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

2019 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/region/alaska 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	2020
Aleutian Is. golden king crab (AIGKC)	May	June	Annual	2020
Pribilof Is. blue king crab (PIBKC)	May	June	Biennial	2021
Pribilof Is. golden king crab (PIGKC)	May	June	Triennial	2020
Western Aleutian Is. red king crab (WAIRKC)	May	June	Triennial	2020
EBS snow crab	September	October	Annual	2020
Bristol Bay red king crab (BBRKC)	September	October	Annual	2020
EBS Tanner crab	September	October	Annual	2020
Pribilof Is. red king crab (PIRKC)	September	October	Biennial	2021
Saint Matthew blue king crab (SMBKC)	September	October	Annual	2020

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 which employ data from the EBS NMFS trawl survey thus cannot be assessed until survey data are available in early September. Summer catch data for NSRKC however are not available in time for fall specifications, nor is assessing this stock with the June timing feasible as the CDQ fishery can open as early as May thus this stock is assessed in the winter. Additional information on the OFL and ABC determination process is contained in this report.

The CPT met from September 16-20, 2019 in Seattle, WA to review the final stock assessments as well as additional related issues, in order to provide the recommendations and status determinations contained in this SAFE report. This final 2019 Crab SAFE report contains recommendations for all 10 stocks including those whose OFL and ABC were previously determined in February and June 2019. This SAFE report will be presented to the NPFMC in October 2019 for their annual review of the status of BSAI Crab stocks.

The entire CPT participated in this review. Membership on the CPT includes the following:
Martin Dorn (Co-Chair), Katie Palof (Co-Chair), James Armstrong (Coordinator), William Bechtol, Ben Daly, Ginny Eckert, 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.

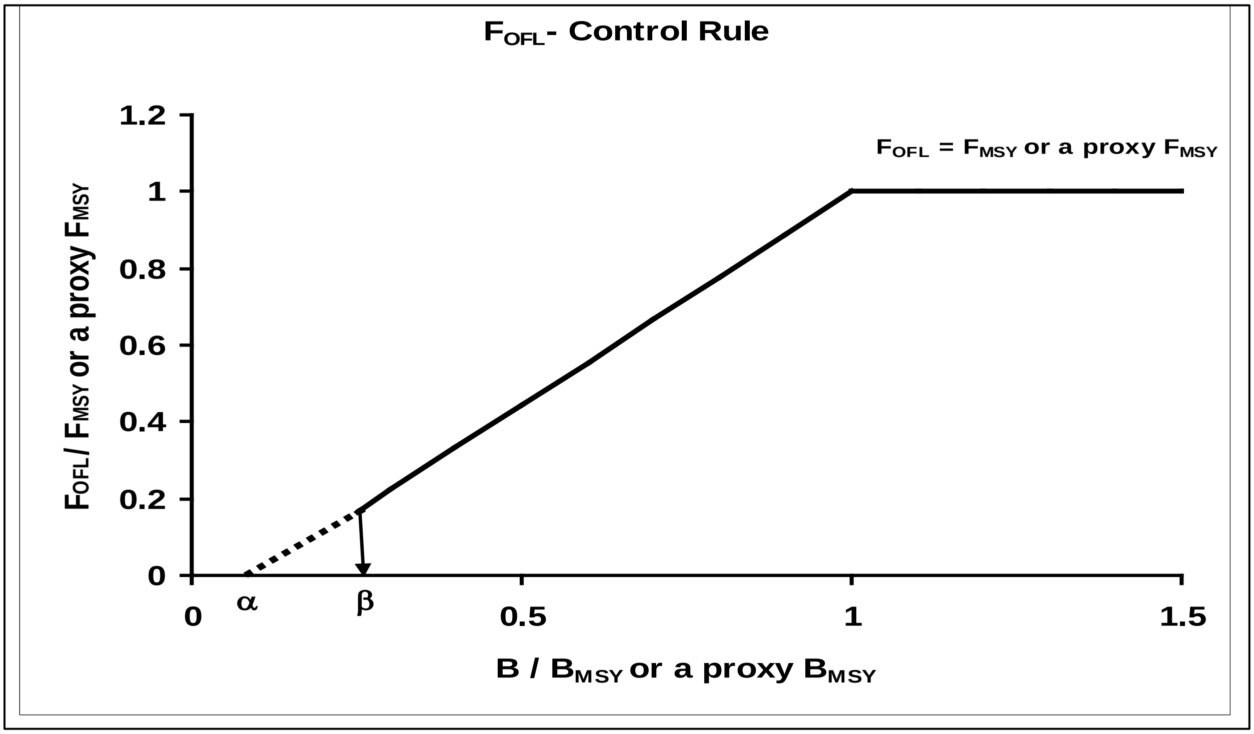

Figure 1. Overfishing control rule for Tiers 1 through 4. Directed fishing mortality is 0 below β.

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 $0 \leq \beta < 1$.
  - α — a parameter with restriction that $0 \leq \alpha \leq \beta$.
- The maximum value of F_{OFL} is F_{MSY}. $F_{OFL} = F_{MSY}$ when $B > B_{MSY}$.
- F_{OFL} decreases linearly from F_{MSY} to $F_{MSY}\cdot(\beta-\alpha)/(1-\alpha)$ as B decreases from B_{MSY} to $\beta\cdot B_{MSY}$
- When $B \leq \beta\cdot B_{MSY}$, F = 0 for the directed fishery and $F_{OFL} \leq F_{MSY}$ for the non-directed fisheries, which will be determined in the development of the rebuilding plan.
- The parameter, β, determines the threshold level of B at or below which directed fishing is prohibited.
- The parameter, α, determines the value of F_{OFL} when B decreases to $\beta\cdot B_{MSY}$ and the rate at which F_{OFL} decreases with decreasing values of B when $\beta\cdot B_{MSY} < B \leq B_{MSY}$.
  - Larger values of α result in a smaller value of F_{OFL} when B decreases to $\beta\cdot B_{MSY}$.
  - Larger values of α result in F_{OFL} decreasing at a higher rate with decreasing values of B when $\beta\cdot B_{MSY} < B \leq B_{MSY}$.
- The parameter, b_y, is the value for the annual buffer calculated from a P* of 0.49 and a probability distribution for the OFL that accounts for scientific uncertainty in the estimate of OFL.
- P* is the probability that the estimate of ABC, which is calculated from the estimate of OFL, exceeds the "true" OFL (noted as OFL') (P(ABC>OFL').

Crab Plan Team Recommendations

Table 3 lists the team's recommendations for 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 2018/19 was 15,400 t (with discard mortality rates applied), while the retained catch in the directed fishery was 12,510 t. Because the total catch mortality for this stock was below the 2018/19 OFL of 29,700 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. 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 model include biomass and length frequency data from the 2019 NMFS Eastern Bering Sea trawl survey, retained and discard catch and length frequencies from the 2018/19 directed fishery, and discard catch and length frequencies from the 2018/19 groundfish fisheries.

The model estimation structure is essentially identical to the 2018 assessment. A jittering approach within a maximum likelihood framework was used to evaluate model stability, and model scenarios were evaluated based on their fits 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.

The assessment author examined eight model scenarios for this assessment. Scenario 18.1 was last year's accepted model fit to last year's data. Scenario 19.1 was last year's accepted model, but updated with 2018/19 data. Scenarios 19.2 and 19.3 imposed prior values on M, based on studies by Hamel and Then et al. (0.27 and 0.315 yr^{-1}, respectively), which differed from the prior value used in 18.1 and 19.1 (0.23 yr^{-1}). Otherwise 19.2 and 19.3 were identical to 19.1. Scenarios 19.4 and 19.5 imposed linear models for growth on females and males, respectively, whereas 19.1 fit sex-specific growth curves that allowed a "kink" (i.e., a change in slope) in the otherwise linear relationship between pre- and post-molt size. Scenario 19.6 estimated sex-specific size distributions for recruits, whereas 19.1 fixed a single size distribution on both sexes. Finally, Scenario 19.7 incorporated both Hamel's prior on M (as in Scenario 19.2) and estimated linear (not kinked) growth for males (as in Scenario 19.5). A scenario based on imposing linear fits to growth data for both sexes failed to converge and was not considered further. The scenarios with increased prior values for M (19.2, 19.3, and 19.7) were suggested by a recent paper (and public comment to the CPT) by Murphy et al. that estimated time-varying mortality rates to be much higher than those used in last year's assessment(18.1 and, by extension, 19.1). Patterns in the time series for abundance of old shell males too small to be caught in the fishery also supported higher M values.

The CPT recommends the author's preferred model scenario, 19.7, to determine stock status and set the OFL and ABC for 2019/20. This scenario exhibited the best retrospective pattern for males among the seven considered, estimated fully-selected NMFS survey catchability (q) near that implied from BSFRF survey data, described male growth as linear, and estimated reasonably higher rates for M than those for the base model (19.1). Scenarios 19.1, 19.4, 19.5, and 19.6 estimated lower values for M due to using

0.23 yr^{-1} as the median prior value for M. Scenario 19.2 exhibited the worst retrospective patterns, while the model instability associated with the kinked growth curves used in 19.3 ruled out that scenario.

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 and 198,400 t in 2018. The 2018 survey mature male biomass was the largest since 1998. In 2019, survey mature male biomass decreased to 169,100 t. 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 159,900 t in 2009/10 to a low in 2015/16 of 42,600 t. MMB increased in subsequent years and was estimated to be 111,400 t in 2018/19. Model-estimated mature female biomass-at-mating (MFB) began to decline somewhat earlier, from a peak in 2006/07 (66,800 t) to a low in 2009/10 (48,500 t), followed by increases in 2010/11 and 2011/12 to 92,800t, after which it declined to 60,300 t in 2015/16. Since 2015/16, it has increased steadily to 140,400 t in 2018/19.

Estimated recruitment to the population has been episodic, with peaks in recruitment generally preceding peak in mature biomass by a few years. The most recent peaks were in 2008/09 (2,664,000 crab), preceding peaks in MMB and MFB in 2009/08 and 2011/12, respectively, and in 2015/16 (2,828,000 crab), preceding the increases in MMB and MFB that began in 2015/16.

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 (126.1 kt) based on average recruitment over 1982 to 2018. Consequently, the minimum stock size threshold (MSST) is 63.0 kt. Projected MMB for 2019/20 (167.3) is above the MSST, so **the stock is not overfished**. The CPT recommends that the ABC be less than maximum permissible ABC. The CPT recommends continuing the buffer of 20% used for the 2017 and 2018 assessments for setting the 2019/20 ABC. This level of buffer is justified given the continuing concerns about model misspecification (growth) and parameter confounding, the ongoing evidence for retrospective patterns, and the uncertainty surrounding rates of natural mortality.

Historical status and catch specifications for snow crab (kt). 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	75.8	91.6	18.4	18.4	21.4	83.1	62.3
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		167.3				54.9	43.9

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2015/16	167.1	201.9	40.6	40.6	47.2	183.2	137.4
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		368.8				121.0	96.8

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 a threshold 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 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 2018/19 was 2.03 kt and total catch mortality was 2.65 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 the time of the 2019 survey and mature male (males ≥120 mm CL) biomass was projected to 15 February 2019. 2018/19 fishery catch 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 1975-2018 NMFS trawl survey dataset was updated with data from the 2019 survey, including sex-specific area-swept estimates of abundance, biomass, and size composition. The 2019 survey biomass estimate for mature males was similar to that in 2018.

Changes to the basic model methods included: (1) treating the Tanner crab fishery bycatch size compositions similarly to those from the groundfish fisheries by having the size compositions sum to 1 for both sexes combined (2) transitioning the mode to the General Model for Assessing Crab Stocks (GMACS) modeling framework by performing a bridging analysis between the current model and a similar model structure in GMACS

Three model scenarios were evaluated for the 2019 assessment. Model 18.0d was the accepted model from the 2018 assessment with 2019 data and separating the groundfish fisheries bycatch data into trawl and fixed gear during 1996-2018. Model 18.0e changed the length compositions of the Tanner crab fishery bycatch in each year to sum to 1 for both sexes combined, thus treating this data the same as the groundfish fisheries bycatch in the model. Model 19.0 is the GMACS model which is as close to model 18.0e as possible between the old framework and GMACS. The differences between models 18.0d and 18.0e were minimal and 18.0e was consistent in the treatment of all bycatch data therefore the model comparisons focused on model 18.0e and 19.0.

The CPT selected model scenario 19.0 as its recommended model for status determination and OFL setting. Results from all scenarios were quite similar, and all of the models overpredicted the very low 2018 and 2019 NMFS survey biomasses. The CPT noted that a similar lack of fit has been found previously when survey biomass dropped suddenly, reflecting uncertainty in whether the underlying cause was a change in availability or mortality (i.e., the "hide 'em/kill 'em" uncertainty). Some of the main differences between models 18.0e and 19.0 were the treatment of penalties and priors in GMACS. Sensitivity analyses showed that, while they could not be mimicked in the model 18.0e framework, they had little effect on model output. Treatment of selectivity is also different between the two models, with model 18.0e having three parameters while model 19.0 has four parameters for male and female logistic curves for a given period. This affects the estimation of selectivity of smaller size groups in model 19.0 and therefore the shape of the selectivity curves. There are also differences between the models in the treatment of the relationship between the NMFS trawl survey and the BSFRF survey. The GMACS model fits the NMFS biomass better than the BSFRF biomass whereas model 18.0e does the opposite. Overall, considerable work has been done to bridge the current model with the GMACS modeling framework and the CPT acknowledges this and recommends adopting model 19.0. This model transitions this stock to the GMACS modeling platform. OFL and ABC's were adopted from the GMACS model, with a 20% buffer for ABC, consistent with last year's ABC buffer and adoptions in other crab stocks.

Stock biomass and recruitment trends

Based on the CPT-recommended scenario, 19.0, the MMB at the time of mating is estimated to have been highest early in the late 1970s (approximately 111 kt), with secondary peaks in 1989 (28 kt) and 2002/03 and 2010/11 (~31 kt). The estimated MMB at time of mating in 2018/19 was 16.92 kt. The projection for the 2019/20 time of mating, which assumes the fishing mortality in 2019/20 matches that corresponding to the OFL, is 15.96 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 (49, 42, and 39 million crab, respectively). The relatively low recruitment estimate of 4.7 million crab for 2019 was lower than that estimated last year.

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

Bristol Bay red king crab is in Tier 3. Based on the author's discussion regarding an apparent reduction in stock productivity associated with the 1976/77 climate regime shift in the EBS, the CPT 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. Following discussions at the January and May 2018 CPT meetings, the CPT concurred with the author's recommendation to drop the terminal year recruitment from the time period for average recruitment because it is highly uncertain. The estimated $B_{35\%}$ is 21.2 kt. MMB projected for 2019/20 is 15.96 kt, 75% of $B_{35\%}$. Consequently, the BBRKC stock is in Tier 3b in 2019/20.

The CPT recommends that the OFL for 2019/20 be set according to model scenario 19.0, for which the calculated OFL is 3.40 kt. Given the inability of the model to adequately fit the last two years (2018 and 2019) survey biomasses, the team recommends that the ABC for 2019/20 be set below the maximum permissible ABC. The team recommends that a 20% buffer from the OFL be used to set the ABC at 2.72 kt. This buffer is consistent with 2018 CPT recommendations, which were based on the rather unusual environmental conditions in the EBS the last two years (e.g., elevated bottom temperatures, lack of a cold pool) and the model's poor fit to the 2018 and 2019 survey data increase the uncertainty associated with this stock and warrant additional precaution.

MMB for 2018/19 was estimated to be 16.92 kt and above MSST (10.62 kt); hence the stock was not overfished in 2018/19. The total catch in 2018/19 (2.65 kt) was less than the 2018/19 OFL (5.34 kt); hence overfishing did not occur in 2018/19. The stock at 2019/20 time of mating is projected to be above the MSST and 75% of $B_{35\%}$ (see above); hence the stock is not approaching an overfished condition in 2019/20.

Historical status and catch specifications for Bristol Bay red king crab (kt). 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	12.89	27.68	4.52	4.61	5.34	6.73	6.06
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		15.96				3.40	2.72

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2015/16	28.4	61.0	9.97	10.17	11.69	14.84	13.36
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		35.2				7.5	6.00

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.

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; 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. Input data sets were updated with the most recent information, including the NMFS EBS trawl survey in 2019; bycatch, and size composition data from the 2018/19 crab fisheries; and data on Tanner crab bycatch in the groundfish fisheries in 2018/19.

The model recommended by the CPT to set the OFL and the ABC incorporated the most recent survey data and fishery data that was updated with both the most recent data and revised historical total catches. These estimates were nearly the same as the original estimates after 1995 but showed much larger changes in 1992-1995 (catches prior to 1992 were not revised). The revised fishery estimates had a relatively large impact on the scale of the population relative to previous assessments--including the data increased the estimated size of the population. However, given the re-analysis, this appears to be the best available information and the CPT recommended adopting them after further discussion at the May 2019 CPT. It was not clear to the CPT what was driving the extreme sensitivity of the model to the revised catch estimates and this could be a topic of further research in the future.

Stock biomass and recruitment trends

The MMB at the time of mating is estimated to have been highest in the early 1970s (approximately 300 kt), with secondary peaks in 1989 (75 kt), 2008/09 (76 kt), and in 2014/15 (83 kt). The estimated MMB at time of mating in 2018/19 was 82.61 kt and the projection for the 2019/20 time of mating is 39.55 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 2017, 2018, and 2019, but these estimates are very 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 has been used in previous OFL determination and follows the most recent recommendation of the SSC.

Based on the estimated biomass at 15 February 2019, the stock is at Tier 3b. The F_{MSY} proxy ($F_{35\%}$) is 1.18 yr^{-1}, and the 2019/20 F_{OFL} is 1.08 yr^{-1} under the Tier 3b OFL Control Rule, which results in a total male and female OFL of 28.86 kt. The CPT recommends a 20% buffer to account for model uncertainty and stock productivity uncertainty be applied to the OFL to set ABC = 23.09 kt. The 20% buffer is the same that the SSC recommended for determination of the 2018/19 ABC.

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

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2015/16	12.82	73.93	8.92	8.91	11.38	27.19	21.75
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		39.55				28.86	23.09

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

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2015/16	28.27	162.99	19.67	19.64	25.09	59.94	47.95
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		87.18				63.62	50.89

4 Pribilof Islands red king crab

The Pribilof Islands red 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 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.

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

Year	**MSST**	**Biomass (MMB_{mating})**	**TAC**	**Retained Catch**	**Total Catch**	**OFL**	**ABC**
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						864	648

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

Year	**MSST**	**Biomass (MMB)**	**TAC**	**Retained Catch**	**Total Catch**	**OFL**	**ABC**
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						1.90	1.43

The stock was above MSST in 2018/19 and was not overfished. Overfishing did not occur during the 2018/19 fishing year.

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		175				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		0.386				0.0026	0.002
2020/21		0.386				0.0026	0.002

The total catch for 2017/18 (0.33 t) and 2018/19 (0.41 t) was less than the associated OFLs (1.16 t for both years) so overfishing did not occur during 2017/18 or 2018/19. The 2019/20 projected MMB estimate of 175 t is below the proxy for MSST (MMB/B_{MSY} = 0.04) so the stock is projected to continue to be in an overfished condition.

6 St. Matthew blue king crab

Fishery information relative to OFL setting

The fishery was prosecuted as a directed fishery from 1977 to 1998. Harvests peaked in 1983/84 when 4,288 t (9.453 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 but differs from the original GMACS model in that natural and fishing mortality are continuous within 5 discrete seasons. 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 18.0 - the 2018 recommended model; (2) Model 19.0 – the reference model updated with new data; (3) Model 19.1, which gives greater weight to fitting the NMFS trawl and the ADF&G pot surveys, and Model 19.2, which estimates an additional CV for the ADF&G pot survey. A variant of model 19.0 (Model 19.0a) differs only in the range of years used to calculate reference points.

The CPT concurs with the author's recommendation to use the reference model 19.0 for the 2019/20 crab year. This stock is in Tier 4. The CPT recommends that the full assessment period (1978/79–2018/19) be used to define the proxy for B_{MSY} in terms of average estimated MMB_{mating}. The projected MMB estimated for 2019/20 under the recommended model is 1,151 t and the F_{MSY} proxy is the natural mortality rate (0.18^{-1} year) and F_{OFL} is 0.042, resulting in a mature male biomass OFL of 0.04 kt. The MMB/B_{MSY} ratio is 0.310. The author recommended and the CPT concurred with a 20% buffer on the OFL for the ABC which was consistent with the approach used last year. The ABC based on this buffer is 0.03 kt.

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

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Male Catch	OFL	ABC
2015/16	1.84	2.11	0.19	0.05	0.05	0.28	0.22
2016/17	1.97	2.23	0.00	0.00	0.001	0.14	0.11
2017/18	1.85	1.29	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		1.08				0.04	0.03

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

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Male Catch	OFL	ABC
2015/16	4.0	4.65	0.41	0.105	0.117	0.62	0.49
2016/17	4.30	4.91	0.00	0.000	0.002	0.31	0.25
2017/18	4.1	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		2.38				0.10	0.08

The stock was below MSST in 2017/18 and was declared overfished. A rebuilding plan for the stock is under development. Total catch was less than the OFL in 2018/19 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 main fisheries: summer commercial, winter commercial, and winter subsistence. The summer commercial fishery, which accounts for most of the catch, reached a peak in the late 1970s at a little over 2.9 million lb. retained catch. Retained catches since 1982 have been below 0.5 million lb., averaging 0.3 million lb., including several low years in the 1990s. As the crab population rebounded, retained catches have increased to around 0.5 million lb. in recent years, but were around 0.3 million lb. in 2018.

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, but none of these surveys have been conducted every year. The assessment is based on a male-only length-based model of male crab abundance that combines multiple sources of data. A maximum likelihood approach was used to estimate abundance, recruitment, and selectivity and catchability of the commercial pot gear. The model has been updated to include the following data: total catch, catch length composition, discard length composition data from the 2018 summer commercial fishery, and 2018 winter commercial and subsistence catch. New trend data in the assessment included 2018 ADFG survey in Norton Sound. In addition, the standardized commercial catch CPUE indices were updated to include data for 1977-2018. The current model assumes a constant M=0.18 yr^{-1} for all length classes except the the > 123mm CL length-class, which had an estimated value of 0.583 yr^{-1}. Logistic functions are used to describe fishery and survey selectivities, except for a dome-shaped function examined for the winter pot fishery.

The assessment author envaulted eight model alternatives, a base model (model 18.0) that assumes fixed retention selectivity and uses retention and discards length-composition data to estimate total catch selectivity, and several other models that incorporate different stanzas (1987-1994 and 2012-2018) of size composition data from the summer and winter commercial fisheries and estimate separate retention selectivities for the summer and winter fisheries.

The CPT recommended model 18.2b which estimates commercial fishery retention selectivity using summer commercial 2012-2018 total catch length composition data, 1987-1994 summer commercial fishery discard length composition data, and 2015-2018 winter commercial fishery retention length composition data. Estimating retention selectivity did not change fit to population dynamics, but improved fits of commercial retention and tag recovery data that inform the size transition matrix and molt probabilities. Estimating separate retention selectivities for the summer and winter fisheries did not improve the model fit.

Stock biomass and recruitment trends

Mature male biomass was estimated to be at an historic low in 1982 following a sharp decline from the peak biomass in 1977. The MMB then exhibited an increase from a low in 1997 to a peak in 2010, before showing minor declines and increases close to the B_{MSY} proxy. The stock is currently estimated to be on a downward trend. Estimated recruitment was weak during the late 1970s and high during the early 1980s, with a slight downward trend from 1983 to 1993. Estimated recruitment has generally been variable, with a slight decrease in the last 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 4.57 million lb. The estimated

2019 mature male biomass on February 1 using Model 18.2b is 3.12 million lb., which is below the $B_{MSY\ proxy}$ for this stock, placing Norton Sound red king crab in status category 4b. The $F_{MSY\ proxy}$ is M =0.18 yr-1 and the F_{OFL}=0.118yr^{-1}, because the 2019 mature male biomass is less than $B_{MSY\ proxy}$, with the CPT choosing the default of gamma =1.0.

The CPT recommends that the OFL for 2019 be set according to model 18.2b, for which the calculated OFL is 0.24 million lb. (0.11 thousand t). The team recommends that the ABC for 2019 be set below the maximum permissible ABC. The team recommends that the SSC-endorsed buffer of 20% from the OFL be used to set the ABC at 0.19 million lb. (0.09 thousand t). The OFL is a retained catch OFL although a total catch OFL is computed as part of the assessment. The recommendation of an ABC less than the maximum permissible is recommended due to concern about model specification and unresolved competing hypotheses about whether the lack of large male crab in the fisheries and surveys is from increased natural mortality or movement out of the area.

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	Retain catch ABC
2015	1.09	2.33	0.18	0.18	0.24	0.33	0.26
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	TBD	TBD	TBD	0.11	0.09

1: Summer commercial fishery

2: Summer commercial fishery, winter commercial fishery and subsistence fishery

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 Catch[1]	Total Catch[2]	Retained Catch OFL	Retain catch ABC
2015	2.41	5.13	0.39	0.40	0.52	0.72	0.58
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	TBD	TBD	TBD	0.24	0.19

Total retained catch during 2018 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. Retained catch peaked in 1986/87 at 14.7 million lb and averaged 11.9 million lb over the 1985/86-1989/90 seasons. Average harvests dropped sharply from 1989/90 to 1990/91 to a level of 6.9 million lb for the period 1990/91–1995/96. Management based on a formally established GHL began with the 1996/97 season. The 5.9 million lb GHL established for the 1996/97 season, which was based on the previous five-year average catch, was subsequently reduced to 5.7 million lb beginning in 1998/99. The GHL (or TAC, since 2005/06) remained at 5.700 million lb for 2007/08, but was increased to 5.985 million lb for the 2008/09-2011/12 seasons, and to 6.290 million lb starting with the 2012/13 season. The TAC was reduced to 5.545 million lb for the 2016/17 season and increased to 6.356 million lb for the 2018/19 season. This fishery is rationalized under the Crab Rationalization Program.

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. Retained catch in the post-rationalized fishery (2005/06-2018/19) has ranged from 5.245 million lb in 2006/07 to 6.536 million lb in 2018/19. Total mortality ranged from 5.427 to 7.396 million lb for the same period.

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 EAG and WAG owing to different abundance trends in each area. A modeling framework based on only fisheries data for AI golden king crab was under development for several years with model assumptions and data inputs refined by reviews by the SSC and CPT. The CIE also reviewed the model and stock assessment in June 2018. 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 (landing and total catch), and mark-recapture data. These data are complete through the 2018/19 season.

The assessment authors examined five model scenarios for EAG and five model scenarios for WAG in this assessment cycle. Model 18_0 was the base model last year (Model 17_0) with new data in the 2017/18 fishing season. Model 18_1 is the same as Model 18_0 except the number of gear codes was reduced for fishery CPUE standardization. Model 19_0 is the same as Model 18_0 with new data from the 2018/19 fishing season. Model 19_1 is the same as Model 18.1 with new data from the 2018/19 fishing season. Model 19_2a is the same as Model 19_1 plus a year and area interaction factor during years 2005/06 - 2018/19 for EAG, and Model 19_2 is the same as Model 19_1 plus a year and area interaction factor during years 1995/96 - 2018/19 for WAG. The authors recommended Model 19_1 or Models 19_2/19_2a for a base model for overfishing determination.

The CPT considered Models 19_0, 19_1, and 19_2/19_2a (all include the 2018/19 fishery data). Model 19_1 is preferred over Model 19_0 due to simplification of gear codes and the fact that model performances were very similar. Models 19_2 and 19_2a include a year and area interaction factor which may be important for fishery CPUE standardization. However, the CPT has concerns about the current area footprint calculation and with not using the year and area interaction factor during 1995/96-2004/05 for EAG due to high estimated log(CPUE) variances. It appears that further improvement is needed for

Models 19_2 and 19_2a before adoption as the base model. The CPT recommends base model 19_1 for OFL and ABC determination for 2019/2020.

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 CPT recommended that the model be used to provide management reference points based on the Tier 3 control rule in January 2017 and this tier recommendation was endorsed by the SSC in February 2017.

An industry-ADF&G collaborative survey has been conducted for this stock during 2015-2018. A preliminary model using the first two years' index from this survey was evaluated in the assessment in 2018; however, additional index development is needed before the model with the survey data is suitable to provide management advice.

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 WAG increased from a low in the 1990s until 2007/08 and then declined again. There has been a slight increase in MMB in WAG since 2014. Recruitment for the EAG was variable and high during 2014-2016 while recruitment for WAG is 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 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 2019/20. 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 $\mathrm{B}_{\mathrm{MSY}}$ in both areas therefore no adjustment is needed to the F_{OFL} to determine the combined OFL for both areas.

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 (scenario 19_1). 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	N/A	N/A	2.853	2.729	3.076	5.69	4.26
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		15.944				5.249	3.937

Status and catch specifications (million lb) for Aleutian Islands golden king crab (scenario 19_1). 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	N/A	N/A	6.290	6.016	6.782	12.53	9.40
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		35.150				11.572	8.679

Total fishery mortality in 2018/19 was 7.396 million lb, less than the OFL of 12.157 million lb, thus overfishing for the 2018/19 season did not occur.

Additional Plan Team recommendations

The CPT recommended additional assessment work in a number of areas. Additional development is needed for fishery CPUE standardization, including further development in year-area interactions. The chela measurement data should be reanalyzed using recently collected fishery and survey data to better estimate the maturity of AIGKC. The bias of retrospective biomass estimates for EAG needs to be checked and investigated for any model misspecifications. Uncertainty of recruitment estimates in the terminal years should be assessed to determine how many years of recruitment estimates in the terminal years are excluded for $B_{35\%}$ estimation. Use of GMACS for the AIGKC assessment should be explored. Finally, additional work is needed to obtain an index using the cooperative pot survey data for use in the EAG assessment model.

9 Pribilof District Golden King Crab

In accordance with the approved schedule, no assessment was conducted for Pribilof District golden king crab this year, however, a full stock assessment will be conducted in 2020. Until then, the values generated from the previous stock assessment (below) will be rolled over for 2018/19 specifications. Additional information listed below summarizes the 2017 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 has been managed with a GHL of 68 t since 2000. No directed fishery occurred during 2006–2009, 2015, and 2016, but one vessel landed catch in 2010, two vessels landed catch in 2011, one vessel landed catch each year from 2012 to 2014, two vessels landed catch in 2017, and one vessel landed catch 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 2001–2018 due to crab fisheries range from 73 t. Estimates of annual fishery mortality during 1991/92–2018 due to groundfish fisheries range from negligible to 8.84 t. Total fishery mortality in groundfish fisheries during the 2018 crab fishing year was 1.54 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 using slope survey data was explored; however, the model fit was poor for mature and legal size male, likely due to small number of data points and the high variance.

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 2018, 2019, and 2020. The CPT concurs with the author’s recommended status quo OFL of 0.20 million lb and an ABC of 0.15 million lb. The ABC was derived by applying a 25% buffer of the OFL, ABC = 0.75 * OFL, the same buffer used for other Tier 5 stocks with similar levels of concern. The 2018–2020 OFL calculation is the same as recommended by the SSC for 2012−2017:

$$OFL_{2018\text{–}2020} = (1+R_{2001\text{–}2010})*RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,1992/93\text{–}1998/99}$$

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.

- $BM_{GF,1992/93–1998/99}$ is the estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99.

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

Calendar Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2015	N/A	N/A	59	0	1.92	91	68
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				93	70

N/A = not available
Conf. = confidential

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

Calendar Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2015	N/A	N/A	0.13	0	0.004	0.20	0.15
2016	N/A	N/A	0.13	0	<0.001	0.20	0.15
2017	N/A	N/A	0.13	Conf.	Conf.	0.20	0.15
2018	N/A	N/A	0.13	Conf.	Conf.	0.20	0.15
2019	N/A	N/A	0.13	Conf.	Conf.	0.20	0.15
2020	N/A	N/A				0.20	0.15

N/A = not available
Conf. = confidential

10 Western Aleutian Islands red king crab

In accordance with the approved schedule, no assessment was conducted for Western Aleutian Islands king crab this year, however, a full stock assessment will be conducted in 2020. Until then, the values generated from the previous stock assessment (below) will be rolled over for 2018/19 specifications. Additional information listed below summarizes the 2017 assessment.

Fishery information relative to OFL and ABC setting

The domestic fishery has been prosecuted every season from 1960/61 to 1995/96. 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. Peak harvest occurred during the 1964/65 season with a retained catch of 9,611 t. 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. 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.

Retained catch from 1985/86 to 1994/95 averaged 426 t, but the retained catch during the 1995/96 season dropped to 18 t. Most of the catch since the 1990/91 season was harvested in the Petrel Bank area (between 179° W longitude and 179° E longitude) and the last two commercial fishery seasons were opened only in the Petrel Bank area with 231 t in 2002/03 and 218 t in 2003/04. Non-retained catch of red king crabs occurs in both the directed red king crab fishery, the Aleutian Islands golden king crab fishery, and in groundfish fisheries. Estimated bycatch mortality in the crab fisheries during the 1995/96 to 2018/19 seasons averaged 1 t in crab fisheries and 1 t in groundfish fisheries. Estimated annual total fishing mortality from 1995/96 to 2018/19 averaged 31 t. The average retained catch during that period was 24 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 2007/08 time series of retained catch (number and pounds of crabs), effort (vessels, landings and pot lifts), average weight and average carapace length of landed crabs, and catch-per-unit effort (number of crabs per pot lift) are available. Bycatch from crab fisheries from 1995/96 to 2018/19 and from groundfish fisheries from 1993/94 to 2018/19 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 2017/18, 2018/19, and 2019/20 seasons. 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 2017/18 to 2019/20 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 2017/18, 2018/19, and 2019/20 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) of Western Aleutian Islands red king crab

Fishing Year	MSST	Biomass (MMB)	TAC	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				56	14

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

Fishing Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2015/16	N/A	N/A	Closed	0	0.00296	0.12387	0.07432
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				0.12387	0.03097

Figures and Tables

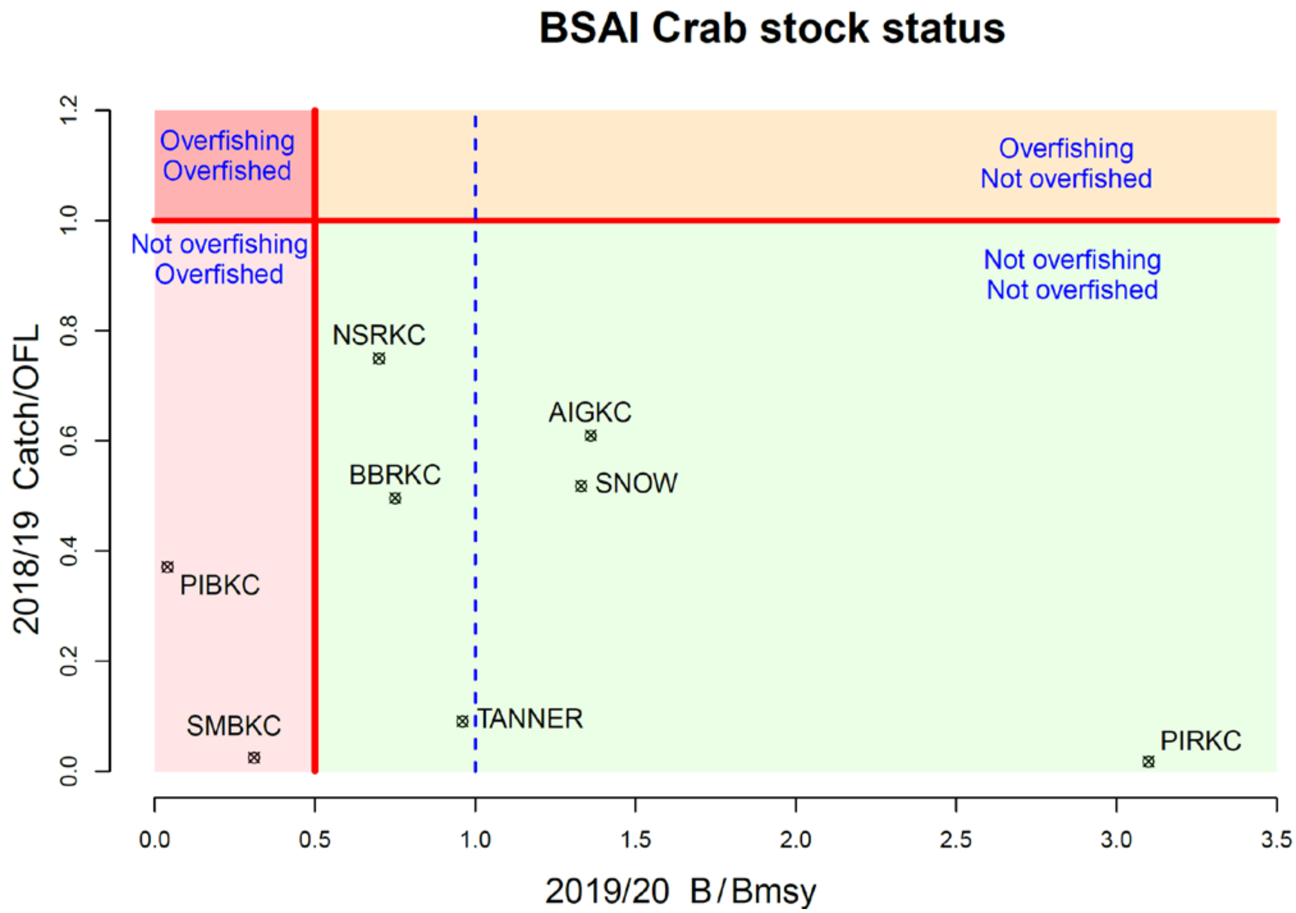

Figure 2. Status of eight Bering Sea and Aleutian Islands crab stocks in relation to status determination criteria (B_{MSY}, MSST, overfishing) for 2019. Note that information is insufficient to assess Tier 5 stocks according to these criteria (WAIRKC, PIGKC).

Table 4. Crab Plan Team recommendations from the September 2019 meeting. Note that recommendations are final values from the SSC for stock 7 (February) and 5 and 8 (June); stocks 9 and 10 were not assessed in 2019. Hatched areas indicate parameters not applicable for that tier. Values are in thousand metric tons (kt).

Chapter	Stock	Tier	Status (a,b,c)	F_{OFL}	B_{MSY} or $B_{MSYproxy}$	B_{MSY} basis years[1]	2019/20[2] MMB	2019/20 MMB / MMB_{MSY}	γ	Mortality (M)	2019/20[3] OFL	2019/20 ABC	ABC Buffer
1	EBS snow crab	3	a	1.93	126.1	1982-2018 [recruitment]	167.3	1.33		0.41 (mat. females) 0.31 (imm.) 0.30 (mat. males)	54.90	43.90	20%
2	BB red king crab	3	b	0.22	21.25	1984-2018 [recruitment]	15.96	0.75		0.18	3.40	2.72	20%
3	EBS Tanner crab	3	b	1.08	41.07	1982-current [recruitment]	39.55	0.96		0.30 (mat. females) 0.23 (imm.) 0.30 (mat. males)	28.86	23.09	20%
4	Pribilof Islands red king crab	4	a	0.21	1.73	2001-present [MMB]	5.37	3.10	1	0.21	0.86	0.65	25%
5	Pribilof Islands blue king crab	4	c	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 Island blue king crab	4	c	0.04	3.48	1978-2018 [MMB]	1.08	0.31	1	0.18	0.044	0.035	20%
7	Norton Sound red king crab	4	b	0.12	2.06	1980-2018 [MMB]	1.41	0.68	1	0.18	0.11	0.09	20%
8	AI golden king crab	3	a	EAG (0.66) WAG (0.60)	11.76	1987/88-2012/13	15.94	1.36		0.21	5.25	3.94	25%
9	Pribilof Islands golden king crab	5				See intro chapter					0.09	0.07	25%
10	Western AI red king crab	5				1995/96-2007/08					0.06	0.01	75%

[1] For Tiers 3 and 4 where B_{MSY} or $B_{MSYproxy}$ is estimable, the years refer to the time period over which the estimate is made. For Tier 5 stocks it is the years upon which the catch average for OFL is obtained.
[2] MMB as projected in Feb 2019 for Norton Sound red king crab, and June 2019 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.

Table 5. Maximum permissible ABCs for 2019/20 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	2019/20 *Max* ABC	2019/20 ABC
EBS Snow Crab[1]	3	54.777	43.9
Bristol Bay RKC[2]	3	3.371	2.72
Tanner Crab[3]	3	28.790	23.09
Pribilof Islands RKC[1]	4	0.853	0.65
Pribilof Islands BKC[4]	4	0.00104	0.00087
Saint Matthew BKC[2]	4	0.0438	0.035
Norton Sound RKC[2]	4	0.109	0.09
Aleutian Islands GKC[2]	3	5.224	3.94
Pribilof Islands GKC[4]	5	0.081	0.07
Western Aleutian Islands RKC[4]	5	0.054	0.01

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 16, 2019

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 the early and mid-nineties (retained catch during 1991, 1992, and 1998 were 143.02, 104.68, and 88.09 kt, respectively). The stock was declared overfished in 1999 at which time retained catches dropped to levels similar to the early 1980s (e.g. retained catch during 2000 was 11.46 kt). Retained catches have slowly increased since 1999 as the stock rebuilt, although retained catch during 2018 was low (12.51 kt) as a result of low estimated mature biomass.

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 mortality was 2.86 kt which was 23% of the retained catch.

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 in the early and mid-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, since 2011, the stock has declined and the observed MMB at the time of survey dropped to an all time low in 2017 of 83.96 kt. MMB is increasing again as a large recruitment moves through the size classes.

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 appears to have persisted to the present, where it is beginning to be seen in the exploitable biomass.

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
2014/2015	73.2	129.3	30.8	30.8	34.3	69	62.1
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	63.0	123.1	12.5	12.5	15.4	29.7	23.8
2019/2020		167.3				54.9	43.9

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

Year	MSST	Biomass (MMB)	TAC	Retained catch	Total catch	OFL	ABC
2014/2015	161.38	285.06	67.9	67.9	75.62	152.12	136.91
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		368.83				121.03	96.78

6. Basis for the OFL

The OFL for 2019 from the chosen model (19.7) was 54.92 kt fishing at $F_{OFL} = 1.93$ (100% of the calculated $F_{35\%}$, 1.93). The calculated OFL was an 85% change from the 2018 OFL of 29.7 kt. The projected ratio of MMB at the time of mating in 2020 to $B_{35\%}$ is 1.33.

Table 3: Metrics used in designation of status and OFL (1,000 t). 'Years' indicates the year range over which recruitment is averaged for use in calculation of B35. 'M' is the natural mortality for immature crab, mature female crab, and mature male crab, respectively.

Year	Tier	BMSY	MMB	Status	FOFL	Years	M
2019/2020	3	126.1	167.3	1.33	1.93	1982-2018	0.31, 0.41, 0.3

Table 4: Metrics used in designation of status and OFL (millions of lb.). '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 the natural mortality for immature crab, mature female crab, and mature male crab, respectively.

Year	Tier	BMSY	MMB	Status	FOFL	Years	M
2019/2020	3	278	368.8	1.33	1.93	1982-2018	0.31, 0.41, 0.3

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 43.93 kt, calculated by subtracting a 20% buffer from the OFL as recommended by the SSC.

A. Summary of Major Changes

1. Management: None
2. Input data:

Data added to the assessment included: 2019 Bering Sea survey biomass and length composition data, 2018 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 2018. Growth data were updated with 4 observations of pre- and post-molt lengths.

3. Assessment methodology:

Management quantities were derived from maximum likelihood estimates of model parameters in a size-based, integrated assessment method. Jittering was performed to identify stable model configurations. Retrospective analyses were performed for selected model configurations.

4. Assessment results

The updated estimate of MMB (February 15, 2018) was 111.41kt which placed the stock at 88% of $B_{35\%}$. Projected MMB on February 15, 2019 from this assessment's chosen model was 167.32 kt after fishing at the OFL, which will place the stock at 133% 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. CPT May 2019 comments, SSC comments, and author response:

Research directions

SSC comment: The SSC suggested the development of a prioritized research plan to improve the snow crab assessment and that it may be helpful to organize the plan into categories: analyses conducted within the assessment model, analyses conducted outside the model, development of alternative models (e.g., GMACS, simplified model), and collection of new data. The SSC also suggested that work that can be conducted with existing data and staff resources should be prioritized versus new work that requires new funding.

Author response (CSS): A prioritized research plan has yet to be formally written down, but a general hierarchy of needs exists. The author's current plan following the September meeting is (listed by priority):

- Develop a GMACs model for snow crab to be presented at CIE review in summer of 2020. This is the number one priority because of the desire to move to GMACs before attempting to solve model pathologies that may or may not exist when using GMACs.
- Address survey catchability and the use of Bering Sea Fishery Research Foundation (BSFRF) data. Given the discussion about changing assumed natural mortality and its confounding with catchability (and growth), it will be necessary to consider how to best inform catchability. First, I will revisit how the BSFRF data are used to establish a mean catchability. Second, I hope to explore time-variation in catchability potentially resulting from changes in spatial distribution and environmental variation. This could address some of the spatial issues related to the fraction of the stock in the northern Bering Sea, poor fits in some years, and retrospective patterns in estimates of MMB.
- A post-doc has just been hired to develop a fully spatial assessment for snow crab using code built on the VAST framework.

These projects will consume at least the next year.

Assessment scenarios for September 2019

The CPT made several recommendations for scenarios with the current assessment methodology to be presented in September based on analyses presented during the May 2019 CPT meeting, including a status quo model, a model with higher M, a model with linear growth for females and kinked growth for males, a model with linear growth for males and kinked growth for females, models that estimate different size distributions for male and female recruitment. The SSC agreed with these suggestions. Last year's accepted model uses kinked growth curves for both males and females, has a median prior for M of 0.23, and specifies the distribution of female and male recruitment (which are equal). The author presents 8 runs based on these recommendations:

- 18.1 – Last year's accepted model fit to last year's data.
- 19.1 – Last year's accepted model fit to this year's data.
- 19.2 – 19.1 + Hamel prior on M (0.27)
- 19.3 – 19.1 + Then prior on M (0.315)
- 19.4 – 19.1 + Linear growth for females
- 19.5 – 19.1 + Linear growth for males
- 19.6 – 19.1 + estimate different recruitment distributions by sex
- 19.7 – 19.2 + linear growth for males

A model in which both male and female growth models were specified as linear did not converge and is not presented here. The author's preliminary preferred model is 19.7. It should be noted that the preferred model increased the assumed mean value for the prior on natural mortality and this results in higher OFLs than if M remained the same as in 2018 (e.g. model 19.1). However, updated methodology for developing empirical estimates of natural mortality, state-space modeling that estimates time-varying natural mortality for snow crab, and closer examination of the survey data all suggest that natural mortality is higher than it has been assumed during the recent history of the snow crab assessment.

The SSC offers the following additional suggestions to the assessment author (followed by author responses):

SSC: Consider whether a higher natural mortality should be incorporated with a suitable prior or as a fixed parameter estimated outside the model.

CSS: For this round of assessment, natural mortality was incorporated with a prior, with the reasoning that allowing the model some flexibility in natural mortality will incorporate some of the uncertainty in M into derived quantities. However, once the assessment is moved to GMACS, a simulation exercise in which data are simulated with a known M and fit with GMACS could show whether or not M can be estimated reliably with the available data.

SSC: Consider the northern Bering Sea data to better understand the influence of snow crab in that area on the eastern Bering Sea assessment. Examine whether snow crab in the northern Bering Sea and higher estimates of natural mortality are linked.

CSS: The model is fit to mature biomass, which is the metric of management. Mature biomass is generally farther from the northern border of the surveyed area (Figure 1), so movement back and forth over the northern border should not be expected to substantially influence fits to those data. (However, it was pointed out at the CPT meeting that 2019 survey data indicate a 'hotspot' of MMB near the northern border, which is unusual.) Further, natural mortality for immature crab and yearly recruitment are estimated parameters, which should temper any impact of small crab moving back and forth. Again, this could be addressed via simulation once the assessment is moved to GMACs by generating data from operating models with time-varying catchability and/or time-varying natural mortality for immature crab, applying the assessment methods, and evaluating the ability of the model to estimate catchability and natural mortality (and other derived quantities used in management).

SSC: Ongoing considerations of catchability/selectivity within the survey area are also encouraged. The potential interplay of crab spatial distribution and habitat-specific catchability is intriguing. Examination of the effects of environmental conditions on snow crab spatial distribution and habitat-based catchability seems to be a potential fruitful avenue of research with existing data. Effects of temperature and survey dates on catchability of yellowfin sole may be a useful case study for comparison.

CSS: In addition to the above responses, I have explored the BSFRF data further in this document and discuss briefly plans in the immediate future for work related to this question.

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 2 & Figure 3). Smaller crabs tend to occupy more inshore northern regions (Figure 4) and mature crabs occupy deeper areas to the south of the juveniles (Figure 5 & Figure 6; 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 7). The total sample size was 21 male crabs (a combination of Tanner and snow crab) from a collection of 105 male crabs from various hauls in the 1992 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 8). 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 5). 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 5: 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	0.27	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 9). 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.

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 7). 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 estimated exploitation rate for total catch divided by mature male biomass ranged from 6% to 51% for the chosen model in this assessment (Figure 10).

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).

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

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 8). 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 2018 was low (12.51 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 mortality was 2.86 kt, which was 23% of the retained catch.

Discard from the directed pot fishery has been estimated from observer data since 1992 and has ranged from 11-55% of the magnitude of retained catch by numbers . In recent years, discards have reached 50-55% 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 11). 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

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

Catch data

Catch data and size composition of retained crab from the directed snow crab pot fishery from survey year 1982 to 2018 were used in this analysis (Table 8). 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 the development of a GMACS model for snow crab.

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 6 for a summary of catch data.

Table 6: Data included in the assessment. Dates indicate survey year.

Data component	Years
Retained male crab pot fishery size frequency by shell condition	1982 - 2018
Discarded Males and female crab pot fishery size frequencey	1992 - 2018
Trawl fishery bycatch size frequencies by sex	1991 - 2018
Survey size frequencies by sex and shell condition	1982 - 2019
Retained catch estimates	1982 - 2018
Discard catch estimates from crab pot fishery	1992 - 2018
Trawl bycatch estimates	1993 - 2018
Total survey biomass estimates and coefficients of variation	1982 - 2019
2009 study area biomass estimates, CVs, and size frequencey for BSFRF and NMFS tows	2009
2010 study area biomass estimates, CVs, and size frequencey for BSFRF and NMFS tows	2010

Survey biomass and size composition data

Abundance was estimated from the annual eastern Bering Sea (EBS) bottom trawl survey conducted by NMFS (see 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: Figure 12). All survey data in this assessment used measured net widths instead of the fixed 50 ft net width based on Chilton et al.'s (2009) survey estimates. Carapace width and shell conditions were measured and reported for snow crab caught in the survey.

Mature biomass for males and females at the time of the survey were the primary indices of population size fit to in this assessment. Total survey numbers (Figure 13 & Figure 14) were input to the model via the .DAT file, after which MMB and FMB at the time of the survey were calculated based on the size composition data, which were delineated by shell condition, maturity state, and sex. Distinguishing between mature and immature crab for the size composition was accomplished by demarcating any female that had eggs reported in the survey as 'mature'. Mature male size composition data were calculated by multiplying the total numbers at length for new shell male crab by a vector of observed proportion of mature males at length. The observed proportion of mature males at length was calculated by chelae height and therefore refers only to 'morphometrically' mature males. All old shell crab of both sexes were assumed to be mature. New shell crab were demarcated as any crab with shell condition index <= 2. The biomass of new and old shell mature individuals was calculated by multiplying the vector of numbers at length by weight at length. These vectors were then summed by sex to provide the index to which the model was fit (Table 9). The size composition data were also fit within the assessment.

Spatial distribution of survey abundance and catch

Spatial gradients exist in the survey data by maturity and size for both sexes. For example, larger males have been more prevalent on the southwest portion of the shelf (Figure 5) while smaller males have been more prevalent on the northwest portion of the shelf (Figure 2). Females have exhibited a similar pattern (compare Figure 3 to Figure 6). 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 15 & Figure 16). 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 16).

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 in 27 survey stations and the goal was to improve understanding snow crab densities and the selectivity of NMFS survey gear (Figure 17). 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 18 & Figure 19) are incorporated into the model by fitting them as an extra survey that is linked to the NMFS survey through a shared selectivity (see appendix A for a description of the way in which the surveys are related in the assessment model). Abundances estimated by the industry surveys were generally higher than the NMFS estimates, which provides evidence that the catchability of the NMFS survey gear is less than 1.

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 20). Empirical estimates of catchability/selectivity vary by year and size class across the different BSFRF data sets (Figure 21). The number of snow crab used to develop estimates of numbers at length probably contribute to these differences among years (Figure 22), 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, $\mathrm{N}_{s,v,m,y,l}$. 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 (19.1), 366 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 (Table 10 & Table 11). 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 a 'jittering' approach was used to find the parameter vector that produced the smallest negative log likelihood (Turnock, 2016). Jittering was implemented here by running each model to produce a .PAR file, then creating 100 replicates of a .PIN file using that .PAR file. Each .PIN file consisted of the values in the .PAR file multiplied by a random normal error term with a mean of 1 and a standard deviation of 0.1. Only values for parameters that are estimated were 'jittered'. Each of the .PIN files were used as starting values to run the model and the output was stored and compared among model scenarios. The model that returned the lowest negative log likelihood within a given model scenario was then used for comparison here.

Retrospective analyses were performed in which the terminal year of data was removed sequentially from the model fitting. 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) 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 to quantify the retrospective patterns.

Model selection and evaluation

Models were evaluated based on their fit to the data (Table 12), the credibility of the estimated population processes, stability of the model (Figure 23), the magnitude of retrospective patterns (Figure 24), and the strength of the influence of the assumptions of the model on the outcomes of the assessment. Maximum likelihood estimates of parameters can be seen in Table 11.

Results

Several of the models exhibited unstable behavior when jittered (Figure 23). Models appeared to 'converge' (i.e. returned small gradients) over a range of likelihood values and derived management quantities exhibited bimodality to some degree for several models. This bimodality has been linked to the change point growth model in the past (Turnock, 2016; Szuwalski, 2017 & 2018). The model that provided the most stable estimates of management quantities was model 19.5, in which the male growth curve was forced to be linear.

All models for which retrospective analyses were performed displayed retrospective patterns (Figure 24). 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). No model produced the lowest retrospective patterns for both sexes; 19.7 (higher M and linear growth for males) performed best for males and 19.5 (linear growth for males) performed best for females.

Below, the fits to the data and estimated population processes for all considered models are described. The data for all eight models were the same, consequently the likelihoods can be directly compared.

Fits to data

Survey biomass data

Fits to the survey mature male biomass were visually similar for all models for the majority of years in the the time series (Figure 25). Model 19.4 (linear female growth) fit the survey biomass data somewhat better as seen through the likelihoods. The updated survey data did not increase as much as expected given previous years' numbers at length, which caused a revision of the most recent years of MMB downward (see Figure 24). All models fits exceeded the final year of observed survey MMB (169.108 kt) and observed survey MFB (110.429 kt).

Growth data

A range of growth curves were estimated to fit the female growth increment data (Figure 26), depending upon the assumed functional form and the prior on M. Two models produced roughly linear growth for females: 19.3 (highest M) and 19.4 (assumed female linear growth). Presumably, with the higher M, larger individuals were able to be killed within the model more quickly, which allowed the model to accommodate larger growth increments at larger sizes. Model 19.3 produced by far the best fits to the female growth data (Table 12). It should be noted that much of the 'fit' improved here is to data that are outside of the size range modeled by the assessment.

Models 19.5 and 19.7 both produced linear growth curves for males, but were also both forced to be linear. All models fit the male growth data similarly (Table 12). Notably, the model in which linear growth was forced for males (19.5) had the most stable performance under the jittering analysis in terms of spread of 'converged' models. Model 19.7 also produced the smallest retrospective patterns for MMB of the models analyzed (Figure 24).

Catch data

Retained catch data were fit by all models well, with no visually discernible differences among models (Figure 27). Female discard data were fit adequately given the specified uncertainty (Figure 27 & Table 12). Male discard data during the period for which data exist (early 1990s to the present) were well fit by every model with little visually discernible difference (Figure 27), though model 19.6 fit the data best as seen through the likelihoods (Table 12). Fits to the trawl data were adequate for all models given the uncertainty in the data (Figure 27).

Size composition data

Retained catch size composition data were visually well fit by all models (Figure 28); total catch size composition data were similarly well fit (Figure 29). Retained and total catch size composition length composition data were fit similarly by most models, except 19.5 and 19.7, which both had linear growth for males and produced slightly poorer fits (e.g. neg log like 1031 vs 1025). Trawl size composition data were generally well fit, with several exceptions in certain years. Higher M allowed for slightly better fits to the trawl composition data (Figure 30 & Table 12).

Fits to size composition data for the BSFRF survey selectivity experiments produced some notable runs of positive and negative residuals for the males in particular (Figure 31). The number of males was generally underestimated by the industry survey in 2009 and overestimated by the NMFS survey, while the opposite pattern was seen for females. Fits to the 2010 survey size composition data were better than the 2009 fits.

Size composition data for the NMFS survey were generally well fit and fits were visually similar for all models (Figure 32 & Figure 33). The distribution of residuals for male and female survey composition data for the chosen model varied by sex. Size composition data for females tended to be overestimated for larger size classes (Figure 34), whereas a pattern for males was less clear (Figure 35). Models with higher M or estimated variability around the growth increment fit the survey composition data better for most size composition data sources according to the likelihoods (Table 12).

Estimated population processes and derived quantities

Estimated population processes and derived quantities varied among models. Projected MMB for 2019 ranged from 123.07 to 174.87 kt (Figure 36). For the author preferred model (19.7), estimated fishing mortality in the recent past has been below $F_{35\%}$, save the years 2014-2015, which exceeded $F_{35\%}$ (Figure 37). Estimated MMB has been less than $B_{35\%}$ since 2011, and estimates suggest that the population may have been beneath

MSST in the recent past (Figure 37). However, the most recent estimated MMB reversed this trend and estimated MMB is currently near $B_{35\%}$ for the author preferred model (19.7).

Estimates of selectivity and catchability varied among models (Figure 38). Estimated catchability in both eras was lower for males than for females. In era 1 (1982-1988), catchability ranged from 0.42 - 0.53 for males; for females, it ranged from 0.69 - 0.75. In era 2 (1989-present), catchability ranged from 0.7 - 0.83 for males; for females, it was 1 for all models. Estimated size at 50% selection in the survey gear for era 1 ranged from ~40 mm to ~42 mm for both females and males. Size at 50% selection in the survey gear during era 2 ranged from 36 mm to 38 mm for females and 35 mm to 39 mm for males. The BSFRF 'availability' curves varied from 2009 to 2010 and among models, with the availability of crab to the experimental survey generally increasing in 2010 (Figure 39).

In general, the shape of the curve representing the probability of maturing for both sexes was consistent, but the magnitude of the probabilities varied slightly. For all models, the probability of maturing by size for female crab was ~50% at ~47.5 mm and increased to 100% at ~60mm (Figure 40). The probability of maturing for male crab was ~15% to 20% at ~60 mm and increased sharply to 50% at ~97.5mm, and 100% at 107.5 mm. The region from 60 mm to 90 mm male carapace width displayed the largest differences in estimates of the probability of maturing among models.

Estimated fishing mortality in the directed fishery was similar for all models, except for in the most recent years. In those year, the 2018 model (18.1) estimated lower fishing mortality, which is probably related to lower estimates of MMB compared to models with 2019 data (Figure 41). Total and retained fishery selectivity was very similar for all models because of the weight put on the retained catch and its associated size composition data (Figure 41). Estimated size at 50% selection in the trawl fishery varied more than selectivity in the directed fishery, ranging from 110 - 111 mm (Figure 41). Size at 50% selection for discarded females was similar for all models (Figure 41).

Patterns in recruitment by sex were similar for all models (Figure 42). A period of high recruitment was observed in which 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 2013. All models indicated a large (relative to the past) recruitment to the survey gear occurred around 2013. Recruitment entering the model was placed primarily in the first three size bins, except for model 19.6 (Figure 42). Although model 19.6 (estimating separate distributions for recruitment by sex) fit the data better overall than 19.1, the differences among the estimated recruitment by sex did not change. Stock recruitment relationships were not apparent between the estimates of MMB and recruitment for any model (Figure 42). Relationships were not apparent between mature female biomass and recruitment either (not shown).

Estimated natural mortality ranged from 0.27 to 0.33 for immature crab, 0.26 to 0.34 for mature male crab, and 0.34 to 0.48 for mature females (Table 11).

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).

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

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

Calculated OFLs and interpretation

OFLs calculated from maximum likelihood estimates of parameters in the suite of presented models ranged from 29.74 to 66.07kt (Table 13). Differences in OFLs were a result of differences in estimated MMB (see above), calculated $B_{35\%}$ (which ranged from 121.27 to 142.77kt; Table 13), $F_{35\%}$ (which ranged from 1.22 to 2.48 yr^{-1}; Table 13), and F_{OFL} (which ranged from 1.04 to 2.48 yr^{-1}; Table 13). Changes in the prior on M strongly influenced the resulting reference points.

G. Calculation of the ABC

The acceptable biological catch (ABC) was set by subtracting a 20% buffer from the OFL to account for scientific uncertainty, as recommended by the SSC.

Author recommendations

When considering overall fit, retrospective patterns and stability of the model under jittering, there is no clear winner among the presented scenarios. Model 19.3 (highest M) fit the data best, model 19.7 (high M + linear male growth) had the smallest retrospective patterns for males, and model 19.5 was the most stable under jittering. Among the models presented, the key choices are between natural mortality priors and functional forms of growth.

Natural mortality should be higher than assumed in the past, given empirical meta-analyses and survey data for mature individuals not selected by the fishery. However, given confounding with other parameters and the large impact on management advice, it may be wise to chose a more precautionary prior for M in the assessment until other confounded processes are explored more fully.

The question of using a linear growth curve or kinked growth curve does not have a clear answer. It makes sense that maturing individuals would grow less. It has been noted in previous assessments that growth data from maturing individuals were thrown out because the increments were smaller than others. However, the current growth function does not capture this process because it is kinked at a specific size and the molt to maturity occurs over a range of sizes. The kinked growth curve has also been a sources of model instability to this point. 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.

Given these observations, the author preferred model is 19.7. Natural mortality should be higher than previously assumed and the instability of the kinked growth curve overshadows any perceived (though potentially misguided) realism introduced.

H. Data gaps and research priorities

Methodology

Moving to GMACS is currently the highest priority for the snow crab assessment.

Data sources

Efforts should continue to incorporate as many raw data sources as possible in the assessment. Estimating parameters outside of the model and inputting them as 'known' artificially decreases the uncertainty represented in the standard errors of management quantities. In addition to pulling as much data into the model as possible, continuing to standardize and automate the creation of data files from the survey and catch databases would be very useful given the short time frame of the assessment cycle, but this is currently difficult for the catch data. Procuring all available growth data (including previously excluded points and information about maturity state) would facilitate implementing a more sensible 'kinked' growth curve.

Modeling and weighting

In theory, we have data to inform all of the confounded processes. Catchability is informed by the BSFRF studies. Natural mortality is informed by the survey length composition data as a result of large portions of the population being unfished. Recruitment is also informed by the survey length composition data and growth is increasingly well characterized due to the efforts of the NMFS shellfish assessment program. In spite of these data, changing the prior on M can result in large changes in many different estimated population processes. This suggests that data weighting is a key hurdle to providing management advice using this assessment and needs to be carefully considered. Some data weighting issues will be more easily explored within GMACS.

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.

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 highly correlated with the Arctic Oscillation (AO) and the AO is significantly correlated with estimated snow crab recruitment (Figure 43). 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.

J. Literature cited

Chilton, E.A., C.E. Armisted and R.J. Foy. 2009. Report to industry on the 2009 Eastern Bering Sea crab survey. AFSC Processed Report 2009-XX.

Clark, W.G. 1991. Groundfish exploitation rates based on life history parameters. Can. J. fish. Aquat. Sci. 48: 734-750.

Dawe, E.G., D.M. Taylor, J.M. Hoenig, W.G. Warren, and G.P. Ennis. 1991. A critical look at the idea of terminal molt in male snow crab (Chionoecetes opilio). Can. J. Fish. Aquat. Sci. 48: 2266-2275.

Ernst, B, J.M.(Lobo) Orensanz and D.A. Armstrong. 2005. Spatial dynamics of female snow crab (Chionoecetes opilio) in the eastern Bering Sea. Can. J. Fish. Aquat. Sci. 62: 250-268.

Fonseca, D. B., B. Sainte-Marie, and F. Hazel. 2008. Longevity and change in shell condition of adult male snow crab Chionoecetes opilio inferred from dactyl wear and mark-recapture data. Transactions of the American Fisheries Society 137:1029-1043.

Fournier, D.A. and C.P. Archibald. 1982. A general theory for analyzing catch-at-age data. Can.J.Fish.Aquat.Sci. 39:1195-1207.

Greiwank, A. and G.F. Corliss(eds). 1991. Automatic differentiation of algorithms: theory, implementation and application. Proceedings of the SIAM Workshop on the Automatic Differentiation of Algorithms, held Jan. 6-8, Breckenridge, CO. Soc. Indust. And Applied Mathematics, Philadelphia.

Hamel, O. 2015. A method for calculating a meta-analytical prior for the natural mortality rate using multiple life history correlates. ICES Journal of Marine Science. 72: 62-69.

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

Lang, C. A., J. I. Richar, and R. J. Foy. 2019. The 2018 eastern Bering Sea continental shelf and northern Bering Sea trawl surveys: Results for commercial crab species. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-386, 220 p.

Mcbride (1982). Tanner crab tag development and tagging experiments 1978-1982. In Proceedings of the International Symposium of the Genus Chionoecetes. Lowell Wakefield Fish. Symp. Ser., Alaska Sea Grant Rep. 82-10. University of Alaska, Fairbanks, Alaska. Pp. 383-403.

Methot, R. D. 1990. Synthesis model: An adaptable framework for analysis of diverse stock assessment data. Int. N. Pac. Fish. Comm. Bull. 50:259-277.

Murphy, J.T. Rugolo, L.J., Turnock, B.J. 2018. Estimation of annual, time-varying natural mortality and survival for Eastern Bering Sea snow crab (Chionoecetes opilio) with state-space population models. Fish Res 205: 122-131.

Murphy, J.T. Rugolo, L.J., Turnock, B.J. 2017. Integrating demographic and environmental variables to calculate an egg production index for the Eastern Bering Sea snow crab (Chionoecetes opilio). Fisheries Research. 193: 143-157.

Murphy, J. T., A. B. Hollowed, J. J. Anderson. 2010. Snow crab spatial distributions: examination of density-dependent and independent processes. Pp. 49-79. In G. Kruse, G. Eckert, R. Foy, G. Kruse, R. Lipcius, B. St. Marie, D. Stram, D. Woodby (Eds.), Biology and management of Exploited Crab Populations

Under Climate Change. Alaska Sea Grant Program Report AK-SG-10-01, University of Alaska Fairbanks, AK. Doi:10.4027/bmecppc.2010.19

Myers, R.A. 1998. When do environment-recruitment correlations work? Reviews in Fish Biology and Fisheries. 8(3): 285-305.

Nevissi, A.E., J.M. Orensanz, A.J.Paul, and D.A. Armstrong. 1995. Radiometric Estimation of shell age in Tanner Crab, Chionoecetes opilio and C. bairdi, from the eastern Bering Sea, and its use to interpret indices of shell age/condition. Presented at the International symposium on biology, management and economics of crabs from high latitude habitats October 11-13, 1995, Anchorage, Alaska.

NPFMC (North Pacific Fishery Management Council). 2007. Environmental Assessment for Amendment 24. Overfishing definitions for Bering Sea and Aleutian Islands King and Tanner crab stocks. North Pacific Fishery Management Council,Anchorage, AK, USA..

NPFMC (North Pacific Fishery Management Council). 2000. Bering Sea snow crab rebuilding plan. Amendment 14. Bering Sea Crab Plan Team, North Pacific Fishery Management Council,Anchorage, AK, USA..

NPFMC 1998. Bering Sea and Aleutian Islands Crab FMP. Bering Sea Crab Plan Team, North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Orensanz, J.M., J. Armstrong, D. Armstrong and R. Hilborn. 1998. Crustacean resources are vulnerable to serial depletion - the multifaceted decline of crab and shrimp fisheries in the Greater Gulf of Alaska. Reviews in Fish Biology and Fisheries 8:117-176.

Otto, R.S. 1998. Assessment of the eastern Bering Sea snow crab, Chionoecetes opilio, stock under the terminal molting hypothesis. In Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Edited by G.S. Jamieson and A. Campbell. Can. Spec. Publ. Fish. Aquat. Sci. 125. pp. 109-124.

Parada, C., Armstrong, D.A., Ernst, B., Hinckley, S., and Orensanz, J.M. 2010. Spatial dynamics of snow crab (Chionoecetes opilio) in the eastern Bering Sea–Putting together the pieces of the puzzle. Bulletin of Marine Science. 86(2): 413-437.

Paul, A.J., J.M. Paul and W.E. Donaldson. 1995. Shell condition and breeding success in Tanner crabs. Journal of Crustacean Biology 15: 476-480.

Restrepo, V.R, G.G. Thompson, P.M. Mace, W.L. Gabriel, L.L. Low, A.D. MacCall, R.D. Methot, J E. Powers, B.L. Taylor, P.R. Wade, and J.F. Witzig. 1998. Technical guidance on the use of precautionary approaches to implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act. NOAA Technical Memorandum NMFS-F/SPO-31.

Rugolo, L.J., D. Pengilly, R. MacIntosh and K. Gravel. 2005. Reproductive dynamics and life-history of snow crab (Chionoecetes opilio) in the eastern Bering Sea. Final Completion Report to the NOAA, Award NA17FW1274, Bering Sea Snow Crab Fishery Restoration Research.

Rodionov, S. 2004. A sequential algorithm for testing climate regime shifts. Geophysical Research Letters 21: L09204.

Sainte-Marie, B., Raymond, S., and Brethes, J. 1995. Growth and maturation of the male snow crab, Chionoecetes opilio (Brachyura: Majidae). Can.J.Fish.Aquat.Sci. 52:903-924.

Sainte-Marie, B., J. Sevigny and M. Carpentier. 2002. Interannual variability of sperm reserves and fecundity of primiparous females of the snow crab (Chionoecetes opilio) in relation to sex ratio. Can.J.Fish.Aquat.Sci. 59:1932-1940.

Szuwalski, C.S. and Punt, A.E. 2013. Regime shifts and recruitment dynamics of snow crab, Chionoecetes opilio, in the eastern Bering Sea. Fisheries Oceanography, 22: 345-354.

Szuwalski, C.S. and Punt, A.E. 2012. Fisheries management for regime-based ecosystems: a management strategy evaluation for the snow crab fishery in the eastern Bering Sea. ICES Journal of Marine Science. 70:

955-967.

Tamone, S.L., M. Adams and J.M. Dutton. 2005. Effect of eyestalk ablation on circulating ecdysteroids in hemolymph of snow crab Chionoecetes opilio: physiological evidence for a terminal molt. Integr. Comp. Biol., 45(120), p.166-171.

Then, A. Y., Hoenig, J. M., Hall, N. G., and Hewitt, D. A. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science, 72: 82–92.

Turnock, B.J. 2016. Snow crab assessment model scenarios and convergence testing. Alaska Fishery Science Center.

Zheng, J., S. Siddeek, D. Pengilly, and D. Woodby. 2002. Overview of recommended harvest strategy for snow crabs in the Eastern Bering Sea. Regional Information Report No. 5J02-03. Alaska Department of Fish and Game. Juneau, Alaska.

Zheng, J., G.H. Kruse, and D.R. Ackley. 2001. Spatial distribution and recruitment patterns of snow crabs in the eastern Bering Sea. Spatial Processes and management of marine populations. Alaska sea grant college program. AK-SG-01-02, 2001.

Appendix A: Model structure

Population dynamics

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

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

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

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

The dynamics after the initial year were described by:

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

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

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

Where $N_{s,v,m,y,l}$ represented the numbers, N, of sex s during year y of shell condition v and maturity state m at length l. $Z_{x,v,m,y,l}$ represented the total mortality experienced by the population and consisted of the sum of instantaneous rates of natural mortality by sex and maturity state, $M_{s,m}$, and fishing mortality, $F_{s,f,y,l}$ from each fishery. Each fishing mortality was subject to 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 $\gamma_{natM,m}$ was estimated subject to constraints (see Table 10; 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, $Y_{s,l,l'}$.

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

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

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

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

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

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

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

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

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

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).

Likelihood components

Three general types of likelihood components were used to fit to the available data (Table 14). Multinomial likelihoods were used for size composition data, log-normal likelihoods were used for indices of abundance data, and normal likelihoods were used for catch data, growth data, priors, and penalties. Multinomial likelihoods were implemented in the form:

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

L_x was the likelihood associated with data component x, where λ_x represented an optional additional weighting factor for the likelihood, $N^{eff}_{x,y}$ was the effective sample sizes for the likelihood, $p^{obs}_{x,y,l}$ was the observed proportion in size bin l during year y for data component x, and $\hat{p}_{x,y,l}$ was the predicted proportion in size bin l during year y for data component x. 10 multinomial likelihood components were included in the assessment (see Table 14 for descriptions, weighting factors, and effective sample sizes).

Iterative methods for determining appropriate effective samples sizes for composition data are suggested to avoid over-weighting the size composition data and washing out the signal from the indices of abundance. Although the code has the capability to implement these methods, they were not used for this assessment.

Log normal likelihoods were implemented in the form:

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

L_x was the contribution to the objective function of data component x, λ_x was any additional weighting applied to the component, $\hat{I}_{x,y}$ was the predicted value of quantity I from data component x during year y, $\mathrm{I}_{x,y}$ was the observed value of quantity I from data component x during year y and $\mathrm{CV}_{x,y}$ was the coefficient of variation for data component x during year y. 5 log normal likelihood components were included in this assessment (see Table 14 for descriptions, weighting factors, and CVs).

Normal likelihoods were implemented in the form:

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

L_x was the 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. 12 normal likelihood components were included in the base assessment (see Table 14 for descriptions, weighting factors, and translated standard deviations).

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

Table 7: 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		

Female premolt length (mm)	Female postmolt length (mm)	Male premolt length (mm)	Male postmolt length (mm)
23.09	29.26		
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 8: 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	1.27	0.37
1983	12.16	0.01	1.24	0.48
1984	29.94	0.01	2.76	0.51
1985	44.45	0.01	4.01	0.44
1986	46.22	0.02	4.25	1.88
1987	61.4	0.03	5.52	0.01
1988	67.79	0.04	5.82	0.67
1989	73.4	0.05	6.68	0.78
1990	149.1	0.05	15.21	0.6
1991	143	0.06	12	1.88
1992	104.7	0.12	17.06	1.78
1993	67.94	0.08	5.32	1.76
1994	34.13	0.06	4.03	3.54
1995	29.81	0.02	5.75	1.34
1996	54.22	0.07	7.44	0.92
1997	114.4	0.01	5.73	1.47
1998	88.09	0.01	4.67	1.01
1999	15.1	0	0.52	0.61
2000	11.46	0	0.62	0.53
2001	14.8	0	1.89	0.39
2002	12.84	0	1.47	0.23
2003	10.86	0	0.57	0.76
2004	11.29	0	0.51	0.95
2005	16.77	0	1.36	0.36
2006	16.49	0	1.78	0.83
2007	28.59	0.01	2.53	0.43
2008	26.56	0.01	2.06	0.27
2009	21.78	0.01	1.23	0.63
2010	24.61	0.01	0.62	0.17
2011	40.29	0.18	1.69	0.16
2012	30.05	0.03	2.32	0.22
2013	24.49	0.07	3.27	0.12
2014	30.82	0.17	3.52	0.16
2015	18.42	0.07	2.96	0.16
2016	9.67	0.02	1.31	0.08
2017	8.6	0.02	1.93	0.02
2018	12.51	0.02	2.86	0.02

Table 9: 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	0.18	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	0.18	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	0.18	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 10: Parameter bounds and symbols

Parameter	Lower	Upper	Symbol
af	-100	5	α_f
am	-50	5	α_m
bf	1	10	$\beta_{f,1}$
bm	1	5	$\beta_{m,1}$
b1	1	1.5	$\beta_{f,2}$
bf1	1	2	$\beta_{m,2}$
deltam	10	50	δ_m
deltaf	5	50	δ_f
st_gr	0.5	0.5	stgr
growth_beta	0.749	0.751	β_g
mateste	-6	-1e-10	$_{m,l}$
matestfe	-6	-1e-10	$_{f,l}$
mean_log_rec	"-inf"	Inf	Rec_{avg}
rec_devf	-15	15	$Rec_{f,dev,y}$
alpha1_rec	11.49	11.51	α_{rec}
beta_rec	3.99	4.01	β_{rec}
mnatlen_styr	-3	15	$\lambda_{male,v,l}$
fnatlen_styr	-10	15	$\lambda_{fem,v,l}$
log_avg_fmort	"-inf"	Inf	$F^{log}_{avg,dir}$
fmort_dev	-5	5	$F^{log}_{dev,dir,y}$
log_avg_fmortdf	-8	-1e-04	$F^{log}_{avg,disc}$
fmortdf_dev	-15	15	$F^{log}_{dev,disc,y}$
log_avg_fmortt	-8	-1e-04	$F^{log}_{avg,trawl}$
fmortt_dev_era1	-15	15	$F^{log}_{dev,trawl,era1}$
fmortt_dev_era2	-15	15	$F^{log}_{dev,trawl,era2}$
log_avg_sel50_mn	4	5	$S_{50,new,dir}$
log_avg_sel50_mo	4	5	$S_{50,old,dir}$
fish_slope_mn	0.1	0.5	$S_{slope,m,d}$
fish_fit_slope_mn	0.05	0.5	$S_{slope,m,d}$
fish_fit_sel50_mn	85	120	$S_{50,old,dir}$
fish_slope_mo2	1.9	2	$S_{slope,m,d}$
fish_sel50_mo2	159	160	$S_{50,old,dir}$
fish_slope_mn2	0.01	2	$S_{slope,m,d}$
fish_sel50_mn2	100	160	$S_{50,old,dir}$
fish_disc_slope_f	0.1	0.7	$S_{slope,m,d}$
fish_disc_sel50_f	1	5	$S_{50,old,dir}$
fish_disc_slope_tf	0.01	0.3	$S_{slope,trawl}$
fish_disc_sel50_tf	30	120	$S_{50,trawl}$
srv1_q	0.2	1	$q_{m,era1,surv}$
srv1_q_f	0.2	1	$q_{f,era1,surv}$
srv1_sel95	30	150	$S_{95,era1,surv}$
srv1_sel50	0	150	$S_{50,era1,surv}$
srv2_q	0.2	1	$q_{m,era2,surv}$
srv2_q_f	0.2	1	$q_{f,era2,surv}$
srv2_sel95	50	160	$S_{95,era2,surv}$
srv2_sel50	0	80	$S_{50,era2,surv}$
srv3_q	0.2	1	$q_{m,era3,surv}$
srv3_sel95	40	200	$S_{95,m,era2,surv}$
srv3_sel50	25	90	$S_{50,m,era2,surv}$

Parameter	Lower	Upper	Symbol
srv3_q_f	0.2	1	$q_{f,era3,surv}$
srv3_sel95_f	40	150	$S_{95,f,era2,surv}$
srv3_sel50_f	0	90	$S_{50,f,era2,surv}$
srvind_q	0.1	1	$q_{m,09,ind}$
srvind_q_f	0.01	1	$q_{f,09,ind}$
srvind_sel95_f	55	120	$S_{95,f,09,ind}$
srvind_sel50_f	-50	110	$S_{50,f,09,ind}$
srv10in_q	0.1	1	$q_{m,10,ind}$
srv10ind_q_f	0.01	1	$q_{f,10,ind}$
selsmo10ind	-4	-0.001	SelVecMaleInd09
selsmo09ind	-4	-0.001	SelVecMaleInd10
Mmult_imat	0.2	2	$\gamma_{natM,imm}$
Mmult	0.2	2	$\gamma_{natM,mat,m}$
Mmultf	0.2	2	$\gamma_{natM,mat,f}$
cpueq	0.0000877	0.00877	q_{cpue}

Table 11: Estimated parameter values by scenario (these are maximum likelihood estimates)

Parameter	18.1	19.1	19.2	19.3	19.4	19.5	19.6	19.7
af	-1.46	-0.77	-0.8	2.49	-0.36	-0.77	-0.77	-0.8
am	-0.78	-0.76	-0.76	-0.75	-0.77	3.52	-1.28	3.49
bf	1.35	1.32	1.32	1.18	1.31	1.32	1.32	1.32
bm	1.36	1.36	1.36	1.36	1.36	1.2	1.38	1.2
b1	1.17	1.17	1.17	1.17	1.17		1.17	
bf1	1.04	1	1	1.34		1	1	1
deltam	32.53	32.52	32.55	32.57	32.53		33.01	
deltaf	41.1	44.42	44.4	26.16		44.42	44.4	44.4
mateste	vector	vector	vector	vector	vector	vector	vector	vector
matestfe	vector	vector	vector	vector	vector	vector	vector	vector
rec_devf	vector	vector	vector	vector	vector	vector	vector	vector
mnatlen_styr	vector	vector	vector	vector	vector	vector	vector	vector
fnatlen_styr	vector	vector	vector	vector	vector	vector	vector	vector
log_avg_fmort	-0.17	-0.05	-0.08	-0.13	-0.07	0.01	0.11	-0.04
fmort_dev	vector	vector	vector	vector	vector	vector	vector	vector
log_avg_fmortdf	-5.62	-5.61	-5.62	-5.93	-5.82	-5.61	-5.59	-5.62
fmortdf_dev	vector	vector	vector	vector	vector	vector	vector	vector
log_avg_fmortt	-4.62	-4.62	-4.65	-4.66	-4.59	-4.58	-4.48	-4.59
fmortt_dev_era1	vector	vector	vector	vector	vector	vector	vector	vector
fmortt_dev_era2	vector	vector	vector	vector	vector	vector	vector	vector
log_avg_sel50_mn	4.66	4.66	4.66	4.66	4.66	4.66	4.66	4.66
fish_slope_mn	0.19	0.2	0.2	0.2	0.2	0.2	0.21	0.2
fish_fit_slope_mn	0.43	0.45	0.44	0.44	0.45	0.45	0.43	0.45
fish_fit_sel50_mn	96.14	96.14	96.18	96.23	96.17	96.04	95.87	96.09
fish_disc_slope_f	0.26	0.25	0.25	0.26	0.26	0.25	0.25	0.25
fish_disc_sel50_f	4.25	4.26	4.25	4.23	4.23	4.26	4.26	4.25
fish_disc_slope_tf	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
fish_disc_sel50_tf	110.18	110	110.26	111.32	111.23	110.44	111.7	111.34
srv1_q						0.63		0.49
srv1_q_f						0.58		0.56
srv1_sel95						63.79		51.43
srv1_sel50						36.51		39.7
srv2_q	0.52	0.53	0.47	0.42	0.52	0.52	0.52	0.46
srv2_q_f	0.75	0.73	0.71	0.69	0.73	0.75	0.83	0.73
srv2_sel95	58.85	59.16	61.05	62.22	58.83	60.14	58.27	62.1
srv2_sel50	39.99	40.22	41.5	42.5	40.08	40.86	41.43	42.18
srv3_q	0.78	0.82	0.76	0.69	0.8	0.82	0.85	0.74
srv3_sel95	49.04	49.19	52.71	56.63	49.28	51.3	48.9	55.21
srv3_sel50	34.94	35.06	36.76	38.62	35.08	35.75	37.02	37.66
srv3_q_f	1	1	1	1		1	1	1
srv3_sel95_f	47.2	47.25	48.59	49.94	47.34	47.24	47.25	48.6
srv3_sel50_f	36.1	36.08	37.13	38.24	36.11	36.06	35.99	37.12
srvind_q	1	1	1	1		1	1	0.29
srvind_q_f	0.16	0.16	0.16	0.17		0.16	0.16	0.16
srvind_sel95_f	54.56	54.73	55.31	55.94	59.92	54.75	55.42	55.3
srvind_sel50_f	49.79	49.9	50.25	50.65	52.82	49.91	50.25	50.24
srv10ind_q_f	1	1	1	1	1	1	1	1
selsmo10ind	vector	vector	vector	vector	vector	vector	vector	vector
selsmo09ind	vector	vector	vector	vector	vector	vector	vector	vector

Parameter	18.1	19.1	19.2	19.3	19.4	19.5	19.6	19.7
Mmult_imat	1.18	1.19	1.15	1.1	1.18	1.19	1.22	1.15
Mmult	1.14	1.14	1.11	1.09	1.14	1.14	1.14	1.12
Mmultf	1.57	1.58	1.51	1.46	1.59	1.58	1.59	1.52
cpueq	0	0	0	0	0	0	0	0

Table 12: Contribution to the objective function by individual likelihood component by modeling scenario. Values in columns after Model 0 are the likelihood contribution of Model 0 minus the likelihood contribution of the model in the column. Positive values represent improvements in fit. Note that some of the model scenarios involve changing the weightings of data sources which invalidate the comparison of likelihoods for a data source among models.

