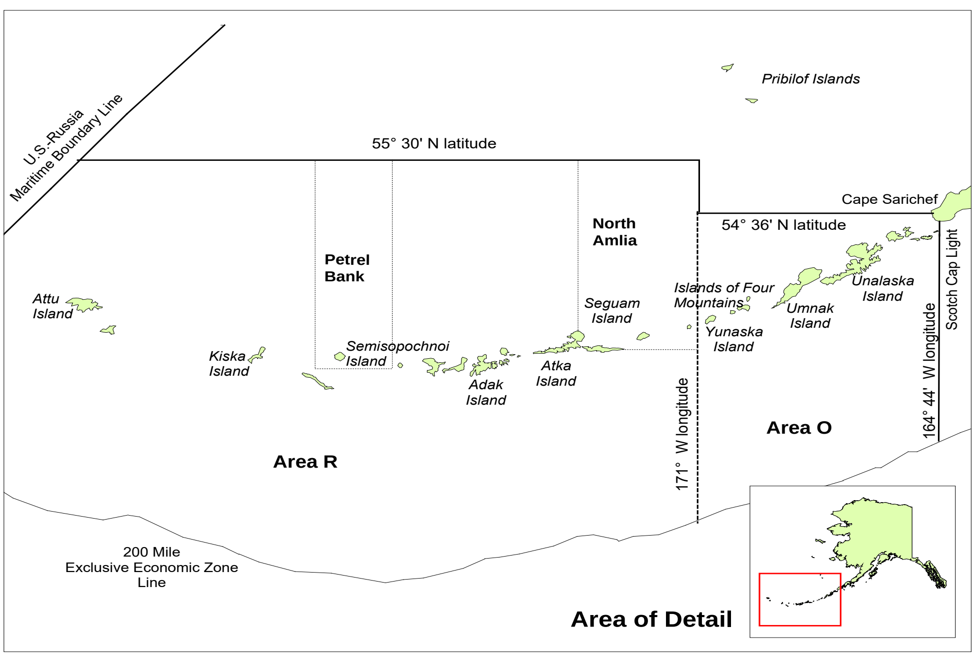

Figure 2. Adak (Area R) and Dutch Harbor (Area O) king crab registration area and districts, 1984/85–1995/96 seasons (Leon *et al.* 2017).

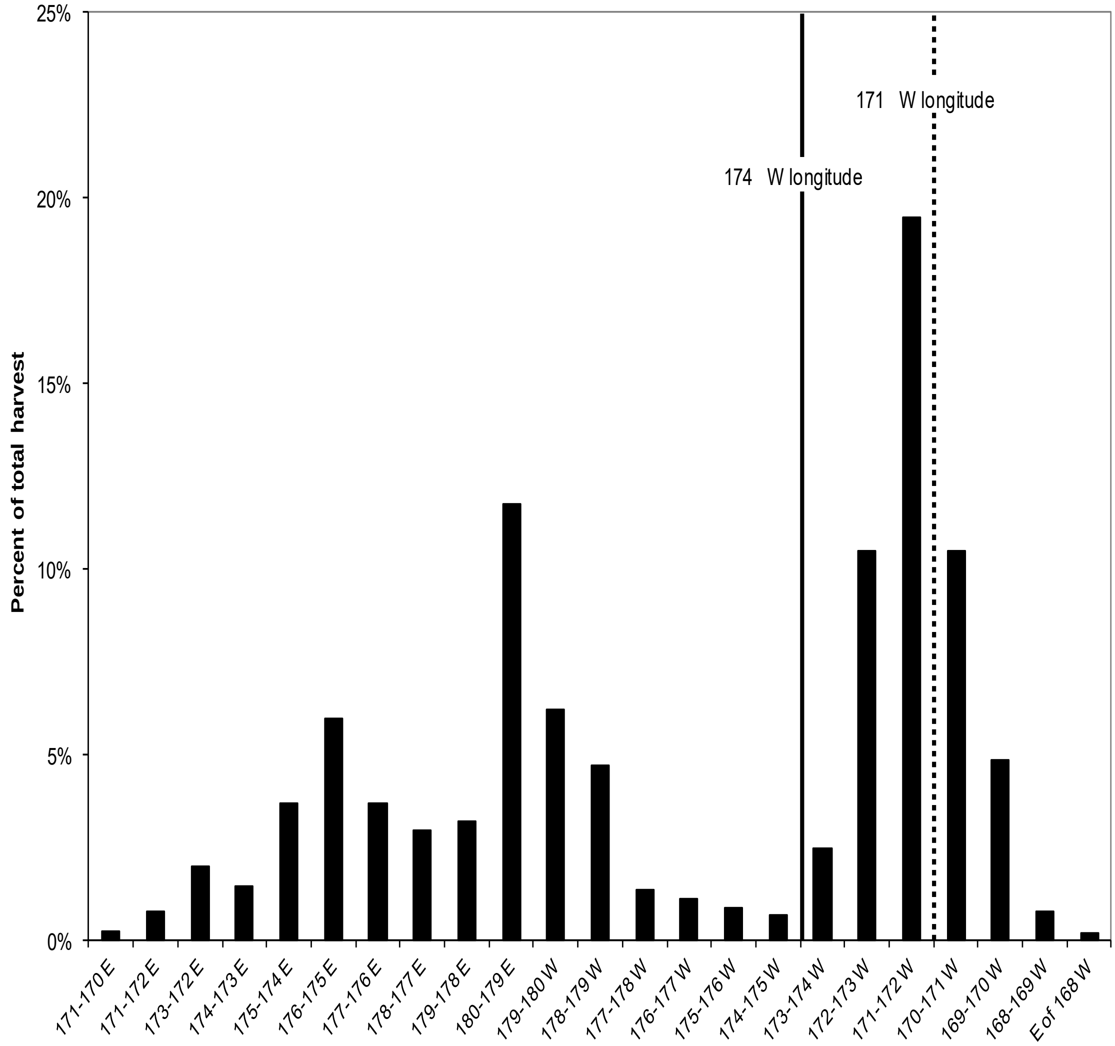

Figure 3. Percent of total 1981/82–1995/96 golden king crab retained catch weight (harvest) from one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor 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).

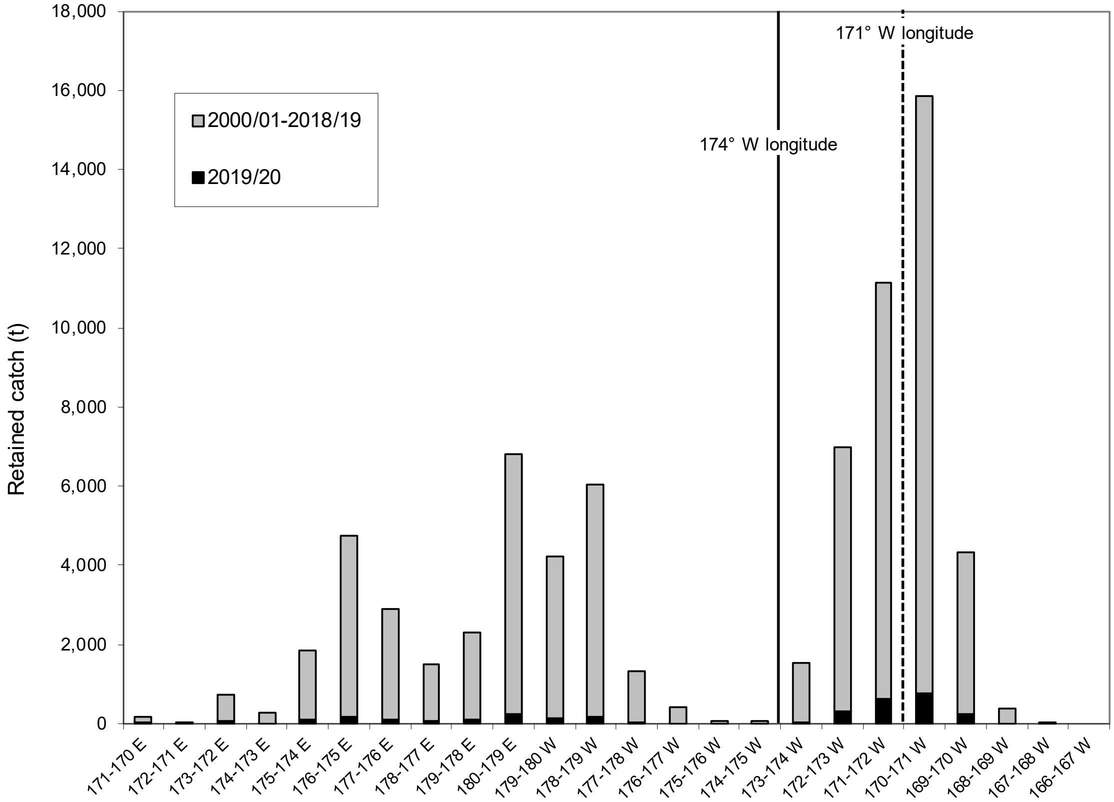

Figure 4. Retained catch (t) of golden king crab within one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2019/20 commercial fishery seasons; solid line denotes the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden 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).

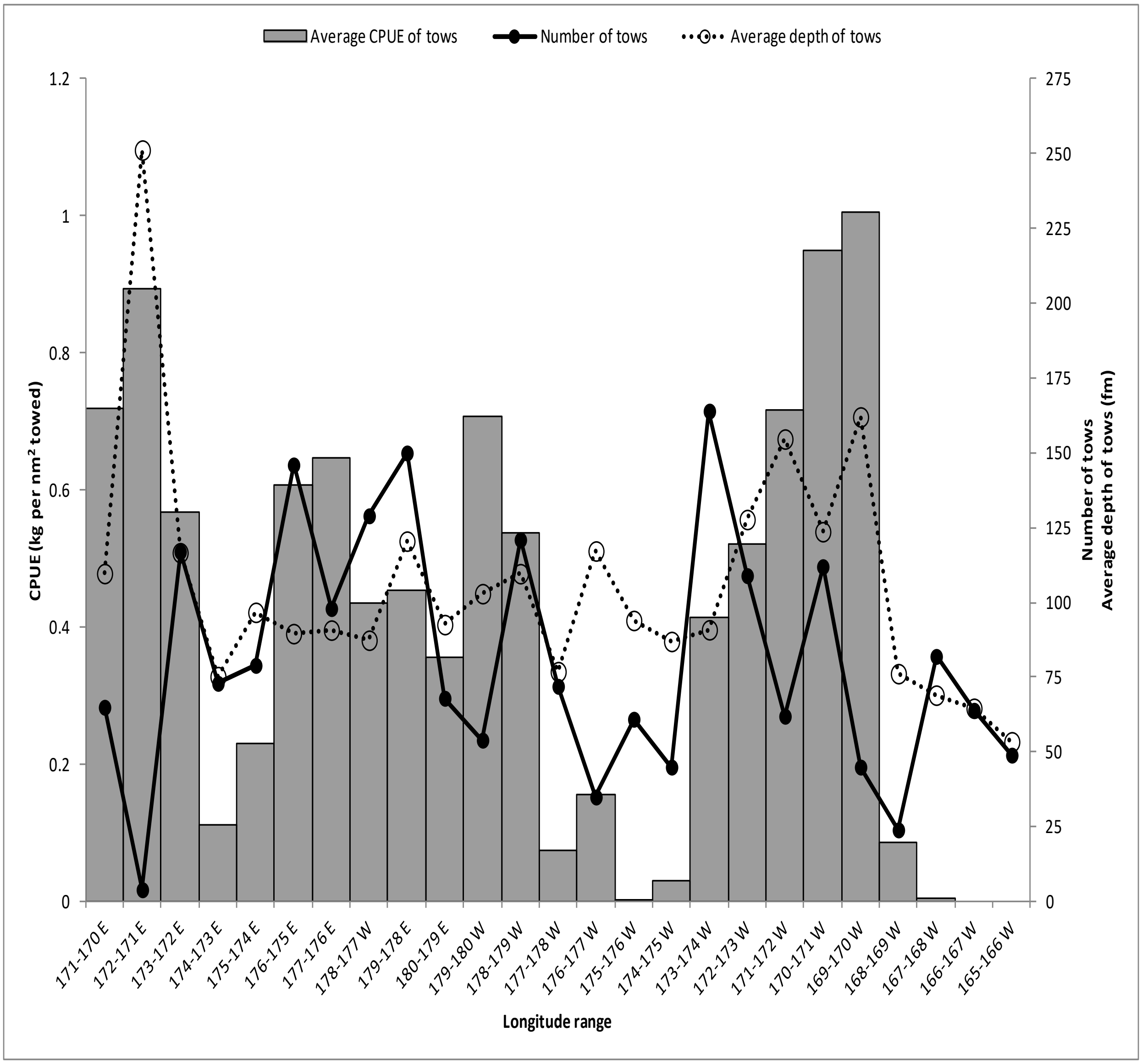

Figure 5. Average golden king crab CPUE (kg/nm2) for tows, number of tows, and average depth of tows from one-degree longitude intervals during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys; preliminary summary of data obtained on 1 April 2013 from http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm.

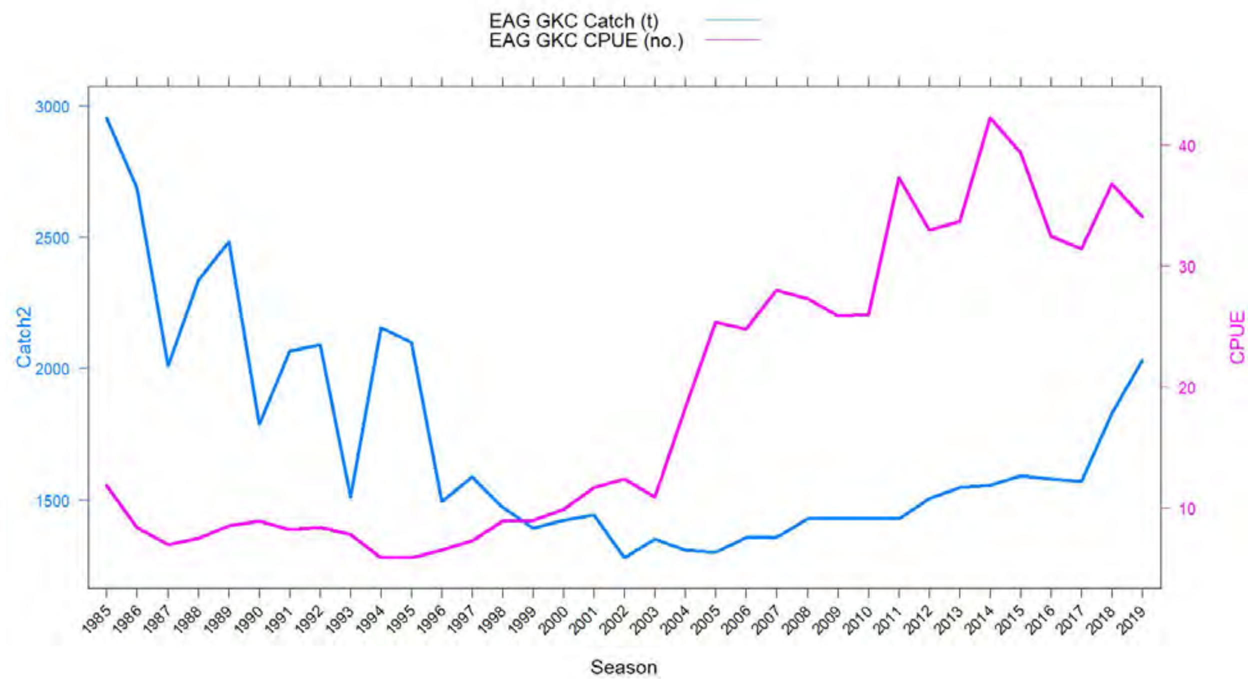

Figure 6. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the EAG, 1985/86–2019/20 fisheries (note: 1985 refers to the 1985/86 fishing year).

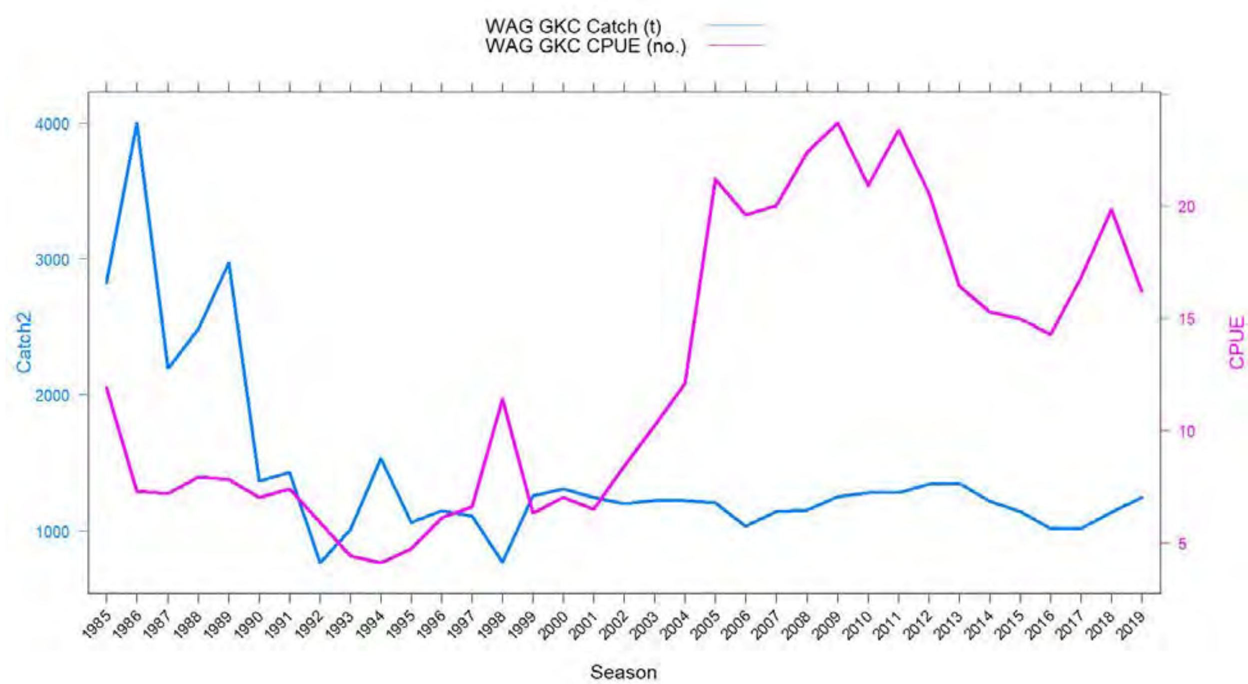

Figure 7. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the WAG, 1985/86–2019/20 fisheries (note: 1985 refers to the 1985/86 fishing year).

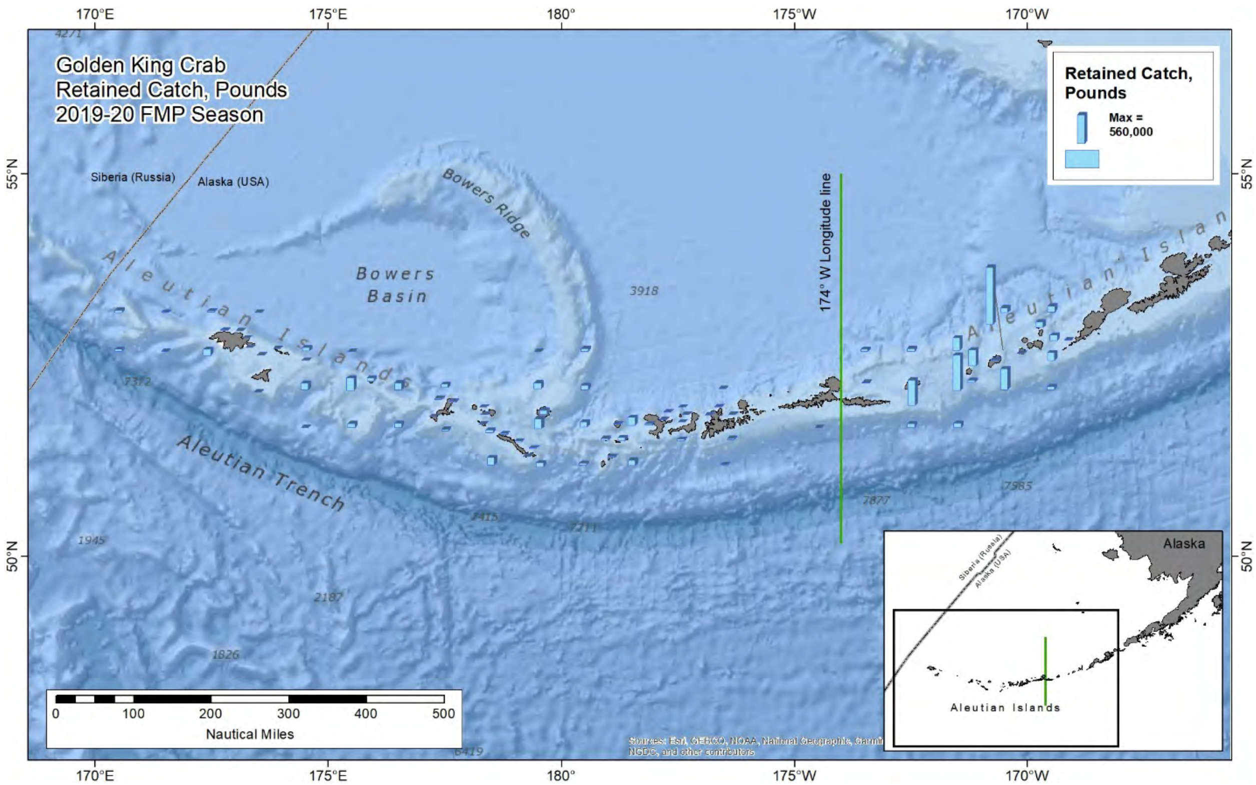

Figure 8. Catch distribution by statistical area.in 2019/20.

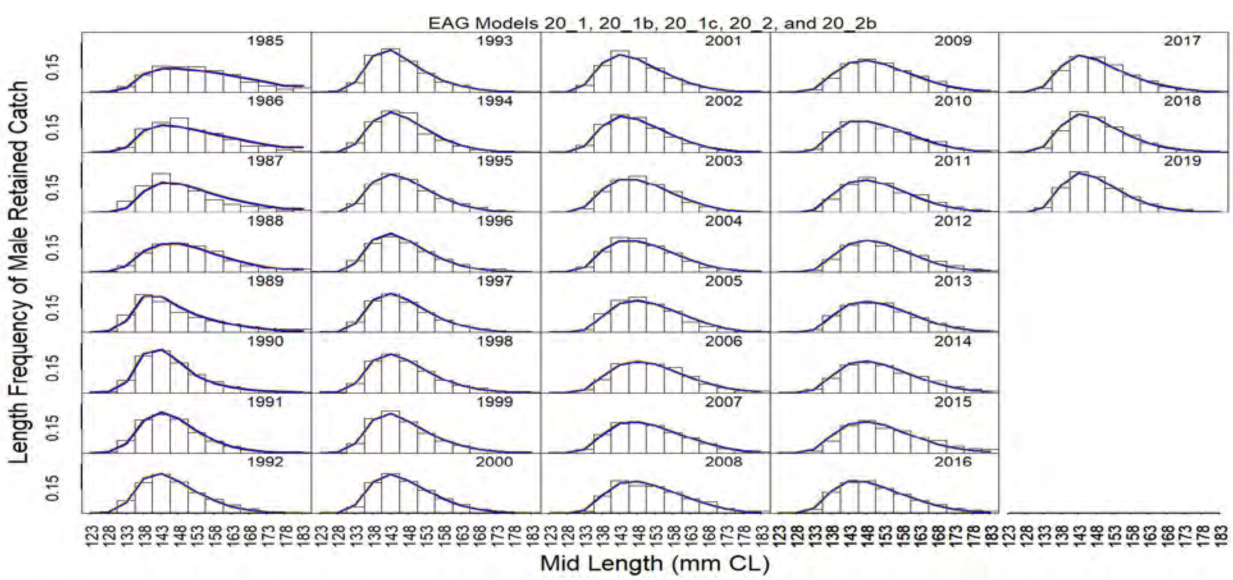

Figure 9. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions under models 20_1 (orange line), 20_1b (black line), 20_1c (dark red line), 20_2 (green line), and 20_2b (blue line) for golden king crab in the EAG, 1985/86 to 2019/20. This color scheme is used in all other figures.

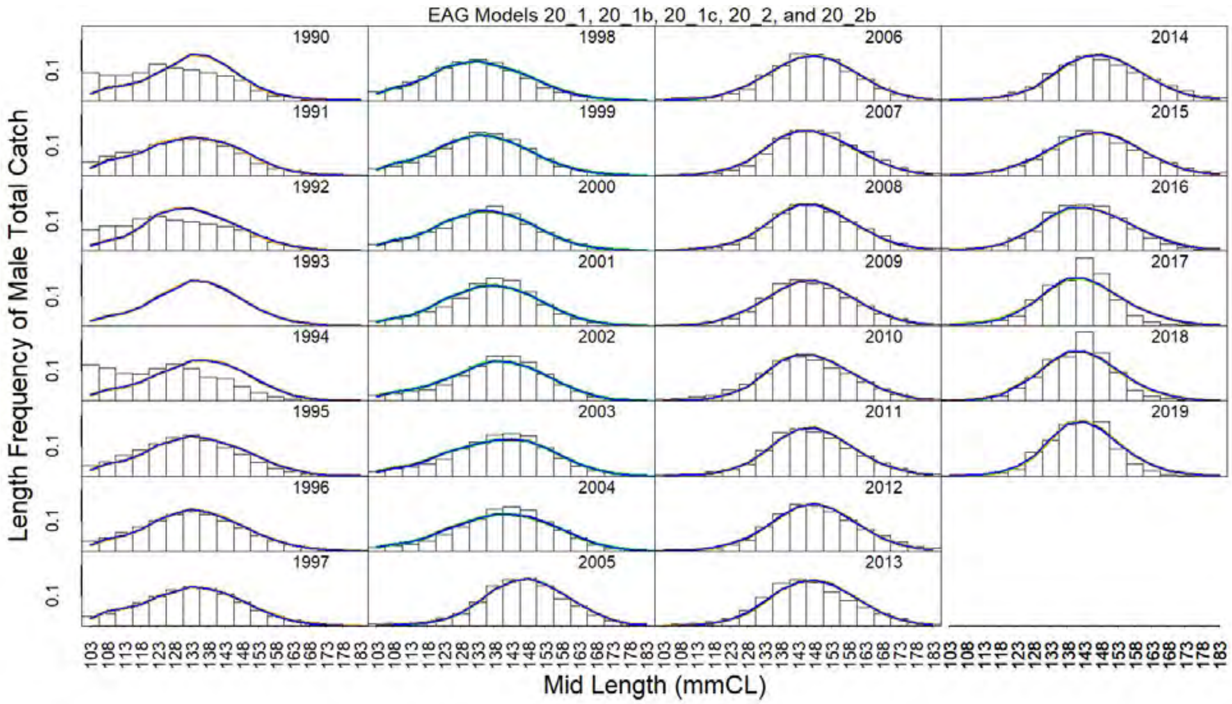

Figure 10. Predicted (line) vs. observed (bar) total catch relative length frequency distributions under models 20_1, 20_1b, 20_1c, 20_2, and 20_2b for golden king crab in the EAG, 1990/91 to 2019/20.

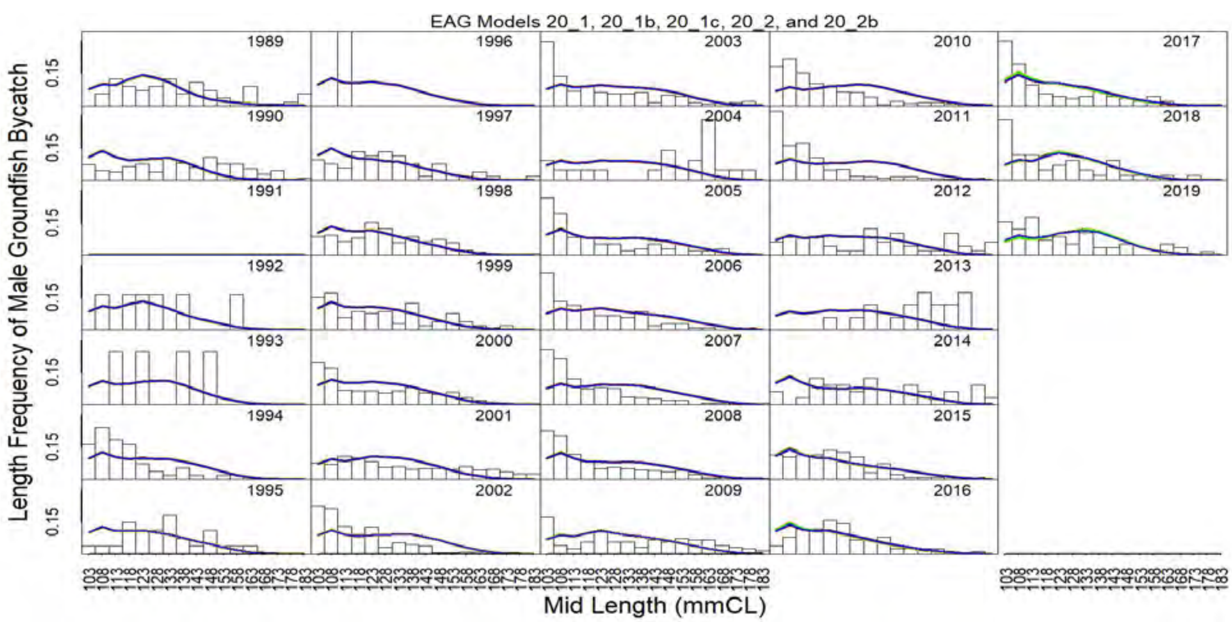

Figure 11. Predicted (line) vs. observed (bar) groundfish discarded bycatch relative length frequency distributions under models 20_1, 20_1b, 20_1c, 20_2, and 20_2b for golden king crab in the EAG, 19989/90 to 2019/20.

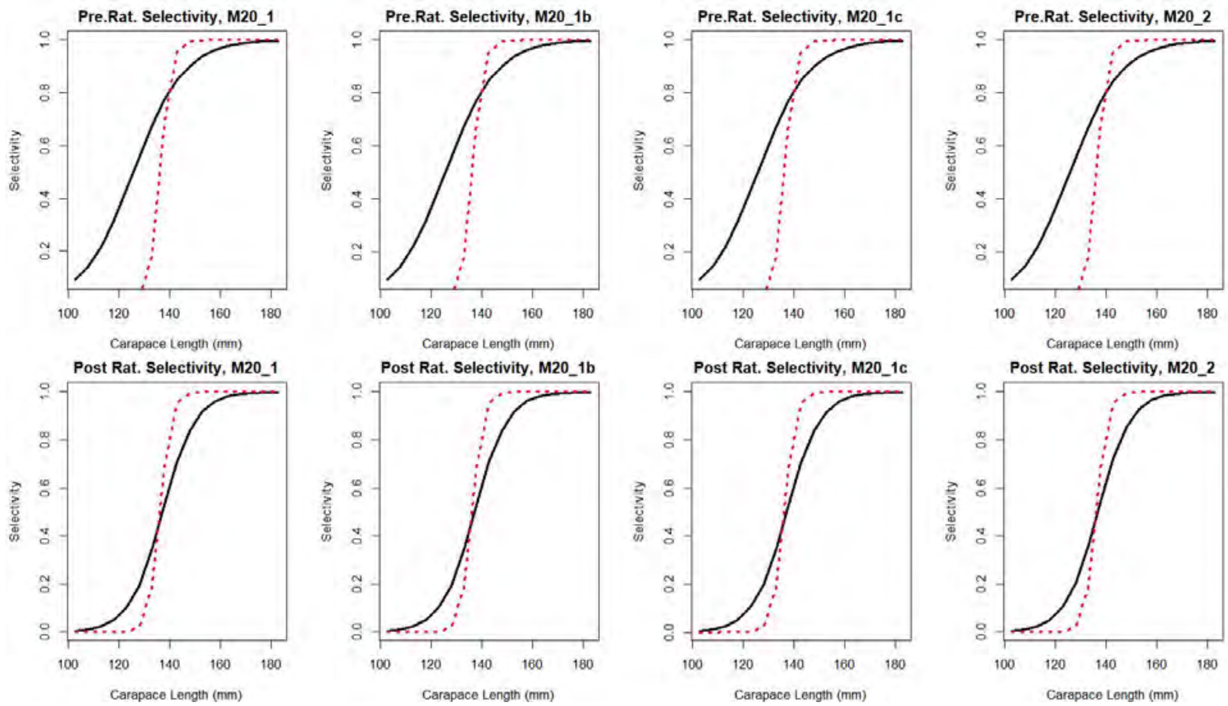

Figure 12. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under models 20_1, 20_1b, 20_1c, and 20_2 fits to golden king crab data in the EAG.

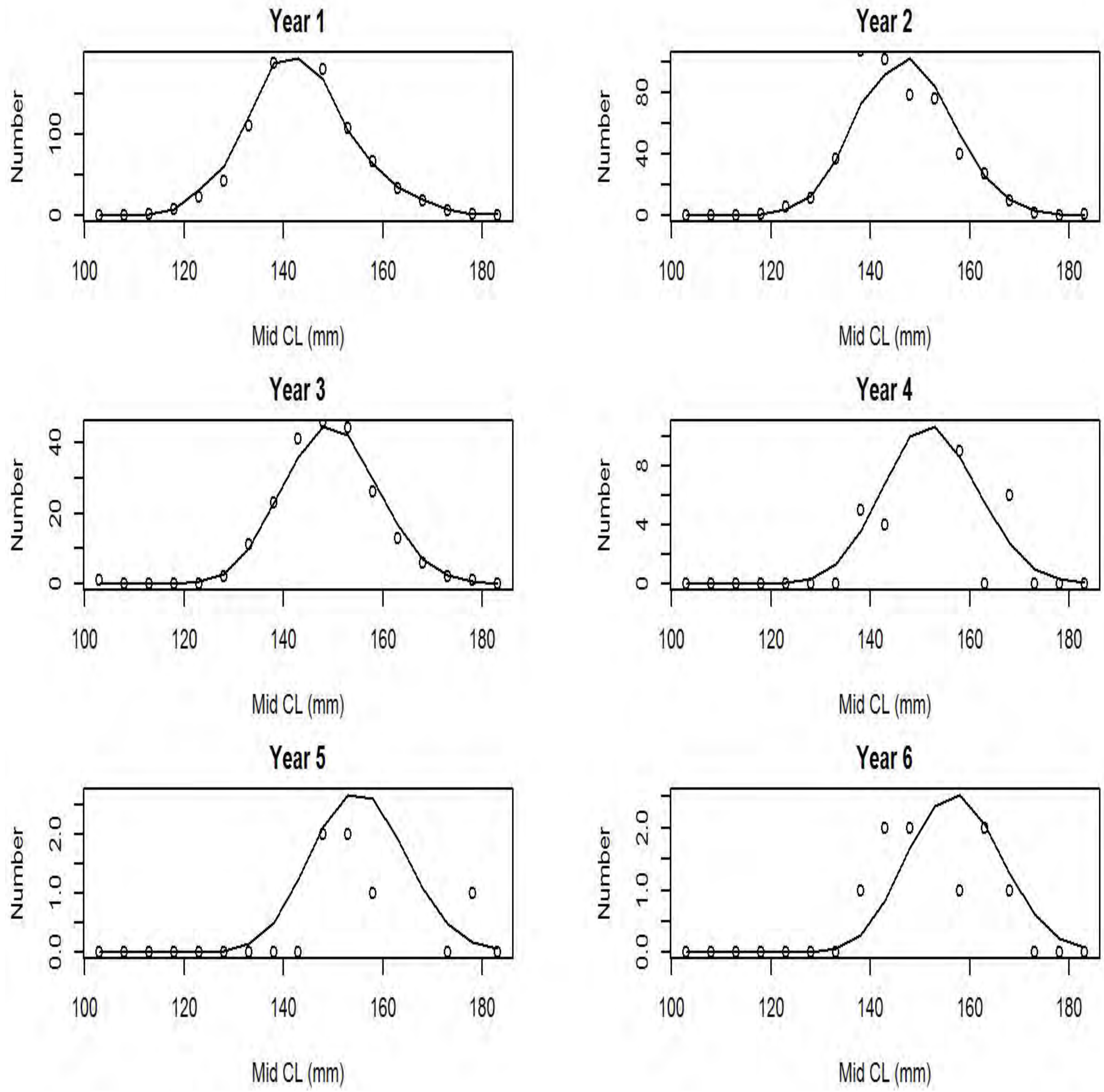

Figure 13. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 post tagging under model 20_1 for EAG golden king crab.

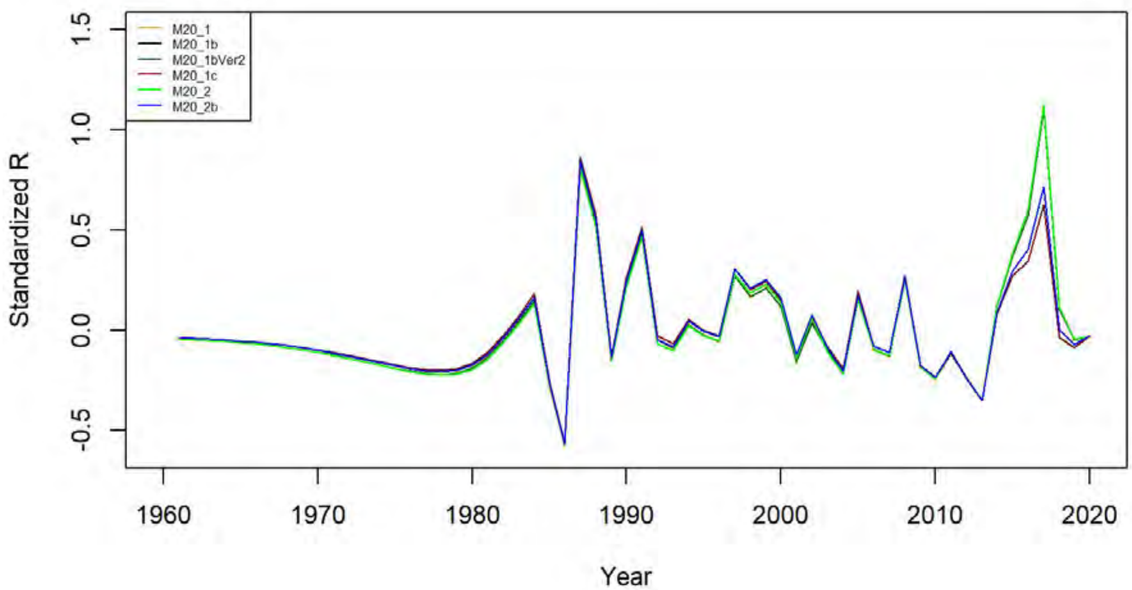

Figure 14. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under models 20_1, 20_1b, 20_1b Ver2, 20_1c, 20_2, and 20_2b fits to EAG golden king crab data, 1961–2020. The numbers of recruits are standardized using (R-mean R)/mean R for comparing different scenarios' results.

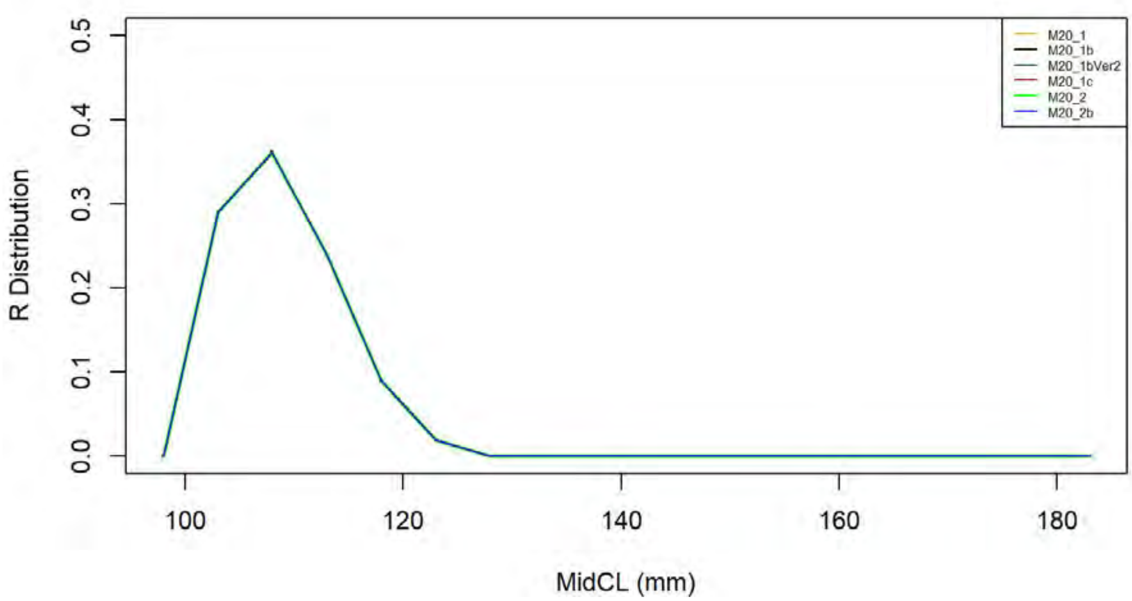

Figure 15. Recruit size distribution to the assessment model under models 20_1, 20_1b, 20_1bVer2, 20_1c, 20_2, and 20_2b fits to EAG golden king crab data.

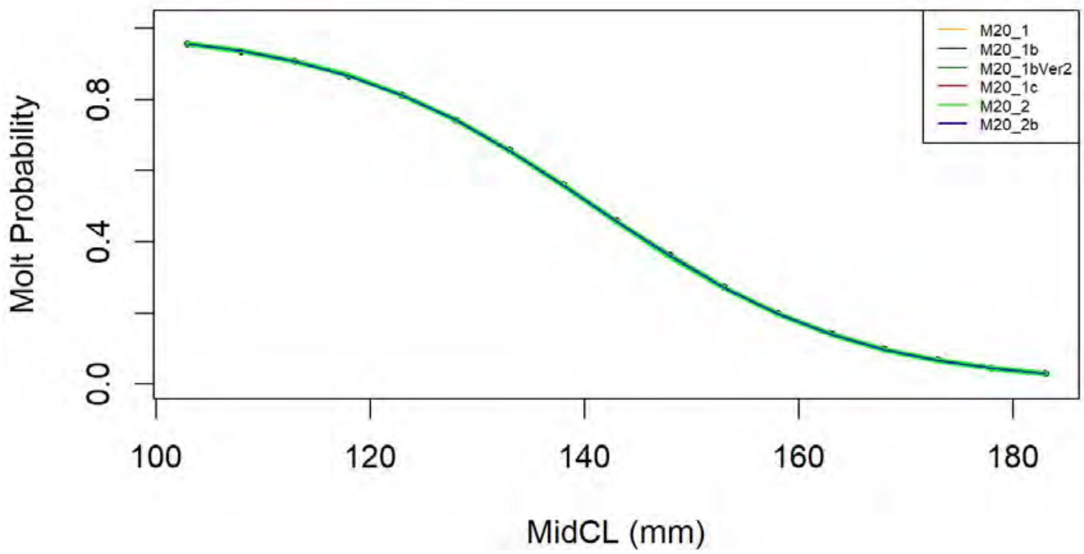

Figure 16. Estimated molt probability vs. carapace length of golden king crab for models 20_1, 20_1b, 20_1bVer2, 20_1c, 20_2, and 20_2b fits to EAG golden king crab data.

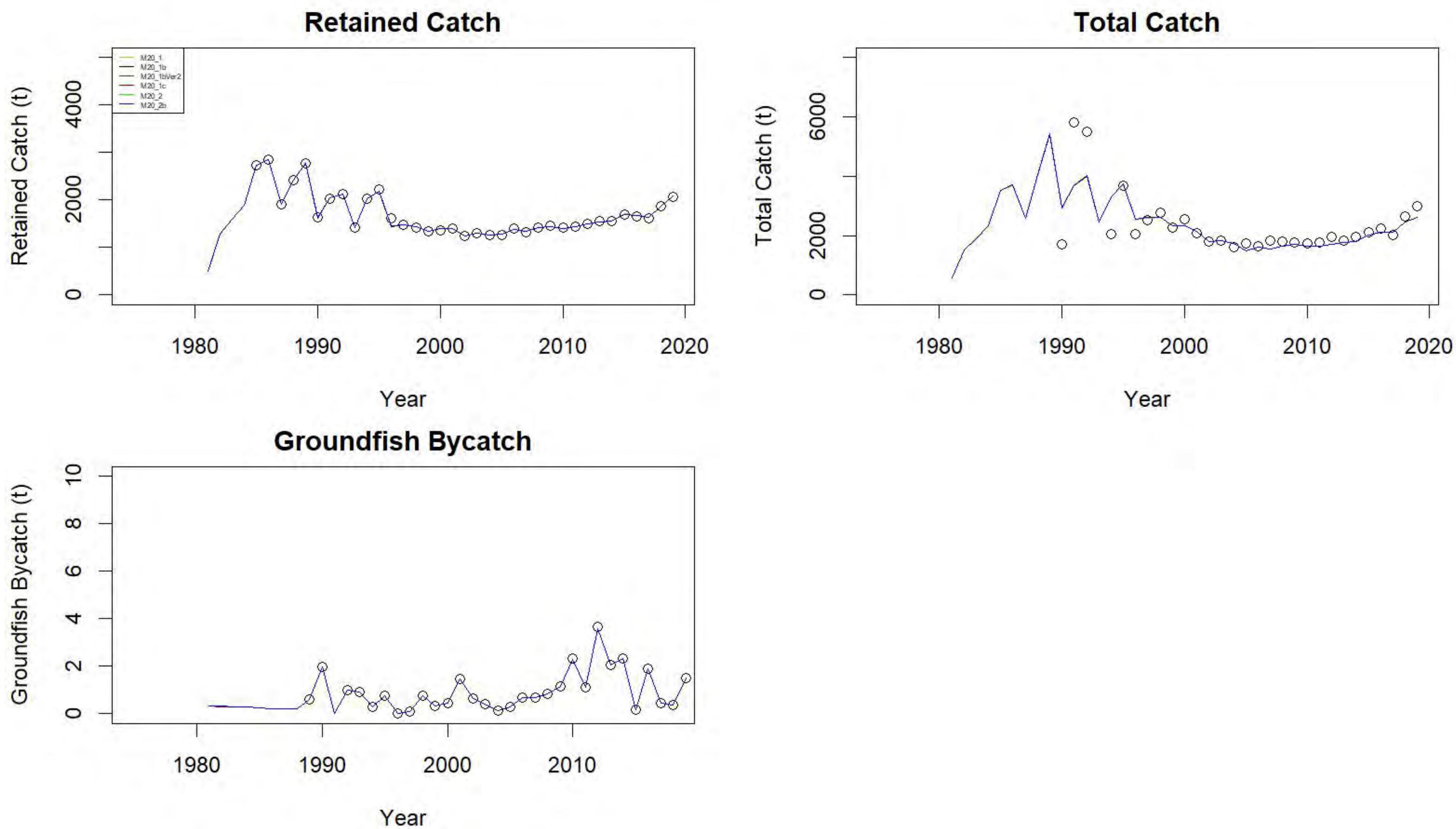

Figure 17. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right in), and groundfish bycatch (bottom left) of golden king crab for models 20_1, 20_1b, 20_1bVer2, 20_1c, 20_2, and 20_2b fits in EAG, 1981/82–2019/20.