Likelihood component	18.1	19.1	19.2	19.3	19.4	19.5	19.6	19.7
Recruitment deviations	70.18	76.44	73.97	71.51	77.46	77.56	72.88	75.39
Initial numbers old shell males small length bins	4.62	4.56	4.52	4.47	4.58	4.59	4.46	4.54
ret fishery length	320.96	324.51	323.97	323.91	324.8	333.85	321.1	332.48
total fish length (ret + disc)	920.93	1026.1	1025.41	1025.39	1026.73	1031.87	1017.57	1030.93
female fish length	241.32	250.83	250.1	247.63	247.19	250.85	251.65	250.13
survey length	4293.05	4420.93	4373.35	4399.53	4458.89	4420.38	4418.77	4375.12
trawl length	300.15	334.82	326.69	323.85	334.72	331.99	344.82	323.33
2009 BSFRF length	-92.24	-91.85	-92.65	-93.44	-82.19	-91.96	-91.58	-90.12
2009 NMFS study area length	-75.15	-74.48	-75.19	-74.77	-70.48	-74.56	-74.07	-74.44
M multiplier prior	77.61	79.37	59.43	43.27	80.69	79.53	85.17	61.1
maturity smooth	43.65	46.55	43.9	41.08	45.2	51.25	48.41	47.66
growth males	140.07	140.59	139.96	139.09	140.8	140.91	137.36	139.69
growth females	394.96	367.22	365.5	333.96	390.95	367.43	367.15	365.66
2009 BSFRF biomass	0.47	0.57	0.43	0.28	4	0.55	0.61	0.27
2009 NMFS study area biomass	0.22	0.27	0.19	0.11	9.44	0.28	0.33	0.26
cpue q	0.21	0.35	0.35	0.35	0.34	0.36	0.39	0.36
retained catch	3.65	4.53	4.55	4.59	4.57	4.98	3.13	5

Likelihood component	18.1	19.1	19.2	19.3	19.4	19.5	19.6	19.7
discard catch	116.77	96.71	100.74	105.08	97.84	107.55	40.05	112.09
trawl catch	6.95	9.81	9.44	9.14	9.73	9.55	9.79	9.11
female discard catch	4.17	4.34	4.33	4.32	4.35	4.32	4.28	4.31
survey biomass	207.32	220.47	214.63	211.66	220.48	223.98	221.62	218.62
F penalty	23.51	26.37	25.96	25.51	26.13	28.54	29.68	27.74
2010 BSFRF Biomass	9.58	7.35	6.21	6.34	10.65	7.22	7.05	7.92
2010 NMFS Biomass	3.44	6.07	5.44	3.14	3.36	6.04	6.52	3.34
Extra weight survey lengths first year	547.47	546.8	546.25	543.9	545.12	546.94	547.24	546.55
2010 BSFRF length	-51.66	-49.86	-50.61	-50.52	-50.33	-49.42	-49.41	-51.15
2010 NMFS length	-64.14	-62.74	-64.22	-67.53	-65.28	-62.74	-61.66	-66.72
smooth selectivity	2.44	2.23	2.23	2.46	1.92	2.11	2.01	0.93
smooth female selectivity	0	0	0	0	0	0	0	0
init nos smooth constraint	43.32	43.01	43.2	43.41	43.1	43.54	41.76	43.87
Total	7493.83	7761.87	7668.08	7627.72	7844.76	7797.49	7707.08	7703.97

Table 13: Changes in management quantities for each scenario considered. Reported management quantities are derived from maximum likelihood estimates.

Model	MMB	B35	F35	FOFL	OFL
18.1	85.84	142.8	1.22	1.04	29.74
19.1	100.5	133.7	1.24	1.24	45.47
19.2	110.8	125.2	1.71	1.71	54.07
19.3	125.7	121.3	2.48	2.48	66.07
19.4	104.5	135.2	1.3	1.3	47.77
19.5	97.41	132.9	1.31	1.31	44.18
19.6	91.75	129.7	1.37	1.37	39.57
19.7	111.4	126.1	1.93	1.93	54.92

Table 14: Likelihoods form and weighting for each likelihood component for models in the analysis (continued below)

Likelihood component	Form	18.1	19.1
Recruitment deviations	normal	0.71	0.71
Initial numbers old shell males small length bins	normal	707.1	707.1
ret fishery length	multinomial	200	200
total fish length (ret + disc)	multinomial	200	200
female fish length	multinomial	200	200
survey length	multinomial	NA	NA
trawl length	multinomial	200	200
2009 BSFRF length	multinomial	200	200
2009 NMFS study area length	multinomial	200	200
M multiplier prior	normal	0.23	0.23
maturity smooth	normal	3.16	3.16
growth males	normal	0.71	0.71
growth females	normal	0.32	0.32
2009 BSFRF biomass	lognormal	NA	NA
2009 NMFS study area biomass	lognormal	NA	NA
cpue q	normal	0.32	0.32
retained catch	normal	0.22	0.22
discard catch	normal	3	3
trawl catch	normal	0.22	0.22
female discard catch	normal	17	17
survey biomass	lognormal	NA	NA
F penalty	normal	0.5	0.5
2010 BSFRF Biomass	lognormal	NA	NA
2010 NMFS Biomass	lognormal	NA	NA
Extra weight survey lengths first year	multinomial	200	200
2010 BSFRF length	multinomial	200	200
2010 NMFS length	multinomial	200	200
smooth selectivity	norm2(firstdiff(firstDiff))	2	2
smooth female selectivity	norm2(firstdiff(firstDiff))	3	3
init nos smooth constraint	norm2(firstdifference)	1	1

19.2	19.3	19.4	19.5	19.6	19.7
0.71	0.71	0.71	0.71	0.71	0.71
707.1	707.1	707.1	707.1	707.1	707.1
200	200	200	200	200	200
200	200	200	200	200	200
200	200	200	200	200	200
NA	NA	NA	NA	NA	NA
200	200	200	200	200	200
200	200	200	200	200	200
200	200	200	200	200	200
0.23	0.23	0.23	0.23	0.23	0.23
3.16	3.16	3.16	3.16	3.16	3.16
0.71	0.71	0.71	0.71	0.71	0.71
0.32	0.32	0.32	0.32	0.32	0.32
NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA
0.32	0.32	0.32	0.32	0.32	0.32
0.22	0.22	0.22	0.22	0.22	0.22
3	3	3	3	3	3
0.22	0.22	0.22	0.22	0.22	0.22
17	17	17	17	17	17
NA	NA	NA	NA	NA	NA
0.5	0.5	0.5	0.5	0.5	0.5
NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA
200	200	200	200	200	200
200	200	200	200	200	200
200	200	200	200	200	200
2	2	2	2	2	2
3	3	3	3	3	3
1	1	1	1	1	1

Table 16: 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). These are maximum likelihood estimates.

Survey year	FMB	MMB	Male >101 biomass	Male >101 (millions)	FMB	MMB	Male >101 biomass	Male >101 (millions)
1982	70.62	125.3	26.15	49.75	112.6	275.2	52.94	100.7
1983	55.72	133.5	45.99	82.08	87.39	293.2	93.13	166.2
1984	40.17	139	61.99	106.2	63.05	305.8	125.5	214.9
1985	34.73	130	61.08	103.1	54.92	286.8	123.7	208.7
1986	43.19	113.7	42.62	71.88	68.99	252.2	93.1	157
1987	103.4	113.3	34.85	60.64	167.3	253.2	76.13	132.5
1988	229.2	210.7	37.85	66.18	235.2	287.1	82.7	144.6
1989	226.1	255.1	47.41	82.7	231.4	347.5	103.6	180.7
1990	185.4	318.3	71.68	124.1	189.6	432.4	156.6	271
1991	156.7	299.2	66.13	114.9	160.4	406	144.5	251
1992	143.4	249.7	54.55	94.72	146.9	338.8	119.2	206.9
1993	148.4	210.8	75.05	127	152.2	287.2	101.2	171.3
1994	163	181.2	44.44	73.77	167.2	247.7	59.93	99.49
1995	171	202.5	40.35	71.55	175.3	275.9	54.41	96.49
1996	150.7	282.2	102.5	179.8	154.1	382.9	138.2	242.4
1997	117.6	333.7	170.1	286.1	120.2	451.9	229.4	385.8
1998	89.77	247.2	120.3	199.1	91.76	334.8	162.2	268.4
1999	72.81	151.3	57.25	96.07	74.48	205.2	77.21	129.6
2000	66.28	118.8	42.03	70.2	67.88	161.4	56.68	94.67
2001	59.53	99.58	30.86	52.32	60.92	135.3	41.62	70.57
2002	50.77	94.02	29.77	51.72	51.93	127.7	40.15	69.75
2003	42.66	99.23	40.38	68.82	43.64	134.7	54.46	92.81
2004	44.83	99.56	44.72	74.41	45.98	135.3	60.31	100.3
2005	68.94	96.6	39.02	64.78	70.92	131.5	52.62	87.36
2006	84.16	103.3	35.42	60.5	86.31	140.7	47.77	81.58
2007	84.23	129.5	49.43	85.08	86.27	176	66.67	114.7
2008	73.43	151.6	66.55	113.4	75.11	205.6	89.75	152.9
2009	61.29	162.5	80.9	135.7	62.69	220.1	109.1	183.1
2010	94.53	156.6	83.82	138.9	97.31	212.1	113	187.3
2011	117	132.2	68.32	112.5	120.1	179.2	92.13	151.7
2012	109.7	95.54	37.6	63.55	112.3	129.7	50.7	85.7
2013	94.59	80.82	27.74	48.5	96.78	109.7	37.41	65.41
2014	84.46	74.81	29.17	49.98	86.47	101.5	39.34	67.41
2015	76.09	55.14	18.15	30.83	77.89	74.93	24.48	41.58
2016	82.03	46.91	11.44	19.57	84.15	64.22	15.43	26.39
2017	124.5	62.69	11.01	19	128.1	86.61	14.85	25.62
2018	176.6	109.1	18.69	33.11	181.5	149.9	25.2	44.66
2019	173.6	195.3	55.06	97.55	177.7	266	74.26	131.6

Table 17: Maximum likelihood estimates of predicted mature male biomass at mating, mature female biomass at mating (in 1000 t), recruitment (millions) from the chosen model, and estimated fully-selected total fishing mortaltiy. These are maximum likelihood estimates.

Survey year	Mature male biomass	Mature female biomass	Recruits	Fishing mortality
1982	214.3	87.14	191.9	0.39
1983	229.5	67.63	544.5	0.22
1984	221.8	48.79	1288	0.42
1985	191.2	42.5	5409	0.7
1986	159.6	53.38	2284	1.09
1987	146.1	129.5	1077	2.45
1988	169.1	182	463.4	2.54
1989	214.3	179.1	1196	1.88
1990	209.2	146.7	1134	4.01
1991	192.4	124.1	1800	4.65
1992	175.4	113.6	1909	3.16
1993	168.2	117.7	1584	1.81
1994	167.2	129.3	360.4	1.36
1995	197.8	135.6	281.2	1.18
1996	263	119.3	307.7	0.78
1997	258.9	92.98	422.2	1.11
1998	186.3	71	593.9	1.27
1999	153.8	57.63	301.3	0.33
2000	121.2	52.53	245.6	0.35
2001	96.18	47.15	223.4	0.69
2002	92.41	40.19	680	0.6
2003	100	33.77	1596	0.34
2004	99.84	35.58	744.3	0.32
2005	91.42	54.89	619.1	0.6
2006	99.31	66.79	282.3	0.66
2007	117	66.76	315.7	0.88
2008	143.5	58.13	2664	0.55
2009	159.9	48.51	889.3	0.34
2010	150.5	75.31	480.1	0.38
2011	107	92.81	562.4	0.91
2012	76.14	86.89	635.1	1.44
2013	65.68	74.88	486.2	1.66
2014	52.45	66.81	1216	2.45
2015	42.57	60.26	2828	2.28
2016	42.88	65.12	2754	1.57
2017	62.45	99.14	331.6	1.4
2018	111.4	140.4	222	1.05

Table 18: Maximum likelihood estimates of predicted total numbers (billions), not subject to survey selectivity at the time of the survey. These are maximum likelihood estimates.

Survey year	Total numbers
1982	4.843
1983	5.28
1984	5.901
1985	7.484
1986	14.99
1987	15.03
1988	15.27
1989	11.36
1990	9.486
1991	8.037
1992	13.15
1993	12.18
1994	10.79
1995	8.166
1996	6.103
1997	4.644
1998	4.364
1999	4.218
2000	3.494
2001	2.928
2002	2.894
2003	4.052
2004	5.747
2005	5.935
2006	5.462
2007	4.3
2008	3.521
2009	6.082
2010	5.582
2011	4.66
2012	3.936
2013	3.571
2014	3.399
2015	5.681
2016	11.73
2017	13.34
2018	10.2
2019	7.706

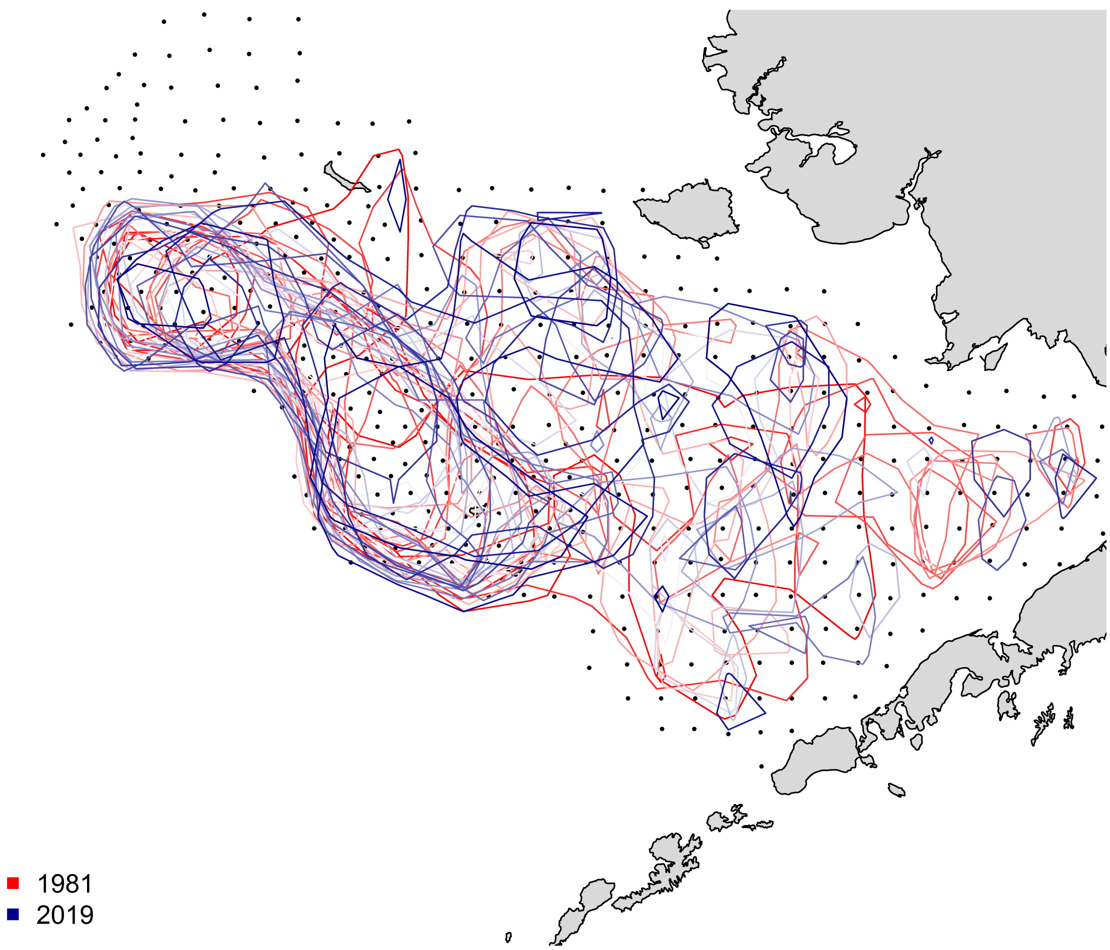

Figure 1: Kernel densities over time of greater than 77 mm carapace width males in the survey. Plotted contours are the lines that contain 99th quantile of the stations at which crab were observed in a given year. Colors are a gradient from red to blue, with red starting at 1981 and blue ending at 2019. Black points are survey stations.

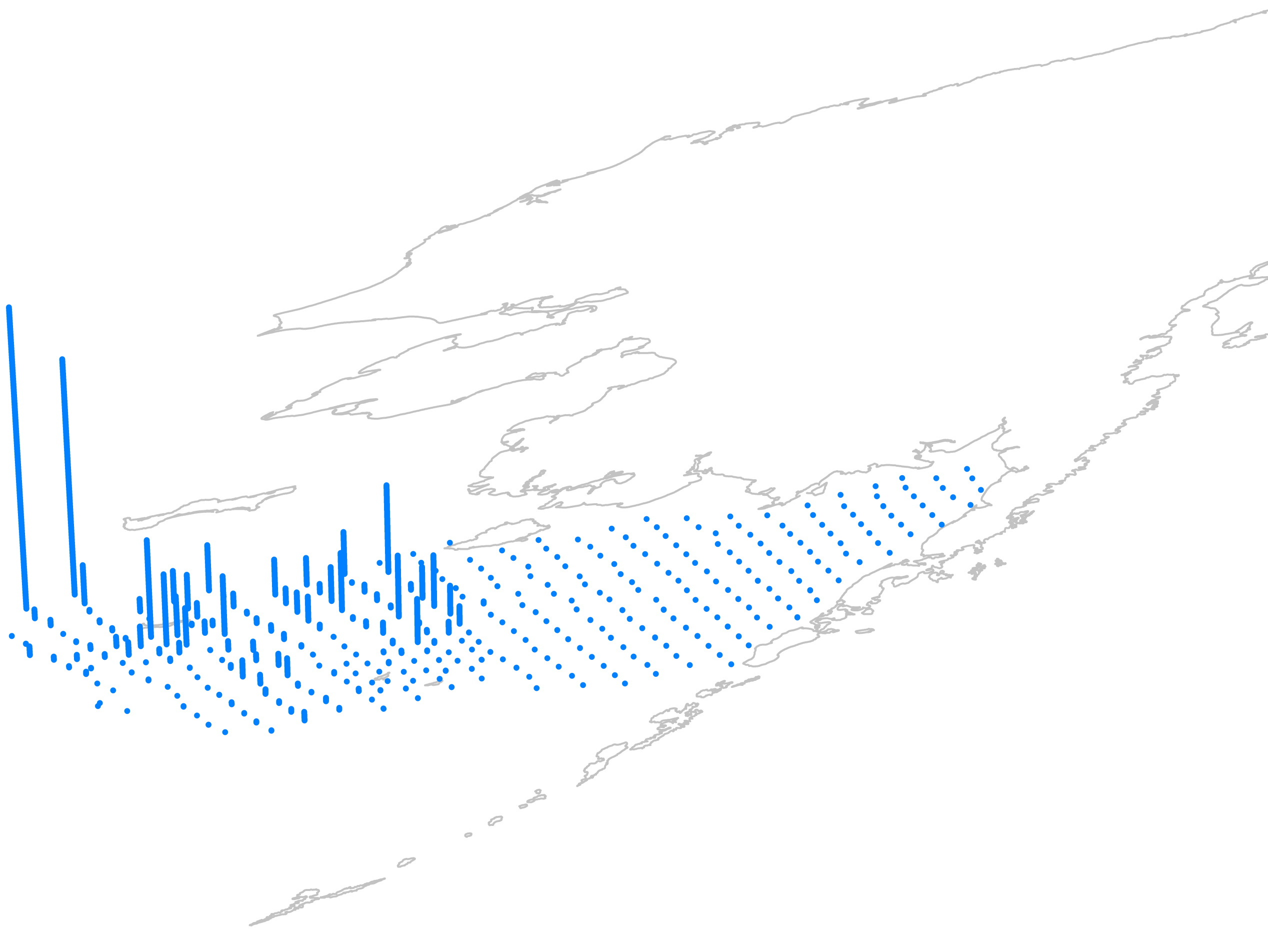

Figure 2: Observed relative density of all males at the time of the 2019 NMFS summer survey

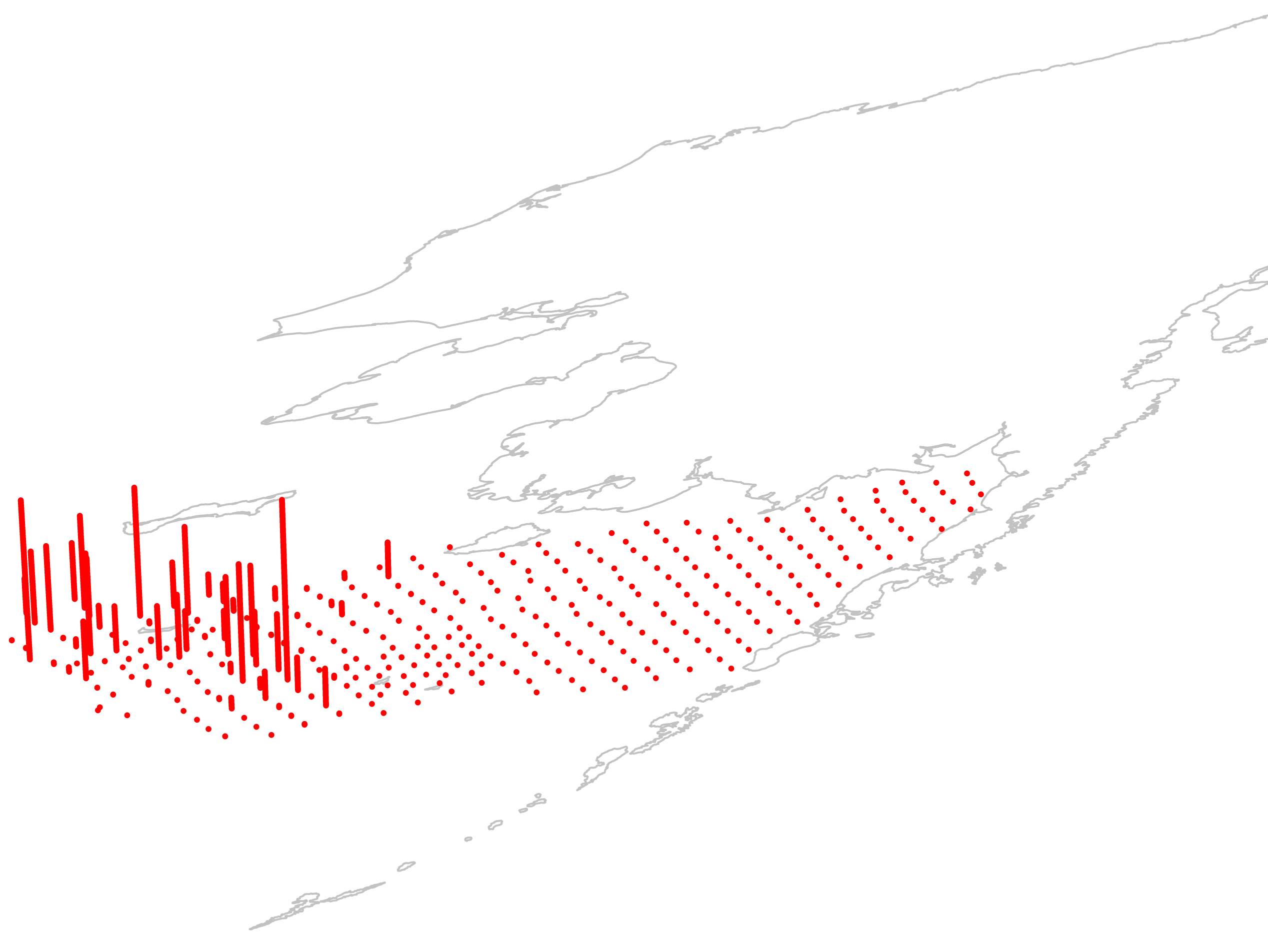

Figure 3: Observed relative density of all females at the time of the 2019 NMFS summer survey

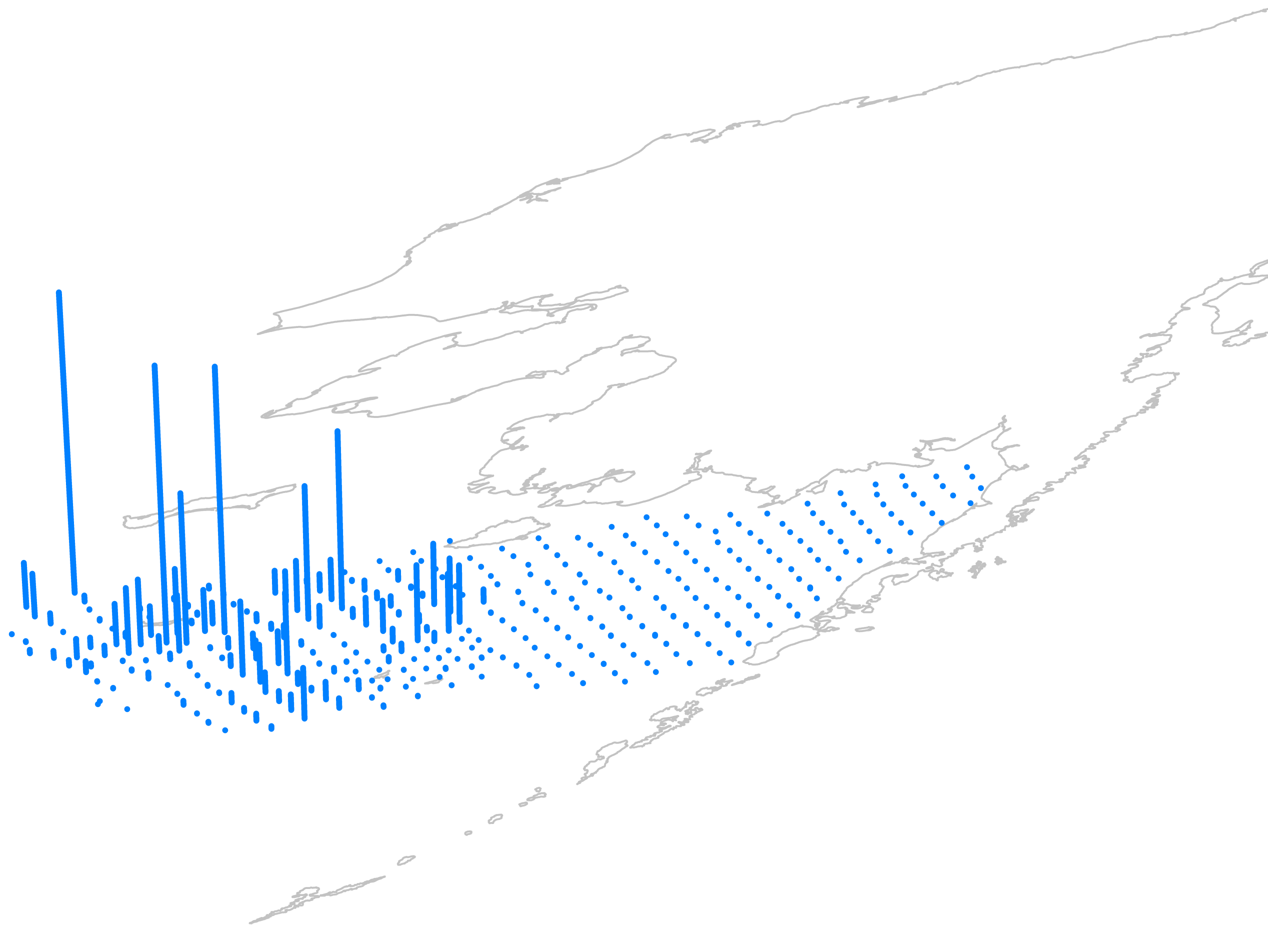

Figure 4: Observed relative density of males >77mm carapace width at the time of the 2019 NMFS summer survey

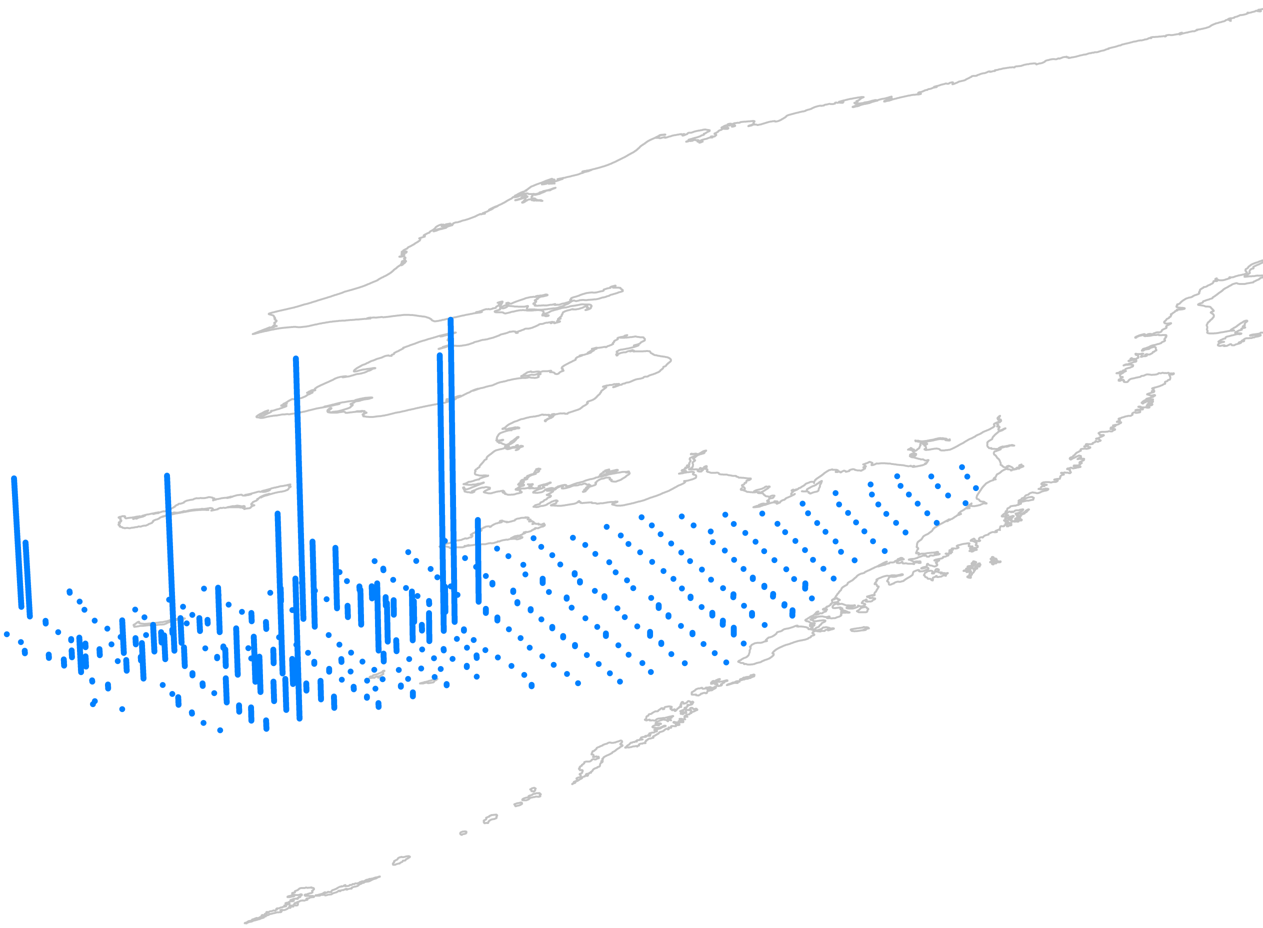

Figure 5: Observed relative density of males >101mm carapace width at the time of the 2019 NMFS summer survey

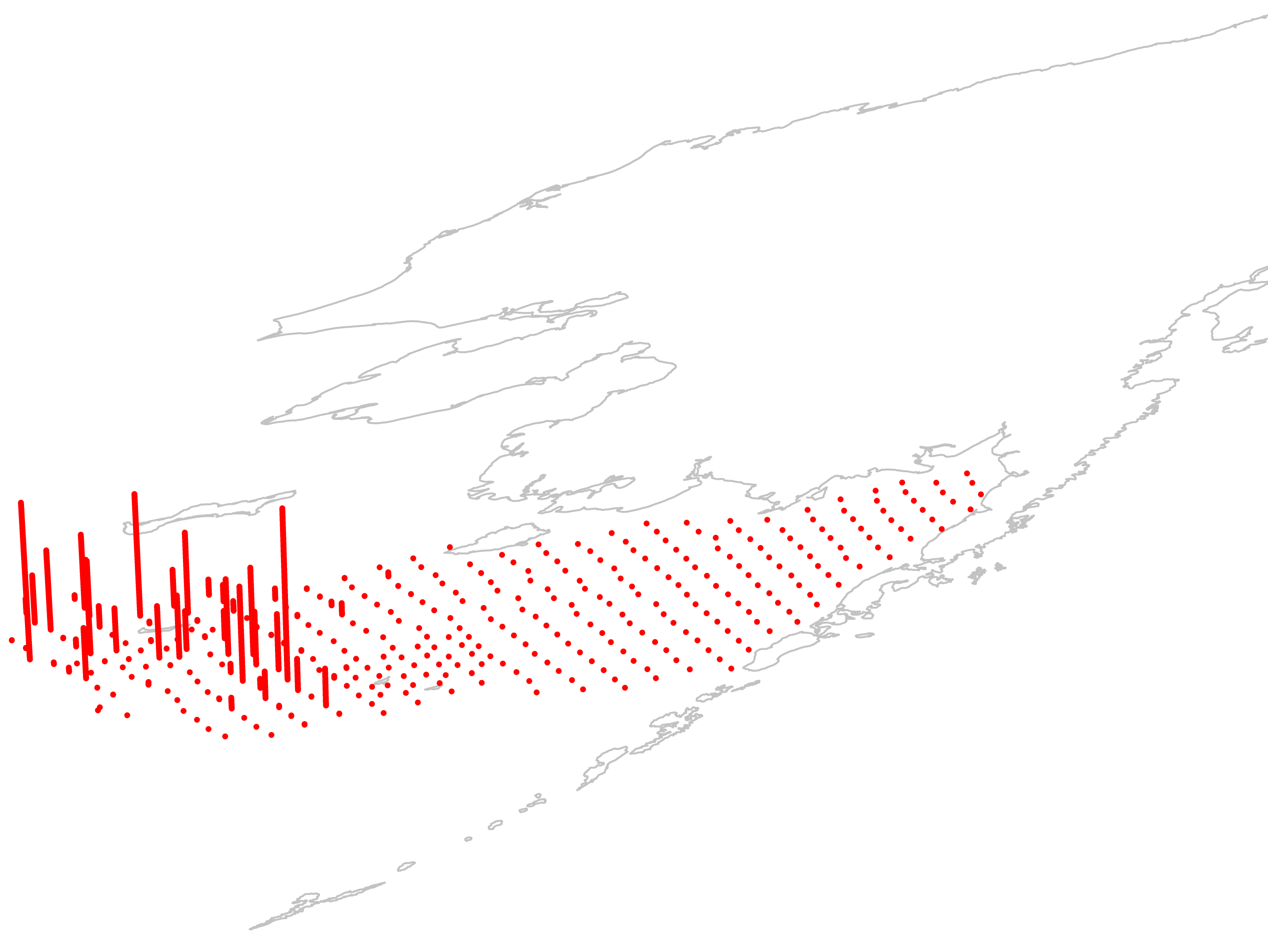

Figure 6: Observed relative density of mature females at the time of the 2019 NMFS summer survey

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 7: 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.

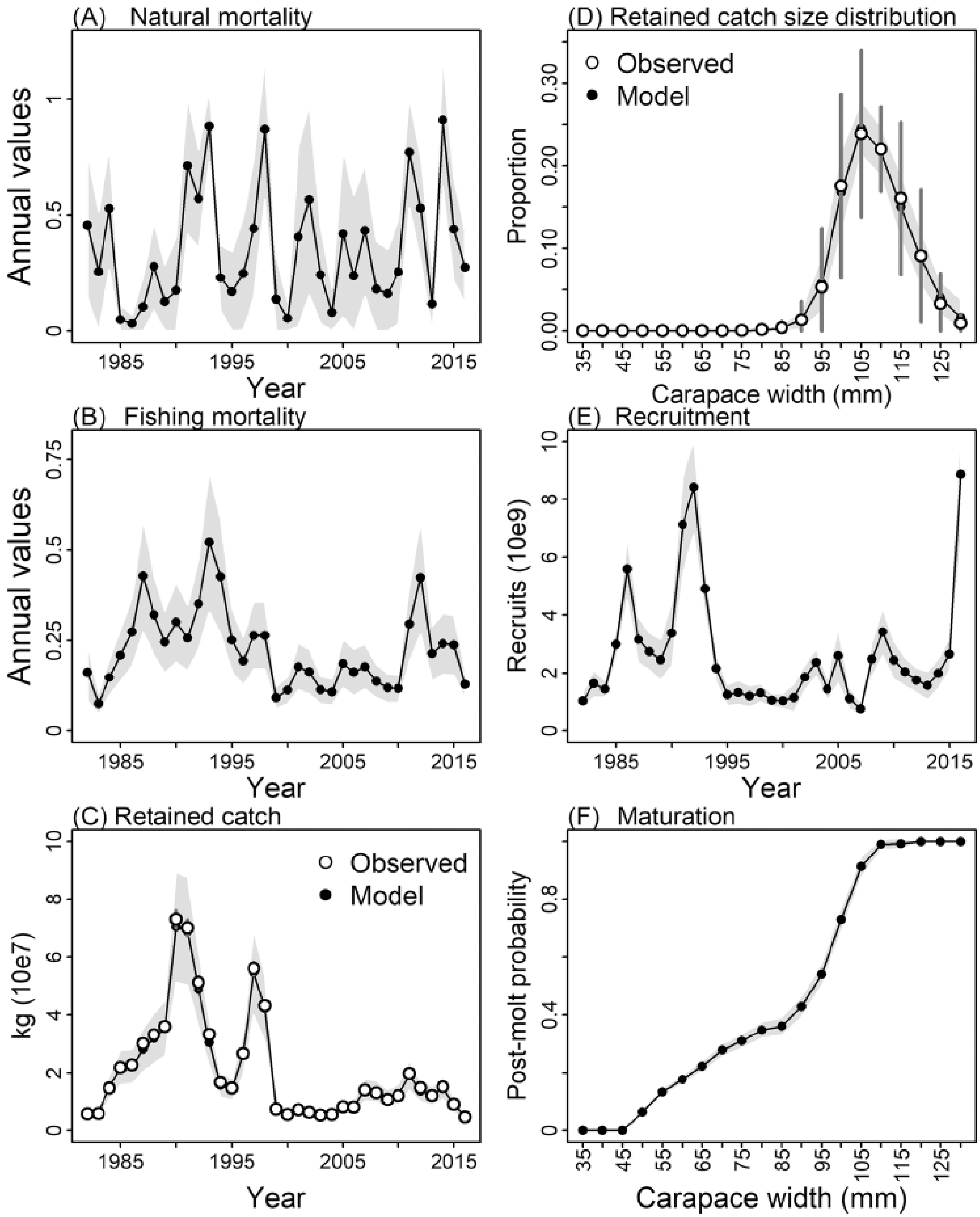

Figure 8: Murphy et al.'s (2018) estimates of natural mortality (and time-variation in M) from a state-space modeling framework.

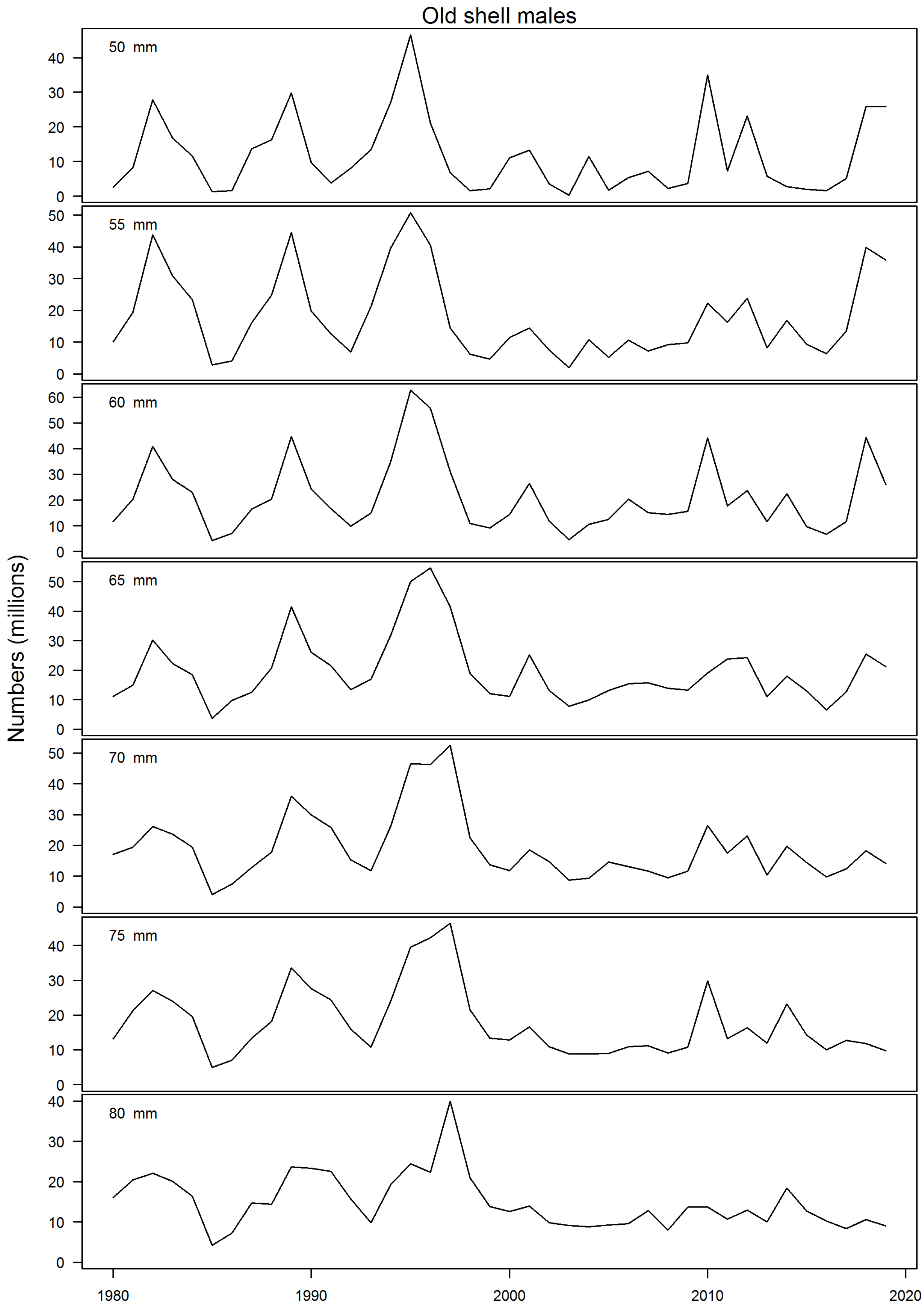

Figure 9: Observed numbers at length of old shell mature males by size class. The presented size bins are not vulnerable to the fishery, so all mortality is 'natural'. The decline in numbers in a size class after the recruitment collapse in the early 1990s demonstrates expected natural mortality for mature male individuals.

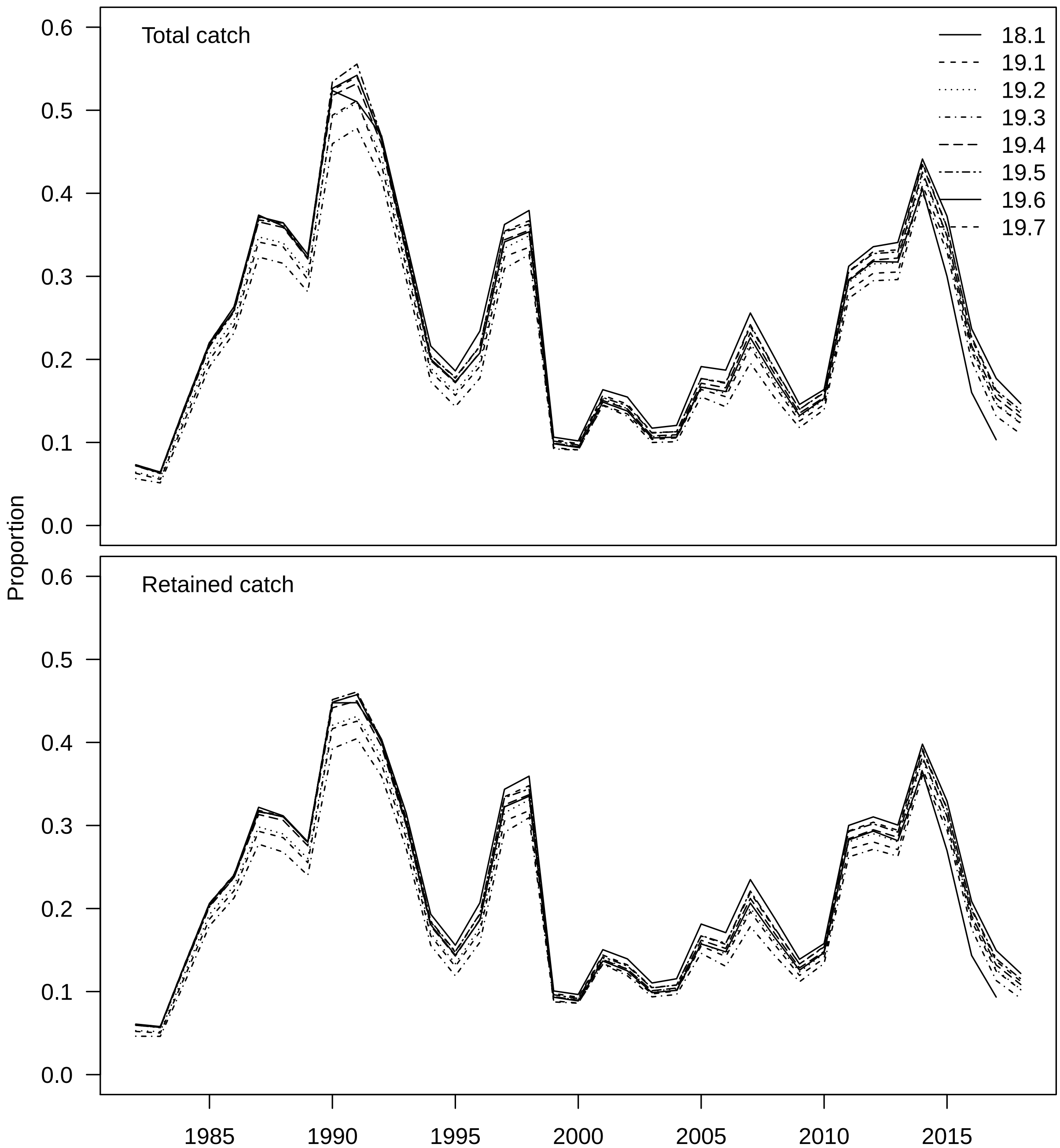

Figure 10: Model predicted ratio of catch to mature male biomass

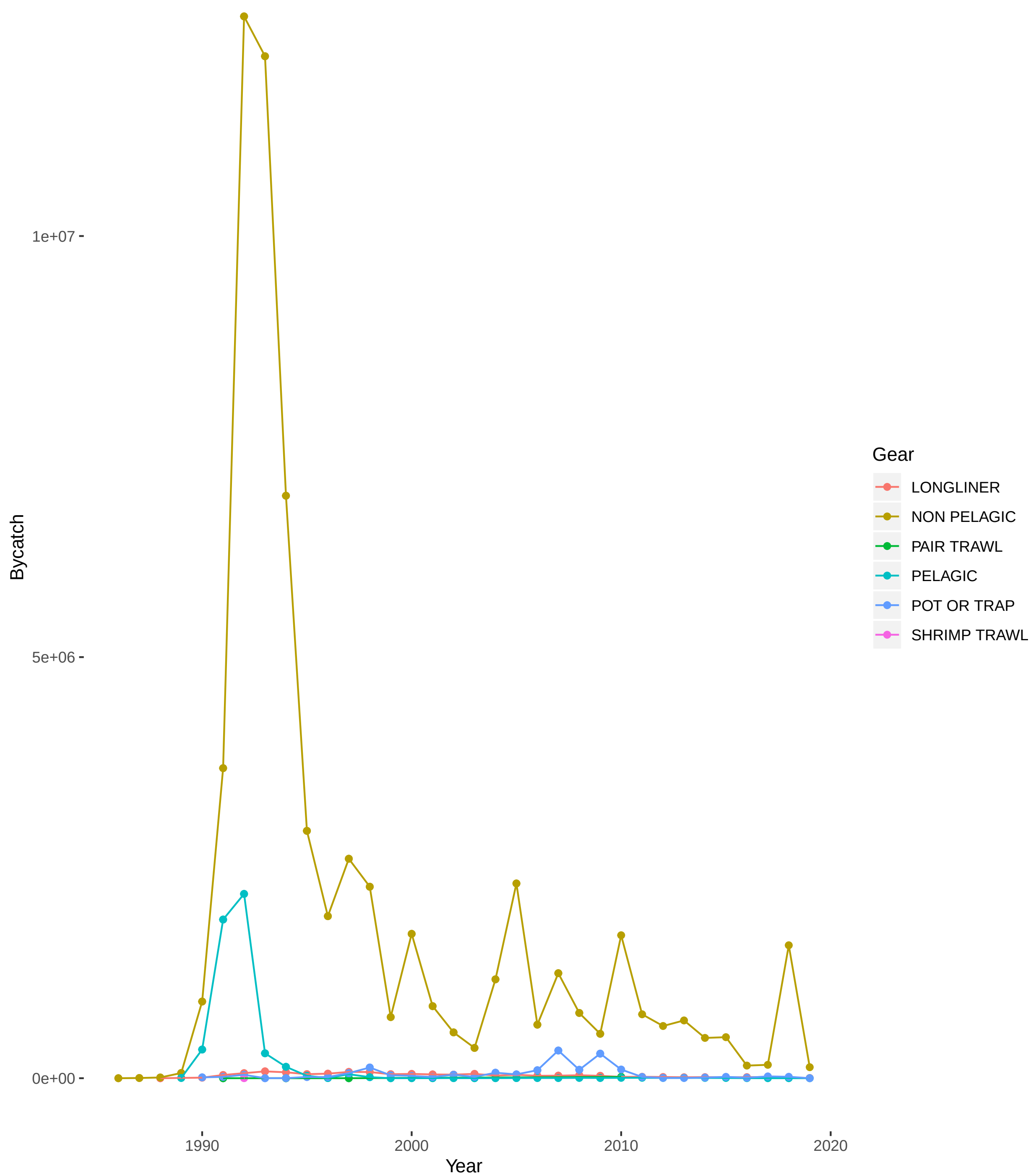

Figure 11: Bycatches in other fishing fleets.

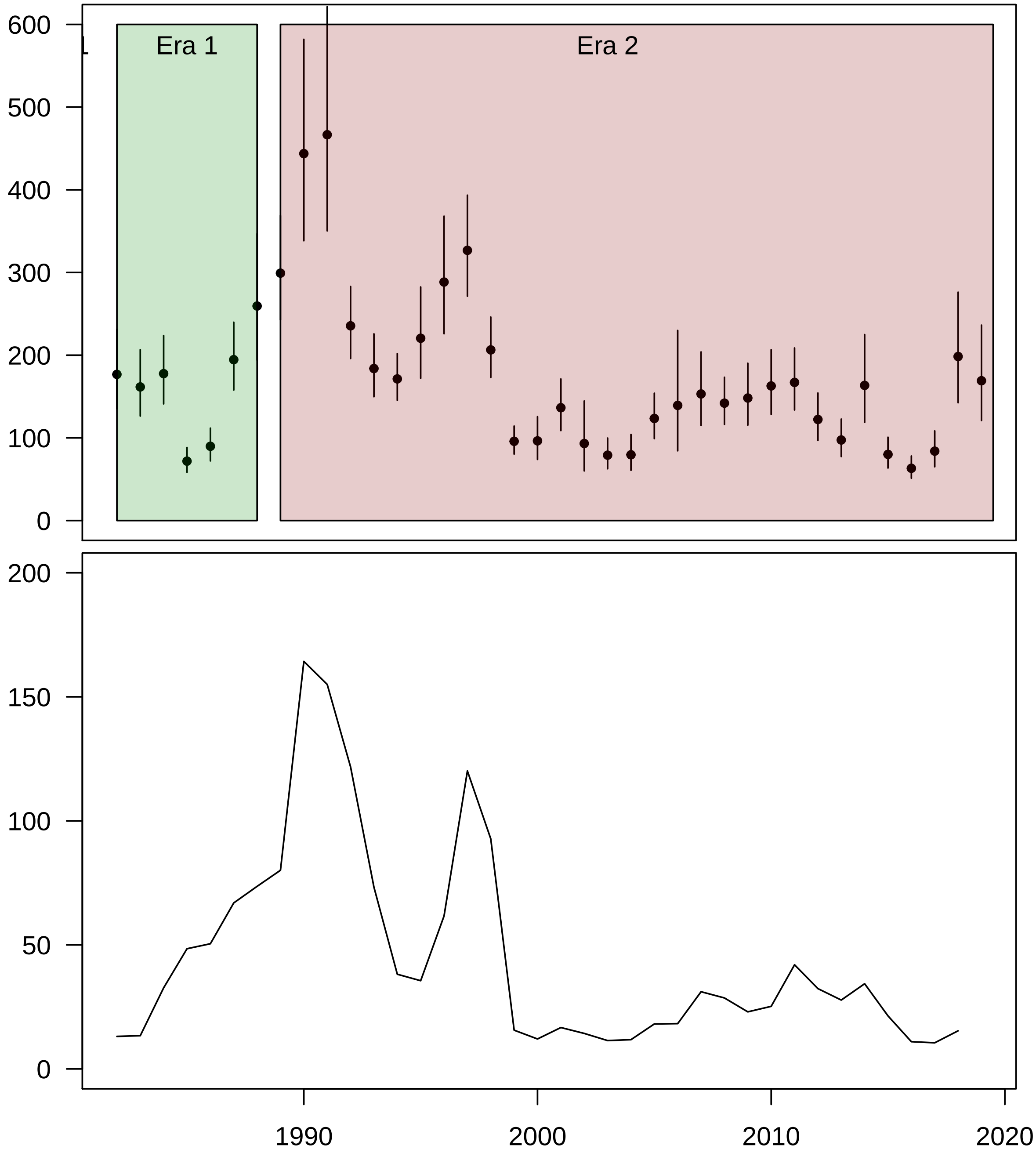

Figure 12: Divisions of survey data for estimation of q (MMB shown for reference; top) and total catches (bottom)

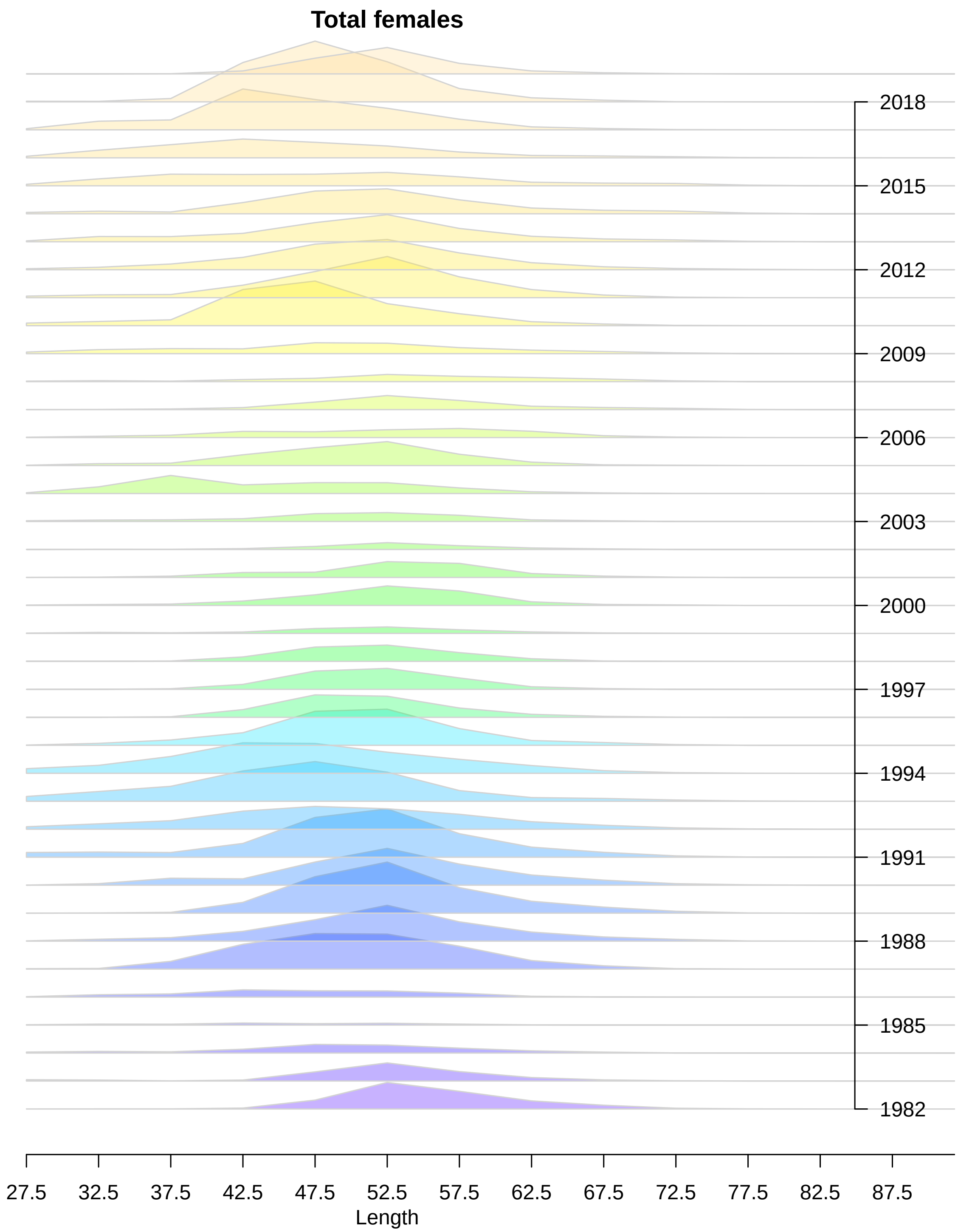

Figure 13: Observed relative numbers of females at length at the time of the survey

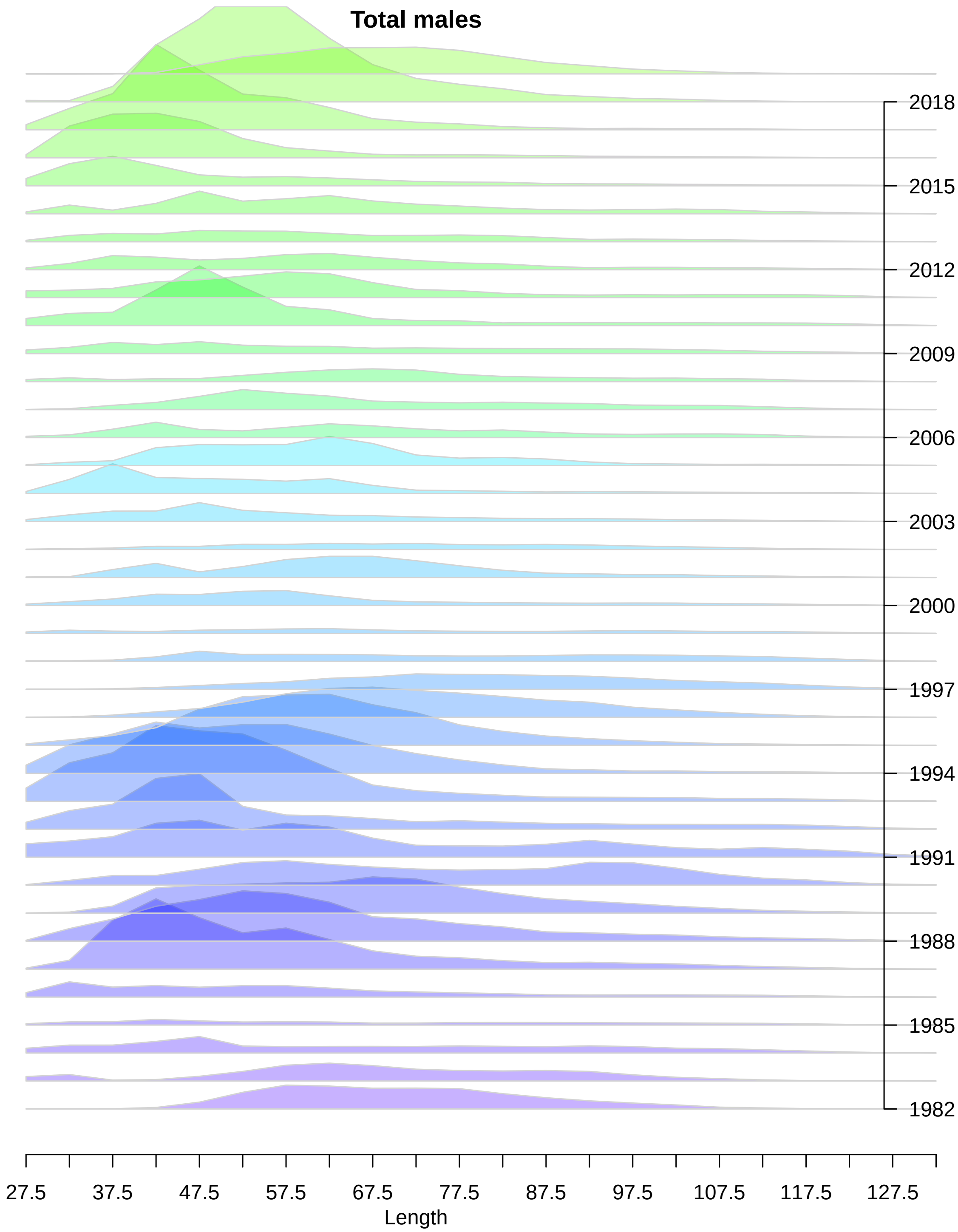

Figure 14: Observed relative numbers of males at length at the time of the survey

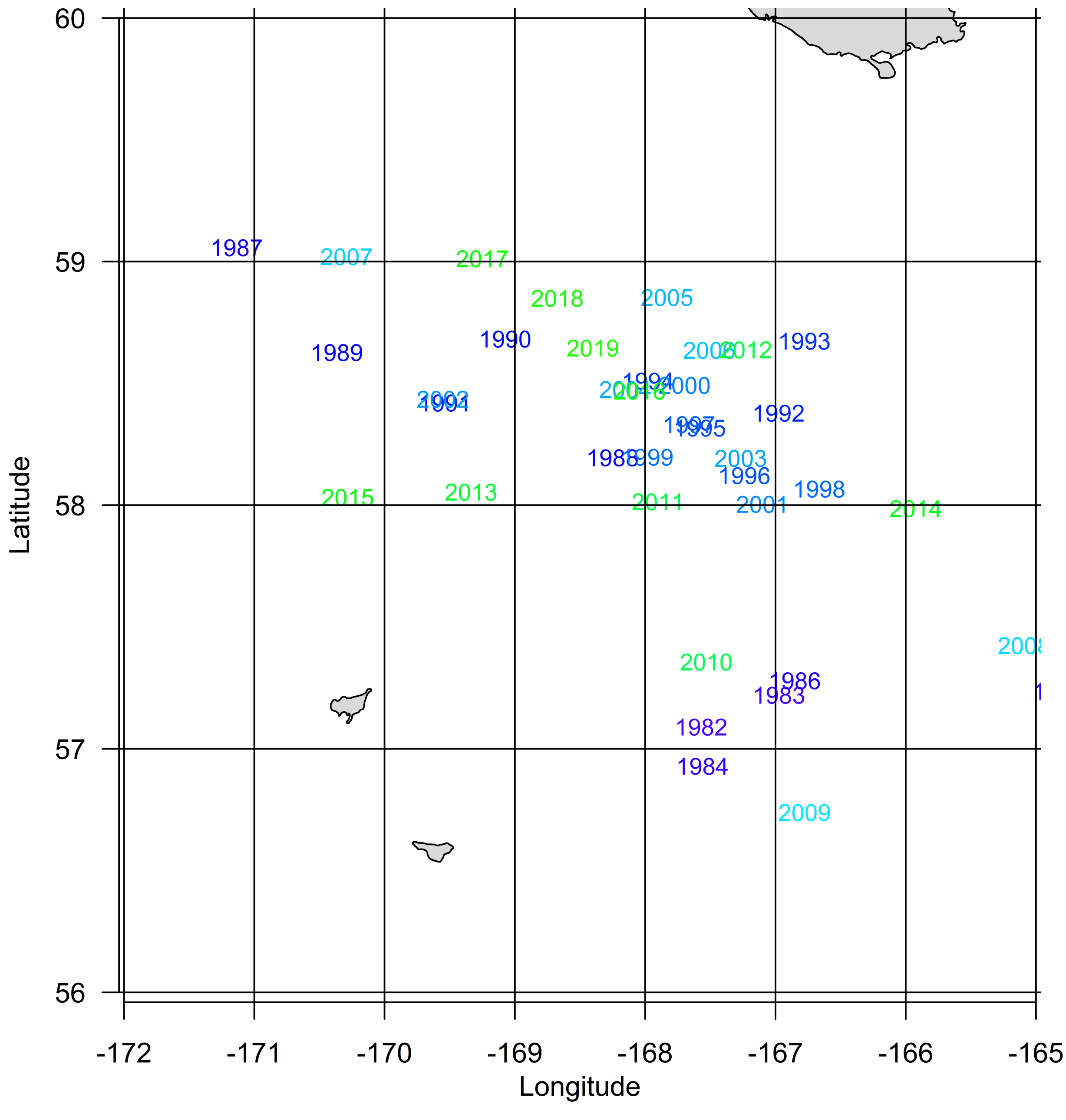

Figure 15: Centroid of mature females observed in the survey over time. Dark blue indicates years early in the time series; green are the most recent years in the time series.

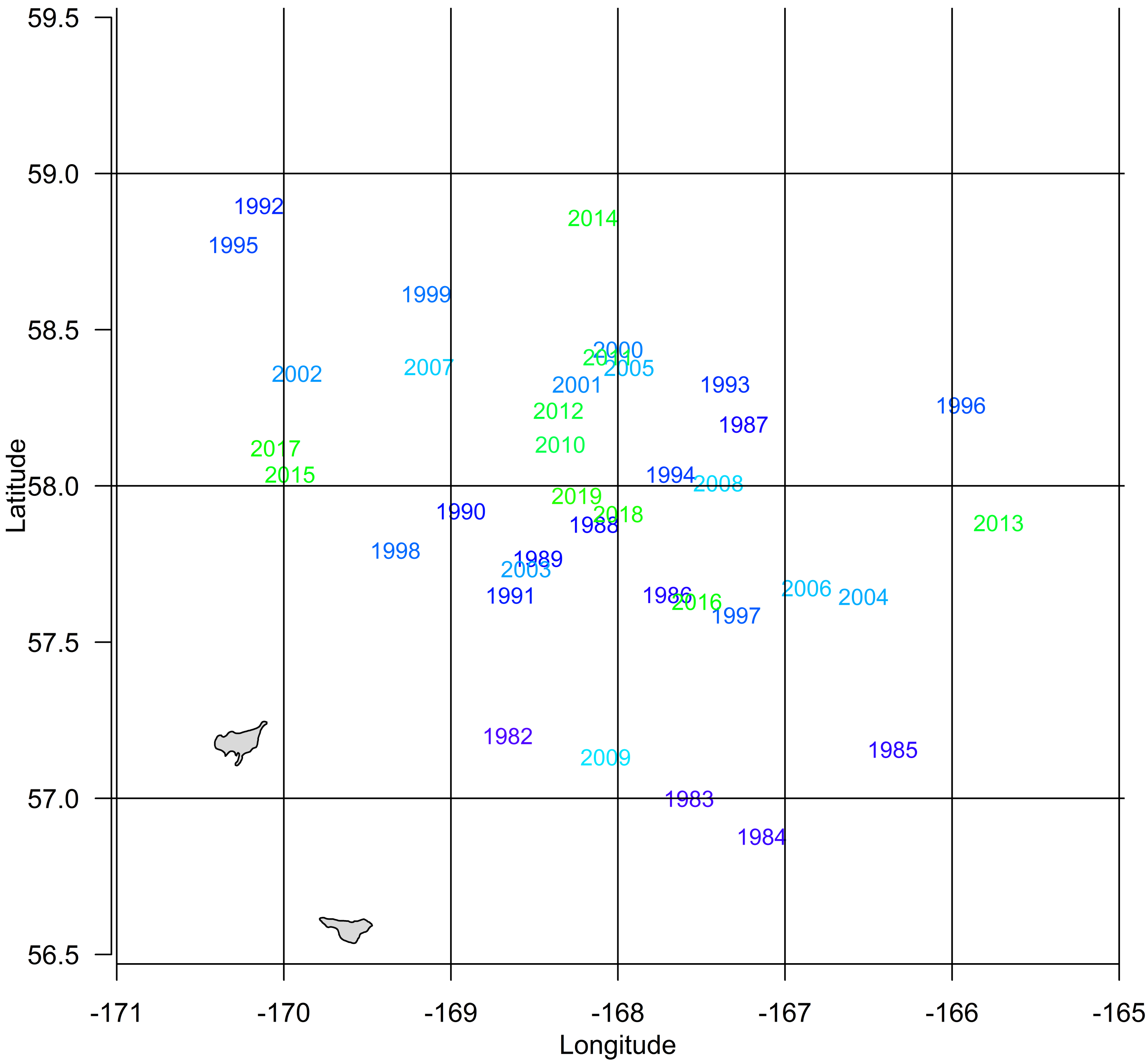

Figure 16: Centroid of large males observed in the survey over time. Dark blue indicates years early in the time series; green are the most recent years in the time series.

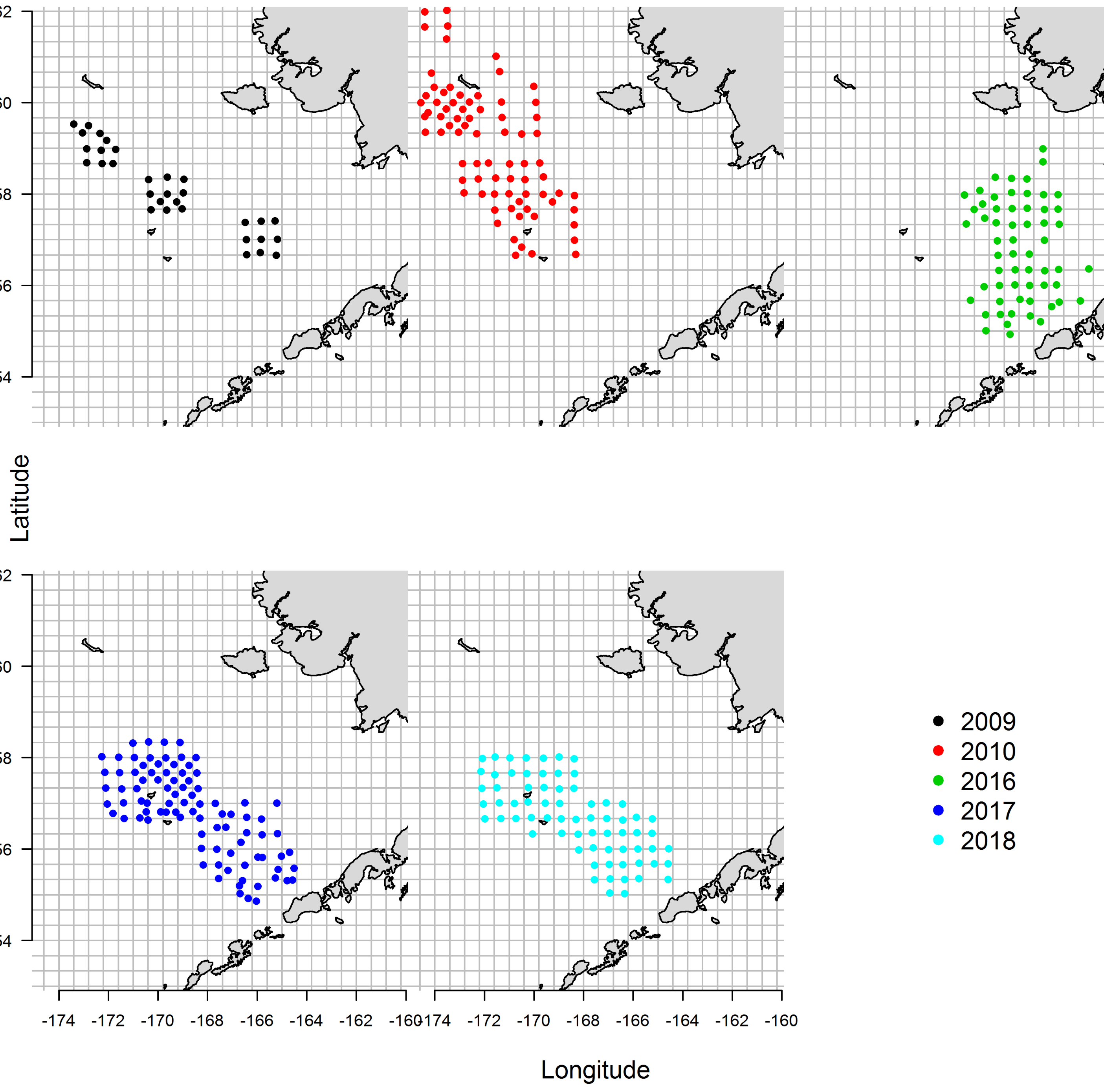

Figure 17: Location of BSFRF survey selectivity experiments.

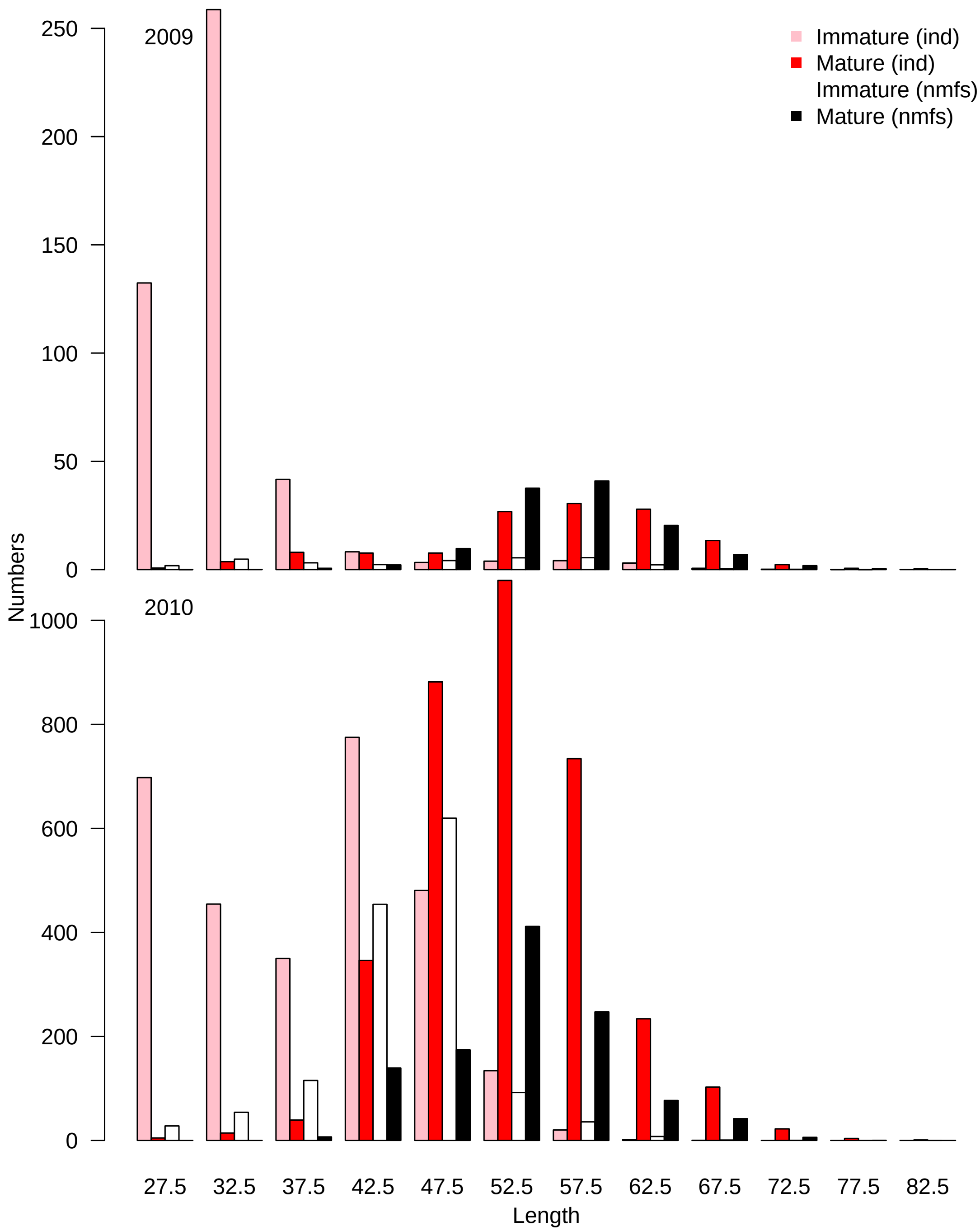

Figure 18: Raw female numbers from BSFRF survey selectivity experiments (2009 & 2010). Note a change in scale on the y-axis from 2009 to 2010

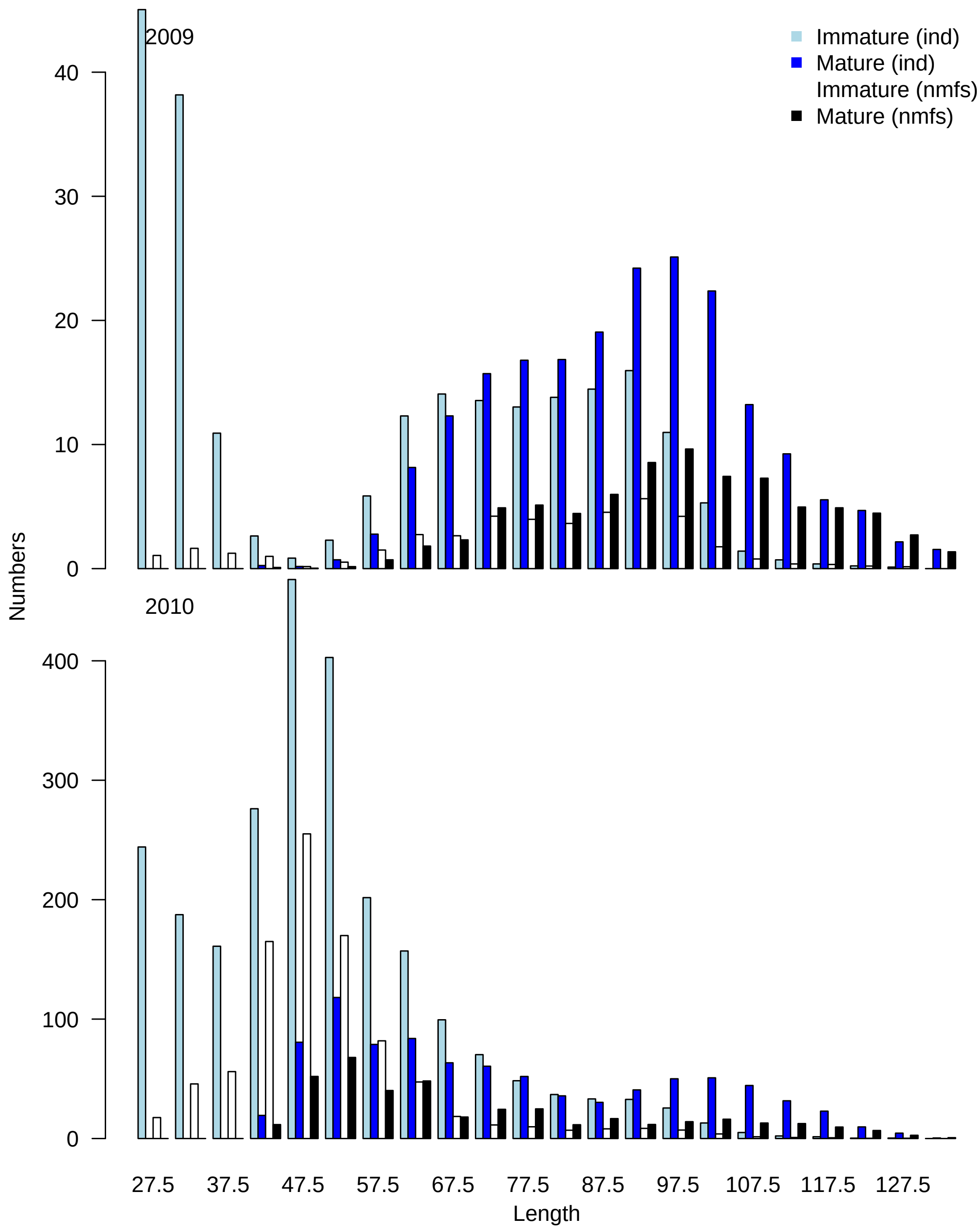

Figure 19: Raw male numbers from BSFRF survey selectivity experiments (2009 & 2010). Note a change in scale from 2009 to 2010 on the y-axis.

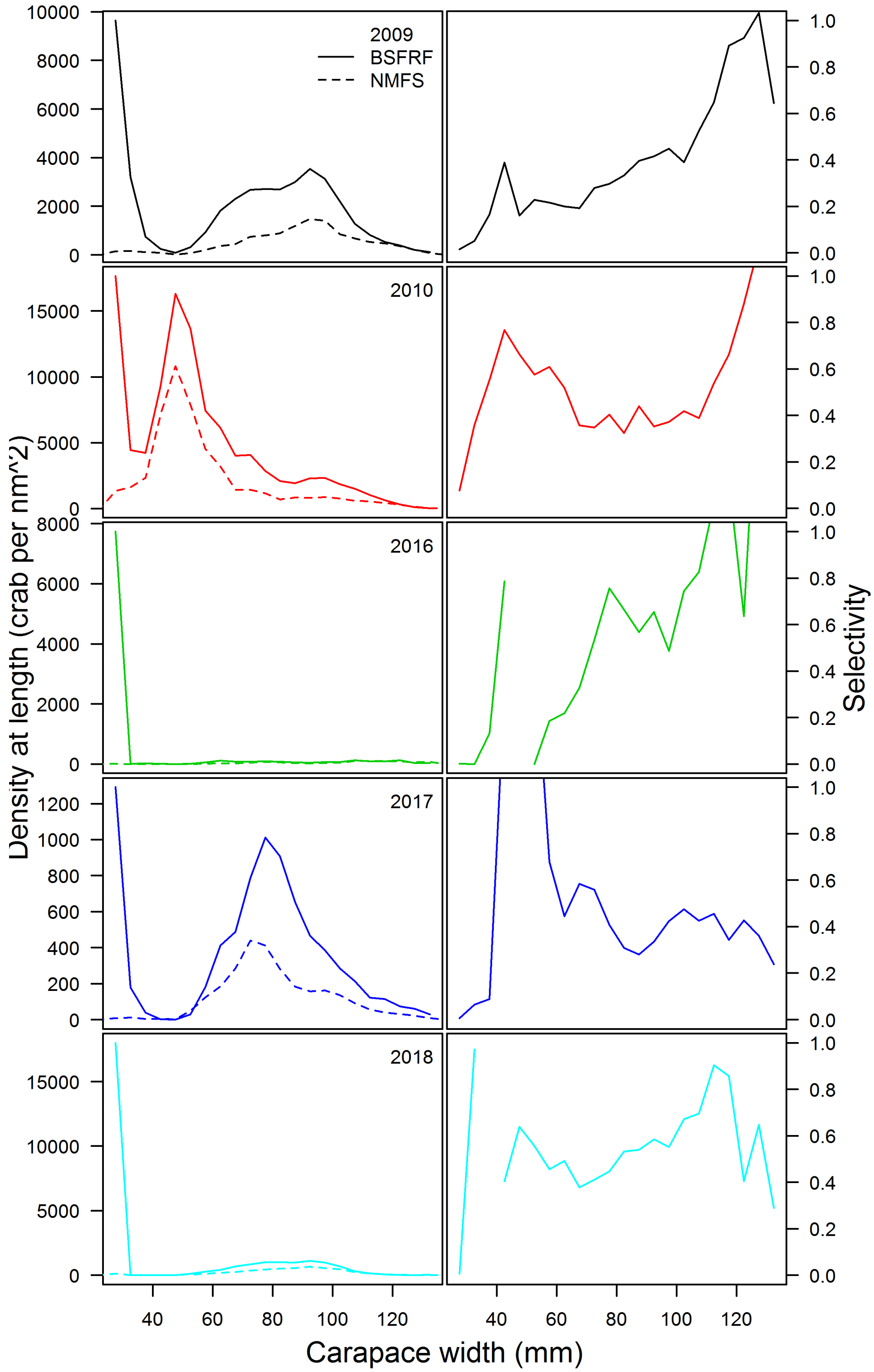

Figure 20: Observed numbers at length extrapolated from length composition data and estimates of total numbers within the survey selectivity experimental areas by year (left). Inferred selectivity (i.e. the ratio of crab at length in the NMFS gear to crab at length in the BSFRF gear.

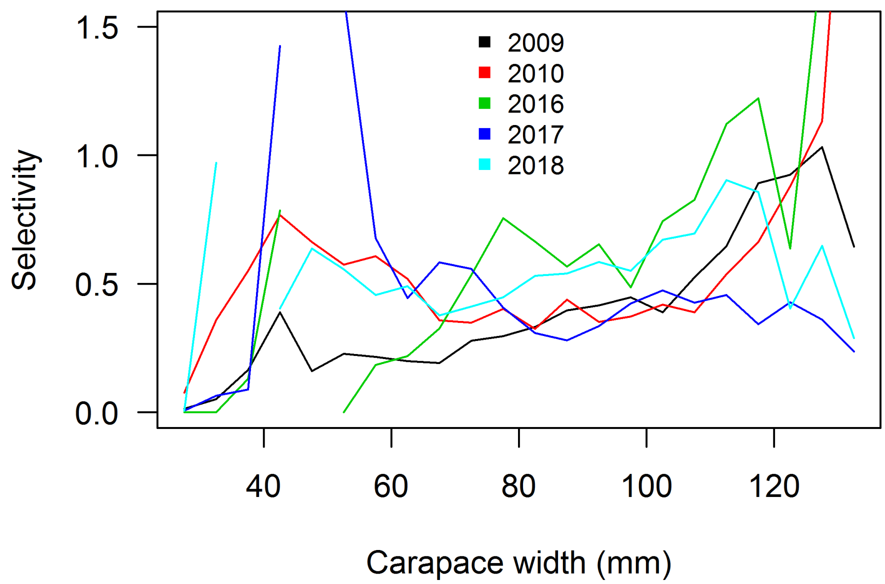

Figure 21: Inferred selectivity for all available years of BSFRF data.

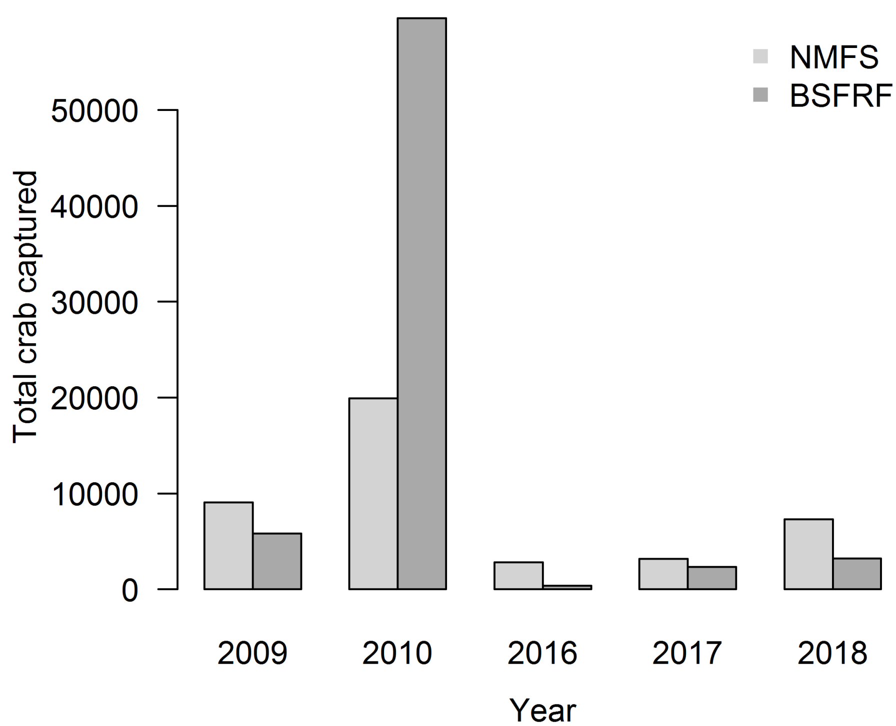

Figure 22: Number of crab from which estimates of biomass and length composition data were inferred within the survey selectivity experimental area.

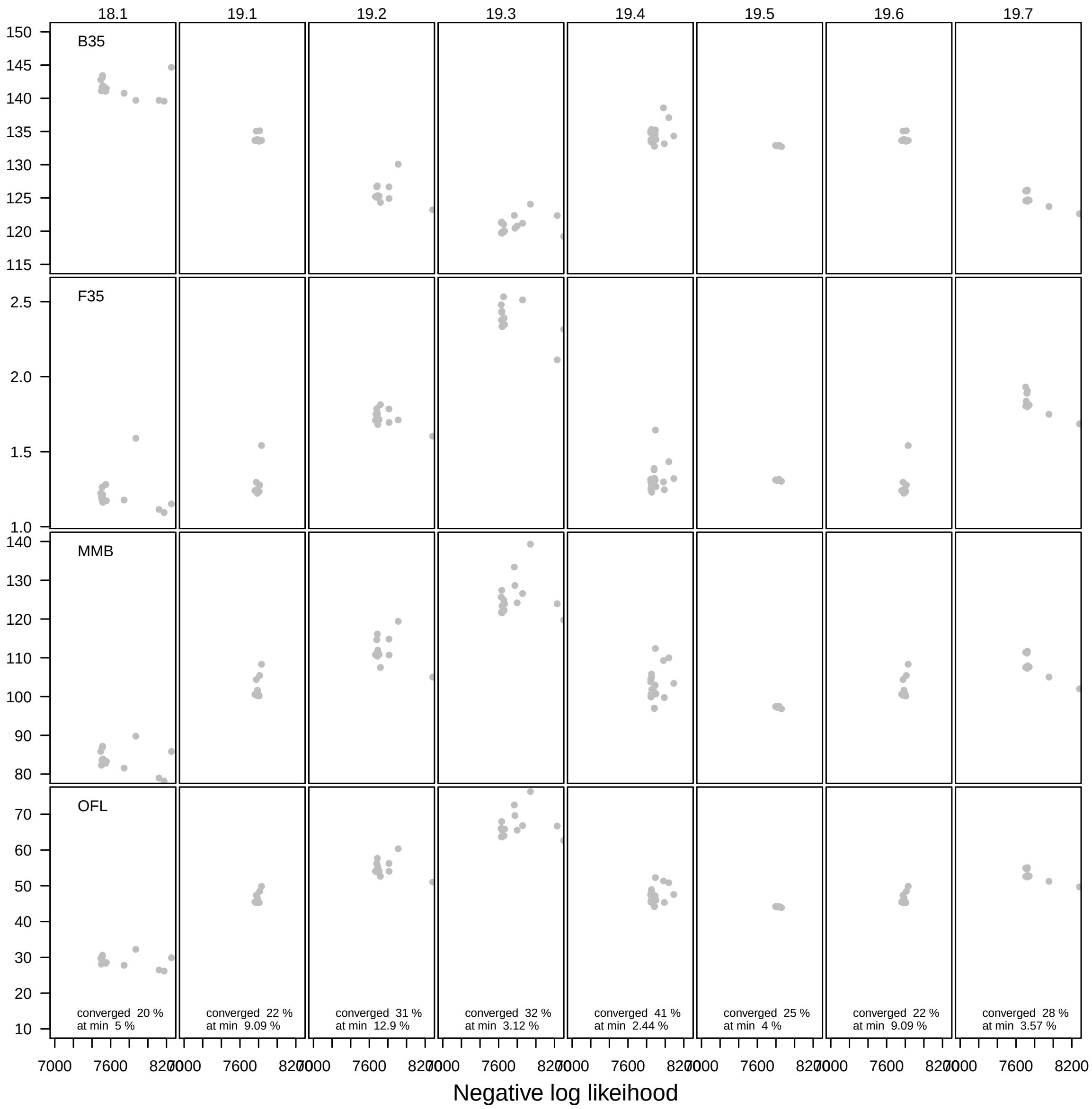

Figure 23: Management quantities after jittering selected models. 'Converged %' indicates the % of jittered models that had a maximum gradient component < 0.005. 'at min %' indicates the number of runs that converged to the minimum observed negative log likelihood

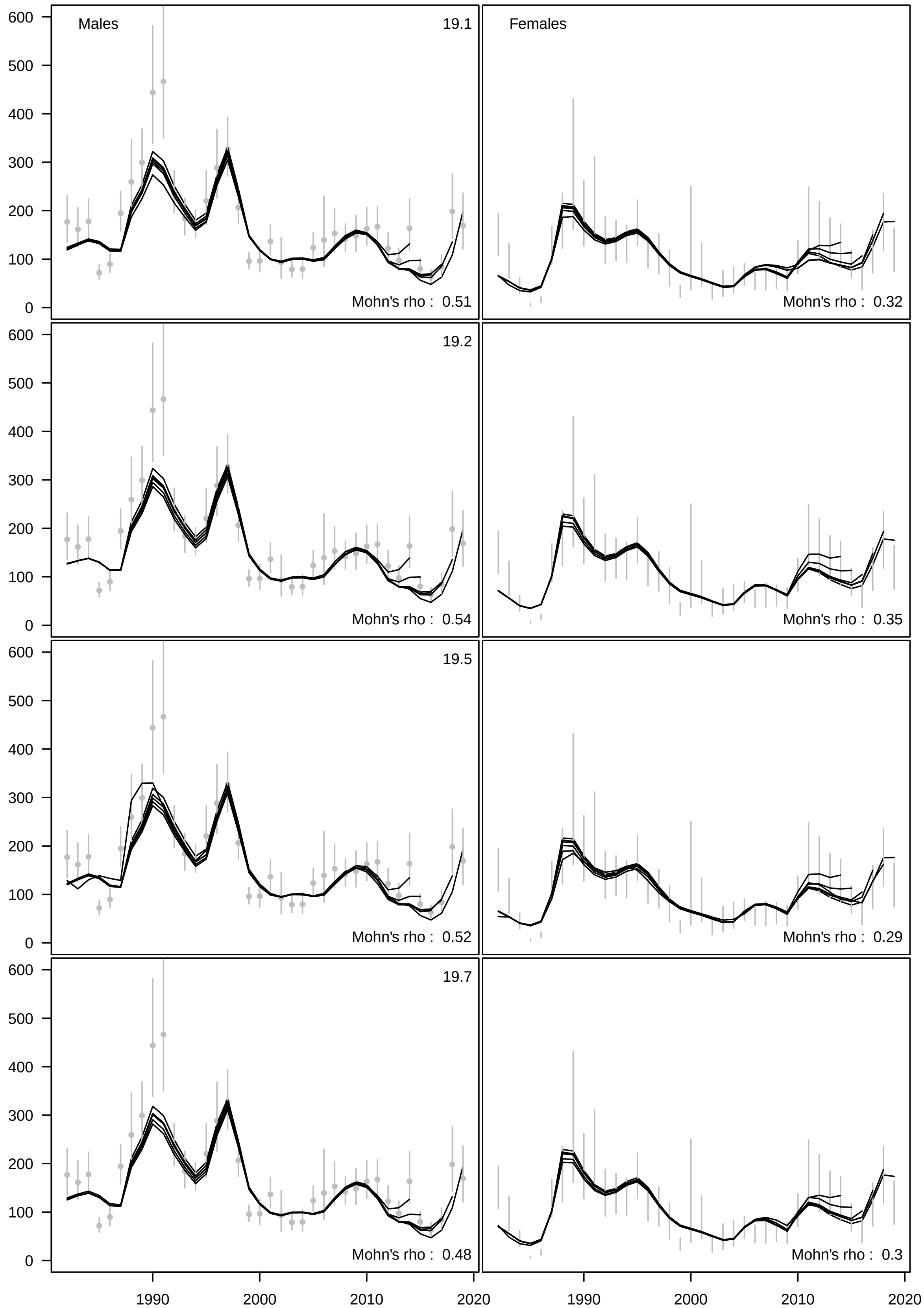

Figure 24: Retrospective analysis for selected models. Each line represents the model predictions for survey mature biomass when successively more years of data are removed from the analysis. Average difference is calculated as the mean relative error over the retrospective period (i.e. (Peeled MMB - 2019 MMB)/ 2019 MMB)

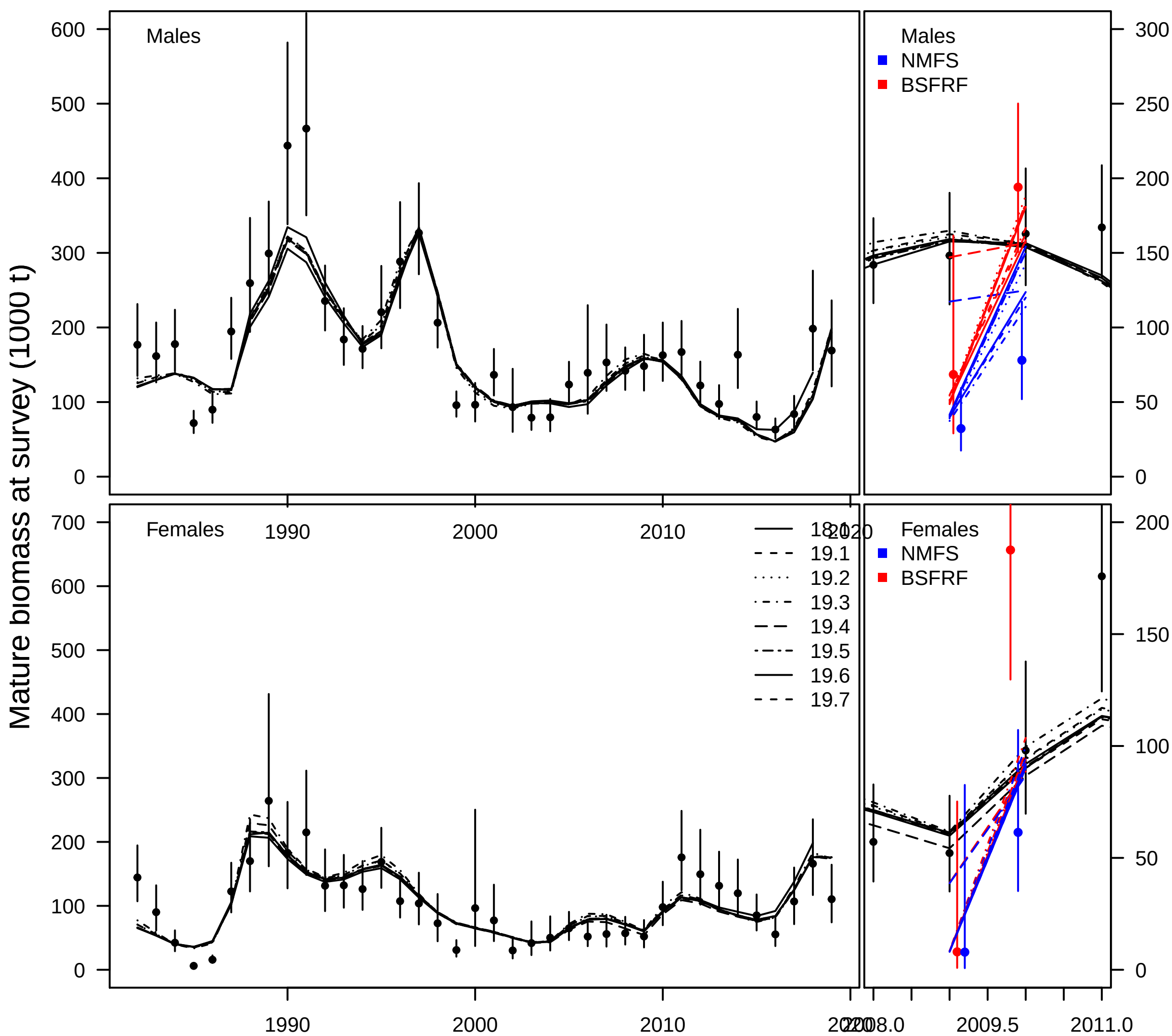

Figure 25: Model fits to the observed mature biomass at survey

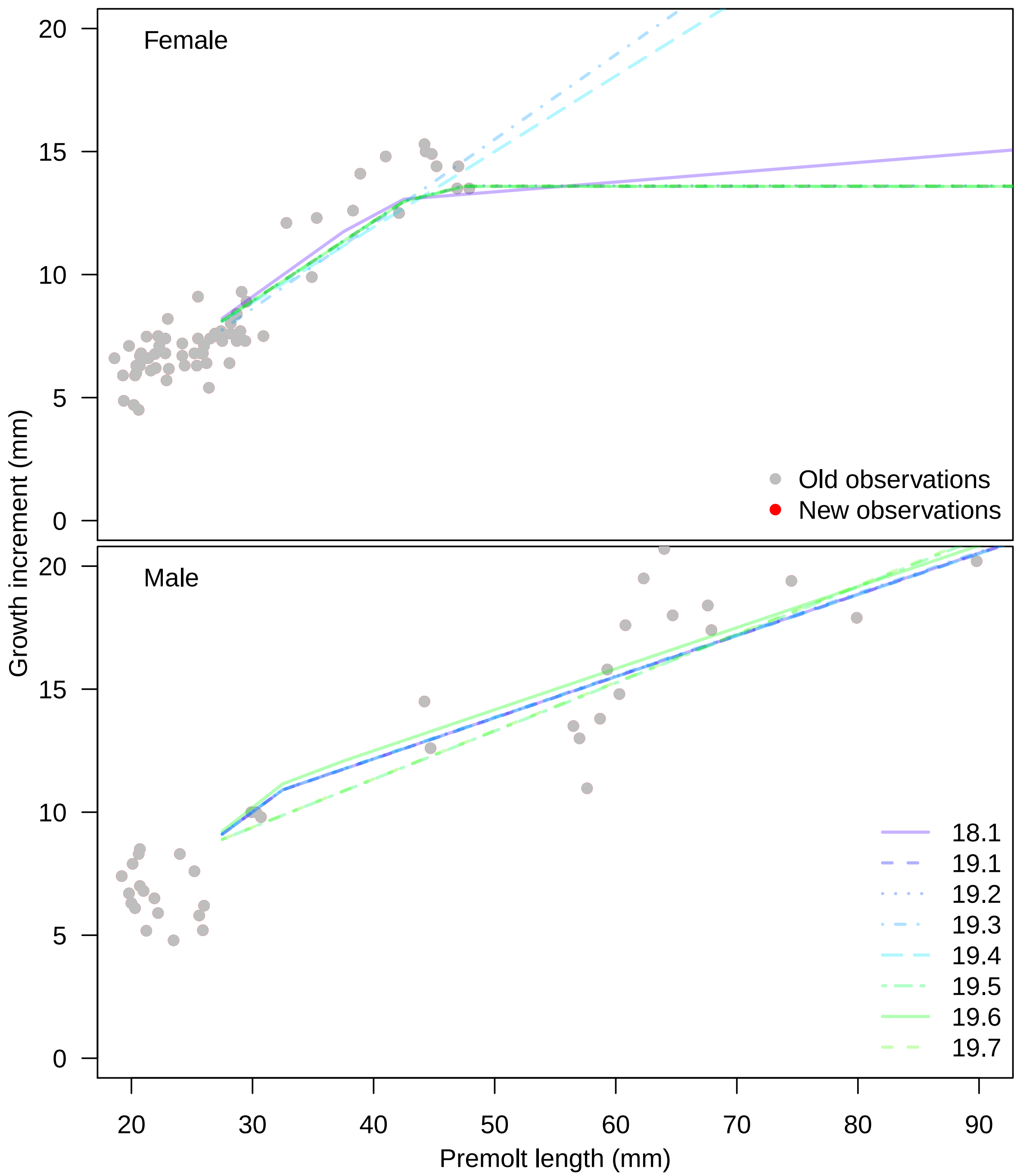

Figure 26: Model fits to the growth data

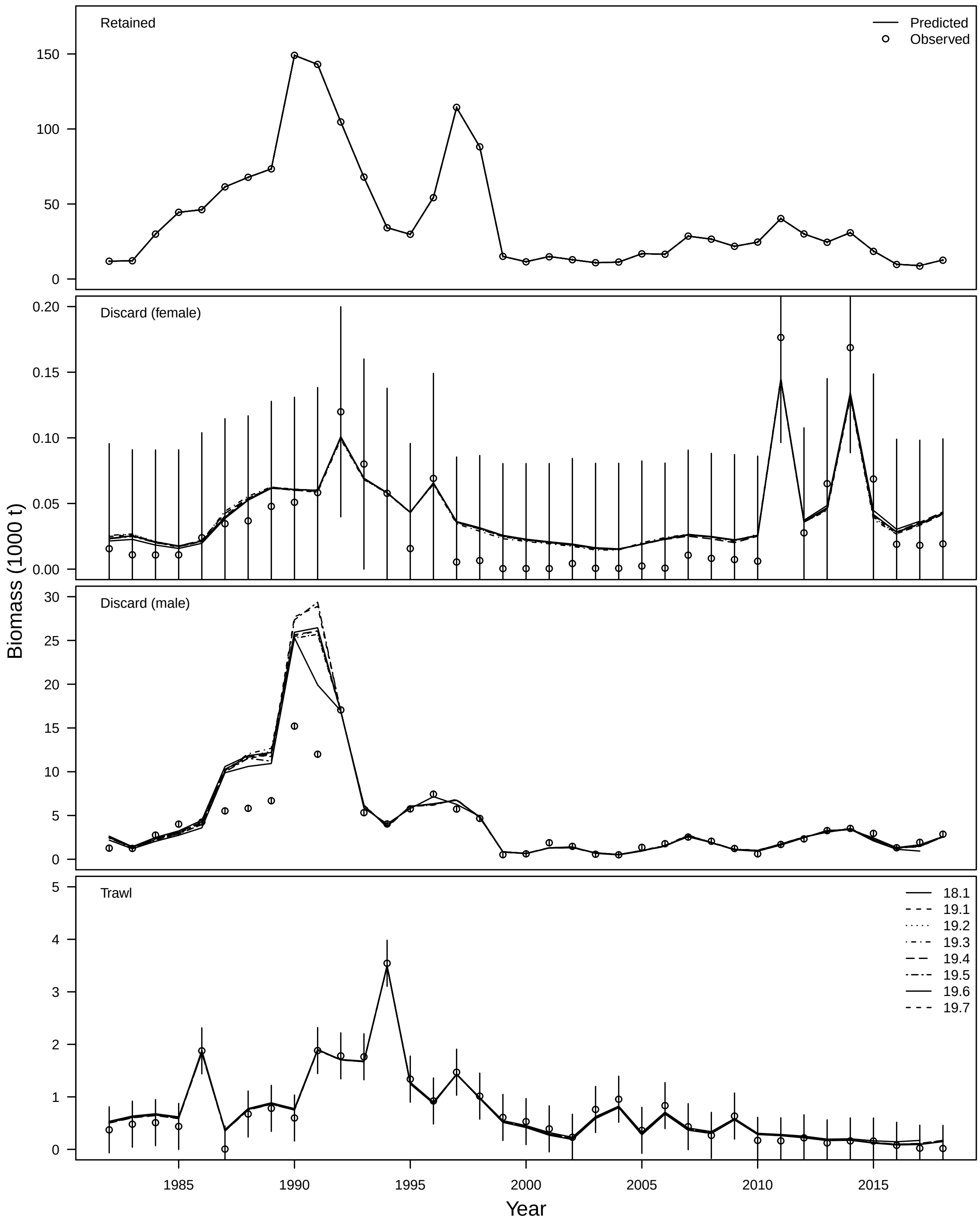

Figure 27: Model fits to catch data

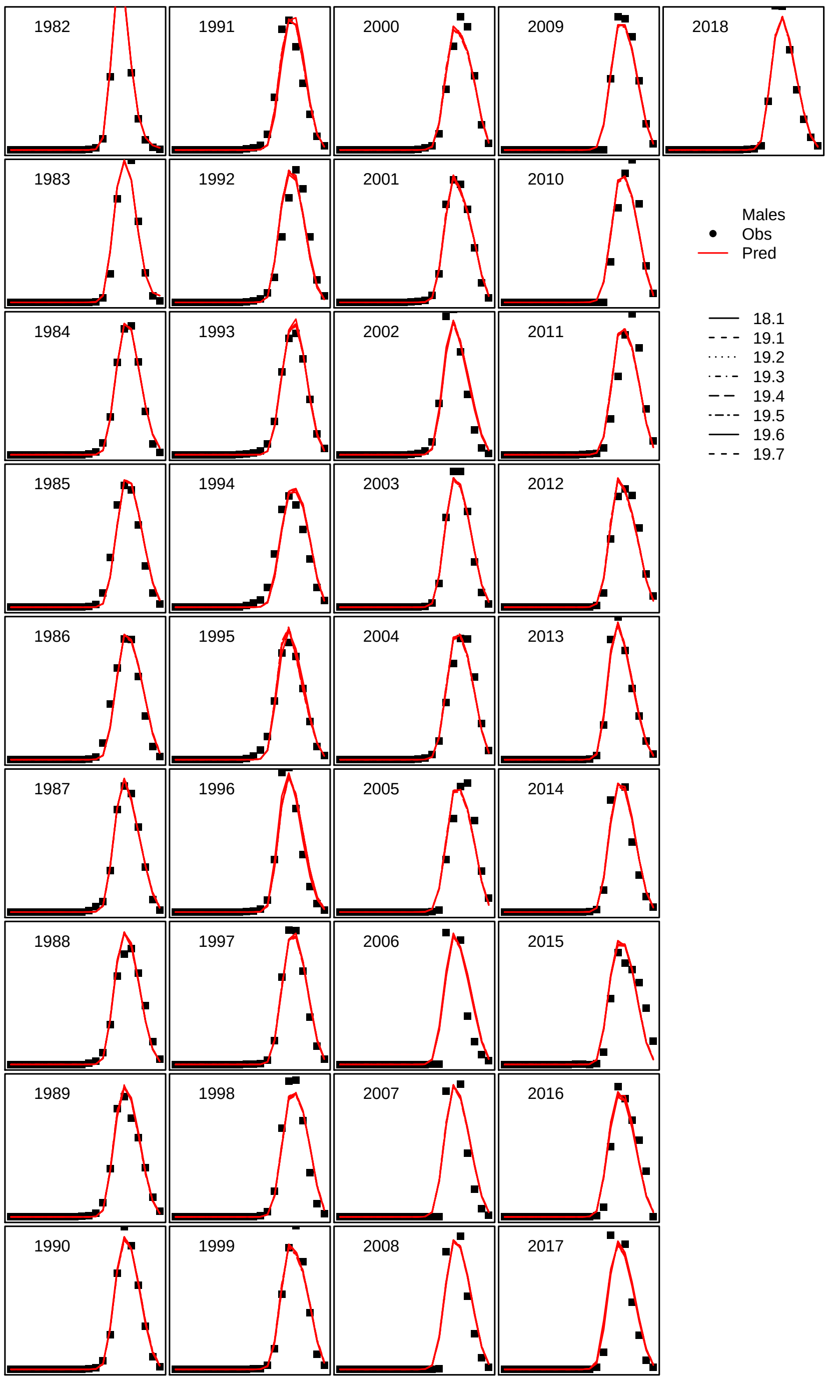

Figure 28: Model fits to retained catch size composition data

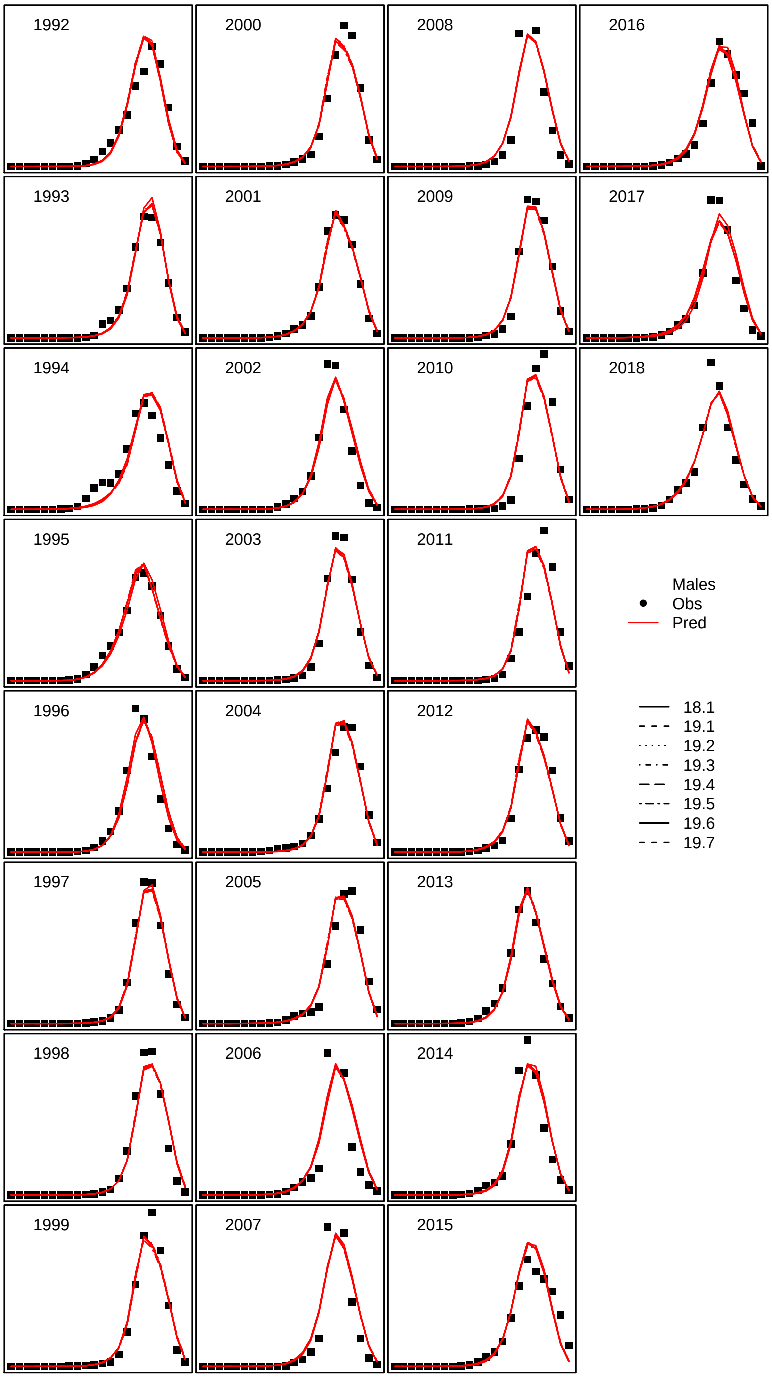

Figure 29: Model fits to total catch size composition data

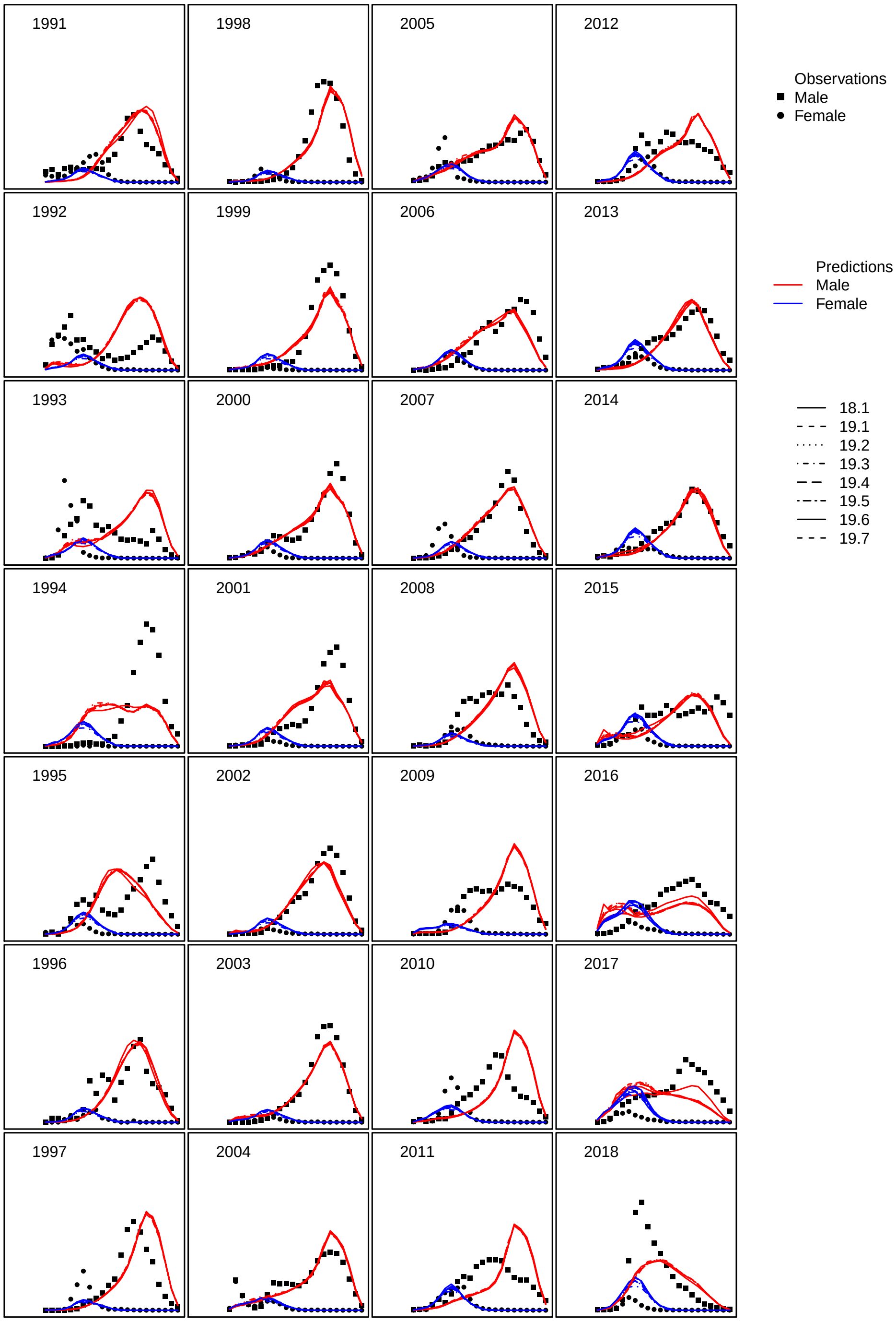

Figure 30: Model fits to trawl catch size composition data

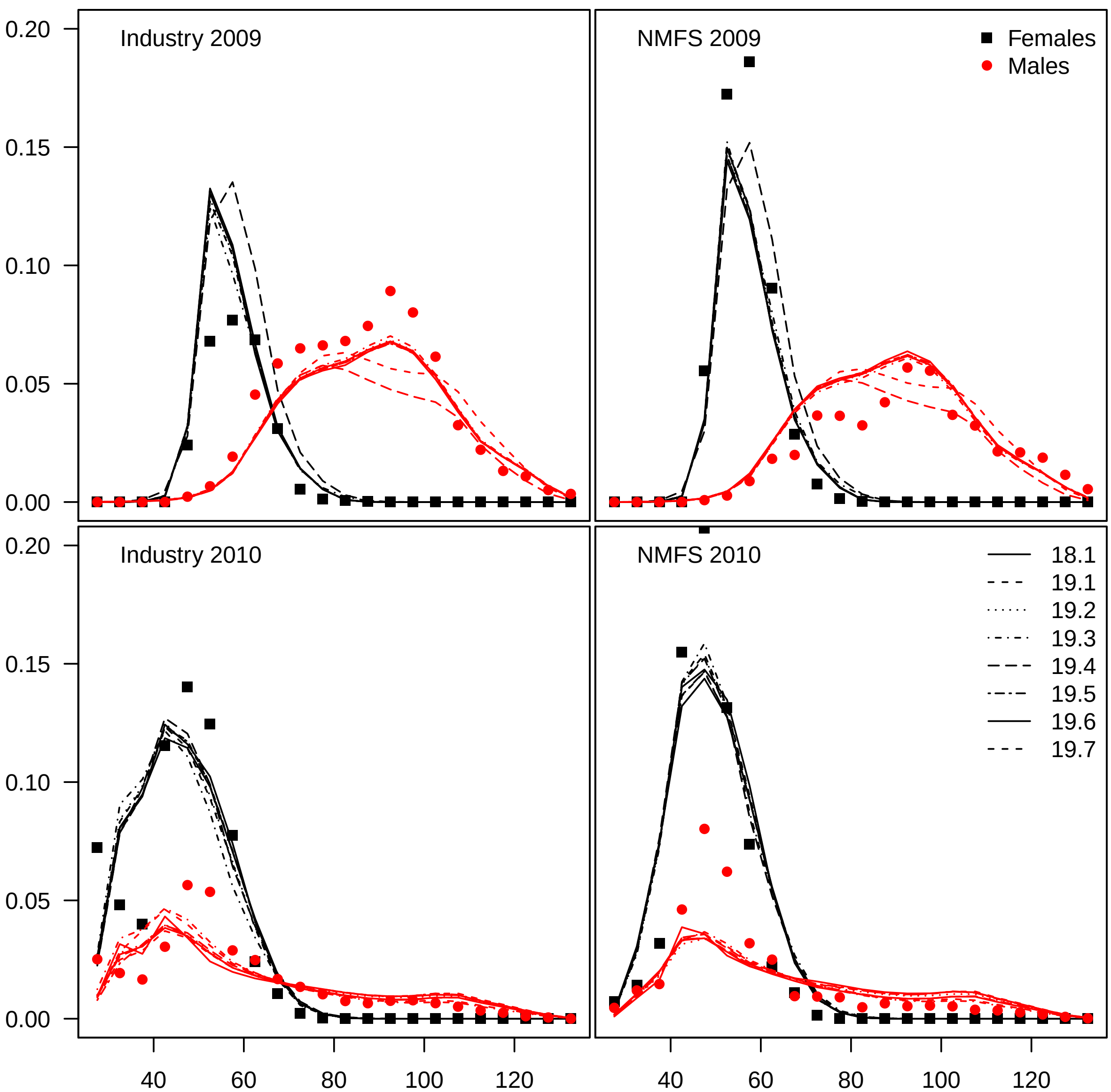

Figure 31: Model fits to size composition data from summer survey experiments (2009 & 2010)

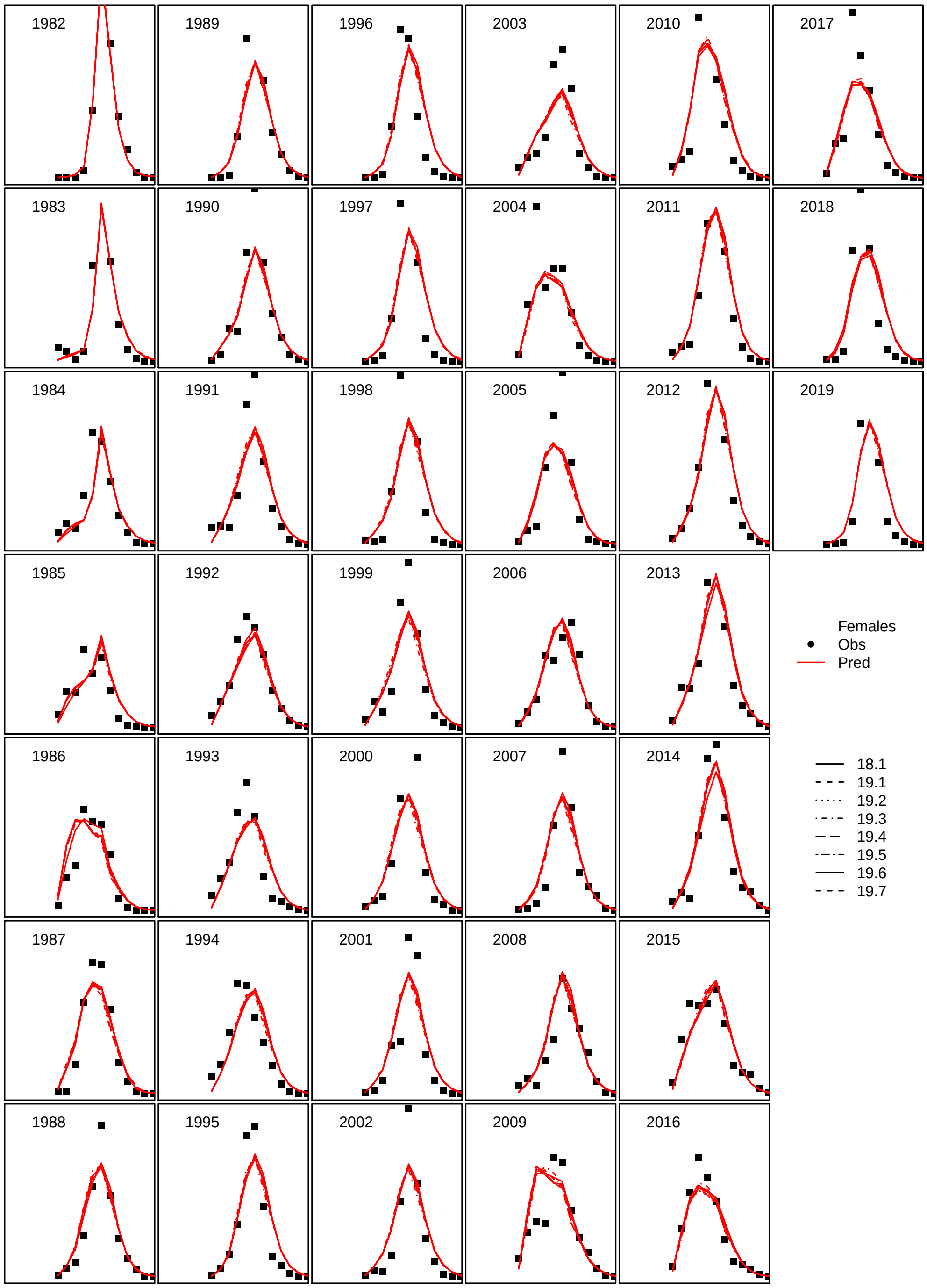

Figure 32: Model fits to female survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

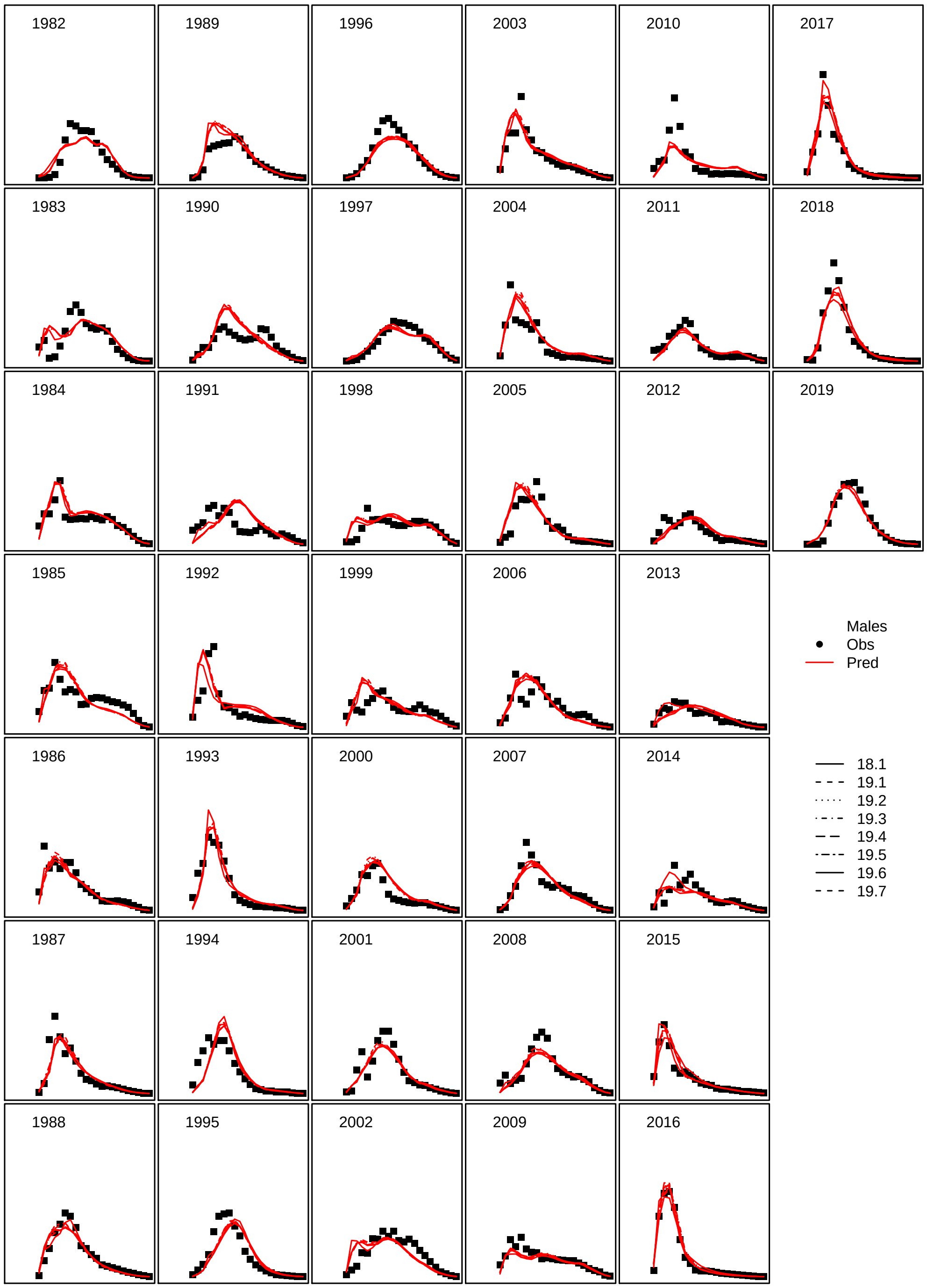

Figure 33: Model fits to male survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

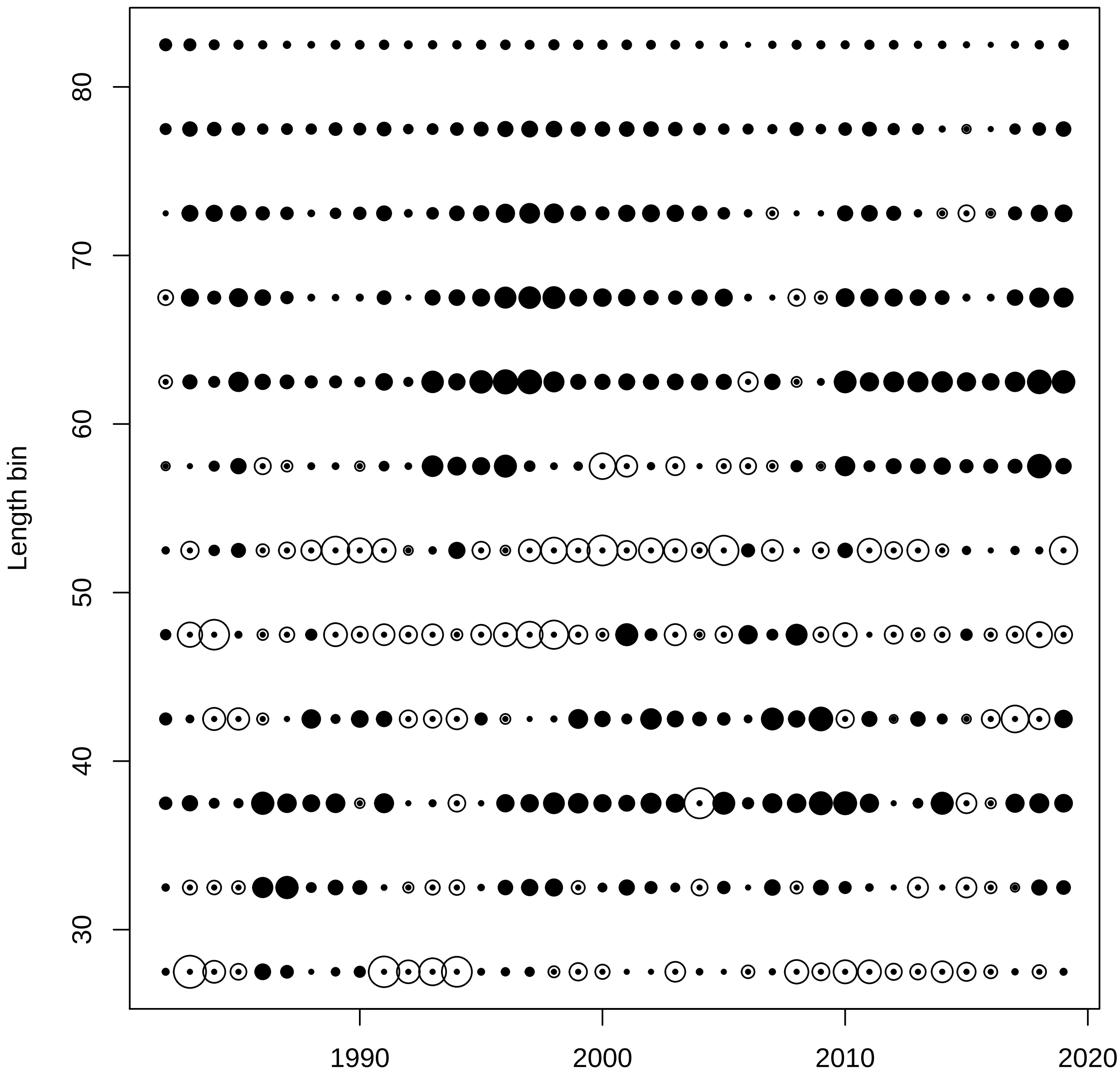

Figure 34: Residuals for female survey length proportion data for the author's preferred model. Open circles are positive residuals, filled are negative, and the size of the circle is proportional to the magnitude of the residual. Stars are residuals > 5.

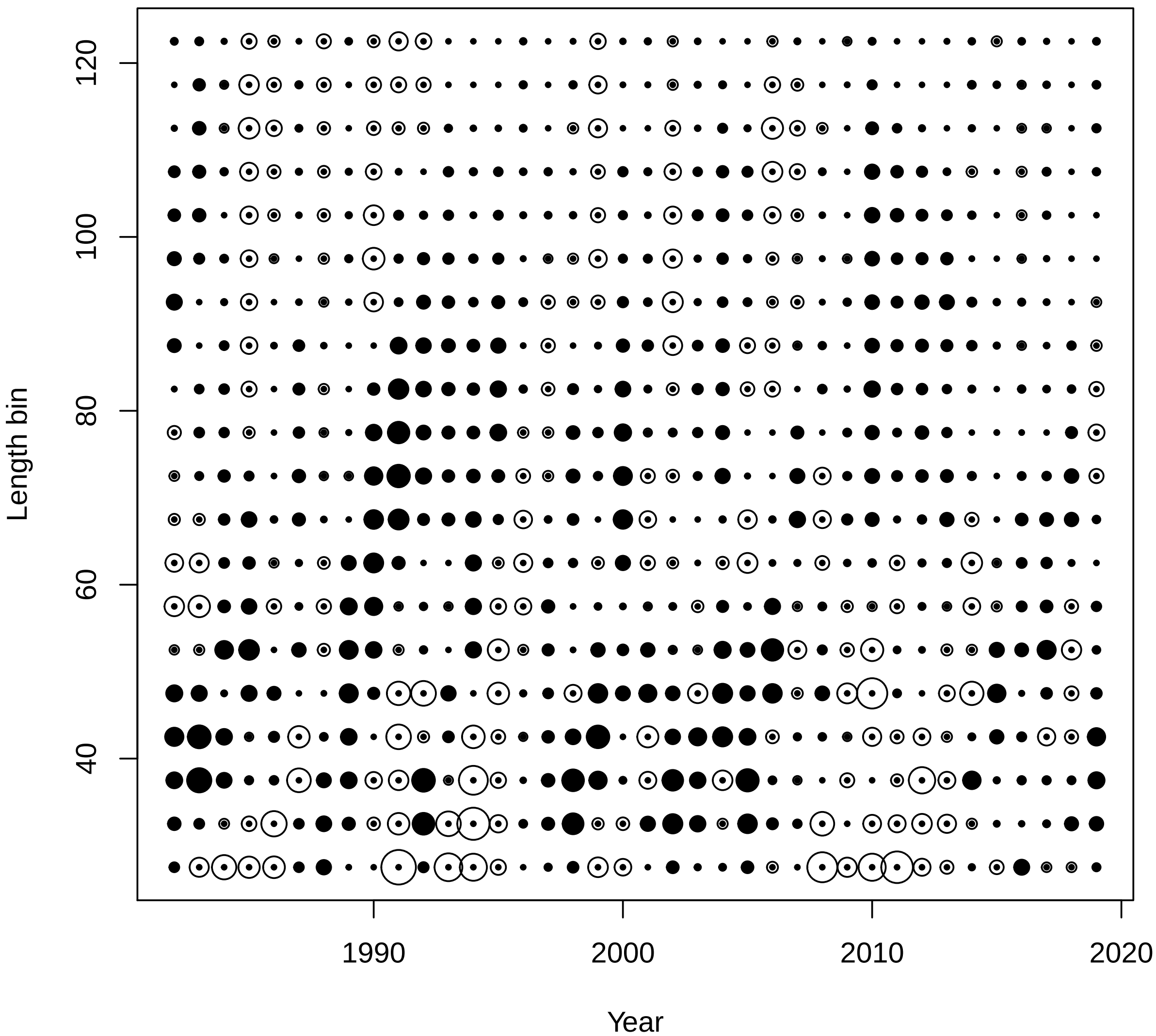

Figure 35: Residuals for male survey length proportion data for the author's preferred model. Open circles are positive residuals, filled are negative, and the size of the circle is proportional to the magnitude of the residual. Stars are residuals > 5.

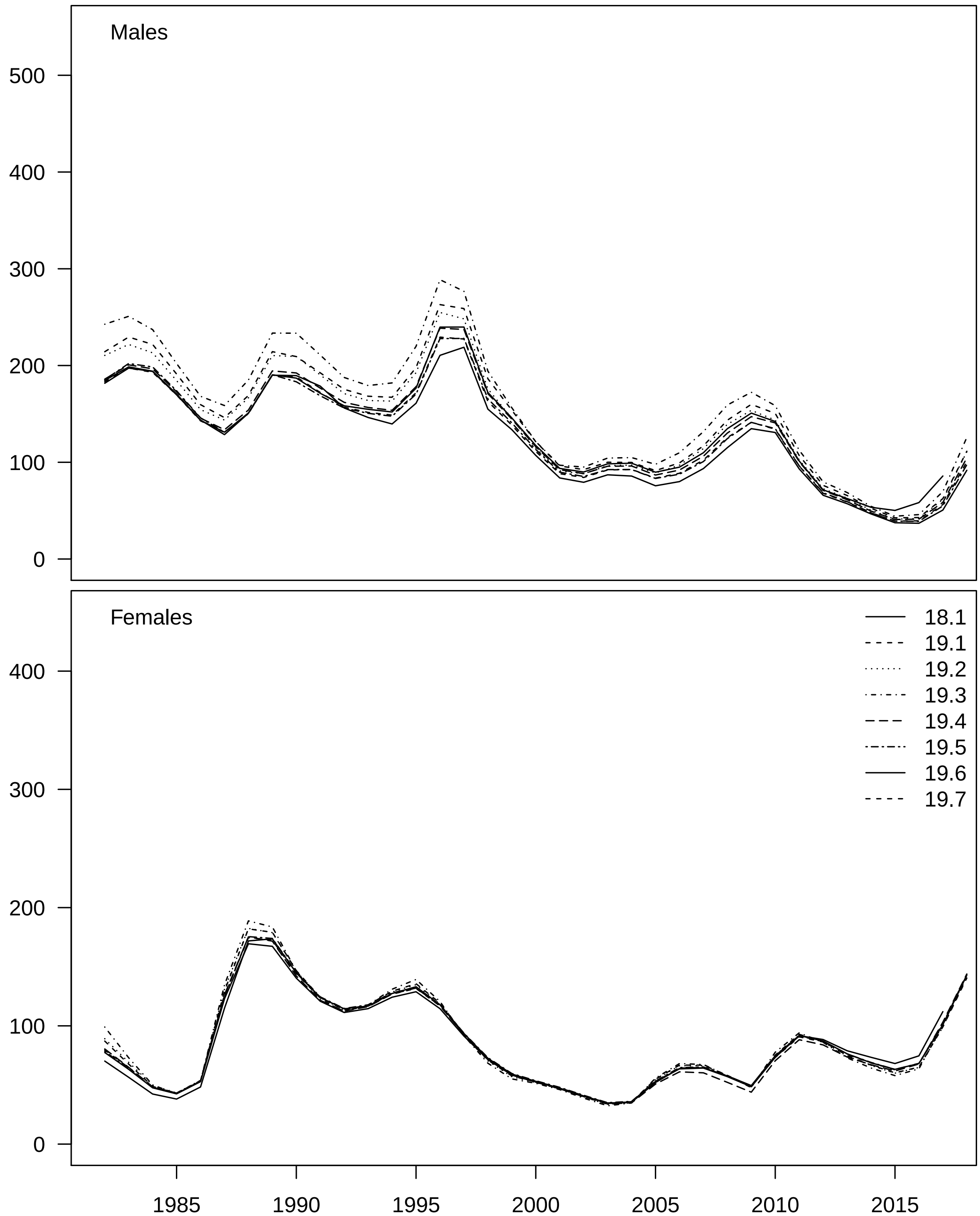

Figure 36: Model predicted mature biomass at mating time

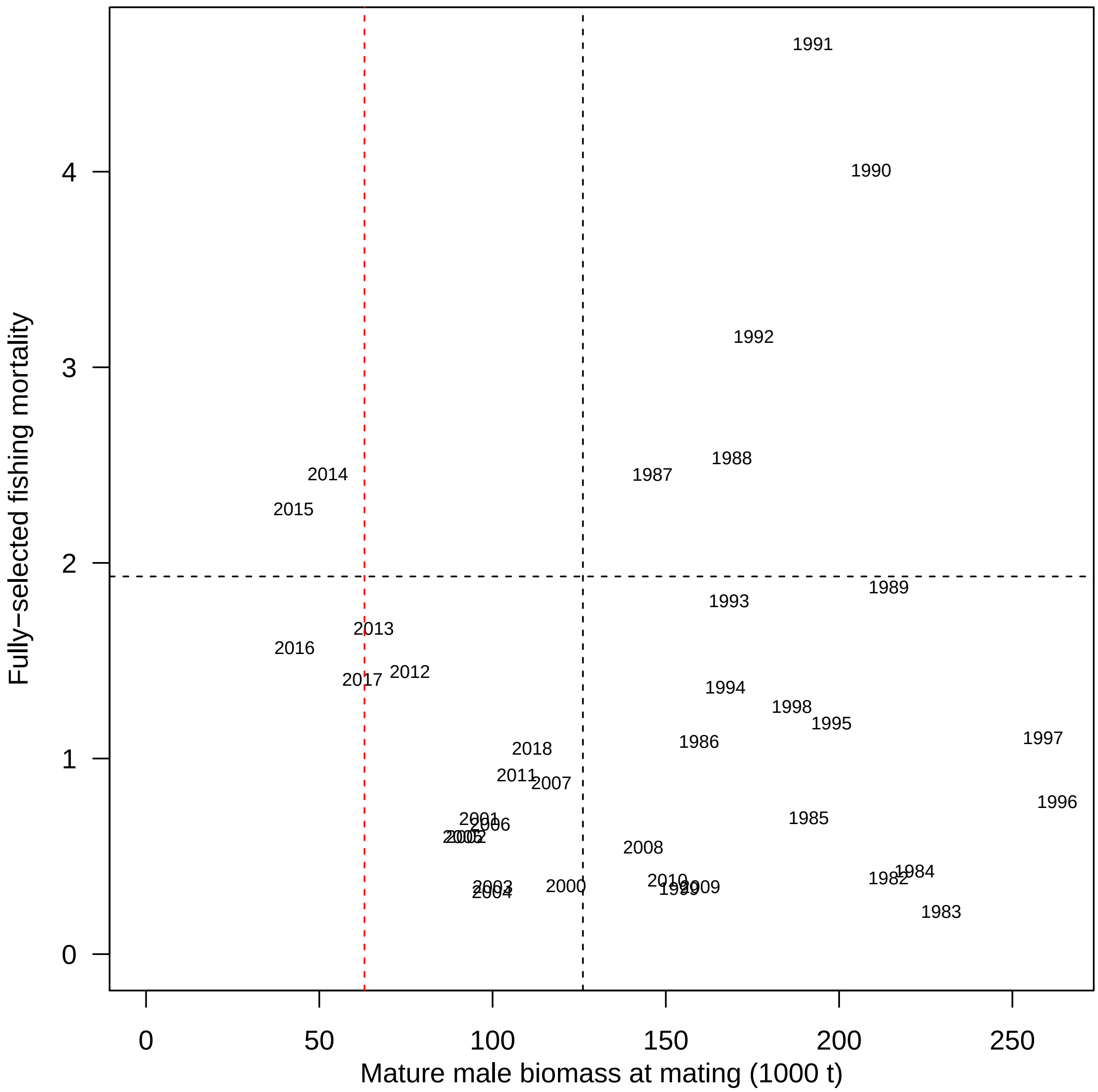

Figure 37: Kobe plot for the author's preferred model. Vertical dashed black line represents the MLE value for B35; Vertical dashed red line represents the overfished level, horizontal dashed black line represents F35

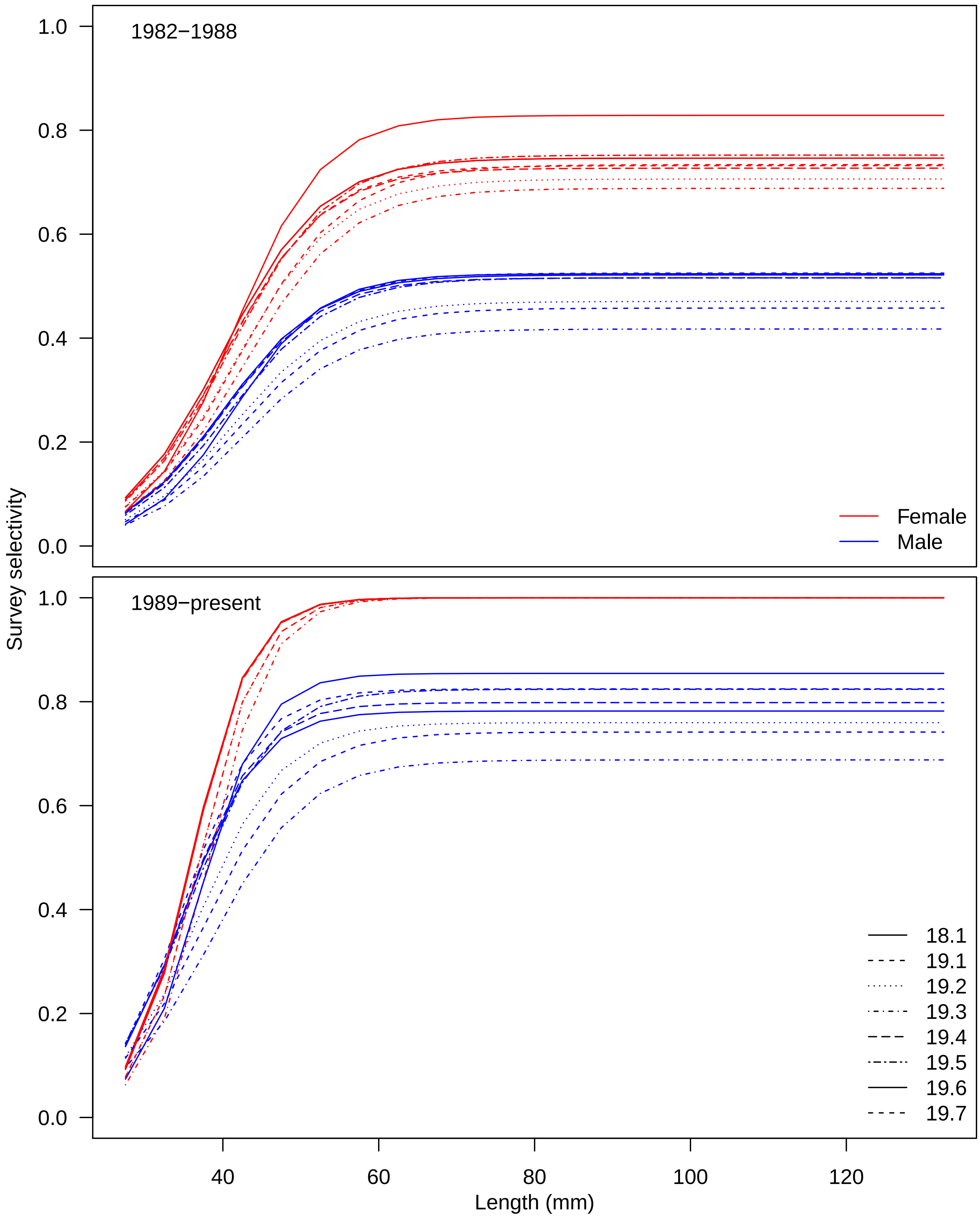

Figure 38: Estimated survey selectivity

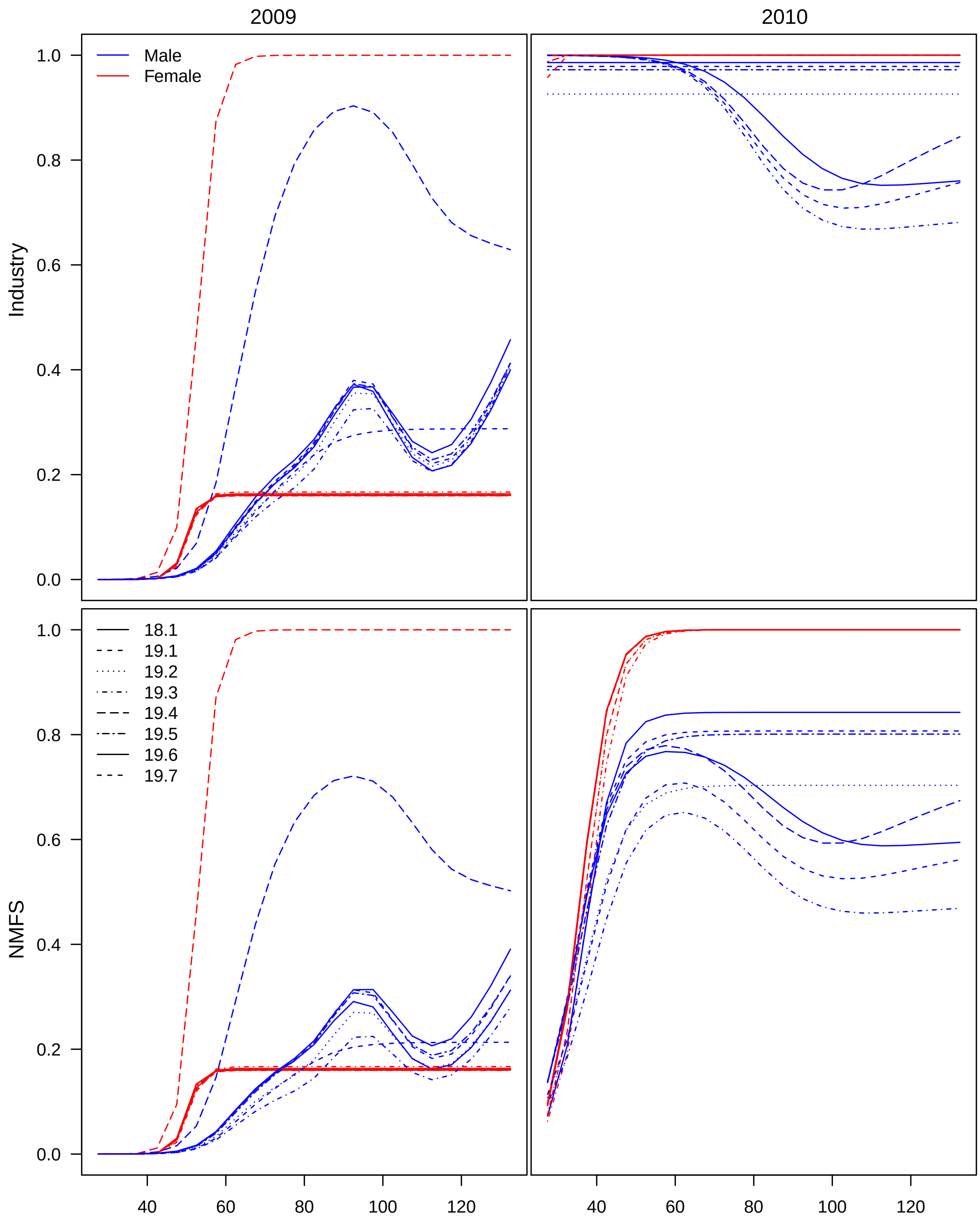

Figure 39: Estimated experimental survey selectivity (availability * survey selectivity)

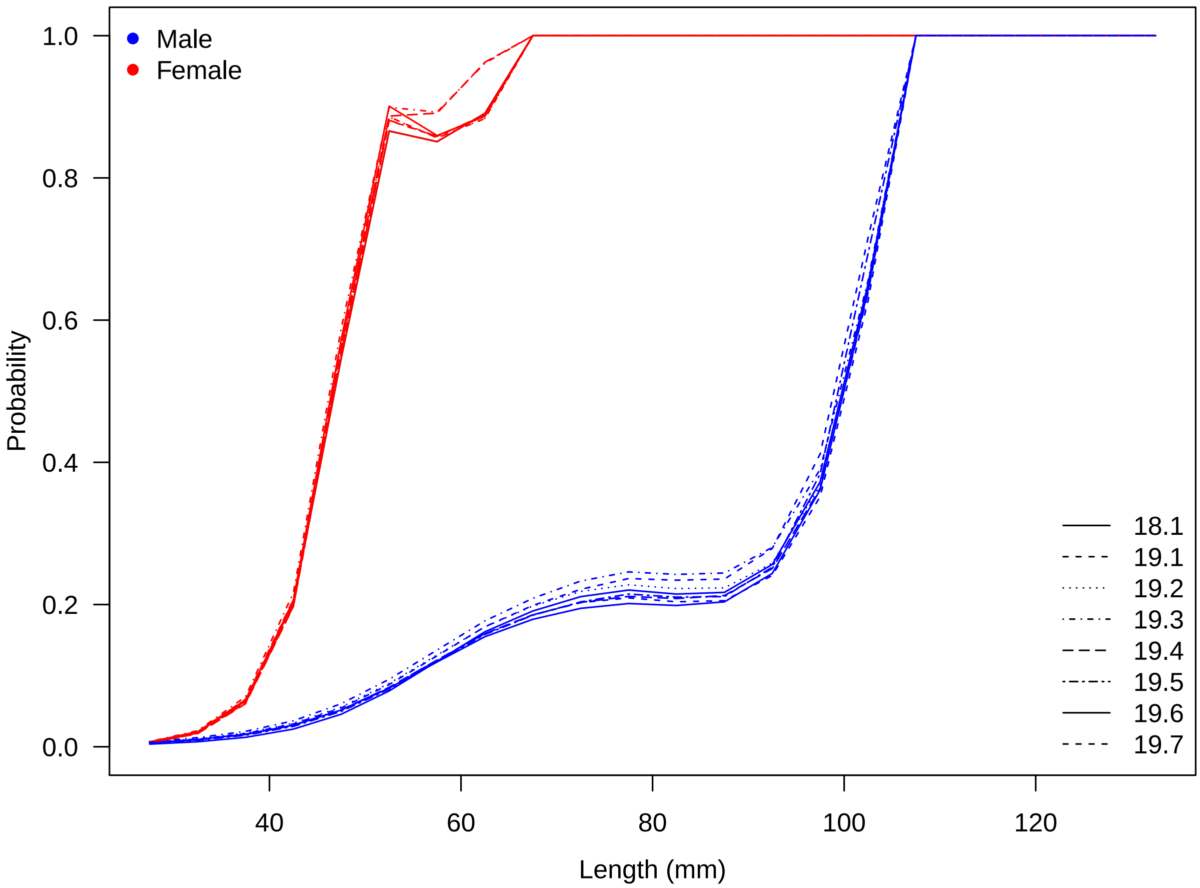

Figure 40: Estimated probability of maturing

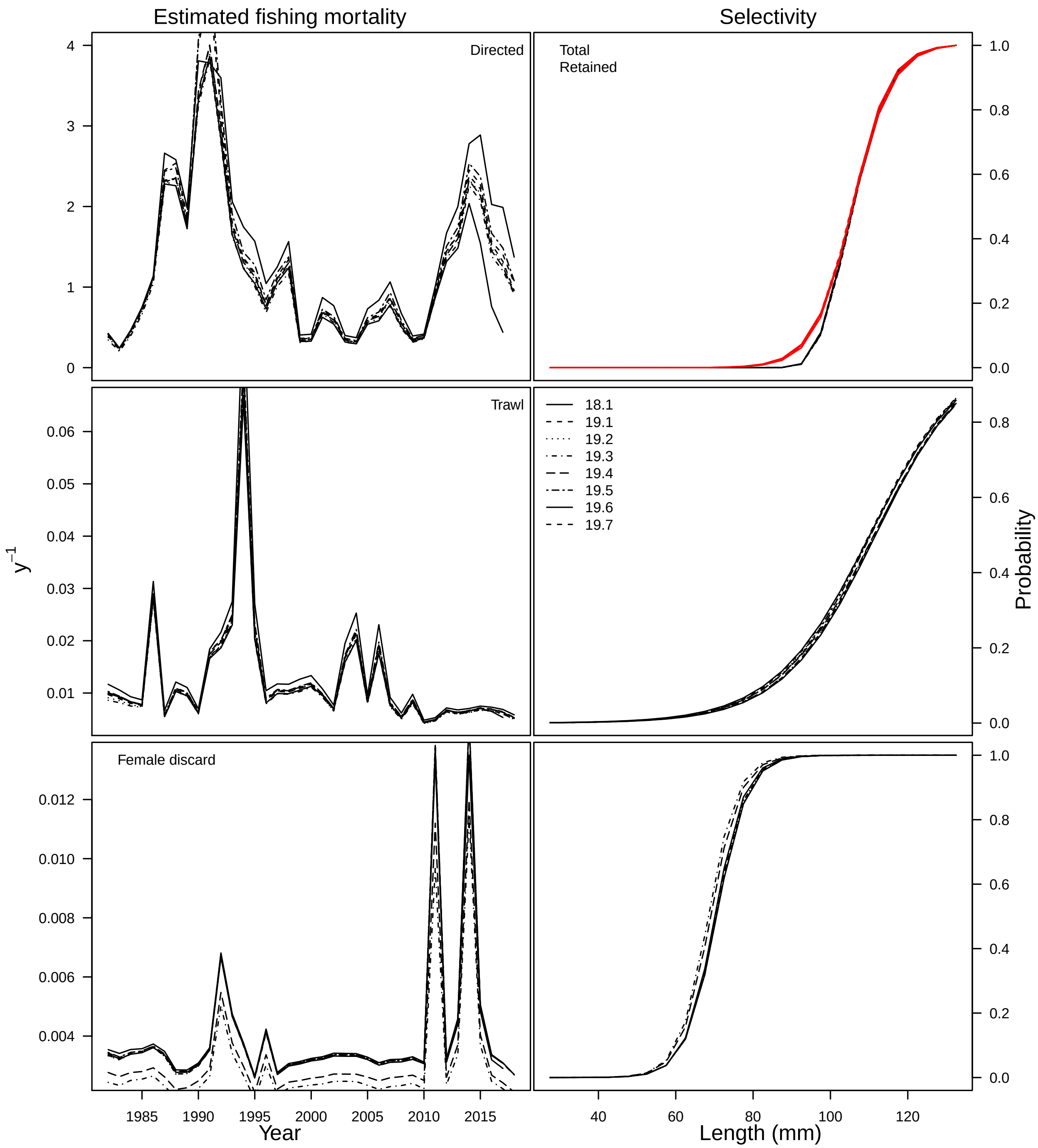

Figure 41: Model predicted fishing mortalities and selectivities for all sources of mortality

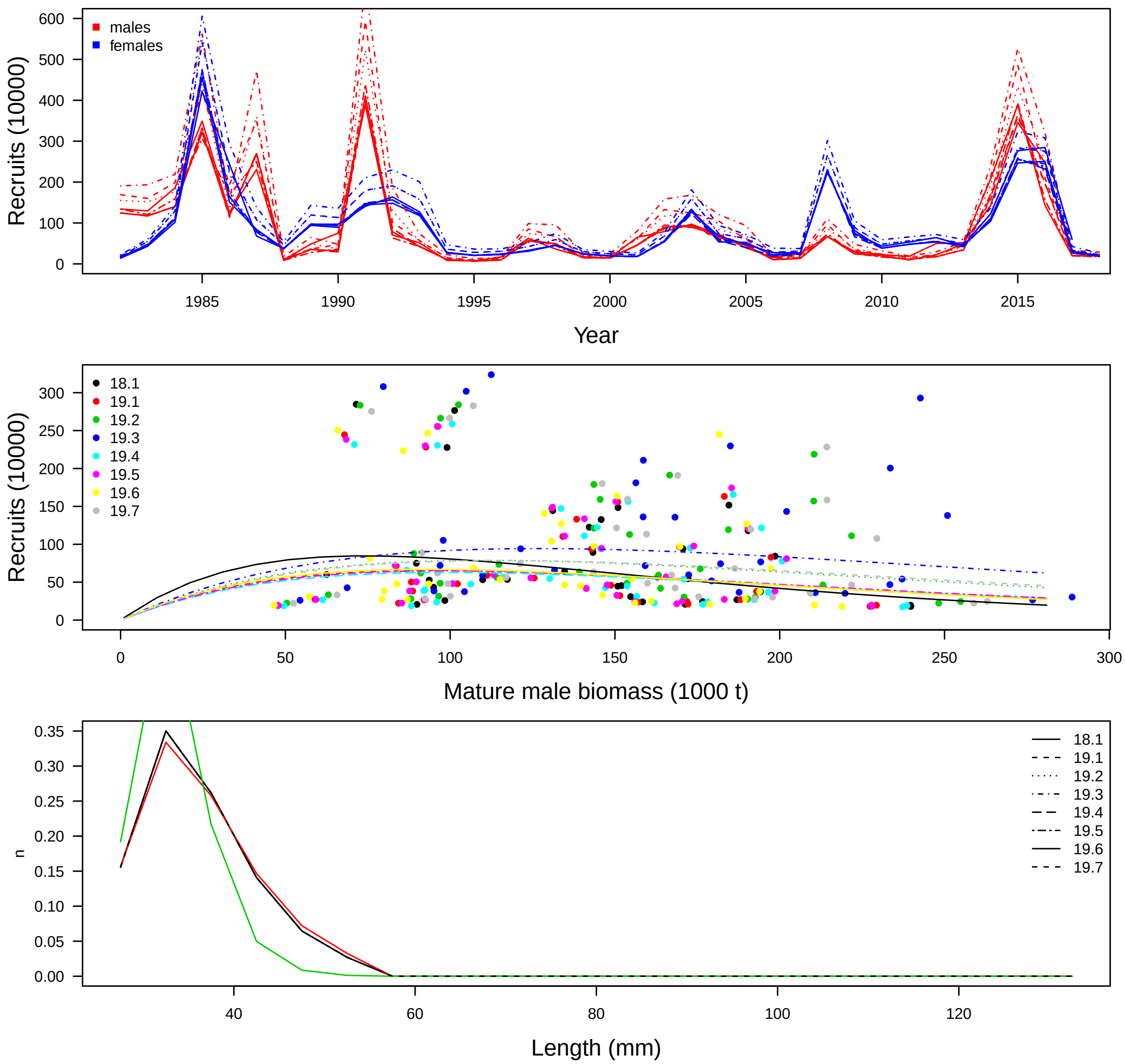

Figure 42: Estimated recruitment, fits to stock recruit curve (MMB lagged 5 years), and proportions recruiting to length bin. For bottom plot, males are red and females are green. Black lines are both sexes combined.