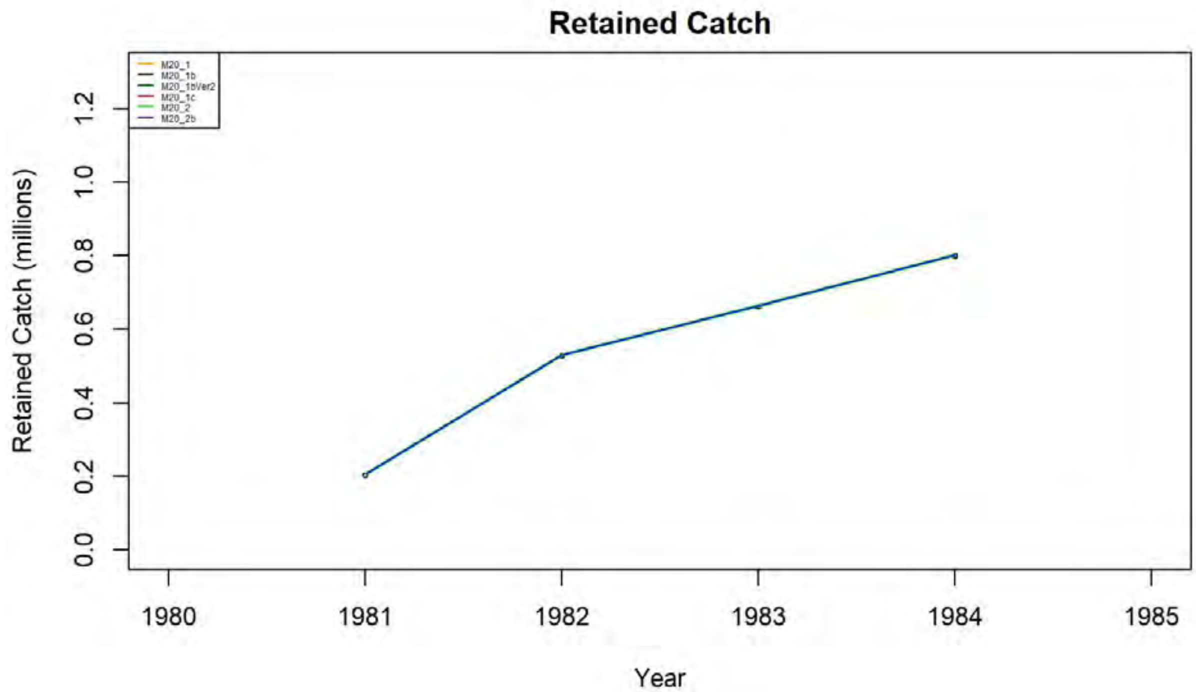

Figure 18. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for models 20_1, 20_1b, 20_1bVer2, 20_1c, 20_2, and 20_2b for golden king crab fits in the EAG, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period were in number of crabs.

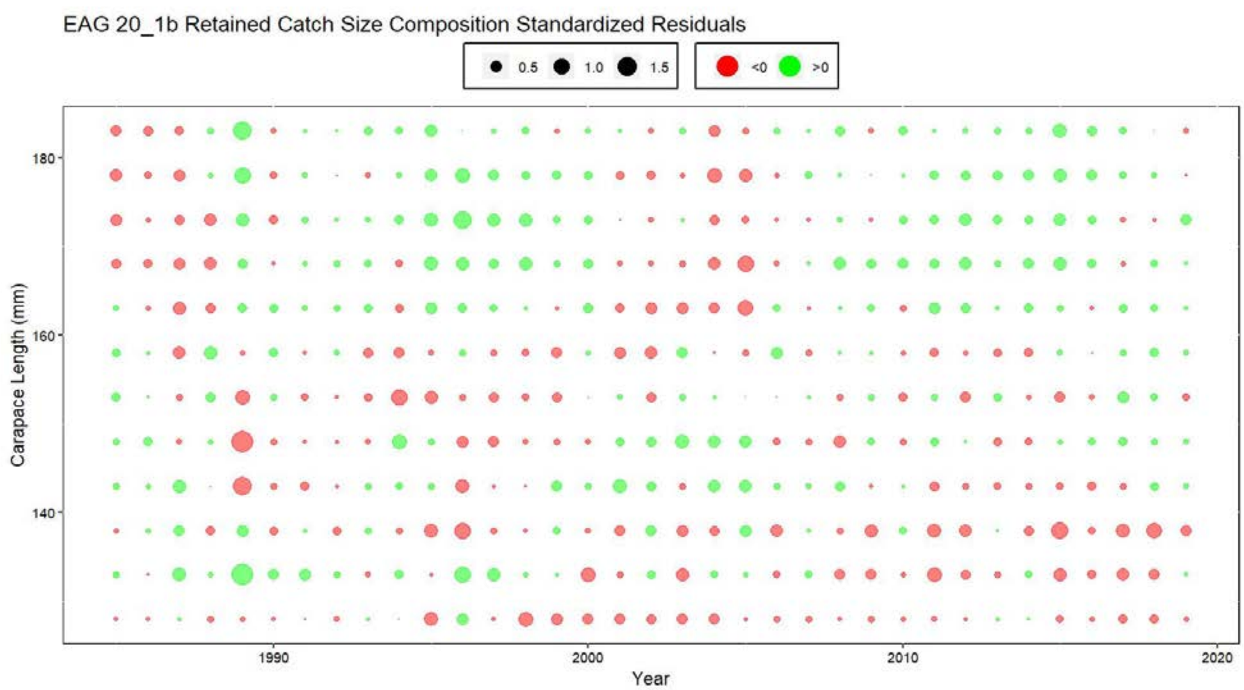

Figure 19. Bubble plot of standardized residuals of retained catch length composition for model 20_1b fit for EAG golden king crab, 1985/86–2019/20. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

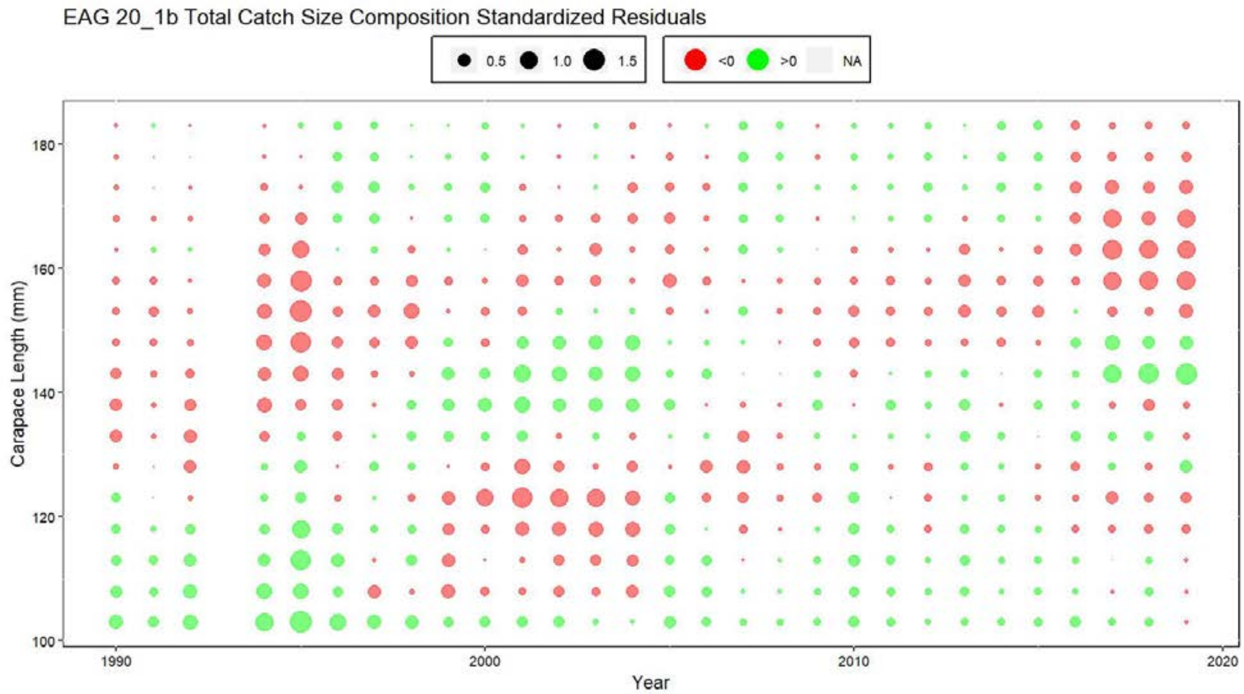

Figure 20. Bubble plot of standardized residuals of total catch length composition for model 20_1b fit for EAG golden king crab, 1990/91–2019/20. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

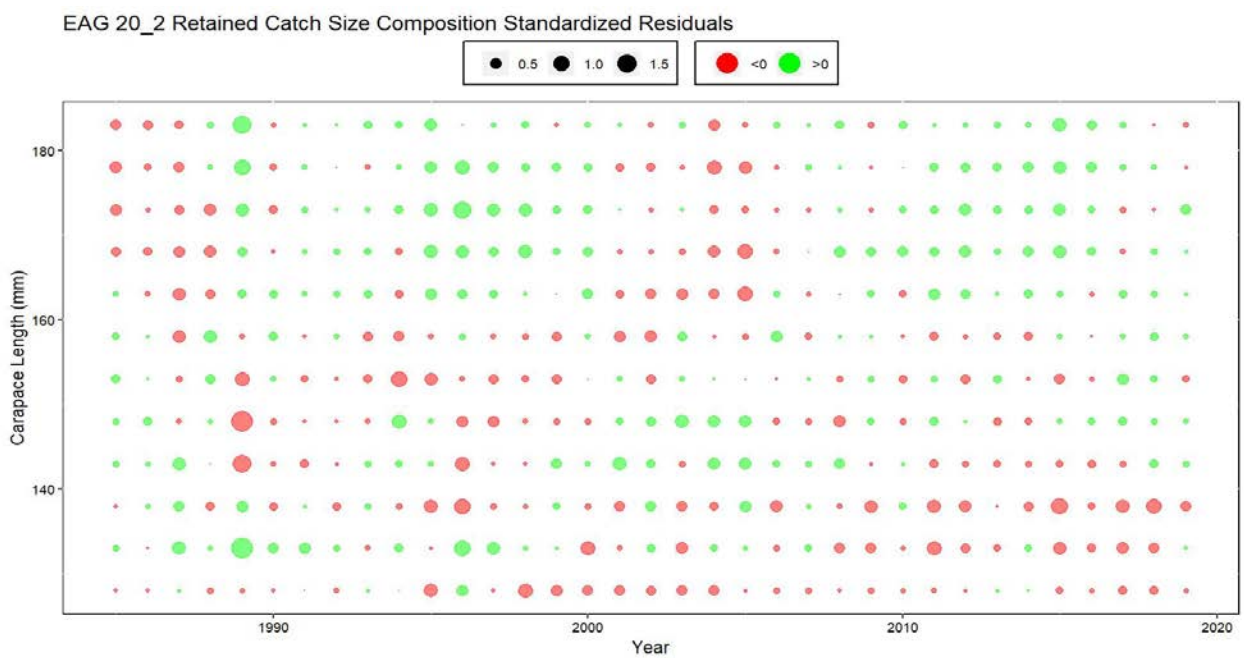

Figure 21. Bubble plot of standardized residuals of retained catch length composition for model 20_2 fit for EAG golden king crab, 1985/86–2019/20. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

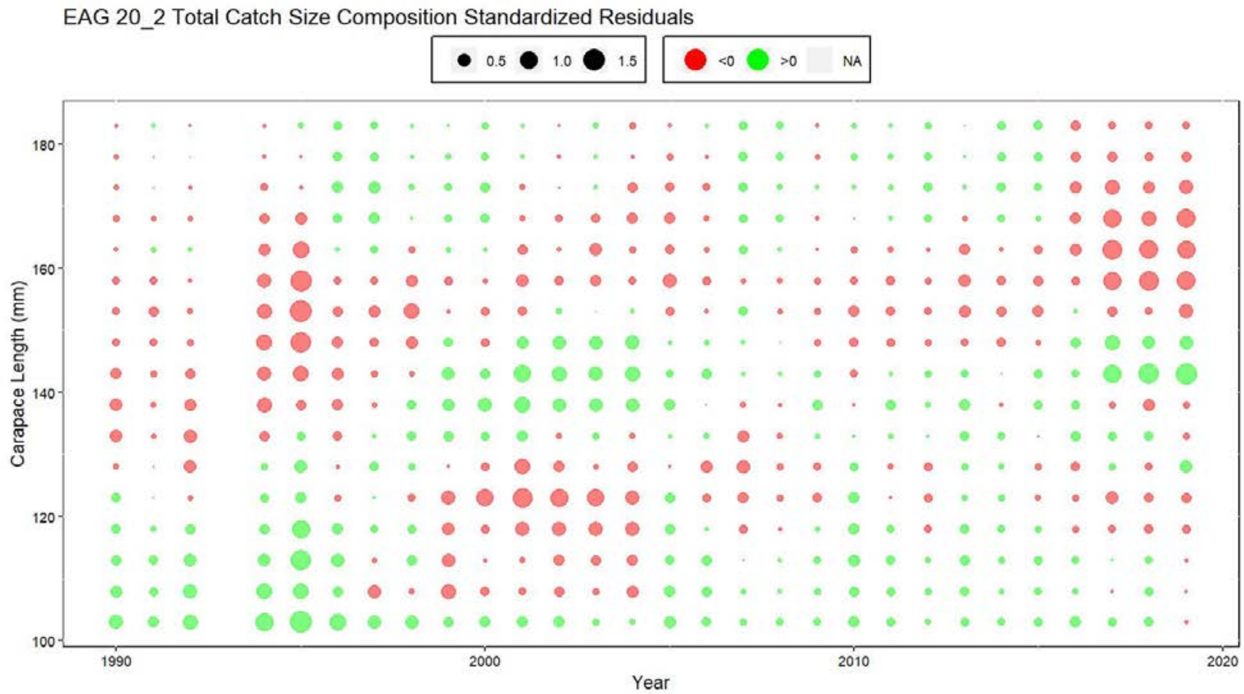

Figure 22. Bubble plot of standardized residuals of total catch length composition for model 20_2 fit for EAG golden king crab, 1990/91–2019/20. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

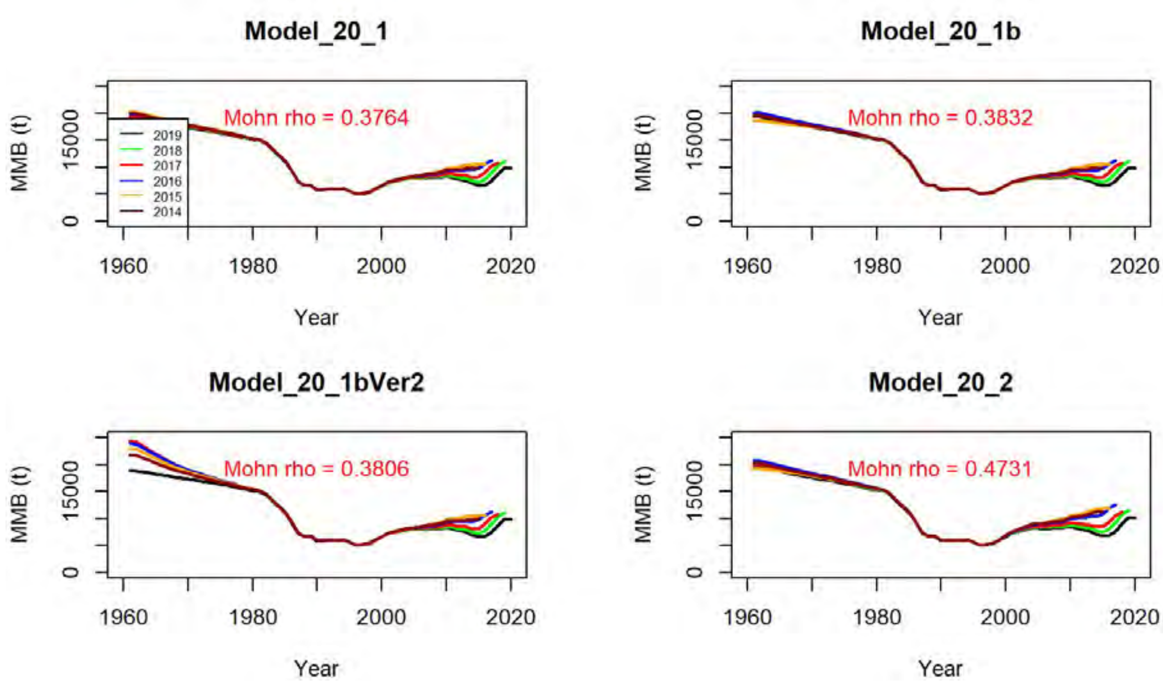

Figure 23. Retrospective fits of MMB by the model following removal of terminal year data under models 20_1, 20_1b, 20_1bVer2, and 20_2 for golden king crab in the EAG, 1960/61–2019/20.

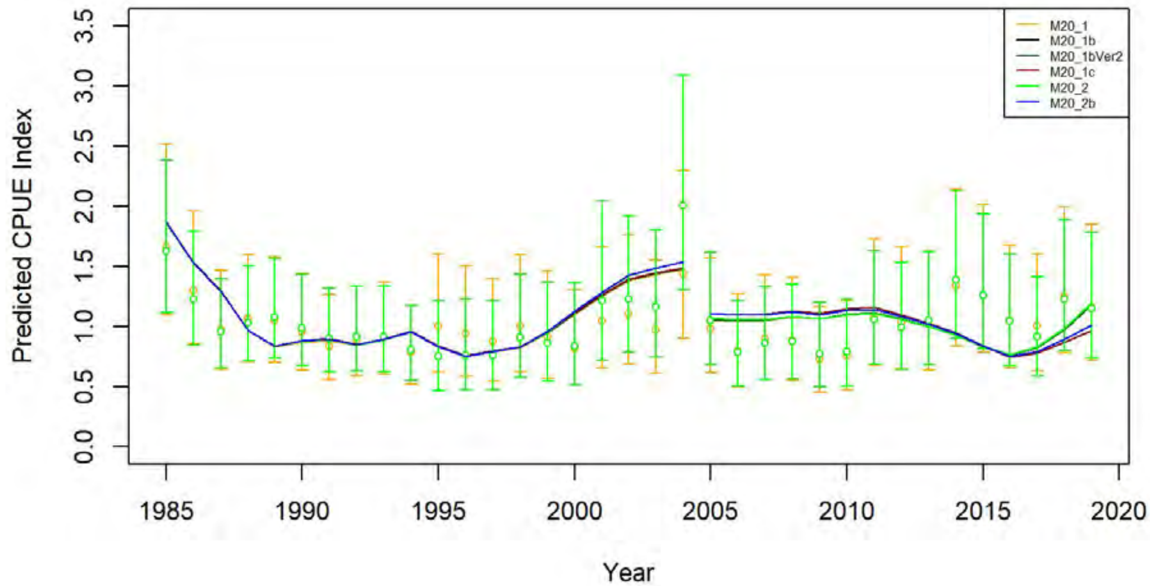

Figure 24. Comparison of input CPUE indices (orange open circles with +/- 2 SE for model 20_1 and green open circles with +/- 2 SE for model 20_2) with predicted CPUE indices (colored solid lines) under models 20_1, 20_1b, 20_1bVer2, 20_1c, 20_2, and 20_2b for EAG golden king crab data, 1985/86–2019/20. Model estimated additional standard error was added to each input standard error.

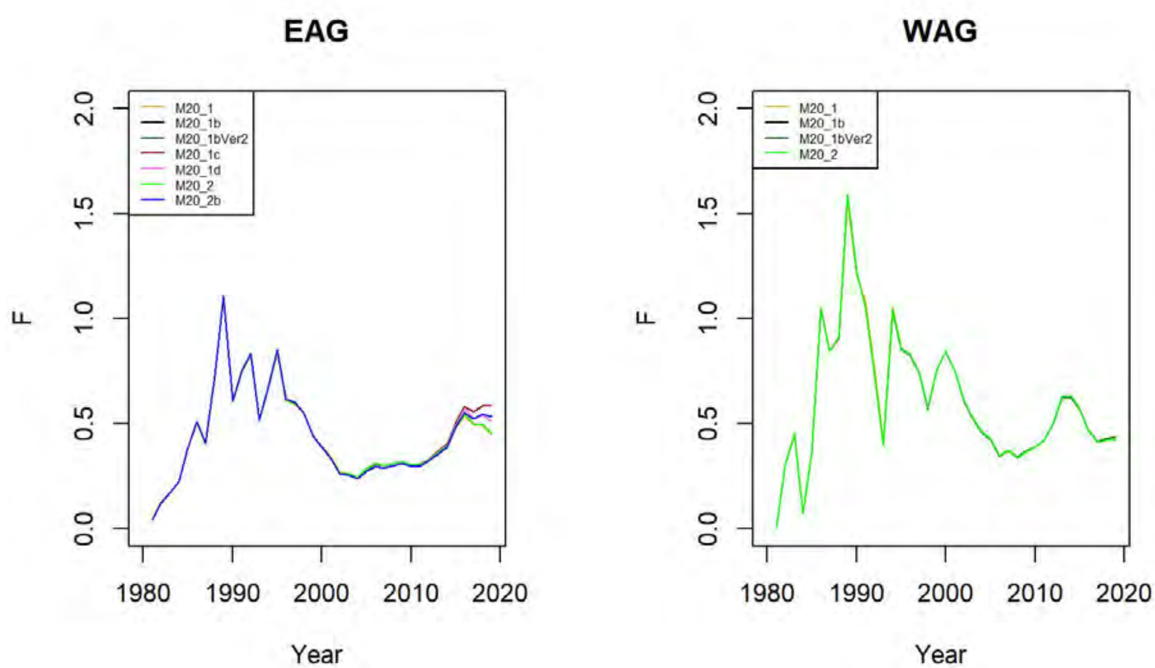

Figure 25. Trends in pot fishery full selection total fishing mortality of golden king crab for models 20_1, 20_1b, 20_1bVer2, 20_1c, 20_1d, 20_2, and 20_2b fits in the EAG (left) and models 20_1, 20_1b, 20_1bVer2, and 20_2 fits to WAG (right) data, 1981/82–2019/20.

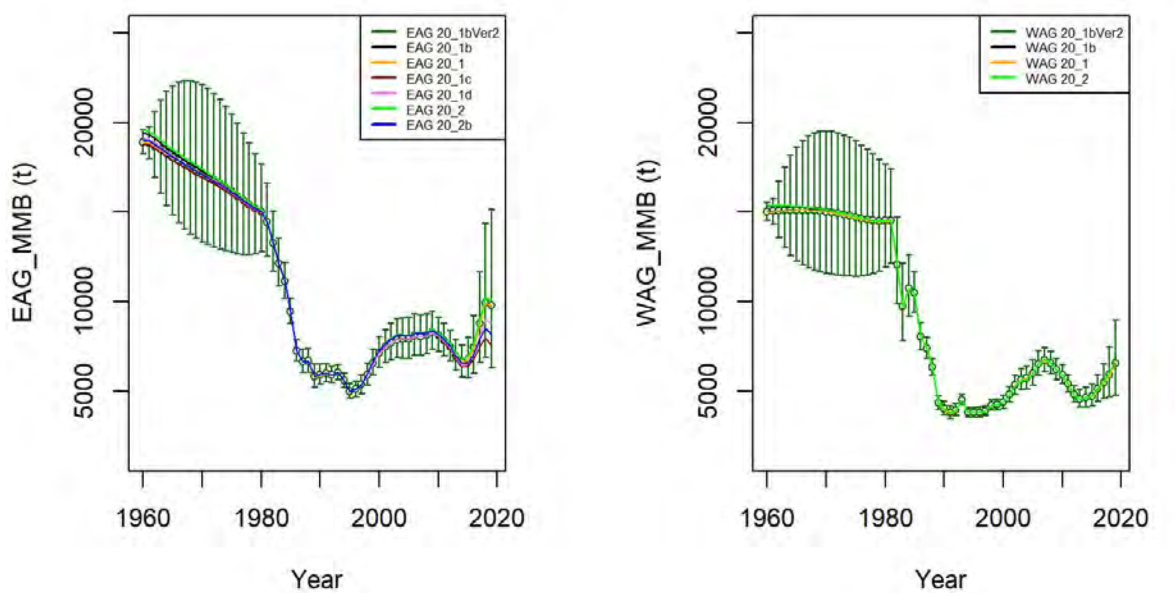

Figure 26. Trends in golden king crab mature male biomass for models 20_1, 20_1b, 20_1bVer2, 20_1c, 20_1d, 20_2, and 20_2b fits to EAG (left) and models 20_1, 20_1b, 20_1bVer2, and 20_2 fits to WAG (right) data, 1960/61–2019/20. Model 20_1bVer2 estimate has two standard error confidence limits.

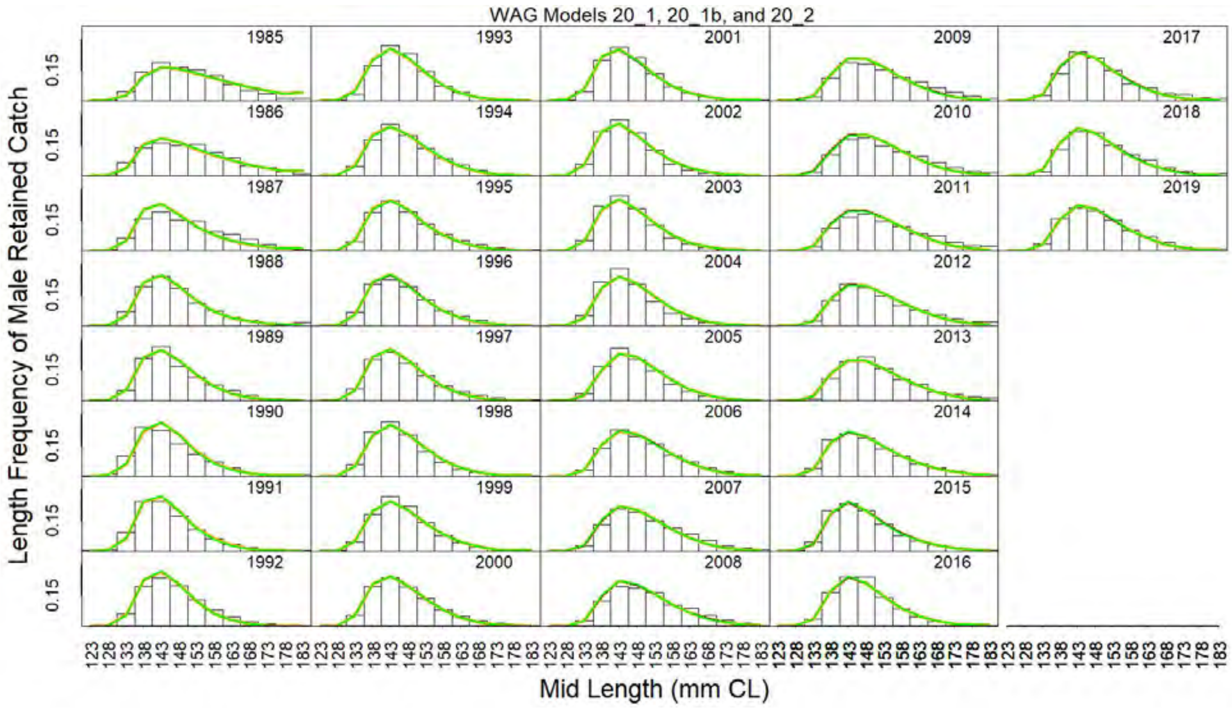

Figure 27. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions under models 20_1, 20_1b, and 20_2 fits to golden king crab data in the WAG, 1985/86 to 2019/20.

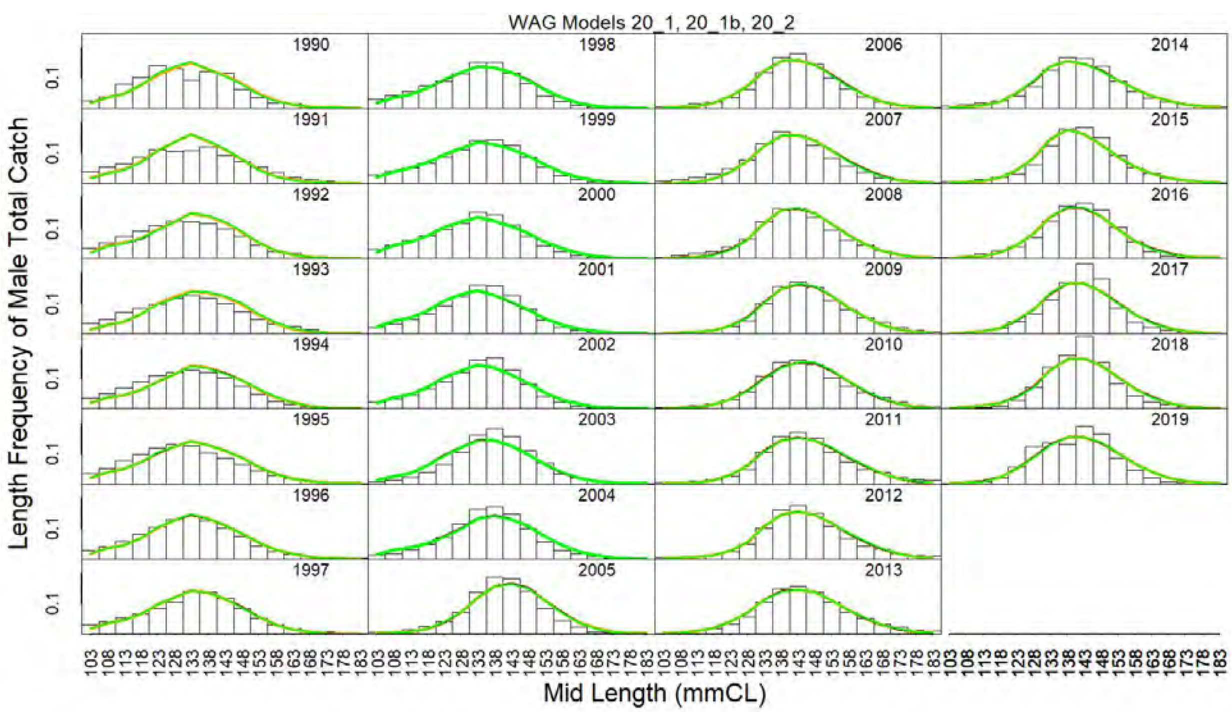

Figure 28. Predicted (line) vs. observed (bar) total catch relative length frequency distributions under models 20_1, 20_1b, and 20_2 fits to golden king crab data in the WAG, 1990/91 to 2019/20.

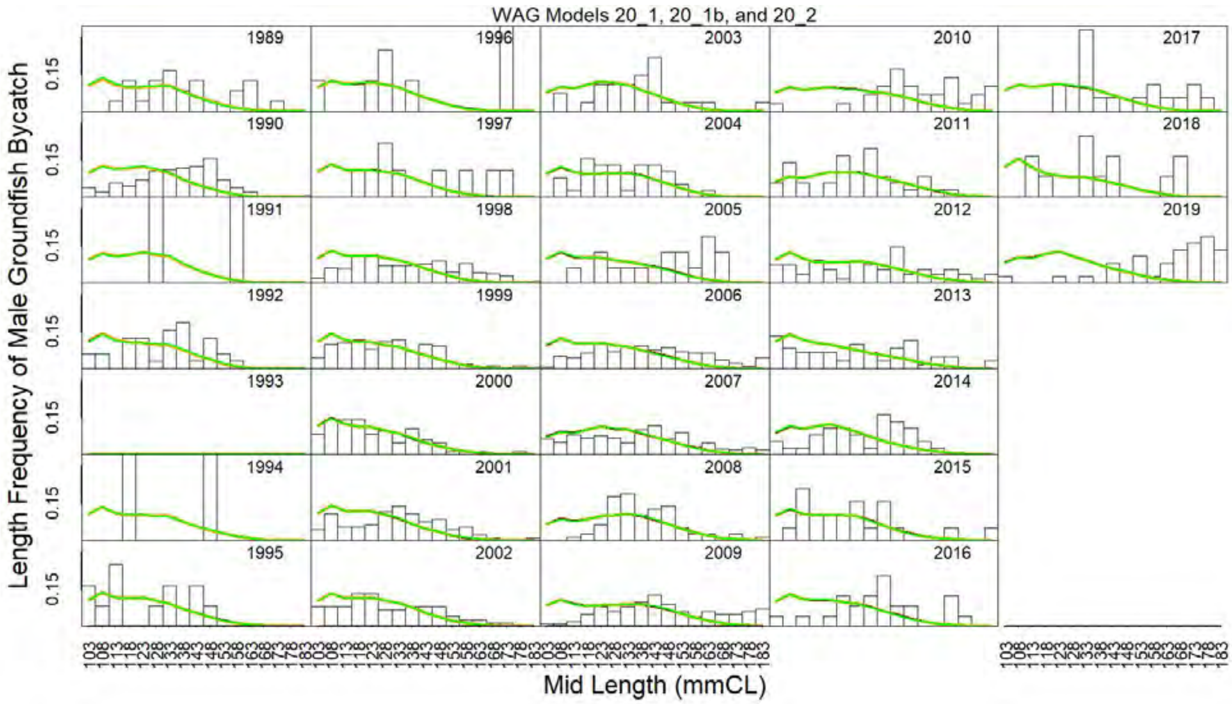

Figure 29. Predicted (line) vs. observed (bar) groundfish discarded bycatch relative length frequency distributions under models 20_1, 20_1b, and 20_2 fits to golden king crab data in the WAG, 1989/90 to 2019/20.

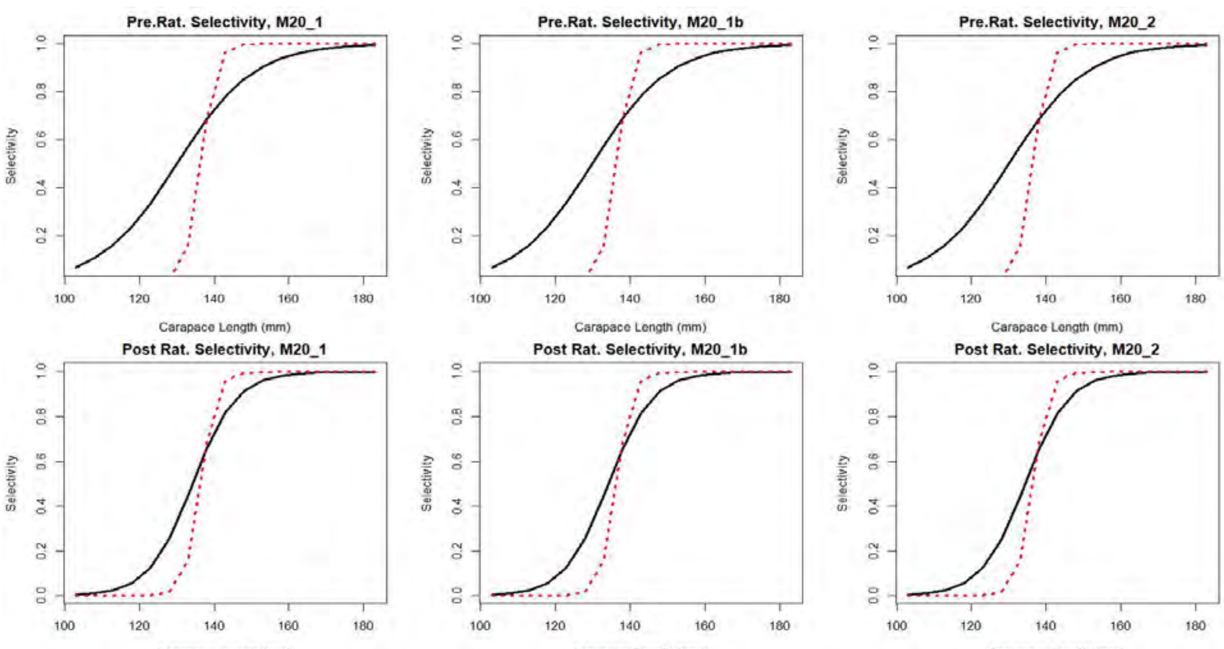

Figure 30. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under models 20_1, 20_1b, and 20_2 fits to golden king crab data in the WAG.

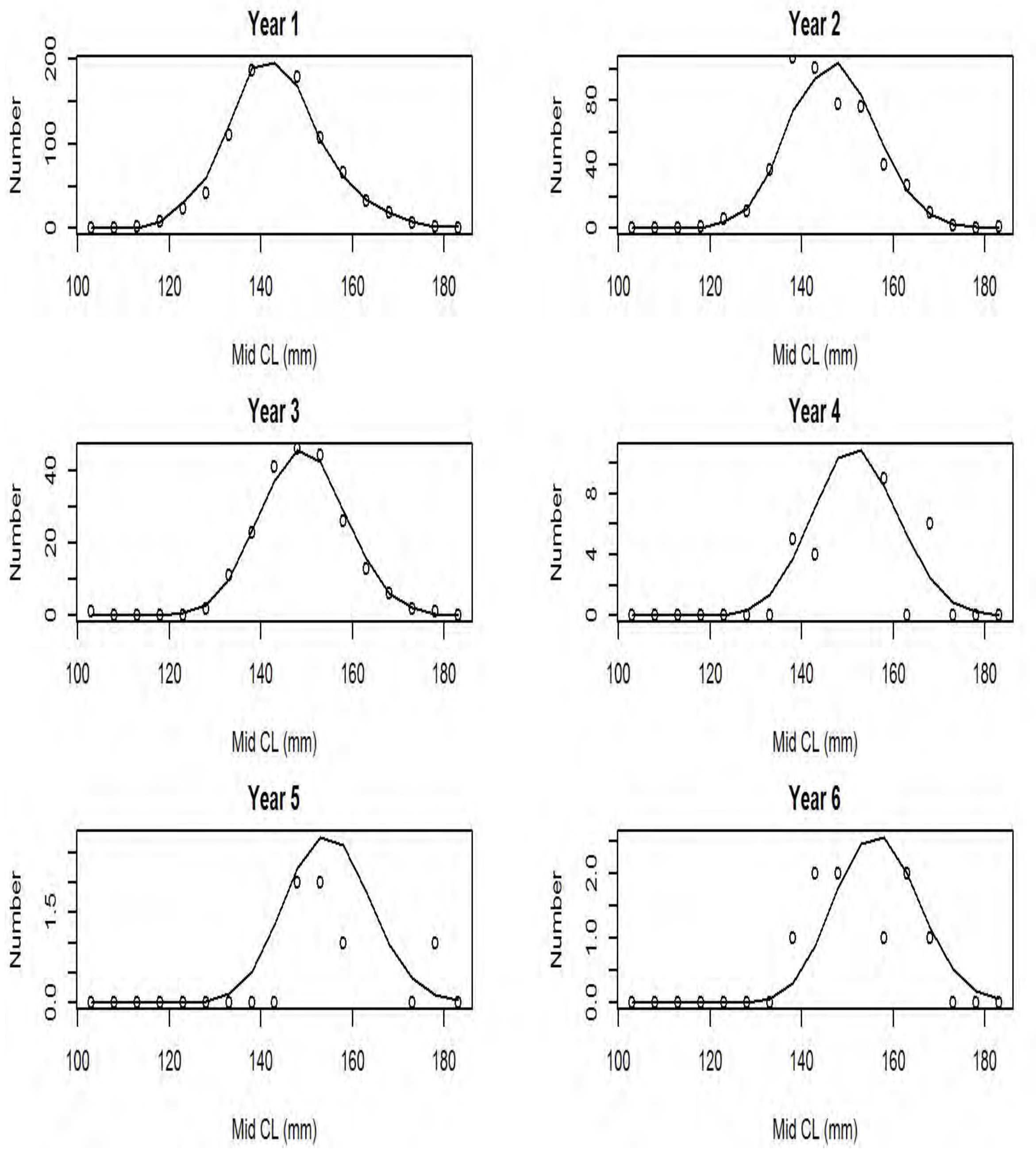

Figure 31. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 post tagging under model 20_1 fit to WAG golden king crab data.

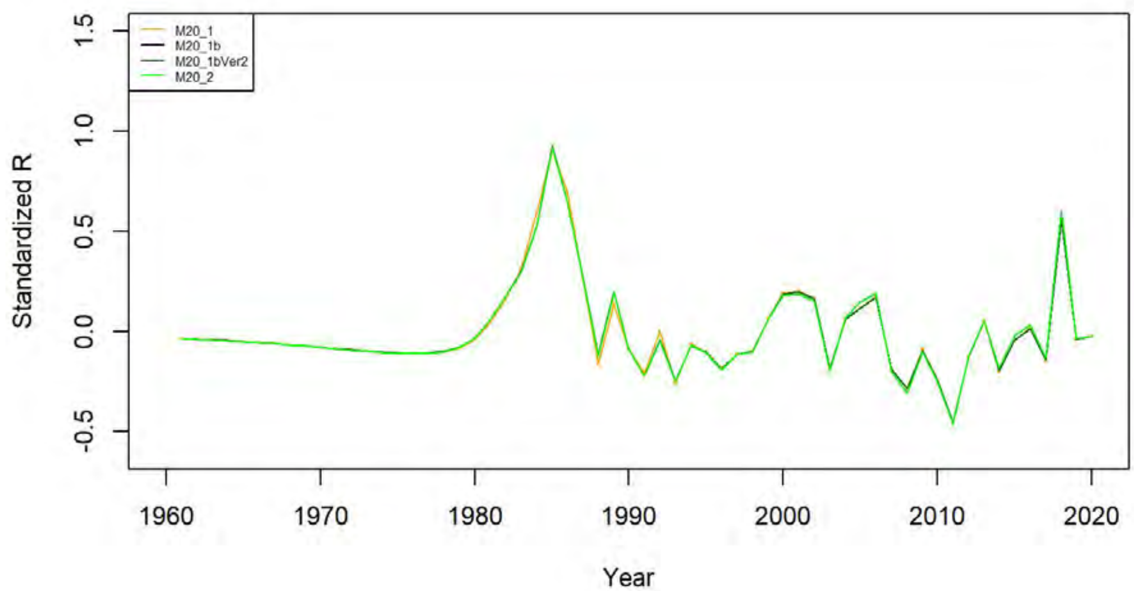

Figure 32. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under models 20_1, 20_1b, 20_1bVer2, and 20_2 fits to WAG golden king crab data, 1961–2020. The numbers of recruits are standardized using (R-mean R)/mean R for comparing different scenarios' results.

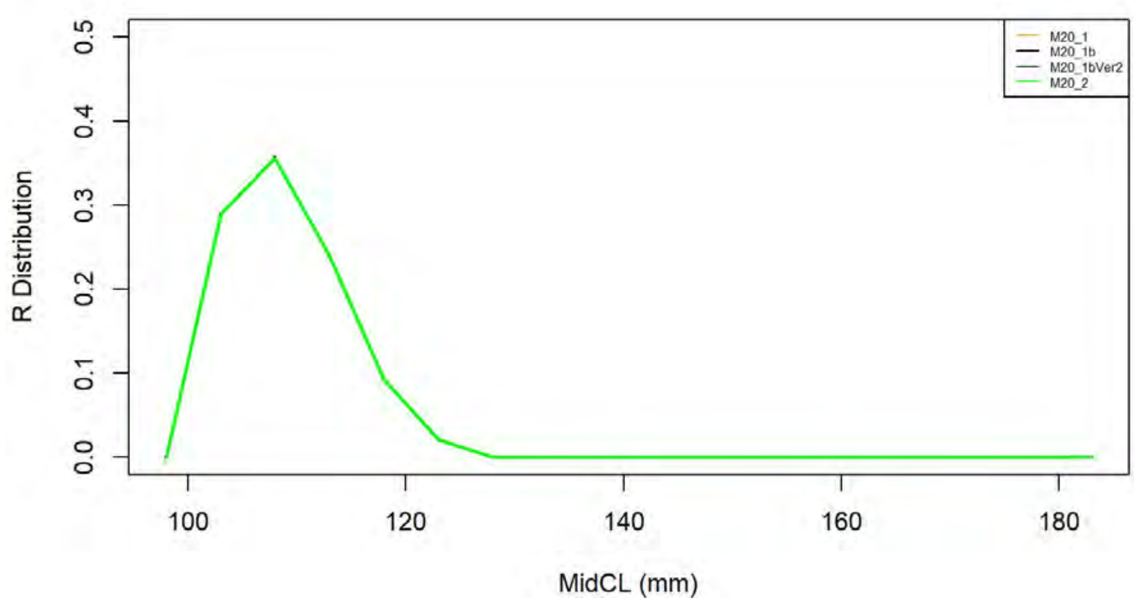

Figure 33. Recruit size distribution to the assessment model under models 20_1, 20_1b, 20_1bVer2, and 20_2 fits to WAG golden king crab data.

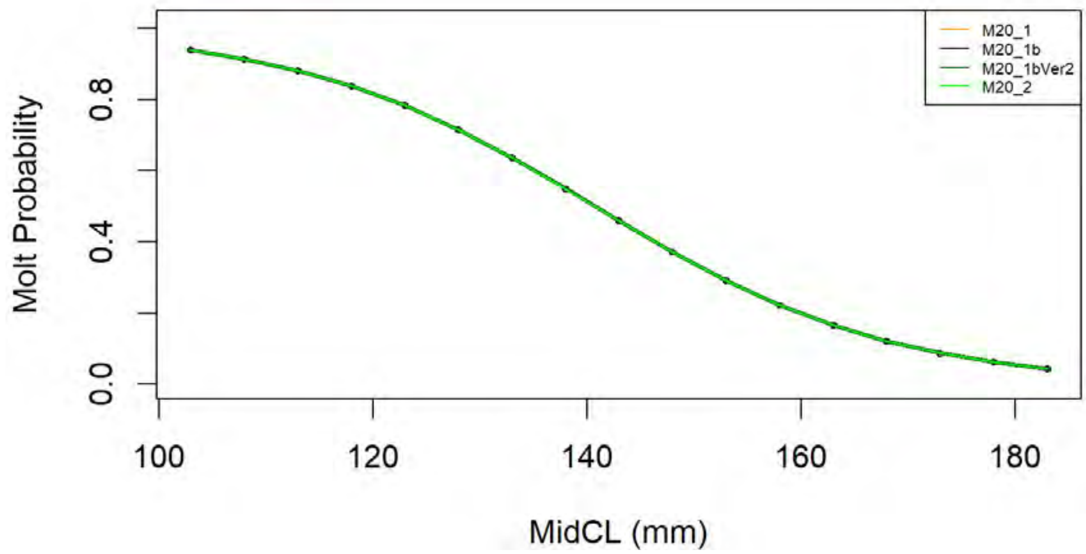

Figure 34. Estimated molt probability vs. carapace length of golden king crab for models 20_1, 20_1b, 20_1bVer2, and 20_2 fits to WAG golden king crab data.