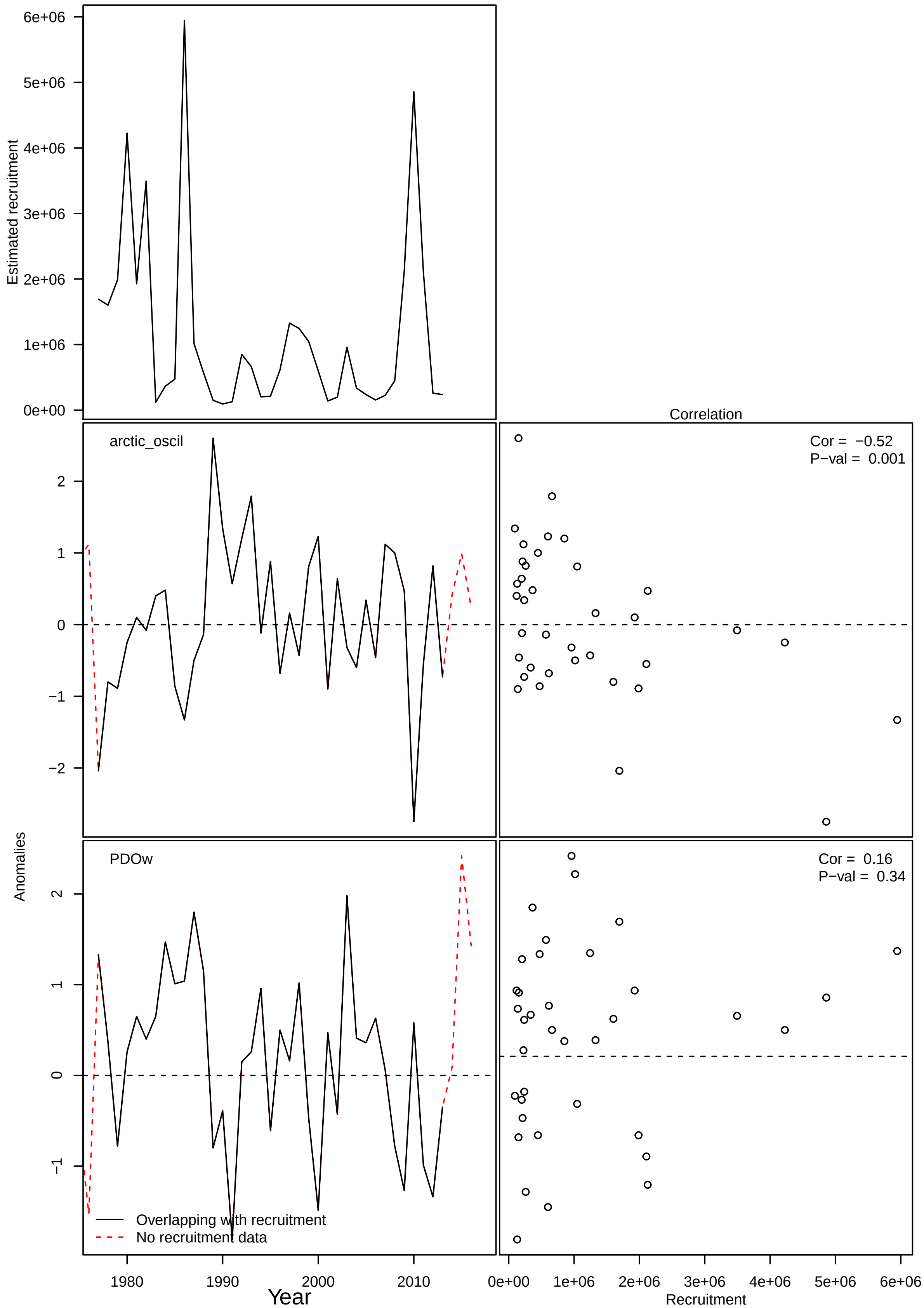

Figure 43: Comparison of estimated recruitment from the author's preferred model with the Pacific Decadal Oscillation and the Arctic Oscillation

BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN FALL 2019

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Executive Summary

1. Stock: Red king crab (RKC), *Paralithodes camtschaticus*, in Bristol Bay, Alaska.
2. Catches: The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs (58,943 t). The catch declined dramatically in the early 1980s and remained at low levels during the last three decades. Catches during recent years until 2010/11 were among the high catches in last 15 years. The retained catch in 2018/19 was approximately 4.5 million lbs (2,027 t), below the catch in 2017/18 (6.8 million lbs, 3,094 t). 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 1970s and early 1980s and has generally been low since 1985 (1979-year class). During 1984-2019, only in 1984, 1986, 1995, 1999, 2002 and 2005 were estimated recruitments above the historical average for 1976-2019. Estimated recruitment was extremely low during the last 12 years.
5. Management performance:

Status and catch specifications (1,000 t) (model 19.0):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2015/16	12.89[A]	27.68[A]	4.52	4.61	5.30	6.73	6.06
2016/17	12.53[B]	25.81[B]	3.84	3.92	4.37	6.64	5.97
2017/18	12.74[C]	24.86[C]	2.99	3.09	3.60	5.60	5.04
2018/19	10.62[D]	16.92D	1.95	2.03	2.65	5.34	4.27
2019/20		15.96[D]				3.40	2.72

The stock was above MSST in 2018/19 and hence was not overfished. Overfishing did not occur.

Status and catch specifications (million lbs):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2015/16	28.4[A]	61.0[A]	9.97	10.17	11.69	14.84	13.36
2016/17	27.6[B]	56.9[B]	8.47	8.65	9.63	14.63	13.17
2017/18	28.1[C]	54.8[C]	6.60	6.82	7.93	12.35	11.11
2018/19	23.4[D]	37.3[D]	4.31	4.31	5.85	11.76	9.41
2019/20		35.2[D]				7.5	6.00

Notes:

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2016

B – Calculated from the assessment reviewed by the Crab Plan Team in September 2017

C – Calculated from the assessment reviewed by the Crab Plan Team in September 2018

D – Calculated from the assessment reviewed by the Crab Plan Team in September 2019

6. Basis for the OFL: Values in 1,000 t (model 19.0):

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2015/16	3b	26.1	24.7	0.95	0.27	1984-2015	0.18
2016/17	3b	25.8	24.0	0.93	0.27	1984-2016	0.18
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

Basis for the OFL: Values in million lbs:

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2015/16	3b	57.5	54.4	0.95	0.27	1984-2015	0.18
2016/17	3b	56.8	52.9	0.93	0.27	1984-2016	0.18
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

A. Summary of Major Changes

1. Changes to management of the fishery: None.

2. Changes to the input data:

a. Updated NMFS trawl survey data through 2019.

b. Updated the directed pot fishery catch and bycatch data through 2018 (i.e., completed 2018/19 fishery).

c. Updated groundfish fisheries bycatch data during 1991-2018.

3. Changes to the assessment methodology:

a. Estimated recruitment in the terminal year is not used for estimating $B_{35\%}$. That is, the mean recruitment from 1984-2018 is used for estimating $B_{35\%}$.

b. For the directed pot fishery, the model fits total observer male biomass and length compositions, instead of discarded male biomass and length compositions. Observers have not separated retained and discarded legal males in the directed pot fishery starting in 2018.

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

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

18.0d: The model rk18A.D18a from May 2019 with the 2019 data, also the model 18.0a in the SAFE report from September 2018 with the 2019 data and separating the groundfish fisheries bycatch data into trawl and fixed gear during 1996-2018, the period the data are available (model 18.0a separated the groundfish data only during 2009-2017). This model assumes that Bering Sea Fisheries Research Foundation (BSFRF) survey capture probabilities are 1.0 for all length groups. Under this assumption, NMFS survey selectivities are the products of crab availabilities (equal to BSFRF survey selectivities) and NMFS survey capture probabilities. A survey capture probability for a length group is simply defined as the proportion of the crab in the length group within the area-swept that is caught by the survey net.

Changes since May 2018 include: (1) the total observer male biomass and total observer male length composition data in the directed pot fishery are used to replace discarded male biomass and discarded male length composition data, (2) total male selectivity and retained proportions in the directed pot fishery are used to replace retained selectivity and discarded male selectivity, (3) due to high grading problems in some years since rationalization, two logistic curves are estimated for retained proportions: one before rationalization (before 2005) and another after 2004, and (4) equal annual effective sample sizes of male and female length compositions are considered.

18.0e: The same as model 18.0d except for the sum of length composition data for Tanner crab fishery bycatch each year is equal to 1.0 for both sexes combined (model 18.0d has the sum equal to 1.0 for each sex). This change treats the Tanner crab fishery bycatch length compositions the same way as the groundfish fisheries bycatch.

19.0: This is the Gmacs version of model 18.0e. This model uses the same input data as model 18.0e and the same approach as much as possible. Some differences are: (1) likelihood values for catch and bycatch biomasses include constant terms under Gmacs while constant terms are not included in the likelihood values under model 18.0e, (2) penalties and prior-densities are much more extensively used with Gmacs than model 18.0e, (3) model 18.0e restricts the estimated survey selectivities to be equal for the smallest length group for both sexes for a given survey (two logistic curves with three parameters) while no such a restriction for Gmacs (two logistic curves with four parameters), (4) model 18.0e uses the smoothed trawl survey length compositions in the initial year divided by the estimated survey selectivities as estimated population length compositions in the initial year before the phase of estimating the population length composition parameters while model 19.0 uses the initial length composition parameters to estimate population length compositions before the estimating phase, and (5) Gmacs uses the BSFRF survey selectivities as a limit to the NMFS trawl survey selectivities while model 18.0e assumes the BSFRF survey selectivities as availabilities to the NMFS trawl survey.

4. Changes to assessment results:

The population biomass estimates in 2019 are lower than those in 2018. Among the three models, model estimated relative NMFS survey biomasses and mature biomasses are very similar. Estimated results are extremely similar for models 18.0d and 18.0e, indicating that normalizing combined sex or single sex length compositions of Tanner crab fishery bycatch has little impacts on the results. Gmacs (model 19.0) results in slightly high relative female biomass estimates after 2004 and slightly low relative male biomasses during the last 30 years. Models 18.0d and 18.0e fit the BSFRF survey biomasses better than model 19.0 (gmacs) while Gmacs fits NMFS survey biomasses better than the other two models. The Gmacs model (19.0) results in lower mature male biomass estimates (thus lower recruitment estimates) than the other two models during the last 30 years, which may be explained by a weaker link between NMFS and BSFRF surveys by Gmacs, resulting in a lower weight for BSFRF survey data through higher estimated additional CV for BSFRF survey biomass. Lower recruitment estimates in the 1970s for models 18.0d and 18.0e than for model 19.0 (gmacs) may be caused by the restriction of equal survey selectivity value of the smallest length group. Also higher recruitment estimates in the 1970s result in higher high M estimates for model 19.0. All three models fit the catch and bycatch biomass extremely well. Since the results are extremely similar for models 18.0d and 18.0e, we prefer 18.0e and recommend either model 18.0e or model 19.0 (gmacs) for overfishing definition determination for September 2019. The Gmacs model (19.0) is preferred due to better fits of NMFS survey biomass during recent years. The Gmacs generally runs well and maybe it is time for it to take over the BBRKC assessments. The CPT adopted Gmacs for overfishing definition determination for September 2019.

Like the results of model 18.0a (rk18A.D18a) in May 2019, terminal year recruitment analysis with model 19.0 (gmacs) also suggests the estimated recruitment in the last year should not be used for estimating $B_{35\%}$.

There are a few areas with the Gmacs model that may need some improvement or further examination: (1) documentation (the current documentation is limited); (2) more options are needed for relationships between NMFS survey and BSFRF survey (the current options are no relationships or NMFS survey selectivity values cannot be larger than BSFRF survey); (3) a jittering option for Gmacs; (4) equations for instantaneous seasons may be problematic and need to be checked (we used continuous seasons, which are fine); and (5) output and R plot scripts need to be further developed for more complex assessments like BBRKC (we revised output and used our R functions and scripts for this report). We will work on (2) for the BBRKC assessment updates before the next CPT meeting in January or May 2020.

B. Responses to SSC and CPT Comments

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

None.

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

Response to CPT Comments (from May 2019):

"Explain why the likelihoods for size-compositions differ given the fits are very similar."

Response: four reasons: (1) Gmacs does not include the constant term whereas we had a constant term in the robust normal for proportion likelihoods, (2) for sex combined normalized length compositions, the effective sample sizes were doubled for Gmacs (Gmacs adds them together), (3) for sex combined normalized length compositions, the robust constant for variance estimation is 1/36 for both males and females with Gmacs, while our past assessment program in May 2019 or earlier used 1/20 for males and 1/16 for females, and (4) although it is an extremely small value, our past program did not compute likelihood for the first several length groups for retained catch due to zero proportions while Gmacs computes it.

We made all length composition likelihoods comparable in this report: models 18.0d and 18.0e drop the constant term; for sex combined normalized length compositions, effective sample sizes in data file are reduced to half for Gmacs and the robust constant 1/36 is used for all models; and for retained length compositions, all groups are used to compute likelihood for models 18.0d and 18.0e.

Also, NMFS survey biomass likelihood was not comparable in the report in May 2019 between models 18.0e and 19.0 (gmacs). Gmacs had an extra term, 0.5σ, in the likelihood function and a constant term. We deleted the extra term from Gmacs and added the constant term to models 18.0d and 18.0e. Now the likelihood function values for both NMFS and BSFRF survey biomass are comparable among the three models in this report.

"Document how the two models penalize parameter values, in particular, differences in the sex ratio of recruits from 1:1, and explore whether the difference in results is due to difference in this penalty."

Response: model 18.0e doesn't have priors on parameters except NMFS survey catchability. Most of penalties of model 18.0e are on recruitment: sex ratio of recruits from 1:1 and recruitment variation over time. Model 18.0e also has a very small penalty on bycatch fishing mortality deviations to make sure that they make sense, and this small penalty generally does not affect the results. Model 19.0 has the same prior on NMFS survey catchability and tried to have the same penalties as model 18.0e on recruitment. However, model 19.0 has further penalty on recruitment, such as sigmaR. Besides sigmaR, model 19.0 has many prior-densities and a penalty on natural mortality (M) deviations. Based on penalty values in negative likelihood components, prior-densities have the highest value, recruitment has the second, and M deviations have the third. Since prior-densities in Gmacs are mostly constants, we examined penalties from sigmaR, recruitment sex ratio, and M deviations on the results of model 19.0.

At first, sigmaR seems to have a huge impact (it was the case in May 2019); however, we found out that the impacts were caused by the interaction of female fishing mortality offset values in the groundfish bycatch. Therefore, we set the offsets for the groundfish bycatch female mortality to be zero for model 19.0, consistent with model 18.0e, the impacts by sigmaR on results are very small. See the following table for sigmaR (the default sigmaR is 0.9):

Gmacs' sensitivity on sigmaR:

SigmaR	0.5	0.7	0.88	1	1.2
Neg. log likelihood	-23550.3	-23549.9	-23548.6	-23547.5	-23545.5
$B_{35\%}$(t)	21389.8	21535.1	21662.2	21724.9	21786.8
$F_{35\%}$	0.299	0.299	0.299	0.299	0.299
MMB_{2019}(t)	15978.2	16043.7	16090.7	16115.5	16148.4
OFL_{2019}(t)	3386.9	3390.2	3389.2	3389.4	3394.2
ABC_{2019}(t)	2709.5	2712.2	2711.4	2711.6	2715.4
$F_{ofl2019}$	0.215	0.214	0.214	0.213	0.213
Q	0.925	0.924	0.925	0.925	0.925

Surprisingly, the weighting factor (emphasis factor/prior) for recruitment ratios does not have large impacts on the results for model 19.0 (the default factor is 10):

Gmacs' sensitivity on mean R sex ratio:

W.factor	1	5	10	20	50
Neg. log likelihood	-23551.2	-23550.8	-23550.3	-23549.5	-23547.6
$B_{35\%}$(t)	21751.2	21518.4	21247.2	20759.3	19601.0
F35%	0.299	0.299	0.299	0.299	0.299
MMB_{2019}(t)	16015.4	15988.1	15956.6	15895.4	15741.6
OFL_{2019}(t)	3336.8	3367.3	3403.4	3469.8	3636.2
ABC_{2019}(t)	2669.4	2693.8	2722.7	2775.8	2908.9
$F_{ofl2019}$	0.211	0.214	0.216	0.221	0.234
Q	0.925	0.925	0.925	0.924	0.924

Finally, the penalty on M deviations has some impacts on the results for model 19.0, but the impacts are not very large (the default factor is 1.0):

Gmacs' sensitivity on M penalty:

W. factor	0.1	0.5	1.0	2.0	5.0
Neg. log likelihood	-23598.2	-23576.6	-23550.3	-23500.2	-23365.1
$B_{35\%}$(t)	21793.0	21531.3	21247.2	20698.5	19462.7
$F_{35\%}$	0.298	0.299	0.299	0.300	0.303

MMB_{2019}(t)	16133.4	16051.6	15956.6	15675.0	15147.8
OFL_{2019}(t)	3374.3	3389.4	3403.4	3384.4	3410.6
ABC_{2019}(t)	2699.5	2711.5	2722.7	2707.5	2728.5
$F_{ofl2019}$	0.212	0.214	0.216	0.219	0.228
Q	0.925	0.925	0.925	0.928	0.922

"Check whether GMACS is fitting to length-composition for males and females combined rather than by sex, and ensure that observed and predicted length-compositions are correctly plotted."

Response: Gmacs has options whether to fit length-composition for males and females combined, or by sex. It is the Gmacs output that causes confusion. Gmacs normalizes all length composition output by sex even fitting to length-composition for males and females combined in the program. We changed Gmacs output to match what are fitted in the program, and all plots are correct.

"Further examine the difference in OFL values from the two models, in particular check the inputs into the OFL calculation such as mean recruitment corresponding to MSY."

Response: we compared mean recruitment, $B_{35\%}$, and OFL between Gmacs and model 18.0e for a lot of runs. The mean male recruitment (50% of total recruitment) for model 18.0e and Gmacs (19.0) are 8.63 and 7.80 million, so Gmacs has a lower $B_{35\%}$ as it should be.

"Explain why the number of estimated parameters in GMACS differs from 18.0e (some of the additional parameters are the fully selected fishing mortalities due to bycatch in the Tanner crab fishery)."

Response: the extra number of estimated parameters for Gmacs is 38 from the fully selected fishing mortalities due to bycatch in the Tanner crab fishery (deriving from fishing effort and model 18.0e does not count them as parameters), 3 for survey selectivity (model 18.0e uses three parameters for two sets of male and female logistic selectivity curves due to assuming the smallest length group has the same selectivity value for both sexes), and 2 for mean fishing mortality and female offset for Tanner crab fishery bycatch (model 18.0e estimates Tanner crab fishing mortalities without mean F and female offset).

"Report fits to biomass indices (NMFS and BSFRF) and residuals by sex rather than aggregated over sex because that is how the data are included in the model likelihood."

Response: done.

"Include the fits by GMACS and 18.0e on the same plot to ease comparisons."

Response: done.

"Evaluate whether the two models have converged using a jitter analysis."

Response: we did jitter analysis for model 18.0d and 18.0e. We tried to do the same for model 19.0 (gmacs); however, our approach (doing in R) does not work for Gmacs (when taking in initial values from a parameter file, Gmacs tried to estimate M, which should be fixed to 0.18). It may need to change initial parameter values from the control file for Gmacs, and we have not figured out how to automate it. We tried many runs with Gmacs, which seems quite robust.

"Apply the CPT-approved naming conventions for the model scenarios."

Response: hopefully we got it right this time.

Response to CPT Comments (from September 2018):

“The CPT requested that the author consider a scenario based on 18.0a in which the asymptote to the retention function is estimated after 2004, rather than fixing it to 1 as it now is.”

Response: Done for all scenarios.

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

“The authors identified seven areas for which the GMACS scenario needs some improvement or additional examination on the bottom of page 4 and top of page 5 of the assessment report. One of these issues includes an unbelievably high estimate of fishing mortality in 1981. The SSC supports the authors’ intentions to investigate these issues for the September assessment. Additionally, the SSC supports the CPT’s recommendations to the authors to provide additional diagnostics to facilitate comparisons among the base model with better bycatch data and GMACS model so that outcomes can be better understood. It is important to understand what drives differences among these models, and such an evaluation is critical before GMACS can be accepted. Finally, the SSC reiterates its request that model names should follow approved conventions.”

Response: we tried to understand Gmacs as much as we could. The Gmacs results in May 2019 and earlier were impacted by one parameter that seems not important at all. It is the offset female mortality for the trawl bycatch, that is, estimating separate mean fishing mortalities for male and female trawl bycatch. Due to unusual conditions for BBRKC in the early 1980s, this parameter causes confoundings among other parameters, especially estimated high natural mortality in the early 1980s. After fixing this parameter to be 0 (no difference between male and female mean trawl bycatch fishing mortalities; the same approach as models 18.0d and 18.0e), Gmacs results are better understood than before. Besides the Gmacs penalty and prior-densities, we believe that the assumption of equal survey selectivity value for the smallest length group for both sexes and different treatments of the relationship between NMFS and BSFRF surveys can explain the differences in results between models 18.0e and 19.0. The difference of estimated NMFS survey selectivity values for small length groups are quite larger for these two models (Figure 8a (18.0e) and Figure 8a (19.0 (gmacs))) due to this survey selectivity assumption. More options are needed for different treatments of the relationship between NMFS and BSFRF surveys in Gmacs; current options are unlikely to work for other stocks: snow and Tanner crabs.

The extremely high estimated fishing mortality in 1981 is a concern for all models. It is caused by a huge decrease of crab abundance. We watched this parameter all the time to make sure it does not cause any convergence problem.

Model names have been changed in this report. We also changed word “scenarios” to “models”.

Response to SSC Comments specific to this assessment (from October 2018):

“The SSC also agreed with the Team’s recommendation that the buffer be raised from 10% to 20%. Justification for this raise is (1) the over-prediction of 2018 observed survey biomass, (2) 20% is the buffer recommended for other crab stocks with similar uncertainty”

Response: We will use a 20% buffer from now on.

“The SSC notes that a reduction of structural fauna providing protection for small crabs and increase in mobile predators of small crabs was reported from current ecosystem studies. The SSC encourages the author to investigate whether these ecosystem changes are linked to changes in natural mortality or reproductive success.”

Response: This is a good idea. We will look at this issue in the future.

C. Introduction

1. Species

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

2. General distribution

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

3. Stock Structure

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

4. Life History

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

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

5. Fishery

The RKC stock in Bristol Bay, Alaska, supports one of the most valuable fisheries in the United States. A review of the history of the Bristol Bay RKC fishery is provided in Fitch et al. (2012) and Otto (1989). The Japanese fleet started the fishery in the early 1930s, stopped fishing from 1940 to 1952, and resumed the fishery from 1953 until 1974. The Russian fleet fished for RKC from 1959 to 1971. The Japanese fleet employed primarily tanglenets with a very small proportion of catch from trawls and pots. The Russian fleet used only tanglenets. United States trawlers started fishing Bristol Bay RKC in 1947, but the effort and catch declined in the 1950s. The domestic

RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs (58,943 t), worth an estimated $115.3 million ex-vessel value. The catch declined dramatically in the early 1980s and has remained at low levels during the last two decades (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 lbs and 15% when ESB is at or above 55.0 million lbs (Zheng et al. 1996). The maximum harvest rate cap of legal males was changed from 60% to 50%. A threshold of 14.5 million lbs of ESB was also added. In 1997, a minimum threshold of 4.0 million lbs was established as the minimum GHL for opening the fishery and maintaining fishery manageability when the stock abundance is low. The Board modified the current harvest strategy in 2003 by adding a mature harvest rate of 12.5% when the ESB is between 34.75 and 55.0 million lbs 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. Updated NMFS trawl survey data through 2019.

b. Updated the directed pot fishery catch and bycatch data through 2018 (2018/19 completed fishery).

c. Updated groundfish fisheries bycatch data during 1991-2018.

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 ADF&G from 1974 to 2017. Bycatch data are available starting from 1990 and were obtained from the ADF&G observer database and reports (Gaeuman 2013). Sample sizes for catch by length and shell condition are summarized in Table 2. Relatively large samples were taken from the retained catch each year. Sample sizes for trawl bycatch were the annual sums of length frequency samples in the National Marine Fisheries Service (NMFS) database.

(i). Catch Biomass

Retained catch and estimated bycatch biomasses are summarized in Table 1a 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. Because most crab bycatch from the groundfish trawl fisheries occurred during the spring, the years in Table 1a are one year less than those from the NMFS trawl bycatch database to approximate the annual bycatch for reporting years defined as July 1 to June 30; e.g., year 2002 in Table 1a for trawl bycatch corresponds to what is reported for year 2003 in the NMFS database. 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.

(ii). Catch Size Composition

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

(iii). Catch per Unit Effort

Catch per unit effort (CPUE) is defined as the number of retained crab per tan (a unit fishing effort for tanglenets) for the Japanese and Russian tanglenet fisheries and the number of retained crab per potlift for the U.S. fishery (Table 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 performed annual trawl surveys of the eastern Bering Sea since 1968. Two vessels, each towing an eastern otter trawl with an 83 ft headrope and a 112 ft footrope, conducted this multispecies, crab-groundfish survey during the summer. Stations were sampled in the center of a systematic 20 X 20 nm grid overlaid in an area of ≈140,000 nm^2. Since 1972, the trawl survey has covered the full stock distribution except in nearshore waters. The survey in Bristol Bay occurs primarily during late May and June. Tow-by-tow trawl survey data for Bristol Bay RKC during 1975-2017 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.

In addition to standard surveys, NMFS also conducted some surveys after the standard surveys to better assess mature female abundance. In addition to the standard surveys conducted in early June (late May to early June in 1999 and 2000), a portion of the distribution of Bristol Bay RKC was re-surveyed in 1999, 2000, 2006-2012, and 2017. 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 by the standard survey. Differences in area-swept estimates of abundance between the standard surveys and resurveys of these same stations are attributed to survey measurement errors or to seasonal changes in distribution between survey and resurvey. More large females were observed in the resurveys than during the standard surveys in 1999 and 2000 because most mature females had not molted prior to the standard surveys. As in 2006, area-swept estimates of males >89 mm CL, mature males, and legal males within the 32 resurvey stations in 2007 were not significantly different (P=0.74, 0.74 and 0.95; paired t-test of sample means) between the standard survey and resurvey tows. However, similar to 2006, area-swept estimates of mature females within the 32 resurvey stations in 2007 were significantly different (P=0.03; paired t-test) between the standard survey and resurvey tows. Resurvey stations were close to shore during 2010-2012, and mature and legal male abundance estimates were lower for the re-tow than the standard survey. Following the CPT recommendation, we used the standard survey data for male abundance estimates and only the resurvey data, plus the standard survey data outside the resurveyed stations, to assess female abundances during these resurvey years.

4. Bering Sea Fisheries Research Foundation Survey Data

The BSFRF conducted trawl surveys for Bristol Bay RKC in 2007 and 2008 with a small-mesh trawl net and 5-minute tows. The surveys occurred at similar times as the NMFS standard surveys and covered about 97% of the Bristol Bay 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 in 2007 and 19.747 million in 2008 with respective CVs of 0.0634 and 0.0765. 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.

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 for 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 2019.

2. Model Description

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

a-f. See Appendix A.

g. Critical assumptions of the model:

i. The base natural mortality is constant 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 are also 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) 1982-2019, 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 1994-2019) based on sizes at maturity. Once mature, female red king crab grow with a much smaller growth increment per molt.

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

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

vi. The prior of 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.

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: The code is available with the first author.

3. Model Selection and Evaluation

a. Alternative model configurations (models):

18.0d: The model rk18A.D18a from May 2019 with the 2019 data, also the model 18.0a in the SAFE report from September 2018 with the 2019 data and separating the groundfish fisheries bycatch data into trawl and fixed gear during 1996-2018, the period data are available (model 18.0a separated the groundfish data only during 2009-2017). This model assumes that BSFRF survey capture probabilities are 1.0 for all length groups. Under this assumption, NMFS survey selectivities are the products of crab availabilities (equal to BSFRF survey selectivities) and NMFS survey capture probabilities. A survey capture probability for a length group is simply defined as the proportion of the crab in the length group within the area-swept that is caught by the survey net.

Model 18.0d includes:

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

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

(5) Estimating effective sample size from observed sample sizes. 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 pot fishery and 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). The effective sample sizes are plotted against the implied effective sample sizes in Figures 6 and 7, where the implied effective sample sizes are estimated as follows:

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

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

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

(7) Estimating initial year length compositions.

(8) The total observer male biomass and total observer male length composition data in the directed pot fishery are used to replace discarded male biomass and discarded male length composition data.

(9) Total male selectivity and retained proportions in the directed pot fishery are used to replace retained selectivity and discarded male selectivity, and due to high grading problems in some years since rationalization, two logistic curves are estimated for retained proportions: one before rationalization (before 2005) and another after 2004.

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

For model 18.0d, survey abundances $\hat{N}^b_{s,y,l}$ (BSFRF survey) and $\hat{N}^n_{s,y,l}$ (NMFS survey) by sex s and in year y and length group l are computed as follows:

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

where $s^b_{s,l}$ and $s^n_{s,l}$ are survey selectivities for BSFRF and NMFS surveys by sex s and in length group l, respectively, and $N_{s,y,l}$ is the population abundance by sex s and in year y and length group l. BSFRF survey selectivities are computed as

$$s^b_{s,l} = \frac{1}{1+e^{-\beta^b_s\,(\iota - L^b_{50,s})}}, \qquad (3)$$

where β and L_{50} are parameters. Survey selectivity for the first length group (67.5 mm) was assumed to be the same for both males and females, so only three parameters (β, *L50* for females, and *L50* for males) were estimated in the model for each survey. The BSFRF survey catchability is assumed to be 1.0.

Model 18.0d assumes that the BSFRF survey capture probabilities are 1.0 for all length groups. Under this assumption, NMFS survey selectivities are the products of crab availabilities (equal to BSFRF survey selectivities) and NMFS survey capture probabilities (*p*):

$$s^{n}_{s,l} = p_{s,l}\, s^{b}_{s,l}. \tag{4}$$

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

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

where β and *L50* are parameters and like the survey selectivities, only three parameters (β, *L50* for females and *L50* for males) were estimated in the model for each sex. *Q* is the NMFS survey catchability and is estimated in the model with or without a prior from the double-bag experiment, depending on models.

Since fishing times for both Tanner crab fishery and groundfish fishery are assumed to occur at the same time, the fraction separation of fishing mortality rates for both fisheries is used to divide the total fishing mortality rate to individual fisheries, that is, F_i/F_{tot}*(1-exp(-F_{tot})) for fishery i, and the sum of $F_i = F_{tot}$.

18.0e: The same as model 18.0d except the sum of length composition data for Tanner crab fishery bycatch each year is equal to 1.0 for both sexes combined (model 18.0d has the sum equal to 1.0 for each sex). This change treats the Tanner crab fishery bycatch length compositions the same way as the groundfish fisheries bycatch.

19.0: This is the Gmacs version of model 18.0e. This model uses the same input data as model 18.0e and the same approach as much as possible. Some differences are: (1) likelihood values for catch and bycatch biomasses include constant terms under Gmacs while constant terms are not included in the likelihood values under model 18.0e, (2) penalties and prior-densities are much more extensively used with Gmacs than model 18.0e, (3) model 18.0e restricts the estimated survey selectivities to be equal for the smallest length group for both sexes for a given survey (two logistic curves with three parameters) while no such a restriction for Gmacs (two logistic curves with four parameters), (4) model 18.0e uses the smoothed trawl survey length compositions in the initial year divided by the estimated survey selectivities as estimated population length compositions in the initial year before the phase of estimating the population length composition parameters while model 19.0 uses the initial length composition parameters to estimate population length compositions before the estimating phase, and (5) Gmacs uses the BSFRF survey selectivities as a limit to the NMFS trawl survey selectivities while model 18.0e assumes the BSFRF survey selectivities as availabilities to the NMFS trawl survey.

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

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

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

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

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

g. Model selection criteria: The likelihood values 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:

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

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

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

where P_{max} and P_{min} are upper and lower bounds of parameters and P_{val} is the estimated parameter value before the jittering. Due to technical issues for model 19.0 (gmacs), the jittering approach is used for models 18.0d and 18.0e in this report. About half of the jittered runs converged, and a few runs converged to the highest log likelihood values (Table 3).

4. Results

a. Effective sample sizes and weighting factors.

i. For model 18.0e, effective sample sizes are illustrated in Figures 6 and 7.

ii. 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, 0.53 for recruitment variation, and 0.23 for recruitment sex ratio for models 18.0d and 18.0e. Model 19.0 has the same CVs except for using sigmaR for recruitment variation and having a penalty M variation and many prior-densities.

iii. Initial trawl survey catchability (Q) is estimated to be 0.896 with a standard deviation of 0.025 (CV about 0.03) based on the double-bag experiment results (Weinberg et al. 2004). These values are used as a prior for estimating Q in all models.

b. Tables of estimates.

i. Parameter estimates for models 18.0d, 18.0e, and 19.0 are summarized in Table 5.

ii. Abundance and biomass time series are provided in Table 6 for models 18.0d, 18.0e, and 19.0.

iii. Recruitment time series for models 18.0d, 18.0e, and 19.0 are provided in Table 6.

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

Negative log-likelihood values and parameter estimates are summarized in Tables 4 and 5, respectively. Length-specific fishing mortality is equal to selectivity-at-length times the full fishing mortality. Estimated full pot fishing mortalities for females and full fishing mortalities for groundfish fisheries bycatch are very low due to low bycatch as well as handling mortality rates less than 1.0. Estimated recruits varied greatly among years (Table 6). 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 (Table 5).

c. Graphs of estimates.

i. Selectivities and molting probabilities by length are provided in Figures 8 and 9 for models 18.0d, 18.0e, and 19.0.

One of the most important results is estimated trawl survey selectivity (Figure 8). Survey selectivity affects not only the fitting of the data but also the absolute abundance estimates. Estimated survey selectivities in Figure 8 are generally smaller than the capture probabilities in Figure A1 because survey selectivities include capture probabilities and crab availability. The NMFS survey catchability 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. Information about crab availability to the survey area at survey times will help estimate the survey selectivities.

For all models, estimated molting probabilities during 1975-2019 (Figure 9) 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 plotted in Figure 10. Absolute mature male biomasses are illustrated in Figure 11.

The population biomass estimates in 2019 are lower than those in 2018. Among the three models, model estimated relative survey biomasses and mature biomasses are very similar. Estimated results are extremely similar for models 18.0d and 18.0e, indicating that normalizing combined sex or single sex length compositions of Tanner crab fishery bycatch has little impacts on the results. Gmacs (model 19.0) results in slightly high relative female biomass estimates after 2004 and slightly low relative male biomasses during the last 30 years. Models 18.0d and 18.0e fit the BSFRF survey biomasses better than model 19.0 (gmacs) while Gmacs fits NMFS survey biomasses better than the other two models. Like model estimated NMFS survey biomasses, the Gmacs model (19.0) results in lower mature male biomass estimates (thus lower recruitment estimates) than the other two models during the last 30 years.

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

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

The recruitment breakpoint analysis done in May 2019 (Appendix B) has similar results to the analysis done in May 2017, estimating 1984 as the breakpoint brood year, or 1990 recruitment year with a Beverton-Holt model, and 1986 as the breakpoint brood year, or 1992 recruitment year with a Ricker model. No recruitment breakpoint is seen in brook year of 2006. Terminal year recruitment analysis suggests the estimated recruitment in the last terminal year should not be used for estimating $B_{35\%}$.

iii. Estimated recruitment time series are plotted in Figure 12 for models 18.0e and 19.0.

iv. Estimated fishing mortality rates are plotted against mature male biomass in Figure 13 for models 18.0d, 18.0e, and 19.0. Recruitment is estimated at the end of year for model 19.0 while at the beginning of year for models 18.0d and 18.0e. Therefore, recruitment year is moved up one year for model 19.0 to match those for models 18.0d and 18.0e.

The average of estimated male recruits from 1984 to 2018 (Figure 12) and mature male biomass per recruit are used to estimate $B_{35\%}$. Alternative periods of 1976-present and 1976-1983 are compared in our report. The full fishing mortalities for the directed pot fishery at the time of fishing are plotted against mature male biomass on Feb. 15 (Figure 13). Estimated fishing mortalities in most years before the current harvest strategy was adopted in 1996 were above $F_{35\%}$ (Figure 13). Under the current harvest strategy, estimated fishing mortalities were at or above the $F_{35\%}$ limits in 1998, 2005, and 2007-2009 for models 18.0d and 18.0e and 1998-1999, 2003, 2005, 2007-2009, and 2010 for model 19.0, but below the $F_{35\%}$ limits in the other post-1995 years.

For model 18.0e, estimated full pot fishing mortalities ranged from 0.00 to 3.91 during 1975-2018. Estimated values were greater than 0.40 during 1975-1982, 1984-1987, 1990-1991, 1993, 1998 and 2007-2008 (Table 5, Figure 13). For model 19.0 (gmacs), estimated full pot fishing mortalities ranged from 0.00 to 2.95 during 1975-2018, with estimated values over 0.40 during 1975-1976, 1978-1982, 1984-1987, 1990-1991, 1993, 1998, and 2007-2008 (Figure 13). Estimated fishing mortalities for pot female and groundfish fisheries bycatches are generally less than 0.07.

v. Estimated mature male biomass and recruitment are plotted to illustrate their relationships with model 18.0e (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).

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 the last three years is relatively low.

d. Graphic evaluation of the fit to the data.

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

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

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

The models (three 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, trawl and fixed gear bycatch, the deviations of observed and predicted (estimated) fishery biomass are mainly due to size composition differences.

The model also fit the length composition data well (Figures 18-24). 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).

Standardized 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. Standardized residuals of survey biomasses did not show any consistent patterns (Figure 17). Standardized residuals of proportions of survey males appear to be random over length and year (Figure 25). There is an interesting pattern for residuals of proportions of survey females. Residuals are generally negative for large-sized mature females during 1975-1987 for the three models

(Figure 26). Also, there are large negative residuals for the last length group during the last 17 years for model 19.0. Changes in growth over time or increased mortality may cause this pattern. The inadequacy of the model can be corrected by adding parameters to address these factors or with improved growth data.

e. Retrospective and historic analyses.

Two kinds of retrospective analyses were conducted for this report: (1) the 2019 model (model 19.0) hindcast results and (2) historical results. The 2019 model results are based on sequentially excluding one-year of data to evaluate the current model performance with fewer data. The historical results are the trajectories of biomass and abundance from previous assessments that capture both new data and changes in methodology over time. Treating the 2019 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 2019 model includes sequentially excluding one-year of data. Model 19.0 produced some upward biases during 2009-2018 with higher terminal year estimates of mature male biomass in 2009-2010 and 2014-2017 (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 2019.

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 16 historical assessments for comparison with the 2019 assessment model results (Figure 29). The main differences of the 2004 model were weighting factors and effective sample sizes for the likelihood functions. In 2004, the weighting factors were 1,000 for survey biomass, 2,000 for retained catch biomass and 200 for bycatch biomasses. The effective sample sizes were set to be 200 for all proportion data but weighting factors of 5, 2, and 1 were also respectively applied to retained catch proportions, survey proportions and bycatch proportions. Estimates of time series of abundance in 2004 were generally higher than those estimated after 2004 (Figure 29).

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

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

During 2009-2013, the model was extended to the data through 1968. No 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 consistence of trawl survey data. Two levels of molting probabilities over time were used, shell conditions for males were combined, and length composition data of the BSFRF survey were used as well. In 2014 and 2015, the trawl survey time series were re-estimated and a trawl survey catchability was estimated for some models.

Overall, both historical results (historic analysis) and the 2019 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 2019 as a function of number of years estimated in the model show converging to 1.0 as the number of years increase (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 18.0d, 18.0e, and 19.0. Estimated standard deviations of mature male biomass are listed in Table 6.

ii. Probabilities for NMFS trawl survey catchability Q are illustrated in Figure 30 for model 18.0e using the mcmc approach; estimated Qs are less than 1.0. Probabilities for mature male biomass and OFL in 2019 are illustrated in Figure 31 for model 18.0e using the mcmc approach. The confidence intervals are quite narrow.

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

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

g. Comparison of alternative 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) results 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 are similar between models. Using only standard survey data (scenario 1b) results in a poorer fit of survey length compositions and biomass than scenarios using both standard and re-tow data (scenarios 1, 1a, and 1c) and has the lowest likelihood value. Although the likelihood value is higher for using both standard survey and re-tow data for males (scenario 1) than using only standard survey for males (scenario 1c), estimated abundances and biomasses are almost identical. The higher likelihood value for scenario 1 over scenario 1c is due to trawl bycatch length compositions.

In this report (September 2019), three models are compared. The population biomass estimates in 2019 are lower than those in 2018. Among the three models, model estimated relative NMFS survey biomasses and mature biomasses are very similar. Estimated results are extremely similar for models 18.0d and 18.0e, indicating that normalizing combined sex or single sex length compositions of Tanner crab fishery bycatch has little impact on the results. Gmacs (model 19.0) results in slightly high relative female biomass estimates after 2004 and slightly low relative male biomasses during the last 30 years. Models 18.0d and 18.0e fit the BSFRF survey biomasses better than model 19.0 (gmacs) while Gmacs fits NMFS survey biomasses better than the other two models. The Gmacs model (19.0) results in lower mature male biomass estimates (thus lower recruitment estimates) than the other two models during the last 30 years, which may be explained by a weaker link between NMFS and BSFRF surveys by Gmacs, resulting in a lower weight for BSFRF survey data through higher estimated additional CV for BSFRF survey biomass. Lower recruitment estimates in the 1970s for models 18.0d and 18.0e than for model 19.0 (gmacs) may be caused by the restriction of the survey selectivity value of the smallest length group. Also, higher recruitment estimates in the 1970s result in higher high M estimates for model 19.0. All three models fit the catch and bycatch biomass extremely well.

For negative likelihood value comparisons (Table 4b), models 18.0d and 18.0e have almost the same likelihood value except for the difference of Tanner crab fishery bycatch length composition component due to different normalizations. Model 19.0 (gmacs) has many more penalties and prior-densities than models 18.0d and 18.0e and thus a lower likelihood value. Generally speaking, model 18.0e fits all length compositions better than model 19.0 except for the directed pot fishery female discard. Model 19.0 fits the NMFS survey biomass much better than model 18.0e while model 18.0e fits the BSFRF survey biomass slightly better.

Since the results are extremely similar for models 18.0d and 18.0e, we prefer 18.0e and recommend either model 18.0e or model 19.0 (gmacs) for an overfishing definition determination for September 2019. The Gmacs model (19.0) is preferred due to better fits of NMFS survey biomass during recent years. The Gmacs generally runs well and maybe it is time for it to take over the BBRKC assessments.

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) $\beta < \frac{B}{B^*} \le 1 \qquad F_{OFL} = F^*\left(\frac{B/B^* - \alpha}{1-\alpha}\right) \qquad (8)$

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 restriction that $0 \le \beta < 1$. A default value of 0.25 is used.

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

Because trawl bycatch fishing mortality is not related to pot fishing mortality, average trawl bycatch fishing mortality during 2009 to 2018 is used for the per recruit analysis as well as for projections in the next section. Pot female bycatch fishing mortality is set equal to pot male fishing mortality times 0.02, an intermediate level during 1990-2018. Some discards of legal males occurred since 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. For models 18.0d and 18.0e, the averages of retained proportions and total male selectivities during 2017-2018 are used to represent current trends for per recruit analysis and projections. Average molting probabilities during 2009-2018 are used for per recruit analysis and projections. For model 19.0, averages of values during the last five year are used for per recruit analysis. For the models in 2019, the averages are the same since they are constant over time during at least last 14 years.

Average recruitments during three periods are used to estimate $B_{35\%}$: 1976-2018, 1984-2018, and 1991-2018 (Figure 12). Estimated $B_{35\%}$ is compared with historical mature male biomass in Figure 13a. We recommend using the average recruitment during 1984-2018, corresponding to the 1976/77 regime shift. Note that recruitment period 1984-present has been used since 2011 to set the overfishing limits. Several factors support our recommendation. First, estimated recruitment was lower after 1983 than before 1984, which corresponded to brood years 1978 and later, after the 1976/77 regime shift. Second, high recruitments during the late 1960s and 1970s generally occurred when the spawning stock was primarily located in the southern Bristol Bay, whereas the current spawning stock is mainly in the middle of Bristol Bay. The current flows favor larvae hatched in the southern Bristol Bay (see the section on Ecosystem Considerations for SAFE reports in 2008 and 2009). Finally, stock productivity (recruitment/mature male biomass) was higher before the 1976/1977 regime shift.

If we believe that differences in productivity and other population characteristics before 1978 were caused by fishing, not by the regime shift, then we should use the recruitment from 1976-1983 (corresponding to brood years before 1978) as the baseline to estimate $B_{35\%}$. If we believe that the regime shift during 1976/77 caused the productivity differences, then we should select the recruitments from period 1984-2018 as the baseline.

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

The estimated probability distribution of MMB in 2019 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 also recommended ABC = 0.8*OFL in May 2018, which is used to estimate ABC in this report.

Status and catch specifications (1,000 t) (model 19.0):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2015/16	12.89^{A}	27.68^{A}	4.52	4.61	5.30	6.73	6.06
2016/17	12.53^{B}	25.81^{B}	3.84	3.92	4.37	6.64	5.97
2017/18	12.74^{C}	24.86^{C}	2.99	3.09	3.60	5.60	5.04
2018/19	10.62^{D}	16.92D	1.95	2.03	2.65	5.34	4.27
2019/20		15.96^{D}				3.40	2.72

The stock was above MSST in 2018/19 and hence was not overfished. Overfishing did not occur.

Status and catch specifications (million lbs):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2015/16	28.4[A]	61.0[A]	9.97	10.17	11.69	14.84	13.36
2016/17	27.6[B]	56.9[B]	8.47	8.65	9.63	14.63	13.17
2017/18	28.1[C]	54.8[C]	6.60	6.82	7.93	12.35	11.11
2018/19	23.4[D]	37.3[D]	4.31	4.31	5.85	11.76	9.41
2019/20		35.2[D]				7.5	6.00

Notes:

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2016

B – Calculated from the assessment reviewed by the Crab Plan Team in September 2017

C – Calculated from the assessment reviewed by the Crab Plan Team in September 2018

D – Calculated from the assessment reviewed by the Crab Plan Team in September 2019

6. Basis for the OFL: Values in 1,000 t (model 19.0):

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2015/16	3b	26.1	24.7	0.95	0.27	1984-2015	0.18
2016/17	3b	25.8	24.0	0.93	0.27	1984-2016	0.18
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

Basis for the OFL: Values in million lbs:

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2015/16	3b	57.5	54.4	0.95	0.27	1984-2015	0.18
2016/17	3b	56.8	52.9	0.93	0.27	1984-2016	0.18
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

4. Based on the $B_{35\%}$ estimated from the average male recruitment during 1984-2018, 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, ABC = 0.8*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.
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 1984-2019. Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2019. The 2019 abundance is randomly selected from the estimated normal distribution of the assessment model output for each replicate. Three models of fishing mortality for the directed pot fishery are used in the projections:

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

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

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

Each model is replicated 1,000 times and projections made over 10 years beginning in 2019 (Table 7).

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

2. Near Future Outlook

The near future outlook for the Bristol Bay RKC stock is a declining trend. The three recent above-average year classes (hatching years 1990, 1994, and 1997) had entered the legal population by 2006 (Figure 34). Most individuals from the 1997-year class will continue to gain weight to offset loss of the legal biomass to fishing and natural mortalities. The above-average year class (hatching year 2000) with lengths centered around 87.5 mm CL for both males and females in 2006 and with lengths centered around 112.5-117.5 mm CL for males and around 107.5 mm CL for females in 2008 has largely entered the mature male population in 2009 and the legal population by 2014 (Figure 34). No strong cohorts have been observed in the survey data after this cohort through 2010 (Figure 34). There was a huge tow of juvenile crab of size 45-55 mm in 2011, but these juveniles were not tracked during 2012-2019 surveys. This single tow is unlikely to be an indicator for a strong cohort. The high survey abundance of large males and mature females in 2014 cannot be explained by the survey data during the previous years and were also inconsistent with the 2016-2019 survey results (Figure 34). Due to lack of recruitment, mature and legal crab should continue to decline next year. Current crab abundance is still low relative to the late 1970s, and without favorable environmental conditions, recovery to the high levels of the late 1970s is unlikely.

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K. Literature Cited

Alaska Department of Fish and Game (ADF&G). 2012. Commercial king and Tanner crab fishing regulations, 2012-2013. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau. 170 pp.

Balsiger, J.W. 1974. A computer simulation model for the eastern Bering Sea king crab. Ph.D. dissertation, Univ. Washington, Seattle, WA. 198 pp.

Fitch, H., M. Deiman, J. Shaishnikoff, and K. Herring. 2012. Annual management report for the commercial shellfish fisheries of the Bering Sea, 2010/11. *In* Fitch, H. M. Schwenzfeier, B. Baechler, T. Hartill, M. Salmon, M. Deiman, E. Evans, E. Henry, L. Wald, J. Shaishnikoff, K. Herring, and J. Wilson. 2012. Annual management report for the commercial and subsistence fisheries of the Aleutian Islands, Bering Sea and the Westward Region's shellfish observer program, 2010/11. Alaska Department of Fish and Game, Fishery Management report No. 12-22, Anchorage.

Fournier, D.A., J. Hampton, and J.R. Sibert. 1998. MULTIFAN-CL: a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, *Thunnus alalunga*. Can.J.Fish.Aquat. Sci., 55:2105-2116.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Gaeuman, W.G. 2013. Summary of the 2012/13 mandatory crab observer program database for the Bering Sea/Aleutian Islands commercial crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 13-54, Anchorage.

Gray, G.W. 1963. Growth of mature female king crab *Paralithodes camtschaticus* (Tilesius). Alaska Dept. Fish and Game, Inf. Leafl. 26. 4 pp.

Griffin, K. L., M. F. Eaton, and R. S. Otto. 1983. An observer program to gather in-season and post-season on-the-grounds red king crab catch data in the southeastern Bering Sea. Contract 82-2, North Pacific Fishery Management Council, Anchorage, 39 pp.

Haynes, E.B. 1968. Relation of fecundity and egg length to carapace length in the king crab, *Paralithodes camtschaticus*. Proc. Nat. Shellfish Assoc. 58: 60-62.

Hoopes, D.T., J.F. Karinen, and M. J. Pelto. 1972. King and Tanner crab research. Int. North Pac. Fish. Comm. Annu. Rep. 1970:110-120.

Ianelli, J.N., S. Barbeaux, G. Walters, and N. Williamson. 2003. Eastern Bering Sea walleye Pollock stock assessment. Pages 39-126 *in* Stock assessment and fishery evaluation report for the groundfish resources of the Bering Sea/Aleutian Islands regions. North Pacific Fishery Management Council, Anchorage.

Jackson, P.B. 1974. King and Tanner crab fishery of the United States in the Eastern Bering Sea, 1972. Int. North Pac. Fish. Comm. Annu. Rep. 1972:90-102.

Loher, T., D.A. Armstrong, and B.G. Stevens. 2001. Growth of juvenile red king crab (*Paralithodes camtschaticus*) in Bristol Bay (Alaska) elucidated from field sampling and analysis of trawl-survey data. Fish. Bull. 99:572-587.

Matsuura, S., and K. Takeshita. 1990. Longevity of red king crab, *Paralithodes camtschaticus*, revealed by long-term rearing study. Pages 247-266 *in* Proceedings of the International Symposium on King and Tanner Crabs. University Alaska Fairbanks, Alaska Sea Grant College Program Report 90-04, Fairbanks. 633 pp.

McCaughran, D.A., and G.C. Powell. 1977. Growth model for Alaskan king crab (*Paralithodes camtschaticus*). J. Fish. Res. Board Can. 34:989-995.

North Pacific Fishery Management Council (NPFMC). 2007. Environmental assessment for proposed amendment 24 to the fishery management plan for Bering Sea and Aleutian Islands king and Tanner crabs to revise overfishing definitions. A review draft.

Otto, R.S. 1989. An overview of eastern Bering Sea king and Tanner crab fisheries. Pages 9–26 *in* Proceedings of the International Symposium on King and Tanner Crabs, Alaska Sea Grant Collecge Program Report No. 90-04.

Parma, A.M. 1993. Retrospective catch-at-age analysis of Pacific halibut: implications on assessment of harvesting policies. Pages 247-266 *in* G. Kruse, D.M. Eggers, R.J. Marasco, C. Pautzke, and T.J. Quinn II (eds.). Proceedings of the international symposium on management strategies for exploited fish populations. University of Alaska Fairbanks, Alaska Sea Grant Rep. 90-04.

Paul, J.M., and A.J. Paul. 1990. Breeding success of sublegal size male red king crab *Paralithodes camtschaticus* (Tilesius, 1815) (Decapopa, Lithodidae). J. Shellfish Res. 9:29-32.

Paul, J.M., A.J. Paul, R.S. Otto, and R.A. MacIntosh. 1991. Spermatophore presence in relation to carapace length for eastern Bering Sea blue king crab (*Paralithodes platypus*, Brandt, 1850) and red king crab (P. camtschaticus, Tilesius, 1815). Journal of Shellfish research, Vol. 10, No. 1, 157-163.

Pengilly, D., S.F. Blau, and J.E. Blackburn. 2002. Size at maturity of Kodiak area female red king crab. Pages 213-224 *in* A.J. Paul, E.G. Dawe, R. Elner, G.S. Jamieson, G.H. Kruse, R.S. Otto, B. Sainte-Marie, T.C. Shirley, and D. Woodby (eds.). Crabs in Cold Water Regions: Biology, Management, and Economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks.

Pengilly, D., and D. Schmidt. 1995. Harvest strategy for Kodiak and Bristol Bay red king crab and St. Matthew Island and Pribilof Islands blue king crab. Alaska Dep. Fish and Game, Comm. Fish. Manage. and Dev. Div., Special Publication 7. Juneau, AK. 10 pp.

Phinney, D.E. 1975. United States fishery for king and Tanner crabs in the eastern Bering Sea, 1973. Int. North Pac. Fish. Comm. Annu. Rep. 1973: 98-109.

Powell, G.C. 1967. Growth of king crabs in the vicinity of Kodiak, Alaska. Alaska Dept. Fish and Game, Inf. Leafl. 92. 106 pp.

Powell, G. C., and R.B. Nickerson. 1965. Aggregations among juvenile king crab (*Paralithodes camtschaticus*, Tilesius) Kodiak, Alaska. Animal Behavior 13: 374–380.

Schmidt, D., and D. Pengilly. 1990. Alternative red king crab fishery management practices: modeling the effects of varying size-sex restrictions and harvest rates, p.551-566. *In* Proc. Int. Symp. King and Tanner Crabs, Alaska Sea Grant Rep. 90-04.

Sparks, A.K., and J.F. Morado. 1985. A preliminary report on diseases of Alaska king crabs, p.333-340. *In* Proc. Int. Symp. King and Tanner Crabs, Alaska Sea Grant Rep. 85-12.

Stevens, B.G. 1990. Temperature-dependent growth of juvenile red king crab (*Paralithodes camtschaticus*), and its effects on size-at-age and subsequent recruitment in the eastern Bering Sea. Can. J. Fish. Aquat. Sci. 47: 1307-1317.

Stevens, B.G., and K. Swiney. 2007. Hatch timing, incubation period, and reproductive cycle for primiparous and multiparous red king crab, *Paralithodes camtschaticus*. J. Crust. Bio. 27(1): 37-48.

Swiney, K. M., W.C. Long, G.L. Eckert, and G.H. Kruse. 2012. Red king crab, *Paralithodes camtschaticus*, size-fecundity relationship, and interannual and seasonal variability in fecundity. Journal of Shellfish Research, 31:4, 925-933.

Webb. J. 2014. Reproductive ecology of commercially important Lithodid crabs. Pages 285-314 In B.G. Stevens (ed.): King Crabs of the World: Biology and Fisheries Management. CRC Press, Taylor & Francis Group, New York.

Weber, D.D. 1967. Growth of the immature king crab *Paralithodes camtschaticus* (Tilesius). Int. North Pac. Fish. Comm. Bull. 21:21-53.

Weber, D.D., and T. Miyahara. 1962. Growth of the adult male king crab, *Paralithodes camtschaticus* (Tilesius). Fish. Bull. U.S. 62:53-75.

Weinberg, K.L., R.S. Otto, and D.A. Somerton. 2004. Capture probability of a survey trawl for red king crab (*Paralithodes camtschaticus*). Fish. Bull. 102:740-749.

Zheng, J. 2005. A review of natural mortality estimation for crab stocks: data-limited for every stock? Pages 595-612 *in* G.H. Kruse, V.F. Gallucci, D.E. Hay, R.I. Perry, R.M. Peterman, T.C. Shirley, P.D. Spencer, B. Wilson, and D. Woodby (eds.). Fisheries Assessment and Management in Data-limited Situation. Alaska Sea Grant College Program, AK-SG-05-02, Fairbanks.

Zheng, J., and G.H. Kruse. 2002. Retrospective length-based analysis of Bristol Bay red king crabs: model evaluation and management implications. Pages 475-494 *in* A.J. Paul, E.G. Dawe, R. Elner, G.S. Jamieson, G.H. Kruse, R.S. Otto, B. Sainte-Marie, T.C. Shirley, and D. Woodby (eds.). Crabs in Cold Water Regions: Biology, Management, and Economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks.

Zheng, J., M.C. Murphy, and G.H. Kruse. 1995a. A length-based population model and stock-recruitment relationships for red king crab, *Paralithodes camtschaticus*, in Bristol Bay, Alaska. Can. J. Fish. Aquat. Sci. 52:1229-1246.

Zheng, J., M.C. Murphy, and G.H. Kruse. 1995b. Updated length-based population model and stock-recruitment relationships for red king crab, *Paralithodes camtschaticus,* in Bristol Bay, Alaska. Alaska Fish. Res. Bull. 2:114-124.

Zheng, J., M.C. Murphy, and G.H. Kruse. 1996. Overview of population estimation methods and recommended harvest strategy for red king crabs in Bristol Bay. Alaska Department of Fish and Game, Reg. Inf. Rep. 5J96-04, Juneau, Alaska. 37 pp.

Zheng, J., M.C. Murphy, and G.H. Kruse. 1997a. Analysis of the harvest strategies for red king crab, *Paralithodes camtschaticus,* in Bristol Bay, Alaska. Can. J. Fish. Aquat. Sci. 54:1121-1134.

Zheng, J., M.C. Murphy, and G.H. Kruse. 1997b. Alternative rebuilding strategies for the red king crab *Paralithodes camtschaticus* fishery in Bristol Bay, Alaska. J. Shellfish Res. 16:205-217.

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.

Year	Retained Catch				Pot Bycatch		Trawl Bycat.	Fixed Bycat.	Tanner Fishery Bycat.	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	34.2	118.8	42.0	5390.8
2015	4522.3	91.4	0	4613.7	266.1	216.3	45.4	77.4	84.2	5303.1
2016	3840.4	83.4	0	3923.9	237.4	105.4	71.1	29.3	0.0	4367.1
2017	2994.1	99.6	0	3093.7	225.2	53.3	96.1	11.0	0.0	3598.7
2018	1954.1	72.4	0	2026.5	279.6	114.8	84.3	148.1	0.0	2653.3

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	

Table 2. 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			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	1,443	853		
2010	708	1,004	20,137	66,659	6,862	624	843		
2011	531	912	10,706	40,226	1,752	566	1,071		
2012	585	707	8,956	20,161	562	1,508	1,752		
2013	647	569	10,197	30,261	6,070	4,809	4,198	218	596
2014	1,107	1,257	9,618	28,540	1,953	1,975	2,584	256	381
2015	615	681	11,746	22,022	5,927	1,154	3,734	726	2163
2016	378	812	10,811	26,510	4,315	1,946	3,020		
2017	385	508	9,867	27,219	3,834	1,031	1,168		
2018	285	359	7,626	22,480	7,386	2,820	3,470		
2019	273	299							

Table 3(18.0d). Summary of jittering results for model 18.0d. Run 80 is used for initial conditions. Runs with “NA” did not converge. The jittering factor is 0.1. Biomass and OFL are in t. The R scripts (100 runs each time) were run twice for total 200 runs; about 100 runs converged. This table has the second 100 runs.

Run	Neg.log.liklihood	Max gradient	$B_{35\%}$	B_{2019}	OFL_{2019}
1	NA	NA	NA	NA	NA
2	NA	NA	NA	NA	NA
3	NA	NA	NA	NA	NA
4	-23551.2	0.00007	24922.1	17613.9	3555.0
5	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA
8	-23555.1	0.00002	24675.6	17795.4	3665.6
9	NA	NA	NA	NA	NA
10	-23551.2	0.00013	24922.1	17613.9	3555.0
11	NA	NA	NA	NA	NA
12	NA	NA	NA	NA	NA
13	NA	NA	NA	NA	NA
14	NA	NA	NA	NA	NA
15	-23570.3	0.00002	24977.9	17867.6	3643.6
16	NA	NA	NA	NA	NA
17	NA	NA	NA	NA	NA
18	NA	NA	NA	NA	NA
19	NA	NA	NA	NA	NA
20	-23558.5	0.00004	24803.0	17802.3	3645.6
21	NA	NA	NA	NA	NA
22	-23570.3	0.00007	24977.9	17867.6	3643.6
23	NA	NA	NA	NA	NA
24	NA	NA	NA	NA	NA
25	NA	NA	NA	NA	NA
26	NA	NA	NA	NA	NA
27	-23551.2	0.00004	24922.1	17613.9	3555.0
28	-23570.3	0.00005	24977.9	17867.6	3643.6
29	-23551.2	0.00002	24922.1	17613.9	3555.0
30	-23551.2	0.00002	24922.1	17613.9	3555.0
31	NA	NA	NA	NA	NA
32	NA	NA	NA	NA	NA
33	NA	NA	NA	NA	NA
34	-23570.0	0.00025	24912.9	17814.5	3632.1
35	NA	NA	NA	NA	NA
36	NA	NA	NA	NA	NA
37	NA	NA	NA	NA	NA
38	NA	NA	NA	NA	NA
39	-23558.5	0.00006	24803.0	17802.3	3645.6
40	NA	NA	NA	NA	NA
41	NA	NA	NA	NA	NA
42	-23551.2	0.00003	24922.1	17613.9	3555.0
43	NA	NA	NA	NA	NA
44	NA	NA	NA	NA	NA
45	NA	NA	NA	NA	NA
46	NA	NA	NA	NA	NA
47	-23570.2	0.00017	24906.9	17818.4	3634.9
48	-23570.3	0.00005	24977.9	17867.6	3643.6
49	-23558.5	0.00004	24803.0	17802.3	3645.6
50	NA	NA	NA	NA	NA
51	NA	NA	NA	NA	NA
52	-23570.3	0.00021	24977.9	17867.6	3643.6
53	-23549.5	0.00008	24841.1	17576.7	3536.1
54	NA	NA	NA	NA	NA
55	-23551.2	0.00001	24922.1	17613.9	3555.0
56	NA	NA	NA	NA	NA
57	-23551.2	0.00007	24922.1	17613.9	3555.0
58	NA	NA	NA	NA	NA
59	NA	NA	NA	NA	NA
60	-23570.3	0.00017	24977.9	17867.6	3643.6
61	NA	NA	NA	NA	NA
62	NA	NA	NA	NA	NA
63	NA	NA	NA	NA	NA
64	-23551.2	0.00007	24922.1	17613.9	3555.0
65	-23570.3	0.00015	24977.9	17867.6	3643.6

66	NA	NA	NA	NA	NA
67	NA	NA	NA	NA	NA
68	-23570.3	0.00004	24977.9	17867.6	3643.6
69	-23549.5	0.00001	24841.1	17576.7	3536.1
70	-23570.3	0.00008	24977.9	17867.6	3643.6
71	NA	NA	NA	NA	NA
72	NA	NA	NA	NA	NA
73	-23551.2	0.00006	24922.1	17613.9	3555.0
74	-23549.5	0.00004	24841.1	17576.7	3536.1
75	NA	NA	NA	NA	NA
76	-23549.5	0.00010	24841.1	17576.7	3536.1
77	NA	NA	NA	NA	NA
78	-23570.0	0.00023	24912.9	17814.5	3632.1
79	NA	NA	NA	NA	NA
80	-23570.3	0.00008	24977.9	17867.6	3643.6
81	-23570.0	0.00010	24912.9	17814.5	3632.1
82	NA	NA	NA	NA	NA
83	NA	NA	NA	NA	NA
84	NA	NA	NA	NA	NA
85	NA	NA	NA	NA	NA
86	NA	NA	NA	NA	NA
87	-23551.2	0.00009	24922.1	17613.9	3555.0
88	NA	NA	NA	NA	NA
89	NA	NA	NA	NA	NA
90	-23551.2	0.00007	24922.1	17613.9	3555.0
91	-23558.5	0.00003	24803.0	17802.3	3645.6
92	NA	NA	NA	NA	NA
93	-23551.2	0.00004	24922.1	17613.9	3555.0
94	-23549.5	0.00001	24841.1	17576.7	3536.1
95	NA	NA	NA	NA	NA
96	-23551.2	0.00012	24922.1	17613.9	3555.0
97	NA	NA	NA	NA	NA
98	-23551.2	0.00005	24922.1	17613.9	3555.0
99	-23570.3	0.00006	24977.9	17867.6	3643.6
100	NA	NA	NA	NA	NA

Table 3(18.0e). Summary of jittering results for model 18.0e. Run 62 is used for initial conditions. Runs with "NA" did not converge. The jittering factor is 0.1. Biomass and OFL are in t. The R scripts (100 runs each time) were run twice for total 200 runs; about 100 runs converged. This table has the second 100 runs.

Run	Neg.log.liklihood	Max gradient	$B_{35\%}$	B_{2019}	OFL_{2019}
1	NA	NA	NA	NA	NA
2	NA	NA	NA	NA	NA
3	-23649.0	0.00005	24985.0	17480.4	3480.6
4	NA	NA	NA	NA	NA
5	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA
8	-23667.7	0.00006	24990.3	17671.5	3550.7
9	-23655.1	0.00008	24810.2	17674.9	3587.0
10	-23649.0	0.00007	24985.0	17480.4	3480.6
11	NA	NA	NA	NA	NA
12	-23649.0	0.00004	24985.0	17480.4	3480.6
13	NA	NA	NA	NA	NA
14	-23667.9	0.00034	25054.1	17723.9	3562.1
15	NA	NA	NA	NA	NA
16	-23667.9	0.00008	25054.1	17723.9	3562.1
17	NA	NA	NA	NA	NA
18	NA	NA	NA	NA	NA
19	-23649.0	0.00017	24985.0	17480.4	3480.6
20	-23649.0	0.00004	24985.0	17480.4	3480.6
21	-23649.0	0.00003	24985.0	17480.4	3480.6
22	-23649.0	0.00005	24985.0	17480.4	3480.6
23	NA	NA	NA	NA	NA
24	-23667.7	0.00130	24990.3	17671.5	3550.7
25	NA	NA	NA	NA	NA
26	NA	NA	NA	NA	NA
27	NA	NA	NA	NA	NA
28	NA	NA	NA	NA	NA
29	NA	NA	NA	NA	NA
30	-23649.0	0.00017	24985.0	17480.4	3480.6
31	NA	NA	NA	NA	NA
32	NA	NA	NA	NA	NA
33	-23649.0	0.00021	24985.0	17480.4	3480.6
34	-23649.0	0.00007	24985.0	17480.4	3480.6
35	NA	NA	NA	NA	NA
36	NA	NA	NA	NA	NA
37	NA	NA	NA	NA	NA
38	-23641.9	0.00008	24485.5	17009.8	3344.5
39	NA	NA	NA	NA	NA
40	-23647.2	0.00002	24906.8	17443.9	3462.0
41	-23649.0	0.00003	24985.0	17480.4	3480.6
42	-23649.0	0.00002	24985.0	17480.4	3480.6
43	-23667.9	0.00005	25054.1	17723.9	3562.1
44	-23649.0	0.00004	24985.0	17480.4	3480.6
45	-23649.0	0.00028	24985.0	17480.4	3480.6
46	NA	NA	NA	NA	NA
47	-23667.9	0.00025	25054.1	17723.9	3562.1
48	NA	NA	NA	NA	NA
49	NA	NA	NA	NA	NA
50	-23649.0	0.00004	24985.0	17480.4	3480.6
51	-23666.3	0.00058	24980.2	17734.0	3583.8
52	-23649.0	0.00002	24985.0	17480.4	3480.6
53	-23647.2	0.00002	24906.8	17443.9	3462.0
54	NA	NA	NA	NA	NA
55	-23649.0	0.00008	24985.0	17480.4	3480.6
56	NA	NA	NA	NA	NA
57	-23649.0	0.00005	24985.0	17480.4	3480.6
58	-23666.4	0.00005	24994.5	17681.7	3555.5
59	NA	NA	NA	NA	NA
60	NA	NA	NA	NA	NA
61	NA	NA	NA	NA	NA
62	-23667.9	0.00001	25054.1	17723.9	3562.1
63	-23647.2	0.00002	24906.8	17443.9	3462.0
64	NA	NA	NA	NA	NA
65	-23649.0	0.00001	24985.0	17480.4	3480.6

66	-23649.0	0.00007	24985.0	17480.4	3480.6
67	-23665.7	0.00015	24994.8	17675.3	3552.5
68	NA	NA	NA	NA	NA
69	NA	NA	NA	NA	NA
70	NA	NA	NA	NA	NA
71	-23649.0	0.00002	24985.0	17480.4	3480.6
72	-23667.7	0.00009	24990.3	17671.5	3550.7
73	-23649.0	0.00004	24985.0	17480.4	3480.6
74	NA	NA	NA	NA	NA
75	NA	NA	NA	NA	NA
76	-23647.2	0.00001	24906.8	17443.9	3462.0
77	-23649.0	0.00005	24985.0	17480.4	3480.6
78	NA	NA	NA	NA	NA
79	-23649.0	0.00006	24985.0	17480.4	3480.6
80	NA	NA	NA	NA	NA
81	-23647.2	0.00001	24906.8	17443.9	3462.0
82	NA	NA	NA	NA	NA
83	-23656.0	0.00004	24868.4	17651.1	3562.5
84	-23649.0	0.00003	24985.0	17480.4	3480.6
85	-23649.0	0.00003	24985.0	17480.4	3480.6
86	-23649.0	0.00001	24985.0	17480.4	3480.6
87	NA	NA	NA	NA	NA
88	NA	NA	NA	NA	NA
89	NA	NA	NA	NA	NA
90	-23649.0	0.00004	24985.0	17480.4	3480.6
91	NA	NA	NA	NA	NA
92	NA	NA	NA	NA	NA
93	-23655.1	0.00000	24810.2	17674.9	3587.0
94	NA	NA	NA	NA	NA
95	NA	NA	NA	NA	NA
96	-23649.0	0.00002	24985.0	17480.4	3480.6
97	-23649.0	0.00002	24985.0	17480.4	3480.6
98	NA	NA	NA	NA	NA
99	NA	NA	NA	NA	NA
100	NA	NA	NA	NA	NA

Table 4a. Number of parameters and the list of likelihood components for the model (Models 18.0d, 18.0e, and 19.0 (gmacs)).

Parameter counts	**18.0d**	**18.0e**	**19.0**
Fixed growth parameters	9	9	9
Fixed recruitment parameters	2	2	2
Fixed length-weight relationship parameters	6	6	6
Fixed mortality parameters	4	4	4
Fixed survey catchability parameter	1	1	1
Fixed high grading parameters	0	0	0
Total number of fixed parameters	22	22	22
Free survey catchability parameter	1	1	1
Free growth parameters	6	6	6
Initial abundance (1975)	1	1	1
Recruitment-distribution parameters	2	2	2
Mean recruitment parameters	1	1	1
Male recruitment deviations	44	44	44
Female recruitment deviations	44	44	44
Natural mortality parameters	3	3	3
Mean & offset fishing mortality parameters	4	4	6
Pot male fishing mortality deviations	44	44	44
Bycatch mortality from the Tanner crab fishery	12	12	50
Pot female bycatch fishing mortality deviations	29	29	29
Trawl bycatch fishing mortality deviations	43	43	43
Fixed gear bycatch fishing mortality deviations	23	23	23
Initial (1975) length compositions	35	35	35
BSFRF survey extra CV	1	1	1
Free selectivity parameters	25	25	28
Total number of free parameters	318	318	361
Total number of fixed and free parameters	340	340	383

Table 4b. Negative log likelihood components for Models 18.0d, 18.0e, and 19.0 (gmacs), their differences and some management quantities. Highlighted cells in yellow color are not comparable between model 19.0 and the other two models due to different constants in likelihood functions and between model 18.0d and the other two models due to sex-specific length compositions and sex combined length compositions for Tanner crab fishery bycatch. Red values show large differences from the other models.

	Model			Difference	
Negative log likelihood	18.0d	18.0e	19.0	18.0d – 18.0e	18.0e – 19.0
R-variation	68.81	69.41	136.83	-0.60	-67.42
Length-like-retained	-3553.66	-3553.84	-3551.90	0.18	-1.94
Length-like-tot male	-2071.65	-2072.02	-2065.00	0.37	-7.02
Length-like-discfemale	-1293.43	-1292.83	-1304.17	-0.60	11.34
Length-like-survey	-6734.97	-6734.48	-6730.33	-0.49	-4.15
Length-like-disctrawl	-5461.31	-5461.65	-5446.30	0.34	-15.35
Length-like-discfix	-3057.86	-3056.94	-3004.06	-0.92	-52.88
Length-like-discTanner	-691.89	-790.47	-780.75	98.58	-9.72
Length-like-bsfrfsurvey	-854.88	-855.28	-846.14	0.40	-9.13
Catchbio_retained	17.32	17.42	-62.26	-0.10	79.68
Catchbio_tot/discmale	60.42	60.55	22.53	-0.13	38.02
Catchbio-discfemale	0.05	0.04	-50.49	0.00	50.53
Catchbio-disctrawl	0.02	0.02	-59.58	0.00	59.60
Catchbio-discfix	0.00	0.00	-87.08	0.00	87.08
Catchbio-discTanner	0.01	0.00	-31.88	0.00	31.88
Biomass-trawl survey	-7.96	-8.67	-22.06	0.71	13.39
Biomass-bsfrfsurvey	-8.90	-8.85	-7.75	-0.05	-1.10
Q-trawl survey	0.59	0.67		-0.09	
Others	19.00	19.01	340.03	-0.01	-321.02
Total	-23570	-23668	-23550	97.60	-118
Free parameters	318	318	361	0	-43
$B_{35\%}$(t)	24978	25054	21247	-76.200	3807
$F_{35\%}$	0.304	0.304	0.299	0.000	0.005
MMB_{2019}(t)	17868	17724	15957	143.700	1767.282
OFL_{2019}	3643.6	3562.1	3403.4	81.450	158.763
ABC_{2019}(t)	2914.9	2849.7	2722.7	65.160	127.010
$F_{ofl2019}$	0.208	0.205	0.216	0.003	-0.011
Q	0.923	0.925	0.925	-0.002	0.000

Table 5(18.0d). Summary of estimated model parameter values and standard deviations and limits for model 18.0d for Bristol Bay red king crab. All values are on a log scale. Male recruit in year t is exp($mean+males_t$), and female recruit in year t is exp($mean+males_t+females_t$).

Year	Recruits				F for Directed Pot Fishery				F for Trawl	
	Females	SD	Males	SD	Males	SD	Females	SD	Estimate	SD
Mean	15.905	0.034	15.905	0.034	-1.570	0.041	0.013	0.001	-4.521	0.074
Limits↑	13,18		13,18		-3.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-15,2.93		-6.0,3.5		-10,10	
1975					0.755	0.136				
1976	0.216	0.572	0.402	0.414	0.726	0.096			0.215	0.129
1977	0.565	0.405	0.567	0.257	0.658	0.075			0.688	0.118
1978	0.582	0.377	0.763	0.232	0.825	0.062			0.734	0.112
1979	0.830	0.284	1.157	0.197	1.130	0.056			0.915	0.110
1980	0.353	0.290	1.636	0.166	2.110	0.059			1.789	0.112
1981	0.174	0.354	0.939	0.249	2.925	0.014			1.648	0.115
1982	0.074	0.150	2.373	0.109	1.381	0.120			2.812	0.119
1983	0.207	0.222	1.464	0.142	-9.999	0.054			2.345	0.113
1984	0.765	0.172	1.118	0.125	1.026	0.096			3.349	0.115
1985	-0.233	0.410	-0.289	0.222	0.945	0.096			2.051	0.114
1986	0.735	0.172	0.425	0.124	1.191	0.074			1.005	0.113
1987	-0.089	0.377	-0.344	0.187	0.765	0.065			0.577	0.110
1988	-0.054	0.401	-0.808	0.211	-0.126	0.054			1.387	0.105
1989	-0.293	0.346	-0.517	0.176	0.010	0.049			-0.025	0.105
1990	0.243	0.179	0.268	0.111	0.703	0.044	1.947	0.088	0.439	0.105
1991	0.018	0.247	-0.111	0.134	0.693	0.046	-0.647	0.089	0.857	0.106
1992	-0.432	0.460	-1.264	0.244	0.104	0.051	2.128	0.090	0.685	0.106
1993	-0.259	0.265	-0.362	0.141	0.823	0.057	1.937	0.093	1.176	0.110
1994	-0.089	0.434	-1.198	0.249	-4.313	0.054	1.285	0.121	-0.564	0.107
1995	-0.032	0.089	1.266	0.068	-4.725	0.045	1.443	0.123	-0.846	0.105
1996	-1.051	0.442	-0.617	0.260	-0.186	0.044	-3.656	0.140	-0.782	0.105
1997	-0.889	0.435	-0.880	0.241	-0.100	0.044	-0.332	0.087	-1.248	0.105
1998	-0.610	0.308	-0.008	0.146	0.683	0.047	1.579	0.086	0.024	0.104
1999	0.023	0.150	0.721	0.096	0.299	0.045	-2.708	0.093	-0.261	0.104
2000	-0.155	0.353	-0.243	0.193	-0.275	0.044	1.179	0.083	-1.020	0.104
2001	0.186	0.353	-0.341	0.212	-0.319	0.044	0.858	0.083	-0.255	0.103
2002	0.378	0.128	0.949	0.093	-0.192	0.043	-1.937	0.088	-0.547	0.103
2003	-0.306	0.453	-0.448	0.252	0.274	0.042	1.156	0.082	-0.632	0.103
2004	-0.191	0.382	-0.185	0.206	0.259	0.042	0.360	0.083	-0.395	0.103
2005	0.128	0.154	0.868	0.095	0.555	0.044	0.859	0.083	-0.674	0.103
2006	-0.200	0.279	0.261	0.137	0.349	0.043	-1.384	0.083	-0.503	0.103
2007	-0.526	0.312	-0.074	0.148	0.662	0.043	-0.278	0.082	-0.448	0.103
2008	-0.002	0.341	-0.725	0.202	0.810	0.046	-0.548	0.084	-0.508	0.103
2009	0.234	0.323	-0.568	0.188	0.582	0.047	-0.761	0.084	-0.893	0.104
2010	0.701	0.193	0.080	0.121	0.412	0.047	-0.318	0.084	-1.073	0.104
2011	0.191	0.350	-0.336	0.165	-0.280	0.046	-1.225	0.085	-1.557	0.105
2012	0.171	0.326	-0.613	0.177	-0.337	0.046	-1.897	0.087	-2.099	0.106
2013	-0.302	0.331	-0.687	0.161	-0.191	0.047	0.116	0.083	-1.423	0.106
2014	-0.181	0.411	-1.292	0.215	0.041	0.049	-0.433	0.085	-2.054	0.108
2015	0.120	0.293	-0.799	0.177	0.080	0.053	0.672	0.087	-1.722	0.109
2016	-0.132	0.275	-0.384	0.167	-0.015	0.059	0.110	0.090	-1.224	0.110
2017	-0.312	0.402	-0.846	0.238	-0.191	0.065	-0.335	0.093	-0.877	0.112
2018	-0.284	0.398	-0.547	0.262	-0.527	0.070	0.829	0.095	-1.068	0.113
2019	-0.275	0.474	-0.773	0.317						

Table 5(18.0d) (continued). Summary of estimated model parameter values and standard deviations and limits for model 18.0d for Bristol Bay red king crab. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

				Initial Length Composition 1975			
Parameter	Value	SD	Limits	Length	Value	SD	Limits
Mm80-84	0.478	0.031	0.184, 1.0	68	1.030	0.422	-4.2. 4.2
Mf80-84	0.843	0.040	0.276, 1.5	73	0.700	0.589	-4.2, 4.2
Mf76-79,85-93	0.090	0.012	0.0, 0.108	78	0.510	0.427	-4.2, 4.2
log_betal, females	0.693	0.130	-0.67, 1.32	83	0.697	0.289	-4.2, 4.2
log_betal, males	-0.050	0.214	-0.67, 1.32	88	0.558	0.270	-4.2, 4.2
log_betar, females	-0.509	0.207	-1.14, 0.5	93	0.445	0.269	-4.2, 4.2
log_betar, males	-0.494	0.173	-1.14, 0.5	98	0.472	0.255	-4.2, 4.2
Bsfrf_CV	0.130	0.066	0.00, 0.40	103	0.334	0.271	-4.2, 4.2
moltp_slope, 75-78	0.109	0.017	0.01, 0.259	108	0.425	0.255	-4.2, 4.2
moltp_slope, 79-19	0.093	0.005	0.01, 0.259	113	0.487	0.248	-4.2, 4.2
log_moltp_L50, 75-78	4.951	0.013	4.445, 5.52	118	0.269	0.286	-4.2, 4.2
log_moltp_L50, 79-19	4.938	0.005	4.445, 5.52	123	0.281	0.281	-4.2, 4.2
log_N75	19.927	0.055	15.0, 22.0	128	0.138	0.309	-4.2, 4.2
log_avg_L50_tot	4.754	0.010	4.38, 5.45	133	0.271	0.263	-4.2, 4.2
tot_fish_slope	0.104	0.006	0.05, 0.57	138	0.080	0.198	-4.2, 4.2
Log_ret_L50, 75-04	4.922	0.002	4.6, 5.1	143	-0.185	0.196	-4.2, 4.2
Ret_fish_slope, 75-04	0.498	0.032	0.05, 0.87	148	-0.362	0.200	-4.2, 4.2
Log_ret_L50, 05-19	4.929	0.003	4.6, 5.1	153	-0.725	0.227	-4.2, 4.2
Ret_fish_slope, 05-19	0.503	0.065	0.05, 0.7	158	-1.257	0.284	-4.2, 4.2
pot disc.fema., slope	0.092	0.016	0.05, 0.43	163	-1.295	0.286	-4.2, 4.2
log_pot disc.fema., L50	4.552	0.038	4.20, 4.666	68	1.620	0.436	-4.2, 4.2
trawl disc slope	0.059	0.003	0.01, 0.20	73	1.513	0.437	-4.2, 4.2
log_trawl disc L50	5.171	0.061	4.50, 5.40	78	1.508	0.357	-4.2, 4.2
log_srv_L50, m, bsfrf	4.362	0.033	3.359, 5.48	83	1.352	0.319	-4.2, 4.2
srv_slope, f, bsfrf	0.044	0.008	0.01, 0.134	88	1.261	0.268	-4.2, 4.2
log_srv_L50, f, bsfrf	4.514	0.049	3.471, 5.539	93	0.763	0.308	-4.2, 4.2
log_srv_L50, m, 75-81	4.343	0.025	3.551, 5.864	98	0.376	0.372	-4.2, 4.2
srv_slope, f, 75-81	0.102	0.013	0.01, 0.303	103	0.103	0.428	-4.2, 4.2
log_srv_L50, f, 75-81	4.444	0.027	3.709, 4.80	108	-0.058	0.426	-4.2, 4.2
log_srv_L50, m, 82-19	4.066	0.279	3.709, 5.10	113	-0.265	0.453	-4.2, 4.2
srv_slope, f, 82-19	0.086	0.029	0.01, 0.43	118	-0.891	0.678	-4.2, 4.2
log_srv_L50, f, 82-19	4.172	0.063	3.709, 4.90	123	-1.093	0.751	-4.2, 4.2
TC_slope, females	0.339	0.104	0.02, 0.40	128	-1.465	0.917	-4.2, 4.2
log_TC_L50, females	4.530	0.015	4.24, 4.90	133	-2.561	1.950	-4.2, 4.2
TC_slope, males	0.212	0.068	0.05, 0.90	138	-2.916	2.403	-4.2, 4.2
log_TC_L50, males	4.567	0.020	4.25, 5.14	143	NA	NA	
Q	0.923	0.022	0.59, 1.2				
log_TC_F, males, 91	-4.011	0.091	-10.0, 1.00				
log_TC_F, males, 92	-5.992	0.093	-10.0, 1.00				
log_TC_F, males, 93	-6.715	0.097	-10.0, 1.00				
log_TC_F, males, 13	-8.208	0.092	-10.0, 1.00				
log_TC_F, males, 14	-7.331	0.091	-10.0, 1.00				
log_TC_F, males, 15	-6.897	0.093	-10.0, 1.00				
log_TC_F, females, 91	-2.897	0.096	-10.0, 1.00				
log_TC_F, females, 92	-4.538	0.099	-10.0, 1.00				
log_TC_F, females, 93	-6.436	0.102	-10.0, 1.00				
log_TC_F, females, 13	-7.724	0.090	-10.0, 1.00				
log_TC_F, females, 14	-7.586	0.090	-10.0, 1.00				
log_TC_F, females, 15	-6.562	0.089	-10.0, 1.00				

Table 5(18.0d) (continued). Summary of estimated model parameter values and standard deviations and limits for model 18.0d for Bristol Bay red king crab. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

Fixed gear bycatch			
Parameter	Value	SD	Limits
log_avg_fmortf	-7.318	0.105	-8.5, -0.5
fmortf_96dev	0.793	0.107	-10, 10
fmortf_97dev	0.149	0.107	-10, 10
fmortf_98ev	-0.038	0.108	-10, 10
fmortf_99dev	0.862	0.104	-10, 10
fmortf_00dev	-1.596	0.121	-10, 10
fmortf_01dev	0.358	0.104	-10, 10
fmortf_02dev	0.113	0.104	-10, 10
fmortf_03dev	-0.724	0.108	-10, 10
fmortf_04dev	-0.548	0.106	-10, 10
fmortf_05dev	-0.265	0.105	-10, 10
fmortf_06dev	-0.321	0.105	-10, 10
fmortf_07ev	0.207	0.103	-10, 10
fmortf_08dev	-0.503	0.107	-10, 10
fmortf_09dev	-1.526	0.117	-10, 10
fmortf_10dev	-2.446	0.139	-10, 10
fmortf_11ev	-0.967	0.108	-10, 10
fmortf_12dev	-0.448	0.105	-10, 10
fmortf_13dev	0.666	0.102	-10, 10
fmortf_143dev	1.465	0.102	-10, 10
fmortf_15dev	1.086	0.103	-10, 10
fmortf_16dev	0.169	0.106	-10, 10
fmortf_17dev	1.719	0.105	-10, 10
fmortf_18dev	1.795	0.106	-10, 10
Fix_slo	0.079	0.007	0, 0.2
log_l50	4.876	0.037	4.5, 5.4

Table 5(18.0e). Summary of estimated model parameter values and standard deviations and limits for model 18.0e for Bristol Bay red king crab. All values are on a log scale. Male recruit in year t is exp($mean+males_t$), and female recruit in year t is exp($mean+males_t+females_t$).

Year	Recruits				F for Directed Pot Fishery				F for Trawl	
	Females	SD	Males	SD	Males	SD	Females	SD	Estimate	SD
Mean	15.901	0.034	15.901	0.034	-1.561	0.041	0.013	0.001	-4.509	0.074
Limits↑	13,18		13,18		-3.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-15,2.93		-6.0,3.5		-10,10	
1975					0.752	0.135				
1976	0.168	0.578	0.402	0.415	0.724	0.096			0.220	0.129
1977	0.532	0.412	0.571	0.257	0.659	0.075			0.691	0.118
1978	0.555	0.382	0.772	0.231	0.823	0.062			0.735	0.112
1979	0.811	0.286	1.170	0.197	1.127	0.056			0.913	0.110
1980	0.332	0.292	1.654	0.166	2.107	0.059			1.788	0.112
1981	0.143	0.358	0.956	0.247	2.925	0.017			1.646	0.115
1982	0.085	0.149	2.383	0.109	1.378	0.120			2.811	0.118
1983	0.208	0.224	1.467	0.142	-9.999	0.053			2.347	0.113
1984	0.789	0.172	1.110	0.125	1.028	0.096			3.357	0.115
1985	-0.261	0.419	-0.300	0.222	0.951	0.096			2.064	0.114
1986	0.772	0.173	0.402	0.125	1.200	0.074			1.021	0.113
1987	-0.025	0.381	-0.374	0.188	0.777	0.065			0.594	0.110
1988	0.003	0.408	-0.839	0.213	-0.112	0.054			1.402	0.105
1989	-0.269	0.360	-0.549	0.181	0.024	0.049			-0.011	0.105
1990	0.263	0.188	0.296	0.111	0.720	0.044	1.927	0.088	0.455	0.105
1991	0.041	0.264	-0.142	0.140	0.716	0.047	-0.679	0.089	0.872	0.106
1992	-0.468	0.464	-1.225	0.243	0.119	0.052	2.089	0.090	0.693	0.107
1993	-0.254	0.269	-0.353	0.142	0.839	0.058	1.897	0.093	1.185	0.110
1994	-0.110	0.442	-1.188	0.249	-4.303	0.054	1.251	0.121	-0.560	0.107
1995	-0.015	0.090	1.271	0.068	-4.722	0.045	1.420	0.123	-0.846	0.105
1996	-1.057	0.446	-0.614	0.260	-0.184	0.044	-3.671	0.140	-0.784	0.105
1997	-0.914	0.440	-0.873	0.240	-0.101	0.044	-0.341	0.087	-1.252	0.105
1998	-0.617	0.315	-0.005	0.146	0.681	0.047	1.574	0.086	0.020	0.104
1999	0.046	0.151	0.724	0.096	0.295	0.045	-2.709	0.093	-0.267	0.104
2000	-0.145	0.357	-0.238	0.193	-0.281	0.044	1.181	0.083	-1.028	0.104
2001	0.172	0.362	-0.336	0.211	-0.326	0.044	0.863	0.083	-0.263	0.103
2002	0.408	0.127	0.950	0.093	-0.199	0.043	-1.931	0.088	-0.555	0.103
2003	-0.334	0.462	-0.445	0.252	0.267	0.042	1.163	0.082	-0.641	0.103
2004	-0.201	0.390	-0.181	0.205	0.252	0.042	0.368	0.083	-0.403	0.103
2005	0.149	0.156	0.871	0.095	0.548	0.044	0.867	0.083	-0.682	0.103
2006	-0.180	0.283	0.265	0.137	0.342	0.043	-1.375	0.083	-0.510	0.103
2007	-0.534	0.318	-0.071	0.148	0.656	0.043	-0.269	0.082	-0.455	0.103
2008	-0.005	0.345	-0.720	0.201	0.803	0.046	-0.539	0.084	-0.514	0.104
2009	0.233	0.328	-0.559	0.187	0.576	0.048	-0.752	0.084	-0.898	0.104
2010	0.709	0.205	0.060	0.125	0.405	0.047	-0.308	0.084	-1.079	0.105
2011	0.166	0.360	-0.297	0.165	-0.287	0.046	-1.213	0.085	-1.563	0.105
2012	0.120	0.342	-0.599	0.181	-0.344	0.046	-1.882	0.087	-2.106	0.107
2013	-0.238	0.340	-0.748	0.172	-0.198	0.047	0.133	0.084	-1.430	0.106
2014	-0.171	0.420	-1.315	0.216	0.035	0.049	-0.415	0.085	-2.059	0.108
2015	0.132	0.294	-0.798	0.175	0.075	0.054	0.690	0.087	-1.727	0.109
2016	-0.132	0.278	-0.390	0.166	-0.023	0.059	0.132	0.090	-1.230	0.110
2017	-0.312	0.406	-0.847	0.237	-0.197	0.065	-0.315	0.093	-0.882	0.112
2018	-0.290	0.402	-0.550	0.261	-0.528	0.070	0.845	0.095	-1.070	0.114
2019	-0.304	0.478	-0.770	0.316						

Table 5(18.0e) (continued). Summary of estimated model parameter values and standard deviations and limits for model 18.0e for Bristol Bay red king crab. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

				Initial Length Composition 1975			
Parameter	Value	SD	Limits	Length	Value	SD	Limits
Mm80-84	0.484	0.031	0.184, 1.0	68	1.034	0.423	-4.0,4.0
Mf80-84	0.844	0.040	0.276, 1.5	73	0.703	0.592	-4.0,4.0
Mf76-79,85-93	0.089	0.012	0.0, 0.108	78	0.512	0.430	-4.0,4.0
log_betal, females	0.749	0.133	-0.67, 1.32	83	0.704	0.291	-4.0,4.0
log_betal, males	-0.042	0.213	-0.67, 1.32	88	0.563	0.271	-4.0,4.0
log_betar, females	-0.470	0.213	-1.14, 0.5	93	0.449	0.270	-4.0,4.0
log_betar, males	-0.501	0.173	-1.14, 0.5	98	0.476	0.255	-4.0,4.0
Bsfrf_CV	0.131	0.067	0.00, 0.40	103	0.337	0.271	-4.0,4.0
moltp_slope, 75-78	0.109	0.017	0.01, 0.259	108	0.429	0.255	-4.0,4.0
moltp_slope, 79-19	0.093	0.005	0.01, 0.259	113	0.491	0.248	-4.0,4.0
log_moltp_L50, 75-78	4.951	0.013	4.445, 5.52	118	0.273	0.286	-4.0,4.0
log_moltp_L50, 79-19	4.939	0.005	4.445, 5.52	123	0.285	0.282	-4.0,4.0
log_N75	19.916	0.054	15.0, 22.0	128	0.142	0.309	-4.0,4.0
log_avg_L50_tot	4.754	0.010	4.38, 5.45	133	0.275	0.263	-4.0,4.0
tot_fish_slope	0.104	0.006	0.05, 0.57	138	0.085	0.198	-4.0,4.0
Log_ret_L50, 75-04	4.922	0.002	4.6, 5.1	143	-0.179	0.195	-4.0,4.0
Ret_fish_slope, 75-04	0.498	0.032	0.05, 0.87	148	-0.356	0.200	-4.0,4.0
Log_ret_L50, 05-19	4.929	0.003	4.6, 5.1	153	-0.719	0.227	-4.0,4.0
Ret_fish_slope, 05-19	0.504	0.066	0.05, 0.7	158	-1.251	0.284	-4.0,4.0
pot disc.fema., slope	0.092	0.016	0.05, 0.43	163	-1.289	0.286	-4.0,4.0
log_pot disc.fema., L50	4.553	0.039	4.20, 4.666	68	1.634	0.427	-4.0,4.0
trawl disc slope	0.059	0.003	0.01, 0.20	73	1.513	0.431	-4.0,4.0
log_trawl disc L50	5.175	0.062	4.50, 5.40	78	1.492	0.354	-4.0,4.0
log_srv_L50, m, bsfrf	4.360	0.033	3.359, 5.48	83	1.333	0.318	-4.0,4.0
srv_slope, f, bsfrf	0.042	0.008	0.01, 0.134	88	1.250	0.270	-4.0,4.0
log_srv_L50, f, bsfrf	4.528	0.052	3.471, 5.539	93	0.760	0.307	-4.0,4.0
log_srv_L50, m, 75-81	4.344	0.025	3.551, 5.864	98	0.374	0.372	-4.0,4.0
srv_slope, f, 75-81	0.103	0.013	0.01, 0.303	103	0.098	0.432	-4.0,4.0
log_srv_L50, f, 75-81	4.441	0.027	3.709, 4.80	108	-0.067	0.432	-4.0,4.0
log_srv_L50, m, 82-19	4.085	0.264	3.709, 5.10	113	-0.259	0.454	-4.0,4.0
srv_slope, f, 82-19	0.086	0.028	0.01, 0.43	118	-0.899	0.686	-4.0,4.0
log_srv_L50, f, 82-19	4.175	0.063	3.709, 4.90	123	-1.090	0.752	-4.0,4.0
TC_slope, females	0.375	0.149	0.02, 0.40	128	-1.475	0.928	-4.0,4.0
log_TC_L50, females	4.510	0.017	4.24, 4.90	133	-2.571	1.971	-4.0,4.0
TC_slope, males	0.146	0.072	0.05, 0.90	138	-2.936	2.452	-4.0,4.0
log_TC_L50, males	4.614	0.041	4.25, 5.14	143	NA	NA	
Q	0.925	0.022	0.59, 1.2				
log_TC_F, males, 91	-5.193	0.100	-10.0, 1.00				
log_TC_F, males, 92	-7.155	0.109	-10.0, 1.00				
log_TC_F, males, 93	-7.411	0.115	-10.0, 1.00				
log_TC_F, males, 13	-9.490	0.117	-10.0, 1.00				
log_TC_F, males, 14	-8.213	0.101	-10.0, 1.00				
log_TC_F, males, 15	-8.250	0.103	-10.0, 1.00				
log_TC_F, females, 91	-3.302	0.095	-10.0, 1.00				
log_TC_F, females, 92	-4.961	0.098	-10.0, 1.00				
log_TC_F, females, 93	-7.133	0.102	-10.0, 1.00				
log_TC_F, females, 13	-8.056	0.092	-10.0, 1.00				
log_TC_F, females, 14	-8.112	0.092	-10.0, 1.00				
log_TC_F, females, 15	-6.860	0.089	-10.0, 1.00				

Table 5(18.0e) (continued). Summary of estimated model parameter values and standard deviations and limits for model 18.0e for Bristol Bay red king crab. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

Fixed gear bycatch			
Parameter	Value	SD	Limits
log_avg_fmortf	-7.321	0.109	-8.5, -0.5
fmortf_96dev	0.794	0.107	-10, 10
fmortf_97dev	0.149	0.107	-10, 10
fmortf_98ev	-0.040	0.108	-10, 10
fmortf_99dev	0.860	0.104	-10, 10
fmortf_00dev	-1.598	0.121	-10, 10
fmortf_01dev	0.356	0.104	-10, 10
fmortf_02dev	0.112	0.104	-10, 10
fmortf_03dev	-0.725	0.108	-10, 10
fmortf_04dev	-0.550	0.106	-10, 10
fmortf_05dev	-0.266	0.105	-10, 10
fmortf_06dev	-0.322	0.105	-10, 10
fmortf_07ev	0.206	0.103	-10, 10
fmortf_08dev	-0.504	0.107	-10, 10
fmortf_09dev	-1.527	0.117	-10, 10
fmortf_10dev	-2.447	0.139	-10, 10
fmortf_11ev	-0.968	0.108	-10, 10
fmortf_12dev	-0.447	0.105	-10, 10
fmortf_13dev	0.668	0.102	-10, 10
fmortf_143dev	1.466	0.102	-10, 10
fmortf_15dev	1.087	0.103	-10, 10
fmortf_16dev	0.171	0.106	-10, 10
fmortf_17dev	1.723	0.105	-10, 10
fmortf_18dev	1.802	0.106	
Fix_slo	0.079	0.007	0, 0.2
log_l50	4.876	0.038	4.5, 5.4

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

index	name	value	std.dev	index	name	value	std.dev
1	theta[4]	19.8860	0.0541	47	log_slx_pars[2]	2.2279	0.0601
2	theta[5]	15.8870	0.0357	48	log_slx_pars[3]	4.4324	0.0158
3	theta[7]	0.6174	0.1108	49	log_slx_pars[4]	1.3801	0.2385
4	theta[9]	-0.6054	0.2492	50	log_slx_pars[5]	5.1654	0.0622
5	theta[13]	0.9618	0.3275	51	log_slx_pars[6]	2.8603	0.0458
6	theta[14]	0.5115	0.3800	52	log_slx_pars[7]	4.7531	0.1952
7	theta[15]	0.6825	0.2992	53	log_slx_pars[8]	2.7840	0.6570
8	theta[16]	0.5458	0.2856	54	log_slx_pars[9]	4.5120	0.0189
9	theta[17]	0.3997	0.2844	55	log_slx_pars[10]	0.9697	0.4020
10	theta[18]	0.3918	0.2726	56	log_slx_pars[11]	4.7388	0.0193
11	theta[19]	0.2547	0.2794	57	log_slx_pars[12]	2.2370	0.1008
12	theta[20]	0.3117	0.2700	58	log_slx_pars[13]	4.1055	0.2218
13	theta[21]	0.3607	0.2659	59	log_slx_pars[14]	1.9086	0.9221
14	theta[22]	0.1665	0.2875	60	log_slx_pars[15]	4.1919	0.1679
15	theta[23]	0.1792	0.2830	61	log_slx_pars[16]	3.2211	0.3563
16	theta[24]	0.0680	0.2956	62	log_slx_pars[17]	4.2620	0.0776
17	theta[25]	0.1355	0.2777	63	log_slx_pars[18]	2.2824	0.2724
18	theta[26]	0.0404	0.2197	64	log_slx_pars[19]	3.7585	437.38
19	theta[27]	-0.1844	0.2132	65	log_slx_pars[20]	0.3462	705.80
20	theta[28]	-0.3530	0.2156	66	log_slx_pars[21]	4.3311	0.0392
21	theta[29]	-0.6881	0.2306	67	log_slx_pars[22]	2.2613	0.1368
22	theta[30]	-1.1358	0.2519	68	log_slx_pars[23]	4.4430	0.0120
23	theta[31]	-1.1660	0.2538	69	log_slx_pars[24]	2.3198	0.0678
24	theta[52]	0.4016	0.8919	70	log_slx_pars[25]	4.9221	0.0016
25	theta[53]	1.7498	0.5125	71	log_slx_pars[26]	0.6971	0.0658
26	theta[54]	1.7336	0.4210	72	log_slx_pars[27]	4.9285	0.0022
27	theta[55]	1.3695	0.3630	73	log_slx_pars[28]	0.6875	0.1266
28	theta[56]	1.1422	0.3196	74	log_fbar[1]	-1.5107	0.0444
29	theta[57]	0.6046	0.3435	75	log_fbar[2]	-4.2908	0.0793
30	theta[58]	0.2403	0.3631	76	log_fbar[3]	-5.3966	0.2026
31	theta[59]	0.0141	0.3652	77	log_fbar[4]	-6.8678	0.0621
32	theta[60]	-0.1622	0.3523	78	log_fdev[1]	0.6155	0.1227
33	theta[61]	-0.4977	0.3726	79	log_fdev[1]	0.6255	0.0905
34	theta[62]	-0.8844	0.3846	80	log_fdev[1]	0.5777	0.0722
35	theta[63]	-1.1433	0.3900	81	log_fdev[1]	0.7350	0.0604
36	theta[64]	-1.3765	0.3888	82	log_fdev[1]	1.0144	0.0557
37	theta[65]	-1.7565	0.3775	83	log_fdev[1]	1.9643	0.0661
38	theta[66]	-1.8673	0.3735	84	log_fdev[1]	2.5926	0.2089
39	theta[67]	-1.8070	0.3523	85	log_fdev[1]	0.9540	0.2505
40	Grwth[21]	0.9626	0.1940	86	log_fdev[1]	-8.9290	0.1417
41	Grwth[42]	1.4708	0.1303	87	log_fdev[1]	0.9397	0.1057
42	Grwth[85]	139.9700	1.6684	88	log_fdev[1]	0.9554	0.0977
43	Grwth[86]	0.0624	0.0094	89	log_fdev[1]	1.1917	0.0777
44	Grwth[87]	139.1200	0.7011	90	log_fdev[1]	0.7571	0.0674
45	Grwth[88]	0.0773	0.0043	91	log_fdev[1]	-0.1530	0.0556
46	log_slx_pars[1]	4.7552	0.0093	92	log_fdev[1]	-0.0138	0.0502
93	log_fdev[1]	0.6557	0.0422	143	log_fdev[2]	-1.1511	0.1042
94	log_fdev[1]	0.6747	0.0445	144	log_fdev[2]	0.1750	0.1047

95	log_fdev[1]	0.1602	0.0484	145	log_fdev[2]	-0.1168	0.1044
96	log_fdev[1]	0.8438	0.0525	146	log_fdev[2]	-0.8987	0.1036
97	log_fdev[1]	-4.2843	0.0504	147	log_fdev[2]	-0.1523	0.1034
98	log_fdev[1]	-4.6742	0.0439	148	log_fdev[2]	-0.4695	0.1030
99	log_fdev[1]	-0.1833	0.0428	149	log_fdev[2]	-0.5752	0.1028
100	log_fdev[1]	-0.1125	0.0439	150	log_fdev[2]	-0.3584	0.1027
101	log_fdev[1]	0.8635	0.0473	151	log_fdev[2]	-0.6603	0.1026
102	log_fdev[1]	0.4649	0.0465	152	log_fdev[2]	-0.5177	0.1023
103	log_fdev[1]	-0.1397	0.0450	153	log_fdev[2]	-0.4748	0.1024
104	log_fdev[1]	-0.2347	0.0444	154	log_fdev[2]	-0.5454	0.1027
105	log_fdev[1]	-0.1348	0.0431	155	log_fdev[2]	-0.9367	0.1030
106	log_fdev[1]	0.3228	0.0418	156	log_fdev[2]	-1.1173	0.1033
107	log_fdev[1]	0.2714	0.0419	157	log_fdev[2]	-1.5942	0.1034
108	log_fdev[1]	0.5351	0.0422	158	log_fdev[2]	-2.1316	0.1038
109	log_fdev[1]	0.2559	0.0414	159	log_fdev[2]	-1.4479	0.1043
110	log_fdev[1]	0.5998	0.0414	160	log_fdev[2]	-2.0697	0.1051
111	log_fdev[1]	0.7377	0.0435	161	log_fdev[2]	-1.7339	0.1066
112	log_fdev[1]	0.5134	0.0446	162	log_fdev[2]	-1.2293	0.1087
113	log_fdev[1]	0.3531	0.0448	163	log_fdev[2]	-0.8725	0.1111
114	log_fdev[1]	-0.2887	0.0447	164	log_fdev[2]	-0.9585	0.1134
115	log_fdev[1]	-0.3695	0.0448	165	log_fdev[3]	-0.0389	0.0685
116	log_fdev[1]	-0.2139	0.0459	166	log_fdev[3]	-0.0389	0.0685
117	log_fdev[1]	0.0891	0.0484	167	log_fdev[3]	1.7534	0.0685
118	log_fdev[1]	0.0901	0.0531	168	log_fdev[3]	1.4486	0.0685
119	log_fdev[1]	0.0036	0.0600	169	log_fdev[3]	1.6752	0.0685
120	log_fdev[1]	-0.1669	0.0677	170	log_fdev[3]	2.5536	0.0685
121	log_fdev[1]	-0.4594	0.0746	171	log_fdev[3]	1.4425	0.0685
122	log_fdev[2]	0.1107	0.1243	172	log_fdev[3]	1.6004	0.0685
123	log_fdev[2]	0.6006	0.1154	173	log_fdev[3]	-0.2471	0.0685
124	log_fdev[2]	0.6425	0.1105	174	log_fdev[3]	0.9281	0.0685
125	log_fdev[2]	0.7947	0.1100	175	log_fdev[3]	0.4544	0.0685
126	log_fdev[2]	1.6043	0.1183	176	log_fdev[3]	0.9396	0.0685
127	log_fdev[2]	1.3880	0.1535	177	log_fdev[3]	1.6528	0.0685
128	log_fdev[2]	2.6138	0.1518	178	log_fdev[3]	1.6604	0.0685
129	log_fdev[2]	2.2314	0.1267	179	log_fdev[3]	3.0526	0.0718
130	log_fdev[2]	3.3382	0.1194	180	log_fdev[3]	1.1358	0.0730
131	log_fdev[2]	2.0779	0.1145	181	log_fdev[3]	0.4561	0.0883
132	log_fdev[2]	1.0265	0.1130	182	log_fdev[3]	-2.9934	0.0685
133	log_fdev[2]	0.5915	0.1099	183	log_fdev[3]	-3.9509	0.0685
134	log_fdev[2]	1.3964	0.1053	184	log_fdev[3]	-3.7277	0.0685
135	log_fdev[2]	-0.0157	0.1043	185	log_fdev[3]	-3.7277	0.0685
136	log_fdev[2]	0.4572	0.1044	186	log_fdev[3]	-4.6440	0.0685
137	log_fdev[2]	0.9000	0.1056	187	log_fdev[3]	-1.1889	0.0726
138	log_fdev[2]	0.7557	0.1059	188	log_fdev[3]	-0.3115	0.0736
139	log_fdev[2]	1.2731	0.1087	189	log_fdev[3]	0.1158	0.0797
140	log_fdev[2]	-0.4836	0.1056	190	log_fdev[4]	0.9289	0.1026
141	log_fdev[2]	-0.7720	0.1041	191	log_fdev[4]	0.2325	0.1017
142	log_fdev[2]	-0.6946	0.1043	192	log_fdev[4]	-0.0097	0.1023
193	log_fdev[4]	0.9084	0.1013	243	log_fdov[1]	0.9102	0.0911
194	log_fdev[4]	-1.5264	0.1008	244	log_fdov[3]	0.0003	0.0967
195	log_fdev[4]	0.4067	0.1003	245	log_fdov[3]	0.0001	0.0967
196	log_fdev[4]	0.1346	0.0999	246	log_fdov[3]	0.0003	0.0967

197	log_fdev[4]	-0.7100	0.0997	247	log_fdov[3]	0.0009	0.0967
198	log_fdev[4]	-0.5622	0.0995	248	log_fdov[3]	0.0008	0.0967
199	log_fdev[4]	-0.3183	0.0994	249	log_fdov[3]	-0.0015	0.0966
200	log_fdev[4]	-0.3793	0.0991	250	log_fdov[3]	-0.0002	0.0967
201	log_fdev[4]	0.1302	0.0991	251	log_fdov[3]	-0.0001	0.0967
202	log_fdev[4]	-0.6114	0.0993	252	log_fdov[3]	0.0000	0.0967
203	log_fdev[4]	-1.6296	0.0991	253	log_fdov[3]	0.0000	0.0967
204	log_fdev[4]	-2.5230	0.0990	254	log_fdov[3]	-0.0002	0.0966
205	log_fdev[4]	-1.0074	0.0991	255	log_fdov[3]	0.0001	0.0967
206	log_fdev[4]	-0.4714	0.0993	256	log_fdov[3]	-0.0010	0.0966
207	log_fdev[4]	0.6424	0.0996	257	log_fdov[3]	0.0004	0.0967
208	log_fdev[4]	1.4444	0.1002	258	log_fdov[3]	0.5920	0.0990
209	log_fdev[4]	1.0746	0.1012	259	log_fdov[3]	0.8809	0.0979
210	log_fdev[4]	0.1743	0.1025	260	log_fdov[3]	-0.2725	0.1096
211	log_fdev[4]	1.7446	0.1041	261	log_fdov[3]	0.0000	0.0967
212	log_fdev[4]	1.9272	0.1055	262	log_fdov[3]	0.0000	0.0967
213	log_foff[1]	-2.9047	0.0389	263	log_fdov[3]	0.0000	0.0967
214	log_foff[3]	0.4411	0.1912	264	log_fdov[3]	0.0000	0.0967
215	log_fdov[1]	2.1181	0.0843	265	log_fdov[3]	0.0000	0.0967
216	log_fdov[1]	-0.5204	0.0840	266	log_fdov[3]	-0.1086	0.0977
217	log_fdov[1]	2.2075	0.0847	267	log_fdov[3]	-0.8455	0.0978
218	log_fdov[1]	2.1379	0.0870	268	log_fdov[3]	-0.2463	0.1007
219	log_fdov[1]	-0.0764	0.0871	269	rec_dev_est	1.6057	0.2177
220	log_fdov[1]	0.0929	0.0843	270	rec_dev_est	1.1328	0.2703
221	log_fdov[1]	-3.5509	0.0846	271	rec_dev_est	1.4406	0.2157
222	log_fdov[1]	-0.2319	0.0813	272	rec_dev_est	2.0024	0.1698
223	log_fdov[1]	1.5432	0.0822	273	rec_dev_est	2.1532	0.1867
224	log_fdov[1]	-2.7062	0.0816	274	rec_dev_est	1.4204	0.2183
225	log_fdov[1]	1.1940	0.0810	275	rec_dev_est	2.4533	0.1020
226	log_fdov[1]	0.9071	0.0807	276	rec_dev_est	1.7026	0.1147
227	log_fdov[1]	-1.8467	0.0800	277	rec_dev_est	1.5312	0.0962
228	log_fdov[1]	1.2166	0.0803	278	rec_dev_est	-0.2839	0.1992
229	log_fdov[1]	0.4402	0.0797	279	rec_dev_est	0.8487	0.0959
230	log_fdov[1]	1.0067	0.0799	280	rec_dev_est	-0.3309	0.2053
231	log_fdov[1]	-1.2075	0.0789	281	rec_dev_est	-0.7010	0.2792
232	log_fdov[1]	-0.1519	0.0789	282	rec_dev_est	-0.8406	0.1952
233	log_fdov[1]	-0.4046	0.0795	283	rec_dev_est	0.4051	0.0983
234	log_fdov[1]	-0.6073	0.0798	284	rec_dev_est	-0.3699	0.1419
235	log_fdov[1]	-0.1566	0.0797	285	rec_dev_est	-1.6763	0.2988
236	log_fdov[1]	-1.1315	0.0788	286	rec_dev_est	-0.7517	0.1451
237	log_fdov[1]	-1.7937	0.0786	287	rec_dev_est	-1.8760	0.3490
238	log_fdov[1]	0.2206	0.0790	288	rec_dev_est	1.1290	0.0572
239	log_fdov[1]	-0.3855	0.0798	289	rec_dev_est	-0.6753	0.1897
240	log_fdov[1]	0.7779	0.0815	290	rec_dev_est	-1.3762	0.2777
241	log_fdov[1]	0.2223	0.0842	291	rec_dev_est	-0.2849	0.1319
242	log_fdov[1]	-0.2250	0.0875	292	rec_dev_est	0.5601	0.0809
293	rec_dev_est	-0.3057	0.1626	336	logit_rec_prop_est	0.2585	0.1512
294	rec_dev_est	-0.2522	0.1781	337	logit_rec_prop_est	0.6368	0.3684
295	rec_dev_est	0.9736	0.0807	338	logit_rec_prop_est	-0.4041	0.3532
296	rec_dev_est	-0.4218	0.2205	339	logit_rec_prop_est	0.0362	0.1364
297	rec_dev_est	-0.4082	0.2059	340	logit_rec_prop_est	-0.2141	0.4344
298	rec_dev_est	0.8933	0.0777	341	logit_rec_prop_est	0.4569	0.4442

299	rec_dev_est	0.0825	0.1280	342	logit_rec_prop_est	-0.1929	0.1355
300	rec_dev_est	-0.2140	0.1314	343	logit_rec_prop_est	0.4468	0.2792
301	rec_dev_est	-0.8396	0.1999	344	logit_rec_prop_est	0.3874	0.2764
302	rec_dev_est	-0.6482	0.1844	345	logit_rec_prop_est	0.0264	0.3914
303	rec_dev_est	0.2996	0.1036	346	logit_rec_prop_est	-0.0992	0.3579
304	rec_dev_est	-0.1679	0.1455	347	logit_rec_prop_est	-0.5159	0.1872
305	rec_dev_est	-0.6478	0.1741	348	logit_rec_prop_est	0.0047	0.2806
306	rec_dev_est	-0.9285	0.1704	349	logit_rec_prop_est	-0.1722	0.3350
307	rec_dev_est	-1.5382	0.2471	350	logit_rec_prop_est	0.3882	0.3480
308	rec_dev_est	-1.0039	0.1735	351	logit_rec_prop_est	-0.0192	0.4778
309	rec_dev_est	-0.5503	0.1469	352	logit_rec_prop_est	0.2204	0.3377
310	rec_dev_est	-1.3767	0.2872	353	logit_rec_prop_est	0.2387	0.2801
311	rec_dev_est	-0.9514	0.2801	354	logit_rec_prop_est	0.5659	0.5737
312	rec_dev_est	-1.2133	0.4045	355	logit_rec_prop_est	0.3806	0.5224
313	logit_rec_prop_est	-0.6920	0.3714	356	logit_rec_prop_est	-0.1638	0.7338
314	logit_rec_prop_est	-1.1781	0.4992	357	m_dev_est[1]	1.4105	0.0492
315	logit_rec_prop_est	-0.7408	0.3643	358	m_dev_est[3]	0.5628	0.0388
316	logit_rec_prop_est	-1.0340	0.2759	359	m_dev_est[4]	1.8791	0.0353
317	logit_rec_prop_est	-0.5971	0.2758	360	survey_q[1]	0.9247	0.0246
318	logit_rec_prop_est	-0.6504	0.3470	361	log_add_cv[2]	-1.2996	0.3189
319	logit_rec_prop_est	0.1114	0.1575	362	sd_rbar	15607000	434050
320	logit_rec_prop_est	-0.0593	0.2092	363	sd_ssbF0	60706.0	24341.0
321	logit_rec_prop_est	-0.5666	0.1771	364	sd_Bmsy	21247.0	8519.3
322	logit_rec_prop_est	-0.0358	0.3901	365	sd_depl	0.7510	0.2551
323	logit_rec_prop_est	-0.7848	0.1778	366	sd_fmsy	0.2990	0.0051
324	logit_rec_prop_est	-0.1967	0.3894	367	sd_fmsy	0.0038	0.0004
325	logit_rec_prop_est	-0.5111	0.4979	368	sd_fmsy	0.0017	0.0003
326	logit_rec_prop_est	0.8451	0.4901	369	sd_fmsy	0.0044	0.0003
327	logit_rec_prop_est	-0.4149	0.1724	370	sd_fmsy	0.0000	0.0000
328	logit_rec_prop_est	0.4282	0.3097	371	sd_fmsy	0.0000	0.0000
329	logit_rec_prop_est	0.4718	0.6161	372	sd_fofl	0.2163	0.0848
330	logit_rec_prop_est	0.3344	0.2944	373	sd_fofl	0.0038	0.0004
331	logit_rec_prop_est	-0.5598	0.6403	374	sd_fofl	0.0017	0.0003
332	logit_rec_prop_est	0.1098	0.0834	375	sd_fofl	0.0044	0.0003
333	logit_rec_prop_est	1.9895	0.6395	376	sd_fofl	0.0000	0.0000
334	logit_rec_prop_est	0.6947	0.5815	377	sd_fofl	0.0000	0.0000
335	logit_rec_prop_est	0.7705	0.3058	378	sd_ofl	3403.4	1211.0

Table 6(18.0d). 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 18.0d) from 1975-2019. Mature male biomass for year *t* is on Feb. 15, year *t*+1. Size measurements are mm carapace length.

Year (t)	Males				Females	Total Recruits	Total Survey Biomass	
	Mature (>119 mm)	Legal (>134mm)	MMB (>119 mm)	SD MMB	Mature (>89 mm)		Model Est. (>64 mm)	Area-Swept (>64 mm)
1975	60.031	29.488	87.311	9.288	61.746		254.789	202.731
1976	69.275	36.952	102.099	8.245	98.922	27.072	290.871	331.868
1977	72.498	42.178	109.316	6.572	122.581	39.315	296.211	375.661
1978	73.932	44.272	107.789	4.732	117.258	48.334	282.262	349.545
1979	63.591	42.902	84.055	3.072	103.569	84.667	255.690	167.627
1980	43.303	32.196	20.017	0.787	97.763	100.486	222.204	249.322
1981	12.192	6.733	3.314	0.344	46.200	45.250	92.560	132.669
1982	4.881	1.364	4.023	0.464	21.841	180.012	47.927	143.740
1983	5.407	1.658	6.195	0.507	16.642	77.943	46.066	49.320
1984	6.207	2.367	5.372	0.501	17.408	77.817	46.872	155.311
1985	8.630	2.221	11.243	0.799	15.317	10.849	37.452	34.535
1986	13.643	5.195	17.199	1.153	20.986	38.143	48.057	48.158
1987	15.759	7.429	22.355	1.328	24.785	10.972	53.251	70.263
1988	15.796	9.195	26.816	1.382	28.180	7.017	55.674	55.372
1989	16.735	10.461	29.296	1.333	25.562	8.411	57.424	55.941
1990	16.370	11.068	25.506	1.275	21.494	24.044	56.949	60.321
1991	12.875	9.342	20.169	1.222	19.971	14.599	51.241	85.055
1992	10.279	7.233	18.893	1.187	20.443	3.765	45.966	37.687
1993	11.246	6.787	16.882	1.213	18.746	9.973	44.995	53.703
1994	11.059	6.353	22.462	1.279	15.799	4.672	40.190	32.335
1995	11.693	8.248	25.598	1.274	15.489	56.406	47.164	38.396
1996	12.033	9.022	24.061	1.225	21.338	5.881	55.815	44.649
1997	11.559	8.285	22.850	1.214	28.840	4.732	60.793	85.277
1998	16.872	8.146	26.033	1.389	27.247	12.366	64.458	85.176
1999	18.139	10.134	30.141	1.566	24.168	33.605	64.281	65.604
2000	15.770	11.299	30.262	1.563	26.339	11.771	66.438	68.102
2001	15.320	10.926	30.228	1.518	30.027	12.663	69.980	53.188
2002	17.758	10.833	33.430	1.514	30.202	51.313	75.199	69.786
2003	18.613	12.132	32.903	1.494	36.251	8.961	80.561	116.794
2004	16.951	11.797	30.450	1.433	42.993	12.263	81.979	131.910
2005	18.800	11.012	30.796	1.404	41.117	41.140	84.116	107.341
2006	18.452	11.520	31.622	1.405	42.233	19.076	85.210	95.676
2007	16.926	11.590	27.371	1.357	46.143	11.941	87.600	104.841
2008	17.782	10.147	26.911	1.421	44.567	7.824	85.630	114.430
2009	18.257	10.367	29.039	1.526	40.562	10.366	81.532	91.673
2010	17.122	11.060	28.819	1.532	37.170	26.395	78.826	81.642
2011	14.805	10.678	28.941	1.486	38.061	12.760	76.276	67.053
2012	13.616	10.285	27.827	1.427	40.705	9.577	76.212	61.248
2013	13.764	9.651	27.401	1.402	39.424	7.068	74.994	62.410
2014	13.719	9.513	26.299	1.410	36.202	4.072	71.898	114.103
2015	12.571	9.111	24.192	1.421	32.206	7.728	67.046	64.240
2016	11.157	8.318	22.115	1.432	28.730	10.334	61.908	61.231
2017	9.681	7.502	20.025	1.421	26.873	6.007	57.679	52.922
2018	8.793	6.678	18.984	1.414	25.180	8.195	54.449	28.932
2019	9.040	6.333	17.868	1.257	23.196	6.562	52.381	28.744

Table 6(18.0e). 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 18.0e) from 1975-2019. Mature male biomass for year *t* is on Feb. 15, year *t*+1. Size measurements are mm carapace length.

Year (t)	Males				Females	Total Recruits	Total Survey Biomass	
	Mature (>119 mm)	Legal (>134mm)	MMB (>119 mm)	SD MMB	Mature (>89 mm)		Model Est. (>64 mm)	Area-Swept (>64 mm)
1975	59.708	29.357	86.794	9.288	60.901		253.555	202.731
1976	68.850	36.736	101.362	8.245	97.382	26.264	289.362	331.868
1977	72.022	41.881	108.769	6.572	120.490	38.495	294.618	375.661
1978	73.648	44.072	107.463	4.732	115.766	47.767	281.477	349.545
1979	63.458	42.791	84.008	3.072	102.577	84.296	255.554	167.627
1980	43.342	32.195	20.032	0.787	97.257	100.718	222.907	249.322
1981	12.233	6.738	3.304	0.344	46.243	45.065	93.241	132.669
1982	4.881	1.361	4.014	0.464	21.824	182.201	48.027	143.740
1983	5.399	1.654	6.161	0.507	16.891	77.868	46.141	49.320
1984	6.169	2.353	5.308	0.501	17.529	78.203	46.770	155.311
1985	8.533	2.195	11.083	0.799	15.458	10.554	37.153	34.535
1986	13.469	5.131	16.896	1.153	21.079	38.069	47.599	48.158
1987	15.495	7.308	21.899	1.328	24.976	10.932	52.594	70.263
1988	15.497	9.019	26.274	1.382	28.397	6.966	54.890	55.372
1989	16.395	10.260	28.713	1.333	25.903	8.197	56.598	55.941
1990	16.028	10.854	24.875	1.275	21.900	24.902	56.285	60.321
1991	12.553	9.117	19.715	1.222	20.524	14.259	50.724	85.055
1992	10.074	7.078	18.456	1.187	21.223	3.846	45.964	37.687
1993	11.142	6.648	16.573	1.213	19.416	10.036	45.089	53.703
1994	10.961	6.268	22.188	1.279	16.362	4.649	40.307	32.335
1995	11.596	8.172	25.337	1.274	15.954	56.942	47.335	38.396
1996	11.967	8.951	23.859	1.225	21.905	5.870	56.017	44.649
1997	11.511	8.232	22.694	1.214	29.361	4.709	60.995	85.277
1998	16.838	8.109	25.916	1.389	27.773	12.327	64.665	85.176
1999	18.115	10.111	30.061	1.566	24.610	33.962	64.496	65.604
2000	15.748	11.285	30.203	1.563	26.807	11.835	66.642	68.102
2001	15.298	10.914	30.180	1.518	30.502	12.576	70.161	53.188
2002	17.734	10.822	33.384	1.514	30.655	52.111	75.405	69.786
2003	18.593	12.123	32.863	1.494	36.872	8.847	80.750	116.794
2004	16.932	11.789	30.415	1.433	43.657	12.209	82.119	131.910
2005	18.770	11.004	30.747	1.404	41.753	41.545	84.242	107.341
2006	18.419	11.508	31.566	1.405	42.891	19.243	85.317	95.676
2007	16.894	11.574	27.313	1.357	46.809	11.891	87.681	104.841
2008	17.748	10.130	26.848	1.421	45.228	7.816	85.689	114.430
2009	18.226	10.350	28.978	1.526	41.129	10.405	81.574	91.673
2010	17.093	11.045	28.763	1.532	37.648	25.902	78.815	81.642
2011	14.781	10.663	28.894	1.486	38.408	13.040	76.183	67.053
2012	13.594	10.273	27.785	1.427	40.847	9.407	76.040	61.248
2013	13.700	9.637	27.306	1.402	39.508	6.811	74.757	62.410
2014	13.687	9.478	26.236	1.410	36.207	3.981	71.607	114.103
2015	12.587	9.097	24.211	1.421	32.194	7.760	66.717	64.240
2016	11.121	8.330	22.069	1.432	28.736	10.225	61.548	61.231
2017	9.588	7.480	19.882	1.421	26.872	5.976	57.261	52.922
2018	8.694	6.620	18.799	1.414	25.149	8.121	53.989	28.932
2019	8.938	6.263	17.724	1.257	23.157	6.475	51.898	28.744

Table 6(19.0 (gmacs)). 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 19.0) from 1975-2019. Mature male biomass for year *t* is on Feb. 15, year *t*+1. Size measurements are mm carapace length.

Year (t)	Males				Females	Total Recruits	Total Survey Biomass	
	Mature (>119 mm)	Legal (>134mm)	MMB (>119 mm)	SD MMB	Mature (>89 mm)		Model Est. (>64 mm)	Area-Swept (>64 mm)
1975	60.013	31.266	89.668	9.026	59.402		245.609	199.643
1976	68.767	37.982	103.099	8.150	101.748	79.100	286.741	327.615
1977	73.301	42.737	111.413	6.758	127.694	49.292	297.867	371.223
1978	76.290	45.682	112.315	5.184	122.553	67.057	288.972	343.189
1979	65.780	44.876	88.970	3.893	110.496	117.610	265.792	165.449
1980	46.428	34.324	22.284	1.449	107.015	136.747	237.289	247.226
1981	13.282	7.357	4.406	1.000	48.577	65.721	95.769	131.145
1982	5.844	1.798	5.002	0.853	22.574	184.622	56.314	141.898
1983	5.827	2.023	6.485	0.624	14.163	87.142	51.163	48.476
1984	6.089	2.425	5.002	0.482	13.672	73.417	48.779	152.607
1985	8.160	2.119	10.494	0.779	10.874	11.954	37.092	34.138
1986	13.016	5.016	16.119	1.122	15.728	37.103	47.952	47.434
1987	15.244	7.162	21.384	1.297	19.162	11.406	53.809	69.245
1988	15.147	8.928	25.688	1.324	23.539	7.877	56.368	54.597
1989	16.078	10.112	28.107	1.245	21.216	6.851	57.494	55.136
1990	15.426	10.675	24.071	1.148	17.598	23.809	56.091	59.451
1991	11.850	8.810	18.388	1.071	15.844	10.969	49.885	83.892
1992	9.431	6.593	16.988	1.026	16.274	2.970	43.918	37.334
1993	10.368	6.181	15.120	1.065	13.681	7.488	41.818	52.906
1994	9.981	5.804	20.284	1.138	10.628	2.433	36.021	32.104
1995	10.389	7.509	22.954	1.121	10.526	49.105	41.818	38.068
1996	10.480	8.083	21.040	1.065	15.191	8.082	50.924	43.959
1997	9.696	7.185	19.337	1.040	22.961	4.010	56.929	84.030
1998	15.080	6.984	21.774	1.248	21.144	11.942	61.268	84.101
1999	16.300	8.808	25.643	1.423	18.714	27.801	60.442	64.754
2000	14.183	9.877	26.160	1.438	20.209	11.696	62.886	67.381
2001	14.087	9.649	26.795	1.415	23.118	12.340	67.141	52.455
2002	16.781	9.912	30.610	1.440	23.367	42.039	72.670	69.086
2003	17.806	11.439	30.459	1.423	27.869	10.414	79.331	115.760
2004	16.258	11.166	28.517	1.358	33.605	10.556	81.671	130.556
2005	18.610	10.587	29.917	1.360	32.486	38.793	84.149	105.727
2006	17.982	11.452	30.976	1.358	34.000	17.244	86.136	94.477
2007	16.516	11.446	26.773	1.311	39.312	12.820	89.784	103.327
2008	17.324	10.018	26.378	1.381	37.971	6.858	88.219	113.082
2009	17.616	10.254	28.203	1.476	35.000	8.305	84.053	90.547
2010	16.550	10.806	27.986	1.478	31.940	21.424	80.599	80.501
2011	14.173	10.382	27.772	1.427	31.872	13.424	77.823	66.408
2012	12.836	9.842	26.402	1.361	34.208	8.308	77.765	60.697
2013	12.981	9.149	25.863	1.335	33.254	6.275	76.588	62.217
2014	13.187	9.033	24.778	1.349	30.592	3.410	73.272	113.135
2015	11.990	8.679	22.755	1.372	27.207	5.818	67.561	64.175
2016	10.455	7.881	20.503	1.398	24.032	9.158	61.615	60.958
2017	8.816	6.976	18.163	1.396	22.168	4.008	56.695	52.935
2018	7.901	6.052	16.932	1.398	20.652	6.132	52.748	28.805
2019	8.125	5.673	15.957	1.496	18.570	4.720	49.822	28.539

Table 7(18.0e). Comparison of projected mature male biomass (1000 t) on Feb. 15, retained catch (1000 t), their 95% limits, and mean fishing mortality with no directed fishery, $F_{40\%}$, and $F_{35\%}$ harvest strategy with $F_{35\%}$ constraint during 2018-2027. Parameter estimates with model 18.0e are used for the projection.

Year	MMB	95% LCI	95% UCI	Catch	95% LCI	95% UCI
No Directed Fishery						
2019	20.911	17.712	23.932	0.000	0.000	0.000
2020	22.863	19.365	26.166	0.000	0.000	0.000
2021	24.595	20.832	28.149	0.000	0.000	0.000
2022	26.250	22.328	30.138	0.000	0.000	0.000
2023	29.361	23.989	39.509	0.000	0.000	0.000
2024	33.884	25.578	52.244	0.000	0.000	0.000
2025	38.730	27.121	61.231	0.000	0.000	0.000
2026	43.296	28.544	70.041	0.000	0.000	0.000
2027	47.428	30.699	77.976	0.000	0.000	0.000
2028	51.265	32.069	84.474	0.000	0.000	0.000
$F_{40\%}$						
2019	18.287	15.823	20.552	2.678	1.928	3.448
2020	17.992	15.792	19.981	2.518	1.883	3.148
2021	17.796	15.769	19.612	2.445	1.876	2.998
2022	17.785	15.891	19.590	2.417	1.898	2.941
2023	19.193	16.083	27.580	2.607	1.959	3.699
2024	21.686	16.276	36.240	3.046	2.010	5.078
2025	24.081	16.406	40.001	3.650	2.046	6.730
2026	25.897	16.834	44.376	4.212	2.152	7.530
2027	27.174	17.548	46.821	4.647	2.290	8.384
2028	28.209	17.872	48.426	4.952	2.402	8.975
$F_{35\%}$						
2019	17.798	15.458	19.941	3.175	2.300	4.070
2020	17.212	15.187	19.033	2.852	2.156	3.536
2021	16.841	15.007	18.477	2.689	2.089	3.267
2022	16.726	15.016	18.330	2.612	2.076	3.152
2023	18.024	15.125	25.831	2.807	2.113	4.147
2024	20.330	15.235	34.276	3.312	2.149	5.751
2025	22.455	15.322	37.051	3.998	2.169	7.621
2026	23.969	15.740	40.553	4.606	2.275	8.397
2027	24.961	16.363	43.313	5.047	2.409	9.320
2028	25.750	16.680	44.114	5.338	2.534	9.887

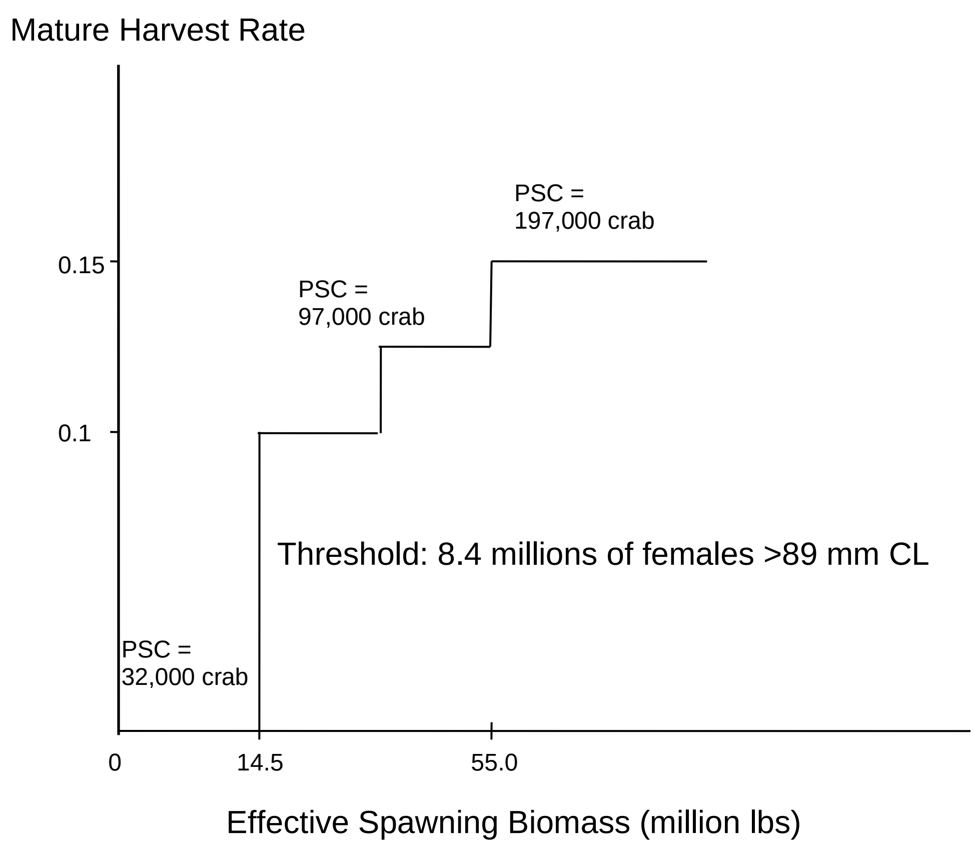


Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crab) of Bristol Bay red king crab in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates of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

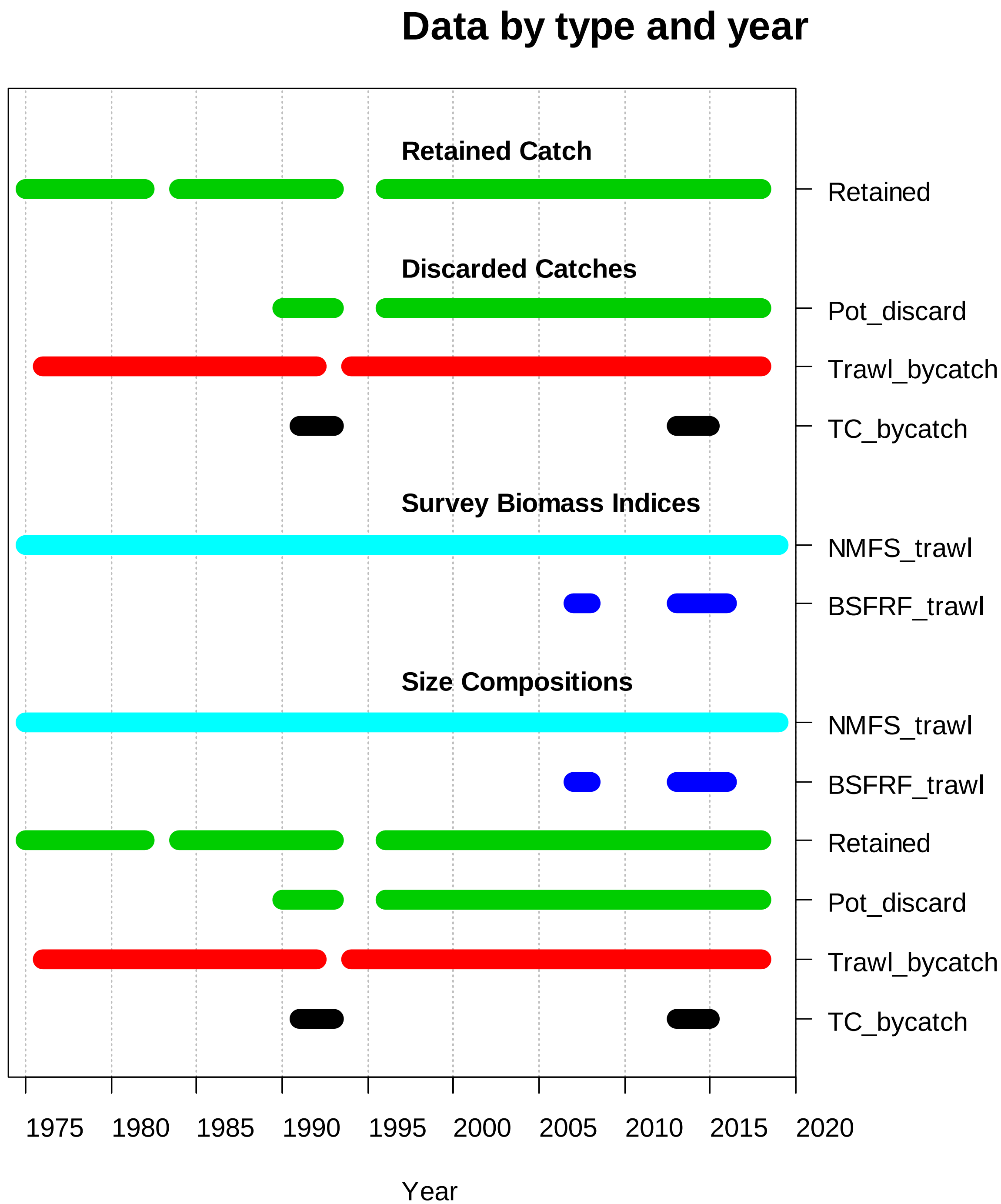


Figure 2. Data types and ranges used for the stock assessment.

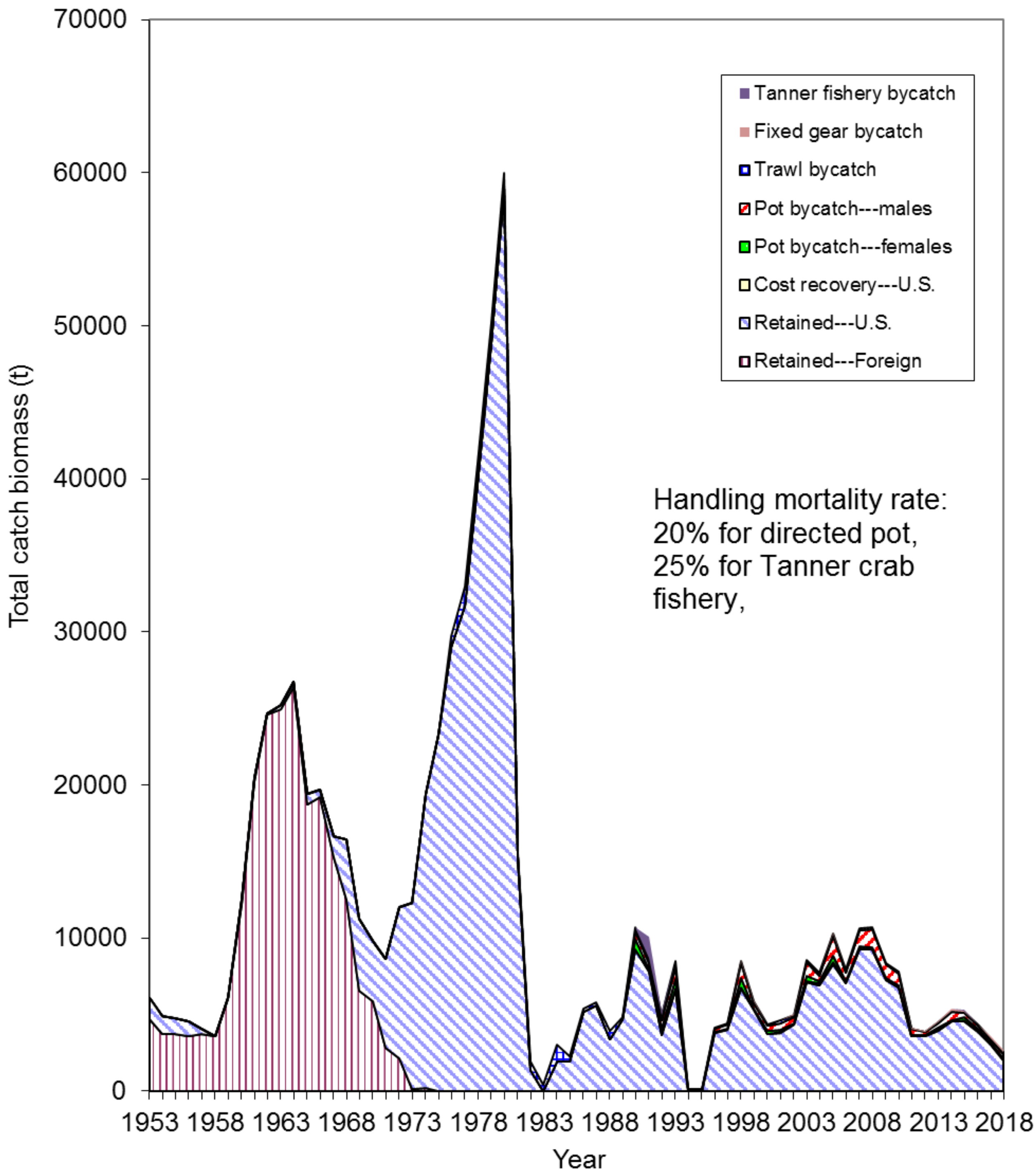


Figure 3. Retained catch biomass and bycatch mortality biomass (t) for Bristol Bay red king crab from 1953 to 2018. Handling mortality rates were assumed to be 0.2 for the directed pot fishery, 0.25 for the Tanner crab fishery, 0.8 for the trawl fisheries, and 50% for the fixed gear fisheries.

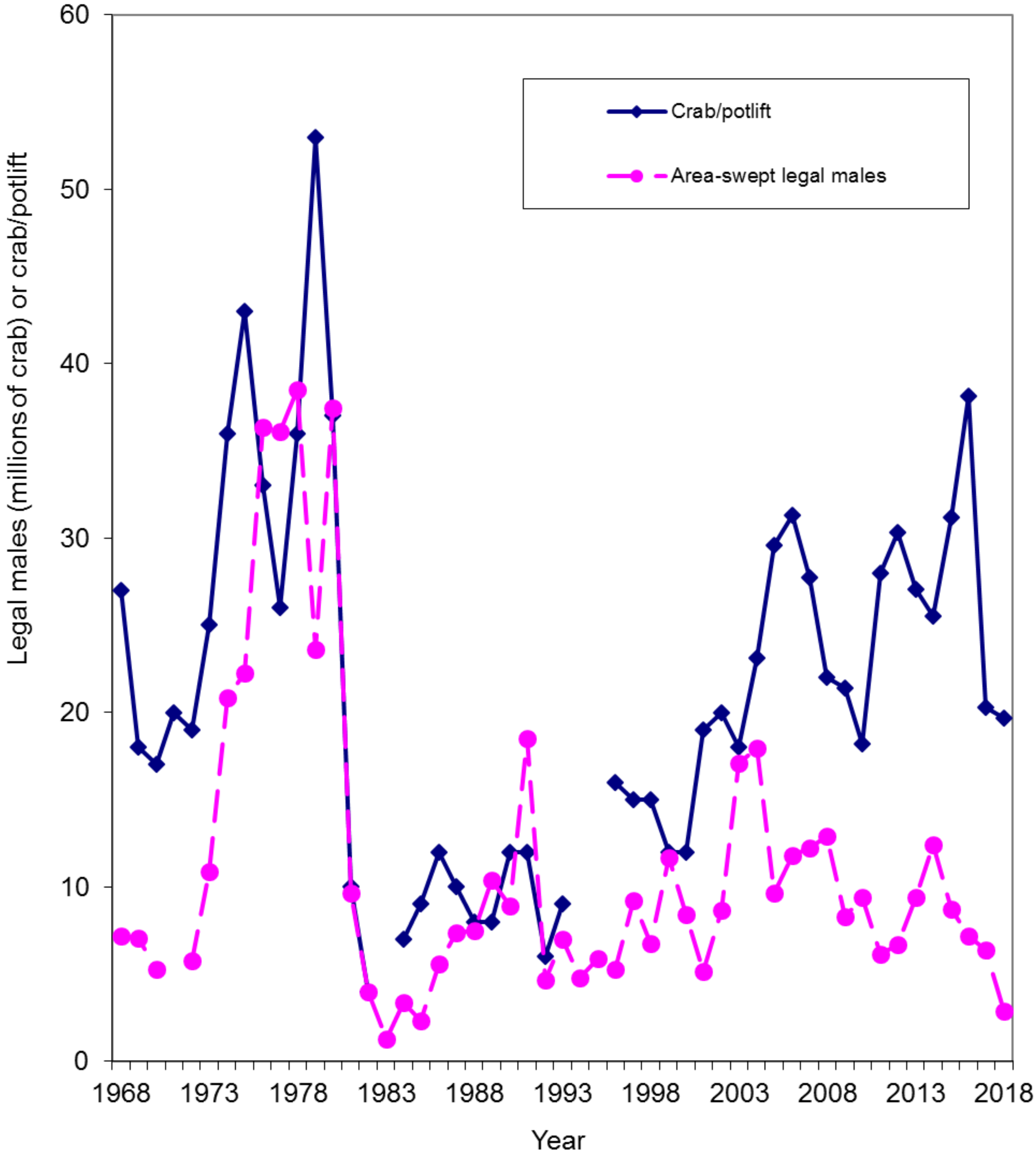


Figure 4. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2018.

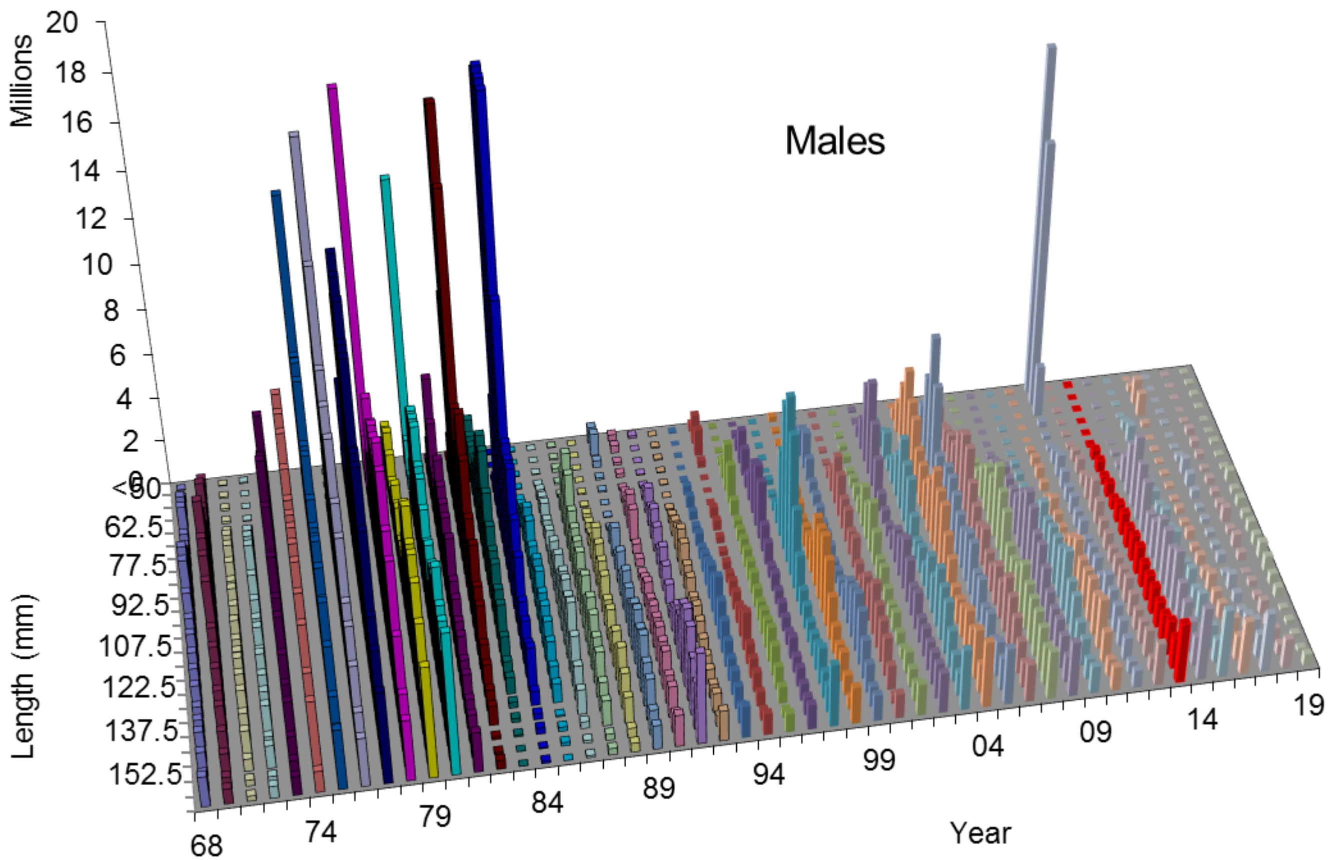


Figure 5a. Survey abundances by 5-mm carapace length bin for male Bristol Bay red king crab from 1968 to 2019.

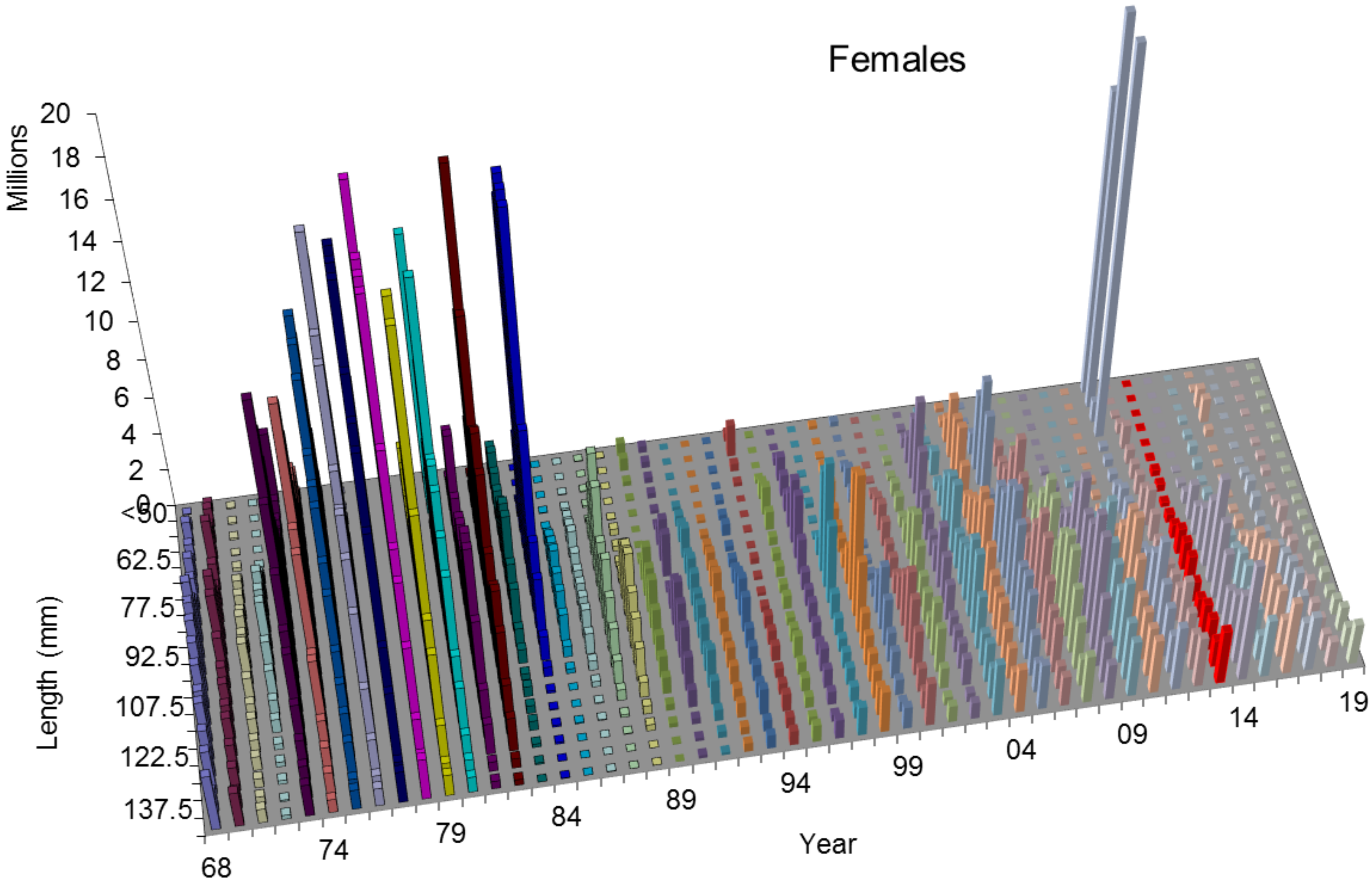
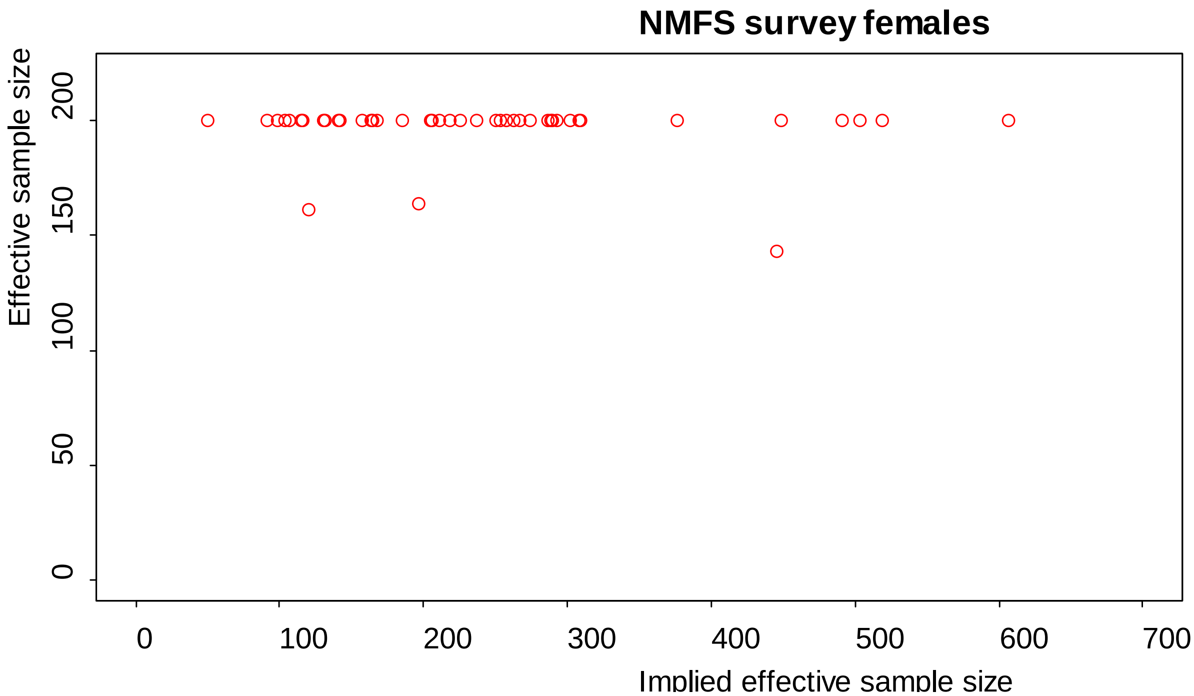


Figure 5b. Survey abundances by 5 mm carapace length bin for female Bristol Bay red king crab from 1968 to 2019.



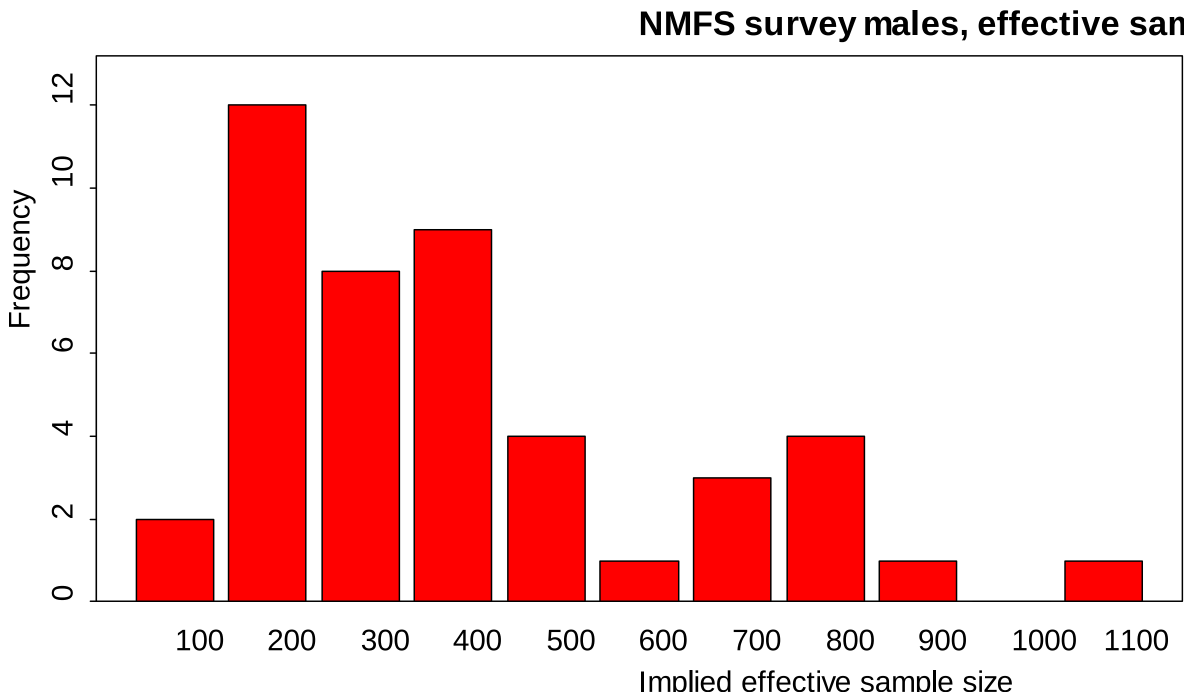


Figure 6. Relationship between implied effective sample sizes (section 3(a)(5)(i)) and effective sample sizes for length/sex composition data with model 18.0e: trawl survey data.

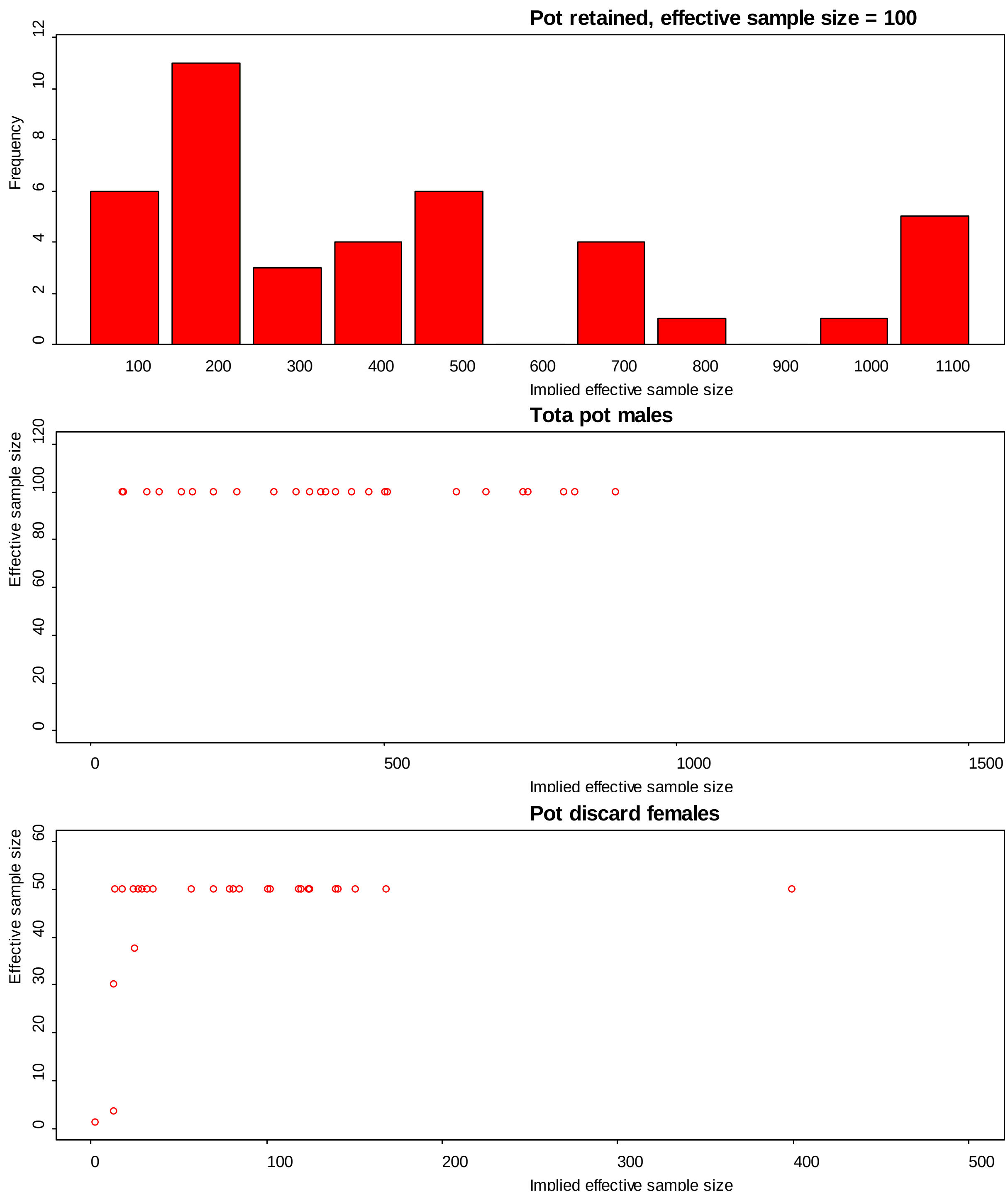


Figure 7. Relationship between implied effective sample sizes (section 3(a)(5)(i)) and effective sample sizes for length/sex composition data with model 18.0e: directed pot fishery data.