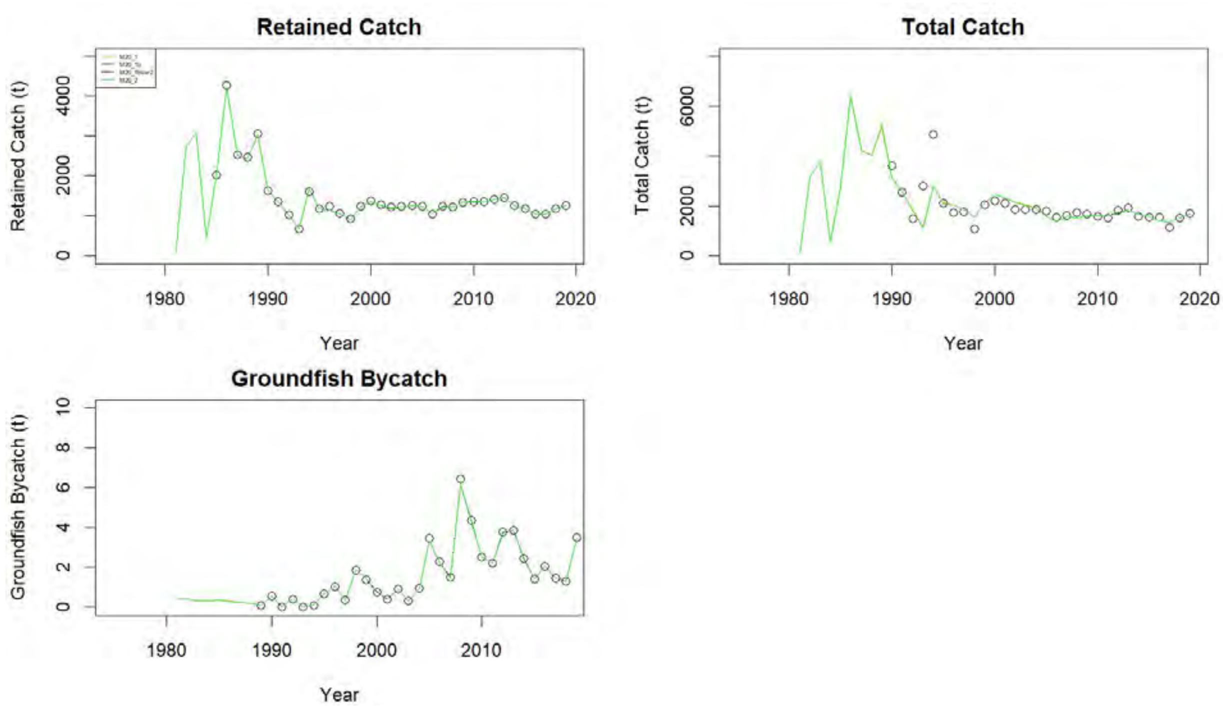

Figure 35. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right in), and groundfish bycatch (bottom left) of golden king crab for models 20_1, 20_1b, 20_1bVer2, and 20_2 fits to WAG data, 1981/82–2019/20.

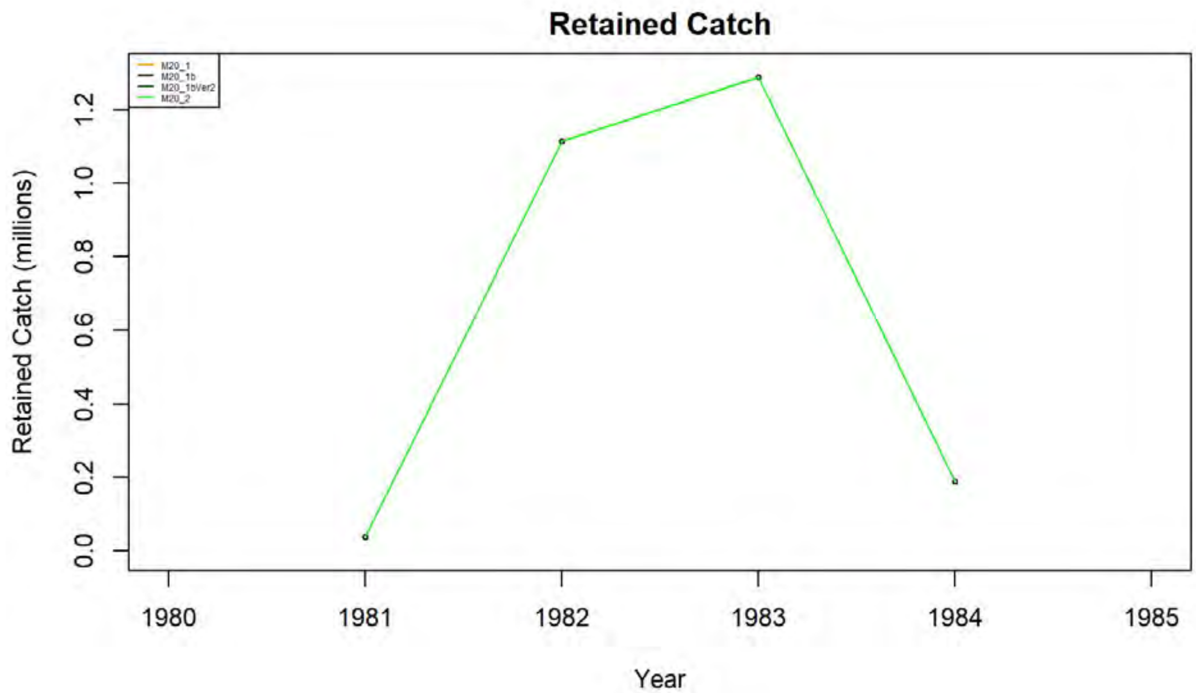

Figure 36. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for models 20_1, 20_1b, 20_1bVer2, and 20_2 fits to WAG data, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period was in number of crabs.

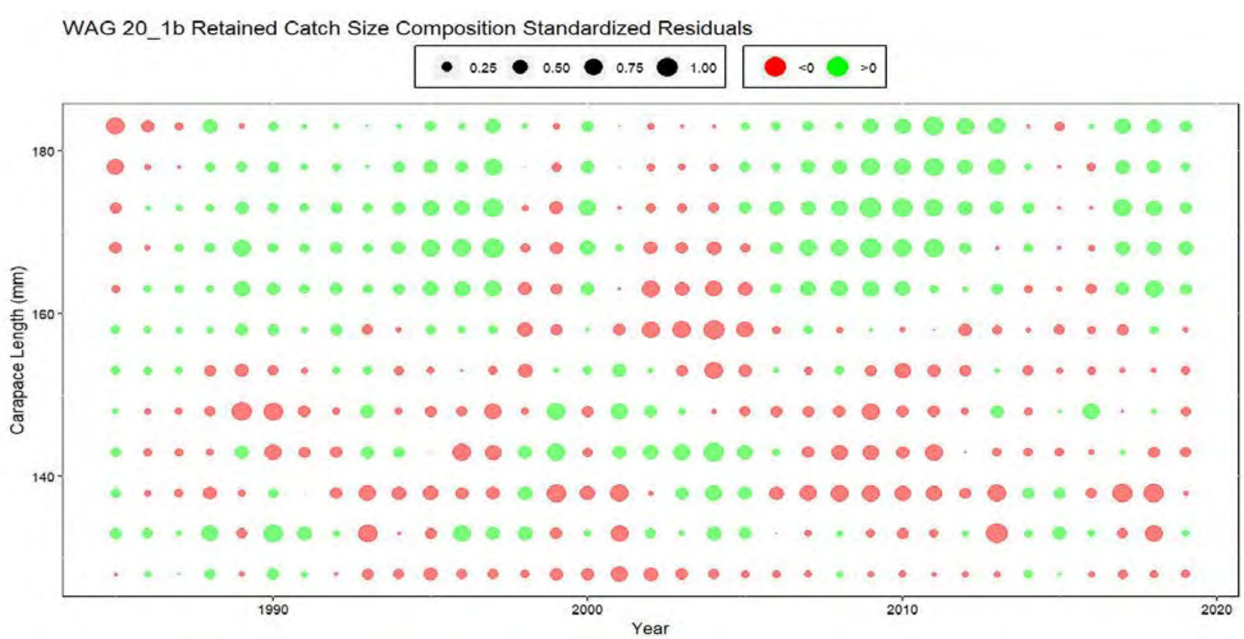

Figure 37. Bubble plot of standardized residuals of retained catch length composition for model 20_1b fit to WAG golden king crab data, 1985/86–2019/20. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

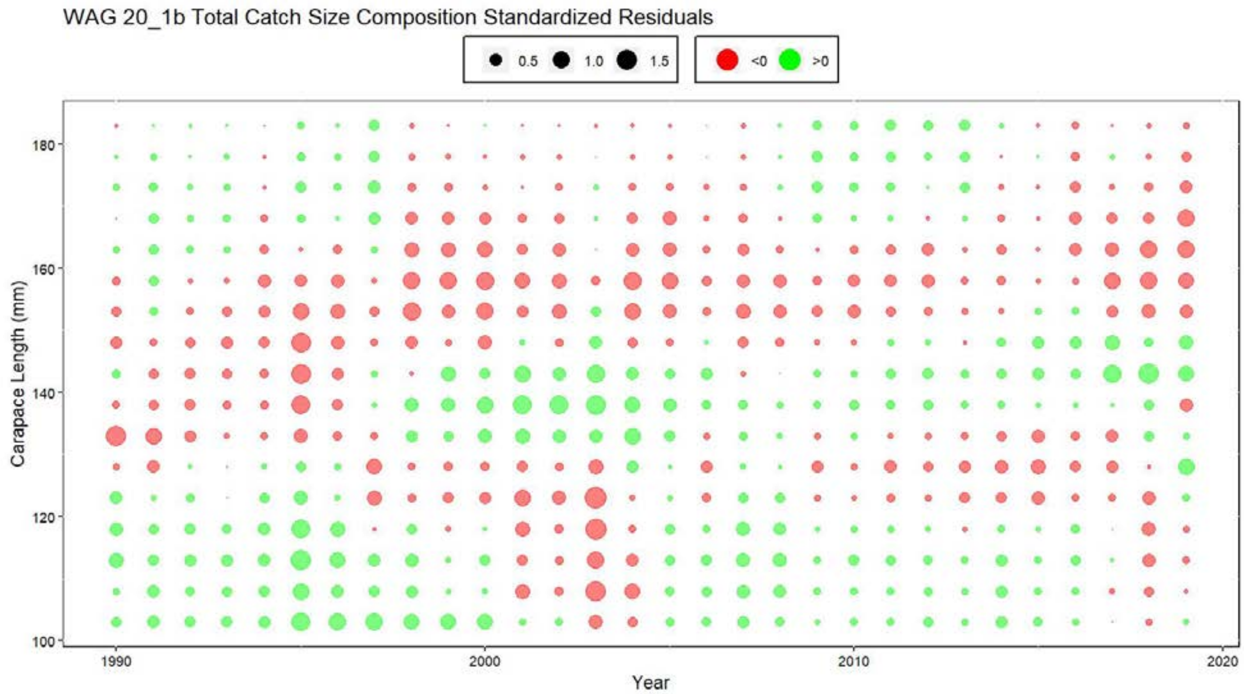

Figure 38. Bubble plot of standardized residuals of total catch length composition for model 20_1b fit to WAG golden king crab dat, 1990/91–2019/20. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

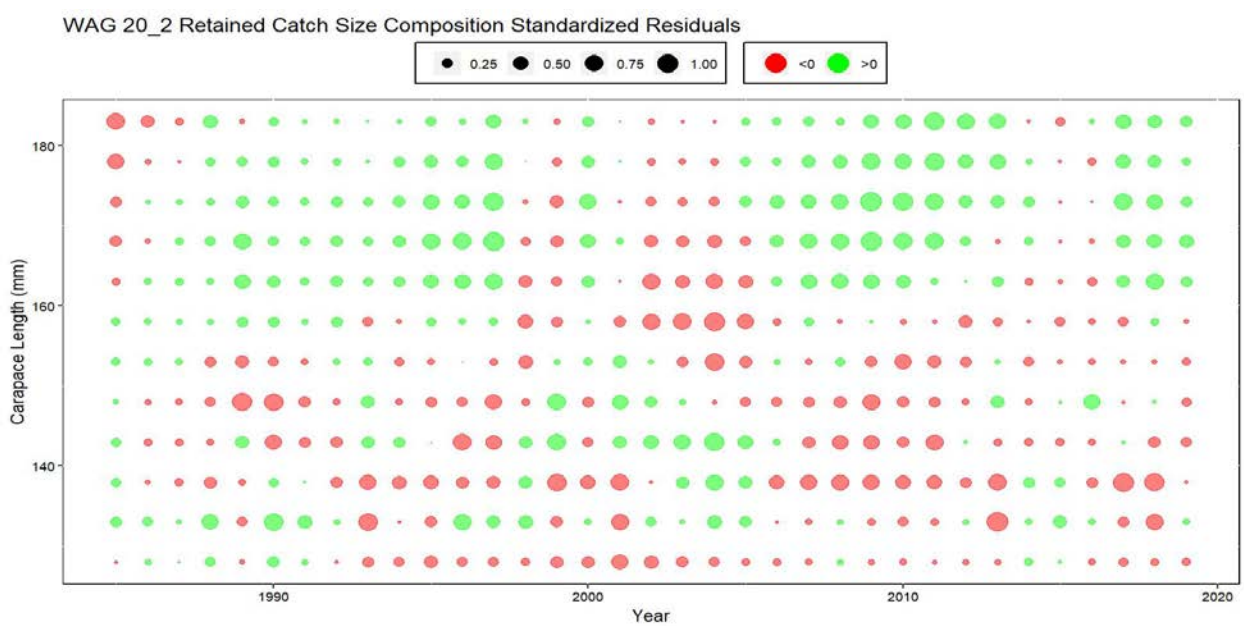

Figure 39. Bubble plot of standardized residuals of retained catch length composition for model 20_2 fit to WAG golden king crab data, 1985/86–2019/20. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

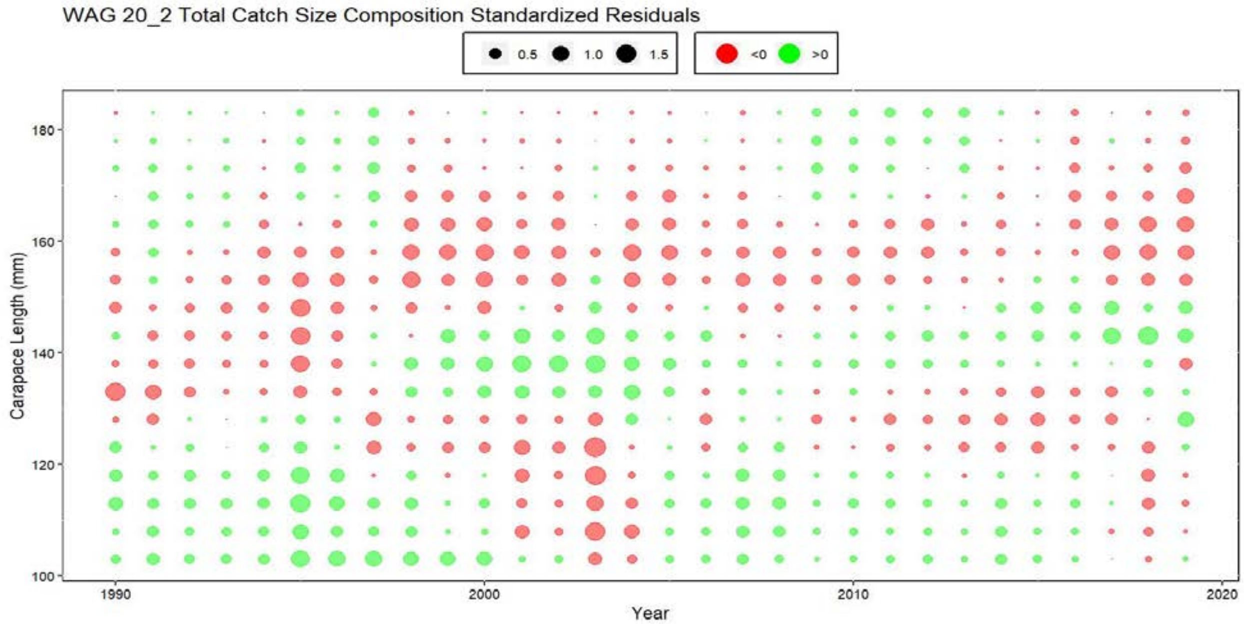

Figure 40. Bubble plot of standardized residuals of total catch length composition for model 20_2 fit to WAG golden king crab data, 1990/91–2019/20. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

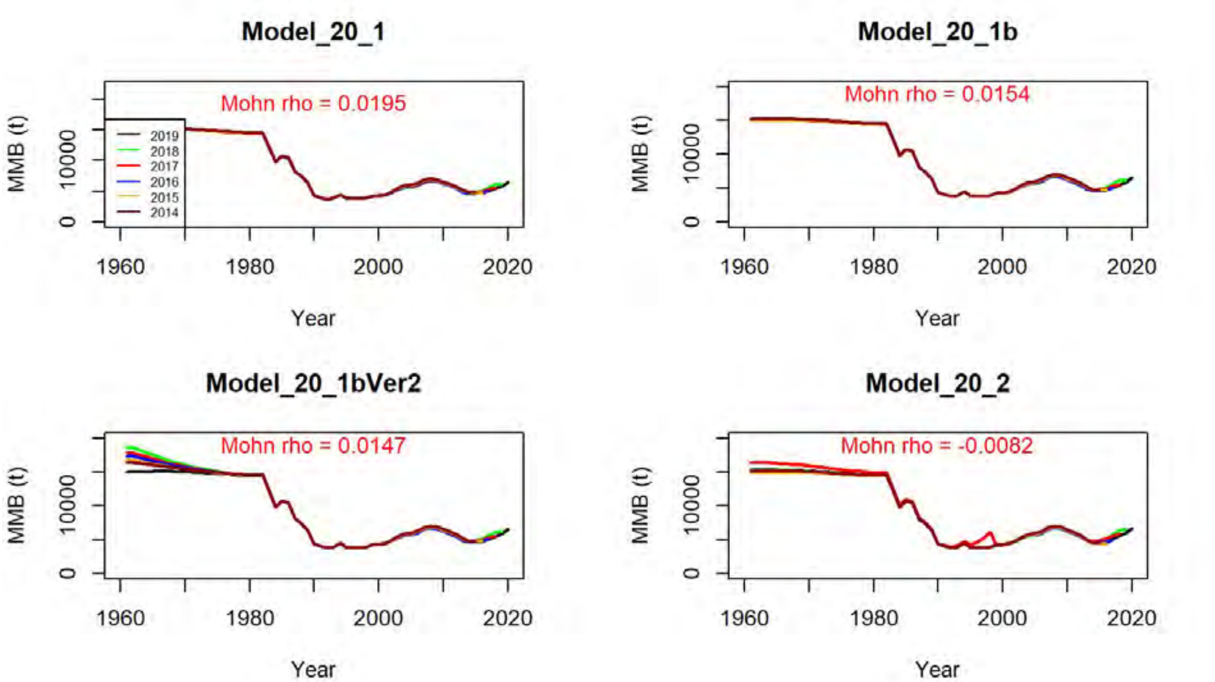

Figure 41. Retrospective fits of MMB by the model following removal of terminal year data under models 20_1, 20_1b, 20_1bVer2, and 20_2 fits for golden king crab in the WAG, 1960/61–2019/20.

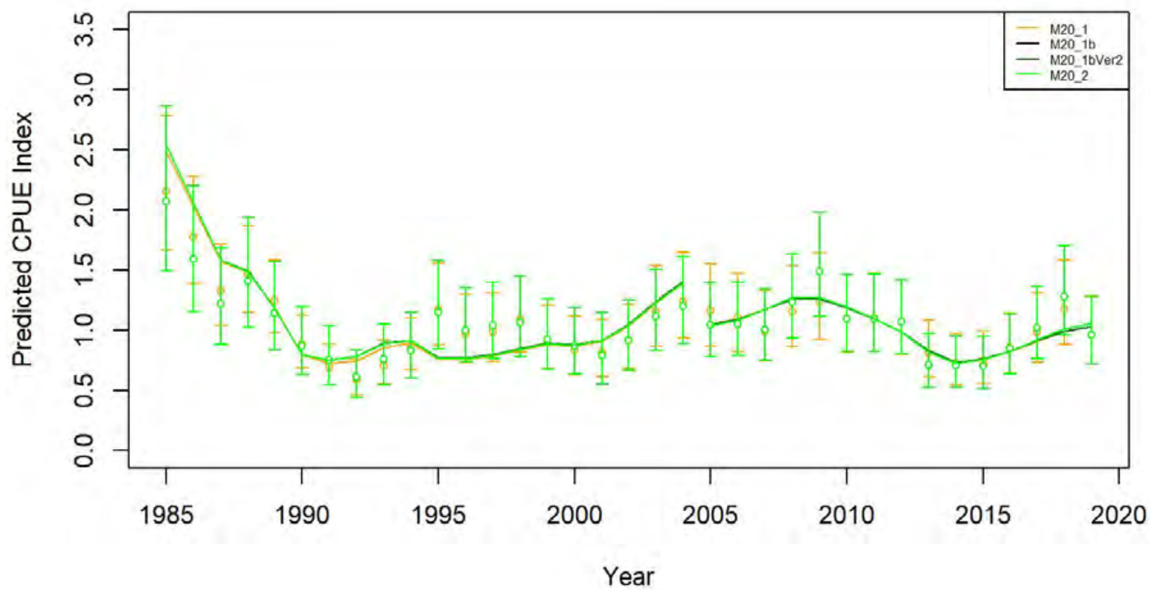

Figure 42. Comparison of input CPUE indices (orange open circles with +/- 2 SE for model 20_1 and green open circles with +/- 2 SE for model 20_2) with model predicted CPUE indices (colored solid lines) under models 20_1, 20_1b, 20_1bVer2, and 20_2 fits to WAG golden king crab data, 1985/86–2019/20. Model estimated additional standard error was added to each input standard error.

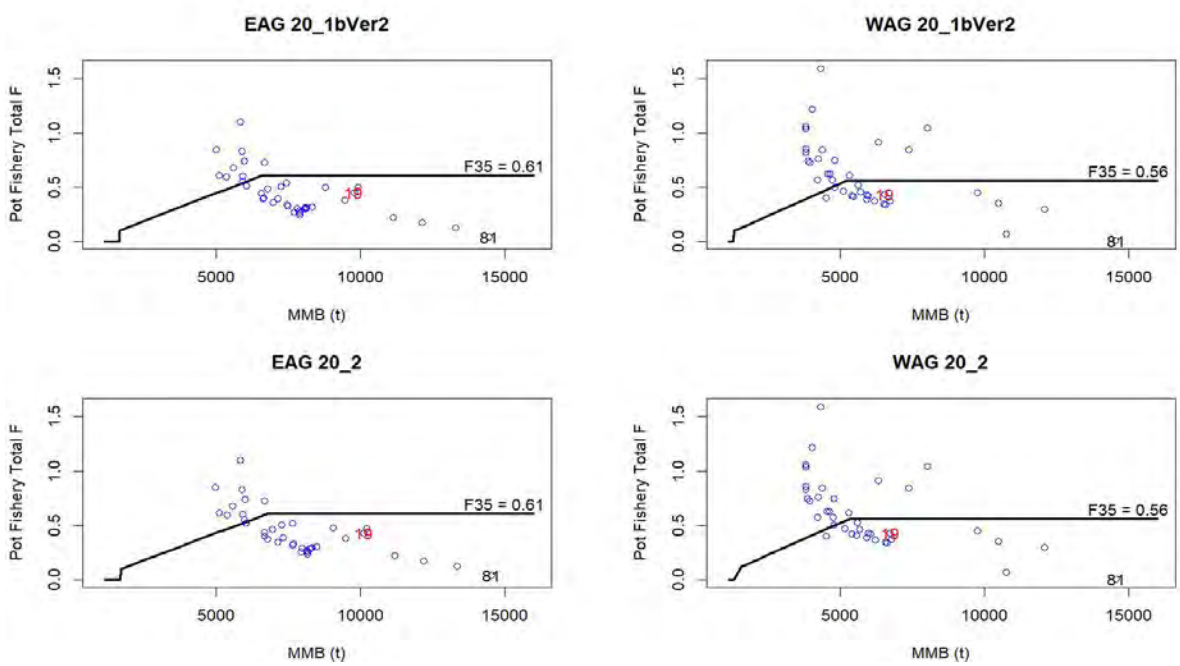

Figure 43. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass during 1981/82–2019/20 under models 20_1bVer2 and 20_2 fits to EAG and WAG data. F in 2019/20 (red) and 1981/82 (black) are shown in the plots.

Appendix A: Integrated model

Aleutian Islands Golden King Crab (*Lithodes aequispinus*) Stock Assessment Model Development- east of 174° W (EAG) and west of 174° W (WAG) Aleutian Island stocks

Basic population dynamics

The annual [male] abundances by size are modeled using the equation:

$$N_{t+1,j} = \sum_{i=1}^{j}[N_{t,i}e^{-M} - (\hat{C}_{t,i} + \widehat{D}_{t,i} + \widehat{Tr}_{t,i})e^{(y_t-1)M}]X_{i,j} + R_{t+1,j} \quad \text{(A.1)}$$

where $N_{t,i}$ is the number of [male] crab in length class i on 1 July (start of fishing year) of year t; $\hat{C}_{t,i}$, $\hat{D}_{t,i}$, and $\hat{T}r_{t,i}$ are respectively the predicted fishery retained, pot fishery discard dead, and groundfish fishery discard dead catches in length class *i* during year *t*; $\widehat{D}_{t,i}$ is estimated from the intermediate total $(\widehat{T}_{t,i\ temp})$ catch and the retained $(\hat{C}_{t,i})$ catch by Equation A.2c. $X_{i,j}$ is the probability of length-class *i* growing into length-class *j* during the year; y_t is elapsed time period from 1 July to the mid –point of fishing period in year *t*; *M* is instantaneous rate of natural mortality; and $R_{t+1,j}$ recruitment to length class *j* in year *t+1*.

The catches are predicted using the equations

$$\hat{T}_{t,j,temp} = \frac{F_t s_{t,j}^T}{Z_{t,j}} N_{t,j}e^{-y_t M}(1 - e^{-Z_{t,j}}) \quad \text{(A.2a)}$$

$$\hat{C}_{t,j} = \frac{F_t s_{t,j}^T s_{t,j}^r}{Z_{t,j}} N_{t,j}e^{-y_t M}(1 - e^{-Z_{t,j}}) \quad \text{(A.2b)}$$

$$\widehat{D}_{t,j} = 0.2(\hat{T}_{t,j,temp} - \hat{C}_{t,j}) \quad \text{(A.2c)}$$

$$\widehat{Tr}_{t,j} = 0.65\frac{F_t^{Tr} s_j^{Tr}}{Z_{t,j}} N_{t,j}e^{-y_t M}(1 - e^{-Z_{t,j}}) \quad \text{(A.2d)}$$

$$\hat{T}_{t,j} = \hat{C}_{t,j} + \widehat{D}_{t,j} \quad \text{(A.2e)}$$

where $Z_{t,j}$ is total fishery-related mortality on animals in length-class *j* during year *t*:

$$Z_{t,j} = F_t s_{t,j}^T s_{t,j}^r + 0.2F_t s_{t,j}^T(1 - s_{t,j}^r) + 0.65\, F_t^{Tr} s_j^{Tr} \quad \text{(A.3)}$$

F_t is the full selection fishing mortality in the pot fishery, F_t^{Tr} is the full selection fishing mortality in the trawl fishery, $s_{t,j}^T$ is the total selectivity for animals in length-class *j* by the pot fishery during year *t*, s_j^{Tr} is the selectivity for animals in length-class *j* by the trawl fishery, $s_{t,j}^r$ is the probability of retention for animals in length-class j by the pot fishery during year t. Pot bycatch mortality of 0.2 and groundfish bycatch mortality of 0.65 (average of trawl (0.8) and fish pot (0.5) mortality) were assumed.

Initial abundance

The initial conditions are computed as the equilibrium initial condition using the following relations:

The equilibrium stock abundance is

$$N = X.S.N + R \tag{A.4}$$

The equilibrium abundance in 1960, N_{1960} , is

$$\underline{N}_{1960} = (I - XS)^{-1}\underline{R} \tag{A.5}$$

where X is the growth matrix, S is a matrix with diagonal elements given by e^{-M} , I is the identity matrix, and $\underline{R}$ is the product of average recruitment and relative proportion of total recruitment to each size-class.

We used the mean number of recruits from 1987 to 2012 in equation (A.5) to obtain the equilibrium solution under only natural mortality in year 1960, and then projected the equilibrium abundance under natural mortality with recruitment estimated for each year after 1960 up to 1985 with removal of retained catches during 1981/82 to 1984/85.

Growth Matrix

The growth matrix X is modeled as follows:

$$X_{i,j} = \begin{cases} 0 & if\ j < i \\ P_{i,j} + (1 - m_i) & if\ j = i \\ P_{i,j} & if\ j > i \end{cases} \tag{A.6}$$

where:

$$P_{i,j} = m_i \begin{cases} \int_{-\infty}^{j_2 - L_i} N\ (x\ |\mu_i, \sigma^2)\ dx & if\ \ j = i \\ \int_{j_1 - L_i}^{j_2 - L_i} N\ (x\ |\mu_i, \sigma^2)\ dx & if\ \ i < j < n\ , \\ \int_{j_1 - L_i}^{\infty} N\ (x\ |\mu_i, \sigma^2)\ dx & if\ \ \ i = n \end{cases}$$

$$N(x|\mu_i, \sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-(\frac{x-\mu_i}{\sqrt{2}\sigma})^2},\ and$$

μ_i is the mean growth increment for crab in size-class i:

$$\mu_i = \omega_1 + \omega_2 * \bar{L}_i. \tag{A.7}$$

ω_1 , ω_2 , and σ are estimable parameters, and j_1 and j_2 are the lower and upper limits of the receiving length-class j (in mm CL), and $\bar{L}_i$ is the mid-point of the contributing length interval i. The quantity m_i is the molt probability for size-class i:

$$m_i = \frac{1}{1 + e^{c(\tau_i - d)}} \quad \text{(A.8)}$$

where τ_i is the mid-length of the *i*-th length-class, *c* and *d* are parameters.

Selectivity and retention

Selectivity and retention are both assumed to be logistic functions of length. Selectivity depends on the fishing period for the pot fishery:

$$S_i = \frac{1}{1 + e^{\left[-ln\,(19)\frac{\tau_i - \theta_{50}}{\theta_{95} - \theta_{50}}\right]}} \quad \text{(A.9)}$$

where θ_{95} and θ_{50} are the parameters of the selectivity/ retention pattern (Mark Maunder, unpublished generic crab model). In the program, we re-parameterized the denominator (θ_{95} - θ_{50}) to $log\ (delta\theta)$ so that the difference is always positive and transformed θ_{50} to $log(\theta_{50})$ to keep the estimate always positive.

Recruitment

Recruitment to length–class i during year *t* is modeled as $R_{t,i} = \bar{R}e^{\epsilon_i}\Omega_i$ where Ω_i is a normalized gamma function

$$gamma(x|\alpha_r, \beta_r) = \frac{x^{\alpha_r - 1}e^{\frac{x}{\beta_r}}}{{\beta_r}^{\alpha_r}\,\Gamma_{(\alpha_r)}} \quad \text{(A.10)}$$

with α_r and β_r (restricted to the first five length classes).

Parameter estimation

Table A1 lists the parameters of the model indicating which are estimated and which are pre-specified. The objective function includes contributions related to the fit of the model to the available data and penalties (priors on various parameters).

Tables A2 lists parameter values (with the corresponding coefficient of variations in parentheses) used to weight the components of the objective functions for EAG and WAG.

Likelihood components

Catches

The contribution of the catch data (retained, total, and groundfish discarded) to the objective function is given by:

$$LL_r^{catch} = \lambda_r \sum_t \{\ell n(\sum_j \hat{C}_{t,j} w_j + c) - \ell n(\sum_j C_{t,j} w_j + c)\}^2 \quad \text{(A.11a)}$$

$$LL_T^{catch} = \lambda_T \sum_t \{ln\,(\sum_j \hat{T}_{t,j} w_j + c) - ln\,(\sum_j T_{t,j} w_j + c)\}^2 \quad \text{(A.11b)}$$

$$LL_{GD}^{catch} = \lambda_{GD} \sum_t \{ln\,(\sum_j \widehat{Tr}_{t,j} w_j + c) - ln\,(\sum_j Tr_{t,j} w_j + c)\}^2 \quad \text{(A.11c)}$$

where λ_r, λ_T, and λ_{GD} are weights assigned to likelihood components for the retained, pot total, and groundfish discard catches; w_j is the average mass of a crab is length-class j; $C_{t,j}$, $T_{t,j}$, and $Tr_{t,j}$ are, respectively, the observed numbers of crab in size class j for retained, pot total, and groundfish fishery discarded crab during year t, and c is a small constant value. We assumed c = 0.001.

An additional retained catch likelihood (using Equation A.11a without w) for the retained catch in number of crabs during 1981/82 to 1984/85 was also considered in all scenarios.

Catch-rate indices

The catch-rate indices are assumed to be lognormally distributed about the model prediction. Account is taken of variation in addition to that related to sampling variation:

$$LL_r^{CPUE} = \lambda_{r,CPUE}\left\{0.5\sum_t ln\left[2\pi\left(\sigma_{r,t}^2 + \sigma_e^2\right)\right] + \sum_t \frac{\left(ln(CPUE_t^r+c) - ln\,(\widehat{CPUE}_t^r+c)\right)^2}{2\left(\sigma_{r,t}^2+\sigma_e^2\right)}\right\} \quad \text{(A.12)}$$

where $CPUE_t^r$ is the standardized retain catch-rate index for year t, $\sigma_{r,t}$ is standard error of the logarithm of $CPUE_t^r$, and $\widehat{CPUE}_t^r$ is the model-estimate of $CPUE_t^r$:

$$\widehat{CPUE}_t^r = q_k \sum_j S_j^T\, S_j^r \left(N_{t,j} - 0.5\left[\widehat{C_{t,J}} + \widehat{D_{t,J}} + \widehat{Tr_{t,J}}\,\right]\right)e^{-y_t M} \quad \text{(A.13)}$$

in which q_k is the catchability coefficient during the k-th time period (e.g., pre- and post-rationalization time periods), σ_e is the extent of over-dispersion, c is a small constant to prevent zero values (we assumed c = 0.001), and $\lambda_{r,CPUE}$ is the weight assigned to the catch-rate data. We used the same likelihood formula (A.12) for fish ticket and cooperative survey retained catch rate indices. However, for cooperative survey catch rate prediction we used a different catchability parameter.

Following Burnham *et al.* (1987), we computed the ln(CPUE) variance by:

$$\sigma_{r,t}^2 = \ln\left(1 + CV_{r,t}^2\right) \quad \text{(A.14)}$$

Length-composition data

The length-composition data are included in the likelihood function using the robust normal for proportions likelihood, i.e., generically:

$$LL_r^{LF} = 0.5\sum_t\sum_j \ell n(2\pi\sigma_{t,j}^2) - \sum_t\sum_j \ell n\left[\exp\left(-\frac{(P_{t,j}-\hat{P}_{t,j})^2}{2\sigma_{t,j}^2}\right) + 0.01\right] \quad \text{(A.15)}$$

where $P_{t,j}$ is the observed proportion of crabs in length-class j in the catch during year t, $\hat{P}_{t,j}$ is the model-estimate corresponding to $P_{t,j}$, i.e.:

$$\hat{L}_{t,j}^r = \frac{\hat{C}_{t,j}}{\sum_j^n \hat{C}_{t,j}}$$

$$\hat{L}^{T}_{t,j} = \frac{\hat{T}_{t,j}}{\sum_j^n \hat{T}_{t,j}}$$

$$\hat{L}^{GF}_{t,j} = \frac{\widehat{Tr}_{t,j}}{\sum_j^n \widehat{Tr}_{t,j}} \qquad (A.16)$$

$\sigma^2_{t,j}$ is the variance of $P_{t,j}$:

$$\sigma^2_{t,j} = \left[(1-P_{t,j})P_{t,j} + \frac{0.1}{n}\right] / S_t \qquad (A.17)$$

and S_t is the effective sample size for year *t* and *n* is the number of size classes.

Note: The likelihood calculation for retained length composition starts from length-class 6 (mid length 128 mm CL) because the length-classes 1 to 5 mostly contain zero data.

Tagging data

Let $V_{j,t,y}$ be the number of tagged male crab that were released during year *t* that were in size-class *j* when they were released and were recaptured after *y* years, and $\underline{\rho}_{j,t,y}$ be the vector of recaptures by size-class from the males that were released in year *t* that were in size-class *j* when they were released and were recaptured after *y* years. The log-likelihood corresponding to the multinomial distribution for the tagging data is then:

$$lnL = \lambda_{y,tag} \sum_j \sum_t \sum_y \sum_i \rho_{j,t,y,i} ln\hat{\rho}_{j,t,y,i} \qquad (A18)$$

where $\lambda_{y,tag}$ is the weight assigned to the tagging data for recapture year *y*, $\hat{\rho}_{j,t,y,i}$ is the proportion in size-class *i* of the recaptures of males that were released during year *t* that were in size-class *j* when they were released and were recaptured after *y* years:

$$\hat{\underline{\rho}}_{j,t,y} \propto \underline{s}^T [\mathbf{X}]^y \underline{Z}^{(j)} \qquad (A19)$$

where $Z^{(j)}$ is a vector with $V_{j,t,y}$ at element *j* and 0 otherwise, and S^T is the vector of total selectivity for tagged male crab by the pot fishery. This log-likelihood function is predicated on the assumption that all recaptures are in the pot fishery and the reporting rate is independent of the size of crab.

Penalties

Penalties are imposed on the deviations of annual pot fishing mortality about mean pot fishing mortality, annual trawl fishing mortality about mean trawl fishing mortality, recruitment about mean recruitment, and the posfunction (fpen):

$$P_1 = \lambda_F \sum_t (\ell n F_t - \ell n \bar{F})^2 \qquad (A.20)$$

$$P_2 = \lambda_{F^{Tr}} \sum_t (\ell n F_t^{Tr} - \ell n \bar{F}^{Tr})^2$$

(A.21)

$$P_3 = \lambda_R \sum_t (\ell n \varepsilon_t)^2 \tag{A.22}$$

$$P_5 = \lambda_{posfn} * fpen \tag{A.23}$$

Standardized Residual of Length Composition

$$\text{Std. Res}_{t,j} = \frac{P_{t,j} - \widehat{P_{t,j}}}{\sqrt{2\sigma^2_{t,j}}} \tag{A.24}$$

Output Quantities

Harvest rate

Total pot fishery harvest rate:

$$E_t = \frac{\sum_{j=1}^{n}(\hat{C}_{j,t} + \hat{D}_{j,t})}{\sum_{j=1}^{n} N_{j,t}} \tag{A.25}$$

Exploited legal male biomass at the start of year t:

$$LMB_t = \sum_{j=legal\ size}^{n} s_j^T s_j^r N_{j,t}\ w_j \tag{A.26}$$

where w_j is the weight of an animal in length-class *j*.

Mature male biomass on 15 February spawning time (NPFMC 2007a, b) in the following year:

$$MMB_t = \sum_{j=mature\ size}^{n}\{N_{j,t}e^{-y'M} - (\hat{C}_{j,t} + \hat{D}_{j,t} + \widehat{Tr}_{j,t})e^{(y_t - y')M}\}w_j \tag{A.27}$$

where y' is the elapsed time from 1 July to 15 February in the following year.

For estimating the next year limit harvest levels from current year stock abundances, a F_{OFL} value is needed. Current crab management plan specifies five different Tier formulas for different stocks depending on the strength of information available for a stock, for computing F_{OFL} (NPFMC 2007a, b). For the golden king crab, the following Tier 3 formula is applied to compute F_{OFL}:

If,
$MMB_{current} > MMB_{35\%}, F_{OFL} = F_{35\%}$

If,
$MMB_{current} \leq MMB_{35\%}$ *and* $MMB_{current} > 0.25 MMB_{35\%}$,

$$F_{OFL} = F_{35\%} \frac{\left(\frac{MMB_{current}}{MMB_{35\%}} - \alpha\right)}{(1-\alpha)} \tag{A.28}$$

If,
$MMB_{current} \leq 0.25 MMB_{35\%}$,

$F_{OFL} = 0.$

where α is a parameter, $\text{MMB}_{\text{current}}$ is the mature male biomass in the current year and $MMB_{35\%}$ is the proxy MMB_{MSY} for Tier 3 stocks. We assumed α = 0.1.
Because projected MMB_{t} (i.e., $\text{MMB}_{\text{current}}$) depends on the intervening retained and discard catch (i.e., MMB_{t} is estimated after the fishery), an iterative procedure is applied using Equations A.27 and A.28 with retained and discard catch predicted from Equations A.2b-d. The next year limit harvest catch is estimated using Equations A.2b-d with the estimated F_{OFL} value.

Table A1. Pre-specified and estimated parameters of the population dynamics model

Parameter	Number of parameters
Fishing mortalities:	
Pot fishery, F_t	1981–2019 (estimated)
Mean pot fishery fishing mortality, $\overline{F}$	1 (estimated)
Groundfish fishery, F_t^{Tr}	1989–2019 (the mean F for 1989 to 1994 was used to estimate groundfish discards back to 1981 (estimated)
Mean groundfish fishery fishing mortality, $\overline{F}^{Tr}$	1 (estimated)
Selectivity and retention:	
Pot fishery total selectivity, θ_{50}^{T}	2 (1981–2004; 2005+) (estimated)
Pot fishery total selectivity difference, deltaθ^{T}	2 (1981–2004; 2005+) (estimated)
Pot fishery retention, θ_{50}^{r}	1 (1981+) (estimated)
Pot fishery retention selectivity difference, deltaθ^{r}	1 (1981+) (estimated)
Groundfish fishery selectivity	fixed at 1 for all size-classes
Growth:	
Expected growth increment, ω_1, ω_2	2 (estimated)
Variability in growth increment, σ	1 (estimated)
Molt probability (size transition matrix with tag data), a	1 (estimated)
Molt probability (size transition matrix with tag data), b	1 (estimated)
Natural mortality, *M*	1 (pre-specified, 0.21yr^{-1})
Recruitment:	
Number of recruiting length-classes	5 (pre-specified)
Mean recruit length	1 (pre-specified, 110 mmCL)
Distribution to length-class, β_{r}	1 (estimated)
Median recruitment, $\overline{\text{R}}$	1 (estimated)
Recruitment deviations, ε_t	60 (1961–2020) (estimated)
Fishery catchability, q	2 (1985–2004; 2005+) (estimated)
Additional CPUE indices standard deviation, σ_{e}	1 (estimated)
Likelihood weights (coefficient of variation)	Pre-specified, varies by scenario

Table A2. Specifications for the weights with corresponding coefficient of variations* in parentheses for each model for EAG and WAG.

Weight	Model 20_1	Model 20_1b	Model 20_2
Catch:			
Retained catch for 1981–1984 and/or 1985–2019, λ_r	500 (0.032)	500	500
Total catch for 1990–2019, λ_T	Number of sampled pots scaled to a max 250	Number of sampled pots scaled to a max 250	Number of sampled pots scaled to a max 250
Groundfish bycatch for 1989 –2019, λ_{GD}	0.2 (3.344)	0.2	0.2
Catch-rate:			
Observer legal size crab catch-rate for 1995–2019, $\lambda_{r,CPUE}$	1 (0.805)	1	1
Fish ticket retained crab catch-rate for 1985–1998, $\lambda_{r,CPUE}$	1 (0.805)	1	1
Penalty weights:			
Pot fishing mortality dev, λ_F	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase
Groundfish fishing mortality dev, $\lambda_{F^{Tr}}$	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase	Initially 1000, relaxed to 0.001 at phases ≥ select. phase
Recruitment, λ_R	2 (0.533)	2	2
Posfunction (to keep abundance estimates always positive), λ_{posfn}	1000 (0.022)	1000	1000
Tagging likelihood	EAG individual tag returns	EAG tag data	EAG tag data

$*$ Coefficient of Variation, $CV = \sqrt{\exp\left[\frac{1}{2W}\right] - 1}$, w =weight

Appendix B: Catch and CPUE data

The commercial catch and length frequency distribution were estimated from ADF&G landing records and dockside sampling (Bowers *et al.* 2008, 2011). The annual retained catch, total catch, and groundfish (or trawl) discarded mortality are provided in Tables 1, 2, and 2b for EAG and WAG. The weighted length frequency data were used to distribute the catch into 5-mm size intervals. The length frequency data for a year were weighted by each sampled vessel's catch as follows. The *i*-th length-class frequency was estimated as:

$$\sum_{j=1}^{k} C_j \frac{LF_{j,i}}{\sum_{i=1}^{n} LF_{j,i}} \qquad \text{(B.1)}$$

where k = number of sampled vessels in a year, $LF_{j,i}$ = number of crabs in the *i*-th length-class in the sample from *j*-th vessel, n = number of size classes, C_j = number of crabs caught by *j*-th vessel. Then the relative frequency for the year was calculated and applied to the annual retained catch (in number of crabs) to obtain retained catch by length-class.

The annual total catch (in number of crabs) was estimated by the observer nominal (unstandardized) total CPUE considering all vessels multiplied by the total fishing effort (number of pot lifts). The weighted length frequency of the observer samples across the fleet was estimated using Equation B.1. Observer measurement of crab ranged from 20 to 220 mm CL. To restrict the total number of crabs to the model assumed size range (101–185+ mm CL), the proportion of observer total relative length frequency corresponding to this size range was multiplied by the total catch (number of crabs). This total number of crabs was distributed into length-classes using the weighted relative length frequency. Thus, crab sizes < 101 mm CL were excluded from the model. In addition, all crab >185 mm CL were pooled into a plus length class. Note that the total crab catch by size that went into the model did not consider retained and discard components separately. However, once the model estimated the annual total catch, then retained catch was deducted from this total and multiplied by handling mortality [we used a 20% handling mortality (Siddeek *et al.* 2005) to obtain the directed fishery discarded (dead) catch].

Observer data have been collected since 1988 (Moore *et al.* 2000; Barnard *et al.* 2001; Barnard and Burt 2004; Gaeuman 2011), but data were not comprehensive in the initial years, so a shorter time series of data for the period 1990/91–2018/19 was selected for this analysis. During 1990/91–1994/95, observers were only deployed on catcher-processor vessels. During 1995/96–2004/05, observers were deployed on all fishing vessels during fishing activity. Observers have been deployed on all fishing vessels since 2005/06, but catcher-only vessels are only required to carry observers for a minimum of 50% of their fishing activity during a season; catcher-processor vessels are still required to carry observers during all fishing activity. Onboard observers sample seven pots per day (it can be different number of pots per string) and count and measure all crabs caught and categorize catch as females, sublegal males, retained legal males, and non-retained legal males in a sampled pot. Prior to the 2009/10 season, depending on season, area, and type of fishing vessel, observers were also instructed to sample additional pots in which all crab were only counted and categorized as females, sublegal males, retained legal males, and non-retained legal males, but were not measured. Annual mean nominal CPUEs of retained and total crabs were estimated considering all sampled pots within each season (Table 3). The observer CPUE data collection improved over the years and the data since 1995/96 are more reliable. Thus, for model fitting, the observer CPUE time series was restricted to 1995/96–2019/20. The 1990/91–2019/20 observer database consists of 116,508 records and that of 1995/96–2019/20 contains 112,229 records, For CPUE standardization, these data were further reduced by 5% cutoff of Soak time and 1% cutoff of Depth on both ends of the variable range to remove unreliable data or data from dysfunctional pot operations, and restricting to vessels which have made five trips per year for at least three years during 1985/86 –2019/20.

Length-specific CPUE data collected by observers provides information on a wider size range of the stock than did the commercial catch length frequency data obtained from mostly legal-sized landed males.

There were significant changes in fishing practice due to changes in management regulations (e.g., since 1996/97 constant TAC and since 2005/06 crab rationalization), pot configuration (escape web on the pot door increased to 9” since 1999), and improved observer recording in Aleutian Islands golden king crab fisheries since 1998. These changes prompted us to consider two separate observer CPUE time series, 1995/96–2004/05 and 2005/06–2019/20, to estimate CPUE indices for model input.

To include a long time series of CPUE indices for stock abundance contrast, we also considered the 1985/86–1998/99 legal size standardized CPUE as a separate likelihood component in all scenarios. Because of the lack of soak time data before 1990, we estimated the CPUE index considering a limited set of explanatory variables (e.g., vessel, captain, area, month) and fitting the lognormal and negative binomial GLM models to fish ticket data (Tables 4 and 13).

When using CPUE indices in the model fit, we compared the predicted with the observed legal male CPUE in the observer CPUE likelihoods because legal male (retained plus non-retained) data are more reliable than total in the observer samples.

The CPUE standardization followed the GLM fitting procedure (Maunder and Punt 2004; Starr 2012; Siddeek et al. 2018). Following a suggestion made by the CIE reviewers (CIE, June 2018) we reduced the number of gear codes in the database after consulting with the fishing industry (Rip Carlton, Chad Hoefer, and Scott Goodman, personal communication December 2018; Table B1). Following SSC (October 2018) suggestion, we used a hybrid procedure: First, selected a scope of variables set by Akike Information Criterion, AIC (Burnham and Anderson 2002). An increase of more than 2 units in the AIC was used to identify the variable to be included successively (stepAIC program, R Core Team 2018). Then, the model parsimony was improved further by successively removing the term that explained the least proportion of deviance (R2 < 0.01) (stepCPUE R function was used, Siddeek et al. 2018). Feenstra, et al. (unpublished 2019) used a similar hybrid approach.

Table B.1. Updated Gear code for observer data analysis. Only gear code # 5, 6, 7, 8, and 13 were considered following crab industry suggestion. Note: Identical codes were given to those gear codes with similar catchability/selectivity. X stands for the gear codes that were ignored.

Original Gear code	**Pot gear description**	**Mark X against the code that can be ignored**	**Number Encountered by Observers during 1990-2016**	**Updated Gear Code**
1	Dungeness crab pot, small & round	X	2	X
2	Pyramid pot, tunnel openings usually on sides, stackable	X	2121	X
3	Conical pot, opening at top of cone, stackable	X	2000	X
4	4' X 4' rectangular pot		60	X
5	5' X 5' rectangular pot		18032	5
6	6' X 6' rectangular pot		17508	6
7	7' X 7' rectangular pot		23806	7
8	8' X 8' rectangular pot		1936	8
9	5 1/2' X 5 1/2' rectangular pot		6934	5
10	6 1/2' X 6 1/2' rectangular pot		22085	6
11	7 1/2' X 7 1/2' rectangular pot		387	7
12	Round king crab pot, enlarged version of Dungeness crab pot		8259	X
13	10' X 10' rectangular pot		466	13
14	9' X 9' rectangular pot	X	1	X
15	8 1/2' X 8 1/2' rectangular pot	X	1	X
16	9 1/2' X 9 1/2' rectangular pot	X	Not used	X
17	8' X 9' rectangular pot	X	1	X
18	8' X 10' rectangular pot	X	1	X
19	9' X 10' rectangular pot		Not used	X
20	7' X 8' rectangular pot	X	252	X
21	Hair crab pot, longlined and small, stackable		Not used	X
22	snail pot	X	1	X

23	Dome-shaped pot, tunnel opening on top, often longlined in deep-water fisheries	X	6756	X
24	ADF&G shellfish research 7' X 7' X34" rectangular pot with 2.75" stretch mesh and no escapement rings or mesh		Research pot	X
80	Historical: Cod pot, any shape pot targeting cod, usually with tunnel fingers	X	711	X
81	Historical: Rectangular pot, unknown size, with escape rings	X	1123	X

All scenarios used CPUE indices estimated by the hybrid GLM method. Following January 2019 CPT request, we considered an Year:Area interaction factor as a special case for a CPUE standardization scenario.

Thus we estimated two sets of observer CPUE indices for model input, 20_1 (reduced number of gear codes), and 20_2 (reduced number of gear codes and Year:Area interaction).

Observer CPUE index by GLM:

a. *Non-interaction GLM model:*

The CPUE standardization followed the GLM fitting procedure (Maunder and Punt 2004; Starr 2012; Siddeek *et al*. 2016b). We considered the negative binomial GLM on positive and zero catches to select the explanatory variables. The response variable CPUE is the observer sample catch record for a pot haul. The negative binomial model uses the log link function for the GLM fit.

For the non-interaction model, we assumed the null model to be

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year_{y_i}} \quad \text{(B.2)}$$

where Year is a factorial variable.

The maximum set of model terms offered to the stepwise selection procedure was:

$$\ln\,(\mathrm{CPUE_I}) = \mathrm{Year_{y_i}} + \mathrm{ns(Soak_{si}, df)} + \mathrm{Month_{m_i}} + \mathrm{Vessel_{vi}} + \mathrm{Captain_{ci}} + \mathrm{Area_{ai}} + \mathrm{Gear_{gi}} + \mathrm{ns(Depth_{di}, df)}, \quad \text{(B.3)}$$

where Soak is in unit of days and is numeric; Month, Area (Block) code, Vessel code, Captain code, and Gear code are factorial variables; Depth in fathom is a numeric variable; ns=cubic spline, and df = degree of freedom.

We used a log link function and a dispersion parameter (θ) in the GLM fitting process. We used the R^2 criterion for predictor variable selection (Siddeek *et al*. 2016b).

The degrees of freedom and dispersion parameters were determined by calculating AICs for a range of values and locating the best value at the minimum AIC (results are not shown but available with the first author).

Instead of using the traditional AIC (-2log_likelihood+2p) we used the Consistent Akaike Information Criteria (CAIC) (Bozdogan 1987) {-2log_likelihood+[ln(n)+1]*p} for variable selection by StepAIC, where n=number of observations and p= number of parameters to be estimated. The number of selected variables were further reduced for parsimony, if feasible, by the R^2 criterion using the StepCPUE function. i.e., a hybrid selection procedure (Feenstra *et al.* 2019).

Example R codes used for main effect GLM fitting are as follows:

For EAG 1995_04 CPUE indices:

library(MASS)

library(splines)

Step 1:

glm.object<- glm(Legals~Year,family = negative.binomial(1.38),data=datacore)

epotsampleoutAIC<-stepAIC(glm.object,scope=list(upper= ~(Year+ns(SoakDays,df=4)+Month+Vessel+Captain+Area+Gear+ns(Depth,df=16)),lower =~Year),family=negative.binomial(1.38),direction="forward",trace=9,k=log(nrow(datacore))+1.0)

Step 2:

glm.object<- glm(Legals~Year,family = negative.binomial(1.38),data=datacore)

***epotsampleout<-
stepCPUE(glm.object,scope=list(upper=~(Year+Gear+Captain+ns(SoakDays,df=4)+
Month+Area),lower=~Year),family=negative.binomial(1.38),direction="forward",trace=9,
r2.change=0.01)***

The final main effect models for EAG were:

Model 20_1:

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Captain} + \text{ns}(\text{Soak}, 4) + Month + Block$

AIC=203808

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Captain} + \text{ns}(\text{Soak}, 4) + Month \quad \text{(B.4)}$$

for the 1995/96–2004/05 period [θ=1.38, $\text{R}^2 = 0.2205$]

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Gear} + \text{ns}(\text{Soak}, 16)$

AIC=72738

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{ns}(\text{Soak}, 16) + Gear \quad \text{(B.5)}$$

for the 2005/06–2019/20 period [$\theta = 2.33$, $\text{R}^2 = 0.1125$].

The final models for WAG were:

Model 20_1:

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{ns}(\text{Soak}, 15) + \text{Gear} + Area + Month + Vessel$

AIC=191025

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{ns}(\text{Soak}, 15) + Gear \quad \text{(B.6)}$$

for the 1995/96–2004/05 period [θ=0.97, $R^2 = 0.1684$]

Initial selection by stepAIC:

$$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Vessel} + \text{Month} + \text{ns}(\text{Soak}, 19)$$

AIC=110148

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{ns}(\text{Soak}, 19) \quad \text{(B.7)}$$

for the 2005/06–2019/20 period [$\theta = 1.13$, $R^2 = 0.0525$, Soak forced in].

b. Year:Area interaction GLM:

For year and area interaction analysis, we designed the areas in to 1 X 1 nmi grids enmeshed in 10 larger blocks as follows. The number of blocks was restricted to a few to prevent GLM fitting problems.

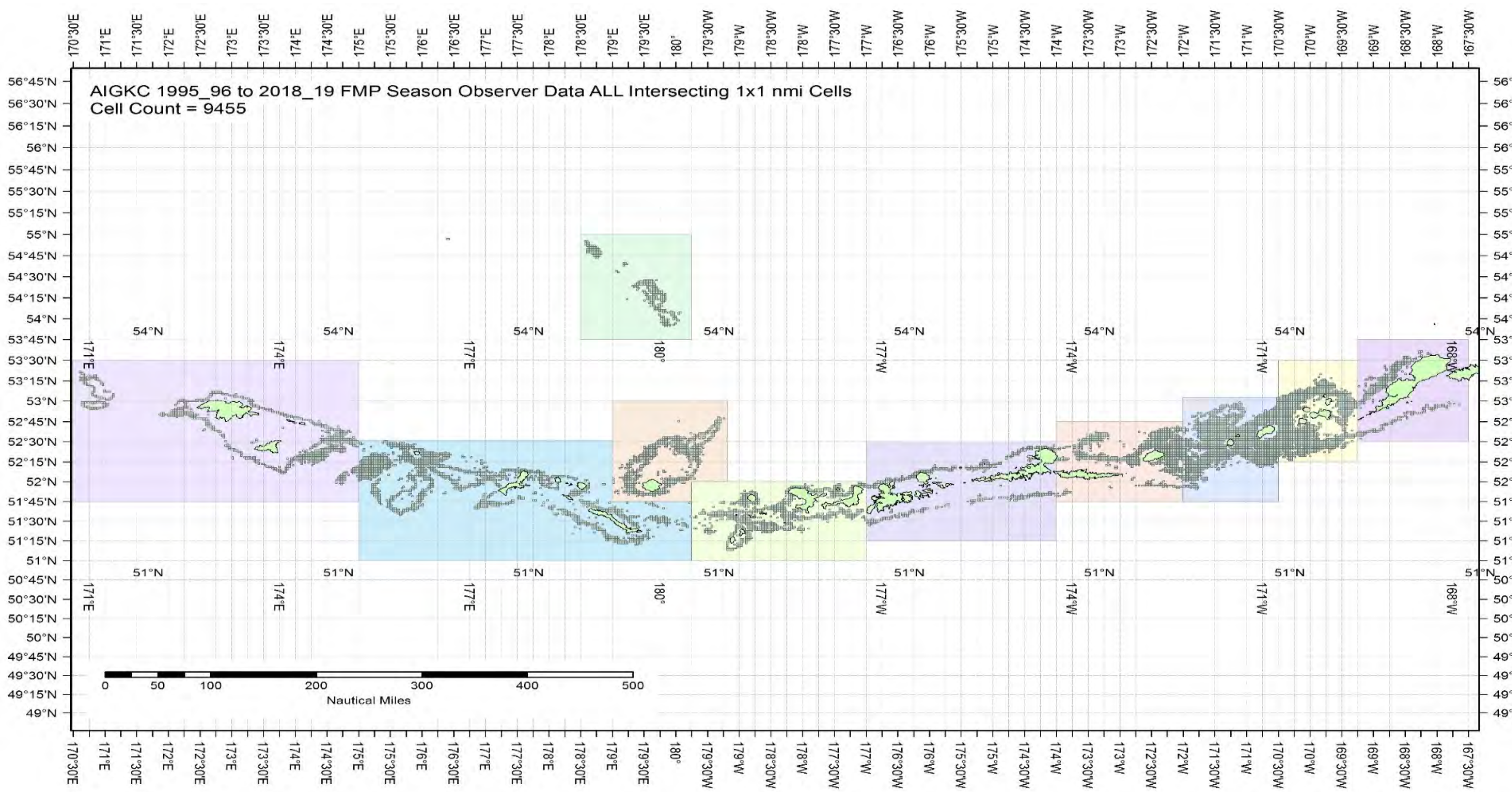

Figure B.1. The 1995/96 to 2019/20 observer pot samples enmeshed in 10 blocks for the Aleutian Islands golden king crab.

The blocks were determined from visually exploring each year's pot distribution locations (each year's data plots are available with the first author). The blocks contain observed patches of crab distribution during this time period.

Table B.1. Number of 1 x 1 nmi grids containing observer sample locations within each block by fishing year for the Aleutian Islands golden king crab, 1995/96–2019/20 data. Blocks 1–4 belong to EAG and 5 – 10 to WAG. Sum of ever fished number of grids for each block is listed at the bottom row.

Year	Block_1	Block_2	Block_3	Block_4	Block_5	Block_6	Block_7	Block_8	Block_9	Block_10
1995	125	529	748	379	218	373	112	722	166	122
1996	149	814	761	372	89	473	359	799	200	35
1997	116	530	755	257	202	443	104	568	274	0
1998	78	581	453	236	18	318	157	251	132	0
1999	123	593	454	231	163	476	182	627	193	145
2000	72	540	754	301	187	440	195	555	547	47
2001	123	507	507	329	45	369	288	634	256	9
2002	97	387	584	271	71	341	205	335	242	37
2003	43	492	530	299	111	347	212	465	150	61
2004	81	289	377	216	77	319	150	359	172	116
2005	0	205	221	118	8	220	83	261	54	0
2006	0	154	248	122	15	191	58	220	39	0
2007	0	111	177	110	24	228	78	173	20	0
2008	0	111	203	93	12	181	67	196	0	0
2009	0	59	146	60	6	137	95	220	25	0
2010	0	81	141	85	1	115	73	260	39	0
2011	0	126	117	33	3	83	73	266	9	0
2012	0	146	110	56	7	91	85	312	53	0
2013	2	149	129	51	12	144	105	293	86	0
2014	1	138	96	41	39	120	114	319	37	0
2015	0	135	147	61	46	163	106	280	16	48
2016	0	145	231	63	26	134	89	210	106	0

2017	0	97	170	110	11	87	79	198	118	0
2018	0	91	158	95	7	69	82	204	121	0
2019	1	112	171	101	0	0	89	316	138	0

	Block_1	Block_2	Block_3	Block_4	Block_5	Block_6	Block_7	Block_8	Block_9	Block_10
1995-2019 - Sum of 1x1 cells ever fished	**375**	**1363**	**1754**	**907**	**452**	**1026**	**777**	**1940**	**998**	**325**

We assumed the null model to be

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year_{y_i}}{:}\mathrm{Area_{ai}} \tag{B.8}$$

The maximum set of model terms offered to the stepwise selection procedure was:

$$\ln\left(\mathrm{CPUE_I}\right) = \mathrm{Year_{y_i}}{:}Area_{ai} + \mathrm{ns}(\mathrm{Soak_{si}}, \mathrm{df}) + \mathrm{Month_{m_i}} + \mathrm{Vessel_{vi}} + \mathrm{Captain_{ci}} + \mathrm{Area_{ai}} + \mathrm{Gear_{gi}} + \mathrm{ns}(\mathrm{Depth_{di}}, \mathrm{df}). \tag{B.9}$$

Example R codes used for interaction effect GLM fitting are as follows:

For WAG 1995_04 CPUE indices:

library(MASS)

library(splines)

Step 1:

glm.object<- glm(Legals~Year:Area,family = negative.binomial(0.97),data=datacore)

wpotsampleoutAIC<-stepAIC(glm.object,scope=list(upper= ~(Year:Area+ns(SoakDays,df=15)+Month+Vessel+Captain+Area+Gear + ns(Depth,df=18)),lower=~Year:Area),family= negative.binomial(0.97),direction="forward",trace=9,k=log(nrow(datacore))+1.0)

Step 2:

glm.object<- glm(Legals~Year:Area,family = negative.binomial(0.97),data=datacore)

wpotsampleout<-stepCPUE(glm.object,scope=list(upper= ~(Captain+ns(SoakDays,df=15)+Gear+Area+Month+Year:Area),lower= ~Year:Area),family= negative.binomial(0.97),direction="forward",trace=9,r2.change=0.01)

The final interaction effect models for EAG were:

Model 20_2:

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Gear} + \text{Captain} + \text{ns}(\text{Soak}, 4) + \text{Month} + Year{:}\,Area$

AIC=203851

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Gear} + \text{Captain} + \text{ns}(\text{Soak}, 4) + Year{:}\,Area \qquad \text{(B.10)}$$

for the 1995/96–2004/05 period [θ=1.38, $R^2 = 0.2235$]

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Vessel} + \text{Gear} + \text{ns}(\text{Soak}, 16) + Year{:}\,Area$

AIC=72860

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Vessel} + \text{ns}(\text{Soak}, 16) + Gear + Year{:}\,Area \qquad \text{(B.11)}$$

for the 2005/06–2019/20 period [$\theta = 2.33$, $R^2 = 0.1238$].

The final interaction effect models for WAG were:

Model 20_2:

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Vessel} + \text{ns}(\text{Soak}, 15) + Gear + Month + Year{:}\,Area$

AIC=191140

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Vessel} + \text{ns}(\text{Soak}, 15) + \text{Gear} + Year{:}\,Area \qquad \text{(B.12)}$$

for the 1995/96–2004/05 period [θ=0.97, $R^2 = 0.1721$]

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Gear} + \text{Vessel} + \text{Month} + Year{:}Area + ns(Soak, 19)$

AIC=110438

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Gear} + Year{:}Area + ns(Soak, 19) \qquad \text{(B.13)}$$

for the 2005/06–2019/20 period [$\theta = 1.13,\ \text{R}^2 = 0.0708$, Soak forced in].

Steps:

1. *Block-scale analysis*:

The estimate of the CPUE index in each Year-Area (Area=Block) was first obtained:

$$CPUE_{ij} = e^{YB_{ij} + \sigma_{ij}^2/2} \qquad \text{(B.14)}$$

Where $CPUE_{ij}$ is the CPUE index in the ith year and jth block, YB_{ij} is the coefficient of the ith year and jth block interaction, and σ_{ij} is the biased correction standard error for expected CPUE value.

The number of 1 x 1 nmi grids in each block can change from year to year; so, we considered using the number of grids **ever fished** in a block, N_{everj} [this is equivalent to assuming that the grids fished in any year randomly sample the stock in that block (see Campbell, 2004)].

The abundance index for jth block in ith year is

$$B_{ij} = N_{ever_j} CPUE_{ij} \qquad \text{(B.15)}$$

As you noticed in Table B.1 that there are no-observer samplings took place in certain years for a whole block. We filled the B_{ij} index gaps by filling them using a log-linear model, i.e.:

$$\hat{B}_{i,j} = e^{A_i + C_j} \qquad \text{(B.16)}$$

where $\boldsymbol{B_{i,j}}$ is the index of biomass for year i and block j, A_i is a year factor, and C_j is a block factor, and used this model to predict the biomass index for blocks x years with no (or very limited) data.

Annual biomass index, B_i , was estimated as,

$$B_i = \sum_j B_{ij} \tag{B.17}$$

The variance of the total biomass index was computed as:

$$\boldsymbol{Var\ (B_i) = \sum_j N_{ever,j}{}^2\ var(CPUE_{i,j})} \tag{B.18}$$

where $\boldsymbol{N_{ever,j}}$ is the total number of 1x1 mni cells ever fished in block j, and $CPUE_{i,j}$ is the CPUE index for year i and block j.

To compare with other CPUE index estimates (Figures 24 for EAG and 42 for WAG) as well as to input into the assessment model (models 20_2 for EAG and WAG, and 20_2b for EAG), we rescaled the B_i indices by the geometric mean of estimated B_i values separately for the pre- and post-rationalization periods. The corresponding coefficient of variation (CV_i) of $CPUE_i$ was estimated by

$$\sqrt{\frac{Var(B_i)}{(B_i)^2}} \tag{B.19}$$

Following Burnham *et al.* (1987), the variance of ln($CPUE_i$) for input to assessment models were estimated by $\sigma_i^2 = \ln(1 + CV_i^2)$.

c. Commercial fishery CPUE index by non-interaction model:

We fitted separate lognormal and negative binomial GLM models for fish ticket retained CPUE time series 1985/86 – 1998/99 offering Year, Month, Vessel, Captain, and Area as explanatory variables and applying the hybrid selection method. Reduced area resolution (grouped ADF&G code- AreaGP) was used for model fitting.

The final model under lognormal error structure for EAG was:

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Month}$
AIC=5,805

Final selection by stepCPUE:
$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Month}$ (B.20)
for the 1985/86–1998/99 period [$R^2 = 0.3700$]

and that for WAG was:

Initial selection by stepAIC:
$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Area}$
AIC= 11,082

Final selection by stepCPUE
$\ln(\text{CPUE}) = \text{Year} + \text{Vessel},\ R^2 = 0.3679$ (B.21)

The final model under negative binomial error structure for EAG was:

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + Month$

AIC=16,997

Final selection by stepCPUE:

$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Month}$ (B.22)

for the 1985/86–1998/99 period [θ=10.45, $R^2 = 0.3328$]

and that for WAG was:

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + Area$

AIC=31,701

Final selection by stepCPUE:

$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Area}$ (B.23)

for the 1985/86–1998/99 period [θ=6.67, $R^2 = 0.3569$]

Appendix C. Cooperative Survey

1.Brief summary of the survey method

The ADF&G and industry collaborative pot survey was initiated in 2015 in the EAG and continued since then. The survey was extended to WAG in 2018. A stratified two-stage sampling design has been implemented in a 2 X 2 nmi grids within 1000 m depth covering the entire golden king crab fishing area. The 2 x 2 nmi choice was the best compromise between scale of fishing gear, accuracy of defining habitat, and number of possible stations (Figure C1).

Figure C.1. Survey design: 2 x 2 nmi grids overlaid on observer pot sample locations (green squares) in EAG.

There are nearly 1100 grids in the EAG divided into three equal size strata for selecting random pot sampling locations (Figures C.2 and C.3).

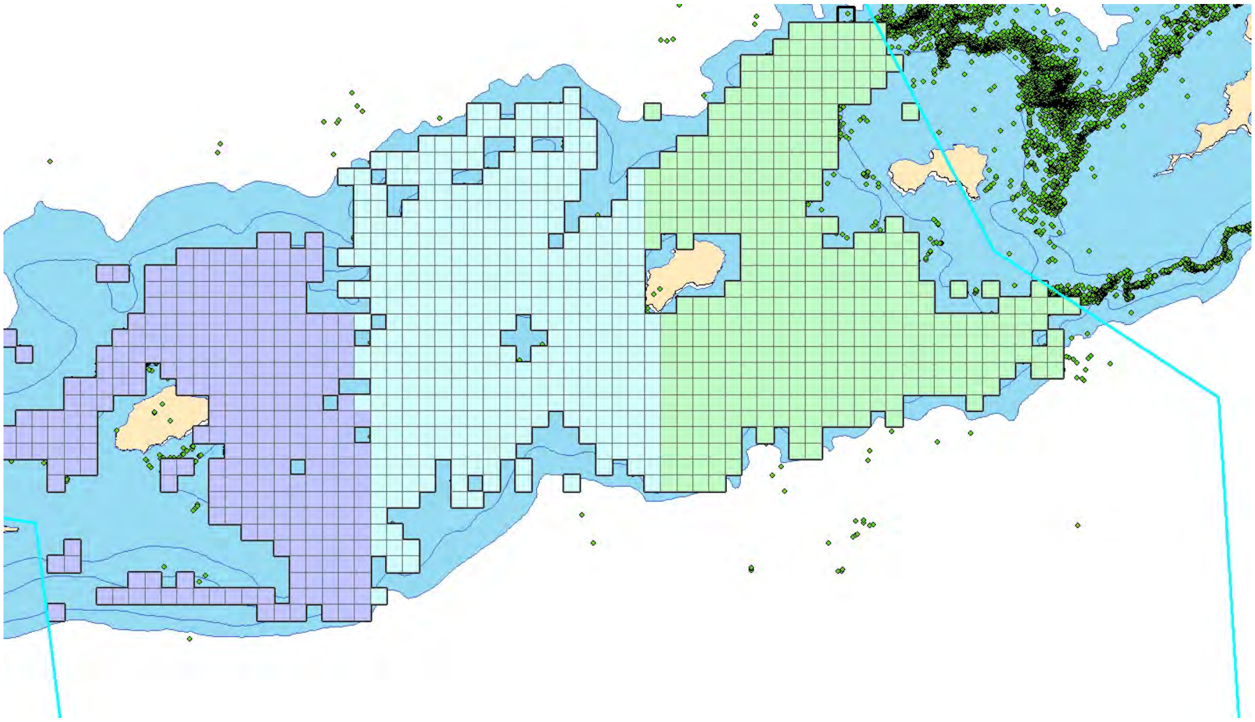

Figure C.2. Survey design: 2 x 2 nmi grids stratified by three equal sizes for selecting random pot sampling locations in EAG.

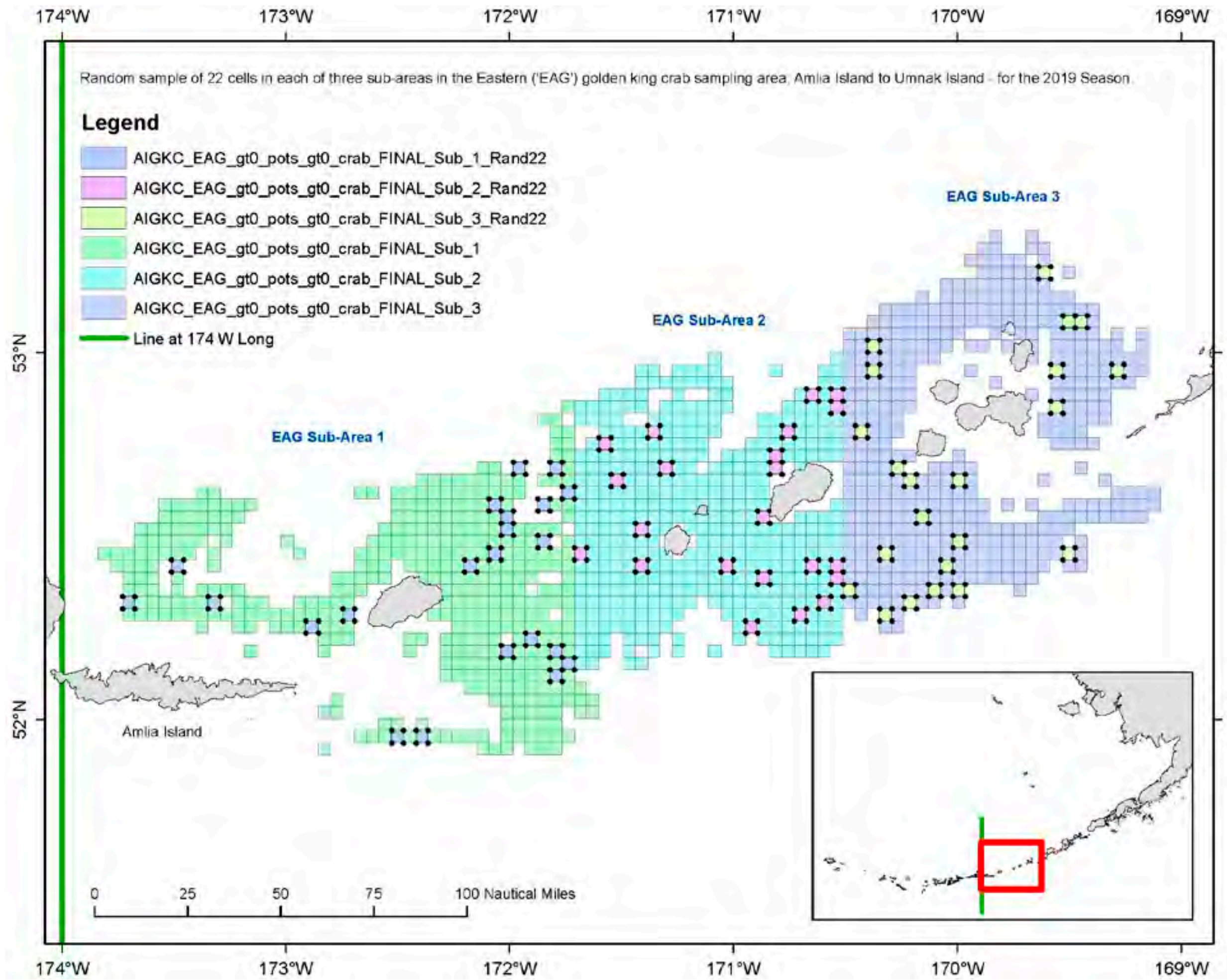

Figure C.3. Random sample of 22 cells selected in each of three sub strata in EAG during the 2019 fishery.

Survey occurs during the first month of each fishing season with one to two ADF&G biologists onboard the fishing vessel to collect fishery and biological data. Fishing operation takes place in a randomly selected set of grids in each strata with long-line pots. The number of pots per string ranges from 30 to 40, 200 m apart, and a vessel carry on average 35 strings. Pot sizes range from 5.5 x 5.5 ft to 7 x 7 ft with large mesh sizes for retention of legal king crab. A few small mesh size research pots are also deployed for special studies. Fishing operation is not standardized for depth or soak time to allow normal fishing practices.

There are multiple pots (typically about 5 pots) sampled for each long-line string with approximately 35 crab measurement made per pot. For example, if 100 crabs are caught in a sampled pot, the biologist measures every third crab. The following snapshot of an observation record will provide details of what stock assessment data are collected.
Work on details size composition plots and CPUE by size, year, and area is not yet finished to present at this time.

fishery	year	vessel	skipper	String#	pot_size	mesh_size	bait	subsample_rate	species_code	sex	size	legal
EAG	2015	20556	Chad_Hoefer	1	5x5	king(large)	halibut	2	923	1	187	1

Pot#	date_in	time_in	depth_start	start_lat	start_lon	depth_out	end_lat	end_lon	date_out	time_out	comments	soak_time
1	8/4/2015	17:00	132	52.74133	-170.692	133	52.7515	-170.675	8/17/2015	3:00		12.41667

2. Standardization of cooperative survey CPUE by mixed random effects model:

The unique property of cooperative survey is that multiple pots from multiple strings are sampled. All sample measurements were taken in EAG except for 2018 and 2019, during which measurements were also taken from WAG. The CPT and SSC suggested to use the random effects model to standardize the survey CPUE data.

Data:
There are 27,255 records from five-year (2015–2019) cooperative surveys.

Data preparation for CPUE standardization:

- i.) Created two new columns by concatenating Vessel Code with String# as well as Pot# because String# and Pot# are not unique numbers to each vessel. The new column names were identified as VesString and VesPot.
  For example, a Vessel Code 20556 with a String# 3 was concatenated to be 205563 in a new column VesString, and a Vessel Code 20556 with a Pot# 5 was concatenated to be 205565 in a new column VesPot.
- ii.) Raised the Catch in each record by the Sample Rate.
- iii.) Subset the data by large mesh king crab pot (Mesh ID not equal to 2), legal size (Size > 135 mm CL), and EAG (EAGWAG=1). The female (Sex=2) catch without any male (Sex=1) in a crab pot was set to 0 to account for the possibility of zero catch for expected CPUE determination.
- iv.) Further subset the data by 5% to 95% trimmed Soak time and 1% to 99% trimmed Depth. This is to exclude catches from any unusual pot operations.
- v.) Summed up the catch across sizes for each Pot# and labelled it as SumCatch. Thus, each Pot# has a single catch number.

The mixed random effects model considered a random intercept procedure with the following model formulation:

Sum Catch = Y+ns(Soak,df=16)+ns(Depth, df=10)+(1|Vessel/Pot)+(1|Block/String)

We used the “lme4” library in R (version 3.5.1, R Core Team, 2018) with the “glmer()” function to fit the mixed random effects model. The glmer() function allows to use any type of error model (we used the negative binomial model) to fit the data:

library(MASS)

library(splines)

library(Matrix)

library(lme4)

best.lmefit<- glmer(SumCatch~ Year+ns(SoakDays, df=16)+ns(Depth, df=10)+(1|Vessel/VesPot) +)+(1|Block/VesString), family = negative.binomial(2.33),control=glmerControl(optimizer="bobyqa", optCtrl=list(maxfun=100000)), data=eSurvey15_19Subtrim)

where Sum Catch= observed CPUE, best.lmefit = expected CPUE. Year, SoakDays and Depth are fixed effect variables. The fixed effect variables were selected from fit of a fixed effect model on the survey data. The dispersion parameter value for the negative binomial error model and the degrees of freedom for cubic splines were borrowed from the observer final GLM model estimate for EAG for the post rationalization period.

The QQ plot for the fit assured model assumptions were correct (Figure C.4).

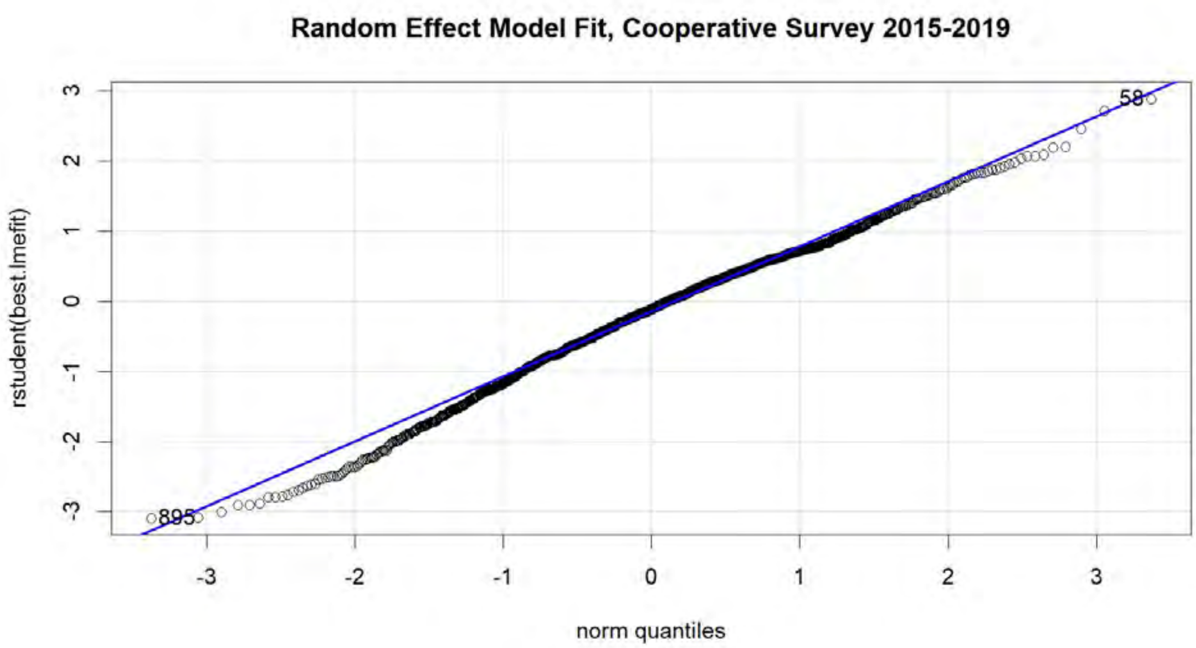

Figure C4. Studentized residual plot for the mixed random effects model fit. The 2015–2019 EAG data were used.

Comparison of standardized CPUE from cooperative survey data (2015–19) for EAG and the corresponding years' observer CPUE indices indicated similar pattern except for 2019 (Figure C5).

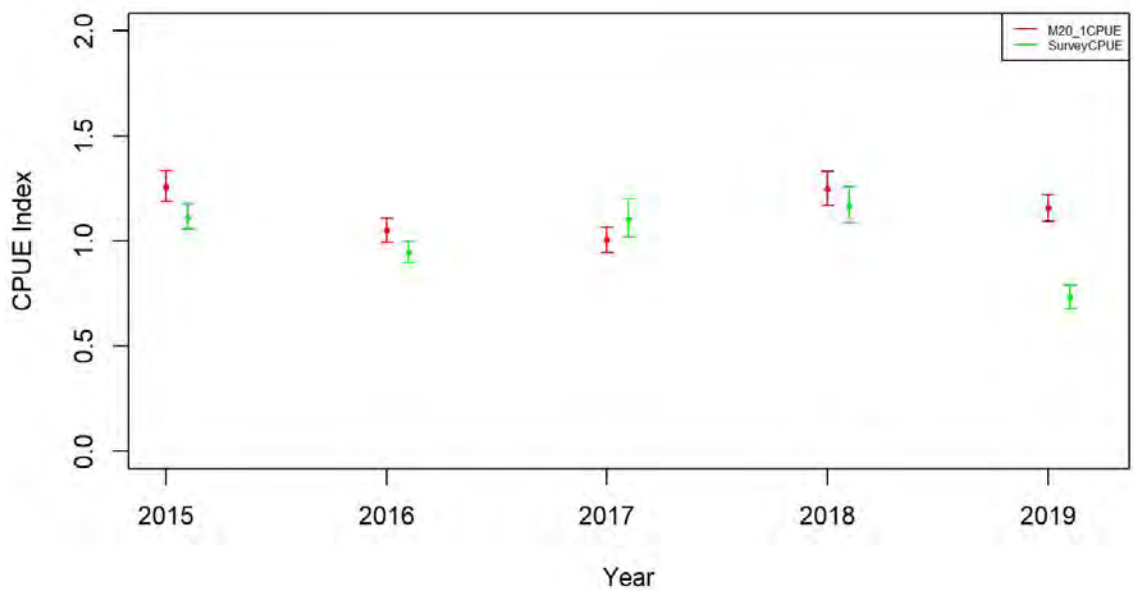

Figure C5. Comparison of cooperative survey CPUE indices (green) and model 20_1 CPUE indices (red). The confidence limits are determined with ±2SE.

We standardized the yearly mean of predicted survey CPUEs for 2015–2019 by the geometric mean to obtain the CPUE indices for input to the assessment model (20_1c and 20_2b) (Table C.1).

Table C.1. The cooperative survey expected legal size male standardized (by geometric mean) CPUE indices by the mixed random effects model, standard errors (SE), and lower- and upper-95% confidence limits for assessment model input for EAG, 2015–2019 data.

Year	Predicted CPUE index	SE	Lower Limit	Upper Limit
2015	1.1137	0.0265	1.0562	1.1743
2016	0.9459	0.0266	0.8968	0.9976
2017	1.1075	0.0417	1.0189	1.2038
2018	1.1690	0.0365	1.0868	1.2575
2019	0.7332	0.0382	0.6793	0.7914

Appendix D: Jittering

Jittering of models 20_1b and 20_2 parameter estimates*:*
We followed the Stock Synthesis approach to do 100 jitter runs of models 20_1b and 20_2 parameter estimates to use as initial parameter values (as .PIN file in ADMB) to assess model stability and to determine whether a global as opposed to local minima has been reached by the search algorithm:

The *Jitter* factor of 0.3 was multiplied by a random normal deviation *rdev*=*N*(0,1), to a transformed parameter value based upon the predefined parameter:

$$temp = 0.5 * rdev * Jitterfactor * \ln\left(\frac{P_{\max} - P_{\min} + 0.0000002}{P_{val} - P_{\min} + 0.0000001} - 1\right), \quad (D.1)$$

with the final jittered initial parameter value back transformed as:

$$P_{new} = P_{\min} + \frac{P_{\max} - P_{\min}}{1.0 + \exp(-2.0\, temp)}, \quad (D.2)$$

where P_{max} and P_{min} are upper and lower bounds of parameter search space and P_{val} is the estimated parameter value before the jittering.

The jitter results are summarized for scenarios 20_1b in Tables D.1 and D.2; and 20_2 in Tables D.3 and D.4 for EAG and WAG, respectively. Almost all runs converged to the highest log likelihood values. We concluded from jitter results that optimization of 20_1b and 20_2 models achieved global minima.