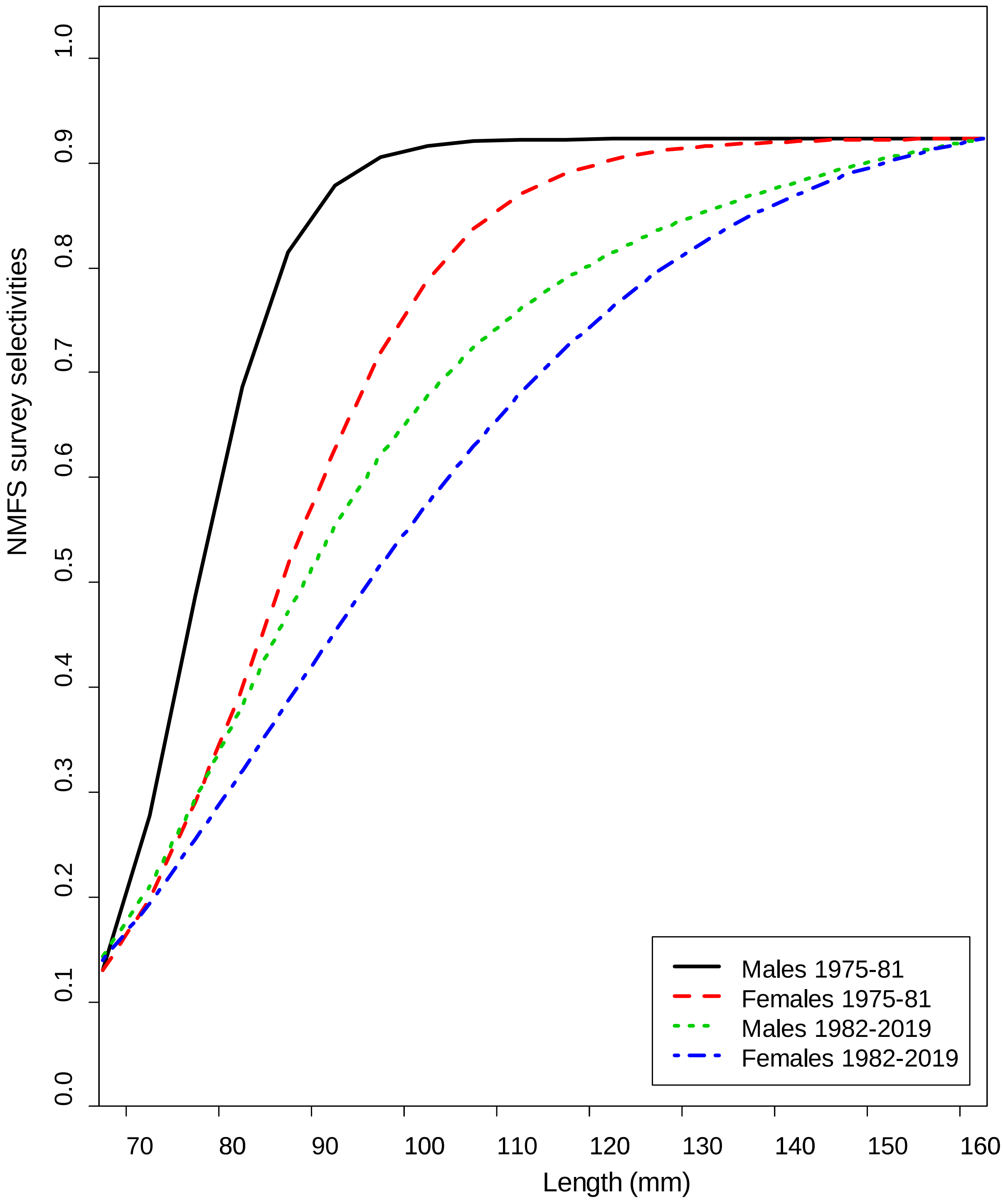


Figure 8a(18.0d). Estimated NMFS trawl survey selectivities under model 18.0d. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

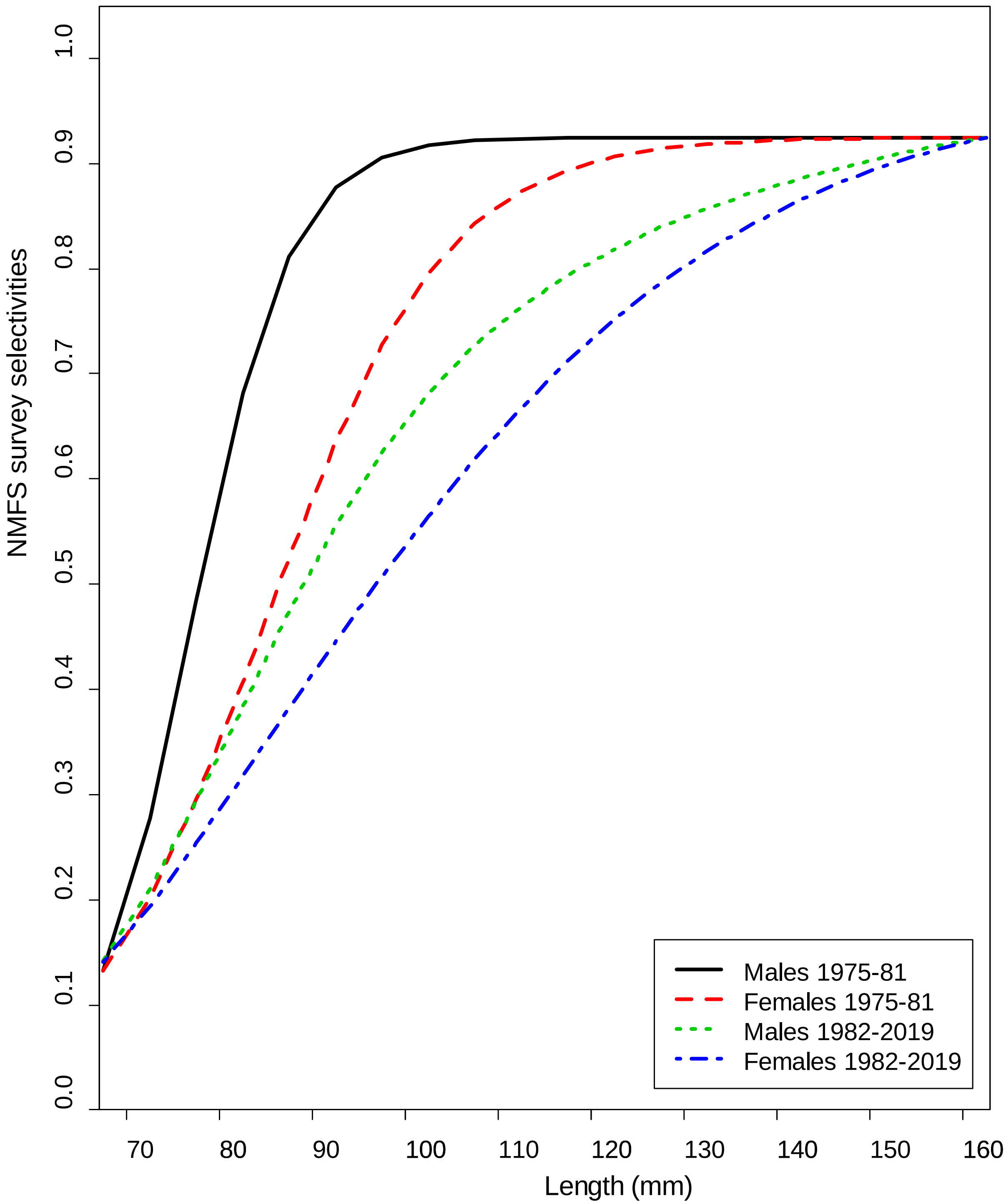


Figure 8a(18.0e). Estimated NMFS trawl survey selectivities under model 18.0e. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

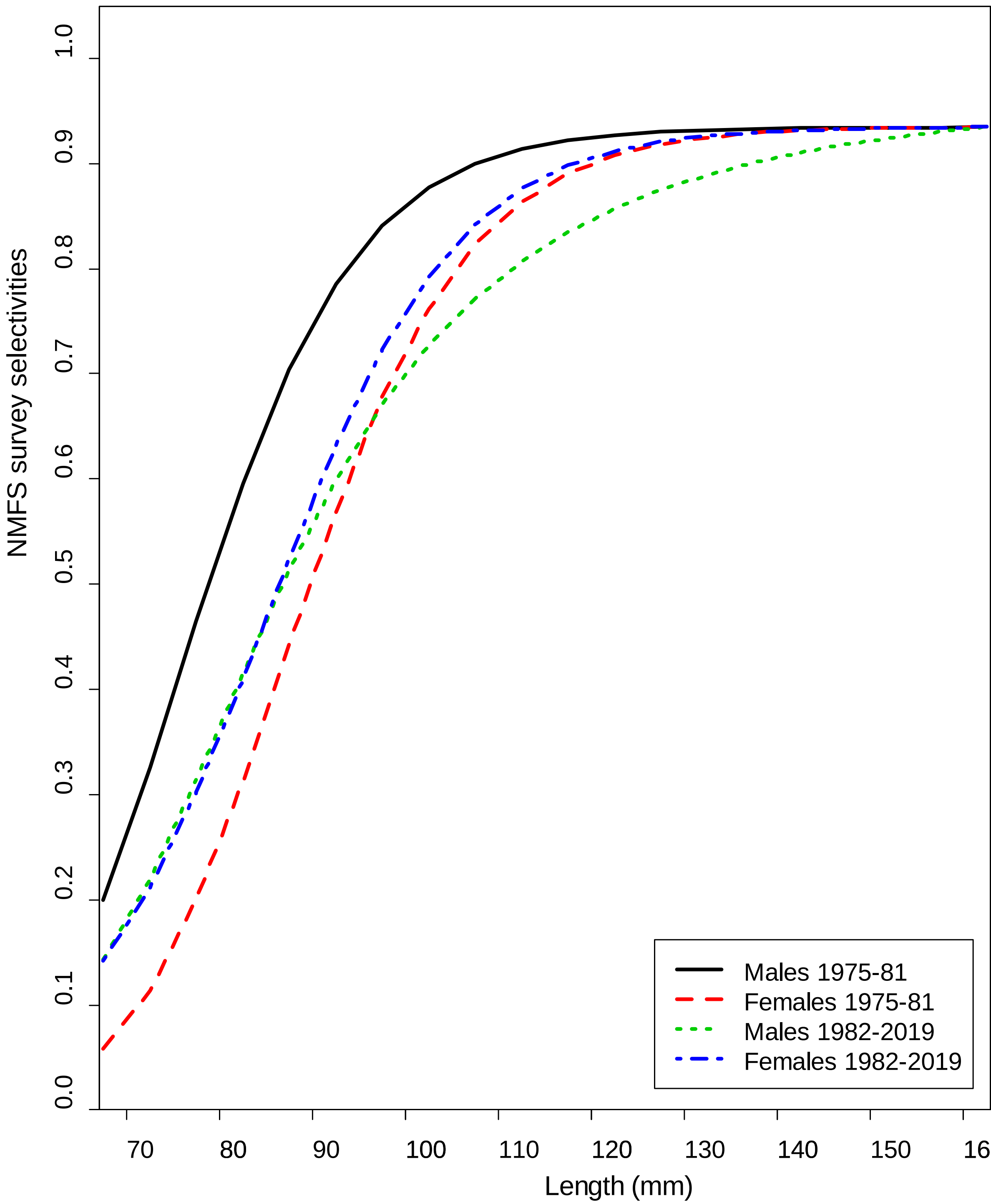


Figure 8a(19.0(gmacs)). Estimated NMFS trawl survey selectivities under model 19.0. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

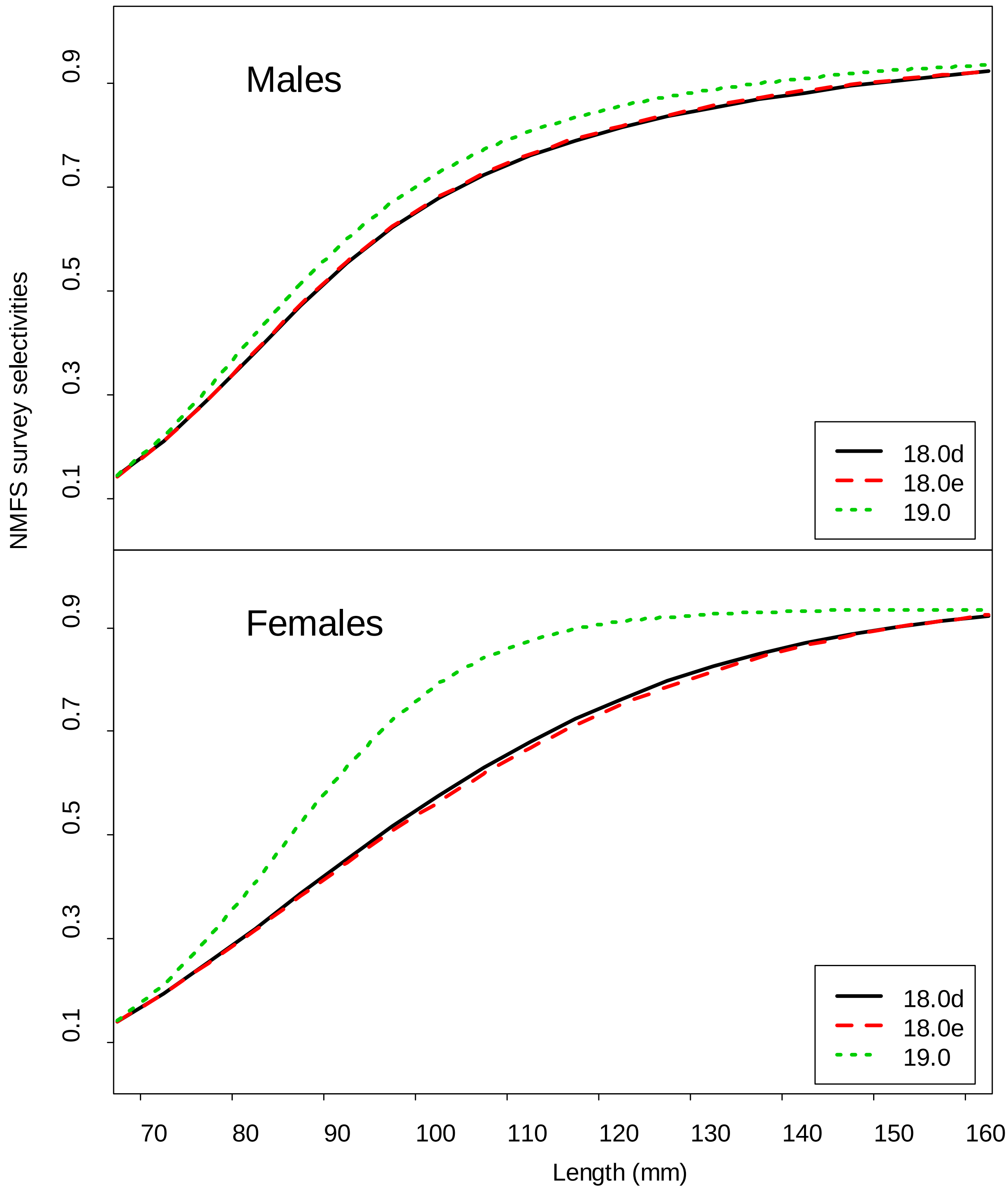


Figure 8b. Comparisons of estimated NMFS trawl survey selectivities for period 1982-2019 under models 18.0d, 18.0e, and 19.0 (gmacs). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

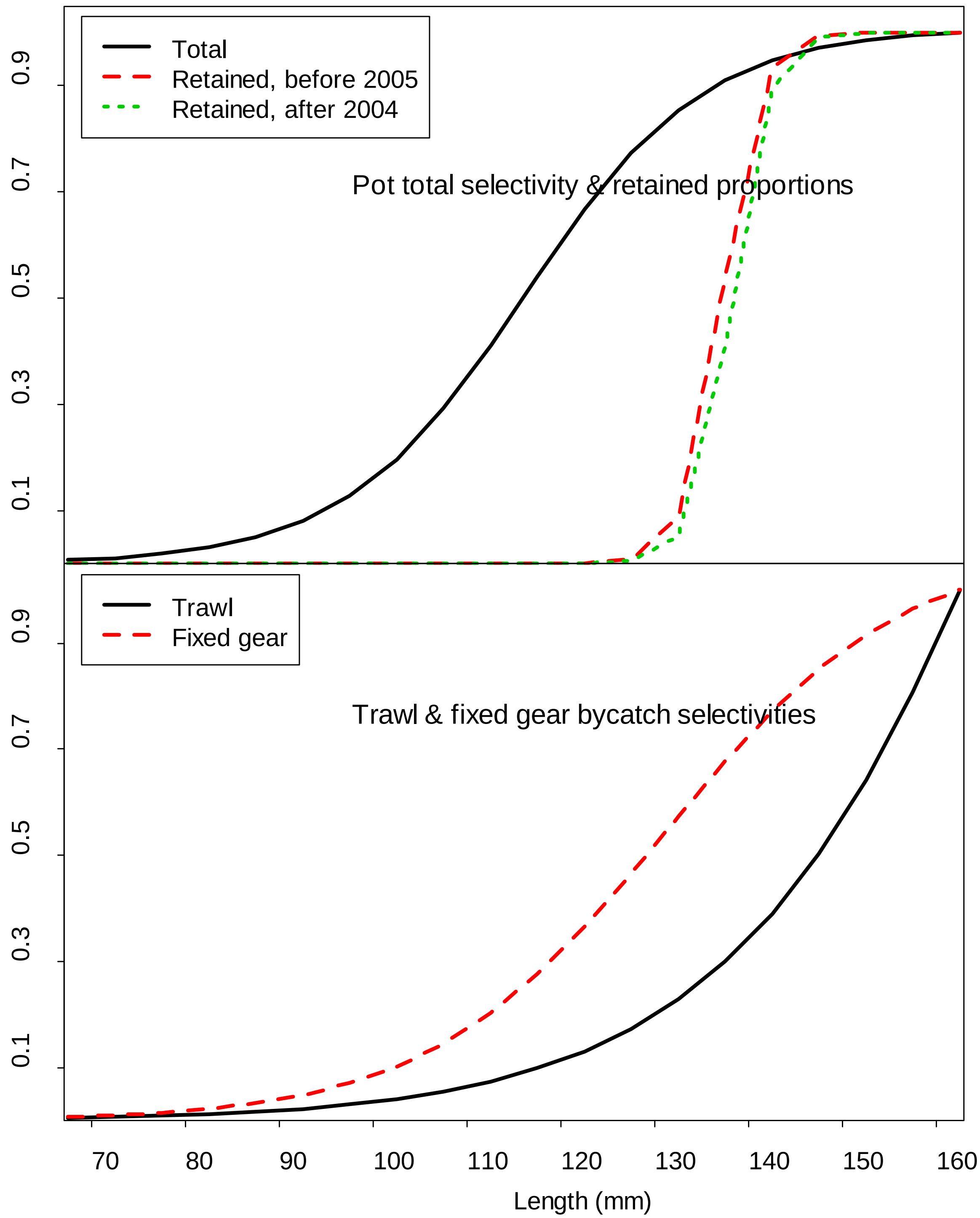


Figure 8c(18.0e). Estimated total pot fishery selectivities and retained proportions and groundfish fisheries bycatch selectivities under model 18.0e. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

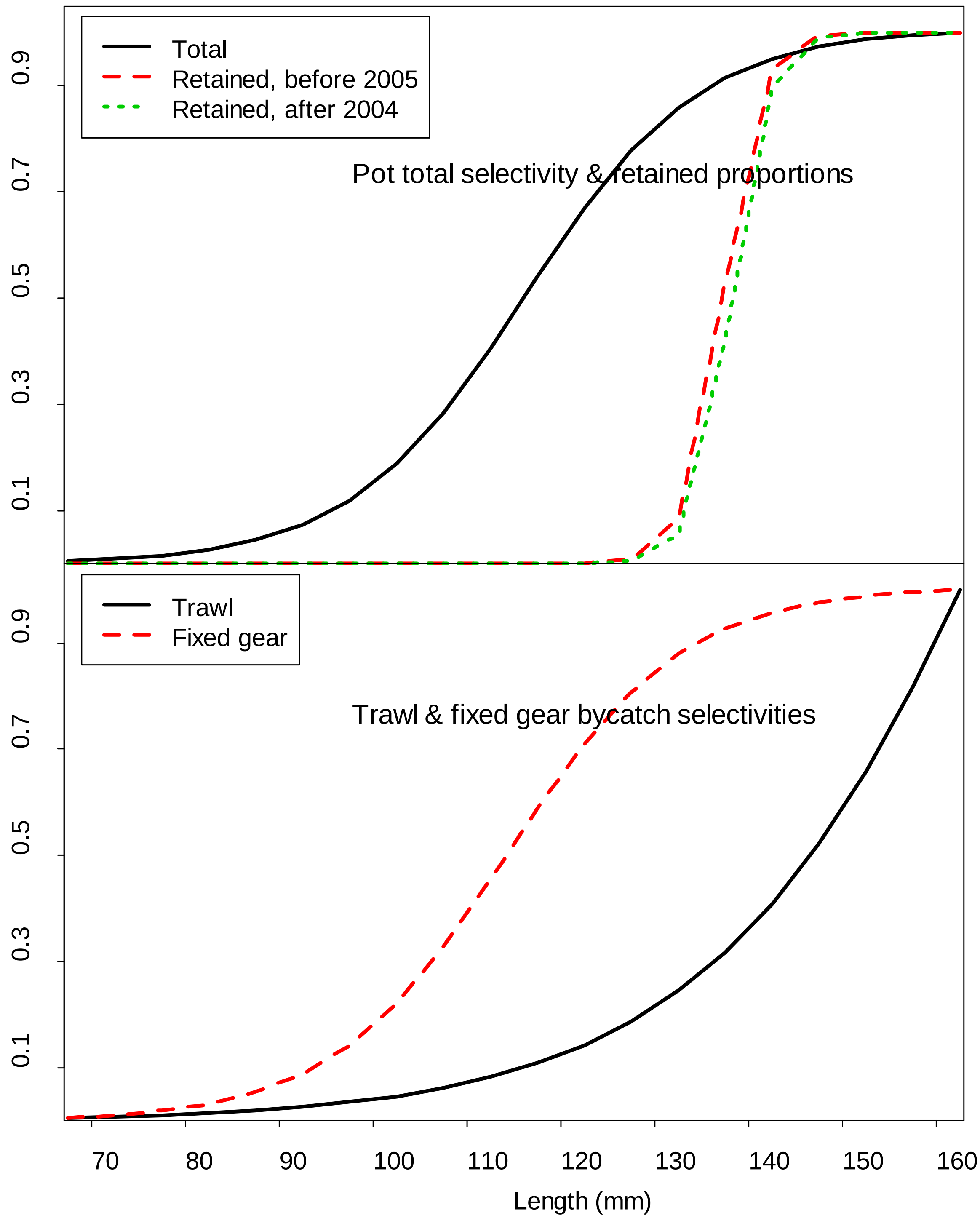


Figure 8c(19.0). Estimated total pot fishery selectivities and retained proportions and groundfish fisheries bycatch selectivities under model 19.0. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

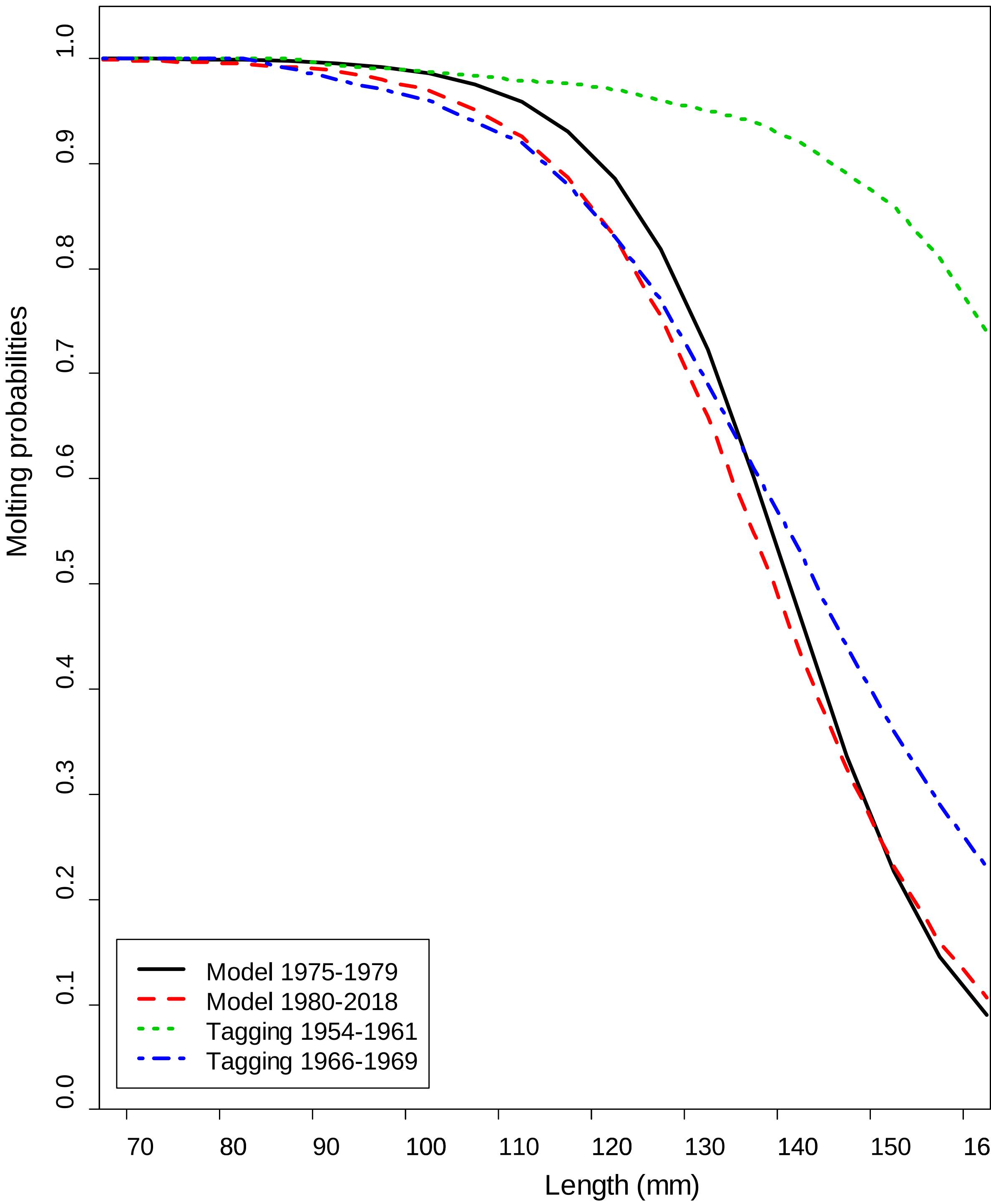


Figure 9(18.0e). Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods with model 18.0e. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-2019 were estimated with a length-based model.

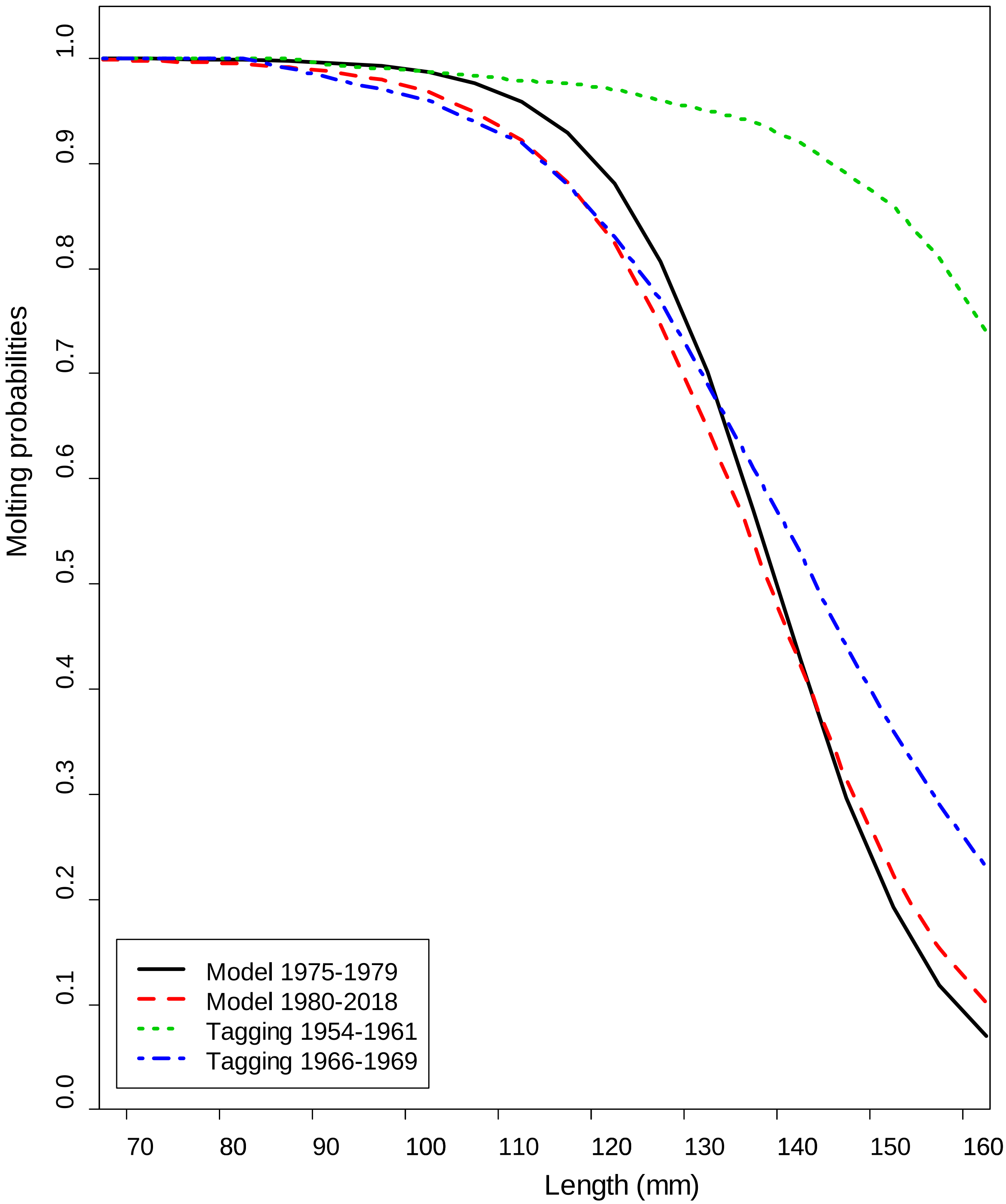


Figure 9(19.0). Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods with model 19.0. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-2019 were estimated with a length-based model.

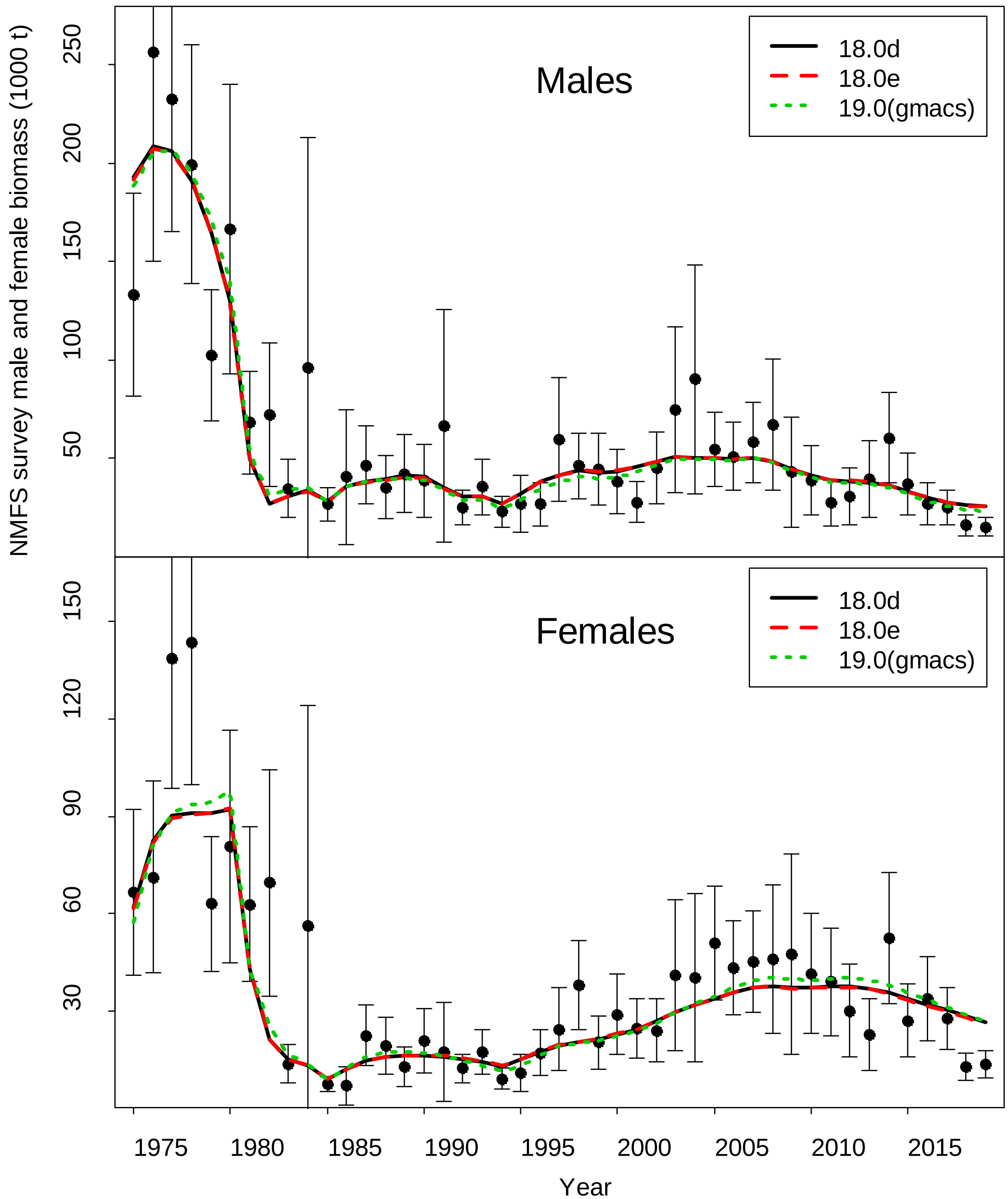


Figure 10a. Comparisons of area-swept estimates of total NMFS survey biomass and model prediction for model estimates in 2019 under models 18.0d, 18.0e, and 19.0 (gmacs). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively. The error bars are plus and minus 2 standard deviations.

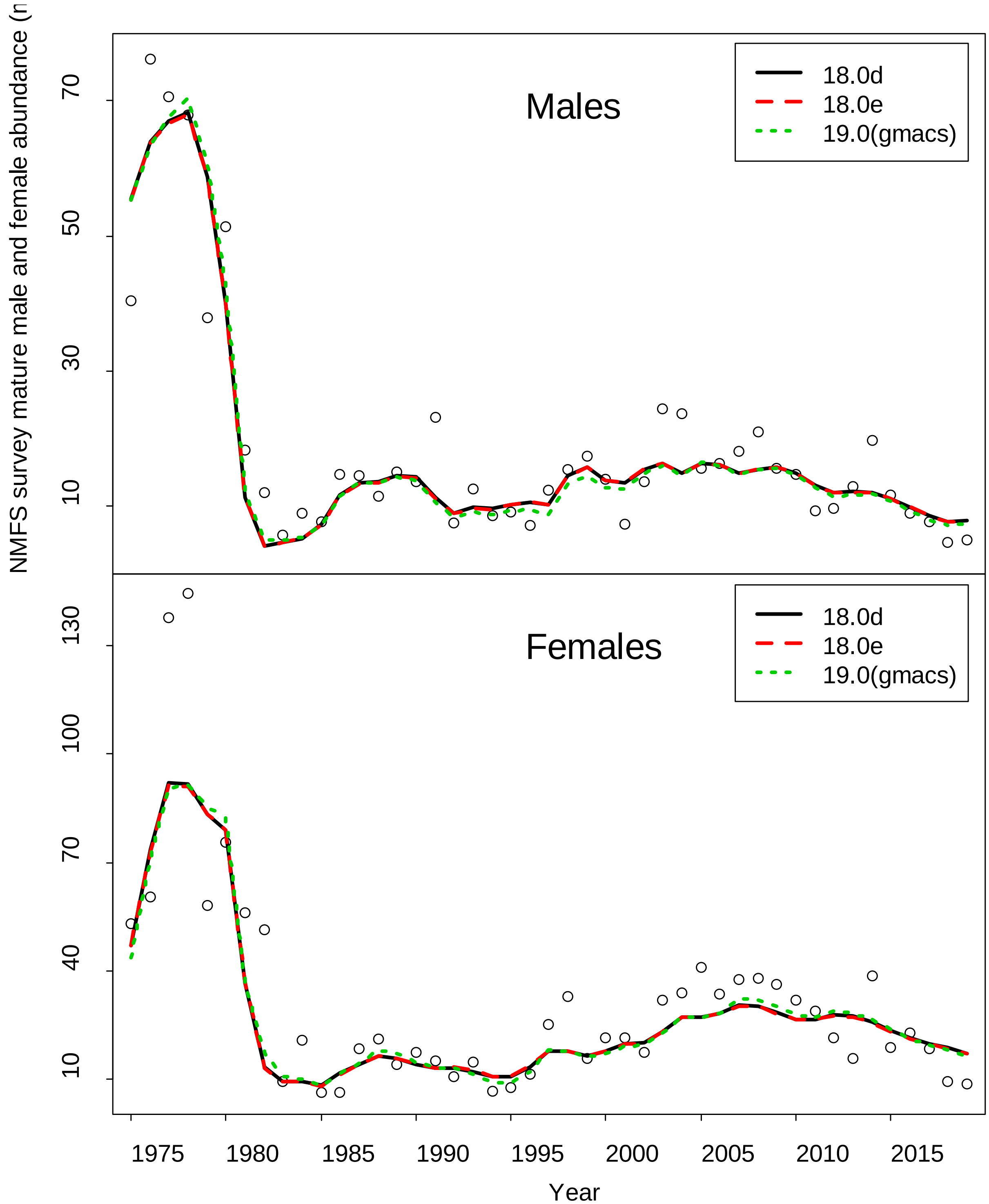


Figure 10b. Comparisons of NMFS survey area-swept estimates of male (>119 mm) and female (>89 mm) abundance and model prediction for model estimates in 2019 under models 18.0d, 18.0e, and 19.0. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

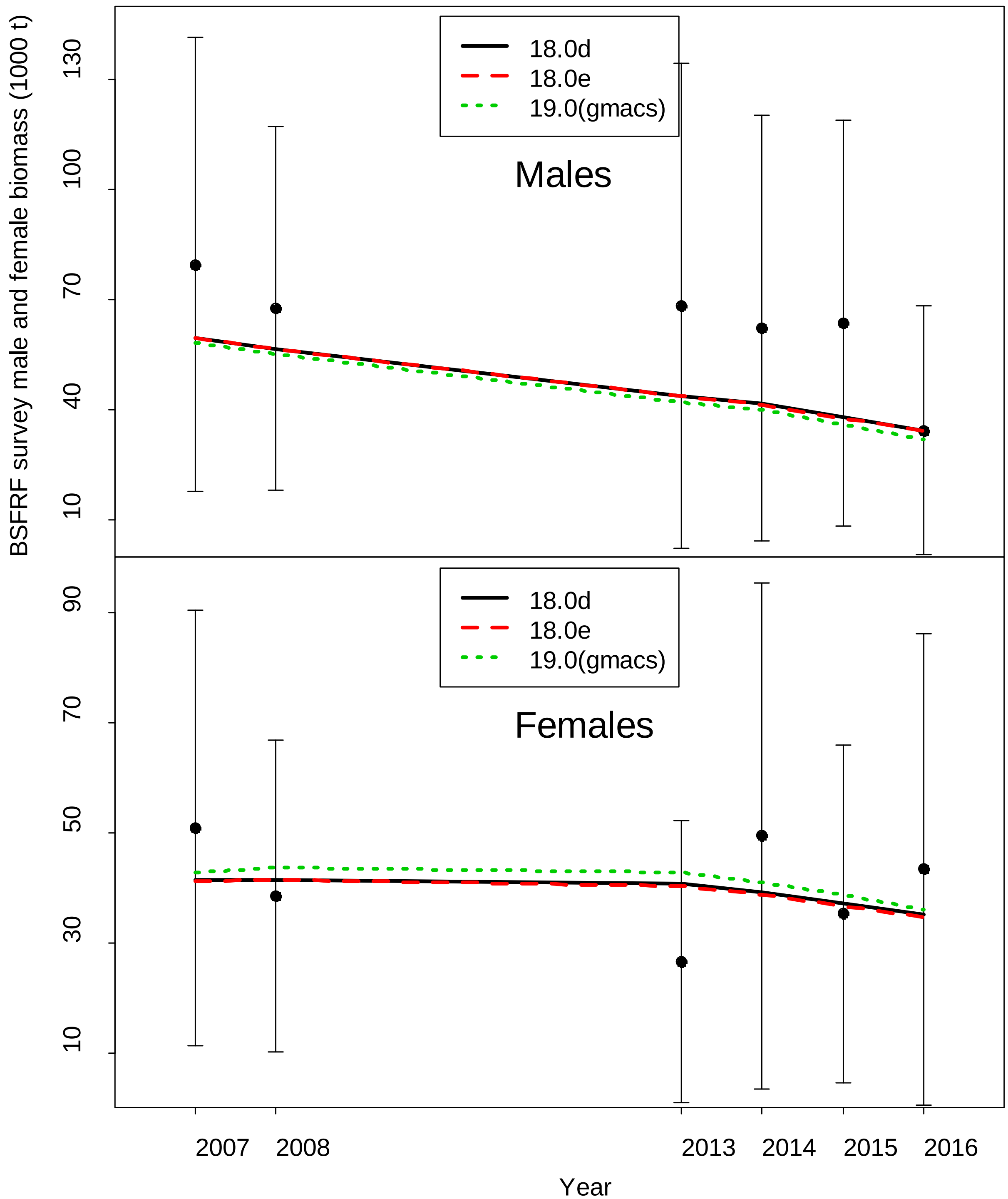


Figure 10c. Comparisons of total survey biomass estimates by the BSFRF survey and the model for model estimates in 2019 (models 18.0d, 18.0e, and 19.0). The error bars are plus and minus 2 standard deviations of model 19.0.

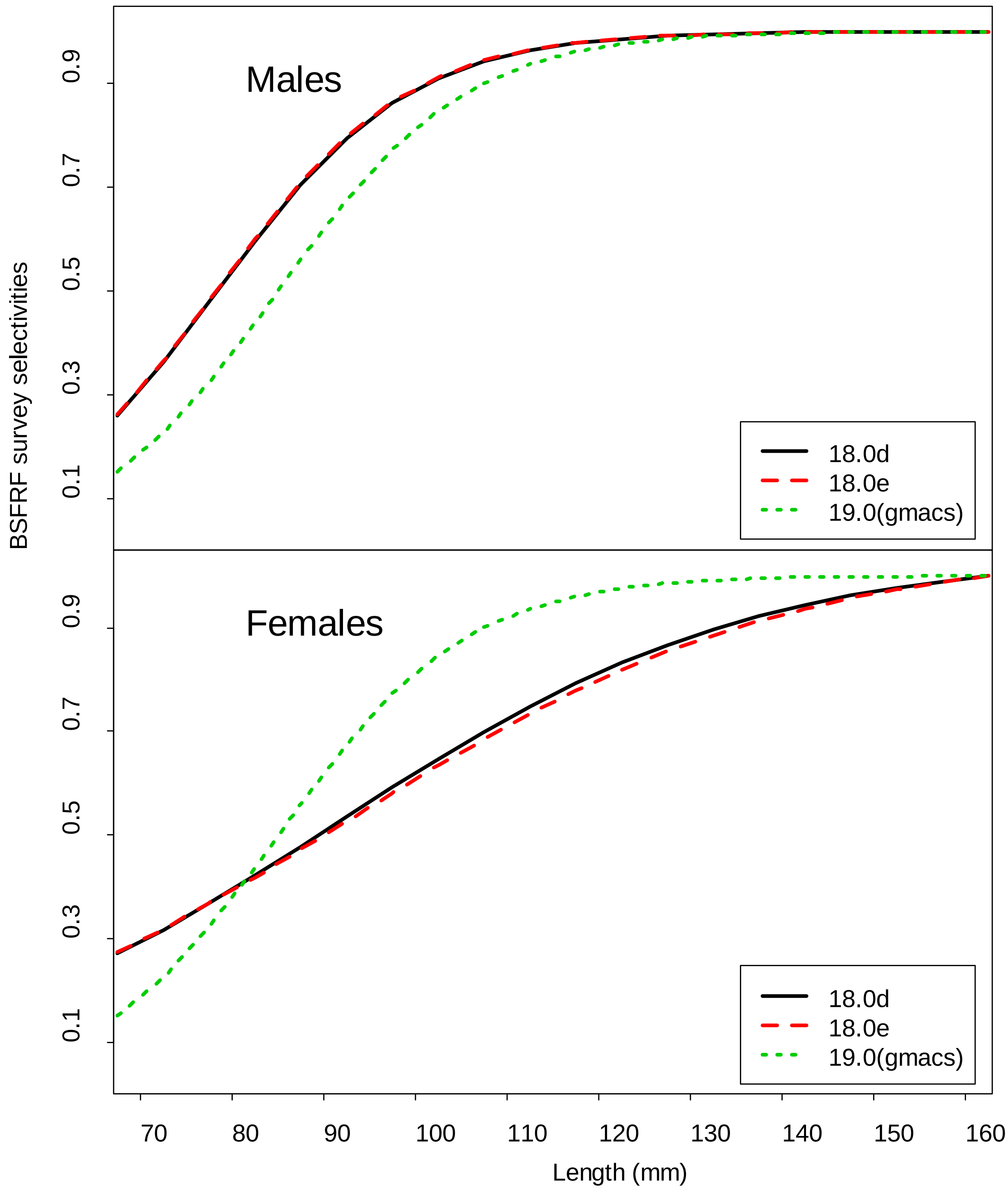


Figure 10d. Comparisons of estimated BSFRF survey selectivities with models 18.0d, 18.0e, and 19.0. The catchability is assumed to be 1.0.

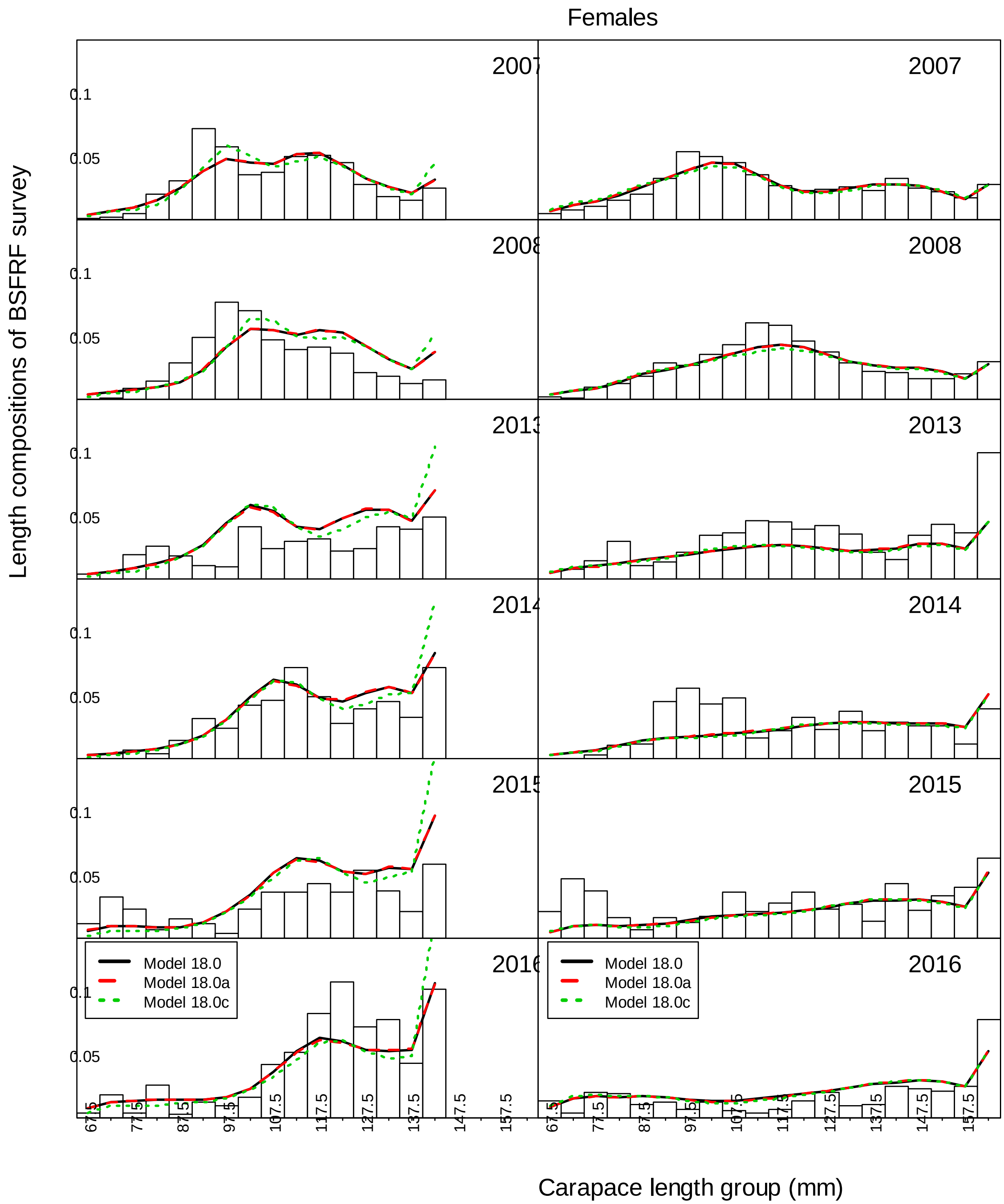


Figure 10e(18.0d, 18.0e & 19.0). Comparisons of length compositions by the BSFRF survey and the model estimates during 2007-2008 and 2013-2016 with models 18.0d (solid black), 18.0e (dashed red) and 19.0 (green lines).

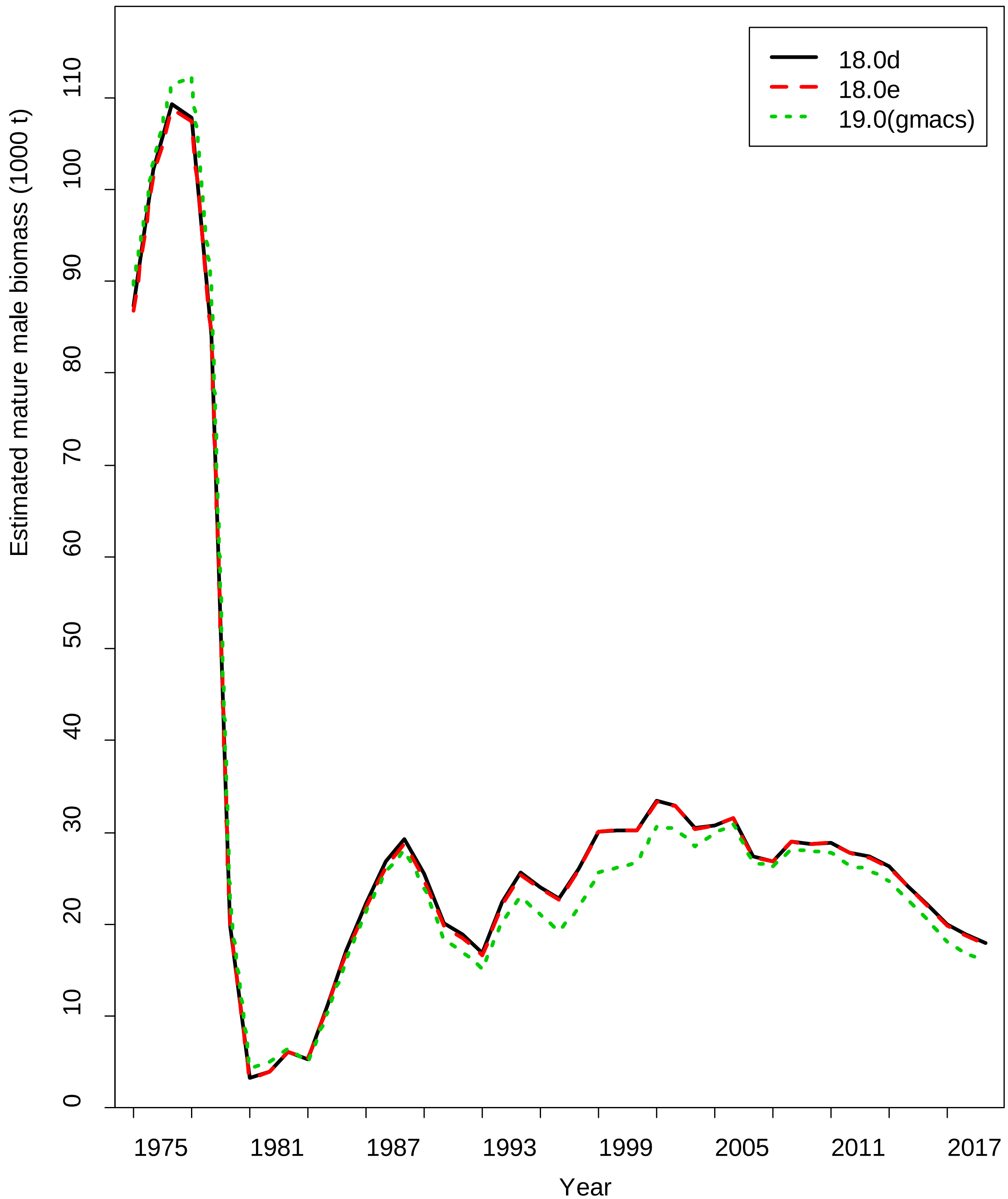


Figure 11. Estimated absolute mature male biomasses during 1975-2019 for models 18.0d, 18.0e, and 19.0.

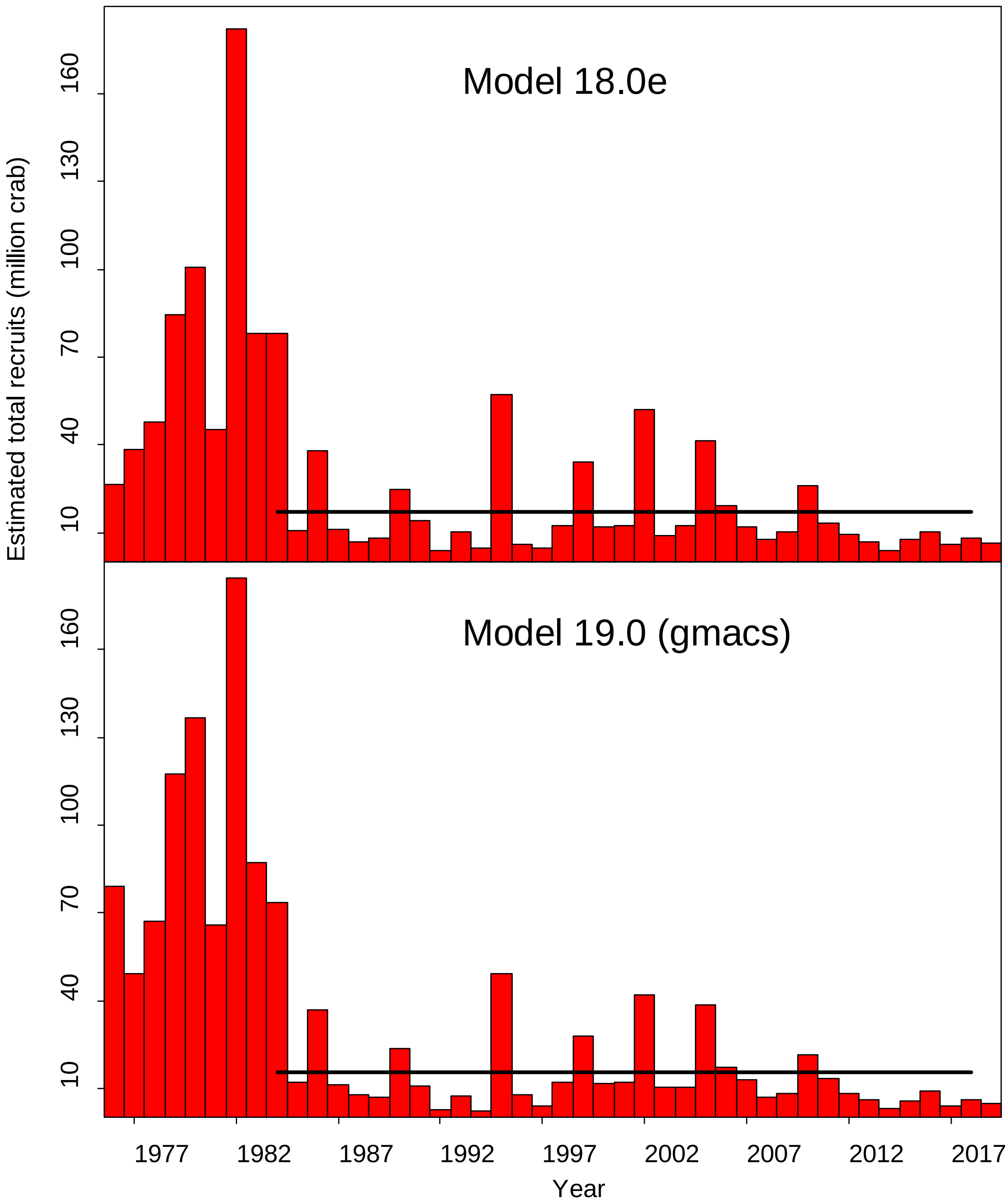


Figure 12(18.0e & 19.0). Estimated recruitment time series during 1976-2019 with models 18.0e and 19.0 (gmacs). Mean male recruits during 1984-2018 was used to estimate $B_{35\%}$.

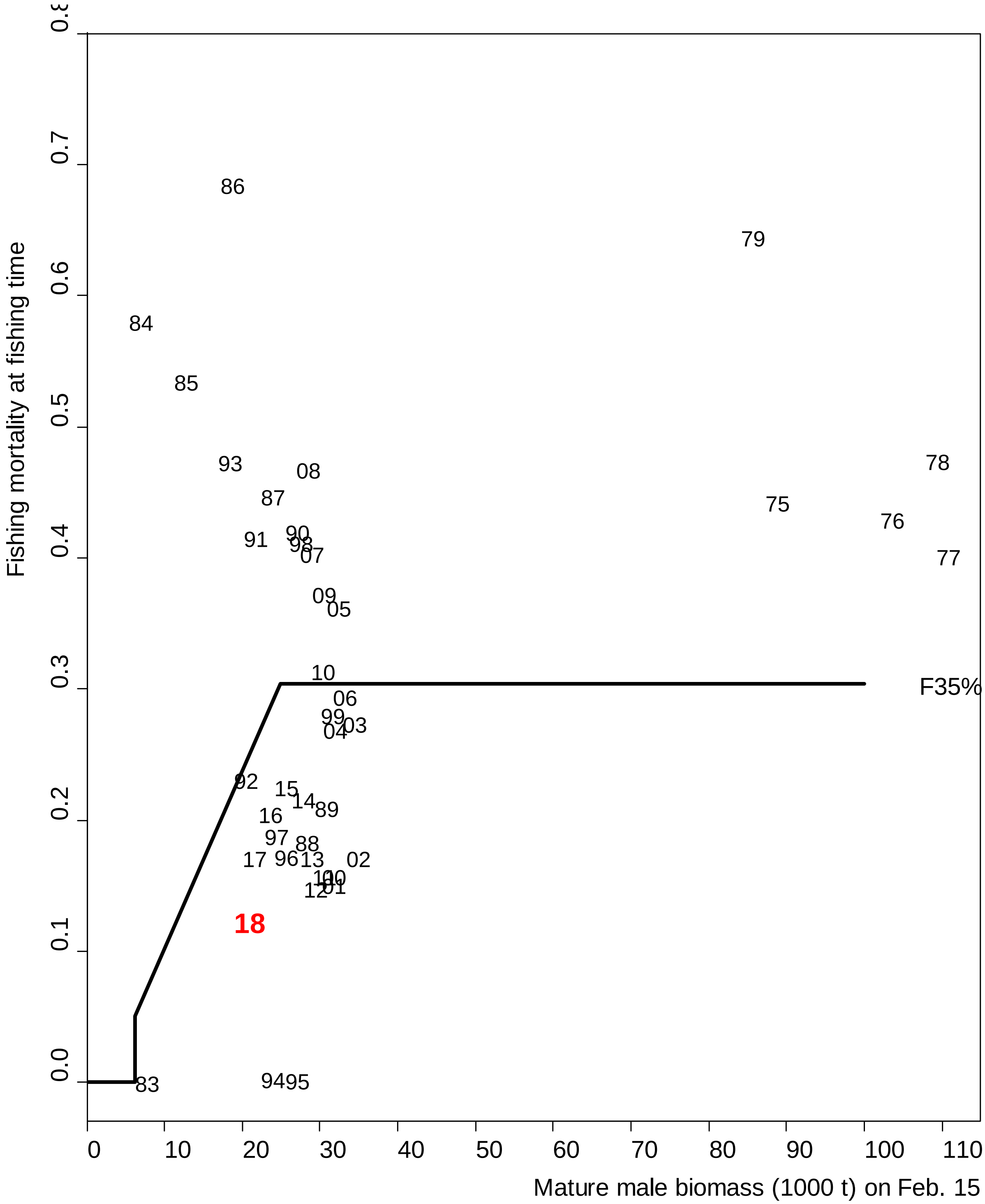


Figure 13a(18.0d). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2019 under model 18.0d. Average of recruitment from 1984 to 2018 was used to estimate B_{MSY}. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

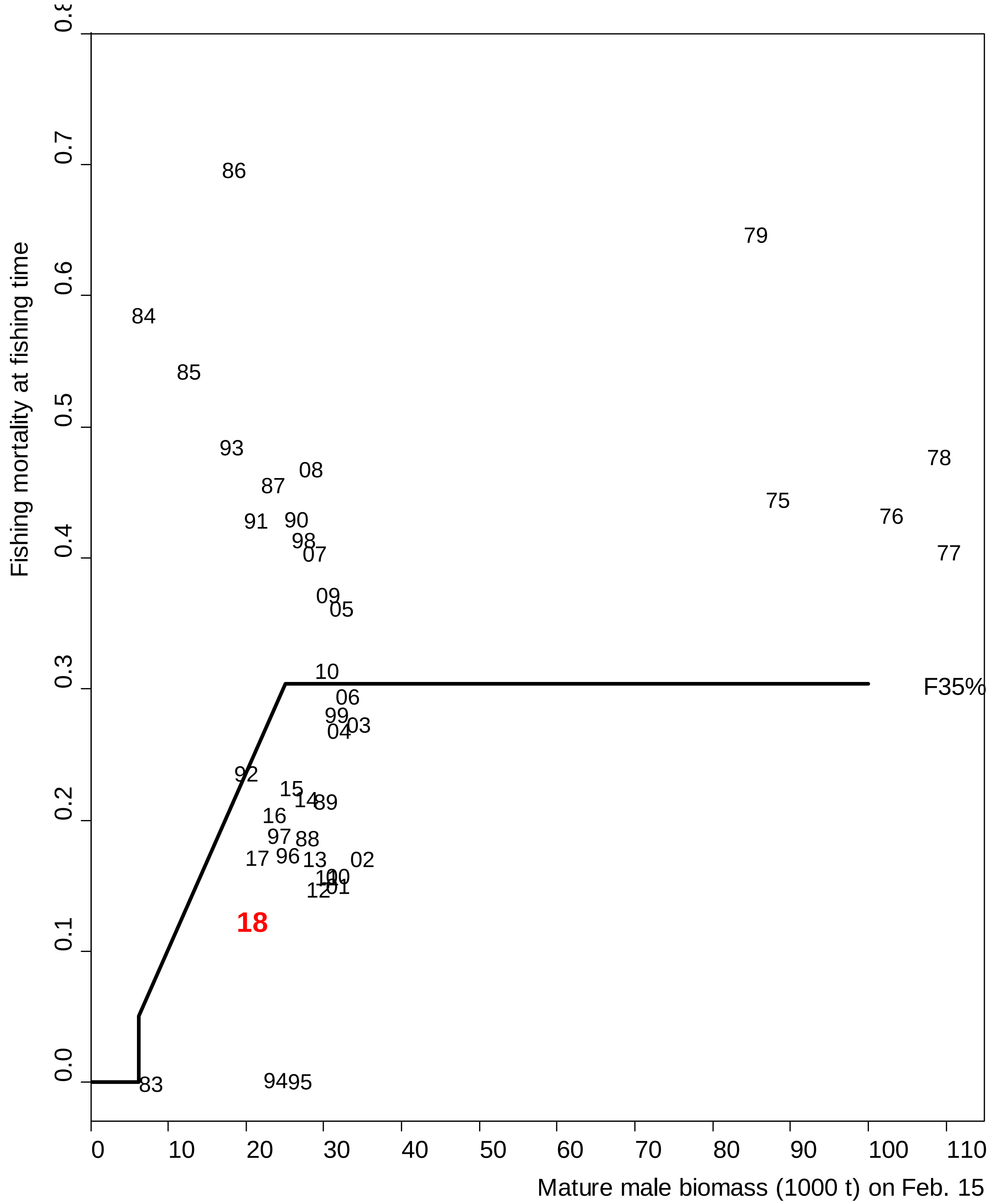


Figure 13a(18.0e). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2019 under model 18.0e. Average of recruitment from 1984 to 2018 was used to estimate B_{MSY}. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

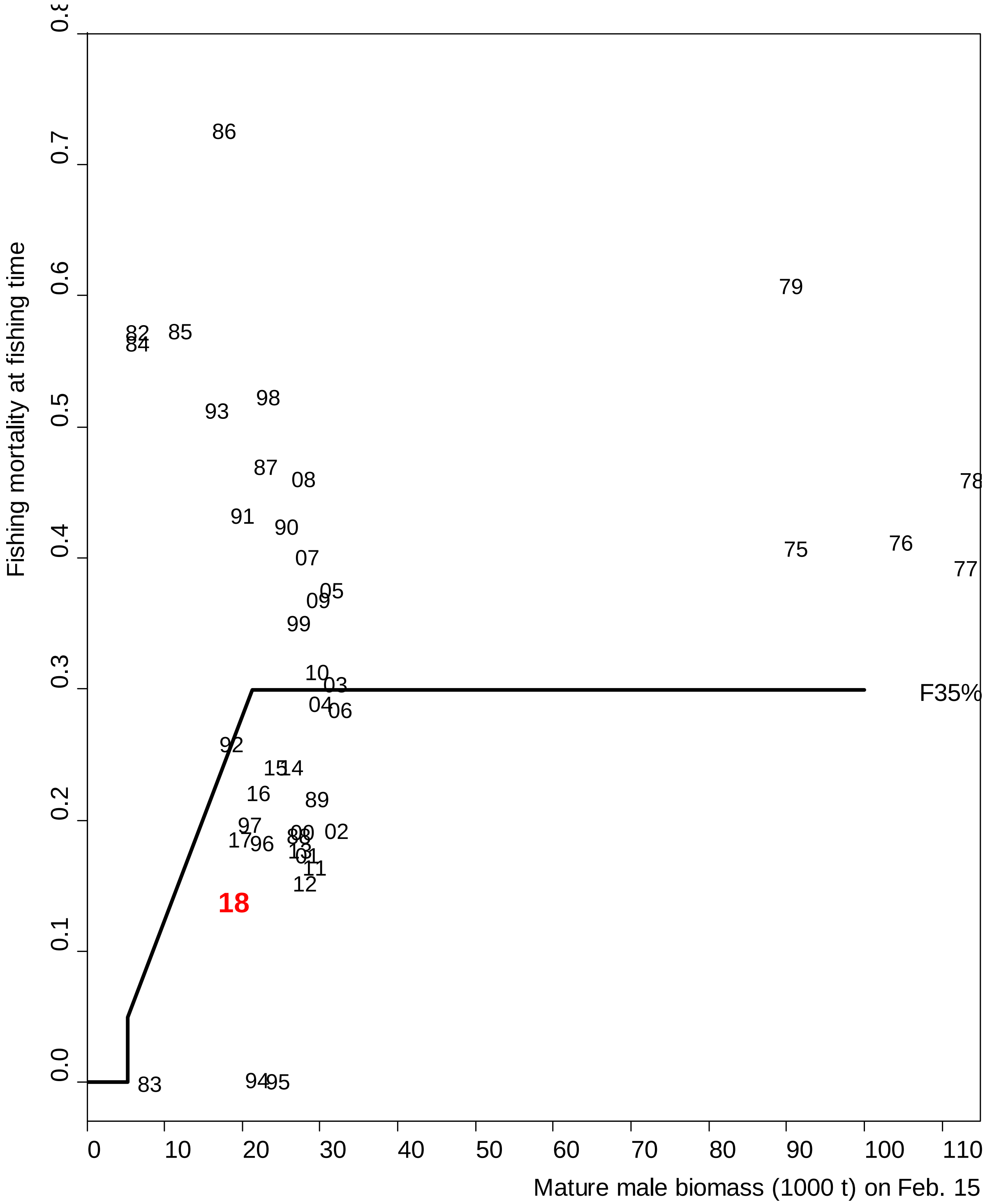


Figure 13a(19.0). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2019 under model 19.0. Average of recruitment from 1984 to 2017 was used to estimate B_{MSY}. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

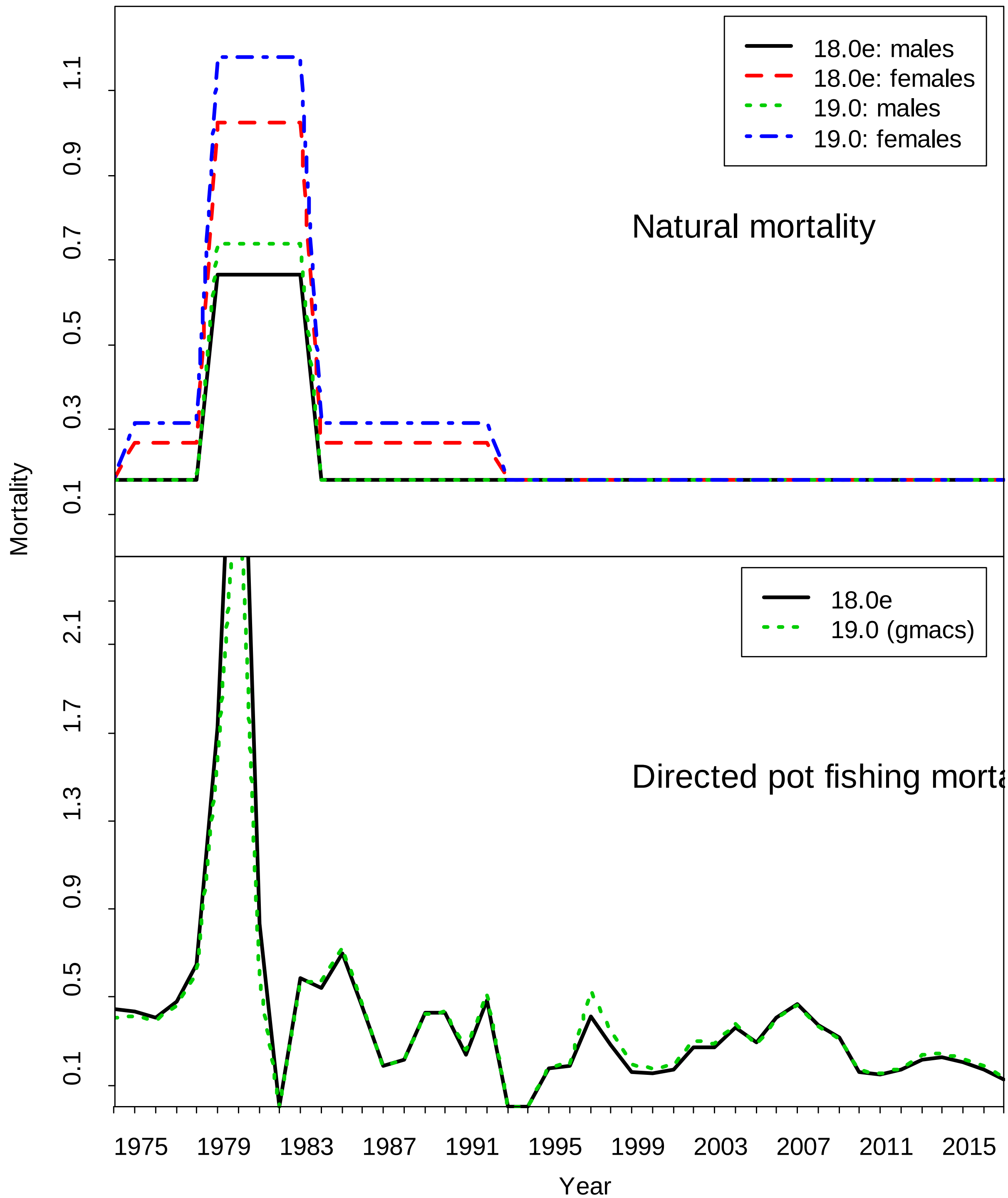


Figure 13b. Comparison of estimated natural mortality and directed pot fishing mortality for models models 18.0e and 19.0. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

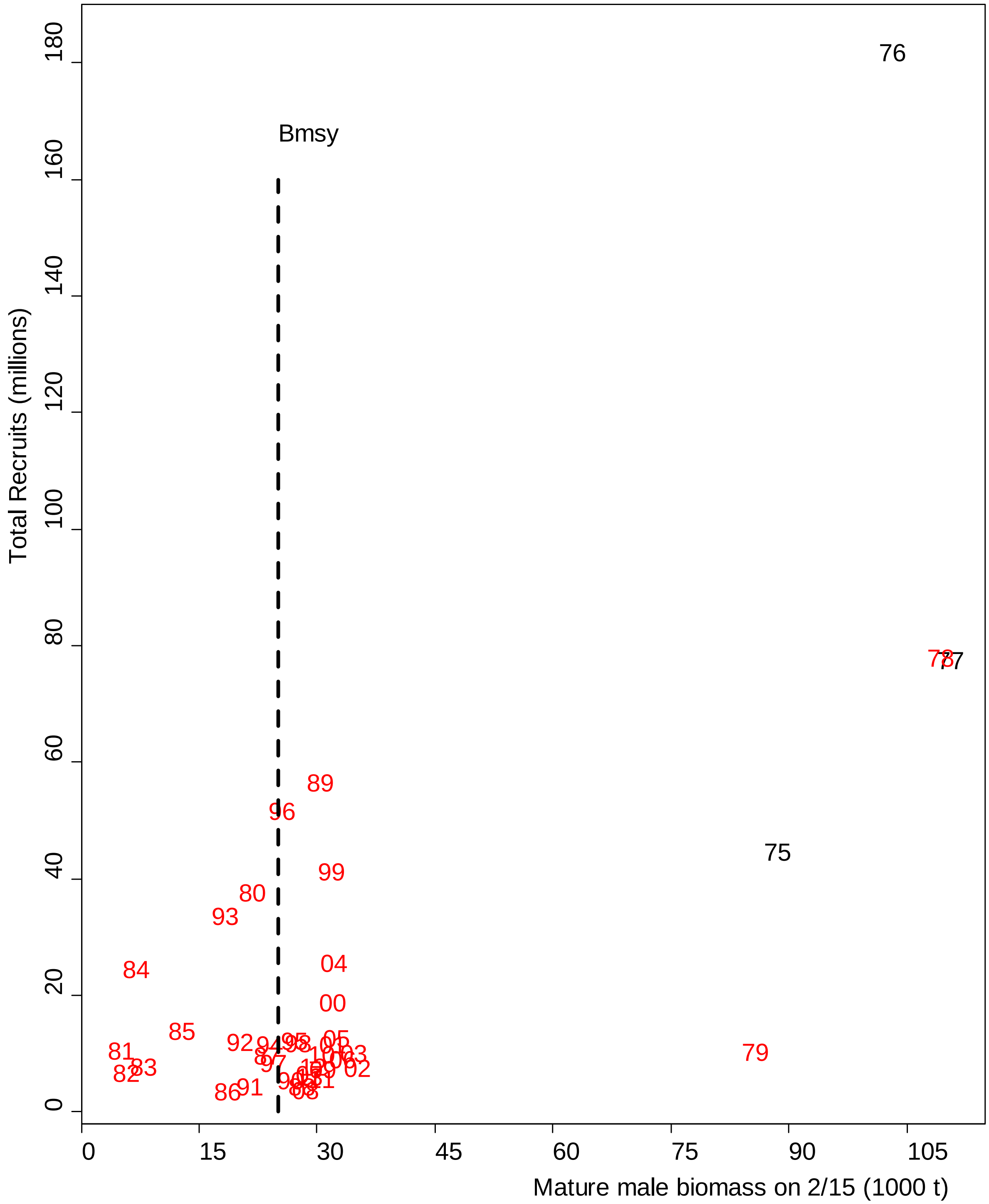


Figure 14a. Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab with pot handling mortality rate of 0.2 under model 18.0e. Numerical labels are years of mating, and the vertical dotted line is the estimated $B_{35\%}$ based on the mean recruitment level during 1984 to 2018.

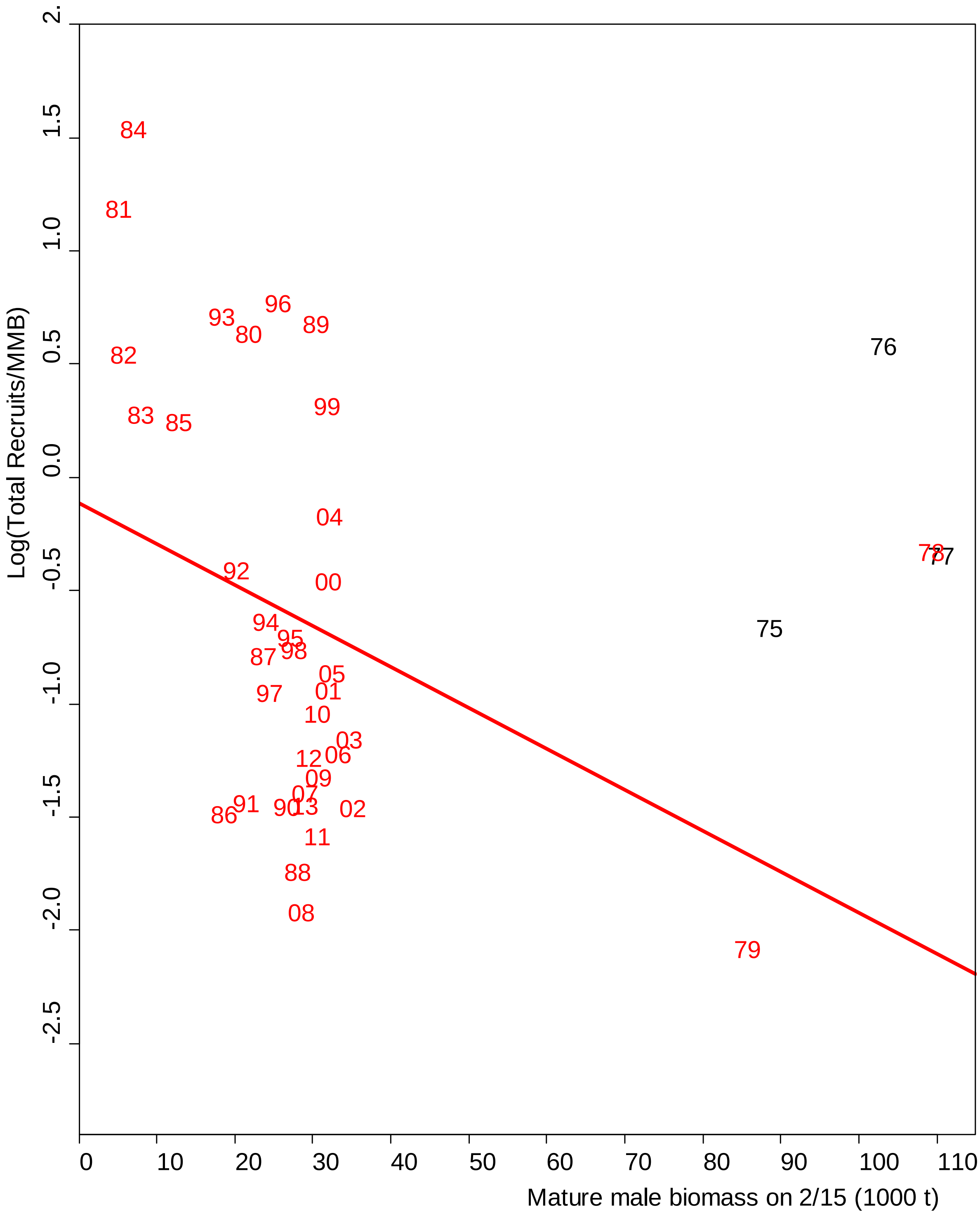


Figure 14b. Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate of 0.2 under model 18.0e. Numerical labels are years of mating, and the line is the regression line for data of 1978-2013.

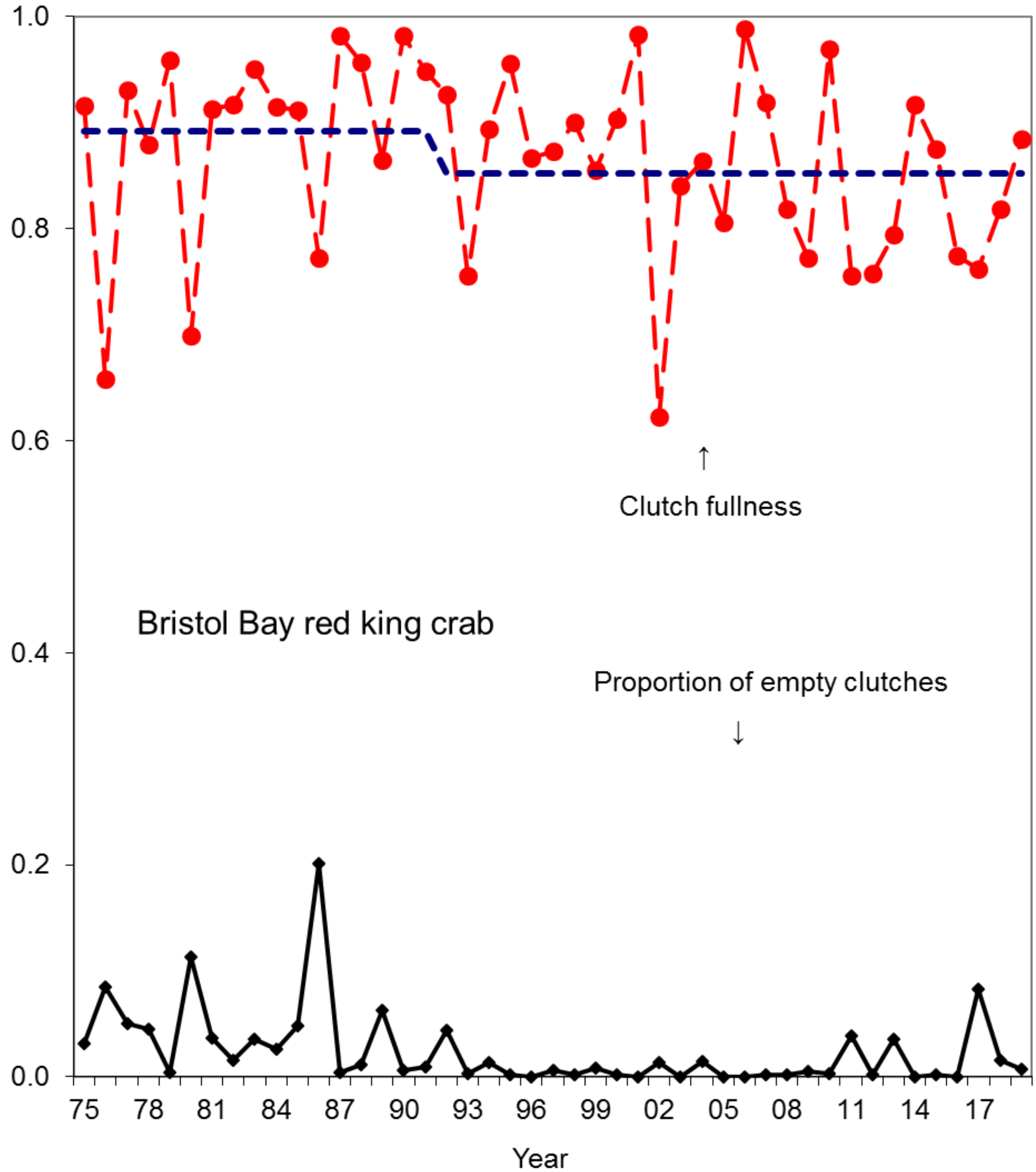


Figure 15. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crab >89 mm CL from 1975 to 2019 from survey data. Oldshell females were excluded. The blue dashed line is the mean clutch fullness during two periods before 1992 and after 1991.

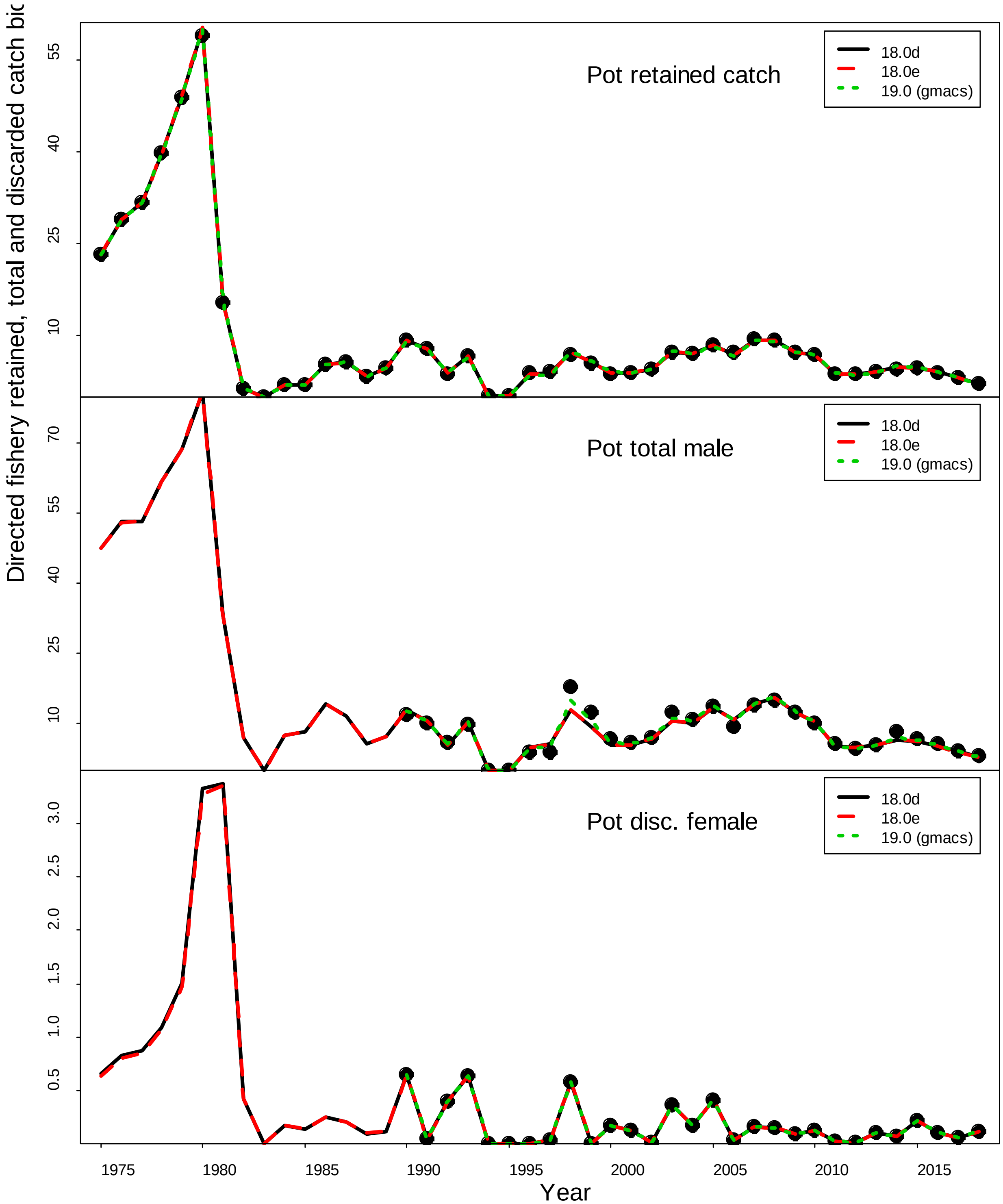


Figure 16a. Observed and predicted RKC catch mortality biomass under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines). Mortality biomass is equal to caught biomass times a handling mortality rate.

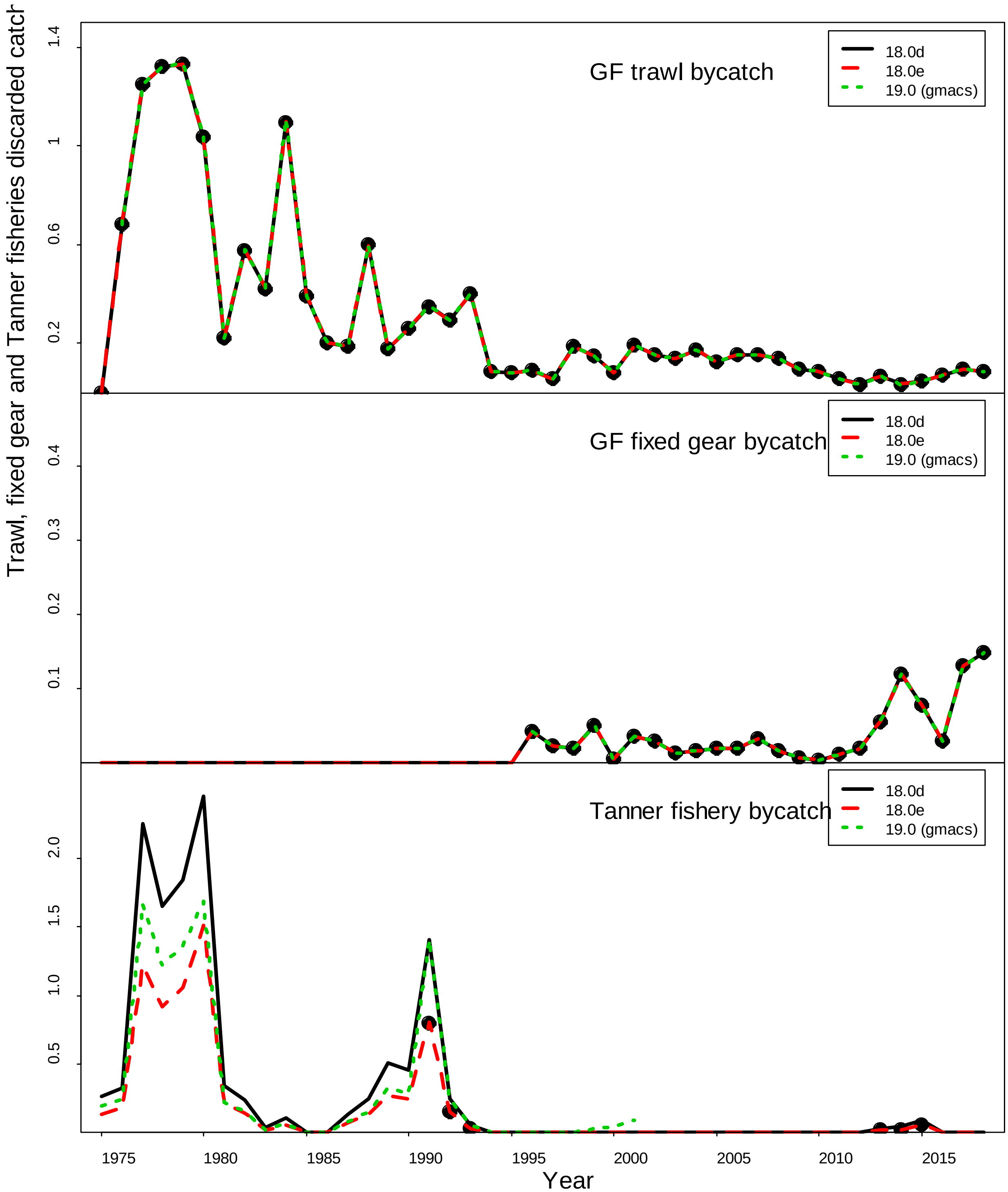


Figure 16b. Observed and predicted RKC bycatch mortality biomass from groundfish fisheries and the Tanner crab fishery under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines). Mortality biomass is equal to caught biomass times a handling mortality rate. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively. Trawl bycatch biomass was 0 before 1976.

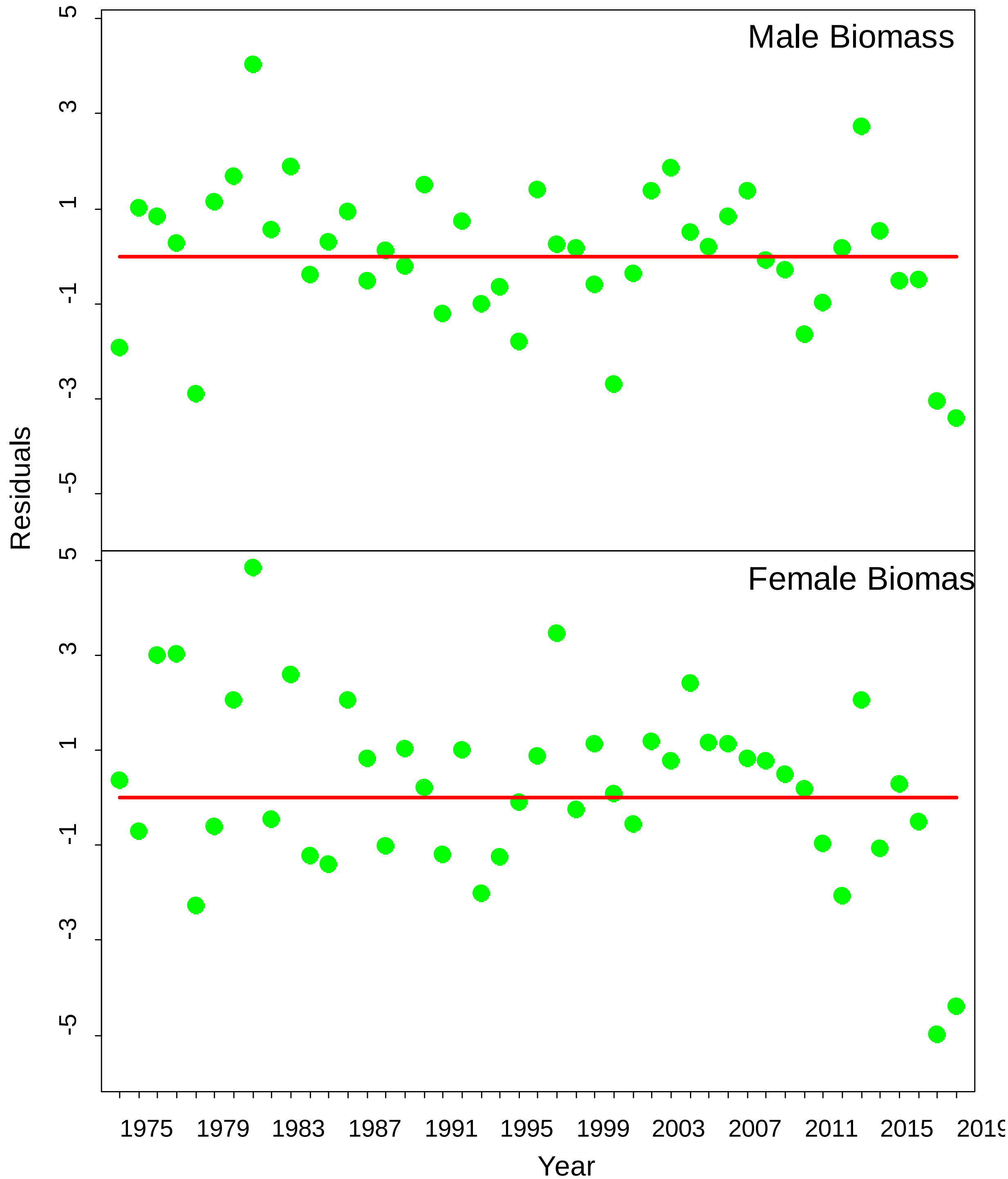


Figure 17(18.0d). Standardized residuals of NMFS survey biomass under model 18.0d. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

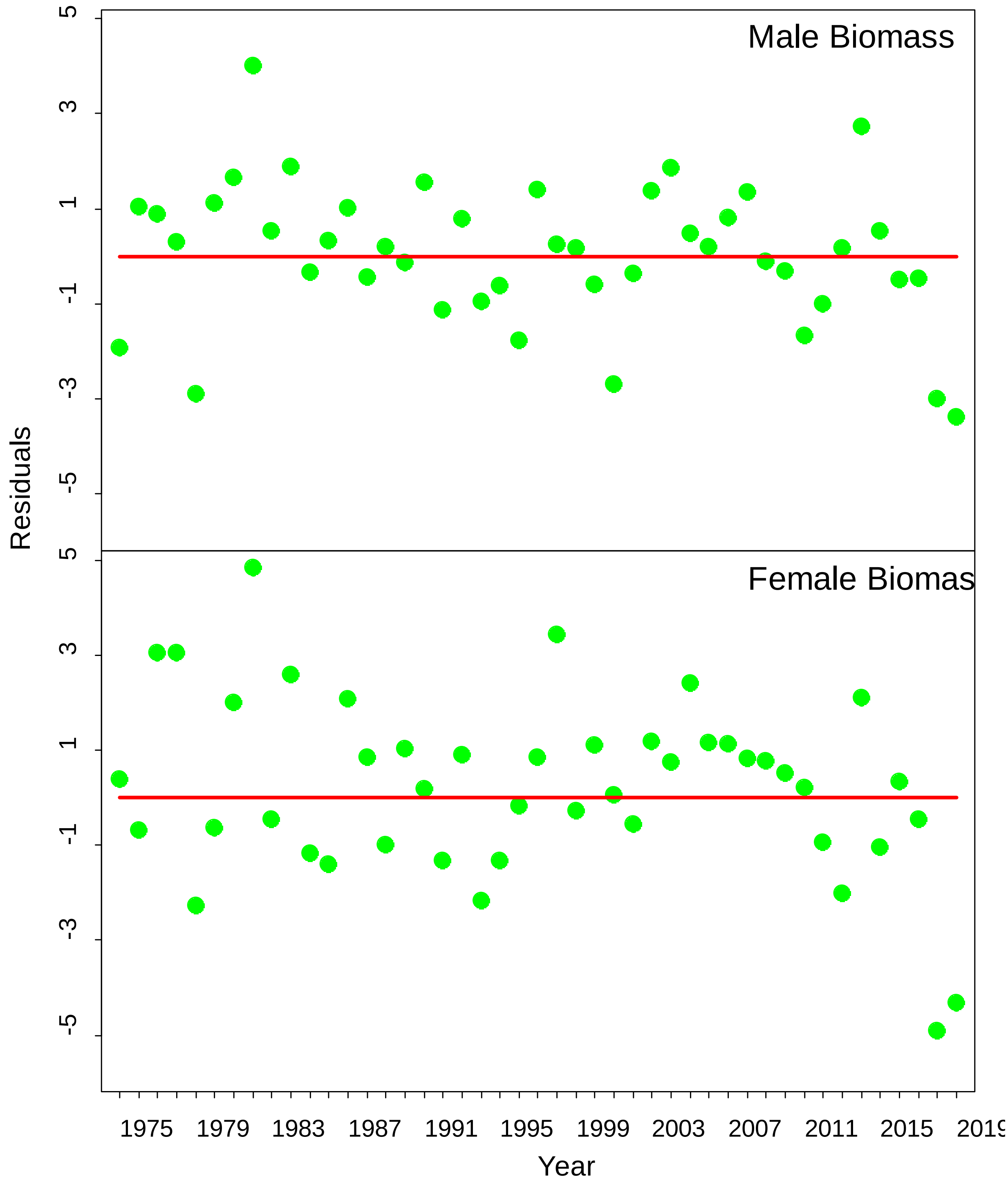


Figure 17(18.0e). Standardized residuals of NMFS survey biomass under model 18.0e. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

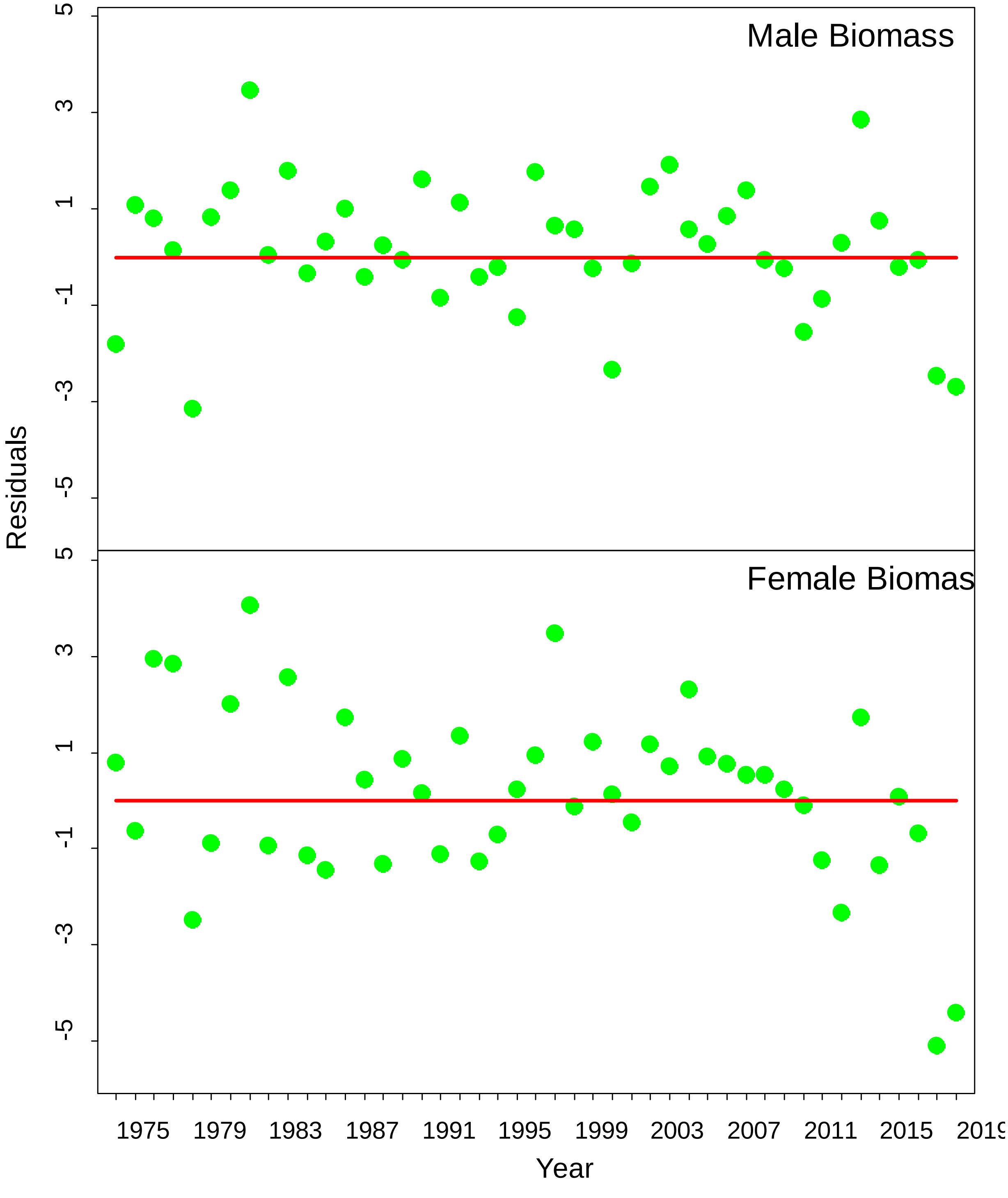


Figure 17(19.0). Standardized residuals of NMFS survey biomass under model 19.0. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

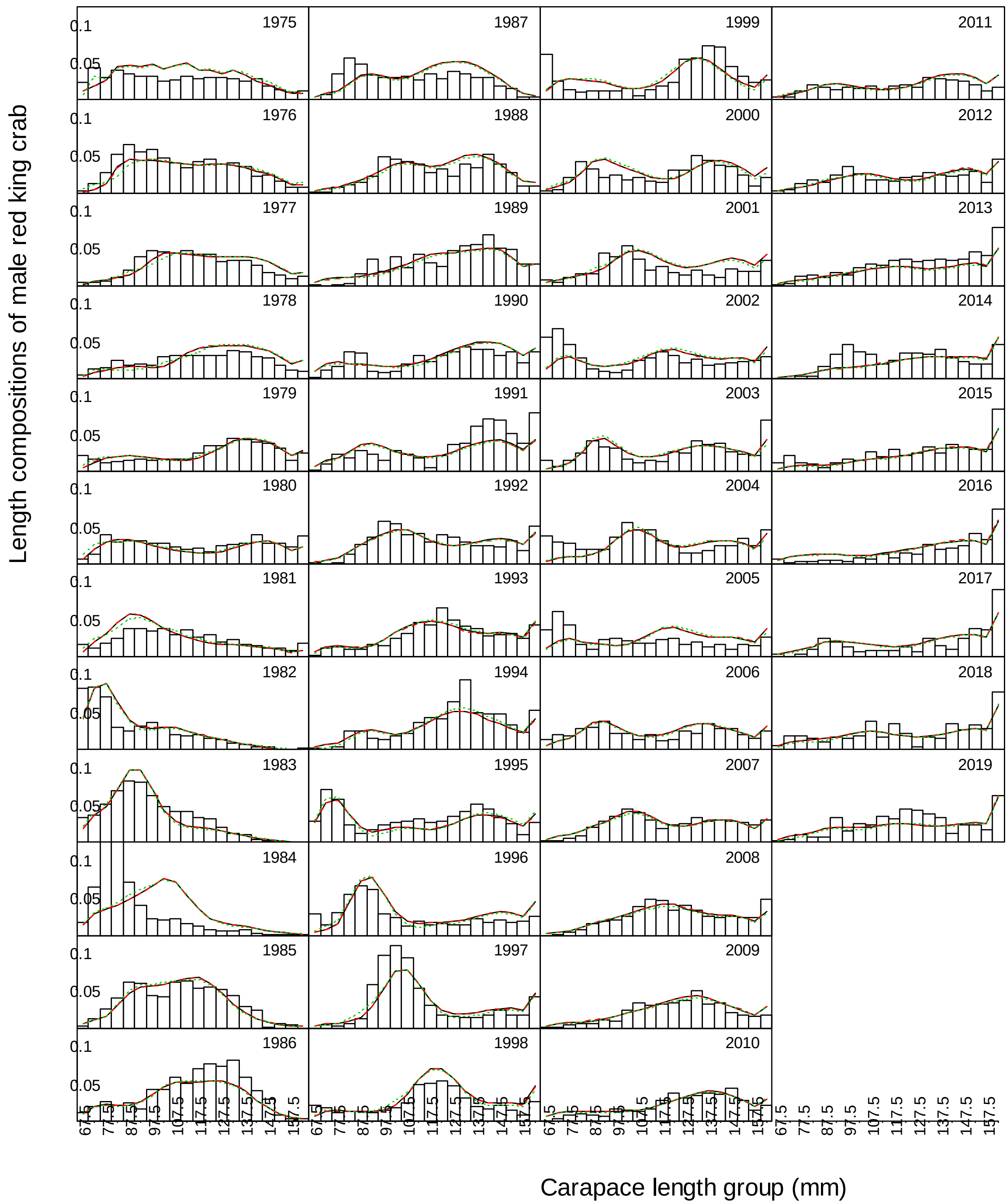


Figure 18(18.0d, 18.0e & 19.0 (gmacs)). Comparison of area-swept and model estimated NMFS survey length frequencies of Bristol Bay male red king crab by year under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

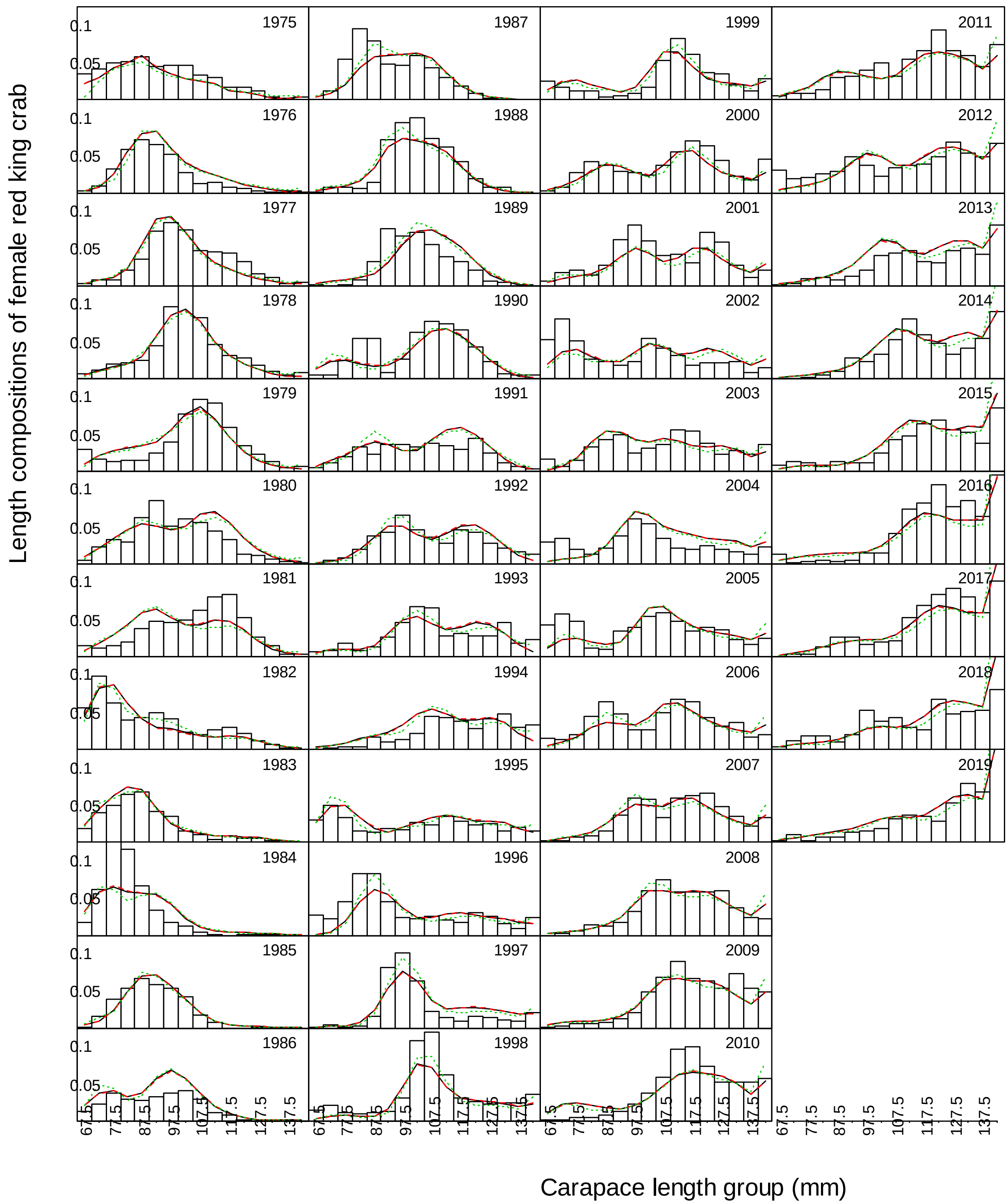


Figure 19(18.0d, 18.0e & 19.0 (gmacs)). Comparison of area-swept and model estimated NMFS survey length frequencies of Bristol Bay female red king crab by year under models 18.0d (solid black), 18.0e (dashed red), and 19.0 (green lines).

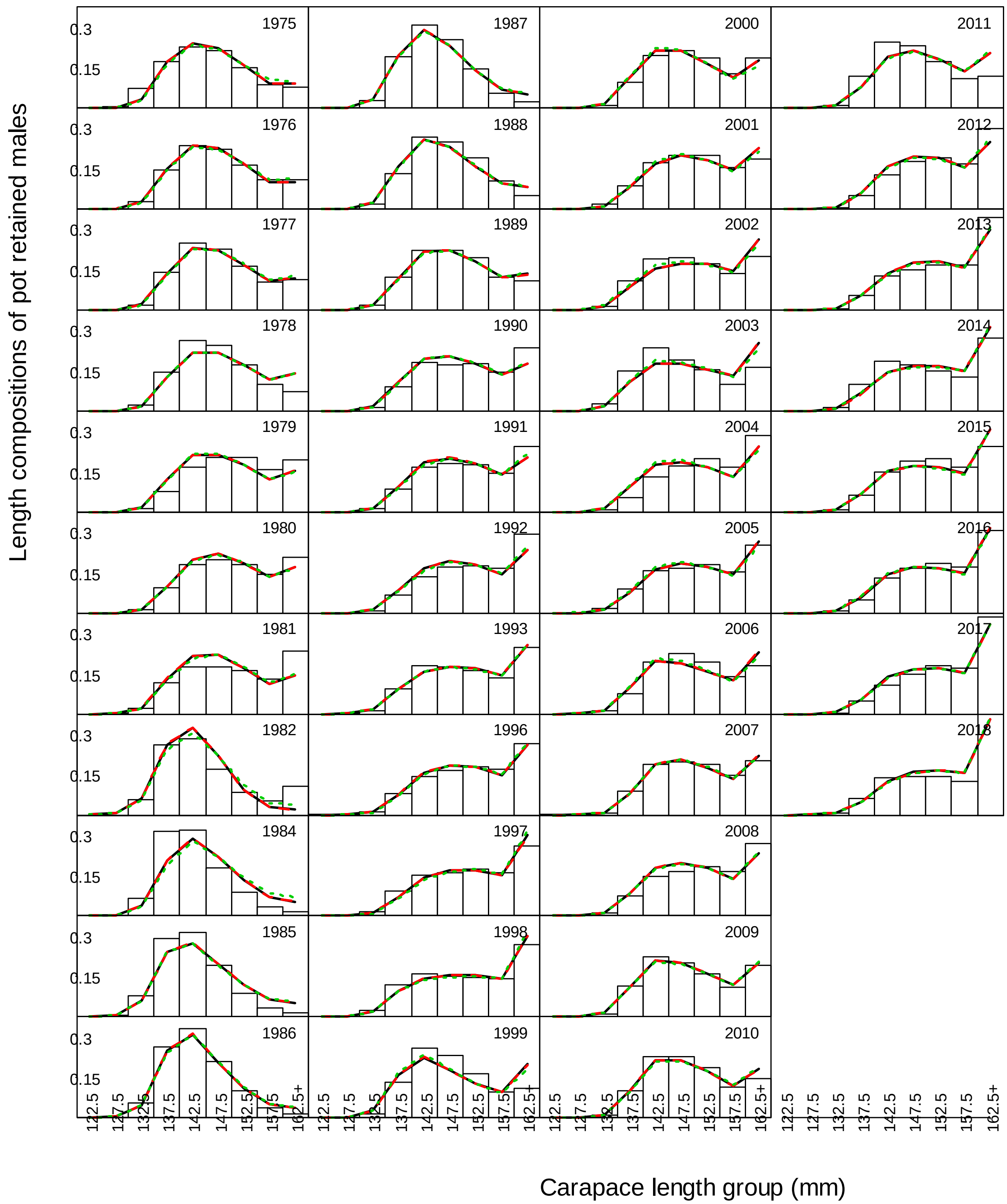


Figure 20(18.0d, 18.0e, & 19.0 (gmacs)). Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

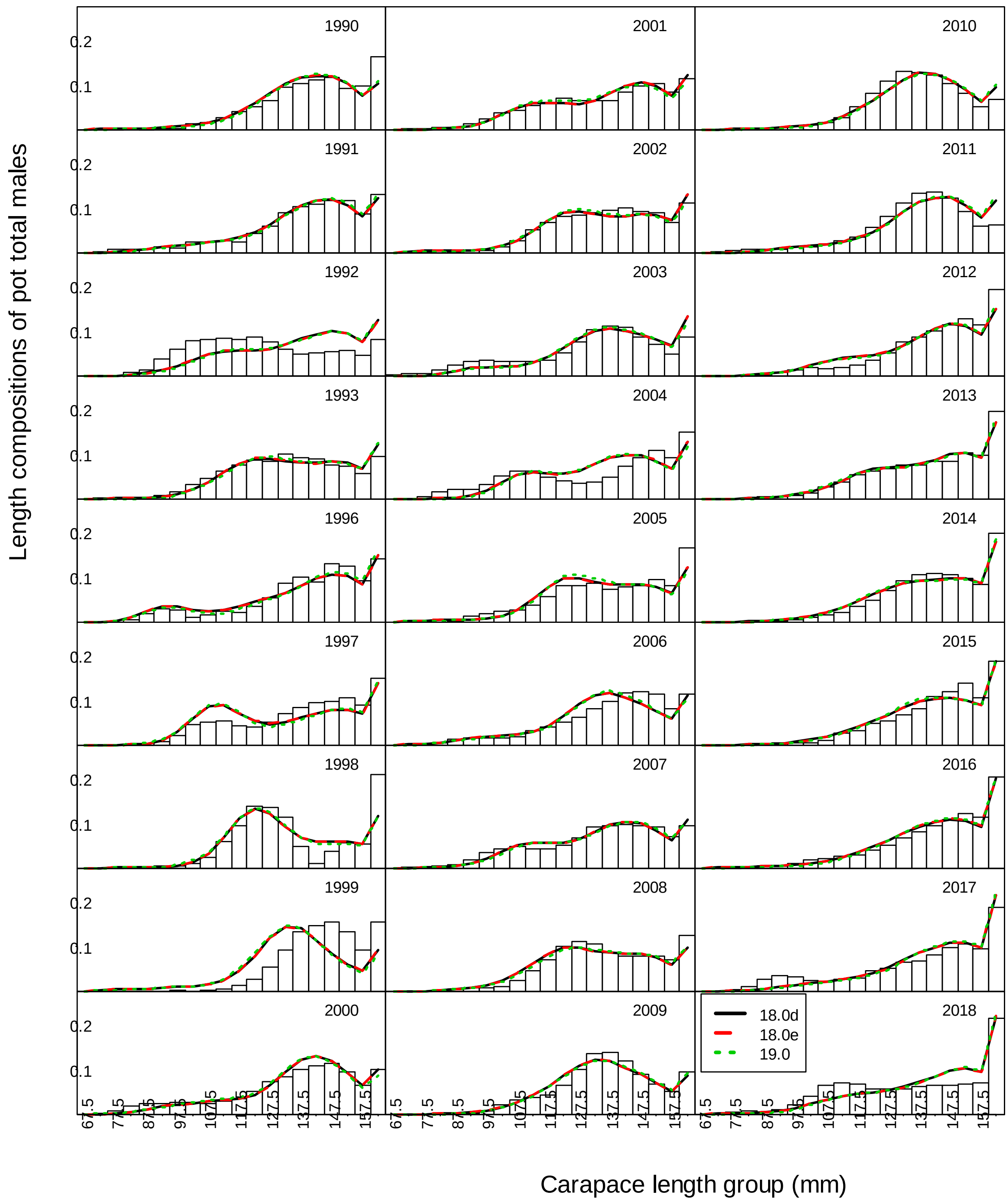


Figure 21(18.0d, 18.0e, & 19.0 (gmacs)). Comparison of observer and model estimated total observer length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

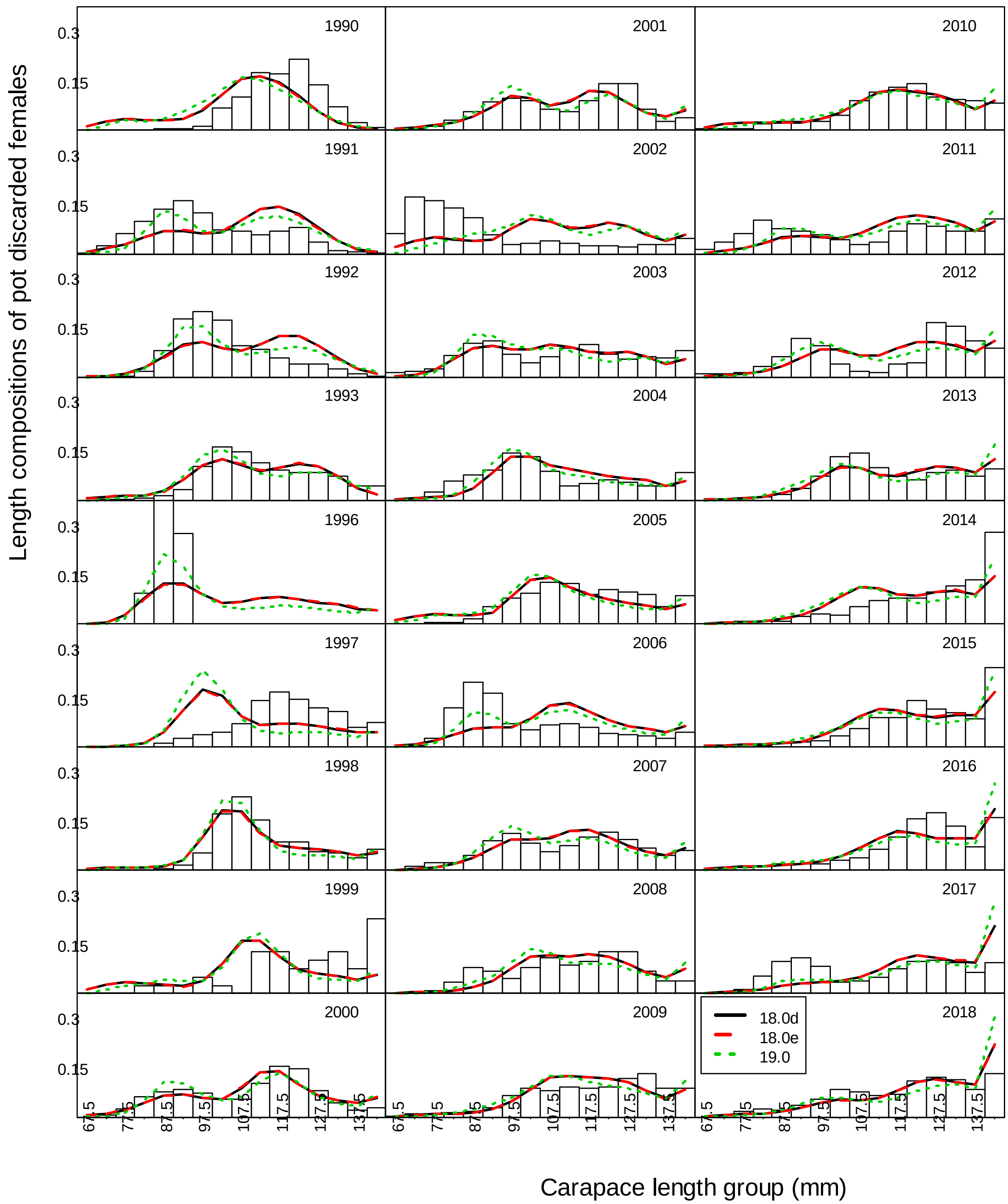


Figure 22(18.0d, 18.0e, & 19.0 (gmacs)). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the directed pot fishery under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

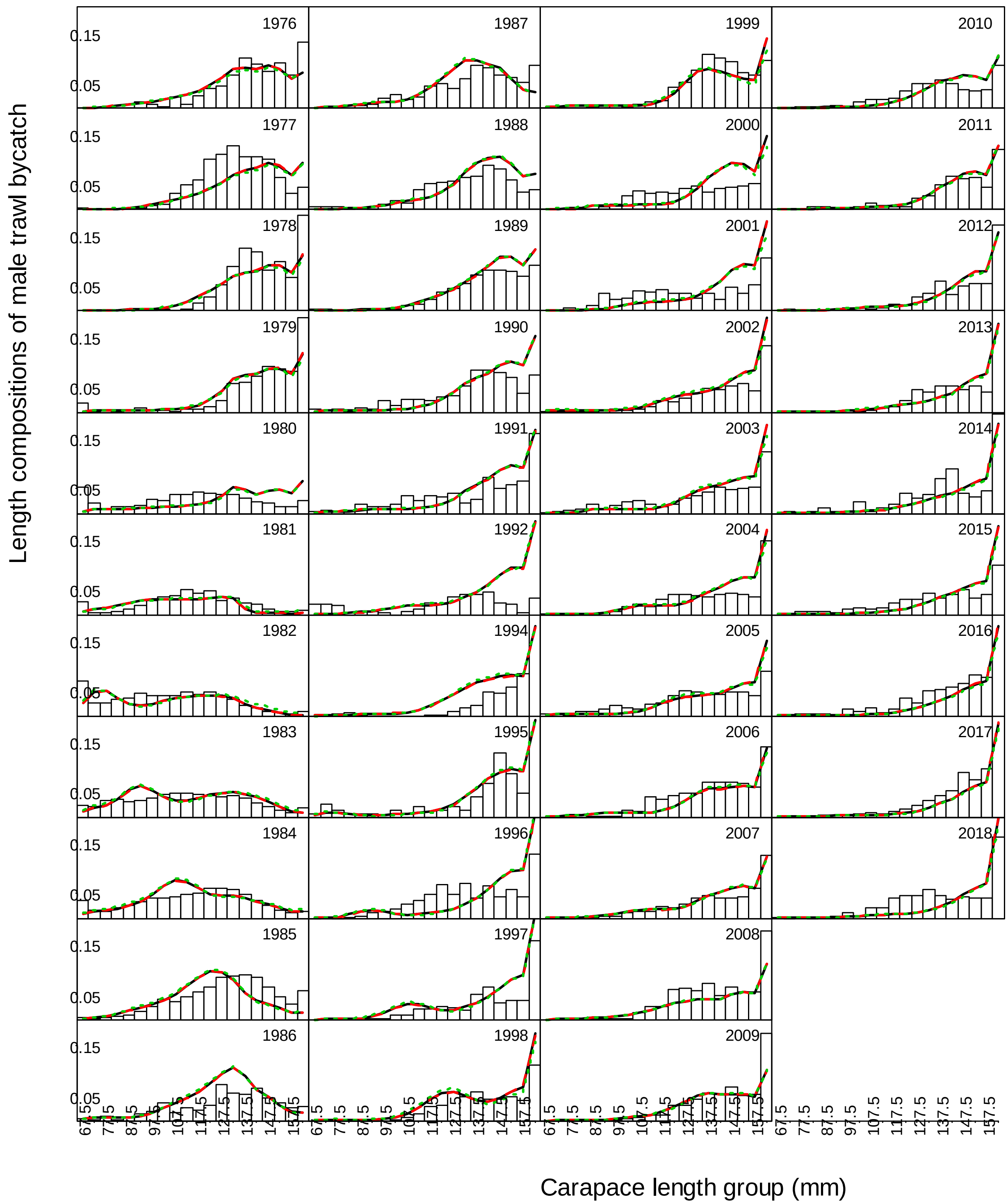


Figure 23(18.0d, 18.0e, & 19.0 (gmacs)). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish trawl fisheries under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

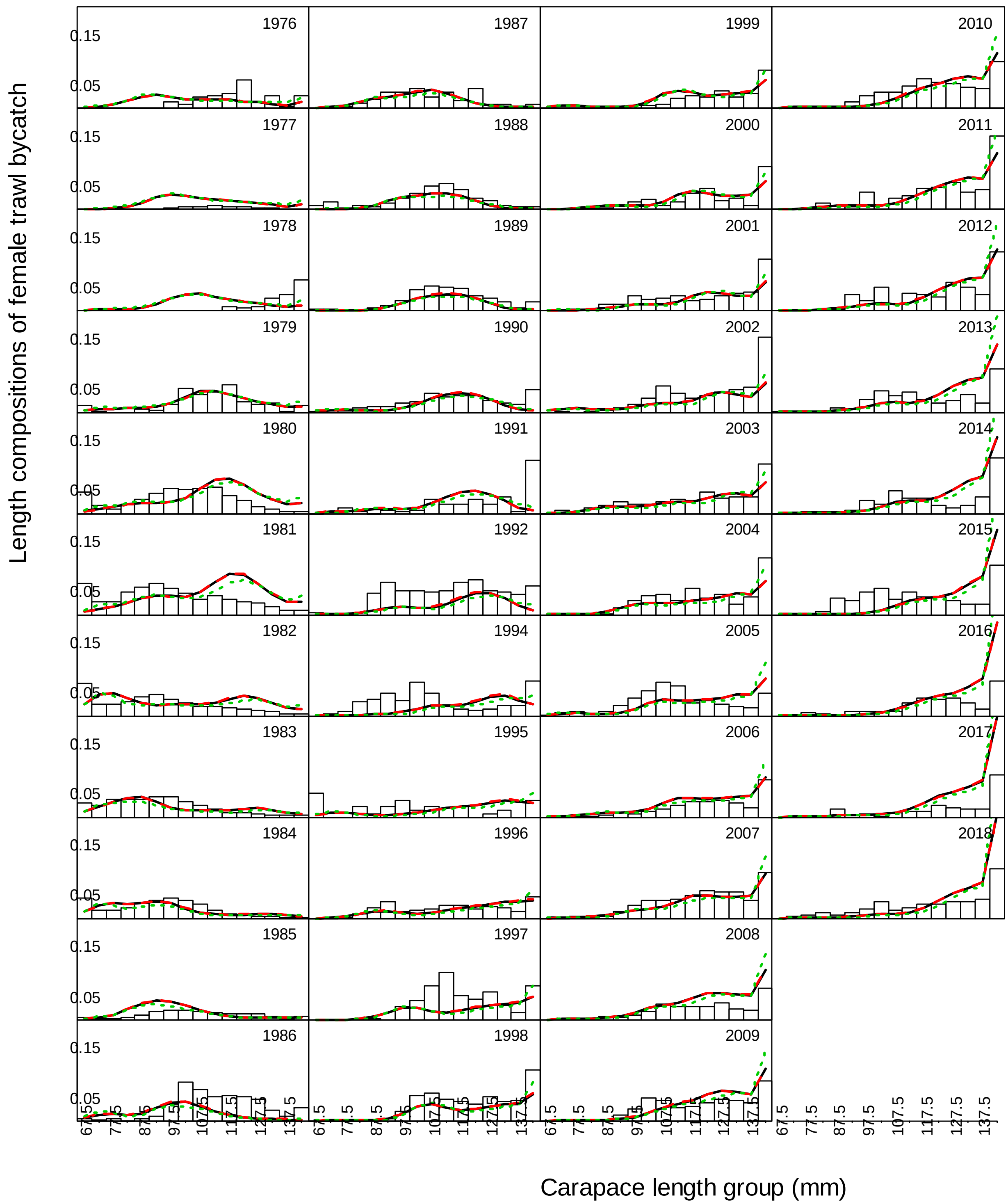


Figure 23(18.0d, 18.0e, & 19.0 (gmacs)). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish trawl fisheries under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

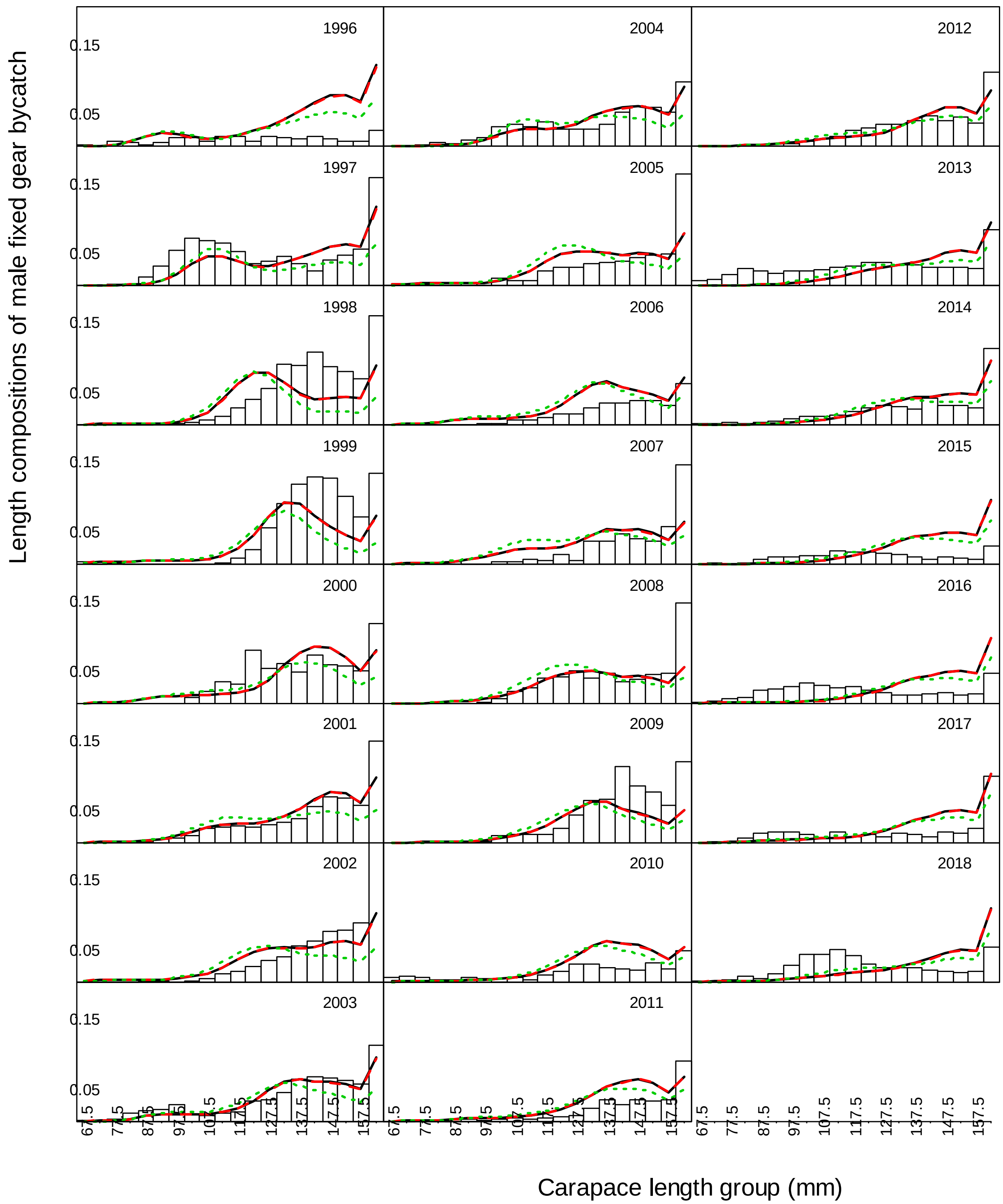


Figure 24(18.0d, 18.0e, & 19.0 (gmacs)). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish fixed gear fisheries under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

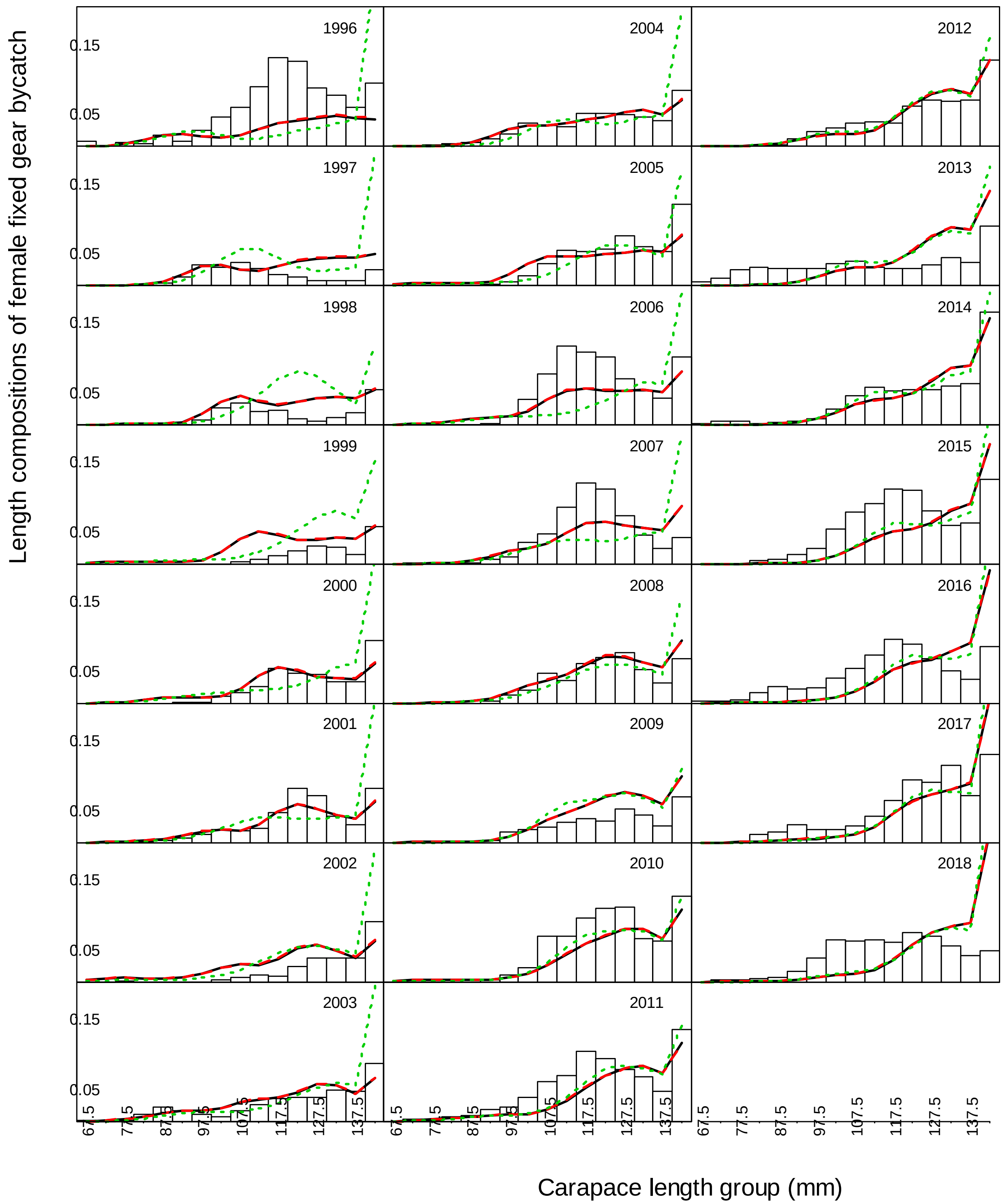


Figure 24(18.0d, 18.0e, & 19.0 (gmacs)). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish fixed gear fisheries under models 18.0d(solid black), 18.0e (dashed red), and 19.0 (green lines).

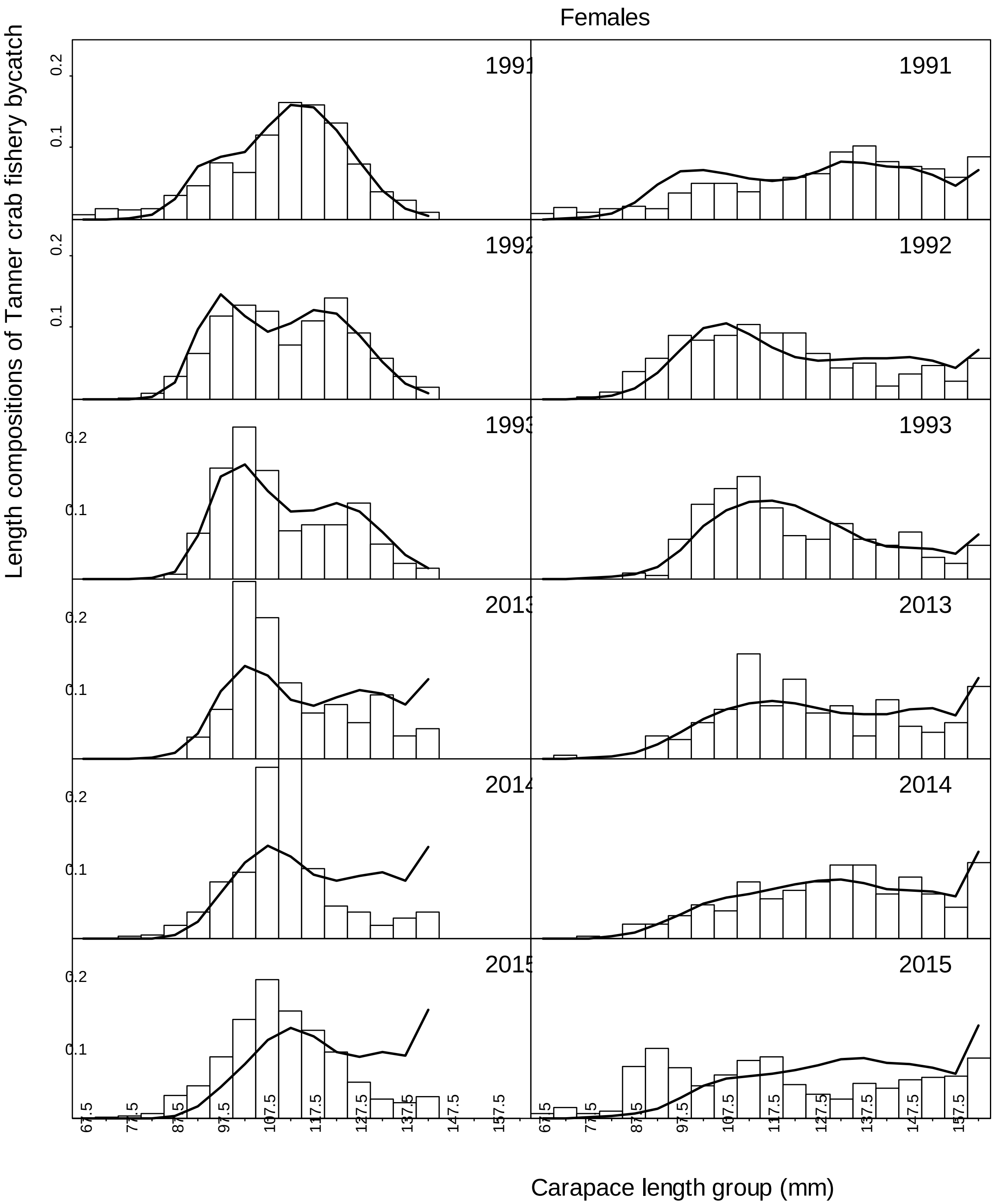


Figure 24(18.0d). Comparison of observer and model estimated discarded length frequencies of Bristol Bay red king crab by year in the Tanner crab fishery under model 18.0d. The sum of each sex length composition for each year is 1.0.

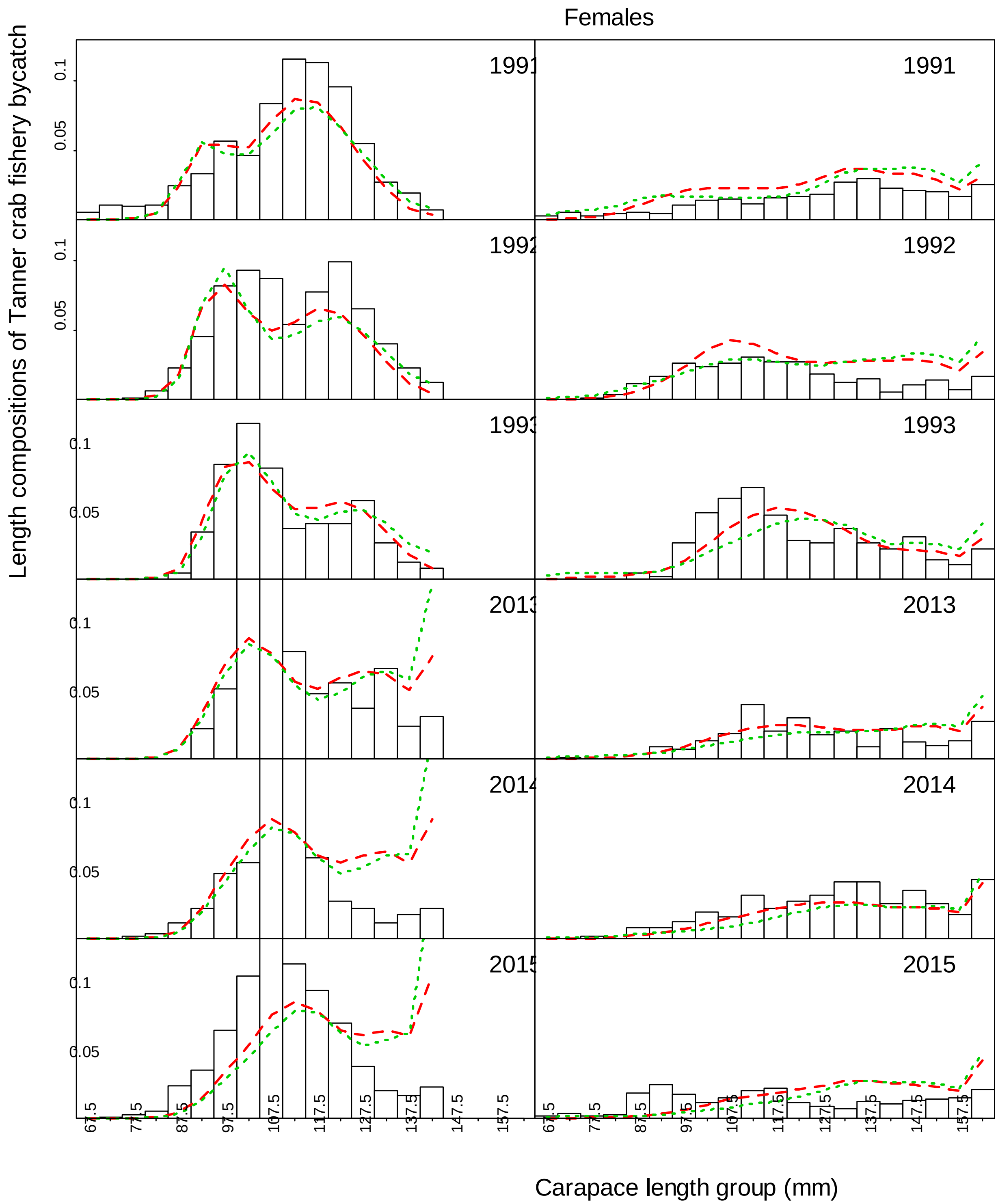


Figure 24(18.0e, & 19.0 (gmacs)). Comparison of observer and model estimated discarded length frequencies of Bristol Bay red king crab by year in the Tanner crab fishery under models 18.0e (dashed red) and 19.0 (green lines).

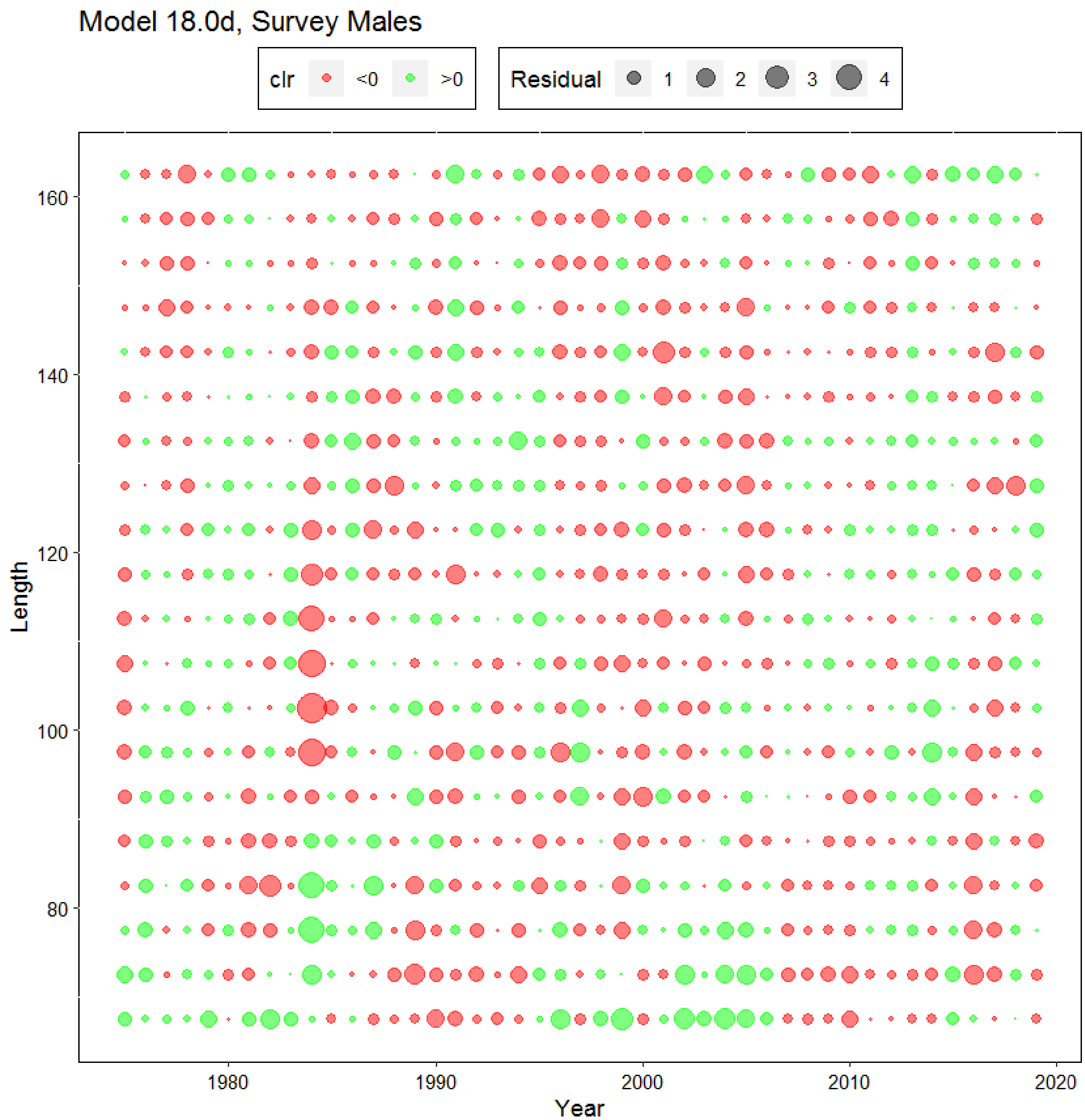


Figure 25(18.0d). Standardized residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 18.0d. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

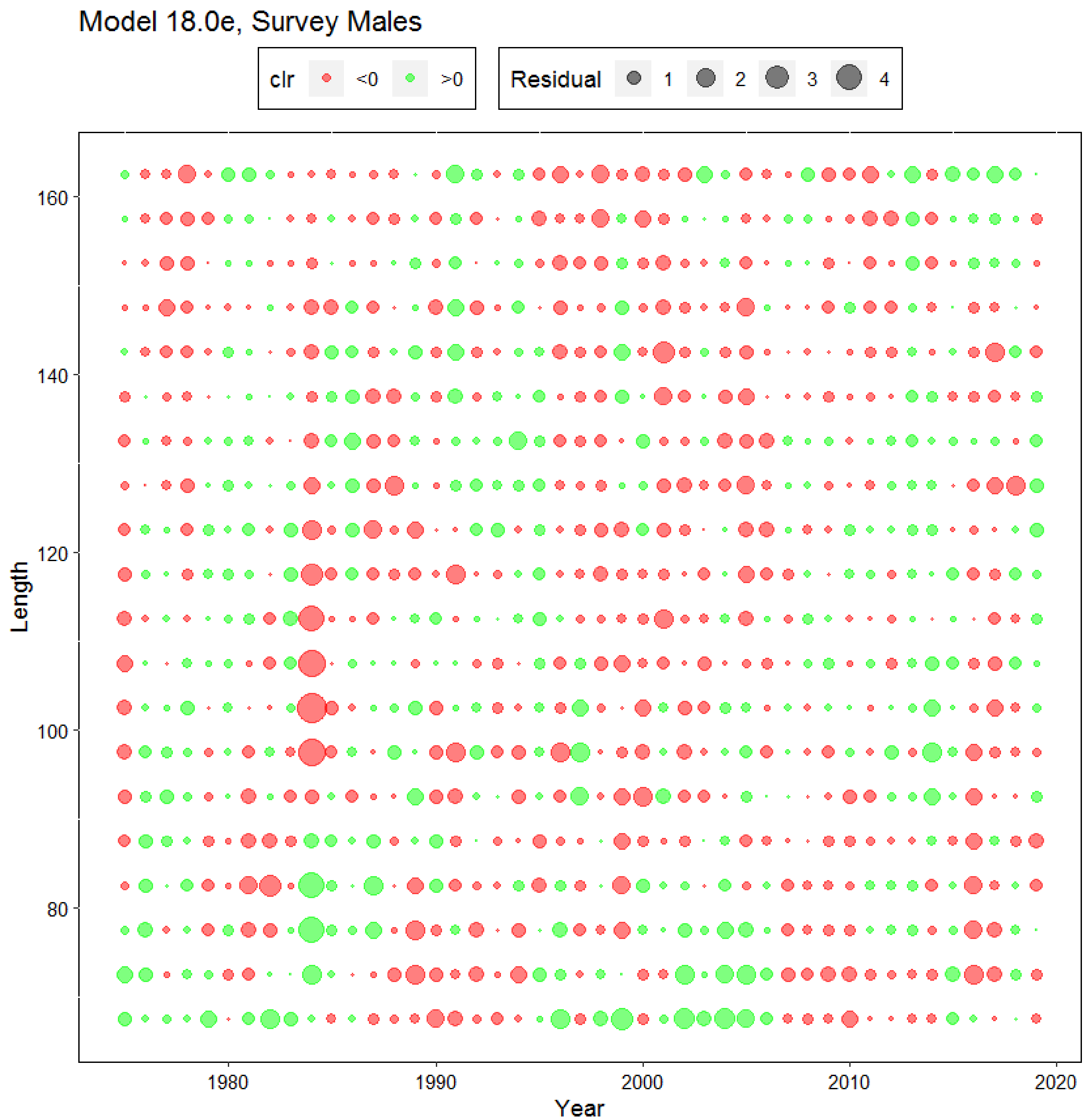


Figure 25(18.0e). Standardized residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 18.0e. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

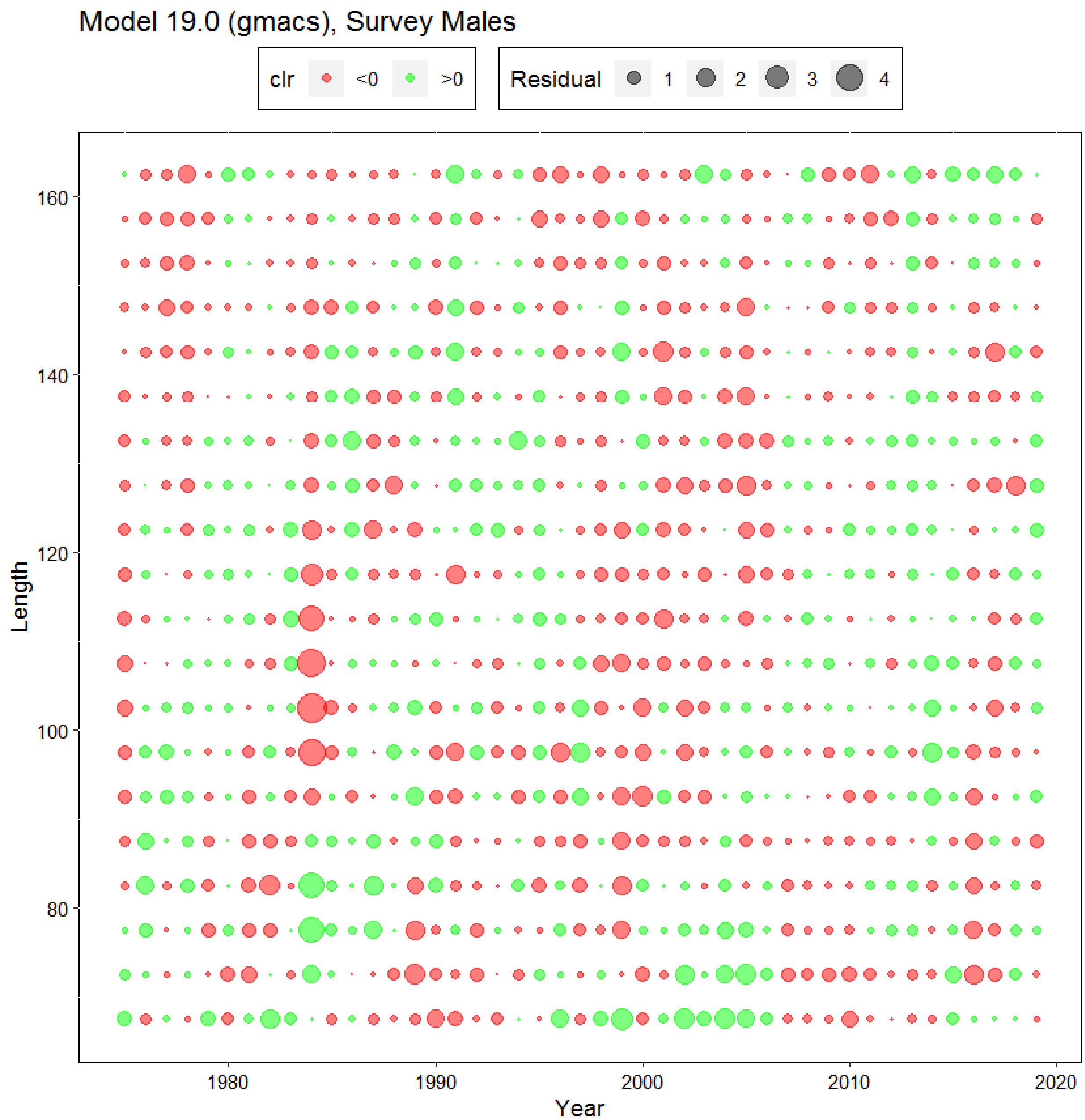


Figure 25(19.0 (gmacs)). Standardized residuals of proportions of NMFS survey male red king crab by year and carapace length (mm) under model 19.0. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

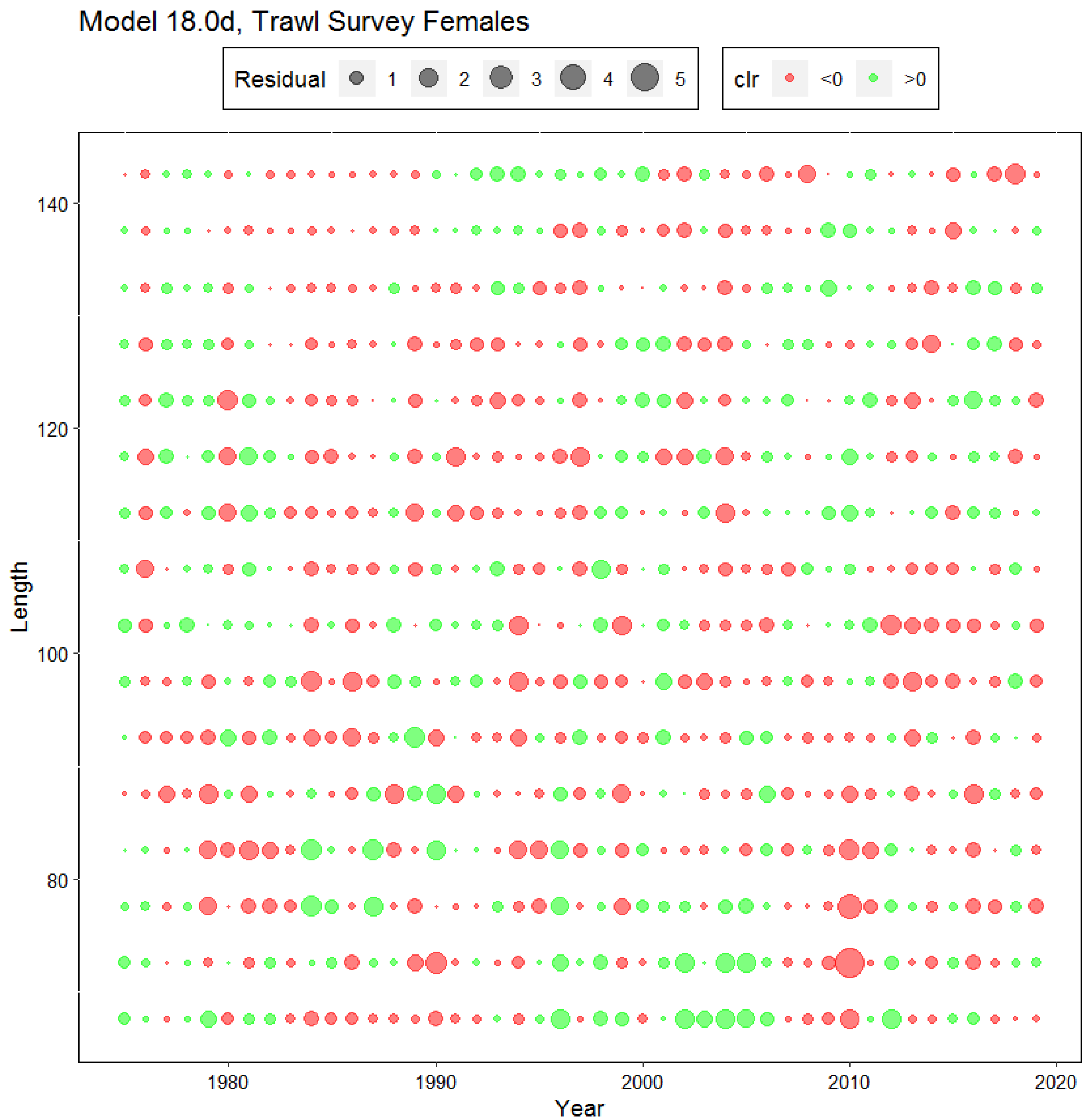


Figure 25(18.0d). Standardized residuals of proportions of NMFS survey female red king crab by year and carapace length (mm) under model 18.0d. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

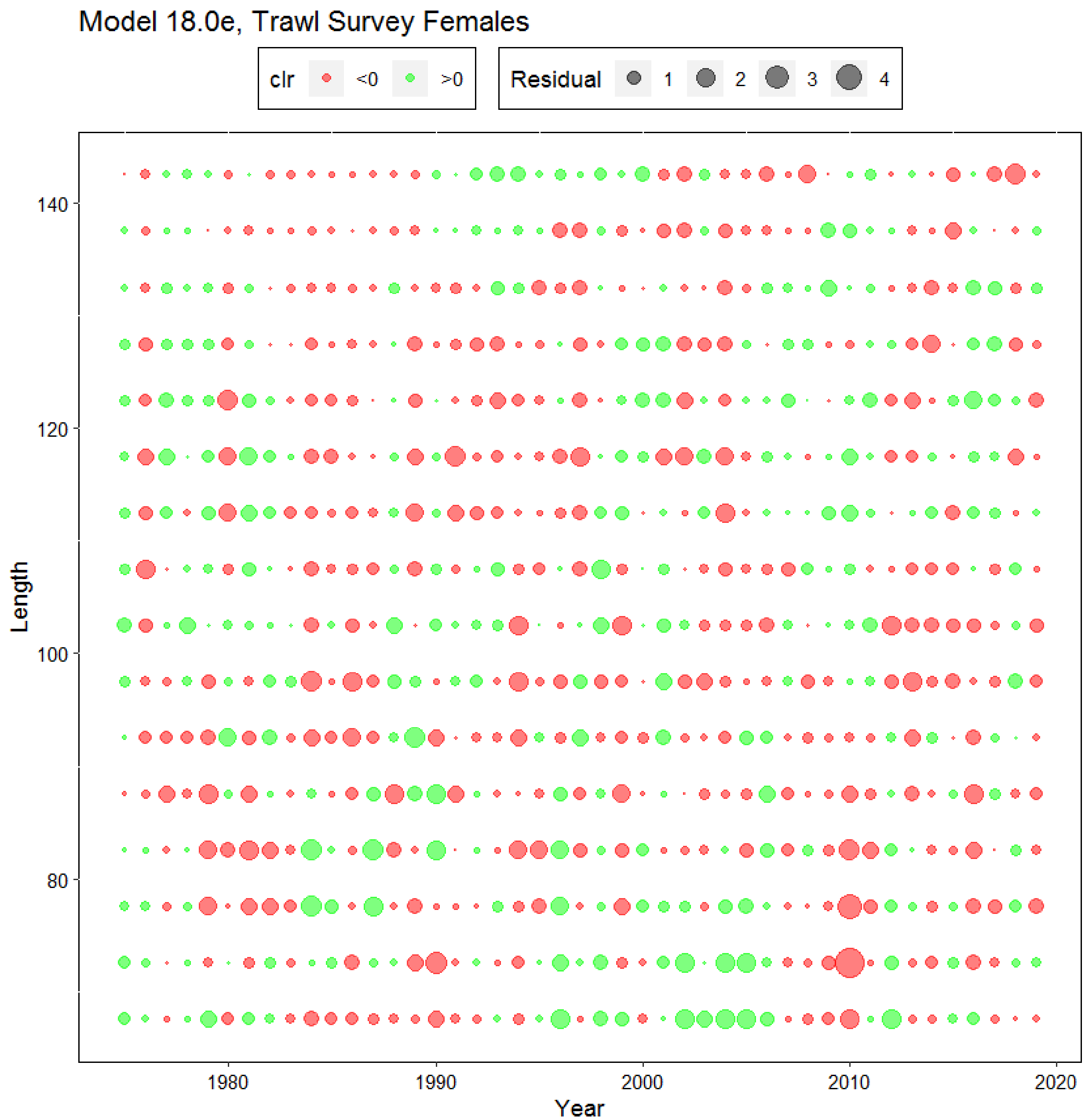


Figure 25(18.0e). Standardized residuals of proportions of NMFS survey female red king crab by year and carapace length (mm) under model 18.0e. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

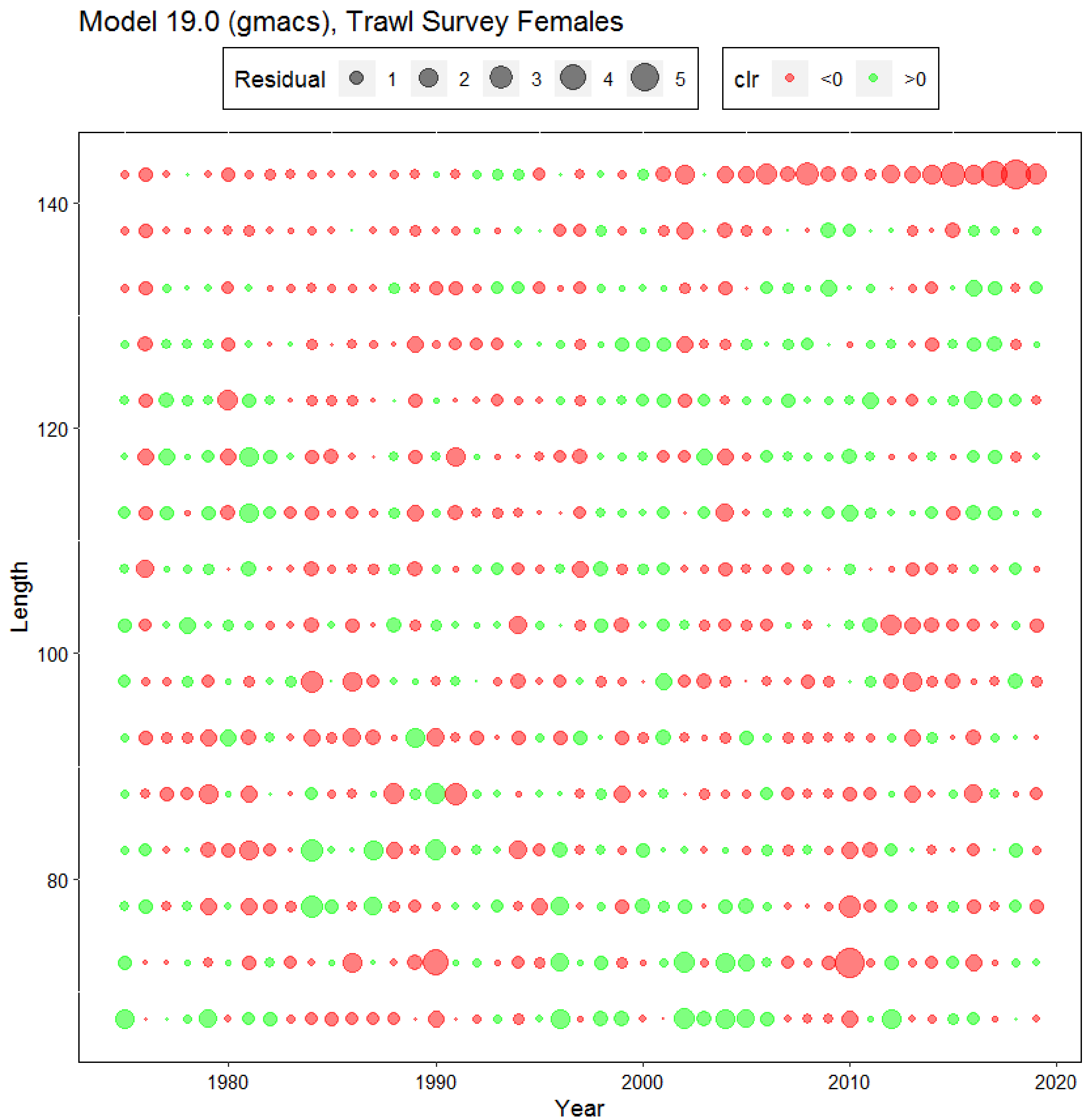
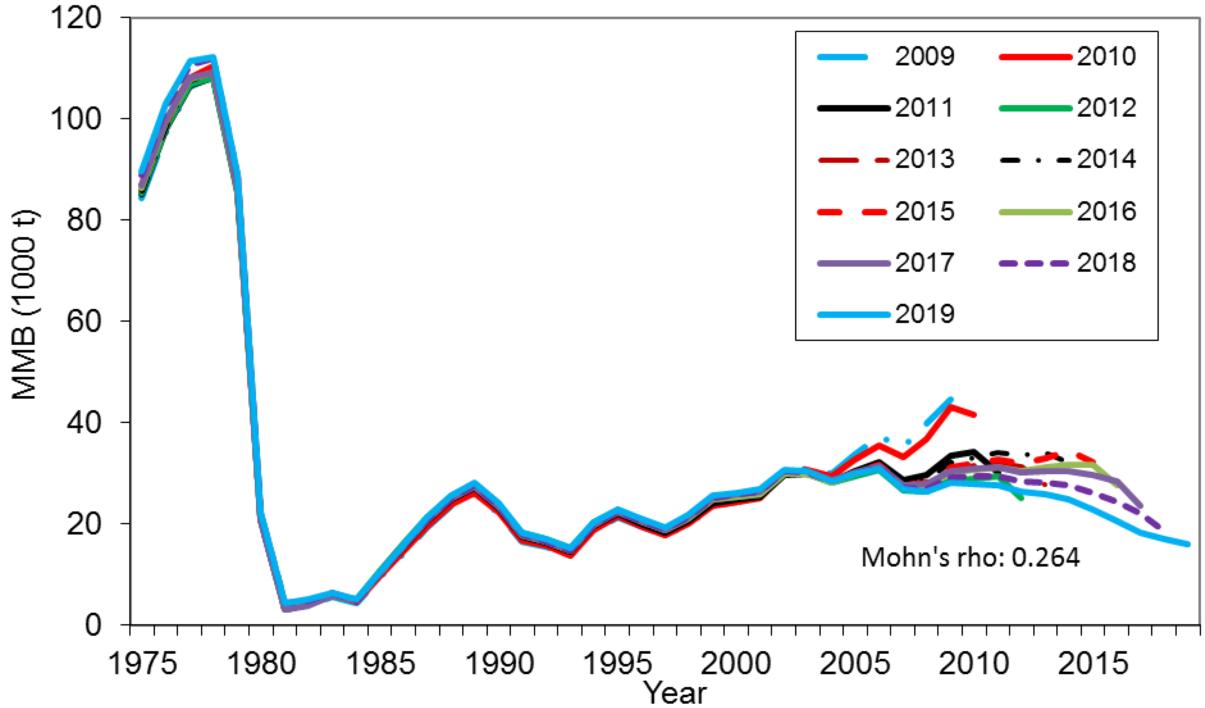


Figure 25(19.0 (gmacs)). Standardized residuals of proportions of NMFS survey female red king crab by year and carapace length (mm) under model 19.0. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.