Table D.1. Results from 100 jitter runs for scenario 20_1b for EAG. Jitter run 0 corresponds to the original optimized estimates.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**12.9831**	**0.003023**	**6,774**	**2,986**	**8,470**
1	12.8964	0.000280	6,774	2,986	8,470
2	12.8964	0.000192	6,774	2,986	8,470
3	12.8964	0.000159	6,774	2,986	8,470
4	12.8964	0.000426	6,774	2,986	8,470
5	12.8964	0.000180	6,774	2,986	8,470
6	12.8964	0.000053	6,774	2,986	8,470
7	12.8964	0.000093	6,774	2,986	8,470
8	12.8964	0.000054	6,774	2,986	8,470
9	12.8964	0.000593	6,774	2,986	8,470
10	12.8964	0.000032	6,774	2,986	8,470
11	12.8964	0.000125	6,774	2,986	8,470
12	12.8964	0.000022	6,774	2,986	8,470

13	12.8964	0.000350	6,774	2,986	8,470
14	12.8964	0.000350	6,774	2,986	8,470
15	12.8964	0.000216	6,774	2,986	8,470
16	12.8964	0.000017	6,774	2,986	8,470
17	12.8964	0.000035	6,774	2,986	8,470
18	12.8964	0.000285	6,774	2,986	8,470
19	12.8964	0.000014	6,774	2,986	8,470
20	12.8964	0.000085	6,774	2,986	8,470
21	12.8964	0.000057	6,774	2,986	8,470
22	12.8964	0.000025	6,774	2,986	8,470
23	12.8964	0.000025	6,774	2,986	8,470
24	12.8964	0.000089	6,774	2,986	8,470
25	12.8964	0.000015	6,774	2,986	8,470
26	12.8964	0.000153	6,774	2,986	8,470
27	12.8964	0.000072	6,774	2,986	8,470
28	12.8964	0.000113	6,774	2,986	8,470
29	12.8964	0.000050	6,774	2,986	8,470
30	12.8964	0.000364	6,774	2,986	8,470
31	12.8964	0.000090	6,774	2,986	8,470
32	20.9858	0.000041	7,180	3,225	8,995
33	12.8964	0.000170	6,774	2,986	8,470
34	12.8964	0.000088	6,774	2,986	8,470
35	12.8964	0.000226	6,774	2,986	8,470
36	12.8964	0.000175	6,774	2,986	8,470
37	12.8964	0.000296	6,774	2,986	8,470
38	12.8964	0.000136	6,774	2,986	8,470
39	12.8964	0.000248	6,774	2,986	8,470
40	12.8964	0.000116	6,774	2,986	8,470
41	12.8964	0.000096	6,774	2,986	8,470
42	12.8964	0.000259	6,774	2,986	8,470
43	12.8964	0.000036	6,774	2,986	8,470
44	12.8964	0.000019	6,774	2,986	8,470
45	12.8964	0.000063	6,774	2,986	8,470
46	12.8964	0.000085	6,774	2,986	8,470
47	12.8964	0.000244	6,774	2,986	8,470
48	12.8964	0.000057	6,774	2,986	8,470
49	12.8964	0.000021	6,774	2,986	8,470
50	12.8964	0.000052	6,774	2,986	8,470
51	12.8964	0.000078	6,774	2,986	8,470
52	12.8964	0.000107	6,774	2,986	8,470
53	12.8964	0.000147	6,774	2,986	8,470
54	12.8964	0.000054	6,774	2,986	8,470
55	12.8964	0.000063	6,774	2,986	8,470

56	12.8964	0.000275	6,774	2,986	8,470
57	12.8964	0.000067	6,774	2,986	8,470
58	12.8964	0.000166	6,774	2,986	8,470
59	12.8964	0.000060	6,774	2,986	8,470
60	12.8964	0.000037	6,774	2,986	8,470
61	12.8964	0.000037	6,774	2,986	8,470
62	12.8964	0.000251	6,774	2,986	8,470
63	12.8964	0.000157	6,774	2,986	8,470
64	12.8964	0.000041	6,774	2,986	8,470
65	12.8964	0.000043	6,774	2,986	8,470
66	12.8964	0.000183	6,774	2,986	8,470
67	12.8964	0.000010	6,774	2,986	8,470
68	12.8964	0.000062	6,774	2,986	8,470
69	12.8964	0.000398	6,774	2,986	8,470
70	12.8964	0.000091	6,774	2,986	8,470
71	12.8964	0.000046	6,774	2,986	8,470
72	12.8964	0.000027	6,774	2,986	8,470
73	12.8964	0.000108	6,774	2,986	8,470
74	12.8964	0.000016	6,774	2,986	8,470
75	12.8964	0.000143	6,774	2,986	8,470
76	12.8964	0.000004	6,774	2,986	8,470
77	12.8964	0.000167	6,774	2,986	8,470
78	12.8964	0.000179	6,774	2,986	8,470
79	12.8964	0.000147	6,774	2,986	8,470
80	12.8964	0.000009	6,774	2,986	8,470
81	12.8964	0.000080	6,774	2,986	8,470
82	12.8964	0.000075	6,774	2,986	8,470
83	12.8964	0.000092	6,774	2,986	8,470
84	12.8964	0.000035	6,774	2,986	8,470
85	12.8964	0.000005	6,774	2,986	8,470
86	12.8964	0.000037	6,774	2,986	8,470
87	12.8964	0.000141	6,774	2,986	8,470
88	12.8964	0.000081	6,774	2,986	8,470
89	12.8964	0.000091	6,774	2,986	8,470
90	12.8964	0.000697	6,774	2,986	8,470
91	12.8964	0.000140	6,774	2,986	8,470
92	12.8964	0.000134	6,774	2,986	8,470
93	12.8964	0.000129	6,774	2,986	8,470
94	12.8964	0.000212	6,774	2,986	8,470
95	12.8964	0.000044	6,774	2,986	8,470
96	12.8964	0.000022	6,774	2,986	8,470
97	12.8964	0.000013	6,774	2,986	8,470
98	12.8964	0.000021	6,774	2,986	8,470

99	12.8964	0.000109	6,774	2,986	8,470
100	12.8964	0.000035	6,774	2,986	8,470

Table D.2 Results from 100 jitter runs for scenario 20_1b for WAG. Jitter run 0 corresponds to the original optimized estimates.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**-75.5594**	**0.000060**	**5,319**	**1,807**	**6,290**
1	-79.6389	0.000115	5,815	1,911	6,641
2	-75.5594	0.000228	5,319	1,807	6,290
3	-75.5594	0.000013	5,319	1,807	6,290
4	-75.5594	0.000048	5,319	1,807	6,290
5	-75.5594	0.000220	5,319	1,807	6,290
6	-75.5594	0.000096	5,319	1,807	6,290
7	-75.5594	0.000040	5,319	1,807	6,290
8	-75.5594	0.000332	5,319	1,807	6,290
9	-75.5594	0.000051	5,319	1,807	6,290
10	-75.5594	0.000144	5,319	1,807	6,290
11	-75.5594	0.000087	5,319	1,807	6,290
12	-75.5594	0.000105	5,319	1,807	6,290
13	-75.5594	0.000085	5,319	1,807	6,290
14	NA	NA	NA	NA	NA
15	-74.3830	0.000516	5,756	1,908	6,583
16	-79.6389	0.000150	5,815	1,911	6,641
17	-75.5594	0.000280	5,319	1,807	6,290
18	-75.5594	0.000088	5,319	1,807	6,290
19	-80.1879	0.000369	5,829	1,902	6,582
20	-75.5594	0.000042	5,319	1,807	6,290
21	-80.1879	0.000046	5,829	1,902	6,582
22	-75.5594	0.000023	5,319	1,807	6,290
23	-75.5594	0.000175	5,319	1,807	6,290
24	-79.6389	0.000163	5,815	1,911	6,641
25	-79.6389	0.000008	5,815	1,911	6,641
26	-75.5594	0.000095	5,319	1,807	6,290
27	-75.5594	0.000033	5,319	1,807	6,290
28	-75.5594	0.000033	5,319	1,807	6,290
29	-75.5594	0.000047	5,319	1,807	6,290
30	-75.5594	0.000103	5,319	1,807	6,290
31	-75.5594	0.000134	5,319	1,807	6,290
32	-75.5594	0.000196	5,319	1,807	6,290
33	-75.5594	0.000051	5,319	1,807	6,290

34	-75.5594	0.000364	5,319	1,807	6,290
35	-75.5594	0.000077	5,319	1,807	6,290
36	-75.5594	0.000119	5,319	1,807	6,290
37	-75.5594	0.000082	5,319	1,807	6,290
38	-75.5594	0.000176	5,319	1,807	6,290
39	-75.5594	0.000099	5,319	1,807	6,290
40	-75.5594	0.000051	5,319	1,807	6,290
41	-75.5594	0.000030	5,319	1,807	6,290
42	-75.5594	0.000235	5,319	1,807	6,290
43	-75.5594	0.000063	5,319	1,807	6,290
44	-75.5594	0.000141	5,319	1,807	6,290
45	-75.5594	0.000102	5,319	1,807	6,290
46	-75.5594	0.000050	5,319	1,807	6,290
47	-80.6251	0.000074	6,107	1,932	6,687
48	-79.6389	0.000407	5,815	1,911	6,641
49	-75.5594	0.000018	5,319	1,807	6,290
50	-75.5594	0.000188	5,319	1,807	6,290
51	-75.5594	0.000205	5,319	1,807	6,290
52	-75.5594	0.000569	5,319	1,807	6,290
53	-75.5594	0.000083	5,319	1,807	6,290
54	-75.5594	0.000137	5,319	1,807	6,290
55	-75.5594	0.000065	5,319	1,807	6,290
56	-75.5594	0.000056	5,319	1,807	6,290
57	-75.5594	0.000131	5,319	1,807	6,290
58	-79.6389	0.000008	5,815	1,911	6,641
59	-75.5594	0.000141	5,319	1,807	6,290
60	-75.5594	0.000159	5,319	1,807	6,290
61	-75.5594	0.000098	5,319	1,807	6,290
62	-75.5594	0.000015	5,319	1,807	6,290
63	-75.5594	0.000129	5,319	1,807	6,290
64	-75.5594	0.000242	5,319	1,807	6,290
65	-75.5594	0.000073	5,319	1,807	6,290
66	-75.5594	0.000022	5,319	1,807	6,290
67	-75.5594	0.000082	5,319	1,807	6,290
68	-75.5594	0.000055	5,319	1,807	6,290
69	-75.5594	0.000105	5,319	1,807	6,290
70	-75.5594	0.000026	5,319	1,807	6,290
71	-80.1879	0.000161	5,829	1,902	6,582
72	-75.5594	0.000076	5,319	1,807	6,290
73	-75.5594	0.000212	5,319	1,807	6,290
74	-75.5594	0.000030	5,319	1,807	6,290
75	-75.5594	0.000214	5,319	1,807	6,290
76	-75.5594	0.000185	5,319	1,807	6,290

77	-75.5594	0.000134	5,319	1,807	6,290
78	-74.2426	0.000012	5,731	1,896	6,564
79	-75.5594	0.000111	5,319	1,807	6,290
80	NA	NA	NA	NA	NA
81	-79.6389	0.000396	5,815	1,911	6,641
82	-75.5594	0.000206	5,319	1,807	6,290
83	-75.5594	0.000406	5,319	1,807	6,290
84	-75.5594	0.000101	5,319	1,807	6,290
85	-75.5594	0.000078	5,319	1,807	6,290
86	-75.5594	0.000156	5,319	1,807	6,290
87	-75.5594	0.000207	5,319	1,807	6,290
88	-75.5594	0.000189	5,319	1,807	6,290
89	-75.5594	0.000088	5,319	1,807	6,290
90	-75.5594	0.000252	5,319	1,807	6,290
91	-75.5594	0.000058	5,319	1,807	6,290
92	-75.5594	0.000174	5,319	1,807	6,290
93	-80.6251	0.000245	6,107	1,932	6,687
94	-75.5594	0.000131	5,319	1,807	6,290
95	-80.1879	0.000158	5,829	1,902	6,582
96	-75.5594	0.000610	5,319	1,807	6,290
97	-75.5594	0.000052	5,319	1,807	6,290
98	-75.5594	0.000107	5,319	1,807	6,290
99	-75.5594	0.000342	5,319	1,807	6,290
100	-74.3830	0.000277	5,756	1,908	6,583

Table D.3. Results from 100 jitter runs for scenario 20_2 for EAG. Jitter run 0 corresponds to the original optimized estimates.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**7.7967**	**0.001281**	**6,794**	**3,133**	**8,665**
1	7.7966	0.000182	6,794	3,133	8,665
2	7.7966	0.000091	6,794	3,133	8,665
3	7.7966	0.000218	6,794	3,133	8,665
4	7.7966	0.000092	6,794	3,133	8,665
5	7.7966	0.000500	6,794	3,133	8,665
6	7.7966	0.000013	6,794	3,133	8,665
7	7.7966	0.000020	6,794	3,133	8,665
8	7.7966	0.000254	6,794	3,133	8,665
9	7.7966	0.000058	6,794	3,133	8,665
10	7.7966	0.000145	6,794	3,133	8,665
11	7.7966	0.000047	6,794	3,133	8,665

12	7.7966	0.000355	6,794	3,133	8,665
13	7.7966	0.000123	6,794	3,133	8,665
14	7.7966	0.000188	6,794	3,133	8,665
15	7.7966	0.000100	6,794	3,133	8,665
16	7.7966	0.000017	6,794	3,133	8,665
17	7.7966	0.000141	6,794	3,133	8,665
18	7.7966	0.000141	6,794	3,133	8,665
19	7.7966	0.000198	6,794	3,133	8,665
20	7.7966	0.000361	6,794	3,133	8,665
21	7.7966	0.000447	6,794	3,133	8,665
22	7.7966	0.000490	6,794	3,133	8,665
23	7.7966	0.000255	6,794	3,133	8,665
24	7.7966	0.000116	6,794	3,133	8,665
25	7.7966	0.000059	6,794	3,133	8,665
26	7.7966	0.000081	6,794	3,133	8,665
27	7.7966	0.000386	6,794	3,133	8,665
28	7.7966	0.000004	6,794	3,133	8,665
29	7.7966	0.000053	6,794	3,133	8,665
30	7.7966	0.000112	6,794	3,133	8,665
31	7.7966	0.000074	6,794	3,133	8,665
32	7.7966	0.000052	6,794	3,133	8,665
33	7.7966	0.000175	6,794	3,133	8,665
34	7.7966	0.000154	6,794	3,133	8,665
35	7.7966	0.000503	6,794	3,133	8,665
36	7.7966	0.000289	6,794	3,133	8,665
37	7.7966	0.000340	6,794	3,133	8,665
38	7.7966	0.000088	6,794	3,133	8,665
39	7.7966	0.000045	6,794	3,133	8,665
40	7.7966	0.000056	6,794	3,133	8,665
41	7.7966	0.000231	6,794	3,133	8,665
42	7.7966	0.000074	6,794	3,133	8,665
43	7.7966	0.000062	6,794	3,133	8,665
44	7.7966	0.000051	6,794	3,133	8,665
45	7.7966	0.000122	6,794	3,133	8,665
46	7.7966	0.000036	6,794	3,133	8,665
47	7.7966	0.000078	6,794	3,133	8,665
48	7.7966	0.000038	6,794	3,133	8,665
49	7.7966	0.000492	6,794	3,133	8,665
50	7.7966	0.000089	6,794	3,133	8,665
51	7.7966	0.000124	6,794	3,133	8,665
52	7.7966	0.000031	6,794	3,133	8,665
53	7.7966	0.000035	6,794	3,133	8,665
54	7.7966	0.000275	6,794	3,133	8,665

55	7.7966	0.000196	6,794	3,133	8,665
56	7.7966	0.000208	6,794	3,133	8,665
57	7.7966	0.000014	6,794	3,133	8,665
58	7.7966	0.000140	6,794	3,133	8,665
59	7.7966	0.000618	6,794	3,133	8,665
60	7.7966	0.000026	6,794	3,133	8,665
61	7.7966	0.000088	6,794	3,133	8,665
62	7.7966	0.000142	6,794	3,133	8,665
63	7.7966	0.000488	6,794	3,133	8,665
64	7.7966	0.000160	6,794	3,133	8,665
65	7.7966	0.000021	6,794	3,133	8,665
66	7.7966	0.000228	6,794	3,133	8,665
67	7.7966	0.000026	6,794	3,133	8,665
68	7.7966	0.000070	6,794	3,133	8,665
69	7.7966	0.000147	6,794	3,133	8,665
70	7.7966	0.000287	6,794	3,133	8,665
71	7.7966	0.000172	6,794	3,133	8,665
72	7.7966	0.000353	6,794	3,133	8,665
73	7.7966	0.000126	6,794	3,133	8,665
74	7.7966	0.000251	6,794	3,133	8,665
75	7.7966	0.000253	6,794	3,133	8,665
76	7.7966	0.000075	6,794	3,133	8,665
77	7.7966	0.000064	6,794	3,133	8,665
78	7.7966	0.000091	6,794	3,133	8,665
79	7.7966	0.000431	6,794	3,133	8,665
80	7.7966	0.000222	6,794	3,133	8,665
81	7.7966	0.000131	6,794	3,133	8,665
82	7.7966	0.000044	6,794	3,133	8,665
83	7.7966	0.000307	6,794	3,133	8,665
84	7.7966	0.000240	6,794	3,133	8,665
85	7.7966	0.000102	6,794	3,133	8,665
86	7.7966	0.000100	6,794	3,133	8,665
87	7.7966	0.000175	6,794	3,133	8,665
88	7.7966	0.000295	6,794	3,133	8,665
89	7.7966	0.000150	6,794	3,133	8,665
90	7.7966	0.000034	6,794	3,133	8,665
91	7.7966	0.000081	6,794	3,133	8,665
92	7.7966	0.000252	6,794	3,133	8,665
93	7.7966	0.000089	6,794	3,133	8,665
94	7.7966	0.000043	6,794	3,133	8,665
95	7.7966	0.000131	6,794	3,133	8,665
96	7.7966	0.000137	6,794	3,133	8,665
97	7.7966	0.000232	6,794	3,133	8,665

98	7.7966	0.000018	6,794	3,133	8,665
99	7.7966	0.000041	6,794	3,133	8,665
100	7.7966	0.000015	6,794	3,133	8,665

Table D.4 Results from 100 jitter runs for scenario 20_2 for WAG. Jitter run 0 corresponds to the original optimized estimates.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**-75.7768**	**0.000171**	**5,343**	**1,860**	**6,441**
1	-75.7768	0.000073	5,343	1,860	6,441
2	-75.7768	0.000131	5,343	1,860	6,441
3	-75.7768	0.000048	5,343	1,860	6,441
4	-75.7768	0.000052	5,343	1,860	6,441
5	-79.5165	0.000122	5,869	1,960	6,750
6	-75.7768	0.000375	5,343	1,860	6,441
7	-75.7768	0.000126	5,343	1,860	6,441
8	-75.7768	0.000262	5,343	1,860	6,441
9	-75.7768	0.000084	5,343	1,860	6,441
10	-75.7768	0.000134	5,343	1,860	6,441
11	-75.7768	0.000099	5,343	1,860	6,441
12	-75.7768	0.000227	5,343	1,860	6,441
13	-75.7768	0.000240	5,343	1,860	6,441
14	-75.7768	0.000447	5,343	1,860	6,441
15	-75.7768	0.000158	5,343	1,860	6,441
16	-75.7768	0.000018	5,343	1,860	6,441
17	-75.7768	0.000124	5,343	1,860	6,441
18	-79.5165	0.000134	5,869	1,960	6,750
19	-74.0867	0.000154	5,769	1,947	6,722
20	-75.7768	0.000029	5,343	1,860	6,441
21	-75.7768	0.000010	5,343	1,860	6,441
22	-75.7768	0.000387	5,343	1,860	6,441
23	-75.7768	0.000218	5,343	1,860	6,441
24	-75.7768	0.000004	5,343	1,860	6,441
25	-75.7768	0.000158	5,343	1,860	6,441
26	-75.7768	0.000566	5,343	1,860	6,441
27	-75.7768	0.000050	5,343	1,860	6,441
28	-75.7768	0.000042	5,343	1,860	6,441
29	-75.7768	0.000084	5,343	1,860	6,441
30	-74.0867	0.000038	5,769	1,947	6,722
31	-75.7768	0.000010	5,343	1,860	6,441
32	-75.7768	0.000093	5,343	1,860	6,441

33	-75.7768	0.000116	5,343	1,860	6,441
34	-75.7768	0.000037	5,343	1,860	6,441
35	-75.7768	0.000126	5,343	1,860	6,441
36	-75.7768	0.000079	5,343	1,860	6,441
37	-75.7768	0.000473	5,343	1,860	6,441
38	-75.7768	0.000459	5,343	1,860	6,441
39	-75.7768	0.000122	5,343	1,860	6,441
40	-75.7768	0.000020	5,343	1,860	6,441
41	-75.7768	0.000124	5,343	1,860	6,441
42	-74.0867	0.000081	5,769	1,947	6,722
43	-75.7768	0.000153	5,343	1,860	6,441
44	-75.7768	0.000287	5,343	1,860	6,441
45	-75.7768	0.000651	5,343	1,860	6,441
46	-75.7768	0.000007	5,343	1,860	6,441
47	-75.7768	0.000247	5,343	1,860	6,441
48	-75.7768	0.000093	5,343	1,860	6,441
49	-75.7768	0.000243	5,343	1,860	6,441
50	-75.7768	0.000183	5,343	1,860	6,441
51	-75.7768	0.000168	5,343	1,860	6,441
52	-75.7768	0.000131	5,343	1,860	6,441
53	-75.7768	0.000080	5,343	1,860	6,441
54	-75.7768	0.000042	5,343	1,860	6,441
55	-75.7768	0.000153	5,343	1,860	6,441
56	-75.7768	0.000297	5,343	1,860	6,441
57	-75.7768	0.000080	5,343	1,860	6,441
58	-75.7768	0.000051	5,343	1,860	6,441
59	-75.7768	0.000013	5,343	1,860	6,441
60	-75.7768	0.000077	5,343	1,860	6,441
61	-75.7768	0.000029	5,343	1,860	6,441
62	-75.7768	0.000050	5,343	1,860	6,441
63	-79.5165	0.000169	5,869	1,960	6,750
64	-75.7768	0.000058	5,343	1,860	6,441
65	-79.0546	0.000104	5,848	1,969	6,810
66	-75.7768	0.000048	5,343	1,860	6,441
67	-75.7768	0.000021	5,343	1,860	6,441
68	-75.7768	0.000060	5,343	1,860	6,441
69	-75.7768	0.000040	5,343	1,860	6,441
70	-75.7768	0.000063	5,343	1,860	6,441
71	-75.7768	0.000527	5,343	1,860	6,441
72	-75.7768	0.000149	5,343	1,860	6,441
73	-75.7768	0.000291	5,343	1,860	6,441
74	-75.7768	0.000058	5,343	1,860	6,441
75	-75.7768	0.000077	5,343	1,860	6,441

76	-75.7768	0.000045	5,343	1,860	6,441
77	-75.7768	0.000059	5,343	1,860	6,441
78	-75.7768	0.000016	5,343	1,860	6,441
79	-75.7768	0.000107	5,343	1,860	6,441
80	-75.7768	0.000178	5,343	1,860	6,441
81	-75.7768	0.000459	5,343	1,860	6,441
82	-75.7768	0.000148	5,343	1,860	6,441
83	-75.7768	0.000505	5,343	1,860	6,441
84	-75.7768	0.000115	5,343	1,860	6,441
85	-75.7768	0.000315	5,343	1,860	6,441
86	-79.5165	0.000168	5,869	1,960	6,750
87	-79.0546	0.000066	5,848	1,969	6,810
88	-75.7768	0.000018	5,343	1,860	6,441
89	-75.7768	0.000086	5,343	1,860	6,441
90	-75.7768	0.000123	5,343	1,860	6,441
91	-75.7768	0.000034	5,343	1,860	6,441
92	-75.7768	0.000392	5,343	1,860	6,441
93	-75.7768	0.000543	5,343	1,860	6,441
94	-75.7768	0.000036	5,343	1,860	6,441
95	-75.7768	0.000102	5,343	1,860	6,441
96	-75.7768	0.000085	5,343	1,860	6,441
97	NA	NA	NA	NA	NA
98	-75.7768	0.000140	5,343	1,860	6,441
99	-75.7768	0.000038	5,343	1,860	6,441
100	-75.7768	0.000357	5,343	1,860	6,441

9. Pribilof Islands Golden King Crab

May 2020 Crab SAFE Draft Report

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Executive Summary

1. **Stock:**

Pribilof Islands (Pribilof District) golden king crab *Lithodes aequispinus*

2. **Catches:**

Commercial fishing for golden king crab in the Pribilof District has been concentrated in the Pribilof Canyon. The domestic fishery developed in 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, 2015, and 2016) 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 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 or 2016, but 2 vessels fished in 2017 and 2019 and one vessel fished in 2018. Discarded (non-retained) catch has occurred in the directed golden king crab fishery, the eastern Bering Sea snow crab fishery, the Bering Sea grooved Tanner crab fishery, and in Bering Sea groundfish fisheries. Estimates of annual total fishery mortality during 2001–2019 due to crab fisheries range from 0 t to 73 t, with an average of 31 t. Estimates of annual fishery mortality during 1991/92–2019 due to groundfish fisheries range from <1 t to 9 t, with an average of 2 t (estimates of annually discarded catch during Bering Sea groundfish fisheries are reported for crab fishing years from 1991 to 2008, and by calendar years from 2009 to 2019). Total fishery mortality in groundfish fisheries during the 2019 crab fishing year was 3.91 t.

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3. Stock biomass:

Stock biomass (all sizes, both sexes) of golden king crab have been estimated for the Pribilof Canyon area using the area-swept technique applied to data obtained from the biennial eastern Bering Sea upper continental slope trawl survey performed by NMFS-AFSC in 2002, 2004, 2008, 2010, 2012, and 2016 (Hoff and Britt 2003, 2005, 2009, 2011; Hoff 2013, 2016). See Appendix A1 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 2008–2016 biennial surveys (J. Hoff, NMFS-AFSC, Kodiak). Biomass estimates by sex and size class from the 2008, 2010, 2012, and 2016 surveys were presented in May 2017 (Pengilly and Daly 2017).

4. Recruitment:

Estimated from size-sex composition data from the eastern Bering Sea upper continental slope trawl survey, mature male biomass in the entire survey area increased slightly from 812 t (1,790,154 lb) in 2012 to 869 t (1,916,329 lb) in 2016, and from 256 t (564,383 lb) in 2012 to 463 t (1,021,602lb) in 2016 in the Pribilof canyon.

5. Management performance:

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 have been presented to, and considered by, the Crab Plan Team (Gaeuman 2013a, 2013b; Pengilly 2015, Pengilly and Daly 2017; Appendix B). Two vessels participated in the 2019 directed fishery and 3.91 t of fishery mortality occurred during groundfish fisheries in 2019 (mostly in Greenland Turbot and Rockfish fisheries). Overfishing did not occur in 2017, 2018, or 2019. The GHL for the 2017-2019 seasons was 59 t. The 2021, 2022, and 2023 OFL and ABC in the table below are the author's recommendations, which follow previous determinations.

Management Performance Table (values in t)

Calendar Year	MSST	Biomass (MMB)	GHL[a]	Retained Catch	Total Catch[b]	OFL	ABC
2016	N/A	N/A	59	0	0.24	91	68
2017	N/A	N/A	59	Conf. [c]	Conf. [c]	93	70
2018	N/A	N/A	59	Conf. [c]	Conf. [c]	93	70
2019	N/A	N/A	59	Conf. [c]	Conf. [c]	93	70
2020	N/A	N/A	59			93	70
2021	N/A	N/A				93	70
2022	N/A	N/A				93	70
2023	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 and bycatch mortality due to groundfish fisheries are included here, but not for 2017-2019 because the directed fishery is confidential.

c. Confidential under Sec. 16.05.815 (SOA statute).

Management Performance Table (values in millions of lb)

Calendar Year	MSST	Biomass (MMB)	GHL[a]	Retained Catch	Total Catch[b]	OFL	ABC
2016	N/A	N/A	130,000	0	<0.001	0.20	0.15
2017	N/A	N/A	130,000	Conf. [c]	Conf. [c]	0.20	0.15
2018	N/A	N/A	130,000	Conf. [c]	Conf. [c]	0.20	0.15
2019	N/A	N/A	130,000	Conf. [c]	Conf. [c]	0.20	0.15
2020	N/A	N/A	130,000			0.20	0.15
2021	N/A	N/A				0.20	0.15
2022	N/A	N/A				0.20	0.15
2023	N/A	N/A				0.20	0.15

a. Guideline harvest level.
b. Total retained catch plus estimated bycatch mortality of discarded catch during crab fisheries and bycatch mortality due to groundfish fisheries are included here, but not for 2017-2019 because the directed fishery is confidential
c. Confidential under Sec. 16.05.815 (SOA statute).

6. Basis for the OFL and ABC:

The values for 2021-2023 are the author's recommendation.

Calendar Year	Tier	Years to define Average catch (OFL)	Natural Mortality[b]	Buffer
2016	5	1993–1998[a]	0.18 yr^{-1}	25%
2017	5	1993–1998[a]	0.18 yr^{-1}	25%
2018	5	1993–1998[a]	0.18 yr^{-1}	25%
2019	5	1993–1998[a]	0.18 yr^{-1}	25%
2020	5	1993–1998[a]	0.18 yr^{-1}	25%
2021	5	1993–1998[a]	0.18 yr^{-1}	25%
2022	5	1993–1998[a]	0.18 yr^{-1}	25%
2023	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 stocks.

7. PDF of the OFL:

Sampling distribution of the recommended Tier 5 OFL was estimated by bootstrapping. The standard deviation of the estimated sampling distribution of the recommended OFL (Alternative 1) is 23 t (CV = 0.25; section G.1).

8. Basis for the ABC recommendation:

A 25% buffer on the OFL, the default; i.e., ABC = (1-0.25)·OFL. This is a data-poor stock.

9. A summary of the results of any rebuilding analyses:

Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. **Changes to the management of the fishery:** 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 to account for bycatch mortality in the directed fishery, non-directed crab fisheries, and groundfish fisheries, and to avoid exceeding the ABC. The GHL remained at 59 t (130,000 lb) from 2016 to 2020.

2. **Changes to the input data:**
   - Retained catch and discarded catch data have been updated with the results for the 2019 directed fishery, during which two vessels participated, but bycatch in other crab fisheries in 2019 was zero.
   - Discarded catch estimates from groundfish fisheries have been listed by calendar year from 2009 to 2019, including 3.91 t of bycatch mortality for 2019.

3. **Changes to the assessment methodology:** This assessment follows the methodology recommended by the CPT since May 2012 and the SSC since June 2012.

4. **Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL:** The 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 2013–2020 Tier 5 OFLs; computations applied directly to data and estimates expressed in metric units resulted in minor changes in results used in previous assessments due to rounding.

B. Responses to SSC and CPT Comments

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

- SSC, October 2019: "*The SSC encourages further efforts to move this analysis to Tier 4 and encourages the CPT to also consider VAST models in addition to RE modelling….. **The SSC strongly supports continued efforts to provide a fishery independent index of abundance for crab and groundfish species on the Bering Sea continental slope.** The SSC supports the development of a collaborative industry-based survey to provide data in the absence of the NMFS slope survey.*"
  - **Response:** We further explored RE modelling. An industry-cooperative survey is in development.
- CPT, September 2019:
  - *Continue the work using the random effects model by incorporating 2004 NMFS slope survey data point and possibly the 2002 data point in model runs. If needed, consider setting a lower bound on process error, although it was noted that this approach did not work for Pribilof Islands red king crab.*
    - **Response:** Included 2002 and 2004 estimates in Tier 4 scenario 2. Did not change process error lower bound, as model appeared to converge.
  - *Explore the feasibility of a simplified Gmacs model to assess the stock.*
- ***Response:*** *Work started; data is being compiled.*
  - *Consider initiating an industry cooperative survey to assess abundance trends.*

- **Response:** In the works.

- SSC, June 2017:
  - *Following up on a SSC request, requests for waivers from harvesters were obtained. However, discussions are still in progress regarding processor waivers. The SSC hopes that these discussions will be fruitful.*
    - **Response:** Inquired. No progress in obtaining confidentiality waivers from processors.
  - *The SSC would appreciate additional insights from the assessment author into the performance of the random effects model.*
    - **Response:** We further explored the random effects model performance and provide details in Appendix A.
- CPT, May 2017:
  - *Investigate whether size frequency data is available for the 2002 and 2004 surveys, so that biomass estimates for mature and legal males could be estimated and included in the model simulations.*
    - **Response:** Crab specimen data collection not part of 2002 survey protocol. Crab specimen data does exist for 2004 survey (in its original form) but we have not been able to acquire it. As a work around, we calculated the ratio of MMB:Total biomass for 2008-2016 surveys, and applied the average to total biomass to obtain MMB for 2002 and 2004.
  - *Investigate the sex ratios in 2008, 2012, 2012, and 2016 data. If the sex ratios are reasonably stable in each of those years, then mature and legal biomass estimates could be made in 2002 and 2004 using the sex ratios from the known survey years (i.e., use 2002 and 2004 raw survey data to get size compositions to extend time series backwards via scaling).*
    - **Response:** See previous comment.
  - *Put bounds on the process error and rerun the model.*
    - **Response:** After investigating the model performance in the .par file, it appears the model did converge (maximum gradient component is <0.0001).

C. Introduction

1. **Scientific name:** *Lithodes aequispinus* J. E. Benedict, 1895

2. **Description of general distribution:**

General distribution of golden king crab:

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 (NMFS 2004).

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, and are frequently found on coral (NMFS 2004, pages 3–43).

The Pribilof District is part of king crab Registration Area Q (Figure 1). Leon et al. (2017) define those boundaries:

> The Bering Sea king crab Registration Area Q southern boundary is 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. The northern boundary is the latitude of Point Hope (68°21′N lat). The 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). The western boundary is the United States-Russia Maritime Boundary Line of 1990 (Figure 2-4). Area Q is divided into 2 districts: the Pribilof District, which includes waters south of Cape Newenham; and the Northern District, which includes all waters north of Cape Newenham.

The NMFS-AFSC conducted an eastern Bering Sea continental slope trawl survey on a biennial schedule during 2002–2016 (the 2014 survey was cancelled). Results of this survey from 2002–2016 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, 2016; Hoff and Britt 2003, 2005, 2009, 2011; Pengilly 2015; Pengilly and Daly 2017). Of the six survey subareas (see Figure 1 in Hoff 2016), biomass and abundance of golden king crab were estimated through 2016 to be highest in the Pribilof Canyon area (survey subarea 2), and most of the commercial fishery catches for golden king crab have occurred there (Neufeld and Barnard 2003; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006; Leon et al. 2017).

Results of the 2002–2016 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 (Hoff and Britt 2003, 2005, 2009, 2011; Haaga et al. 2009; Hoff 2013, 2016). 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. **Evidence of stock structure:**
Although highest densities of golden king crab are found in the deep canyons of the eastern Bering Sea continental slope, golden king crab occur sporadically on the surveyed slope at locations between those canyons in the eastern Bering Sea (Hoff and Britt 2003, 2005, 2009, 2011; Gaeuman 2013b, 2014; Hoff 2013, 2016). 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, Pengilly and Daly 2017; Appendix A1), but the stock relationship between golden king crab within and outside of the Pribilof District has not been evaluated.

4. **Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology):**

The following review of molt timing and reproductive cycle of golden king crab is adapted from Watson et al. (2002):

> Unlike red king crab, golden king crab may have an asynchronous molting cycle (McBride et al. 1982; Otto and Cummiskey 1985; Sloan 1985; Blau and Pengilly 1994). In a sample of male golden king crab 95–155-mm CL and female golden king crab 104–157-mm CL collected from Prince William Sound and held in seawater tanks, Paul and Paul (2000) observed molting in every month of the year, although the highest frequency of molting occurred during May–October. Watson et al. (2002) estimated that only 50% of 139-mm CL male golden king crab in the eastern Aleutian Islands molt annually and that the intermolt period for males ≥150-mm CL averages >1 year.
>
> Female lithodids molt before copulation and egg extrusion (Nyblade 1987). From 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 two 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 lecithoatrophic 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 was reviewed by Webb (2014).

Note that asynchronous, aseasonal molting and the prolonged intermolt period (>1 year) of mature female and the larger mature 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. Brief summary of management history:

A complete summary of the management history through 2015 is provided in Leon et al. (2017).

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 have 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, 2015, and 2016, one vessel fished in each of 2010, 2012–2014, and 2018 and two vessels fished in 2011, 2017, and 2019.

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, 2010–2014, and 2017-2019 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).

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)). 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. <u>Summary of new information</u>:

1. Retained catch and estimated discarded catch during the 2019 directed, estimated discarded catch during other crab fisheries in 2019 (no catch), and the estimated discarded catch in groundfish fisheries during 2019 have been added.

2. <u>Data presented as time series</u>:

a. <u>Total catch</u> and b. <u>Information on bycatch and discards</u>:

- The 1981/82–1983/84, 1984–2019 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 1993–2019 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 within 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, 2010−2014, and 2017-2019. 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 from 1991/92–2008/09, and by calendar years from 2009–2019. The 1991/92–2019 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 2009–2019 are from the State statistical areas falling within the Pribilof District.

- 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 Appendix A for biomass estimates of mature male golden king crab using data from the 2002–2016 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 Appendix A for size data composition by sex of golden king crab during the 2002–2016 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 = 0.0014240 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 is classified as 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, 2013b; Hoff 2016). Data and analysed results pertaining to golden king crab from the 2002–2016 EBS upper continental slope surveys are provided in Appendices A and B but are not used in this Tier 5 assessment.

- 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, 2013b), Pengilly (2015), and Pengilly and Daly (2017) presented assessment-modelling approaches for this stock to the Crab Plan Team using data from the biennial NMFS EBS continental slope survey. However, this stock continued to be managed as a Tier 5 stock for 2018-2020, as had been recommended by NPFMC (2007) and by the CPT and SSC in 2008−2017.

2. Model Description: Subsections a–i are not applicable to a Tier 5 sock.

Only an OFL and ABC is estimated for Tier 5 stocks, where "the OFL represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007). Although NPFMC (2007) defined the OFL in terms of the retained catch, total-catch OFLs may be considered for Tier 5 stocks for which non-target fishery removal data are available (Federal Register/Vol. 73, No. 116, 33926). The CPT (in May 2010) and the SSC (in June 2010) endorsed the use of a total-catch OFL to establish the OFL for this stock. This assessment recommends – and only considers – use of a total-catch OFL for 2021-2023.

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, and 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 2014–2017 Tier 5 OFLs (i.e., the Alternative 1 that was presented in 2013). The 2021-2023 Tier 5 OFL recommended here uses the same approach as used for the 2013–2020 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.,

$$OFL_{2021\text{-}2023} = (1+R_{2001–2010})*RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,92/93–98/99},$$

where,

- $R_{2001–2010}$ 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
- $BM_{GF,92/93–98/99}$ 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).

There are no discarded catch data available for the non-directed fisheries during 1993, thus 1994–1998 is used to estimate average annual bycatch mortality in non-directed fisheries.

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_{2018} is,

$$OFL_{2021\text{-}2023} = (1+0.052)*78.80\text{ t} + 6.09\text{ t} + 3.79\text{ t} = 93\text{ t (204,527 lbs).}$$

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 2010–2020. The time period 1993–1998 provides the longest continuous time period through 2019 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. ***<u>Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring</u>:*** See table below. Because less than three vessels participated in the 2017, 2018, and 2019 directed fisheries, catch numbers are not reported here under the confidentiality requirements of State of Alaska (SOA) statute Sec. 16.05.815. Although fishery mortality occurred during groundfish fisheries in 2017, 2018, and 2019, this and the fishery mortality in the directed fisheries did not exceed the corresponding OFL. As such, overfishing did not occur in 2017, 2018, and 2019. Values for the 2021-2023 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
2016	N/A	N/A	59	0	0.24	91	68
2017	N/A	N/A	59	Conf.	Conf.	93	70
2018	N/A	N/A	59	Conf. [c]	Conf. [c]	93	70
2019	N/A	N/A	59	Conf.	Conf.	93	70
2020	N/A	N/A	59			93	70
2021	N/A	N/A				93	70
2022	N/A	N/A				93	70
2023	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 and groundfish fisheries. Total reratined catch is not listed for 2017–2019 because the directed fishery is confidential under Sec. 16.05.815(SOA statute).
c. Confidential under Sec. 16.05.815 (SOA statute). GHL not attained.

Management Performance Table (values in millions of lb)

Calendar Year	MSST	Biomass (MMB)	GHL[a]	Retained Catch	Total Catch[b]	OFL	ABC
2016	N/A	N/A	130,000	0	<0.001	0.20	0.15
2017	N/A	N/A	130,000	Conf.	Conf.	0.20	0.15
2018	N/A	N/A	130,000	Conf.[c]	Conf.[c]	0.20	0.15
2019	N/A	N/A	130,000	Conf.	Conf.	0.20	0.15
2020	N/A	N/A	130,000				
2021	N/A	N/A					
2022	N/A	N/A					
2023	N/A	N/A					

a. Guideline harvest level, established in lb and converted to t.
b. Total retained catch plus estimated bycatch mortality of discarded catch during crab and groundfish fisheries. Total reratined catch is not listed for 2017–2019 because the directed fishery is confidential under Sec. 16.05.815(SOA statute).
c. Confidential under Sec. 16.05.815 (SOA statute). GHL 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 1993–1998 (Table 5).
= 79 t.

Note that a retained catch of 79 t would exceed the author's recommended ABC for 2021, 2022, 2023 (70 t); see G.4, below.

5. **Recommended F_{OFL}, OFL total catch and the retained portion for the coming year:** See sections ***F.3*** and ***F.4***, above; no F_{OFL} is recommended for a Tier 5 stock.

G. Calculation of ABC

1. PDF of OFL. A bootstrap estimate 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 2020 is unknown.

3. List of additional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

2. **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 2008–2016 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, 2013b), Pengilly and Daly (2017), and Appendix A of this assessment. Cancellation of the survey that was scheduled for 2018 and 2020 raised uncertainties on the prospects for obtaining fishery-independent survey data on this stock in the future. However, ADF&G is currently exploring the feasibility of initiating in industry-cooperative survey as a means to acquire biological data for future assessments.

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Tables

Table 1a. Commercial fishery history for the Pribilof District golden king crab fishery, 1981/82 through 2019: 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	–	–
2016	0	59	0	0	0	–	–
2017	2	59	CF	CF	CF	CF	CF
2018	1	59	CF	CF	CF	CF	CF
2019	2	59	CF	CF	CF	CF	CF

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 2019: 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	–	–
2016	0	130,000	0	0	0	–	–
2017	2	130,000	CF	CF	CF	CF	CF
2018	1	130,000	CF	CF	CF	CF	CF
2019	2	130,000	CF	CF	CF	CF	CF

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, 1993–2019, 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
2016	no fishing	no fishing	0.00	no fishing	0.00
2017	confidential	confidential	0.00	confidential	confidential
2018	confidential	confidential	0.00	no fishing	confidential
2019	confidential	confidential	0.00	no fishing	confidential

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) 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. 1991/92–2008/09 is listed by crab fishery year, while 2009-2019 are listed by calendar year.

Crab fishing year (1991/92–2008/09) or Calendar year (2009-2019)	Bycatch in groundfish fisheries (no mortality rate applied)			Total
	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	2.67	2.55	5.22	3.38
2010	2.13	1.01	3.14	1.87
2011	0.85	1.33	2.18	1.49
2012	0.73	0.82	1.55	1.02
2013	0.50	2.49	2.99	2.24
2014	0.61	0.53	1.14	0.73
2015	0.81	1.89	2.70	1.92
2016	0.23	0.16	0.39	0.24
2017	0.15	1.34	1.49	1.15
2018	0.10	1.59	1.69	1.32
2019	0.05	4.86	4.91	3.91
Average	1.53	1.91	3.44	2.29

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	2.67	2.55
2010	2010/11	Confidential	**Confidential**	0.00	2.13	1.01
2011	2011/12	Confidential	Confidential	0.27	0.85	1.33
2012	2012/13	Confidential	Confidential	0.27	0.73	0.82
2013	2013/14	Confidential	Confidential	0.58	0.50	2.49
2014	2014/15	Confidential	Confidential	0.12	0.61	0.53
2015	2015/16	0.00	0.00	0.00	0.814	1.890
2016	2016/17	0.00	0.00	0.00	0.232	0.158
2017	2017/18	Confidential	Confidential	0.81	0.146	1.345
2018	2018/19	Confidential	Confidential	0.00	0.103	1.589
2019	2019/20	Confidential	Confidential	0.00	0.049	4.861

a. Year convention for retained weights in directed fishery, 1984-2019, estimates of discarded bycatch weights in directed, non-directed crab fisheries, and grounfish (2009-2019).

b. Year convention for retained weights in directed fishery, 1981/82-1983/84, and estimates of discarded bycatch rates in groundfish fisheries (1991/92-2008/09).

Table 5. Data for calculation of $RET_{1993-1998}$ (**t**) and estimates used in calculation of $R_{2001-2010}$ (ratio, t:t), $BM_{NC,1994-1998}$ (**t**), and $BM_{GF,92/93-98/99}$ (**t**) for calculation of the recommended (status quo Alternative 1) Pribilof Islands golden king crab Tier 5 2021-2023 OFL (**t**); values under $RET_{1993-1998}$ are from Table 1, values under $R_{2001-2010}$ 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 $BM_{NC,1994-1998}$ were computed from the non-directed crab fishery discarded catch estimates in Table 2 (assumed bycatch mortality rate = 0.5) and values under $BM_{GF,92/93-98/99}$ are from Table 3.

Calendar Year[a]	Crab Fishing Year[b]	$RET_{1993-1998}$	$R_{2001-2010}$	$BM_{NC,1994-1998}$	$BM_{GF,92/93-98/99}$
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 $RET_{1993-1998}$, $R_{2001-2010}$, and $BM_{NC,1994-1998}$.

b. Year convention corresponding with values under $BM_{GF,92/93-98/99}$.

Figures

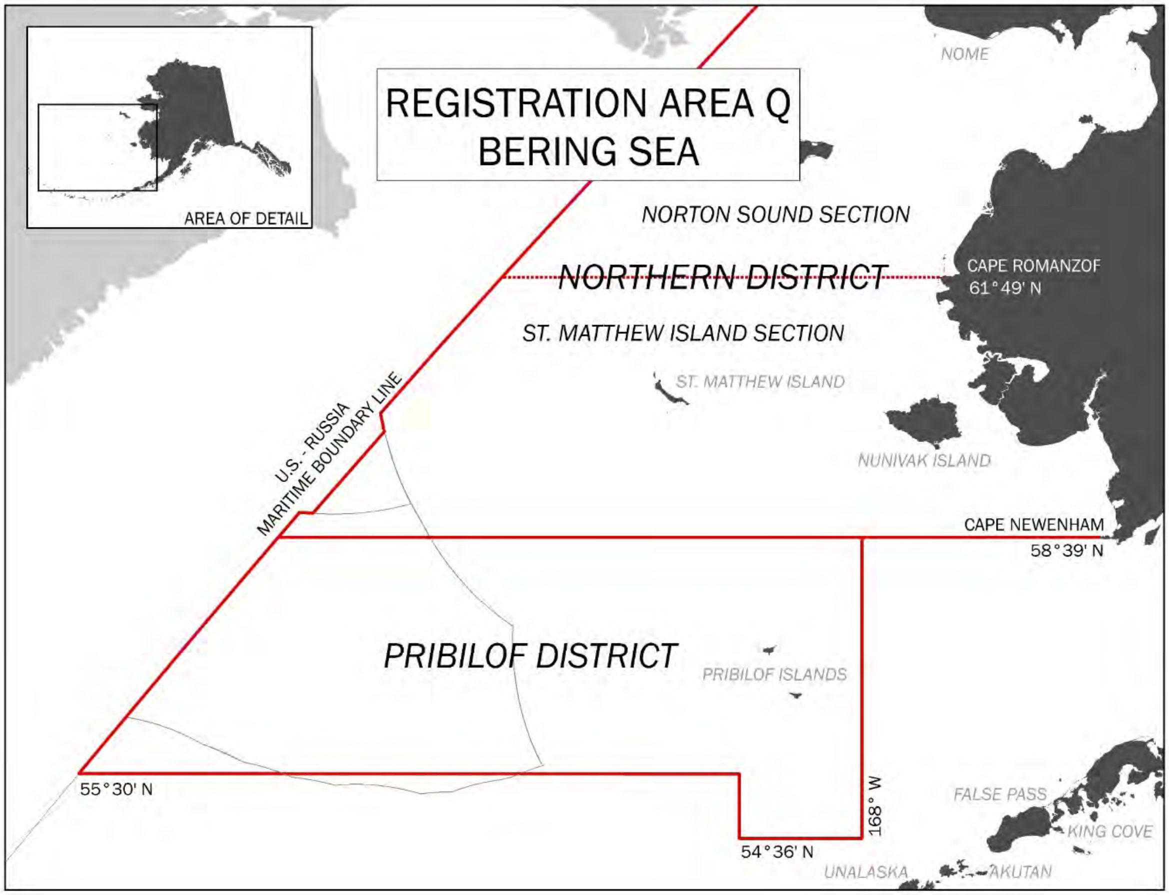

Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District.

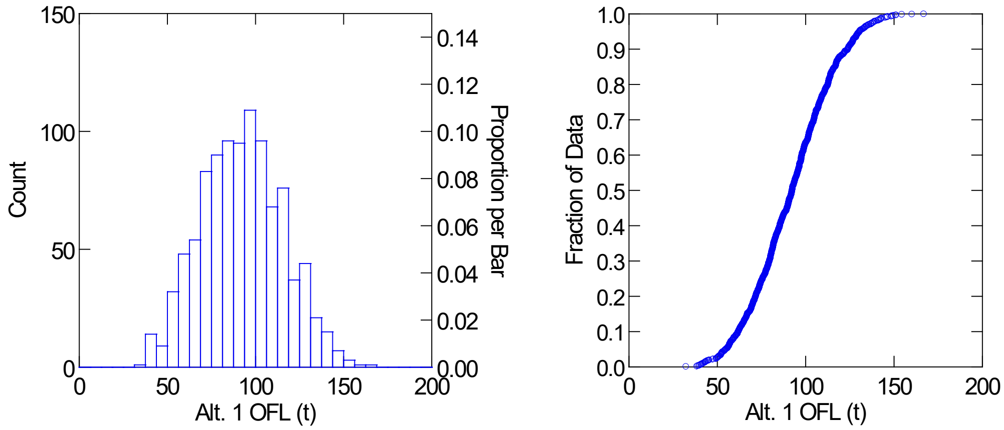

Figure 2. Bootstrapped estimates of the sampling distribution of the 2021-2023 Alternative 1 Tier 5 OFL (total catch, t) for the Pribilof Islands golden king crab stock; histogram on left, quantile plot on right.

Appendix A

Pribilof Islands Golden King Crab Tier 4 Calculations

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The PIGKC stock is currently managed as Tier 5, but we present Tier 4 calculations here. While fishery catch data are available, the OFL calculation presented here uses only NMFS-AFSC eastern Bering Sea continental slope bottom trawl survey data.

Data

Survey biomass estimates and length composition

The NMFS-AFSC conducted an eastern Bering Sea continental slope bottom trawl survey on a biennial schedule during 2002–2016 (2006, 2014, 2018, and 2020 surveys cancelled), and are the sole data source for estimating mature male biomass (MMB) for Pribilof Islands golden king crab (PIGKC, *Lithodes aequispinus*). Results of the 2002–2016 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 (Hoff and Britt 2003, 2005, 2009, 2011; Hoff 2013, 2016). 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, with highest abundance in survey subarea 2 (Pengilly and Daly 2017). For the purpose of this document, we focus on survey subareas 2, 3, and 4 as they generally conform to the ADF&G Pribilof District Management Area (PDMA, Figs. 1-3, ADF&G 2017). Length composition data are available for 2008-2016 surveys but not the 2002 and 2004 surveys (Fig. 4). For the 2008-2016 surveys, we applied length-weight regression to size composition data to estimate the weight of each crab measured. MMB was calculated using a maturity size cut-off of 107 mm CL (Somerton and Otto 1986). 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 associated variances within subareas were summed over subareas to obtain biomass estimates in aggregates of subareas and of the variances of those estimates.

Total catch, bycatch, discards, and retained catch size composition data

- The 1981/82–1983/84, 1984–2019 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 available, but not used in the OFL calculation presented here.

- The 1993–2019 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 available, but not used in the OFL calculation presented here.
- The groundfish fishery discarded catch data (grouped into crab fishery years from 1991/92–2008/09, and by calendar years from 2009–2019) are available, but not used in the OFL calculation presented here.
- Retained catch size composition data is available for 2001-2019, but not used in the OFL calculation presented here.

Growth per molt

The authors are 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 the OFL calculation presented here.

Weight-at length (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 = 0.0014240 and B = 2.781 for females.

Natural mortality rate

The default natural mortality rate assumed for king crab species by NPFMC (2007) is M=0.18.

Analytic Approach

History of Modeling Approaches

The PIGKC stock assessment has followed the Tier 5 methodology since 2012, but interest in a Tier 4 method using a random effect model and NMFS-AFSC EBS slope survey data has received growing interest. In 2017, total biomass and mature male biomass were estimated by a random effects method with the inclusion of the 2016 survey data. At that time, the CPT recommended to use the Tier 5 assessment until the model was further explored and/or additional survey data was available. Here, we further explore the utility of the random effects model, though there has been no additional fishery-independent data since the 2017 assessment.

Random effects model

The program “Survey Average Random Effects” was used to estimate biomass from the area-swept MMB (males ≥107 mm) estimates in surveyed years and to project biomass estimates for unsurveyed years into 2022 via a state-space random walk plus noise model. The state-space random walk plus noise is formulated as a random effect model, where process errors are considered "random effects" drawn from an underlying normal distribution with μ=0 and estimated σ^2 (σ_λ^2), 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 (Spencer et al. 2015).

Model scenarios

We applied the random effects model to six iterations of the EBS slope survey MMB timeseries, which varied by 1) the number of MMB input years, 2) the spatial area extent, and 3) level of stratification (Table 1). Size composition data is only available for 2008, 2010, 2012, and 2016 survey, thus MMB area-swept estimates are only available for those years. However, we calculated the ratio of MMB to total biomass for the 2008, 2010, 2012, 2016 surveys (Table 2) and applied the average ratio to the 2002 and 2004 survey total biomass and variance to approximate MMB for 2002 and 2004 surveys. The Pribilof District Management Area (PDMA) boundaries do not align with those of the EBS slope survey subareas. All of survey subareas 2 and 3, nearly all of subarea 4, and portions of subareas 1 and 5 are encompassed by the PDMA. While most of the survey biomass occurs in subareas 2-4, some GKC occur in subareas 1 and 5. For some iterations, we included portions of these subareas when calculating MMB estimates. Finally, since survey stations towed in a given season are selected from a pool of available stations via a sampling design stratified by subarea and depth range, we included MMB timeseries where MMB was calculated using average survey MMB densities within strata within subareas, and strata within the survey area (i.e., similar depth strata were combined among subareas, and subareas were neglected) (Table 3). Model scenarios were as follows:

1. **2020a**: MMB and variance in MMB 2008-2016 computed among strata within subareas 2-4, summed within subareas, and then across subareas
2. **2020b:** MMB and variance in MMB 2008-2016 computed among strata within the survey area bounded by the Pribilof Islands district and summed across strata
3. **2020c:** MMB density and variance in MMB 2008-2016 density computed among strata within subareas 2-4 and summed across strata
4. **2020d**: The same as 2020a, but included MMB estimates for 2002 and 2004 (computed using the mean ratio of MMB:total biomass from 2008-2016)
5. **2020e**: The same as 2020b, but included MMB estimates for 2002 and 2004 (computed using the mean ratio of MMB:total biomass from 2008-2016)
6. **2020f:** The same as 2020c, but included MMB estimates for 2002 and 2004 (computed using the mean ratio of MMB:total biomass from 2008-2016)

Table 1. Model scenarios, where calculation of MMB inputs varied with changes to survey input years, the spatial extent of the stock, and levels of stratification (i.e., depth stratum, subareas). PDMA refers to the Pribilof District Management Area.

Model	Survey Years	Survey Area	Stratification Levels

2020a	2008 - 2016	Subareas 2 - 4	2
2020b	2008 - 2016	PDMA	1
2020c	2008 - 2016	Subareas 2 - 4	1
2020d	2002 - 2016	Subareas 2 - 4	2
2020e	2002 - 2016	PDMA	1
2020f	2002 - 2016	Subareas 2 - 4	1

Table 2. MMB:total biomass ratios used to estimate 2002 and 2004 MMB by model scenario. Ratios are different among scenarios, depending on the biomass calculation used (i.e., spatial area extent and stratification levels).

Survey year	**2020d**	**2020e**	**2020f**
2008	0.56	0.57	0.57
2010	0.33	0.39	0.40
2012	0.30	0.30	0.30
2016	0.50	0.49	0.49
Mean	0.42	0.44	0.44
SD	0.13	0.12	0.12

Table 3. Area of each stratum within subareas. For stratification, stratum area is computed as the sum of stratum areas among similar depths within the appropriate survey area.

Subarea	Stratum	Depth (m)	Stratum area (km^2)	Stratum area in PDMA (km^2)
1	1	200 - 400	4,012	88
	2	400 - 600	4,063	102
	3	600 - 800	1,742	105
	4	800 - 1,000	1,355	119
	5	1,000 - 1,200	1,107	128
2	1	200 - 400	1,158	1,158
	2	400 - 600	705	705
	3	600 - 800	591	591
	4	800 - 1,000	553	553
	5	1,000 - 1,200	536	536
3	1	200 - 400	904	904
	2	400 - 600	886	886
	3	600 - 800	910	910
	4	800 - 1,000	732	732
	5	1,000 - 1,200	676	676
4	1	200 - 400	1,236	1,094
	2	400 - 600	730	730
	3	600 - 800	694	694
	4	800 - 1,000	708	708
	5	1,000 - 1,200	662	662
5	1	200 - 400	424	167
	2	400 - 600	426	142
	3	600 - 800	432	145
	4	800 - 1,000	552	282
	5	1,000 - 1,200	570	317
6	1	200 - 400	2,596	0
	2	400 - 600	1,706	0
	3	600 - 800	917	0
	4	800 - 1,000	645	0
	5	1,000 - 1,200	496	0

Evaluation of the fit to the data

The random effects model appeared to converge for all MMB input scenarios (maximum gradient component < 0.0001) and fitted MMB and parameter estimation was primarily only sensitive to differing survey year inputs. Large CVs (> 20%) in all model iterations that used only data from 2008 – 2016 contributed to an estimated process error variance that was very small ($\sigma_\lambda \sim 0.001$) (Table 4), resulting in a ‘flat’ trend in fitted MMB (Fig. 5). When including the 2002 and 2004 MMB approximations, the model responded by capturing the relatively low survey biomass estimates in those years following a slight increasing trend (Fig. 5).

Table 4. Model parameter outputs.

Model	Joint Neg. Log Likelihood	σ_λ
2020a	0.40	0.001
2020b	1.21	0.001
2020c	1.09	0.001
2020d	2.00	0.117
2020e	2.54	0.106
2020f	2.59	0.110

Calculation of reference points

The Tier 4 OFL is calculated using the F_{OFL} control rule:

$$F_{OFL} = \begin{cases} 0 & if\ \frac{MMB}{B_{MSY}} \leq 0.25 \\ \frac{M(\frac{MMB}{B_{MSY}} - \alpha)}{1 - \alpha} & if\ 0.25 < \frac{MMB}{B_{MSY}} < 1 \\ M & if\ MMB > B_{MSY} \end{cases}$$

where MMB is quantified at the mean time of mating date (15 February), B_{MSY} is defined as the average MMB for a specified period (either 2002-2016 or 2008-2016, defined in Table 1), M = 0.18 yr^{-1}, and α = 0.1. The Tier 4 OFL (Table 5) was calculated by applying a fishing mortality determined by the harvest control rule (above) to the mature male biomass at the time of fishing, which remained constant starting in 2016 (i.e., the last data input year).

Table 5. Comparisons of management quantities for the six model scenarios.

Model	B_{MSY} (t)	MMB (t)	$MMB_{projected}$	MMB / B_{MSY}	F_{OFL}	OFL (t)	OFL (lbs)
2020a	589.1	589.1	526.4	0.894	0.159	77.256	170,321
2020b	574.6	574.7	513.5	0.894	0.159	75.365	166,152
2020c	639.8	639.8	571.7	0.894	0.159	83.907	184,984
2020d	514.6	614.2	548.8	1.066	0.180	90.404	199,307
2020e	503.7	584.5	522.3	1.037	0.180	86.046	189,699
2020f	557.3	657.6	587.7	1.055	0.180	96.807	213,424

Authors recommendation

Our preferred model scenario is 2020e. While there is uncertainty in the using MMB approximations for 2002 and 2004 survey data inputs, we feel the confident the approximations capture the population trends indicated by total biomass survey estimates for these years. As such, the benefits of incorporating the additional data input years likely outweigh this added uncertainty. Further, we feel that refining the survey data inputs by the PDMA boundaries is more appropriate than using survey subareas 2-4 only, as doing so captures the full extent of this stock within the PDMA. Computing MMB and variance in MMB among stratum, within subareas for the portions of subarea 5 and 1 that are included in the PDMA is not possible due to a small number of stations within individual strata. Since subarea boundaries are likely not meaningful for PIGKC stock delineation, computing MMB estimates with stratification by depth only within the PDMA seems appropriate.

While model estimation of MMB is a step forward in capturing population dynamics of the stock, uncertainty about future bottom trawl surveys and associated data availability is a concern. We recommend PIGKC continue to be managed as a Tier 5 stock until future surveys are solidified. The authors highlight the importance of the NMFS EBS slope bottom trawl survey, and hope that the survey is not discontinued. ADF&G is currently exploring feasibility and design of an industry-cooperative pot survey to meet data needs for PIGKC. This pot survey will be critical if the NMFS EBS slope bottom trawl survey is discontinued, but several years of data collection will be needed before data can be incorporated in model simulations.

Data gaps and research priorities

PIGKC is a data poor stock, with little information for capturing essential population dynamics including abundance and biomass. Fishery independent data are needed for estimating population abundance and biomass, spatial distribution, size at maturity, and length-weight relationships. Increased uncertainty with the future of the NMFS-AFCS biennial bottom trawl survey has elevated the need to establish an industry-cooperative survey to fill these data gaps.

Acknowledgements

We thank the Jerry Hoff for providing survey data, and the Crab Plan Team, Jim Ianelli, Martin Dorn, Katie Palof, and Jack Turnock for guidance on the use of the random effects model.

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Figures

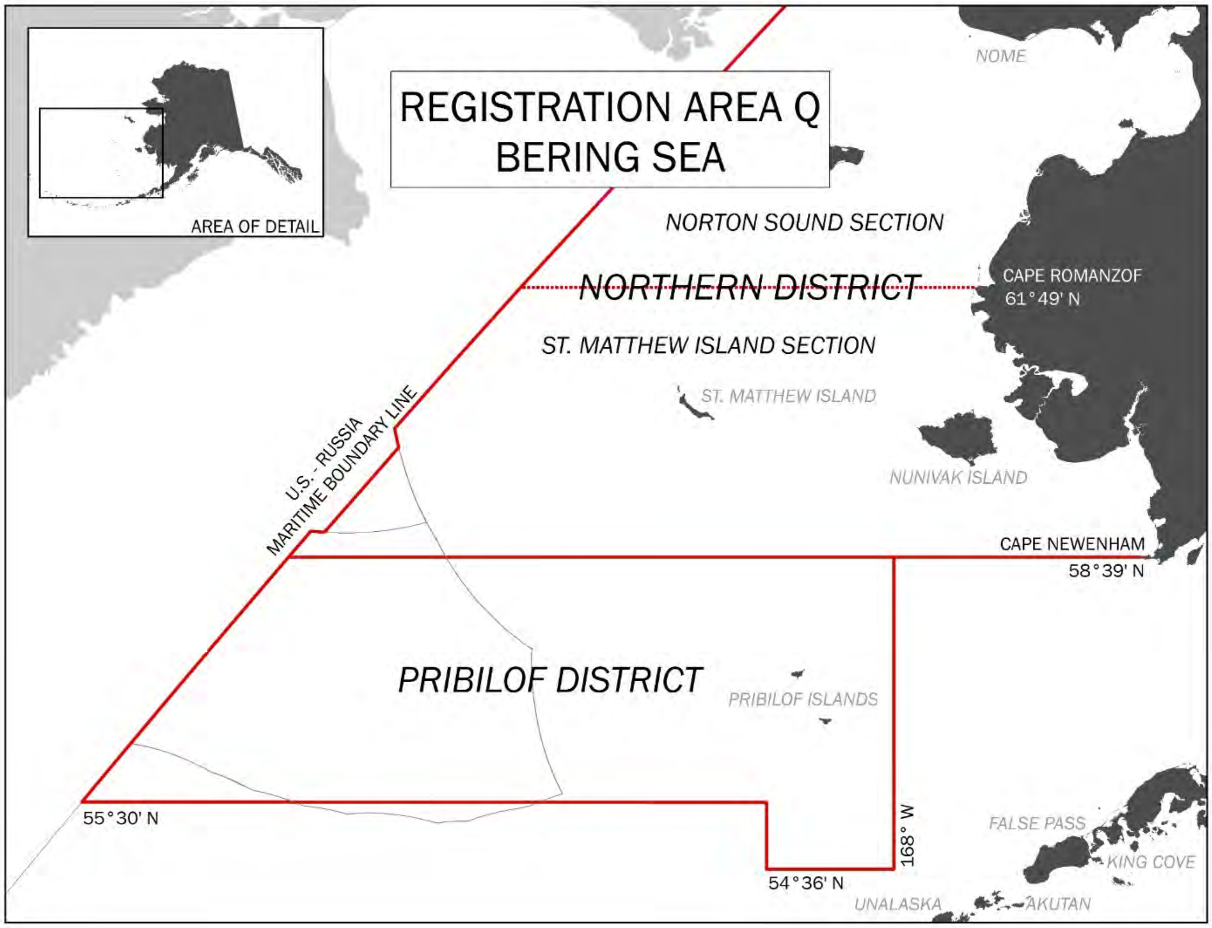

Figure 1. Bering Sea Registration Area Q, subdivided into the Northern District and Pribilof District management areas.

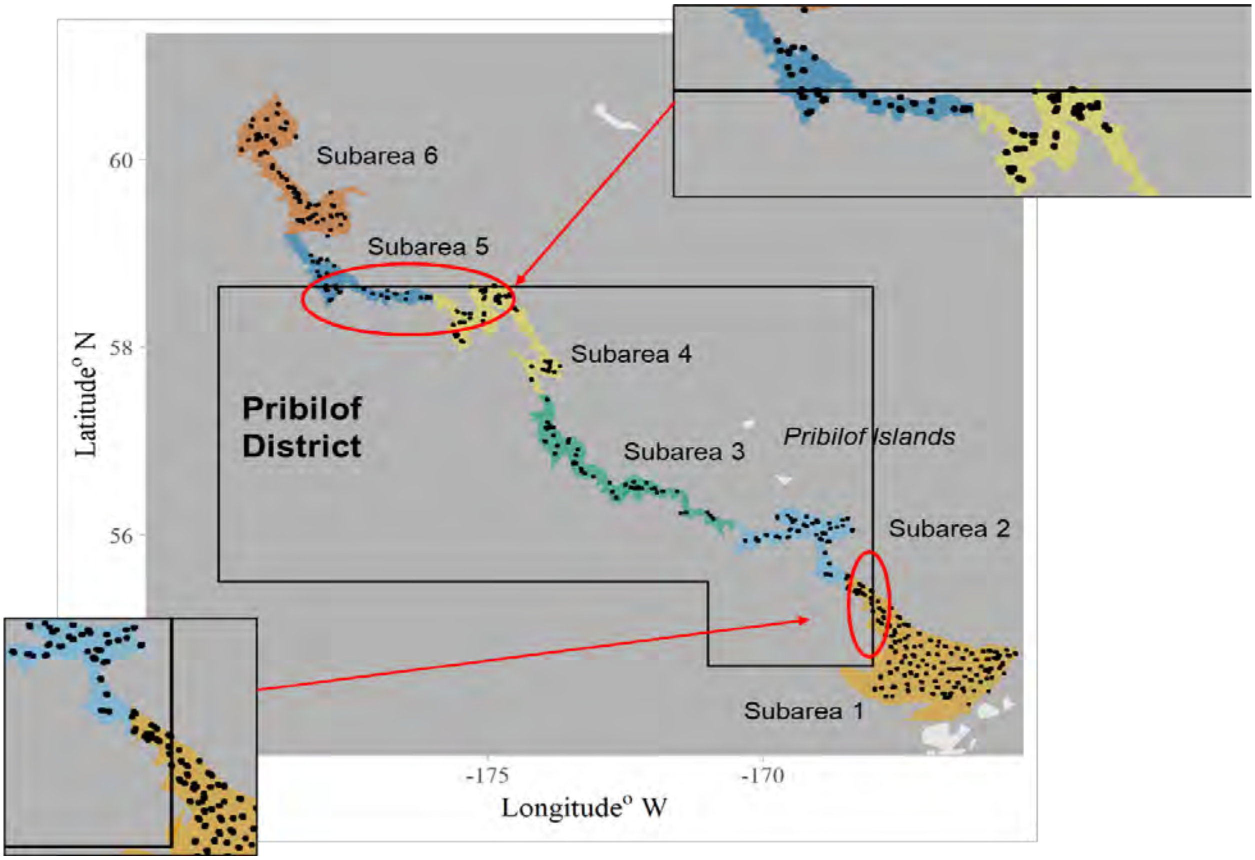

Figure 2. Map of survey subareas, with locations of all possible stations for surveys between 2002 – 2016. Portions of subareas 1 and 5 fall within the Pribilof District Management Area.

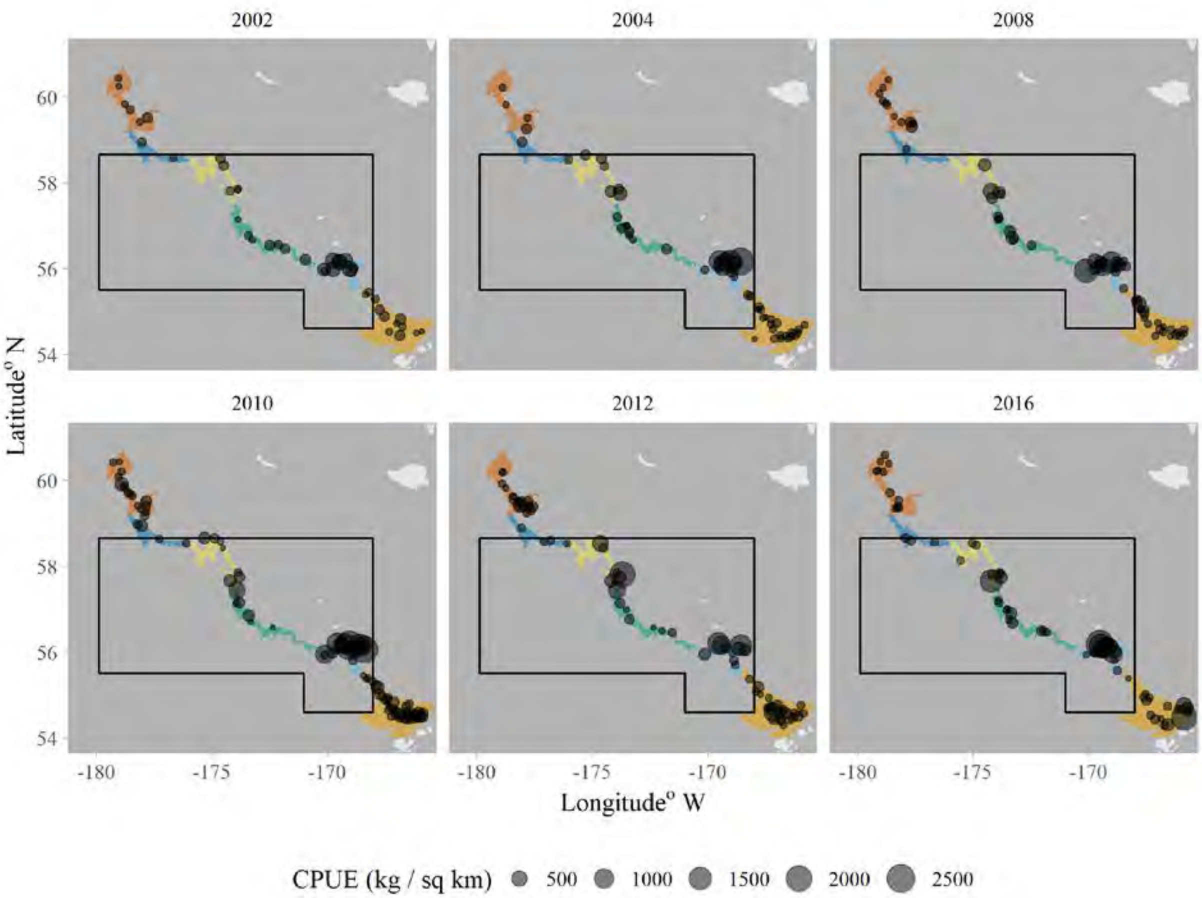

Figure 3. NMFS Eastern Bering Sea upper continental slope bottom trawl survey golden king crab CPUE (kg km^{-2}) total catch biomass for 2002-2016 surveys. Different color polygons correspond to the six different survey subareas with subarea numbering in progressing order from north to south. The black line depicts the Pribilof District Management Area boundary.

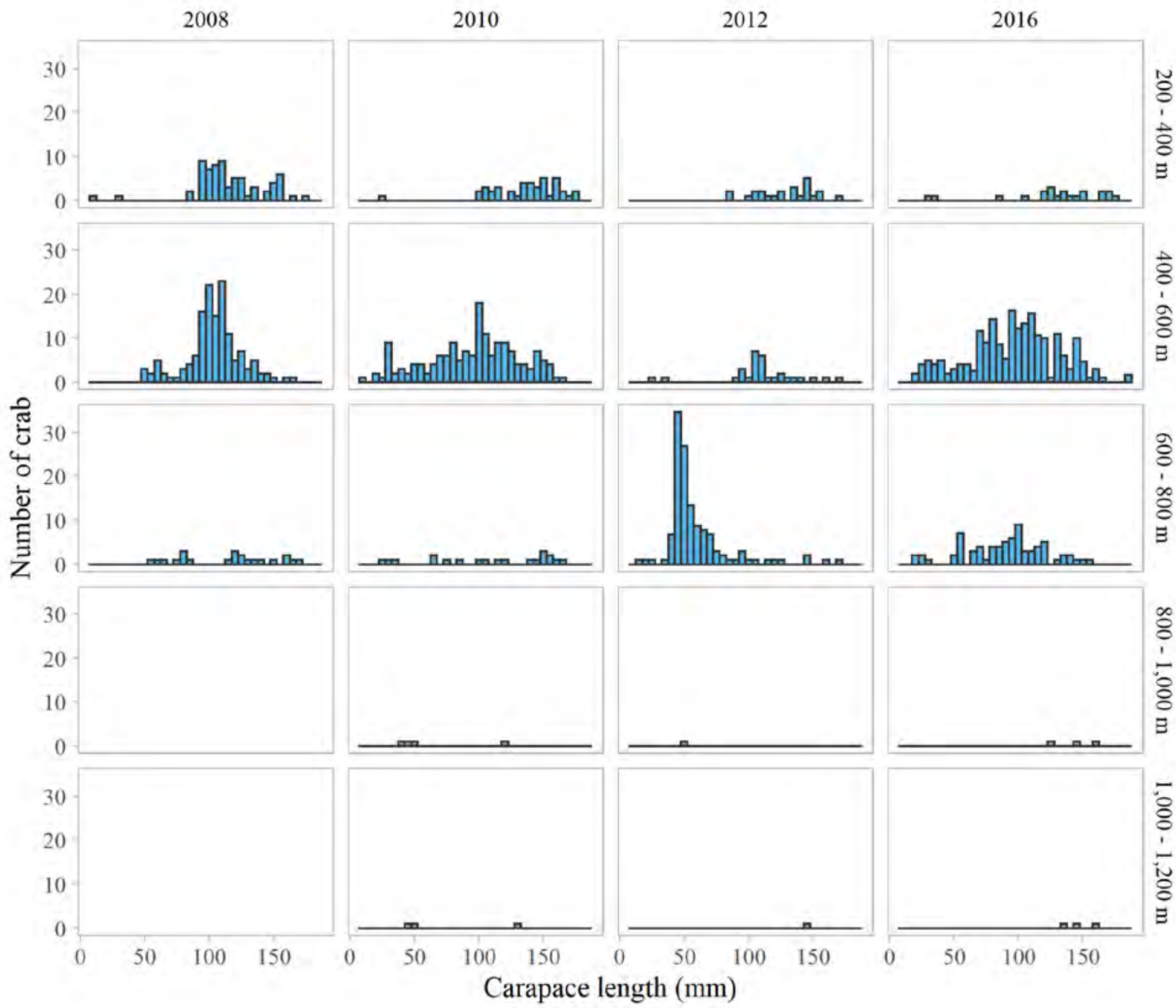

Figure 4. Size frequency of male golden king crab captured in the Pribilof District Management Area during the 2008, 2010, 2012, and 2016 NMFS Eastern Bering Sea upper continental slope bottom trawl survey.

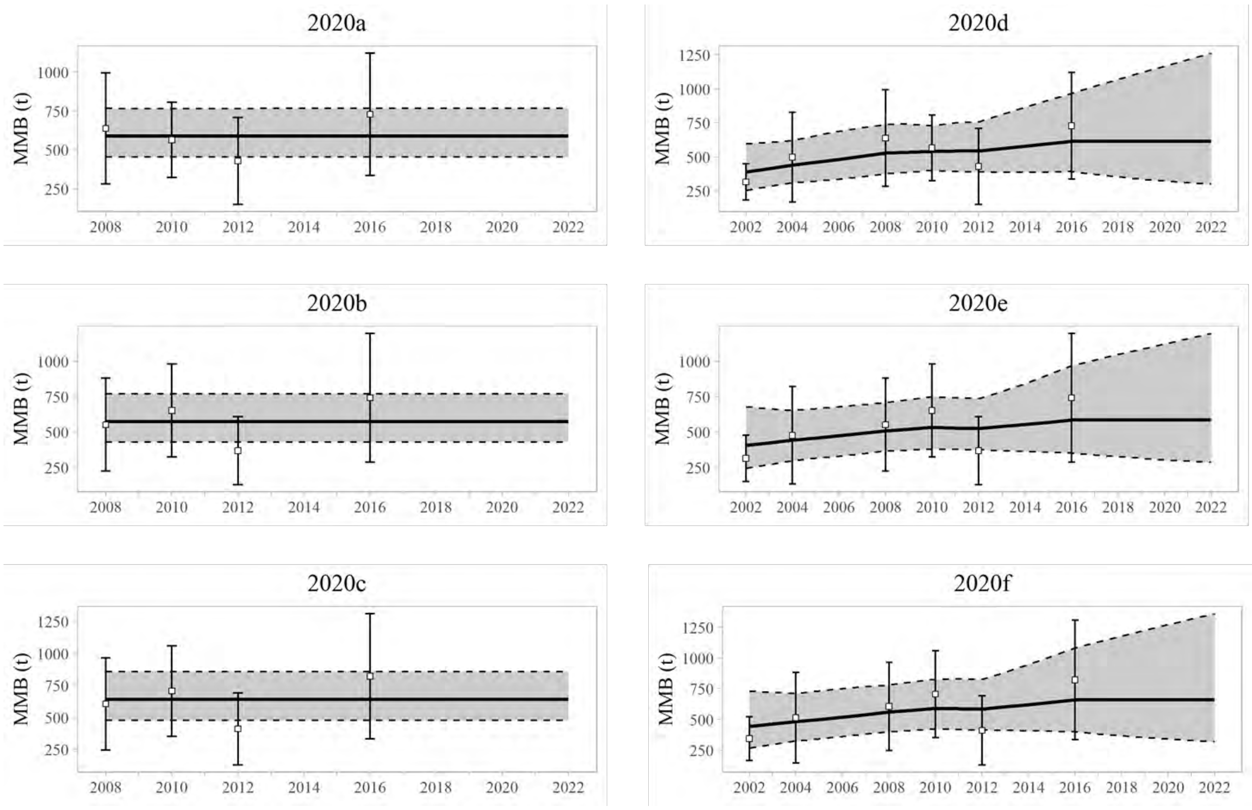

Figure 5. Model fits for PIGKC MMB, with panels referring to different model scenarios. Points correspond to the survey mature male biomass estimates ±95% CI and the black line corresponds to fitted biomass by random effects model ±95% CI (shaded area).

Appendix B

Updated discussion paper for May 2017 Crab Plan Team meeting: Random effects approach to modeling NMFS EBS slope survey area-swept biomass estimates for Pribilof Islands golden king crab.

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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); however, the completion of the 2016 slope survey allows opportunity to revisit this approach.

In May 2015 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). In September 2016 the CPT "*recommends the random effects model be re-evaluated after results from the 2016 slope survey are available.*" The SSC confirmed that request: *"The SSC concurs with the CPT* *recommendation"* ["*that the random effects model be re-evaluated after results from the 2016 slope survey are available*"].

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 or 2014. Details on the methods and survey gear used in the 2002, 2004, 2008, 2010, 2012, and 2016 NMFS EBS slope surveys are provided in Hoff and Britt (2003, 2005, 2009, 2011) and Hoff (2013, 2016), 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 2). 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, 2012 and 2016 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, 2012, and 2016 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) = $(0.0002988)\times(CL)^{3.135}$ (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 2018.[3] 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 2018 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*

[3] The author acknowledges help from Martin Dorn, Jim Ianelli, and Paul Spencer, AFSC, in getting this paragraph completed.

> *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 should consider a biomass estimate for an area that encompasses the majority of historical catches*."

Figures 3–8 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, 2012, and 2016 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 9 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 10 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 fishy, 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, 2012, 2016 NMFS EBS slope surveys are shown in Figures 11–14.

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, 2012 and 2016 are in Table 2.

Estimates and projections through 2018 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 15 and 16, respectively. More detailed results produced by re.exe are provided in Appendices A and B.

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Tables

Table 1. Data on golden king crab recorded during the 2002, 2004, 2008, 2010, 2012, and 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
2016	YES	YES	YES[b]	NO

a. Golden king crab <100 mm CL were subsampled for data recording at one tow in subarea 4 during the 2012 survey.
b. Golden king crab were subsampled for data recording at one tow in subarea 2 during the 2016 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, 2012, and 2016 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
2016	1	217	0.35	116	0.37	98	0.40
2016	2	1060	0.27	475	0.30	336	0.30
2016	3	100	0.34	74	0.42	65	0.47
2016	4	304	0.79	191	0.77	165	0.73
2016	5	23	0.48	10	0.72	4	1.00
2016	6	50	0.30	31	0.46	18	0.75
2016	1–6	1,754	0.22	897	0.24	685	0.24
2016	2–4	1,464	0.26	740	0.28	565	0.28

Figures

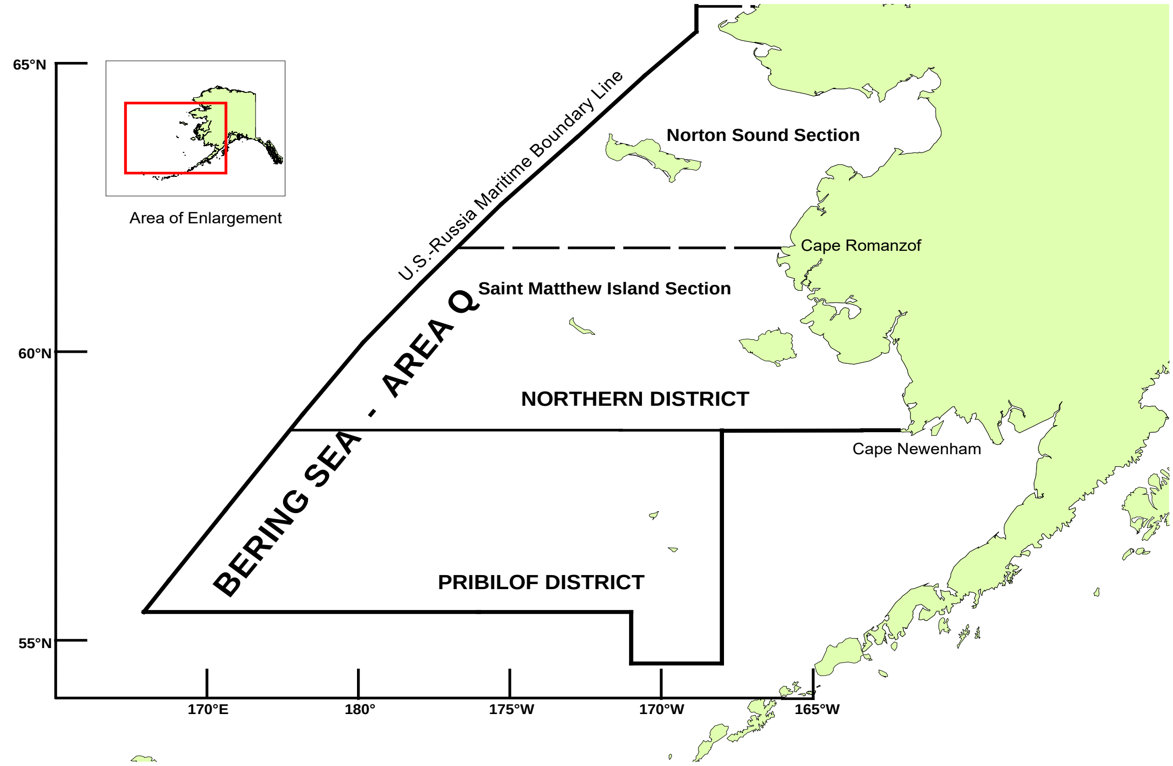

Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District.

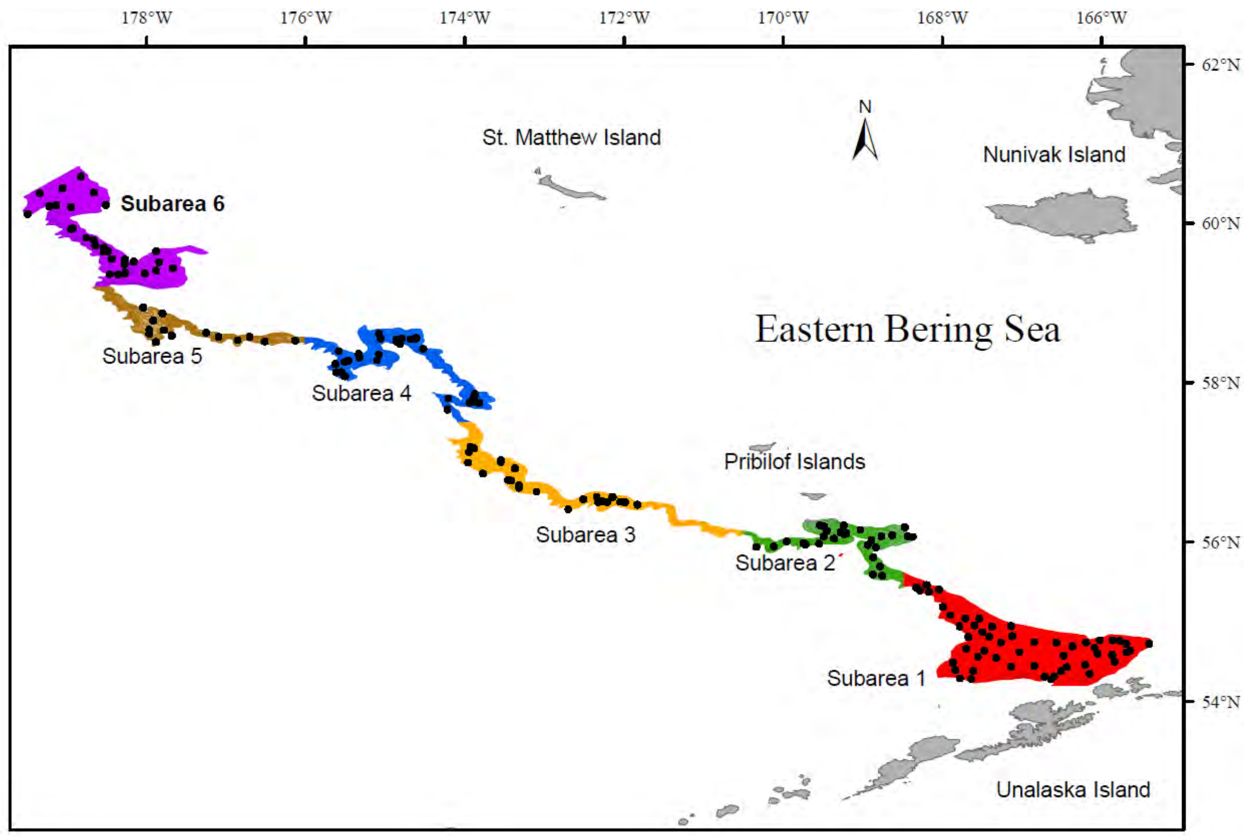

Figure 2. Map of standard survey area and the six subareas. Indicated are the 175 successful trawl stations (black dots) completed during the 2016 EBSS survey (taken form Hoff 2016).

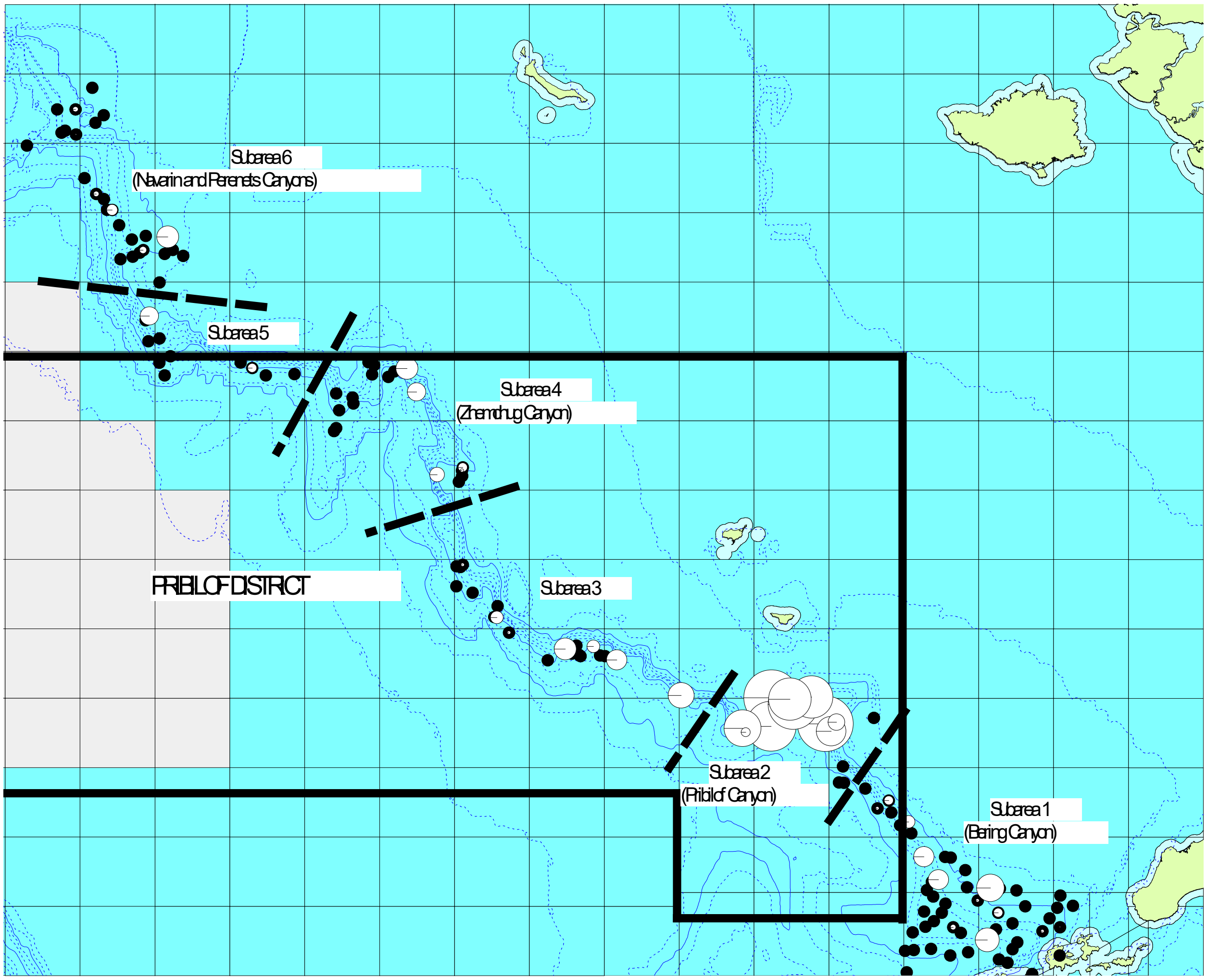

Figure 3. 2002 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 510 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

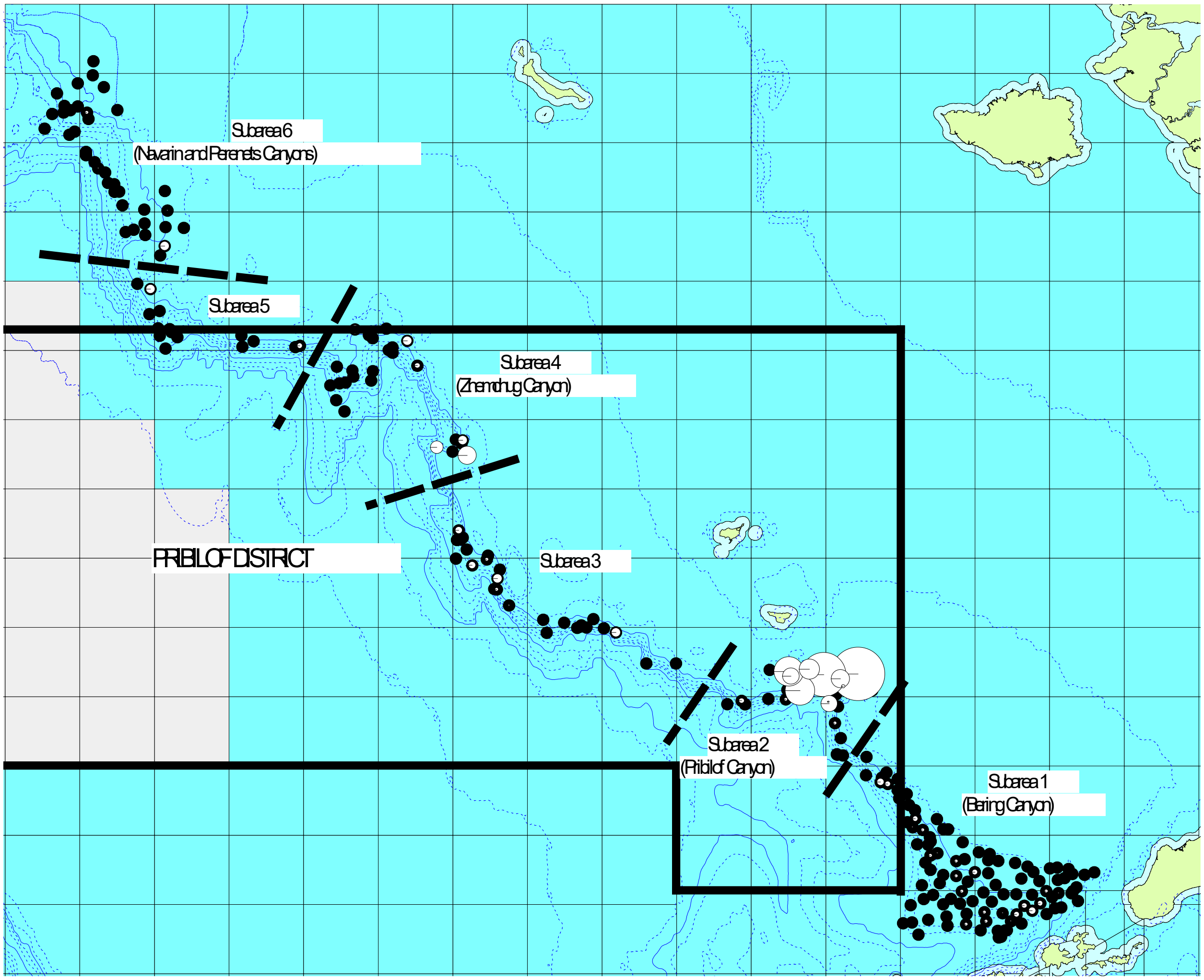

Figure 4. 2004 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 2,300 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

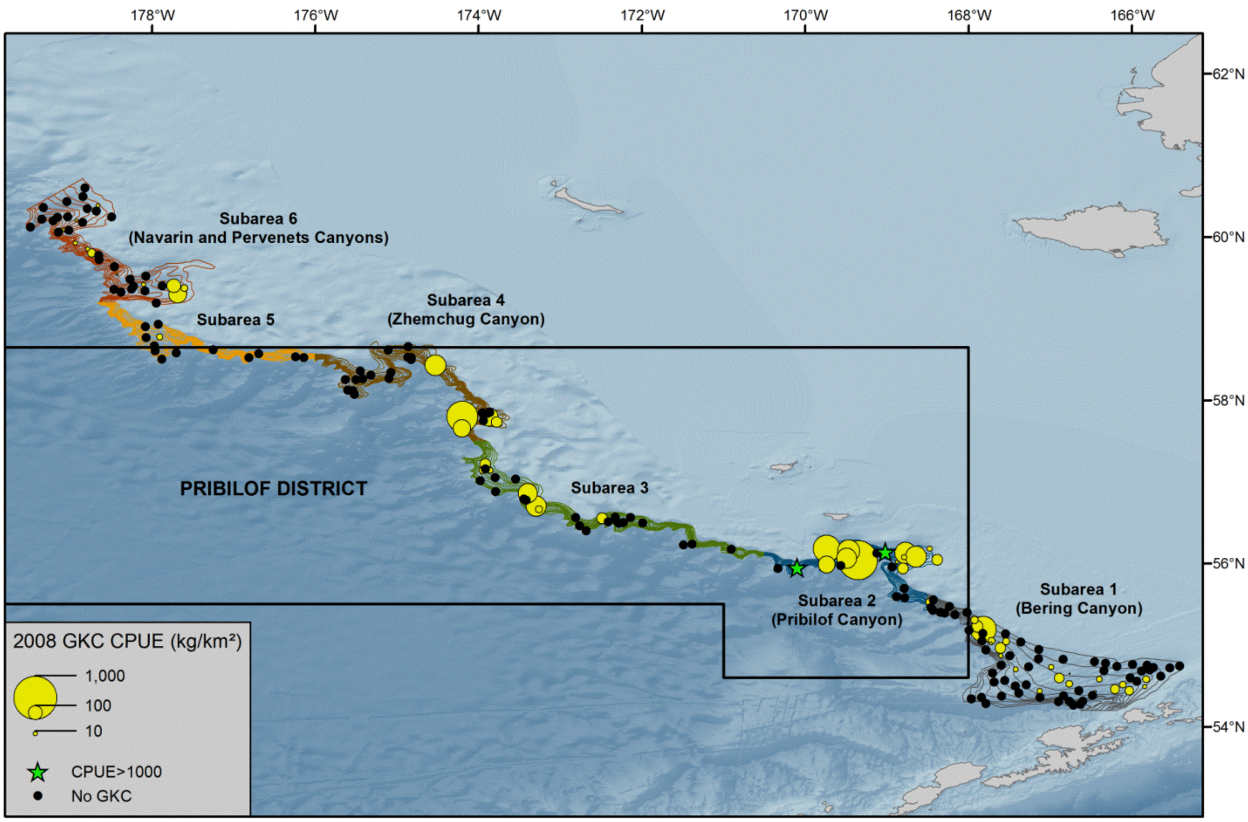

Figure 5. 2008 slope survey tow locations (black circles) and golden king crab CPUE (kg km^{-2}; yellow circles, green stars indicate values outside the normal range).

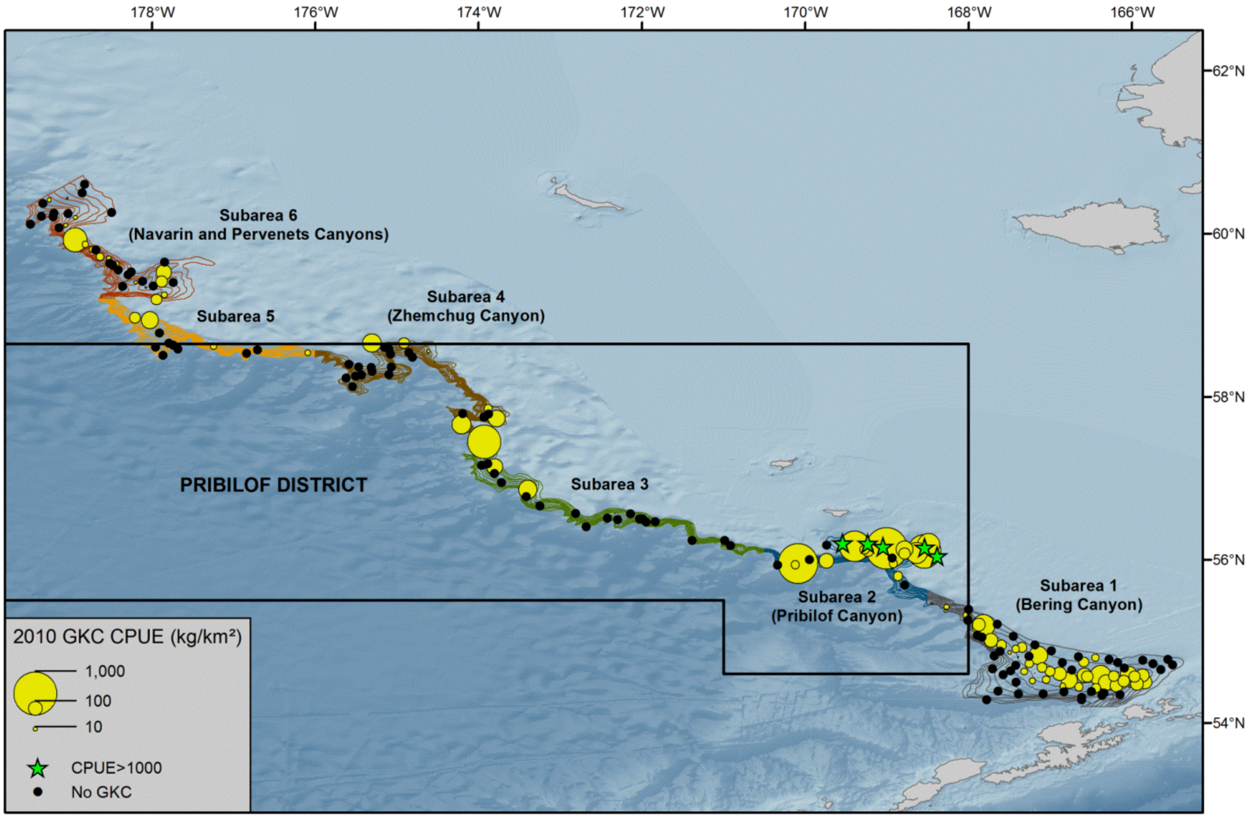

Figure 6. 2010 slope survey tow locations (black circles) and golden king crab CPUE (kg km^{-2}; yellow circles, green stars indicate values outside the normal range).

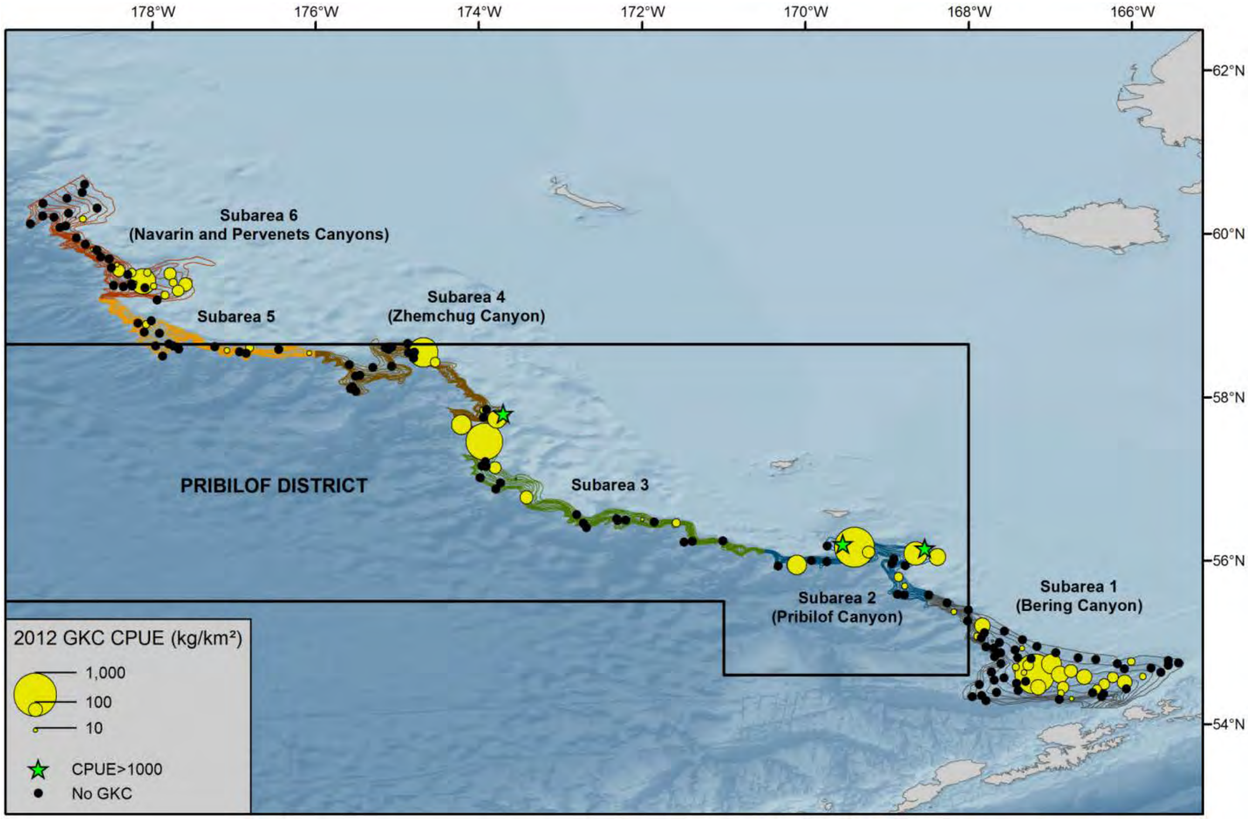

Figure 7. 2012 slope survey tow locations (black circles) and golden king crab CPUE (kg km^{-2}; yellow circles, green stars indicate values outside the normal range).

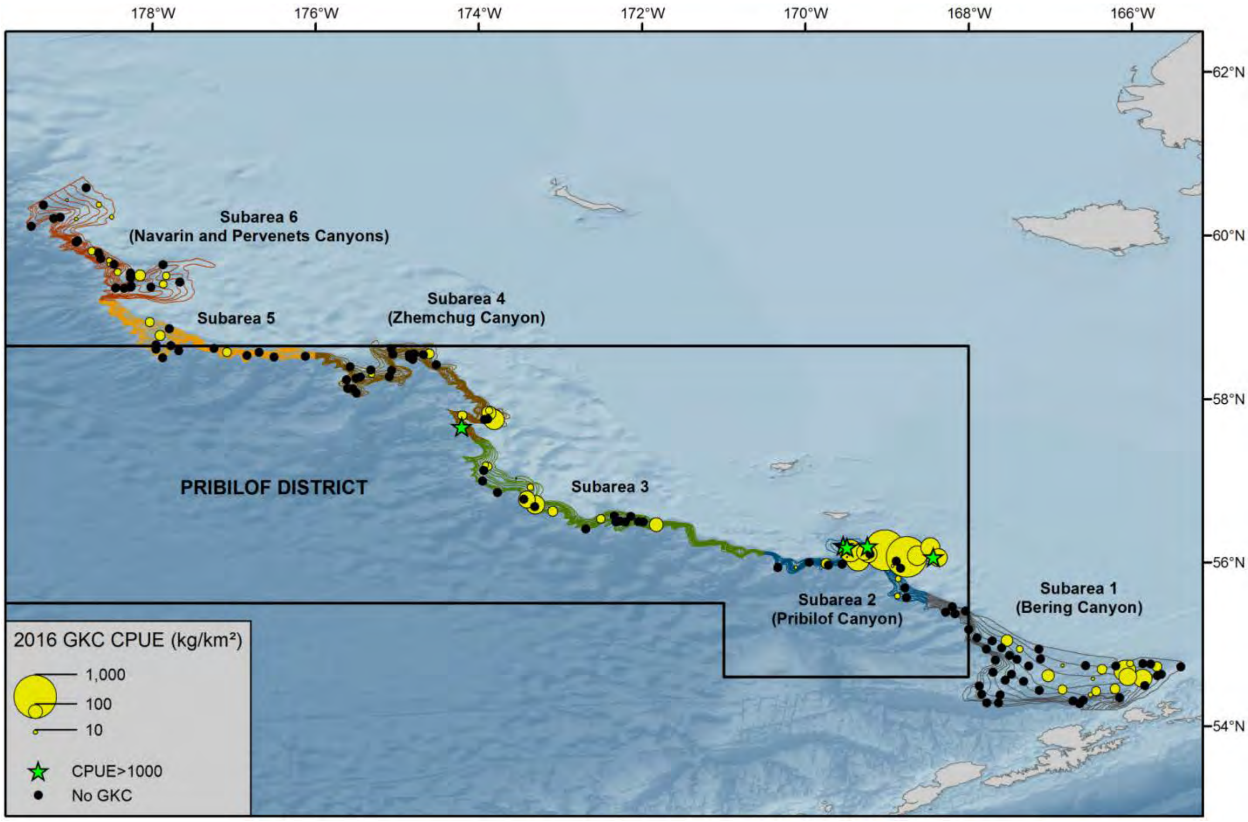

Figure 8. 2016 slope survey tow locations (black circles) and golden king crab CPUE (kg km^{-2}; yellow circles, green stars indicate values outside the normal range).

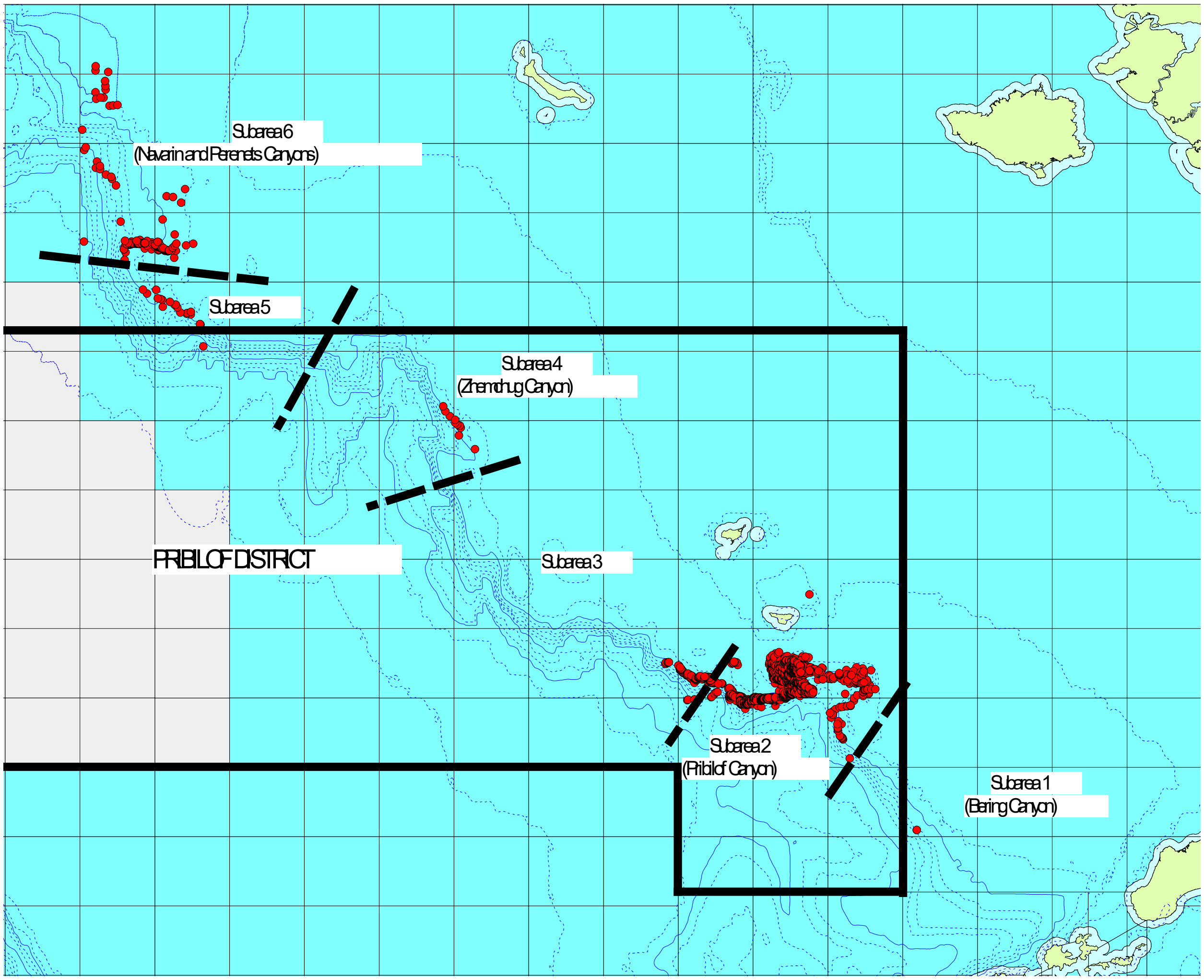

Figure 9. Locations of all pots sampled by observers during Bering Sea golden king crab fisheries (n = 6,104), 1992–2014; pots north of the Pribilof District northern boundary were fished during the Northern District – Saint Matthew Island Section fishery; squares are 1° longitude x 30' latitude State statistical areas.

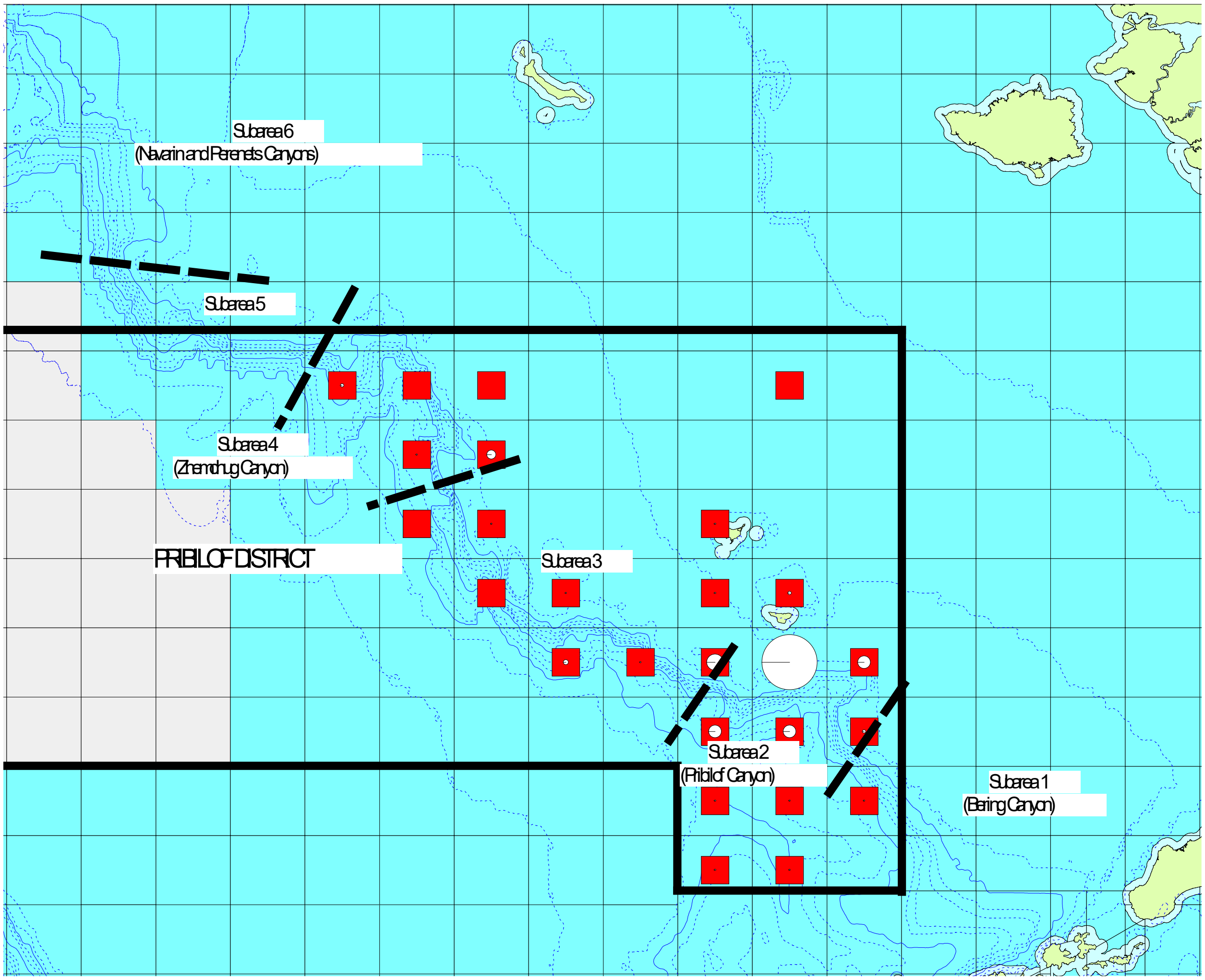

Figure 10. Statistical areas with reported catch during the 1985–2014 Pribilof District golden king crab fisheries: filled red squares denote statistical areas with reported catch; size of overlain white circles are proportional to the percentage of the total 1985–2014 catch reported from statistical area (biggest circle = 68% of total); squares are 1° longitude x 30' latitude State statistical areas.

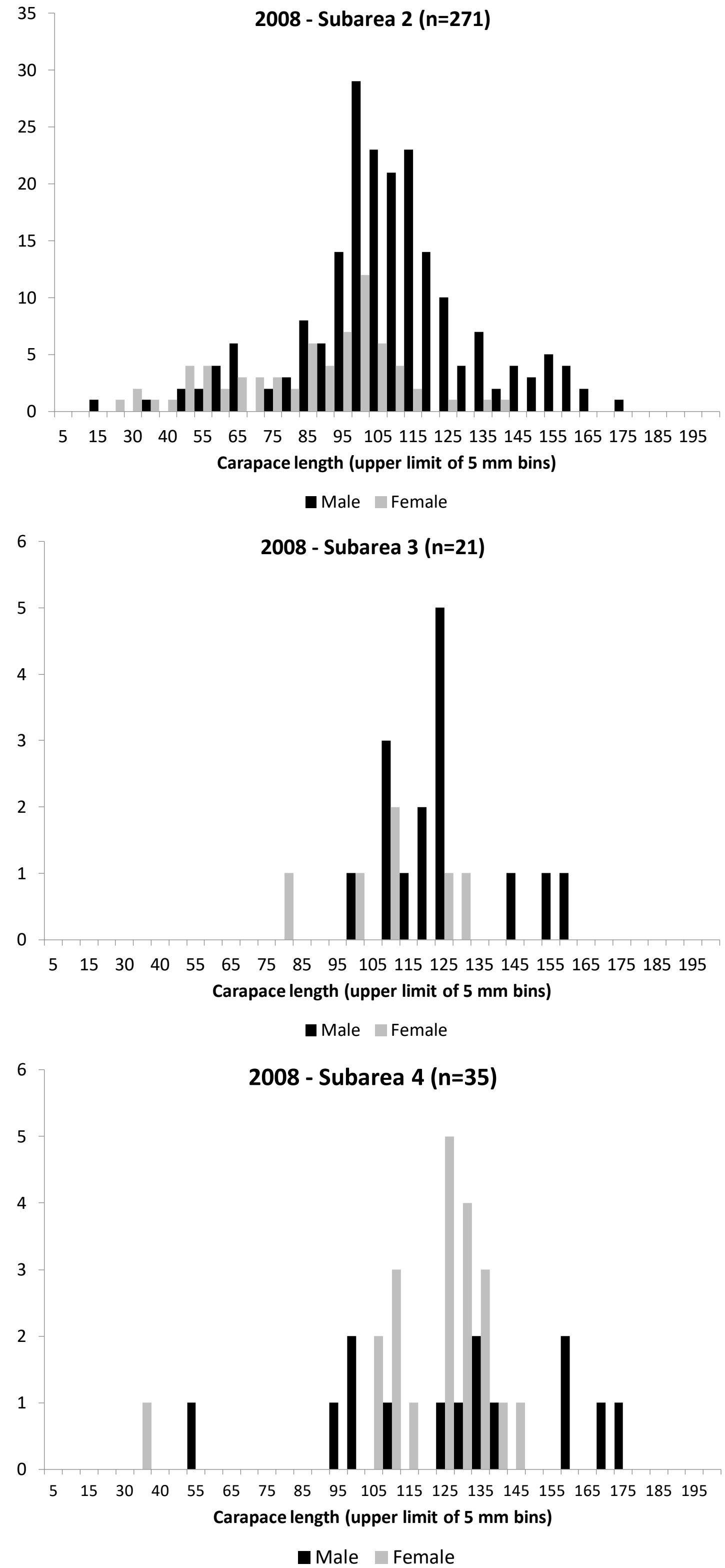

Figure 11. Size distribution of measured golden king crab during the 2008 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

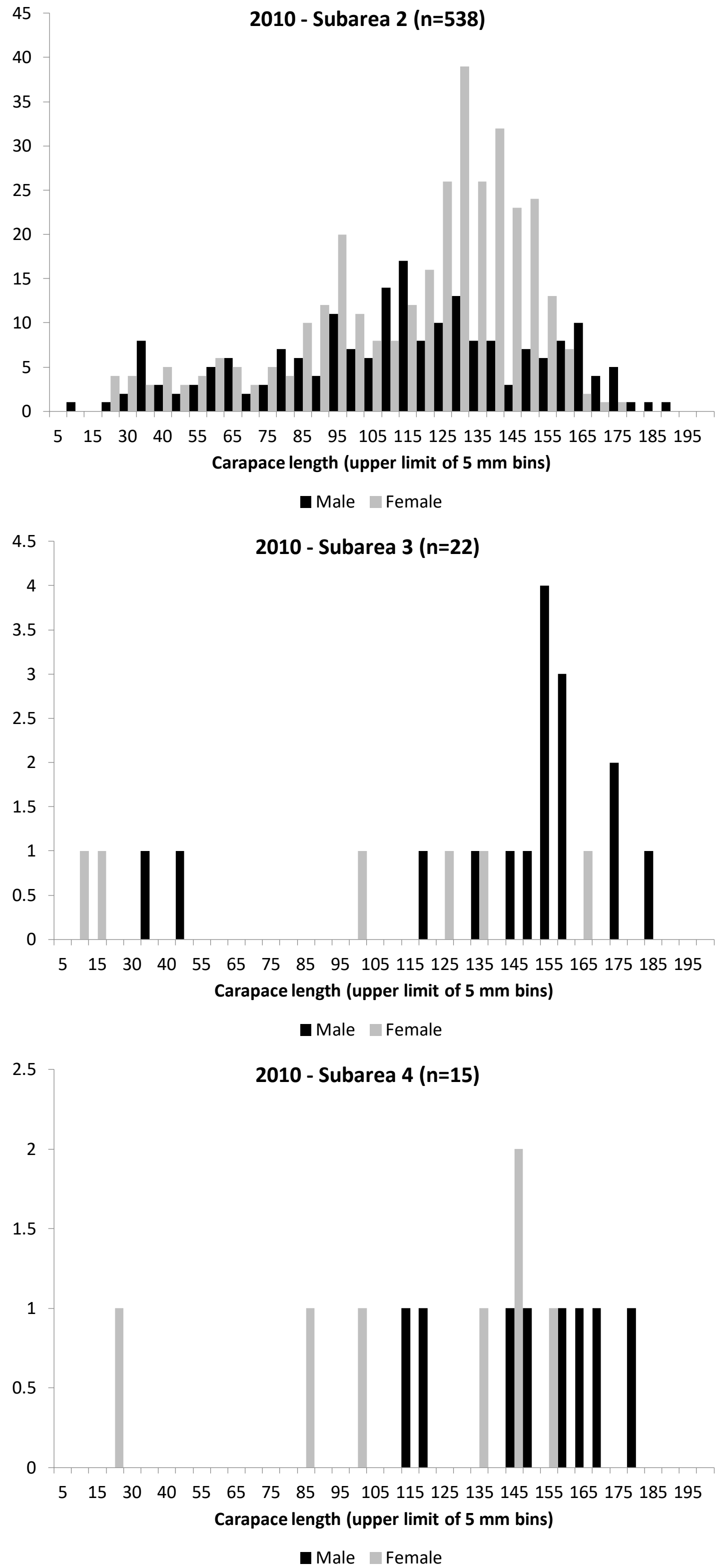

Figure 12. Size distribution of measured golden king crab during the 2010 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

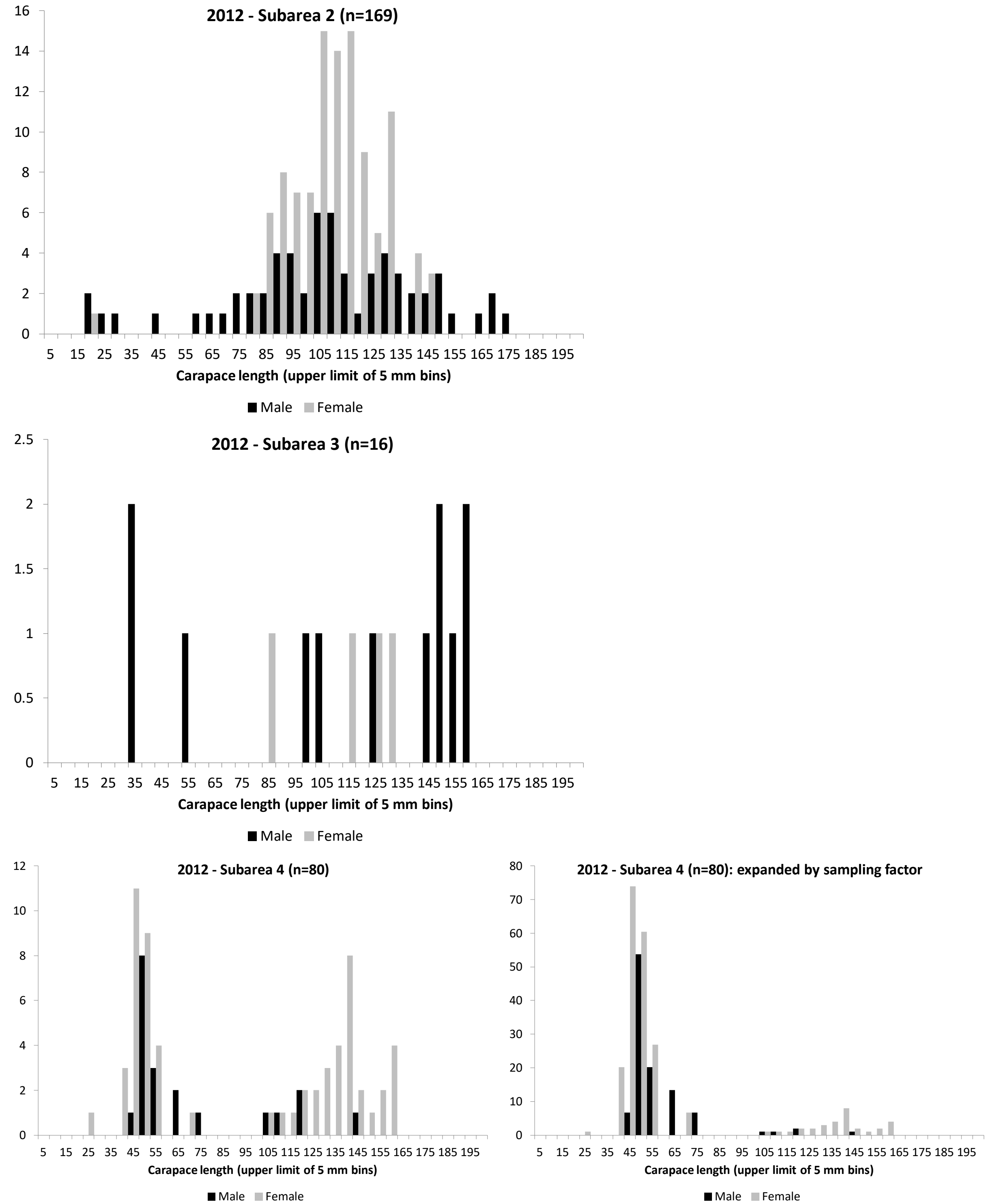

Figure 13. Size distribution of measured golden king crab during the 2012 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

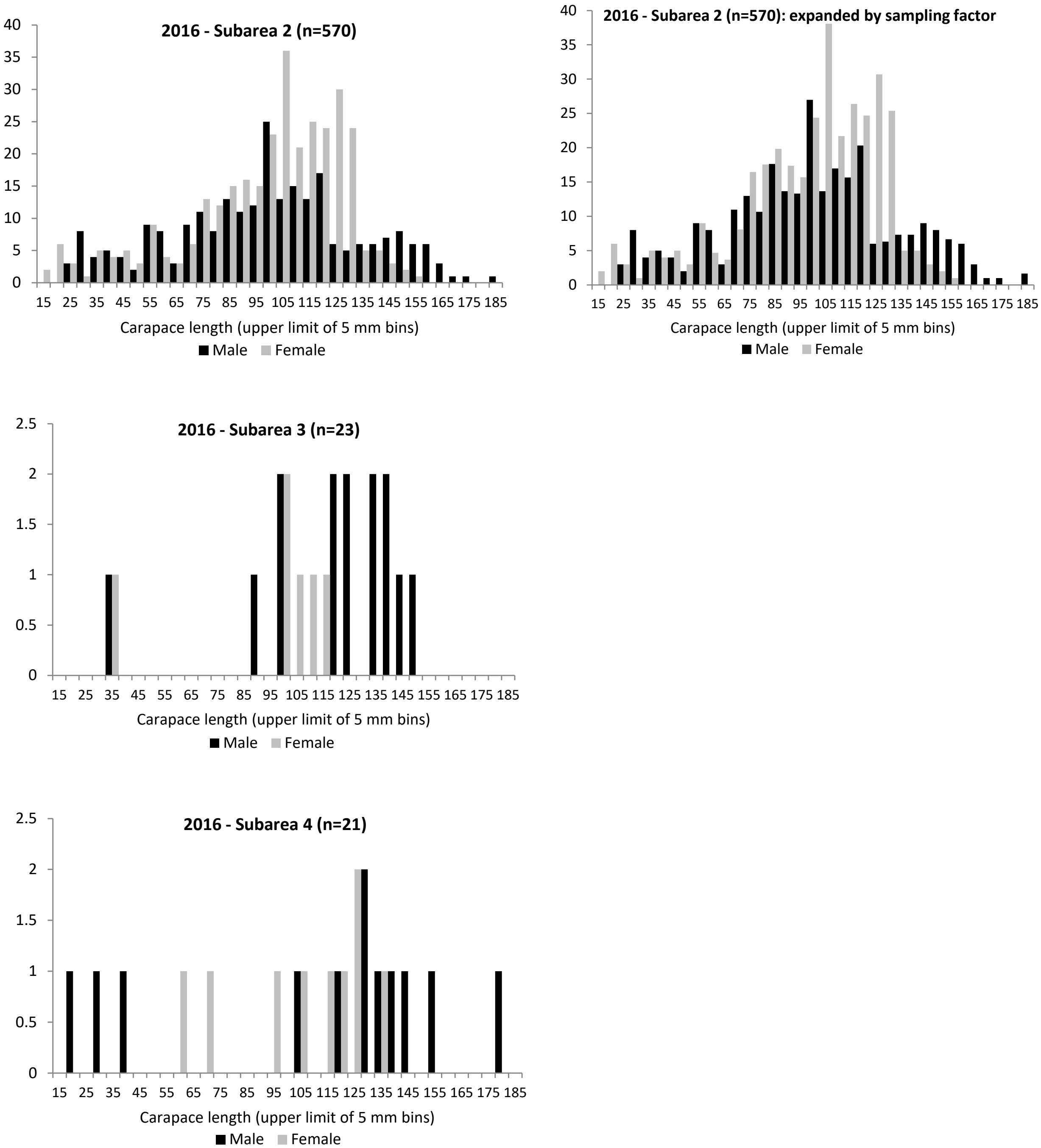

Figure 14. Size distribution of measured golden king crab during the 2016 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

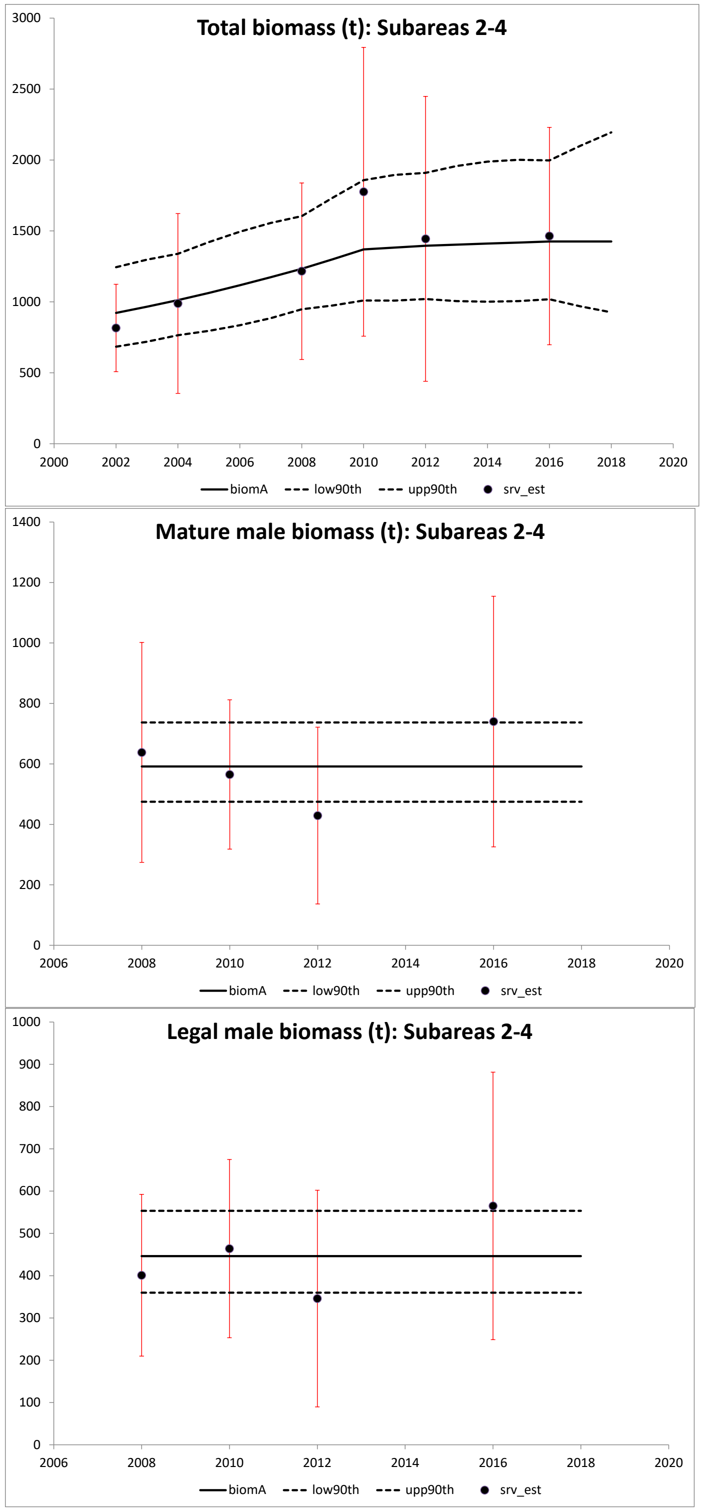

Figure 15. Plots of estimated and projected-into-2018 biomass of total, mature male, and legal male golden king crab in NMFS slope survey Subareas 2–4 with 90% confidence intervals and survey area-swept estimates; red bars are survey estimate plus/minus 2 standard errors.

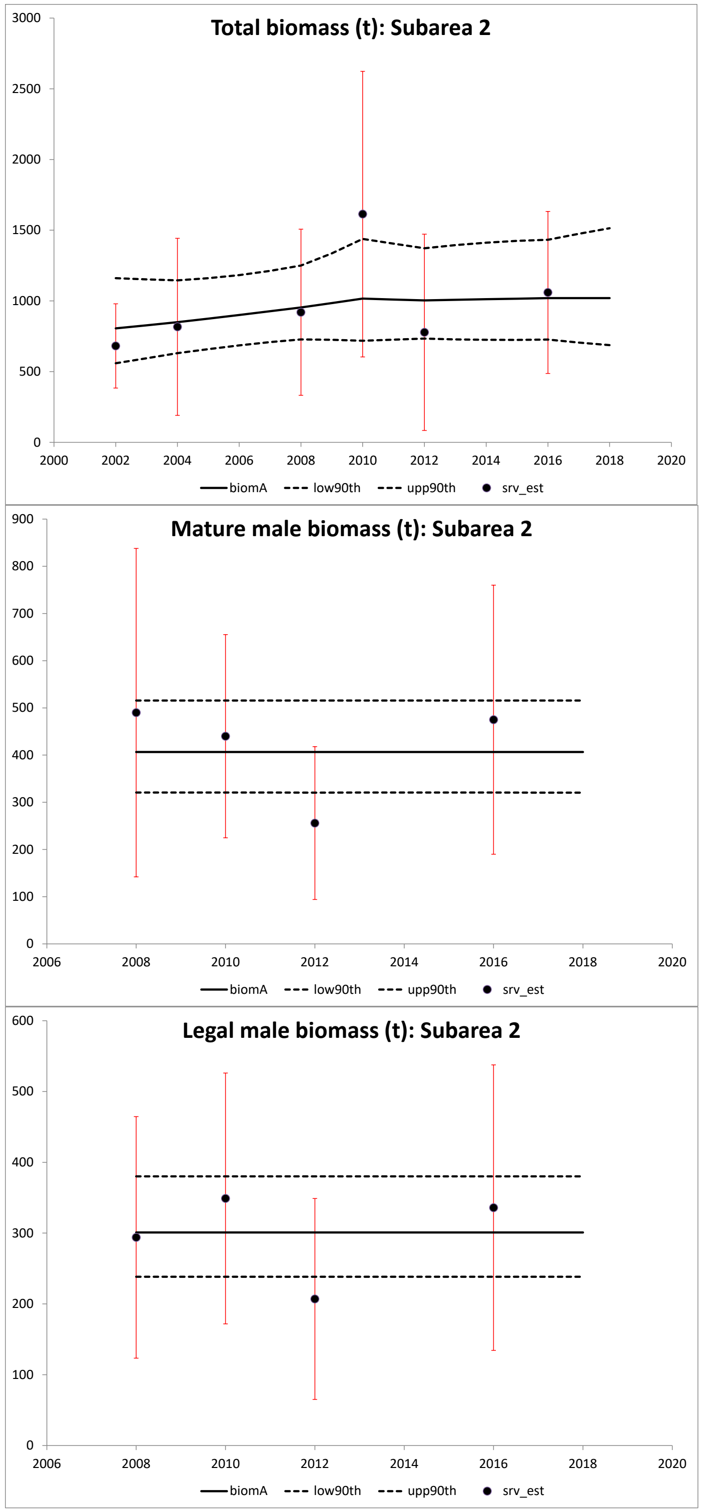

Figure 16. Plots of estimated and projected-into-2018 biomass of total, mature male, and legal male golden king crab in NMFS slope survey Subarea 2 with 90% confidence intervals and survey area-swept estimates; red bars are survey estimate plus/minus 2 standard errors.

Appendix 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.

re.dat file

2002	#Start year of model				
2018	#End year of model				
6	#number of survey estimates				
#Years of survey					
2002	2004	2008	2010	2012	2016
#Biomass estimates					
816	989	1216	1776	1444	1464
#Coefficients of variation for biomass estimates					
0.19	0.32	0.26	0.29	0.35	0.26

rwout.rep file

yrs_srv																	
	2002	2004	2008	2010	2012	2016											
srv_est																	
	816	989	1216	1776	1444	1464											
srv_sd																	
	0.188318	0.312233	0.25576	0.284166	0.339939	0.25576											
yrs																	
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI																	
	645.592	679.925	725.189	752.615	790.057	838.815	901.75	922.256	952.61	949.698	960.644	943.422	937.229	940.902	954.447	899.215	853.018
biomA																	
	922.492	966.221	1012.02	1063.35	1117.29	1173.96	1233.5	1299.86	1369.79	1382.64	1395.6	1403.14	1410.71	1418.33	1425.99	1425.99	1425.99
UCI																	
	1318.16	1373.07	1412.31	1502.39	1580.05	1643	1687.3	1832.06	1969.66	2012.94	2027.5	2086.87	2123.4	2138.02	2130.5	2261.36	2383.83
low90th																	
	683.706	719.43	765.09	795.604	835.309	885.377	948.313	974.552	1009.87	1008.79	1020.07	1005.57	1000.89	1005.05	1018.06	968.382	926.452
upp90th																	
	1244.67	1297.67	1338.66	1421.21	1494.45	1556.59	1604.45	1733.75	1857.98	1895.02	1909.38	1957.89	1988.34	2001.55	1997.37	2099.84	2194.87
biomsd																	
	6.82708	6.87339	6.91971	6.96918	7.01866	7.06813	7.11761	7.17001	7.22241	7.23175	7.24108	7.24647	7.25185	7.25724	7.26262	7.26262	7.26262
biomsd.sd																	
	0.182097	0.179291	0.170039	0.176341	0.176813	0.171502	0.159833	0.175096	0.185309	0.191634	0.19055	0.202527	0.208635	0.209386	0.204842	0.235255	0.262163

Appendix 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.

re.dat file				
2008	#Start year of model			
2018	#End year of model			
4	#number of survey estimates			
#Years of survey				
2008	2010	2012	2016	
#Biomass estimates				
638	565	429	740	
#Coefficients of variation for biomass estimates				
0.29	0.22	0.34	0.28	

rwout.rep file											
yrs_srv											
	2008	2010	2012	2016							
srv_est											
	638	565	429	740							
srv_sd											
	0.284166	0.217406	0.330745	0.274733							
yrs											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI											
	455.113	455.114	455.115	455.114	455.114	455.115	455.113	455.109	455.103	455.099	455.095
biomA											
	591.486	591.485	591.484	591.484	591.485	591.486	591.488	591.49	591.492	591.492	591.492
UCI											
	768.721	768.718	768.715	768.716	768.718	768.721	768.728	768.74	768.756	768.762	768.768
low90th											
	474.693	474.694	474.694	474.694	474.693	474.694	474.693	474.69	474.684	474.681	474.678
upp90th											
	737.014	737.011	737.009	737.01	737.011	737.014	737.02	737.03	737.043	737.048	737.053
biomsd											
	6.38264	6.38264	6.38264	6.38264	6.38264	6.38264	6.38264	6.38265	6.38265	6.38265	6.38265
biomsd.sd											
	0.13372	0.133718	0.133717	0.133718	0.133718	0.133719	0.133722	0.133728	0.133737	0.133741	0.133745

Appendix 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.

re.dat file

2008	#Start year of model			
2018	#End year of model			
4	#number of survey estimates			
#Years of survey				
2008	2010	2012	2016	
#Biomass estimates				
401	464	346	565	
#Coefficients of variation for biomass estimates				
0.24	0.23	0.37	0.28	

rwout.rep file

yrs_srv											
	2008	2010	2012	2016							
srv_est											
	401	464	346	565							
srv_sd											
	0.236648	0.227042	0.358197	0.274733							
yrs											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI											
	345.148	345.153	345.158	345.158	345.158	345.156	345.151	345.143	345.132	345.129	345.126
biomA											
	446.173	446.174	446.175	446.176	446.177	446.178	446.18	446.182	446.184	446.184	446.184
UCI											
	576.768	576.762	576.758	576.759	576.761	576.769	576.781	576.799	576.822	576.828	576.834
low90th											
	359.687	359.692	359.696	359.696	359.696	359.695	359.691	359.684	359.675	359.672	359.669
upp90th											
	553.454	553.45	553.446	553.448	553.449	553.456	553.467	553.481	553.5	553.505	553.509
biomsd											
	6.10071	6.10071	6.10071	6.10071	6.10071	6.10072	6.10072	6.10073	6.10073	6.10073	6.10073
biomsd.sd											
	0.130986	0.13098	0.130975	0.130975	0.130976	0.130981	0.13099	0.131004	0.131022	0.131027	0.131032

Appendix 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.

re.dat file					
2002	#Start year of model				
2018	#End year of model				
6	#number of survey estimates				
#Years of survey					
2002	2004	2008	2010	2012	2016
#Biomass estimates					
682	817	920	1614	778	1060
#Coefficients of variation for biomass estimates					
0.22	0.38	0.32	0.31	0.45	0.27

rwout.rep file																	
yrs_srv																	
	2002	2004	2008	2010	2012	2016											
srv_est																	
	682	817	920	1614	778	1060											
srv_sd																	
	0.217406	0.367261	0.312233	0.302917	0.429421	0.265265											
yrs																	
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI																	
	521.757	558.084	595.708	624.797	650.996	673.321	691.078	684.518	671.956	681.957	691.351	684.38	680.48	679.379	680.946	657.937	637.299
biomA																	
	805.904	827.675	850.035	874.937	900.568	926.95	954.105	984.827	1016.54	1010.12	1003.74	1007.86	1011.99	1016.14	1020.31	1020.31	1020.31
UCI																	
	1244.8	1227.5	1212.94	1225.22	1245.82	1276.12	1317.24	1416.89	1537.82	1496.2	1457.29	1484.23	1505.01	1519.84	1528.81	1582.27	1633.51
low90th																	
	559.517	594.576	630.736	659.541	685.85	708.818	727.844	725.728	718.182	726.402	734.044	728.306	725.297	724.789	726.67	706.005	687.371
upp90th																	
	1160.79	1152.16	1145.58	1160.68	1182.51	1212.21	1250.7	1336.43	1438.84	1404.65	1372.53	1394.72	1412.01	1424.62	1432.61	1474.54	1514.52
biomsd																	
	6.69196	6.71862	6.74528	6.77415	6.80303	6.8319	6.86077	6.89247	6.92416	6.91782	6.91149	6.91558	6.91968	6.92377	6.92786	6.92786	6.92786
biomsd.sd																	
	0.221818	0.201078	0.181392	0.171798	0.165572	0.163101	0.164552	0.185587	0.211207	0.200438	0.190226	0.197485	0.202489	0.205403	0.206316	0.223854	0.240114

Appendix 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.

re.dat file

2008	#Start year of model			
2018	#End year of model			
4	#number of survey estimates			
#Years of survey				
2008	2010	2012	2016	
#Biomass estimates				
490	440	256	475	
#Coefficients of variation for biomass estimates				
0.36	0.24	0.32	0.3	

rwout.rep file

yrs_srv											
	2008	2010	2012	2016							
srv_est											
	490	440	256	475							
srv_sd											
	0.34909	0.236648	0.312233	0.29356							
yrs											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI											
	306.329	306.333	306.335	306.332	306.325	306.327	306.328	306.328	306.327	306.323	306.319
biomA											
	406.596	406.595	406.594	406.592	406.59	406.591	406.592	406.594	406.595	406.595	406.595
UCI											
	539.683	539.674	539.666	539.666	539.673	539.672	539.674	539.678	539.684	539.691	539.698
low90th											
	320.592	320.595	320.597	320.593	320.587	320.589	320.59	320.59	320.589	320.586	320.582
upp90th											
	515.674	515.666	515.66	515.659	515.664	515.664	515.665	515.669	515.674	515.68	515.685
biomsd											
	6.00782	6.00782	6.00782	6.00781	6.0078	6.00781	6.00781	6.00781	6.00782	6.00782	6.00782
biomsd.sd											
	0.14447	0.144463	0.144457	0.14446	0.144469	0.144466	0.144466	0.144468	0.144473	0.144479	0.144486

Appendix 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.

re.dat file				
2008	#Start year of model			
2018	#End year of model			
4	#number of survey estimates			
#Years of survey				
2008	2010	2012	2016	
#Biomass estimates				
294	349	207	336	
#Coefficients of variation for biomass estimates				
0.29	0.25	0.34	0.3	

rwout.rep file											
yrs_srv											
	2008	2010	2012	2016							
srv_est											
	294	349	207	336							
srv_sd											
	0.284166	0.246221	0.330745	0.29356							
yrs											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI											
	227.905	227.906	227.907	227.906	227.905	227.905	227.905	227.904	227.903	227.902	227.901
biomA											
	301.019	301.02	301.02	301.019	301.018	301.019	301.019	301.019	301.02	301.02	301.02
UCI											
	397.589	397.588	397.587	397.587	397.587	397.588	397.59	397.592	397.594	397.596	397.599
low90th											
	238.328	238.329	238.33	238.329	238.328	238.328	238.327	238.327	238.326	238.325	238.324
upp90th											
	380.202	380.201	380.2	380.199	380.2	380.201	380.202	380.203	380.205	380.207	380.209
biomsd											
	5.70717	5.70718	5.70718	5.70717	5.70717	5.70717	5.70717	5.70718	5.70718	5.70718	5.70718
biomsd.sd											
	0.141961	0.14196	0.141958	0.141959	0.141961	0.141961	0.141963	0.141964	0.141966	0.14197	0.141973

Appendix 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, 2012, and 2016. Total biomass estimates generally increased from 2002 through 2012; with no substantial increase in 2016.
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.

Appendix C. Page 2 of 2.

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.

10. Western Aleutian Islands Red King Crab

May 2020 Crab SAFE Draft Report

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Executive Summary

1. **Stock:**

Western Aleutian Islands (the 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 2004/05–2019/20. 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 1995/96–2019/20 averaged 1 t (1,692 lb). Estimated annual weight of bycatch mortality due to groundfish fisheries during 1993/94–2019/20 averaged 7 t (15,818 lb). Estimated weight of annual total fishery mortality during 1995/96–2019/20 averaged 30 t (66,011 lb); the average annual retained catch during that period was 23 t (50,405 lb). A cooperative red king crab survey was performed by the Aleutian

Islands King Crab Foundation (an industry group) and ADF&G in the Petrel Bank area in November 2016 (Hilsinger and Siddon 2016b), which resulted in an estimated bycatch mortality of 0.03 t (59 lb). Estimated total fishery mortality in 2019/20 resulted from groundfish fisheries (0.74t; 1,623 lb) and the Aleutian Islands golden king crab fishery. The 2019/20 Aleutian Islands golden king crab fishery was not completed at the time of this report, but the preliminary bycatch mortality estimate is 0.01 t (14 lb).

3. Stock biomass:

Estimates of past or present 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:

The WAIRKC stock assessment is now conducted on a 3-year cycle. Since the last assessment in 2017, overfishing did not occur during 2017/18, 2018/19, and 2019/20 seasons because the estimated total catch did not exceed the Tier 5 OFL established for those years (56 t; 123,867 lb). Additionally, the 2017/18, 2018/19, and 2019/20 estimated total catch did not exceed the ABC established for those years (14 t; 30,967 lb). No determination has yet been made for a fishery opening or harvest level, if opened, for 2020/21. The OFL and ABC values for 2020/21, 2021/22, and 2022/23 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
2015/16	N/A	N/A	Closed	0	1.3	56	34
2016/17	N/A	N/A	Closed	0	<1	56	34
2017/18	N/A	N/A	Closed	0	<1	56	14
2018/19	N/A	N/A	Closed	0	<1	56	14
2019/20	N/A	N/A	Closed	0	<1	56	14
2020/21	N/A	N/A				56	14
2021/22	N/A	N/A				56	14
2022/23	N/A	N/A				56	14

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
2015/16	N/A	N/A	Closed	0	2,964	123,867	74,320
2016/17	N/A	N/A	Closed	0	454	123,867	74,320
2017/18	N/A	N/A	Closed	0	751	123,867	30,967
2018/19	N/A	N/A	Closed	0	314	123,867	30,967
2019/20	N/A	N/A	Closed	0	1,637	123,867	30,967
2020/21	N/A	N/A				123,867	30,967
2021/22	N/A	N/A				123,867	30,967
2022/23	N/A	N/A				123,867	30,967

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.

6. Basis for the OFL and ABC:

See table below; values are the author's recommended values.

Year	Tier	Years to define Average catch (OFL)	Natural Mortality	Buffer
2015/16	5	1995/96-2007/08[a]	0.18[b]	40%
2016/17	5	1995/96-2007/08[a]	0.18[b]	40%
2017/18	5	1995/96-2007/08[a]	0.18[b]	75%
2018/19	5	1995/96-2007/08[a]	0.18[b]	75%
2019/20	5	1995/96-2007/08[a]	0.18[b]	75%
2020/21	5	1995/96-2007/08[a]	0.18[b]	75%
2021/22	5	1995/96-2007/08[a]	0.18[b]	75%
2022/23	5	1995/96-2007/08[a]	0.18[b]	75%

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 14 t is the same as that recommended by the CPT in 2017, which was less than the ABC that was recommended by the SSC for 2012/13 – 2016/17. The recommended ABC was lowered in 2017 because 1) the industry has not expressed interest in a small test fishery during 2017/18, and 2) because the stock is severely depressed as indicated by the 2016 Petrel survey (CPT minutes for May 2017). This logic remains true for this assessment cycle.

At 14 t, the ABC provides a 75% buffer on the OFL of 56 t; i.e., (1.0-0.75)·56 t = 14 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. **Changes to the management of the fishery:** 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. **Changes to the input data:**
   - Data on retained catch, discarded catch, and estimates of bycatch mortality in crab and groundfish fisheries during 2017/18, 2018/19, and 2019/20 have been added, but were not entered into the calculation of the recommended 2020/21, 2021/22, and 2022/23 total-catch OFL.

3. **Changes to the assessment methodology:** None: the computation of OFL in this assessment follows the methodology recommended by the SSC in June 2010.

4. **Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL:** 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 2010/11–2019/20 OFLs.

B. Responses to SSC and CPT Comments

1. **Responses to the most recent SSC and CPT comments specific to the assessment:**
   - CPT, May 2017: "*The 2015/16 groundfish bycatch was very high compared to previous years. CPT requested the author to report which groundfish gear/target fishery reported high bycatch of red king crab*."
     - Response: Done, see Table 6.
   - SSC, June 2017: "*The SSC broadens the CPT's request for additional information about the source of this bycatch to include fishery, specific area, season, sample sizes used for estimation, etc. The SSC also requests some evaluation to the extent possible about the potential that these removals represent a conservation concern to this crab stock.*"
     - Response: We provide bycatch mortality by year and target fishery in Table 6 and Figure 6. While bycatch mortality in the groundfish fisheries was relatively high in the 2015/16 season (1.19 t) relative to the three prior seasons, it was well below the average for prior rationalized years (2005-2014, 2.25 t). Further, 2015/16 bycatch mortality in groundfish fisheries made up approximately 2% of the OFL, suggesting this level of removals is not a conservation concern for the stock overall. Most (~98%) of the 2015/16 bycatch occurred in the Atka mackerel fishery, of which mostly (~57%) was captured approximately 100 km north of Semisopochnoi Island.

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 was opened only in the Petrel Bank area (i.e., between 179° W longitude and 179° E longitude; Baechler and Cook 2014) during the most recent two years that the fishery was prosecuted (2002/03 and 2003/04). 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). Depth was recorded for 578 pots out of the 580 pot lifts sampled by observers during the 1996/97–2006/07 Aleutian Islands golden king crab fishery that contained 1 or more red king crab (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 ADF&G (2017) 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 long.), 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, and as that Maritime Boundary Agreement Line is depicted on *NOAA Chart #513* (7th Edition, June 2004) and *NOAA Chart #514* (7th Edition, January 2004), adopted by reference, and its northern boundary a line from the latitude of Cape Sarichef (54° 36′ N lat.) to 171° W long., north to 55° 30' N lat., and west to the Maritime Boundary Agreement Line.

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. Evidence of stock structure:

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 (reviewed in Grant et al. 2014).

To date, population genetic studies of red king crab within the WAI have only grouped samples from within this region as one site (i.e., Adak Island) (Grant et al. 2014). Given the complexity of currents throughout the WAI and that canyons deeper than the depth restrictions of red king crab (>1,000 m) separate several islands, the possibility of fine scale genetic structuring exists, but remains uninvestigated. 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. Most catch during that period was 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 upon 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 Islands; 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. Most recently, 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 also suggest that, for males, not molting early in the mating period provides the advantage of mating when primiparous and small, multiparous females tend to ovulate. Alternatively, males that do molt early in the mating period likely participate in mating later, and with 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. <u>Brief summary of management history</u>:

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 2004/05–2019/20.

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 2017/18, 2018/19, and 2019/20 directed fishery has been added; the fishery was closed and the retained catch was 0 t (0 lb) in each year.
- Data on discarded catch in crab and groundfish fisheries has been updated with data from 2017/18, 2018/19, and 2019/20. The 2019/20 Aleutian Islands golden king crab fishery was not completed at the time of this report, but preliminary discard estimates are presented here.
- Discarded catch during the cooperative industry-ADF&G survey in 2016. Data was available as number of crab caught per size/sex group (males: legal, sub-legal, 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 1960/61–2019/20 (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 1995/96–2019/20 (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 2004/05–2019/20 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 1993/94–2019/120 (Tables 4–6, Figure 6). 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 1993/94–2019/20 is also presented in Table 5.
- Annual estimated weight of total fishery mortality for 1995/96–2019/20, partitioned into retained catch, estimated bycatch mortality during crab fisheries, and estimated bycatch mortality during federal groundfish fisheries (Table 7). 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 7 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 7 are from Table 4.
- Table 8 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 1960/61–2019/20 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 1972/73–2019/20 directed fisheries are presented (Table 1, Figure 7).

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, 1988/89–2019/20 (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. Model Description:

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 2020/21, 2021/22, and 2022/230 OFLs 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 2020/21-2022/23 is computed according to the status quo "Alternative 1" approach as:

$$OFL_{20/21\text{-}22/23} = RET_{95/96\text{-}07/08} + BM_{CF,\ 95/96\text{-}07/08} + BM_{GF,\ 95/96\text{-}07/08},$$

where,

- $RET_{95/96\text{-}07/08}$ is the average annual retained catch in the directed crab fishery during 1995/96–2007/08
- $BM_{CF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the directed and non-directed crab fisheries during 1995/96–2007/08, and
- $BM_{GF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the groundfish fisheries during 1995/96–2007/08.

Given the June 2010 SSC recommendations, items ***E.2 a–i*** are not applicable.

3. Model Selection and Evaluation:

a. ***Description of alternative model configurations***
Not applicable; see section E.2.

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 the section A.4.

d. ***Convergence status and convergence criteria for the base-case model (or proposed base-case model):*** Not applicable.

e. ***Table (or plot) of the sample sizes assumed for the compositional data:*** Not applicable.

f. ***Do parameter estimates for all models make sense, are they credible?:***
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 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 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. **Specification of the Tier level and stock status level for computing the OFL:**
   - Recommended as Tier 5, total-catch OFL computed as the estimated average annual total catch over a specified period.
   - Recommended time period for computing retained-catch portion of the OFL: 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 2020/21–2022/23 is estimated by,

$$OFL_{20/21\text{-}22/23} = RET_{95/96\text{-}07/08} + BM_{CF,\ 95/96\text{-}07/08} + BM_{GF,\ 95/96\text{-}07/08},$$

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,

$$OFL_{20/21\text{-}22/23} = 43.97\text{ t} + 1.36\text{ t} + 10.86\text{ t} = 56\text{ t (123,867 lb)}.$$

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 (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 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. No vessels participated in the 2017/18, 2018/19, and 2019/20 directed fisheries and but some bycatch was observed in the Aleutian Islands golden king crab fishery in 2017/18, 2018/19, and 2019/20. Total catch mortality in

2017/18, 2018/19, and 2019/20 consists of what occurred during the Aleutian Islands golden king crab fishery and groundfish fisheries. Overfishing did not occur in 2017/18, 2018/19, and 2019/20. The OFL and ABC values for 2020/21, 2021/22, 2022/23 in the table below are the author's recommended values. The 2020/121 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
2015/16	N/A	N/A	Closed	0	1.3	56	34
2016/17	N/A	N/A	Closed	0	<1	56	34
2017/18	N/A	N/A	Closed	0	<1	56	14
2018/19	N/A	N/A	Closed	0	<1	56	14
2019/20	N/A	N/A	Closed	0	<1	56	14
2020/21	N/A	N/A				56	14
2021/22	N/A	N/A				56	14
2022/23	N/A	N/A				56	14

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
2015/16	N/A	N/A	Closed	0	2,964	123,867	74,320
2016/17	N/A	N/A	Closed	0	454	123,867	74,320
2017/18	N/A	N/A	Closed	0	751	123,867	30,967
2018/19	N/A	N/A	Closed	0	314	123,867	30,967
2019/20	N/A	N/A	Closed	0	1,637	123,867	30,967
2020/21	N/A	N/A				123,867	30,967
2021/22	N/A	N/A				123,867	30,967
2022/23	N/A	N/A				123,867	30,967

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.

4. **Specification of the recommended retained-catch portion of the total-catch OFL:**
   a. Equation for recommended retained portion of the total-catch OFL,
   Retained-catch portion = average retained catch during 1995/96–2007/08
   = 44 t (96,932 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. A bootstrap estimate of the sampling distribution (assuming no error in estimation of the discarded catch) of the OFL is shown in Figure 8 (the sample means of 1,000 samples drawn with replacement from the 1995/96–2007/08 estimates of total fishery mortality in Table 7). 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

7. 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: 14 t (30,967 lb). This is lower than the ABC that has been recommended by the author since the SSC recommended a 34 t (74,320 lb) 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 (123,867 lb). However, the industry has not expressed interest in conducting a test fishery, and the 2016 Petrel survey indicated the stock is severely depressed. Thus, the author recommends keeping the 75% buffer.

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. 2016a). 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. A cooperative survey between industry and ADF&G was also performed in the Petrel area in November 2016 (Hilsinger et al. 2016b). A total of 40 red king crab (39 legal males, 1 sub-legal male, and 0 females) were captured. CPUE or legal-size male red king crab was 0.11.

J. Literature Cited

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Tables

Table 1a. Commercial fishery history for the western Aleutian Islands red king crab commercial fishery, 1960/61–2019/20: 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 2005/06–2019/120, 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
2004/05–2019/20	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, 1960/61–2019/20 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 2005/06–2019/20, 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
2004/05–2019/20	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
2004/05–2019/20	• Fishery closed o 2006 and 2009 ADF&G pot surveys on Petrel Bank o 2015 exploratory/reconnaissance survey in Adak Island area. o 2016 exploratory/reconnaissance survey in the Petrel Bank 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, 1995/96–2019/20. The 2019/20 AIGKC fishery was not completed at the time of this report, but a preliminary estimate is provided below.

Crab fishing	WAI red king crab fishery				AI golden king crab fishery			Total
		Discarded						
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
2016/17	0.00	0.00	0.00	0.00	0.15	0.01	0.07	0.23
2017/18	0.00	0.00	0.00	0.00	0.74	0.25	0.00	1.00
2018/19	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03
2019/20	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03
Average	22.86	0.05	0.77	1.17	1.30	0.29	0.19	3.98

[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), 1993/94–2019/20 (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	0.01	1.73	0.00	1.39	1.39
2010/11	0.00	0.61	0.01	0.49	0.49
2011/12	0.01	0.72	0.00	0.58	0.59
2012/13	0.00	0.08	0.01	0.06	0.06
2013/14	0.01	0.04	0.00	0.03	0.04
2014/15	0.00	0.11	0.02	0.09	0.09
2015/16	0.03	1.46	0.02	1.17	1.19
2016/17	0.00	0.17	0.00	0.13	0.13
2017/18	0.00	0.17	0.00	0.14	0.14
2018/19	0.00	0.17	0.00	0.13	0.13
2019/20	0.00	0.92	0.00	0.74	0.74
Average	2.13	7.63	1.06	6.11	7.17

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, 1993/94–2019/20.

Crab fishing	Reporting Area			
year	541	542	543	Total
1993/94	37.989	2.659	0.037	40.685
1994/95	10.722	0.872	0.103	11.696
1995/96	5.952	1.840	1.776	9.568
1996/97	1.948	3.089	16.526	21.562
1997/98	1.006	3.964	2.077	7.047
1998/99	6.755	7.166	11.333	25.254
1999/00	16.342	8.054	5.423	29.818
2000/01	1.769	3.654	2.096	7.519
2001/02	3.475	24.034	1.925	29.434
2002/03	11.000	21.310	5.938	38.248
2003/04	2.229	3.528	0.016	5.773
2004/05	0.528	5.680	0.015	6.224
2005/06	1.606	0.039	1.033	2.678
2006/07	2.969	0.387	0.000	3.356
2007/08	5.123	3.043	0.725	8.891
2008/09	1.144	7.546	0.867	9.556
2009/10	1.672	3.755	1.114	6.540
2010/11	0.212	1.816	0.000	2.029
2011/12	0.877	1.134	0.000	2.011
2012/13	0.156	0.090	0.000	0.246
2013/14	0.000	0.044	0.012	0.055
2014/15	0.000	0.115	0.000	0.115
2015/16	0.000	0.886	0.610	1.497
2016/17	0.015	0.141	0.145	0.301
2017/18	0.613	0.176	0.000	0.789
2018/19	0.649	0.166	0.000	0.815
2019/20	0.000	0.404	0.517	0.920
Average	4.250	3.911	1.937	10.097

Table 6. Estimated annual proportion of total discarded catch (<u>not</u> 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 target fishery, 2009/10–2019/20.

	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
Arrowtooth Flounder	<0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Atka Mackerel	0.685	0.404	0.945	1.000	0.758	0.977	0.978	0.943	0.471	0.452	0.439
Greenland Turbot	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Halibut	0.000	0.000	0.000	0.000	0.016	0.011	0.000	0.048	0.001	0.000	0.000
Pacific Cod	0.143	0.595	0.015	0.000	0.000	0.000	0.000	0.000	0.010	0.001	0.000
Rockfish	0.172	0.000	0.038	0.000	0.000	0.000	0.000	0.000	0.513	0.547	0.561
Sablefish	0.000	0.000	0.003	0.000	0.226	0.012	0.022	0.009	0.005	0.000	0.000

Table 7. Estimated annual weight (**t**) of total fishery mortality to Western Aleutian Islands red king crab, 1995/96–2019/20, 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		
Crab fishing year	Retained Catch	Crab	Groundfish	Total Estimated 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	0.06	0.09	0.15
2015/16	0.00	0.16	1.19	1.34
2016/17	0.00	0.07	0.13	0.21
2017/18	0.00	0.20	0.14	0.34
2018/19	0.00	0.01	0.14	0.14
2019/20	0.00	0.01	0.74	0.74
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, 1995/96–2019/20	22.86	0.77	6.31	29.94
CV of mean	0.55	0.37	0.26	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 8. 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) 2019/20 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
2016/17	0.00	0.23	0.00	0.17
2017/18	0.00	1.00	0.00	0.17
2018/19	0.00	0.03	0.00	0.17
2019/20	0.00	0.03	0.00	0.92

Figures

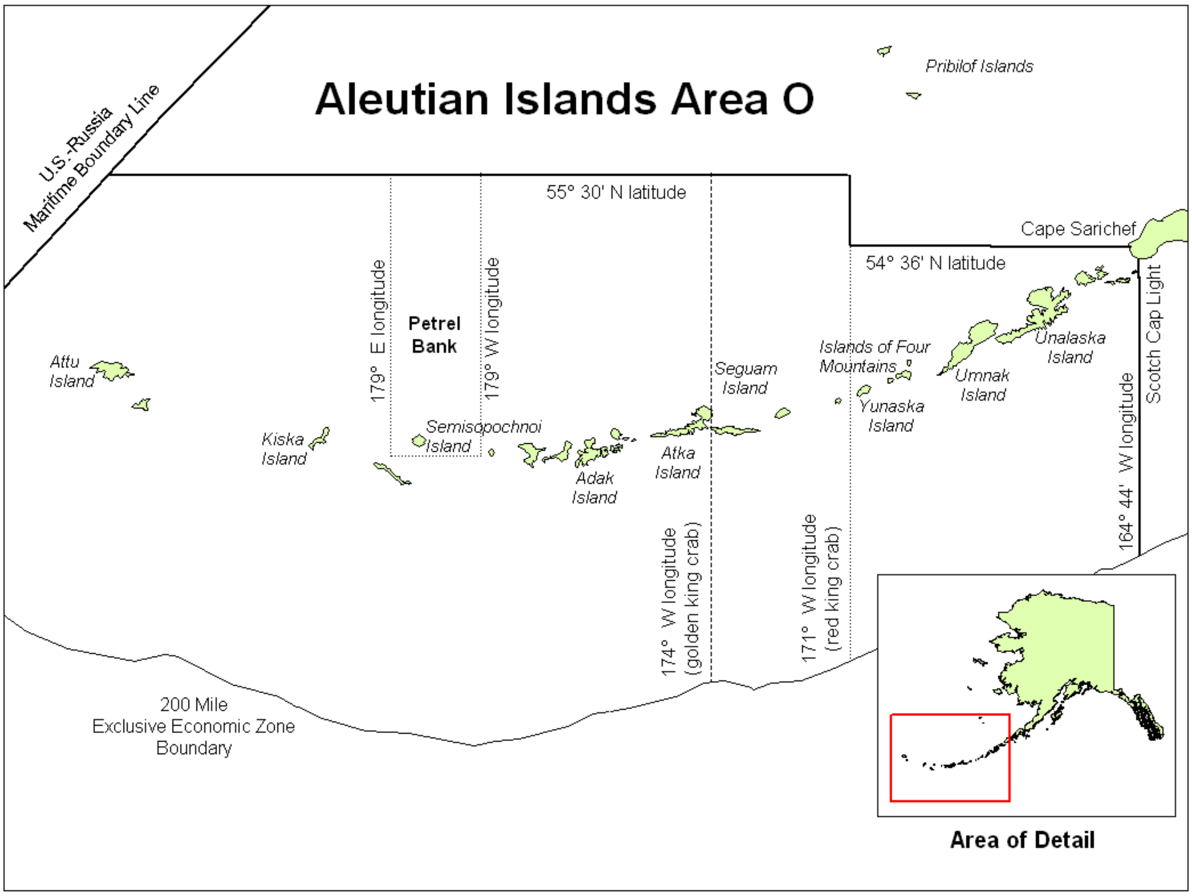

Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Baechler and Cook 2014, updated to show boundaries of the Adak and Petrel Districts for red king crab as established by the Alaska Board of Fisheries in March 2014).

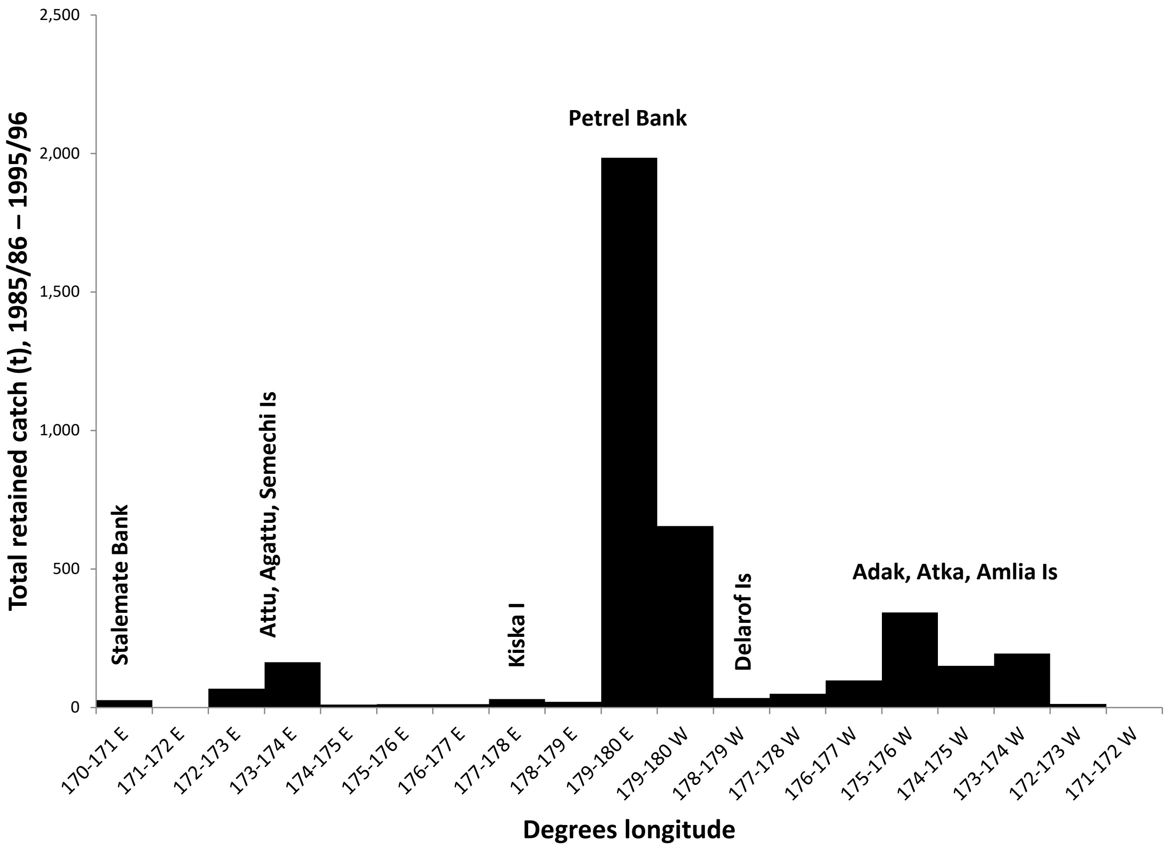

Figure 2. Retained catch (**t**) in the Western Aleutian Islands red king crab fishery, 1985/86–1995/96 by 1-degree longitude grouping, summarized from fish ticket catch by state statistical area landing data.

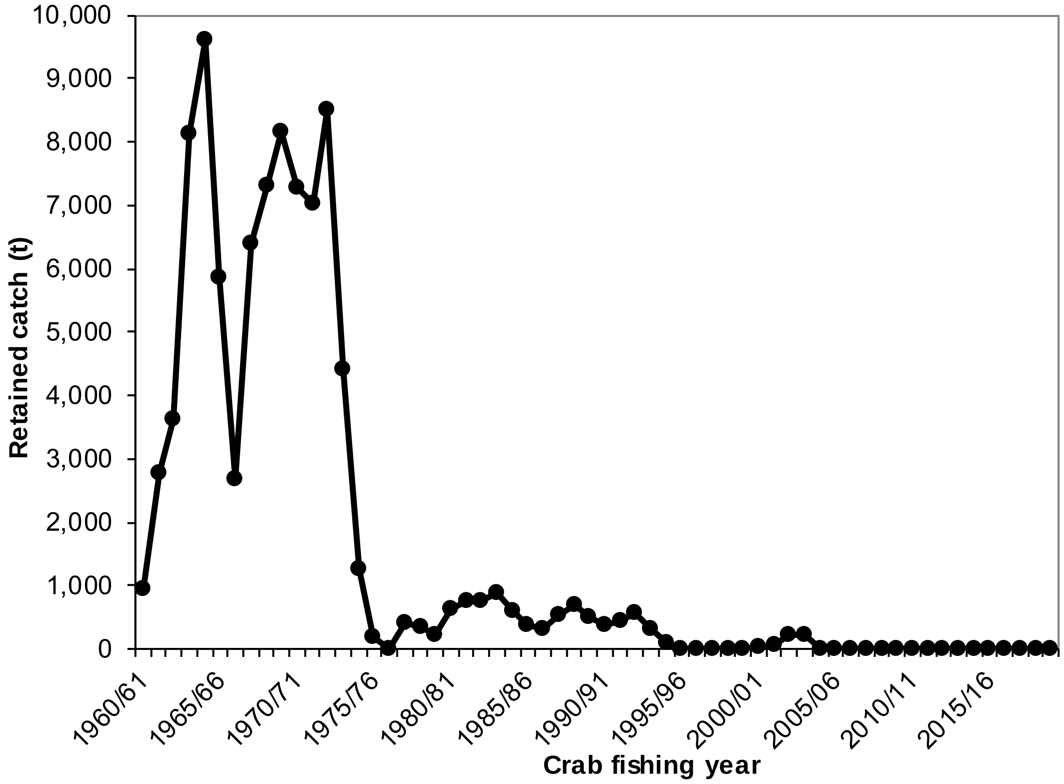

Figure 3. Retained catch (**t**) in the Western Aleutian Islands red king crab fishery, 1960/61–2019/20 (catch is for the area west of 172° W longitude during 1960/61–1983/84 and for the area west of 171° W longitude during 1984/85–2019/20; see Table 1a).

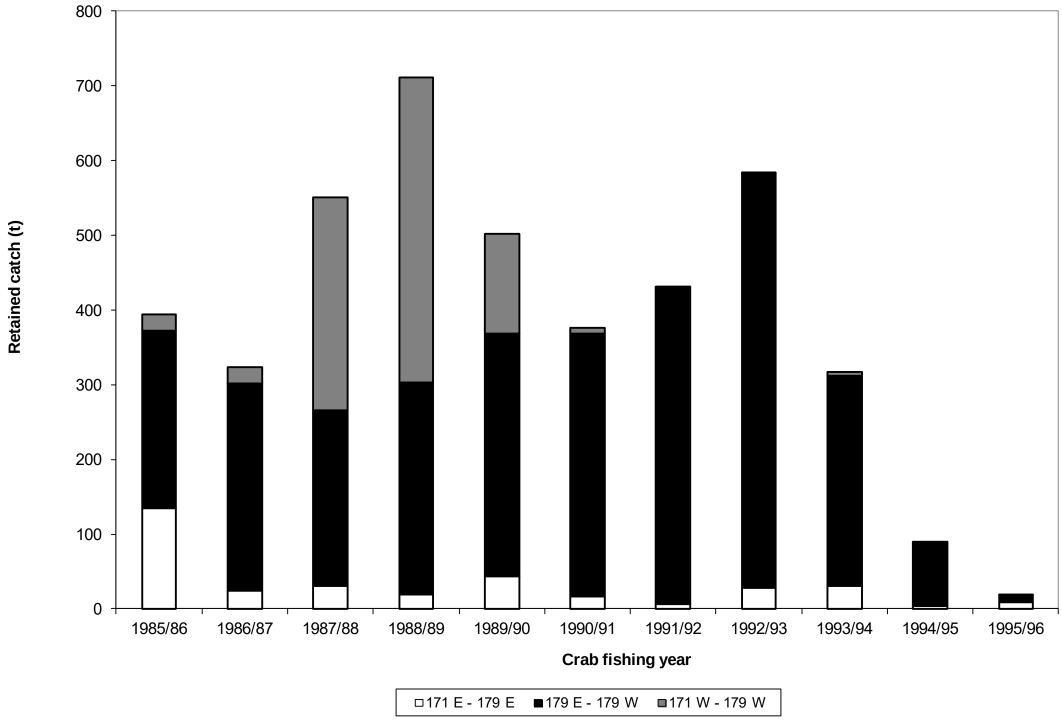

Figure 4. Annual retained catch (**t**) in the Western Aleutian Islands red king crab fishery during 1985/86–1995/96, partitioned into three longitudinal zones: 171º W longitude to 179º W longitude (white bars); 179º W longitude to 179º E longitude (black bars); and 179º E longitude to 171º E longitude.

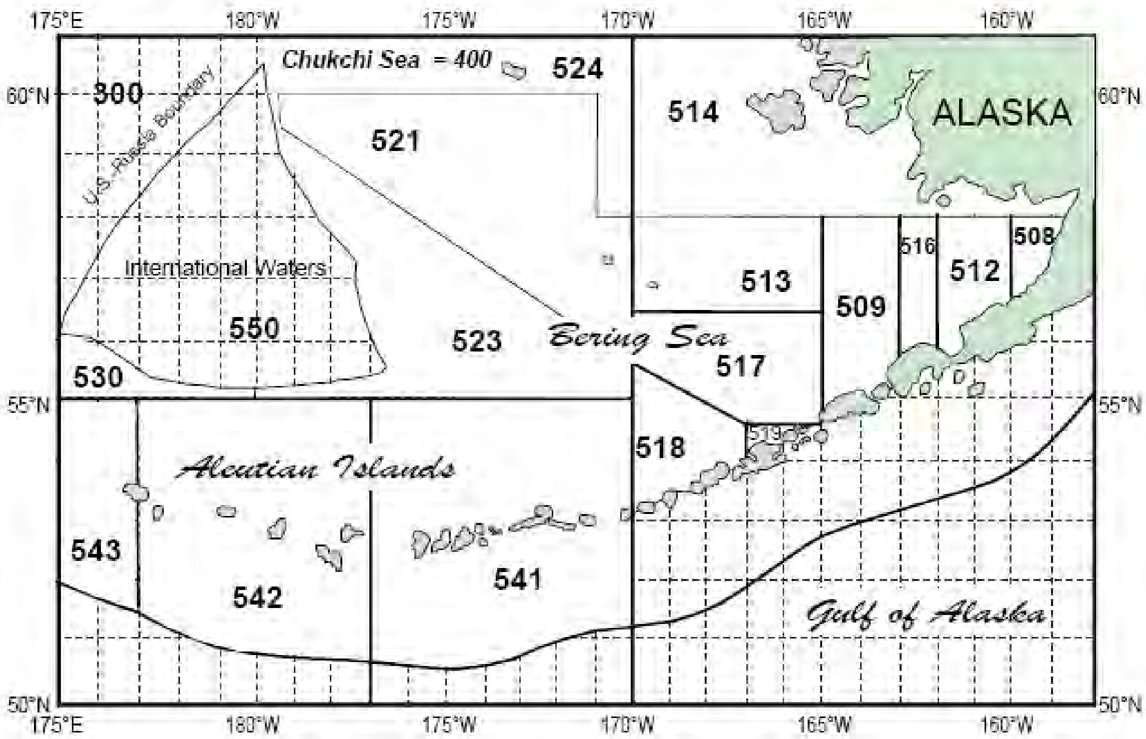

Figure 5. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands. Areas 541, 542, and 543 are used to obtain data on discarded catch of Western Aleutian Islands red king crab during groundfish fisheries (from http://www.alaskafisheries.noaa.gov/rr/figures/fig1.pdf).

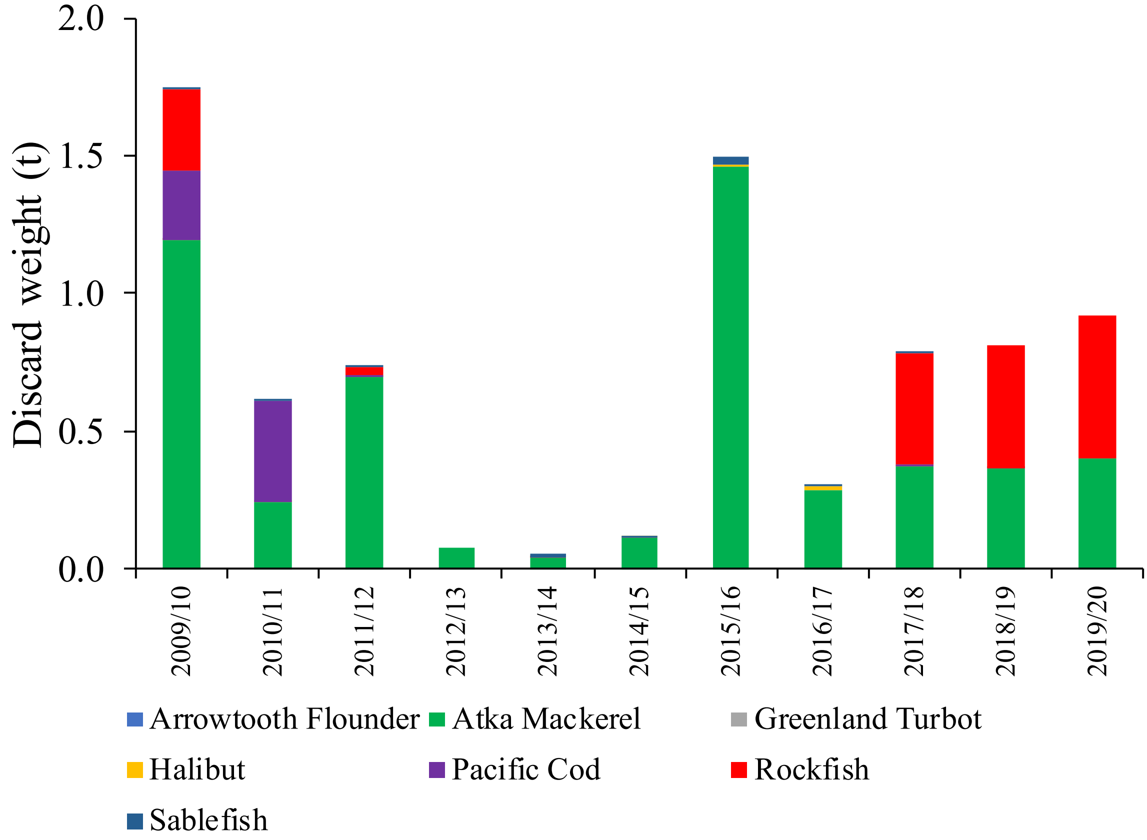

Figure 6. Estimated annual discarded catch (not discounted by an assumed bycatch mortality rate) of red king crab in reporting areas 541, 542, and 543 (Aleutian Islands west of 170° W longitude) during federal groundfish fisheries (all gear types combined) by target fishery, 2009/10–2019/20.

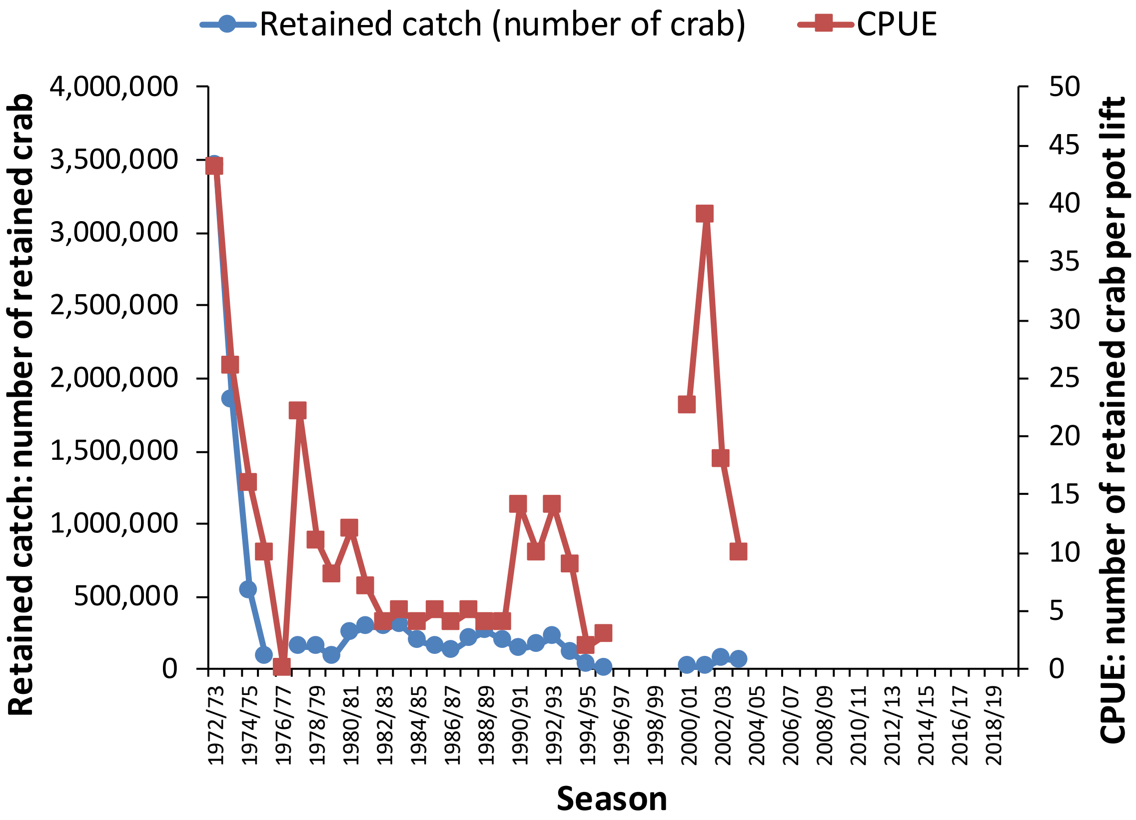

Figure 7. Retained catch (number of crab) and CPUE (number of retained crab per pot lift) in the western Aleutian Islands red king crab fishery, 1972/73–2019/20 (from Table 1a). Data for 1972/73–1983/84 are for the area west of 172° W longitude; data for 1984/85–1997/98, 1999/00, and 2004/05–2019/20 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.

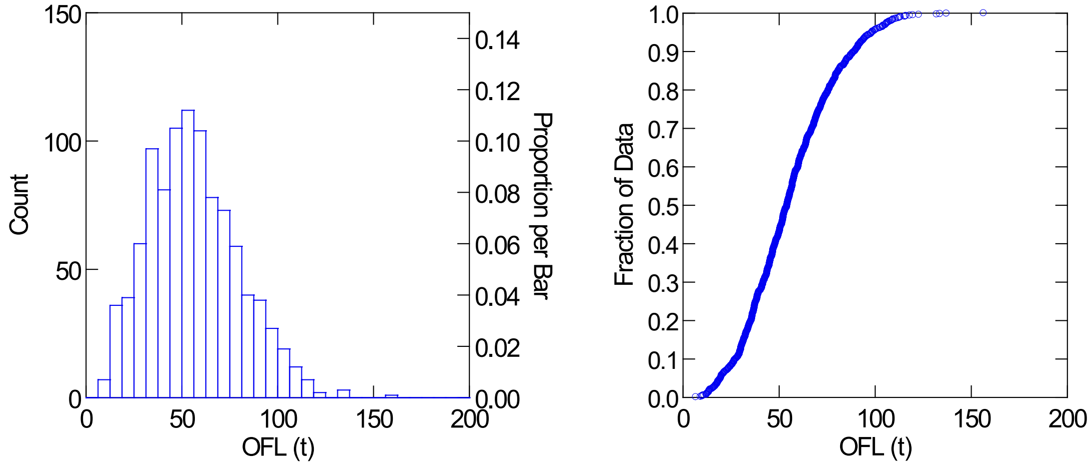

Figure 8. Bootstrapped estimate of the sampling distribution of the recommended 2020/21, 2021/22, and 2022/23 Tier 5 OFL (total-catch, t) for the Western Aleutian Islands red king crab stock; histogram in left column, cumulative distribution in right column.

Appendix A1

Summary of retained catch size frequency data available from Western Aleutian Islands directed red king crab fishery, 1960/61–2019/20.

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
2004/05−2019/20	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

Appendix A3. Page 2 of 3.

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

Appendix A5

Page 1 of 1. Plot of available retained catch size frequency sample data 1961/62–2003/04 western Aleutian Islands directed red king crab fishery (data listed in Appendices A2-A4).