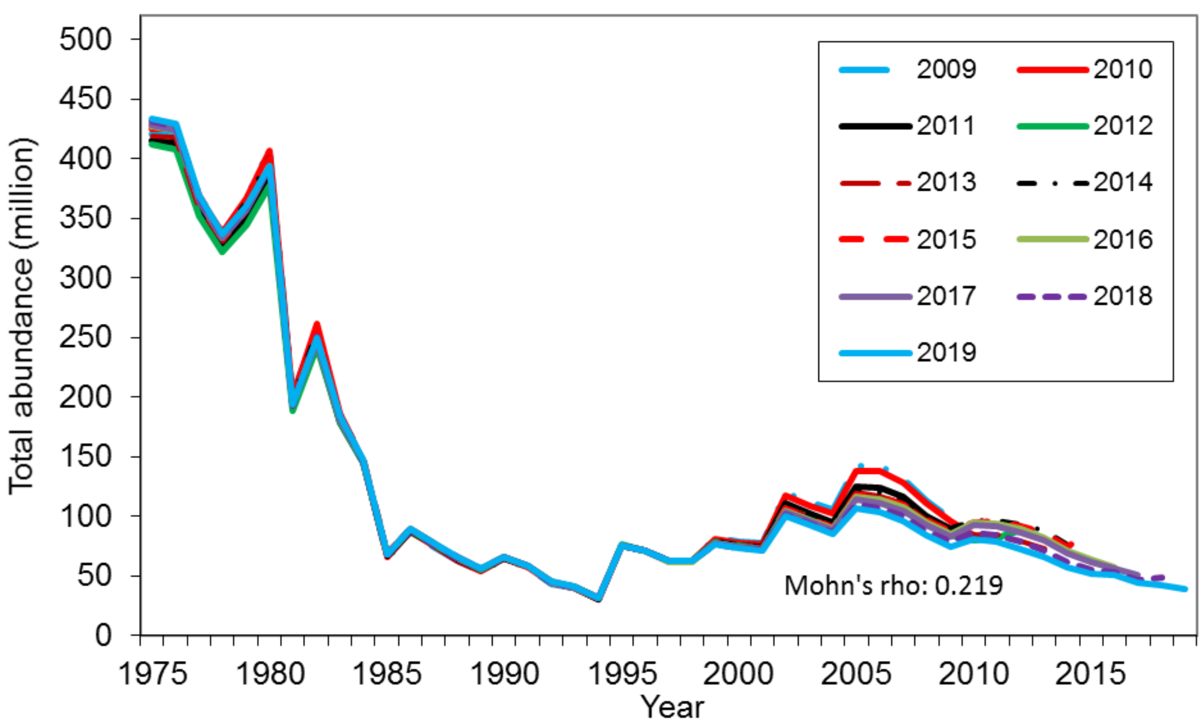


Figure 27. Comparison of hindcast estimates of mature male biomass on Feb. 15 (top) and total abundance (bottom) of Bristol Bay red king crab from 1975 to 2019 made with terminal years 2009-2019 with model 19.0 (gmacs). These are results of the 2019 model. Legend shows the terminal year. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

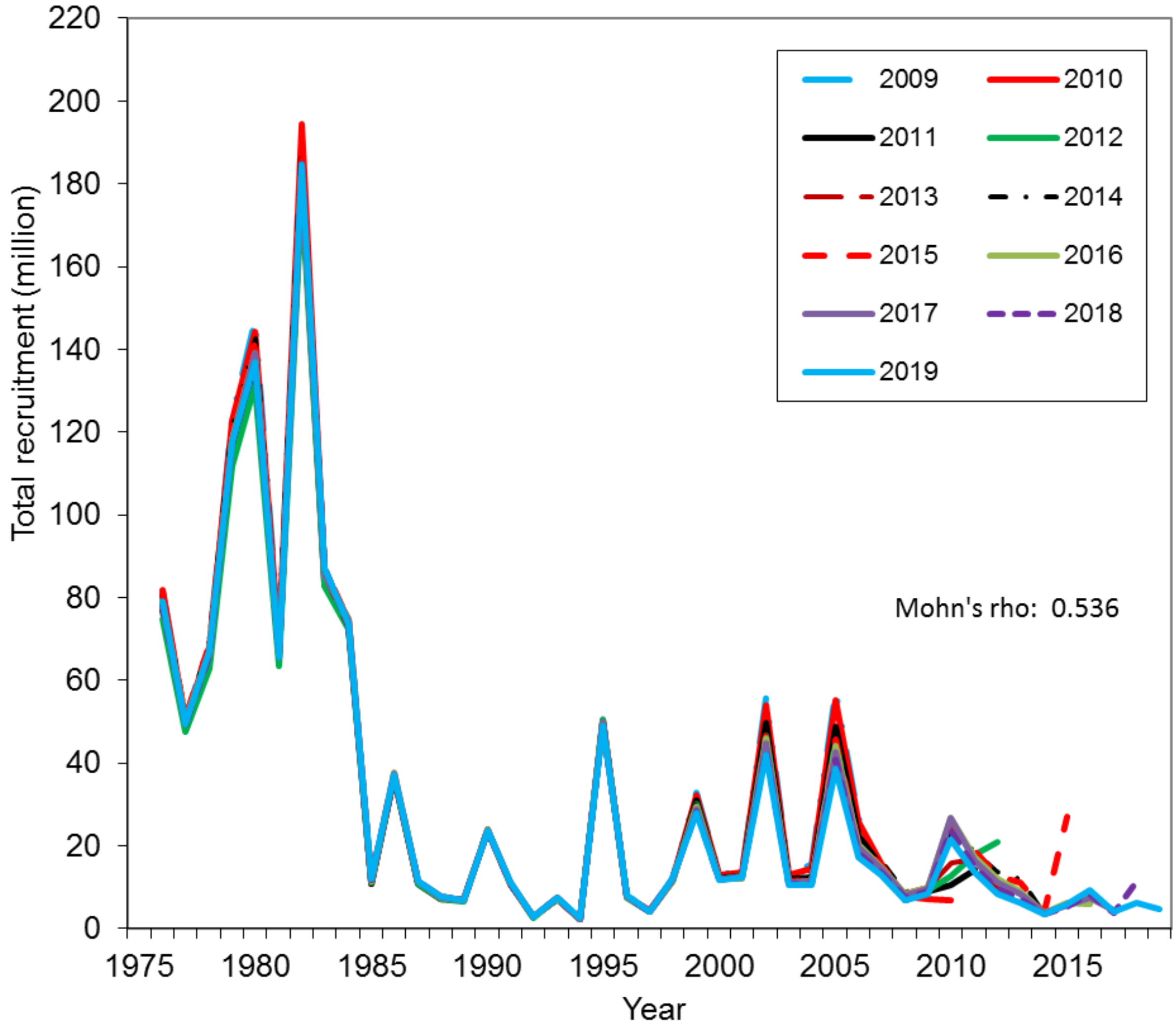


Figure 28a. Comparison of hindcast estimates of total recruitment for model 19.0 (gmacs) of Bristol Bay red king crab from 1976 to 2019 made with terminal years 2009-2019. These are results of the 2019 model. Legend shows the terminal year. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

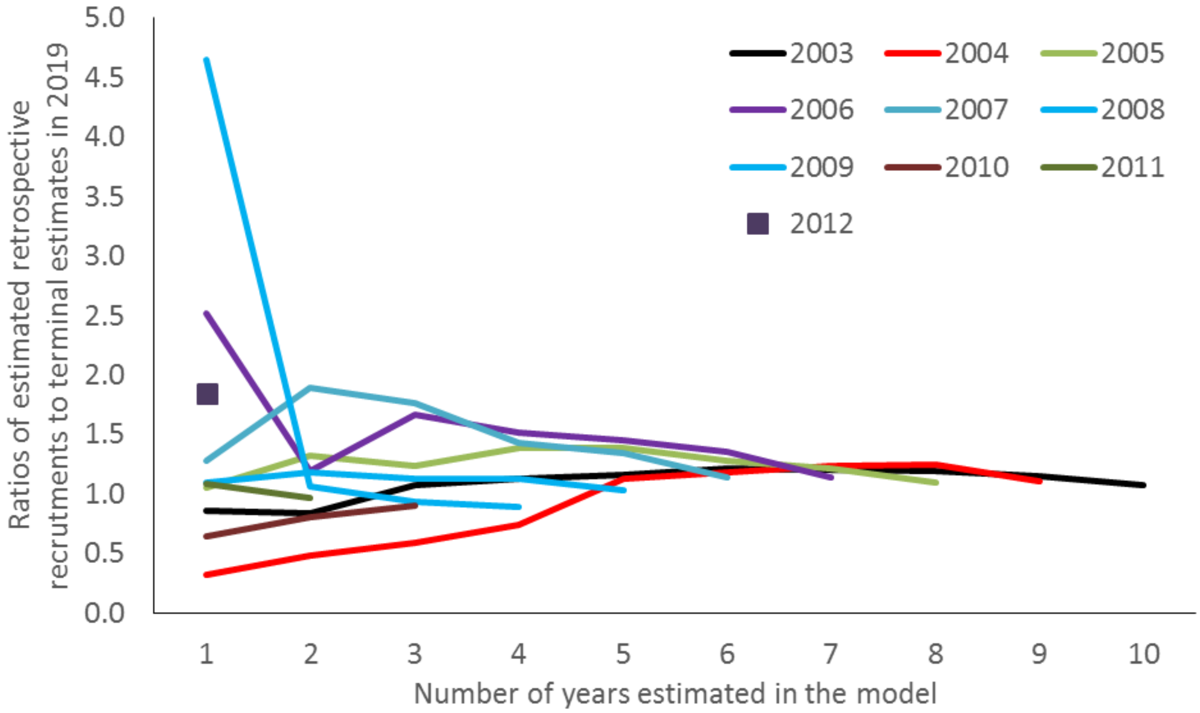


Figure 28b. Evaluation of Bristol Bay red king crab retrospective errors on recruitment estimates as a function of the number of years in the model for model 19.0 (gmacs).

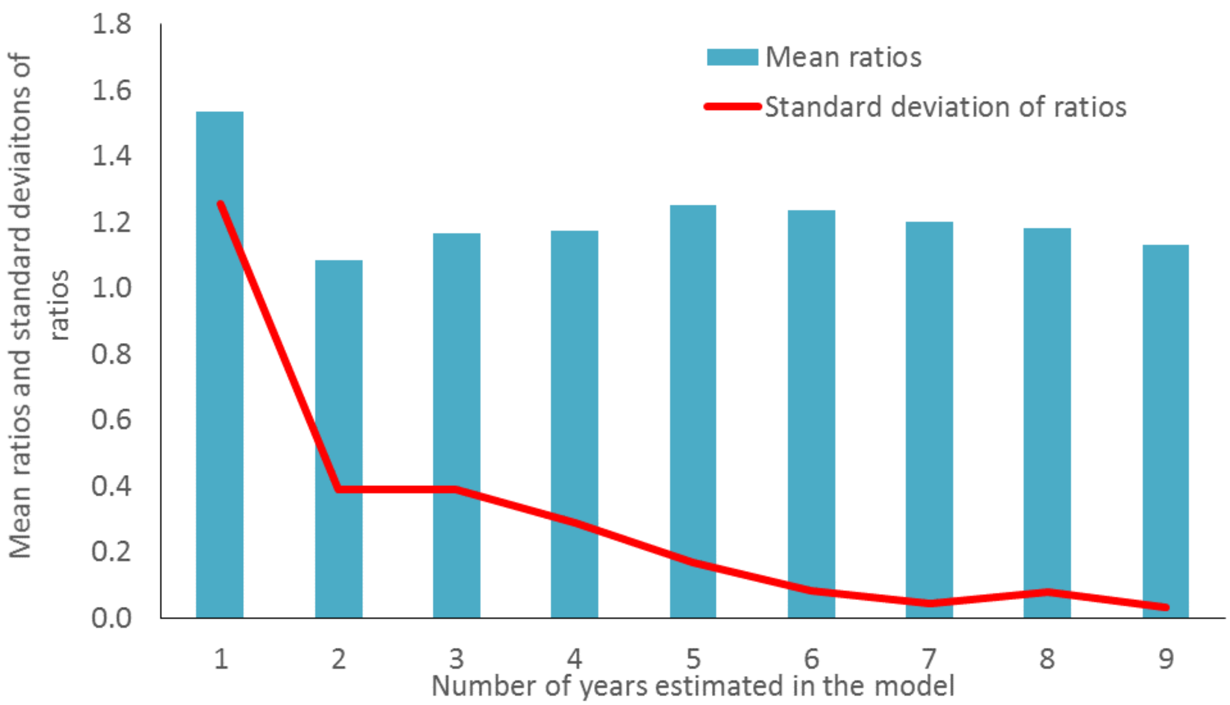


Figure 28c. Mean ratios of retrospective estimates of recruitments to those estimated in the most recent year (2019) and standard deviations of the ratios as a function of the number of years in the model for model 19.0 (gmacs).

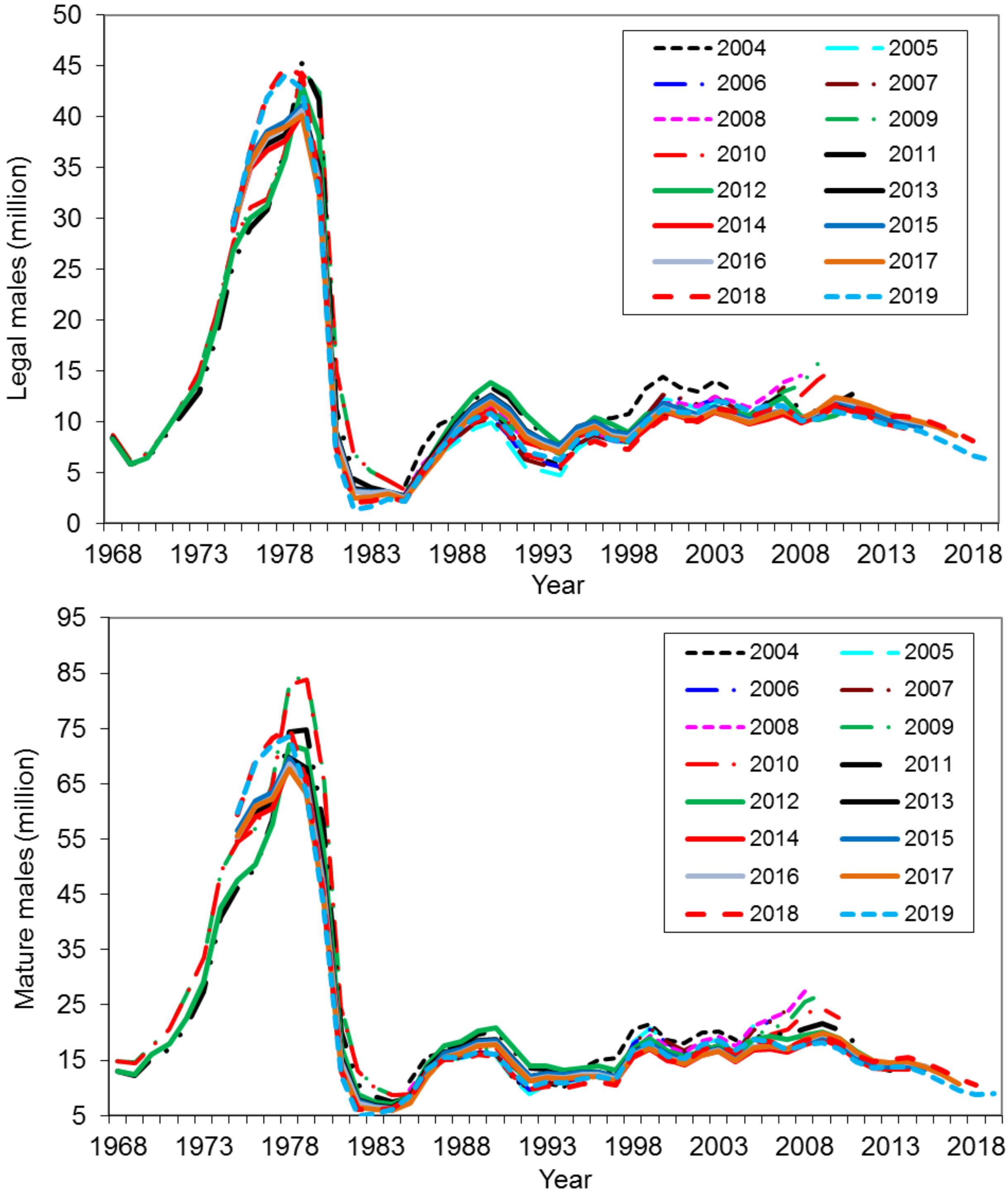


Figure 29. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1968 to 2019 made with terminal years 2004-2019 with the base models. Model 18.0e is used for 2019. These are results of historical assessments. Legend shows the year in which the assessment was conducted. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

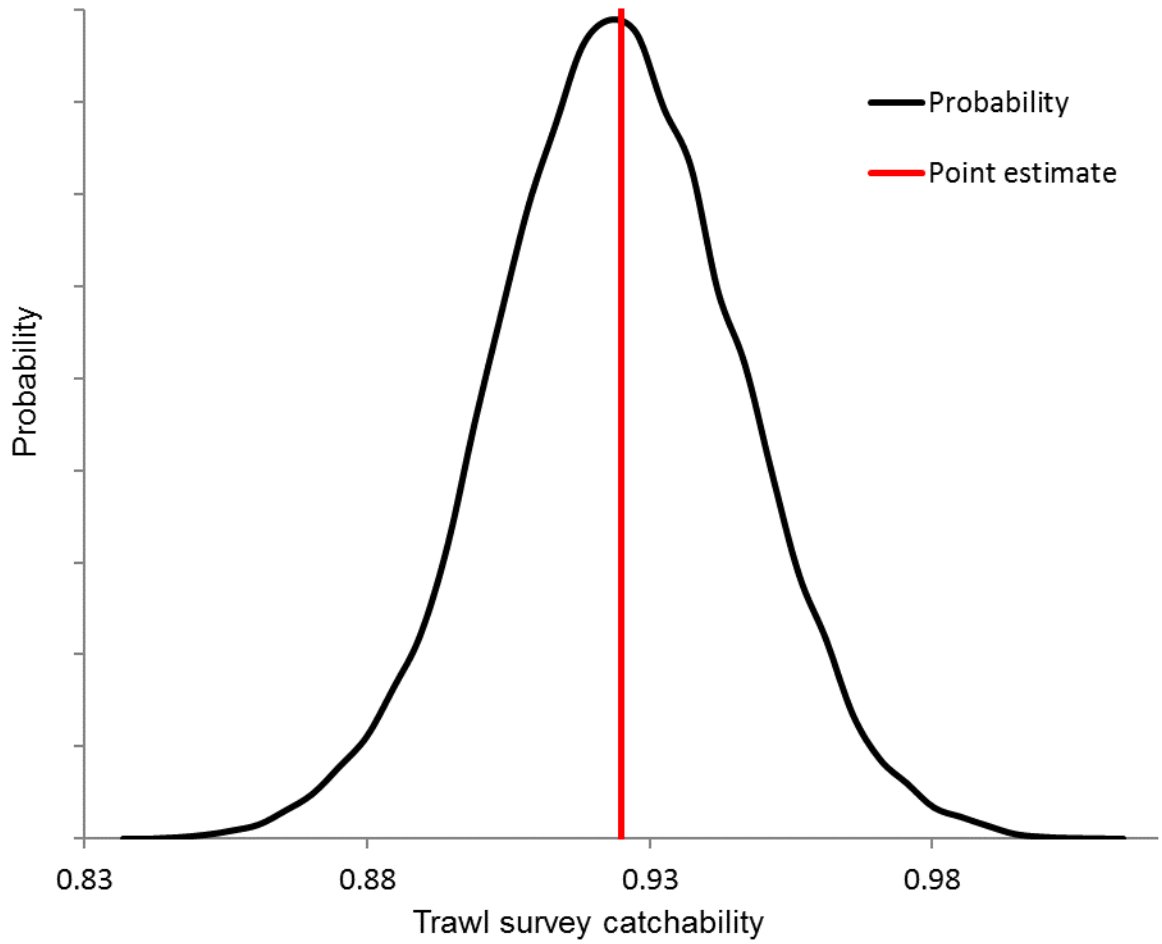


Figure 30. Probability distributions of estimated trawl survey catchability (*Q*) under model 18.0e with the mcmc approach. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

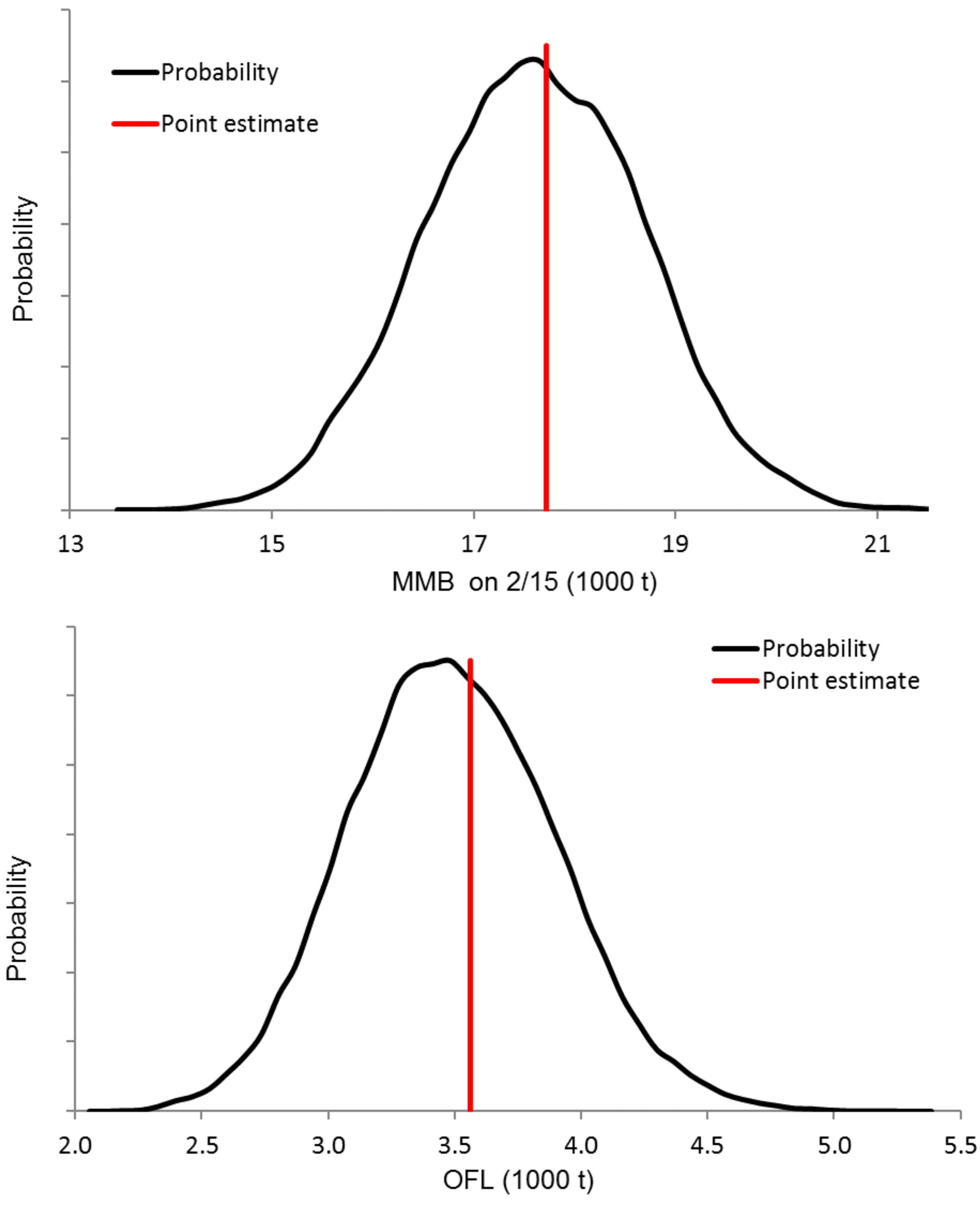


Figure 31. Probability distributions of estimated mature male biomass on Feb. 15, 2019 (upper panel) and probability distributions of the 2019 estimated OFL (lower panel) under model 18.0e with the mcmc approach. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively.

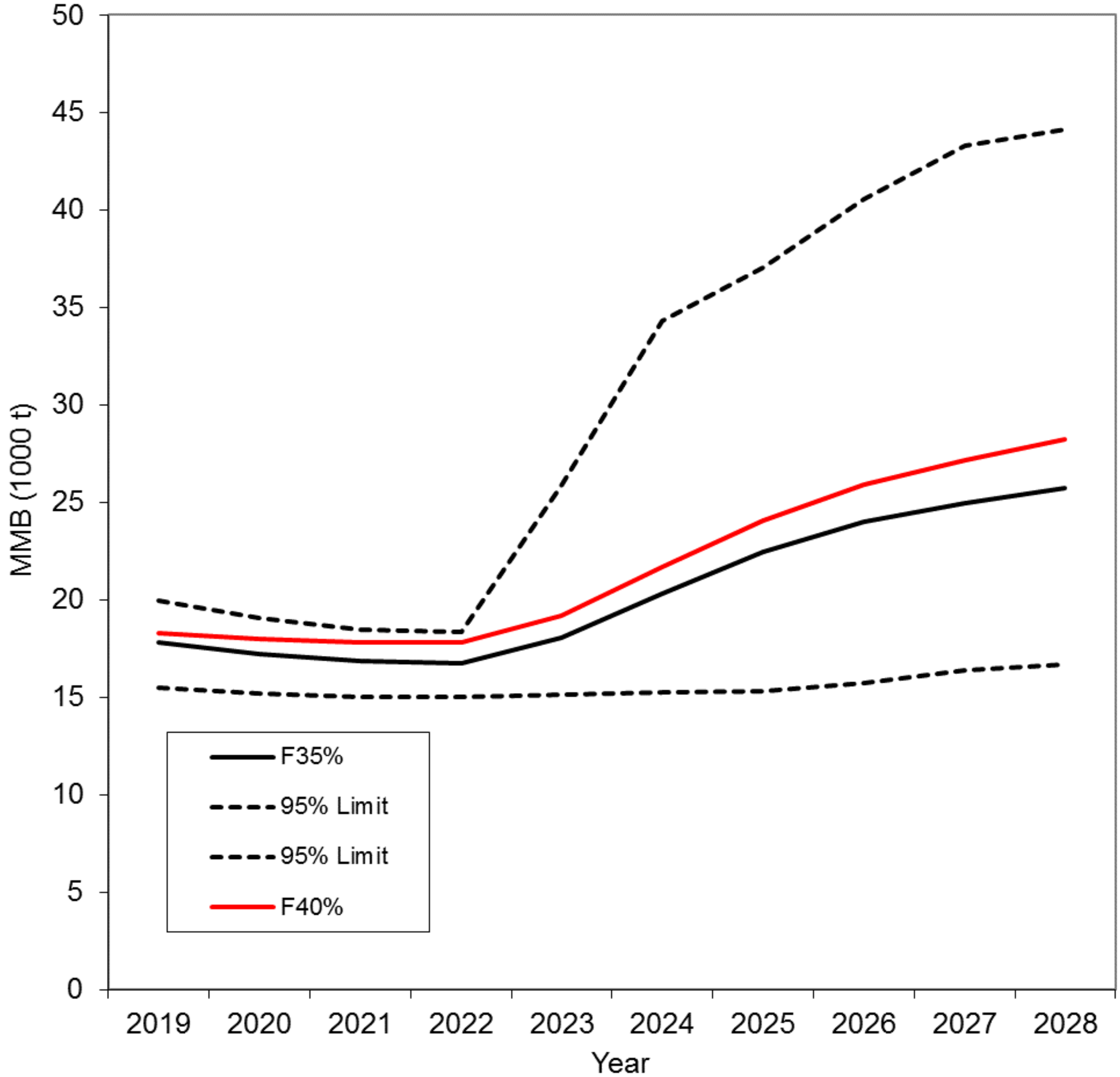


Figure 32. Projected mature male biomass on Feb. 15 with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2019-2029. Input parameter estimates are based on model 18.0e. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

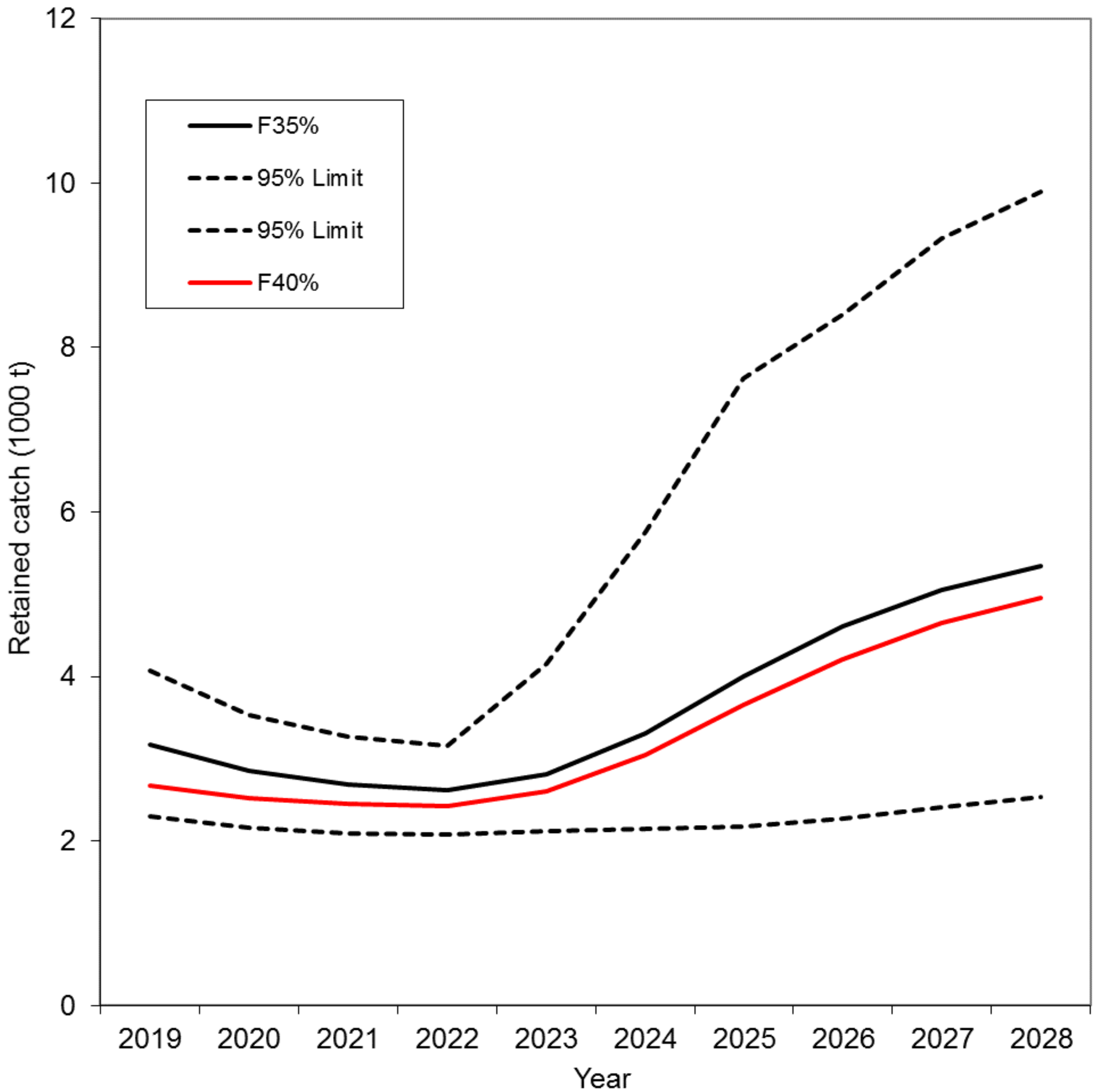


Figure 33. Projected retained catch biomass with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2019-2128. Input parameter estimates are based on model 18.0e. Pot, Tanner crab, fixed gear, and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5, and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

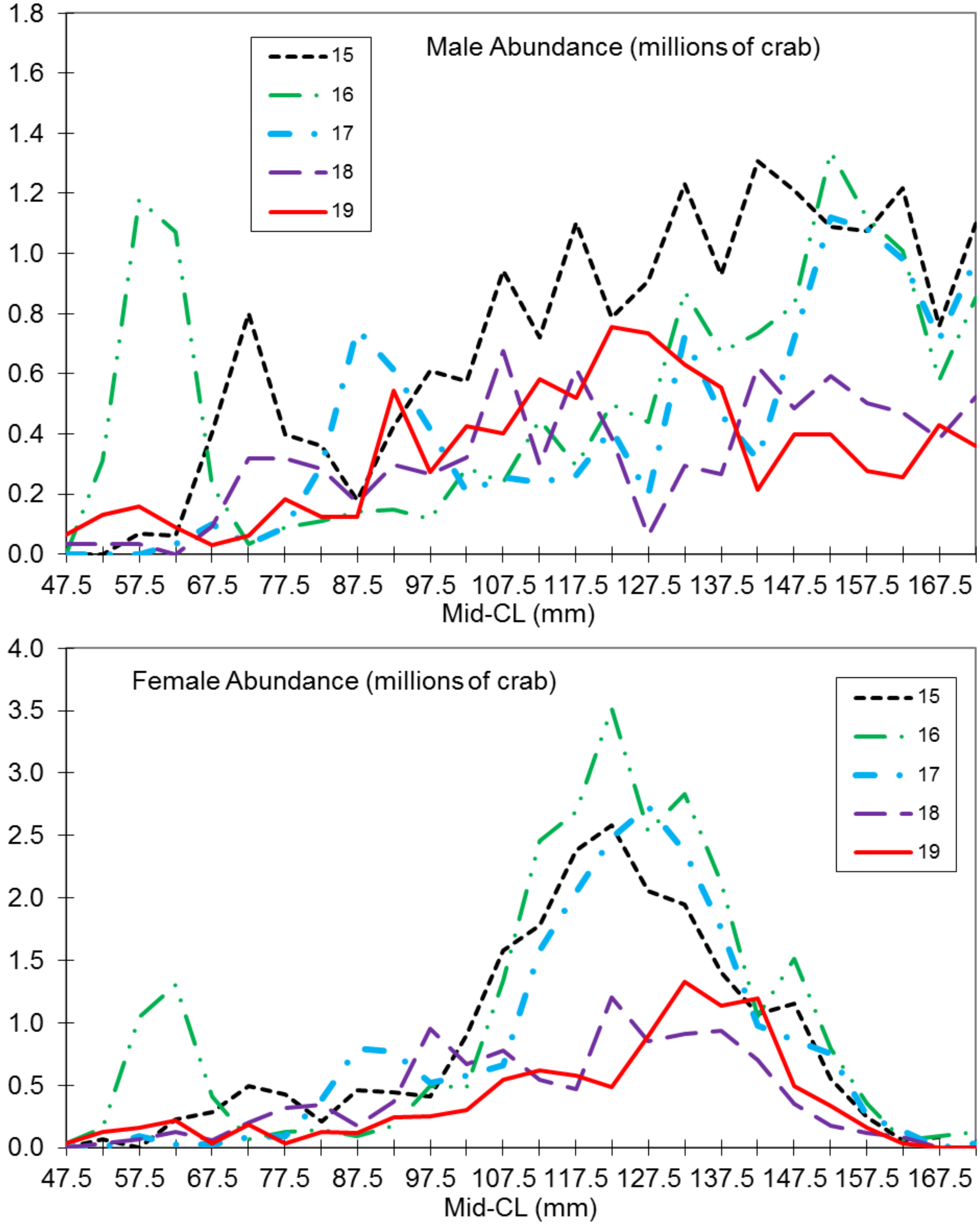


Figure 34. Length frequency distributions of male (top panel) and female (bottom panel) red king crab in Bristol Bay from NMFS trawl surveys during 2015-2019. For purposes of these graphs, abundance estimates are based on area-swept methods.

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

a. Model Description

i. Population model

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

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

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

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

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

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

where L_l is the mid-point of length-class *l*, ΔL the width of each size-class (5 mm carapace length), a^s_t, b^s_t the parameters of the length–growth increment relationship for sex *s* and year *t*, and

β^s the parameter determining the variance of the growth increment. Growth is time-invariant for males, and specified for three time-blocks for females (1968-82; 1983-93; 1994-2019) based on changes to the size at maturity for females. The probability of moulting as a function of length for males is given by an inverse logistic function, i.e.:

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

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

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

ii. Catches and Fisheries Selectivities

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

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

$$G^s_{l,t} = (N^s_{l,t} + O^s_{l,t}) e^{-y_t M^s_t} (1 - e^{-F^s_{l,t}}) \tag{A4}$$

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

$$F^s_{l,t} = \begin{cases} \left[S^{tot,mal}_l S^{ret}_{l,t} + S^{tot,mal}_l \left(1 - S^{ret}_{l,t}\right)\emptyset\right] F^{dir}_t & if\ s = \ mal \\ S^{dir,disc,fem}_l F^{disc,fem}_t & if\ s = fem \end{cases} \tag{A5}$$

where $S^{tot,mal}_l$ is the total male selectivity in the directed fishery, $S^{ret}_{l,t}$ the retained proportions of males in the directed fishery, F^{dir}_t the fully-selected fishing mortality during year *t* (on males),

$S_l^{\mathrm{dir,disc},s}$ the selectivity pattern for the discards in the directed fishery by sex, $F_t^{disc,fem}$ the fully-selected fishing mortality on female animals during year *t* related to discards in the directed fishery, and ϕ the handling mortality (the proportion of animals which die due to being returned to the water following capture).

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

$$C_{l,t}^{mal} = \left(N_{l,t}^{mal} + O_{l,t}^{mal}\right) e^{-y_t\, M_t^{mal}} \left(1 - e^{-S_l^{tot,mal} S_{l,t}^{ret} F_t^{dir}}\right) \quad \text{(A6)}$$

$$D_{l,t}^{mal} = G_{l,t}^{mal} - C_{l,t}^{mal} \quad \text{(A7)}$$

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

$$T_{l,t}^{s} = (N_{l,t}^{s} + O_{l,t}^{s})\, e^{-j_t M_t^s}\, e^{-F_{l,t}^s}\, (1 - e^{-\tilde{F}_{l,t}^s}) \quad \text{(A8)}$$

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

$$\tilde{F}_{l,t}^{s} = S_l^{Tanner,s}\, F_t^{Tanner,s} + S_l^{trawl}\, F_t^{trawl} + S_l^{fix}\, F_t^{fix} \quad \text{(A9)}$$

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

The bycatches by sex are estimated from the Tanner crab fishery, $TC_{l,t}^{s}$, groundfish trawl fishery, $GT_{l,t}^{s}$, and groundfish fixed gear fishery, $GF_{l,t}^{s}$, as follow:

$$\begin{aligned}
TC_{l,t}^{s} &= (N_{l,t}^{s} + O_{l,t}^{s}) e^{-j_t M_t^s}\, e^{-F_{l,t}^s}\, (1 - e^{-\tilde{F}_{l,t}^s})\, S_l^{Tanner,s}\, F_t^{Tanner,s} / \tilde{F}_{l,t}^{s} \\
GT_{l,t}^{s} &= (N_{l,t}^{s} + O_{l,t}^{s}) e^{-j_t M_t^s}\, e^{-F_{l,t}^s}\, (1 - e^{-\tilde{F}_{l,t}^s})\, S_l^{trawl}\, F_t^{trawl} / \tilde{F}_{l,t}^{s} \qquad \text{(A10)} \\
GF_{l,t}^{s} &= (N_{l,t}^{s} + O_{l,t}^{s}) e^{-j_t M_t^s}\, e^{-F_{l,t}^s}\, (1 - e^{-\tilde{F}_{l,t}^s})\, S_l^{fixed}\, F_t^{fixed} / \tilde{F}_{l,t}^{s}
\end{aligned}$$

For models separating mature and immature crab, discarded female bycatch in numbers is separated into immature and mature bycatches. The female bycatches in the directed fishery in length-class *l* and during year *t*, $D_{l,t}^{i}$ and $D_{l,t}^{m}$, and $T_{l,t}^{i}$ and $T_{l,t}^{m}$, are:

$$\begin{aligned}
D_{l,t}^{i} &= N_{l,t}^{i}\, e^{-y_t M_t^{fem}} (1 - e^{-F_{l,t}^{fem}}) \\
D_{l,t}^{m} &= N_{l,t}^{m}\, e^{-y_t M_t^{fem}} (1 - e^{-F_{l,t}^{fem}})
\end{aligned} \qquad \text{(A11)}$$

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

$$T_{l,t}^{i} = N_{l,t}^{i}\, e^{-j_t M_t^{fem}} e^{-F_{l,t}^{fem}} (1 - e^{-\tilde{F}_{l,t}^{fem}})$$
$$T_{l,t}^{m} = N_{l,t}^{m}\, e^{-j_t M_t^{fem}} e^{-F_{l,t}^{fem}} (1 - e^{-\tilde{F}_{l,t}^{fem}}) \qquad \text{(A12)}$$

Selectivity for females in the directed fishery, $S^{\mathrm{dir,disc,fem}}$, total male selectivity, $S_l^{tot,mal}$, retained proportions, $S_{l,t}^{ret}$, selectivities for males and females in the groundfish trawl and fixed gear fisheries, S^{trawl} and S^{fix}, and selectivity for males and females in the Tanner crab fishery, $S^{\mathrm{Tanner},s}$, are all assumed to be logistic functions of length:

$$S_l^{type} = \frac{1}{1 + e^{-\beta^{type}\,(\iota - L_{50}^{type})}} \qquad \text{(A13)}$$

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

iii. Trawl Survey Selectivities

Trawl survey selectivities are estimated as

$$S_{l,t}^{s} = \frac{Q}{1 + e^{-\beta_t^{s}\,(\iota - L_{50,t}^{s})}} \qquad \text{(A14)}$$

with different sets of parameters (β, L_{50}) estimated for males and females as well as two different periods (1975-81 and 1982-19). Survey selectivity for the first length group (67.5 mm) was assumed to be the same for both males and females, so only three parameters (β, L_{50} for females and L_{50} for males) were estimated in the model for each of the four periods. Parameter Q was called the survey catchability that was estimated based on a trawl experiment by Weinberg et al. (2004; Figure A1). Q was assumed to be constant over time.

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

iv. *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

$$F_t^{disc,s} = r^s \; F_t^{dir} \tag{A15}$$

where r^s is the median 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):

$$F_t^{Tanner,s} = a^s \; E_t \tag{A16}$$

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

c. Likelihood Components

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

$$Rf = \prod_{l=1}^{L} \prod_{t=1}^{T} \coprod_{s=1}^{2} \prod_{sh=1}^{2} \frac{\left\{ exp\left[-\frac{\left(p_{l,t,s,sh} - \hat{p}_{l,t,s,sh}\right)^2}{2\sigma_{l,t,s,sh}^2} \right] + 0.01 \right\}}{\sqrt{2\pi\sigma_{l,t,s,sh}^2}} \tag{A17}$$

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

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:

$$Length\ compositions:\ -\sum \ln(Rf_i)$$

$$Catch\ and\ bycatch\ biomasses:\ \lambda_j \sum \left[ln\left(\frac{C_t}{\hat{C}_t}\right)^2\right]$$

$$NMFS\ survey\ biomass:\ \sum\left[ln\left(ln\left(CV_t^{\ 2}\ +1\right)\right)^{0.5} + \frac{ln\left(\frac{B_t}{\hat{B}_t}\right)^2}{2ln\left(\left(CV_t^{\ 2}+1\right)\right)}\right]$$

$$BSFRF\ survey\ biomass:\ \sum\left[ln\left(ln\left(CV_t^{\ 2}\ +AV^2+1\right)\right)^{0.5} + \frac{ln\left(\frac{B_t}{\hat{B}_t}\right)^2}{\left(2ln\left(CV_t^{\ 2}+AV^2+1\right)\right)}\right]$$

$$R\ variation:\ \lambda_R \sum \left[ln\left(\frac{R_t}{\bar{R}}\right)^2\right] \qquad \text{(A18)}$$

$$R\ sex\ ratio:\ \lambda_s \sum \left[ln\left(\frac{\bar{R}_M}{\bar{R}_F}\right)^2\right]$$

$$Groundfish\ bycatch\ fishing\ mortalities:\ \lambda_t \sum \left[ln\left(\frac{F_{t,gf}}{\bar{\bar{F}}_{gf}}\right)^2\right]$$

$$Pot\ female\ bycatch\ fishing\ mortalities:\ \lambda_p \sum \left[ln\left(\frac{F_{t,f}}{\bar{\bar{F}}_{f}}\right)^2\right]$$

$$Trawl\ survey\ catchability:\ \frac{(Q-\hat{Q})^2}{2\sigma^2}$$

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 500 for retained catch biomass, 300 for total directed pot fishery male biomass, 100 for all pot bycatch biomasses, and 50 for groundfish bycatch biomasses (trawl and fixed gear fisheries), 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 0.03, 0.04, 0.07, 0.1, 0.53, 0.23, 3.34, and 12.14, respectively, representing prior assumptions about the accuracy of the observed catch biomass data.

d. Population State in Year 1.

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

e. Parameter estimation framework:

i. Parameters estimated independently

Basic natural mortality, length-weight relationships, and mean growth increments per molt were estimated independently outside of the model. Mean length of recruits to the model depends on growth and was assumed to be 72.5 for both males and females. 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.

(1). Natural Mortality

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

(2). Length-weight Relationship

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

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

Ovigerous Females: $W = 0.003593\, L^{2.666076}$ (A18)

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

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

(3). Growth Increment per Molt

A variety of data are available to estimate male mean growth increment per molt for Bristol Bay RKC. Tagging studies were conducted during the 1950s, 1960s and 1990s, and mean growth increment per molt data from these tagging studies in the 1950s and 1960s were analyzed by Weber and Miyahara (1962) and Balsiger (1974). Modal analyses were conducted for the data during 1957-1961 and the 1990s (Weber 1967; Loher et al. 2001). Mean growth increment per molt may be a function of body size and shell condition and vary over time (Balsiger 1974; McCaughran and Powell 1977); however, for simplicity, mean growth increment per molt was assumed to be only a function of body size in the models. Tagging data were used to estimate mean growth increment per molt as a function of pre-molt length for males (Figure A2). The results from modal analyses of 1957-1961 and the 1990s were used to estimate mean growth increment per molt for immature females during 1975-1993 and 1994-2019, respectively, and the data presented in Gray (1963) were used to estimate those for mature females for scenarios 1, 1n and 2 (Figure A2). To make a smooth transition of growth increment per molt from immature to mature females, weighted growth increment averages of 70% and 30% at 92.5 mm CL pre-molt length and 90% and 10% at 97.5 mm CL were used, respectively, for mature and immature females during 1983-1993. These percentages are roughly close to the composition of maturity. During 1975-1982, females matured at a smaller size, so the growth increment per molt as a function of length was shifted to smaller increments. Likewise, during 1994-2019, females matured at a slightly higher size, so the growth increment per molt was shifted to high increments for immature crab (Figure A2). Once mature, the growth increment per molt for male crab decreases slightly and annual molting probability decreases, whereas the growth increment for female crab decreases dramatically but annual molting probability remains constant at 1.0 (Powell 1967).

(4). Sizes at Maturity for Females

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

(1975-82, 1983-93, and 1994-2019).

(5). Sizes at Maturity for Males

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

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

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

Bristol Bay red king crab abundance had declined sharply during the early 1980s. Many factors have been speculated for this decline: (i) completely wiped out by fishing: the directed pot fishery, the other directed pot fishery (Tanner crab fishery), and bottom trawling; and (ii) high fishing and natural mortality. With the survey abundance, harvest rates in 1980 and 1981 were among the highest, thus the directed fishing definitely had a big impact on the stock decline, especially legal and mature males. However, for the sharp decline during 1980-1984 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^o W. No absolute red king crab bycatch estimates are available until 1991. So there are insufficient data to fully evaluate the impact. Retained catch and potlifts from the eastern Bering Sea Tanner crab fishery are illustrated in Figure A5. The observed red king crab bycatch in the Tanner crab fishery during 1991-1993 and total potlifts east of 163^o W during 1968 to 2005 were used to estimate the bycatch mortality in the current model. Because winter sea surface temperatures and air temperatures were warmer (which means a lower handling mortality rate) and there were fewer potlifts during the early 1980s than during the early 1990s, bycatch in the Tanner crab fishery is unlikely to have been a main factor for the sharp decline of Bristol Bay red king crab.

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

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

ii. Parameters estimated conditionally

The following model parameters were estimated for male and female crab: total recruits for each year (year class strength R_t for t = 1976 to 2019), total abundance in the first year (1975), growth parameter β, and recruitment parameter β_r for males and females separately. Molting probability parameters β and L_{50} were also estimated for male crab. Estimated parameters also include β and L_{50} for retained selectivity, β and L_{50} for pot-discarded female selectivity, β and L_{50} for pot-discarded male and female selectivities from the eastern Bering Sea Tanner crab fishery, β and L_{50} for groundfish trawl discarded selectivity, φ, κ and γ for pot-discarded male selectivity, and β for trawl survey selectivity and L_{50} for trawl survey male and females separately. The NMFS survey catchabilities Q for some models were also estimated. Three selectivity parameters were estimated for the survey data from the Bering Fisheries Research Foundation. Annual fishing mortalities were also estimated for the directed pot fishery for males (1975-2018), pot-discarded females from the directed fishery (1990-2018), 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 (1996-2018). Three additional mortality parameters for Mm_t and Mf_t were also estimated. Some estimated parameters were constrained in the model. For example, male and female recruitment estimates were forced to be close to each other for a given year.

f. Definition of model outputs.

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

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

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

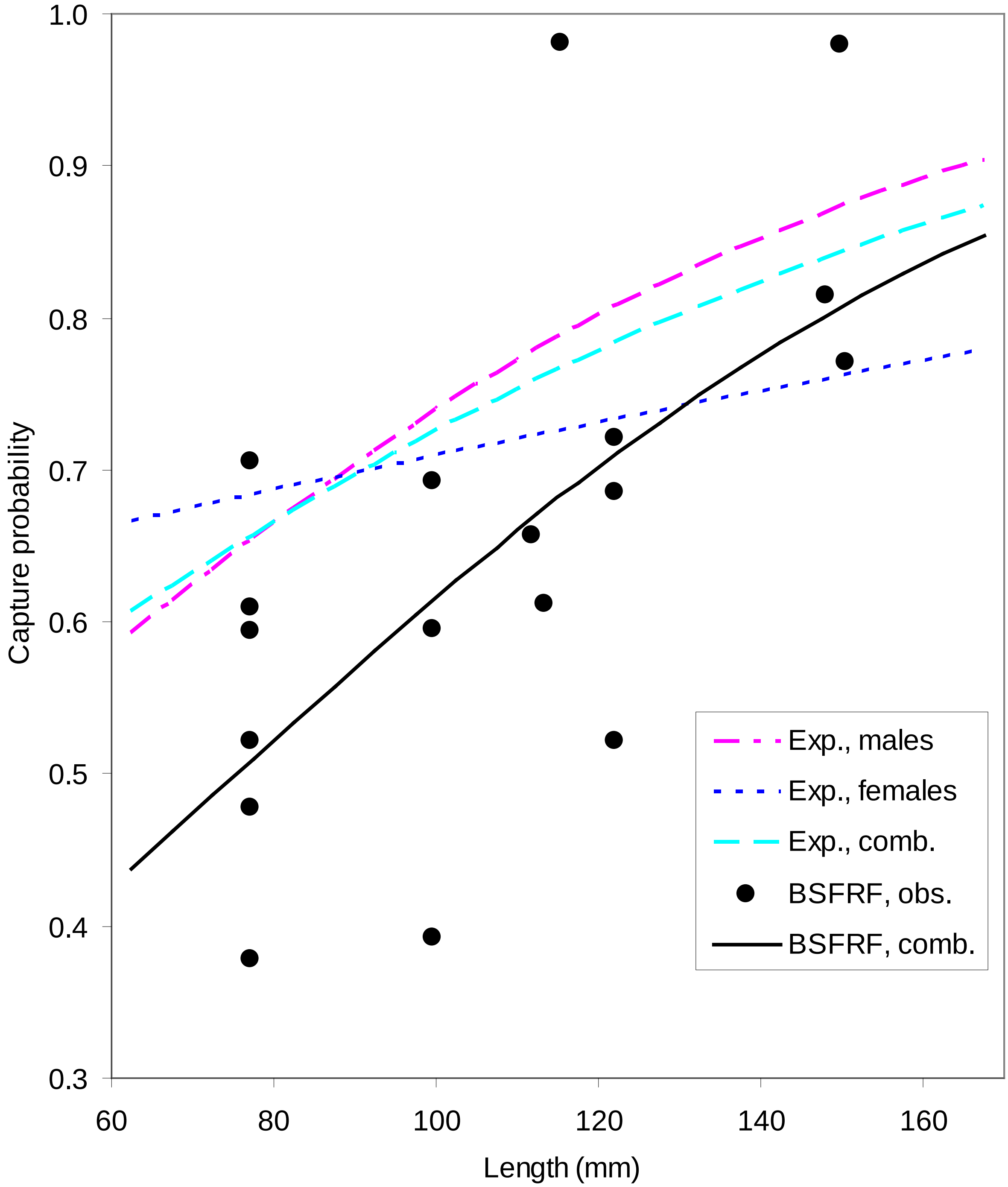
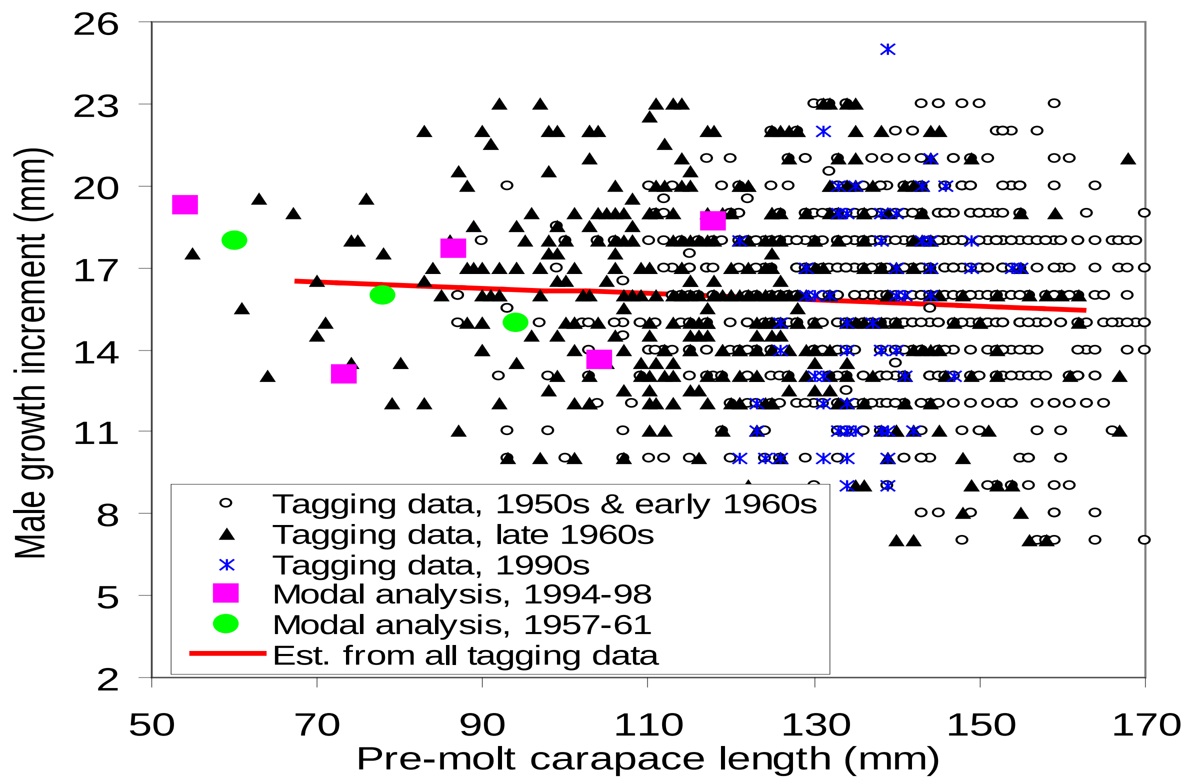


Figure A1. Estimated capture probabilities for NMFS Bristol Bay red king crab trawl surveys by Weinberg et al. (2004) and the Bering Sea Fisheries Research Foundation surveys.



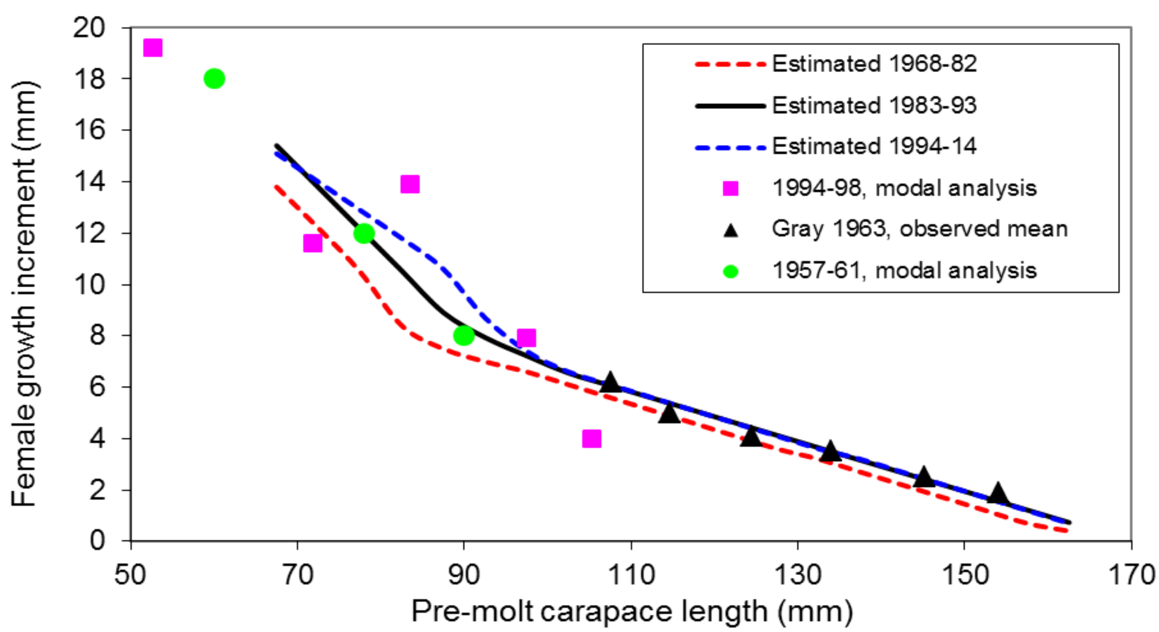


Figure A2. Mean growth increments per molt for Bristol Bay red king crab. Note: “tagging”---based on tagging data; “mode”---based on modal analysis. The female growth increments per molt are for models 18.0d, 18.0e and 19.0.

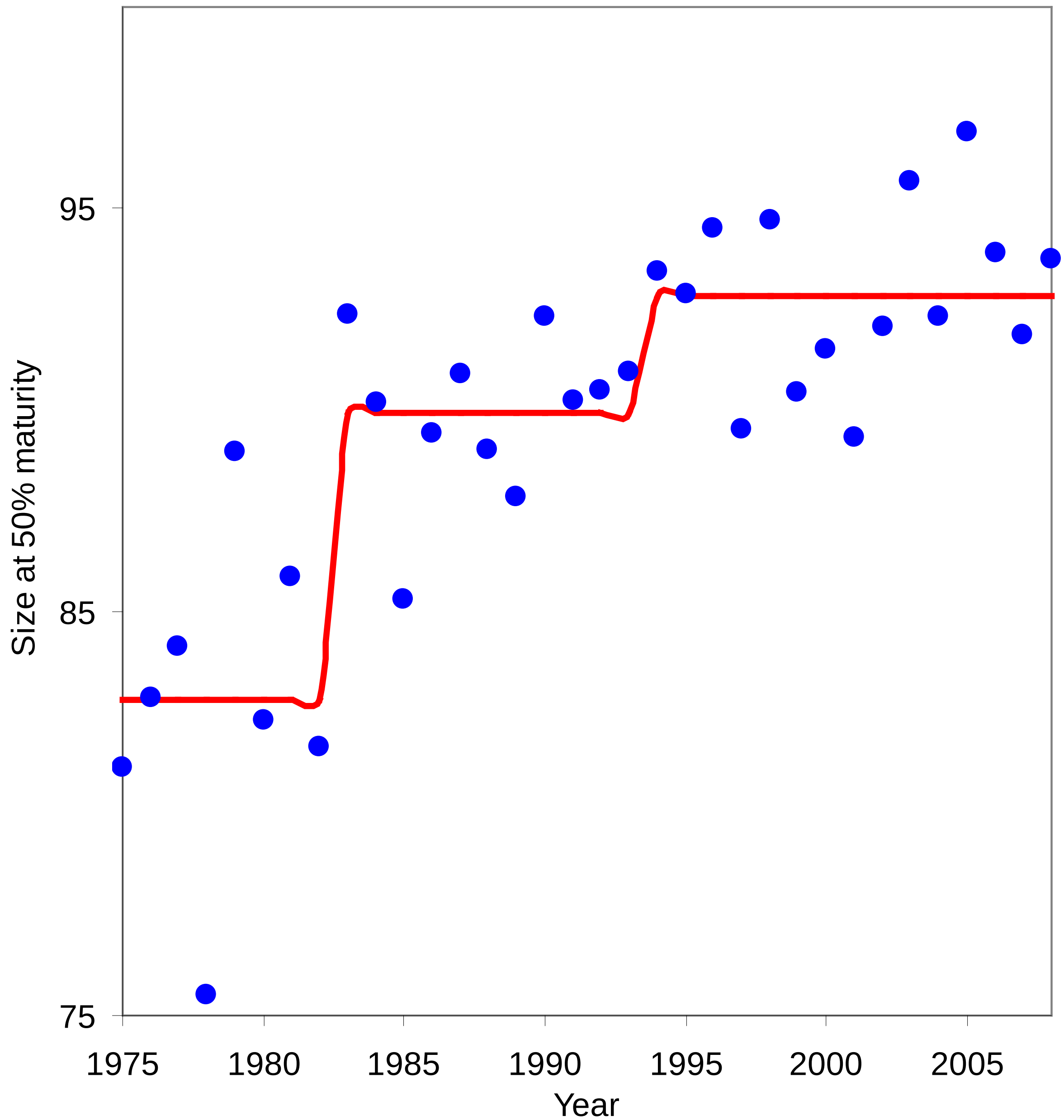


Figure A3. Estimated sizes at 50% maturity for Bristol Bay female red king crab from 1975 to 2008. Averages for three periods (1975-82, 1983-93, and 1994-08) are plotted with a line.

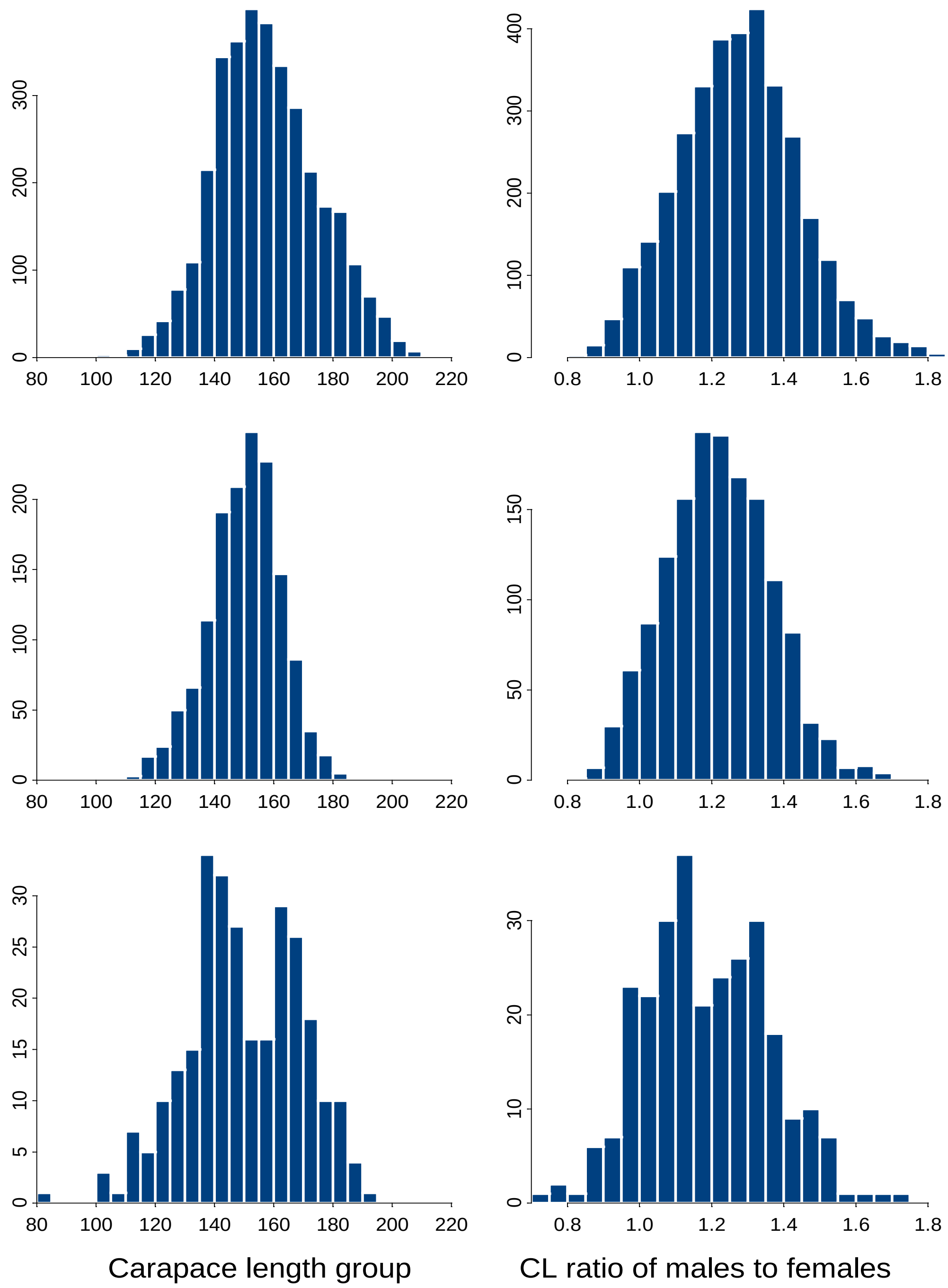


Figure A4. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages ≤13 months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak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

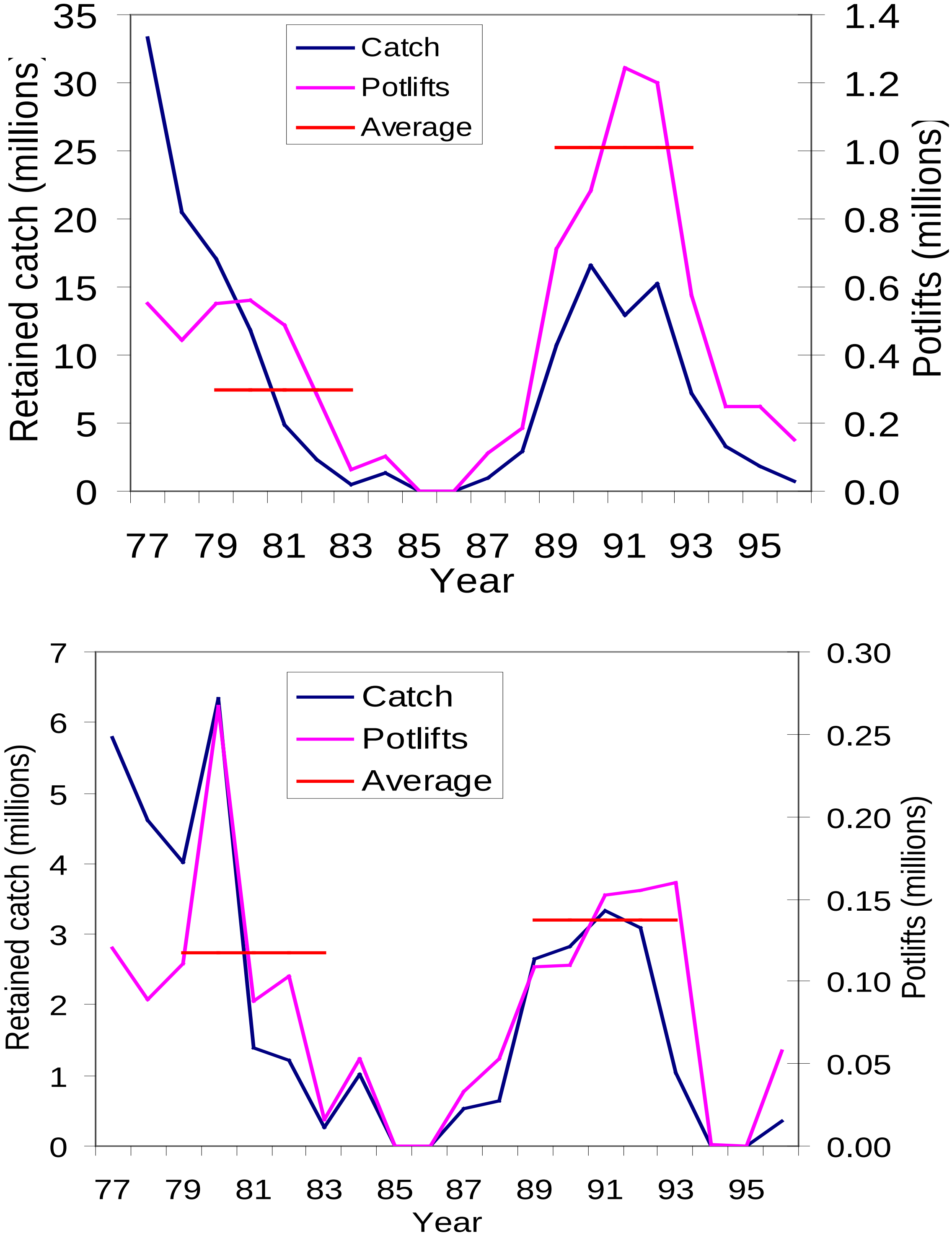


Figure A5. Retained catch and potlifts for total eastern Bering Sea Tanner crab fishery (upper plot) and the Tanner crab fishery east of 163° W (bottom).

Appendix B. Recruitment Breakpoint Analysis in May 2019

Introduction

SSC asked authors to conduct a recruitment breakpoint analysis similar to that conducted for eastern Bering Sea Tanner crab in 2013 (Stockhausen 2013). We obtained the R codes from Dr. William (Buck) Stockhausen of NMFS and slightly modified them to conduct the analysis for Bristol Bay red king crab for better understanding the temporal change of stock productivity and the recruitment time series used for overfishing/overfished definitions. Results from assessment model model 18.0a are used for this analysis. We are very grateful for the help of Dr. Stockhausen for this analysis.

Methods

The methods are the same as Punt et al. (2014) and Stockhausen (2013). Stock productivity is represented by ln(*R/MMB*), where *R* is recruitment and *MMB* is mature male biomass, with recruitment lagging to the brood year of mature biomass. Let y_t = ln(*R/MMB*) and y_t can be estimated directly from the stock assessment model as observed values or from a stock-recruitment model as $\hat{y}_t$. For Ricker stock-recruitment models,

$$\begin{aligned} \hat{y}_t &= \alpha_1 + \beta_1 \cdot MMB \qquad t < b, \\ \hat{y}_t &= \alpha_2 + \beta_2 \cdot MMB \qquad t \ge b, \end{aligned} \tag{1}$$

where α_1 and β_1 are the Ricker stock-recruit function parameters for the early time period before the potential breakpoint in year *b* and α_2 and β_2 are the parameters for the time period after the breakpoint in year *b*. For Beverton-Holt stock-recruitment models,

$$\begin{aligned} \hat{y}_t &= \alpha_1 - \log(1 + e^{\beta_1} \cdot MMB) \qquad t < b, \\ \hat{y}_t &= \alpha_2 + \log(1 + e^{\beta_2} \cdot MMB) \qquad t \ge b, \end{aligned} \tag{2}$$

where α_1 and β_1 are the Beverton-Holt stock-recruit function log-transformed parameters for the early time period before the potential breakpoint in year *b* and α_2 and β_2 are the log-transformed parameters for the time period after the breakpoint in year *b*.

A maximum likelihood approach is used to estimate stock-recruitment model and error parameters. Because y_t is measured with error, the negative log-likelihood function is

$$-\ln(L) = 0.5 \cdot \ln(|\mathbf{\Omega}|) + 0.5 \cdot \sum_t \sum_j (y_t - \hat{y}_t) \cdot \left[\mathbf{\Omega}^{-1}\right]_{t,j} \cdot (y_j - \hat{y}_j), \tag{3}$$

where Ω contains observation and process error as

$$\mathbf{\Omega} = \mathbf{O} + \mathbf{P}, \tag{4}$$

where **O** is the observation error covariance matrix estimated from the stock assessment model and **P** is the process error matrix and is assumed to reflect a first-order autoregressive process to have σ^2 on the diagonal and $\sigma^2 \rho^{|t-j|}$ on the off-diagonal elements. σ^2 represents process error variance and ρ represents the degree of autocorrelation.

For each candidate breakpoint year *b*, the negative log likelihood value of equation (3) is minimized with respect to the six model parameters: α_1, β_1, α_2, β_2, $\ln(\sigma)$ and $\tan(\rho)$. The minimum time span considered as a potential regime is 5 years. Each brood year from 1980 to 2007 is evaluated as a potential breakpoint *b* using time series of ln(R/MMB) and MMB for brood years 1975-2012. A model with no breakpoint is also evaluated. Models with different breakpoints are then ranked using AICc (AIC corrected for small sample size; Burnham and Anderson 2004),

$$AIC_c = -2 \cdot \ln(L) + \frac{2 \cdot k \cdot (k+1)}{n-k-1}, \tag{5}$$

where *k* is the number of parameters and *n* is the number of observations. Using AICc, the model with the smallest AICc is regarded as the "best" model among the set of models evaluated. Different models can be compared in terms of θ_m, the relative probability (odds) that the model with the minimum AICc score is a better model than model *m*, where

$$\theta_m = \exp([(AICc_m - AICc_{\min})/2]. \tag{6}$$

Results

Results are summarized in Tables B1-B4 and Figures B1-B6. Discarding the implausible breakpoint year of 1980 for the Ricker model due to implausible stock-recruitment model parameters, the Ricker model has a breakpoint of brood year of 1986 (recruitment year of 1992), and the Beverton-Holt model results in the same breakpoint brood year of 1984, which corresponds to recruitment year of 1990. The model with no breakpoint (i.e., a single time period) is about 18 times less probable than the 1984 breakpoint model for Beverton-Holt stock-recruitment models and about 17 times less probable for Ricker stock-recruitment relationships, which may suggest a possible change in stock productivity from the early high period to the recent low period. Alternative breakpoint brood years of 1980-1986 for both Ricker and Beverton-Holt models are also reasonably reported. Both Ricker and Beverton-Holt stock-recruitment models fit the data poorly.

Discussion

A recruitment breakpoint analysis was conducted on Bristol Bay red king crab by Punt et al. (2014) with data from 1968 to 2010 to estimate a breakpoint brood year of 1984, corresponding to recruitment year of 1990, which is the same as our estimate with the Beverton-Holt model. Our data start in 1975 and have only two brood-year data points before the regime shift of 1976/77 and thus we cannot detect any stock productivity changes due to the 1976/77 regime shift because of lack of data. Without the early data, the fits of stock-recruitment models to the data are also more poorly.

Time series of estimated recruitment during 1984-present have been used to compute Bmsy proxy. The mean recruitment with model 18.0e during 1984-present is 17.70 million of crab, compared to the mean recruitment of 16.21 million of crab during 1990-present, about 8.4% reduction (Figure 12(18.0a). If the estimated breakpoint year is used to set the new recruitment time series, estimated Bmsy proxy will be correspondingly lower than the current estimated value.

References

Burnham, K.P., and D.R. Anderson. 2004. Multimodal inference: understanding AIC and BIC in model selection. Sociological Methods & Research 33:261–304.

Punt, A.E., C.S. Szuwalski, and W. Stockhausen. 2014. An evaluation of stock-recruitment proxies and environmental change points for implementing the US Sustainable Fisheries Act. Fisheries Research 157:28-40.

Stockhausen, W.T. 2013 Recruitment Analysis for Stock Status Determination and Harvest Recommendations. Appendix to: 2013 Stock Asssessment and Fishery Evaluation Report for the Tanner Crab Fisheries in the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, Anchorage. pp.450-478.

Table B1. Results of the breakpoint analysis, with AICc and the relative probability (odds) against the Ricker stock-recruitment model being correct by breakpoint year. The model with no breakpoint is listed first in the table. The "best" model is shaded with a plausible stock-recruitment model. Years are brood year.

Year	AICc	Odds
NA	30.9238	22.6194
1980	24.6862	1.0000
1981	26.0669	1.9944
1982	26.1803	2.1107
1983	26.1267	2.0549
1984	26.1003	2.0280
1985	25.6051	1.5832
1986	25.3132	1.3682
1987	28.6416	7.2259
1988	29.9626	13.9875
1989	32.4417	48.3160
1990	29.2430	9.7607
1991	31.1066	24.7833
1992	31.1349	25.1368
1993	30.8432	21.7255
1994	31.8353	35.6785
1995	32.0101	38.9364
1996	32.2674	44.2836
1997	30.7012	20.2369
1998	31.6248	32.1144
1999	32.0321	39.3669
2000	29.4065	10.5927
2001	28.6866	7.3904
2002	29.3953	10.5332
2003	30.9657	23.0977
2004	31.5810	31.4179
2005	30.1676	15.4974
2006	29.9998	14.2502
2007	31.0384	23.9530

Table B2. Parameter estimates and standard deviations for the Ricker stock-recruitment model with no breakpoint (first row) and the single breakpoint models (by year of breakpoint). The "best" model is shaded. Years are brood year.

Year	α_1	std.dev.	α_2	std.dev.	β_1	std.dev.	β_2	std.dev.	ln(σ)	std.dev.	tan(ρ)	std.dev.
			-0.319	0.260			0.006	0.006	-0.224	0.127	0.367	0.304
1980	-4.927	3.085	0.825	0.358	-0.043	0.030	0.057	0.014	-0.406	0.123	-0.021	0.282
1981	0.215	0.869	0.789	0.353	0.007	0.009	0.056	0.014	-0.388	0.124	-0.082	0.279
1982	0.527	0.563	0.734	0.394	0.010	0.007	0.054	0.016	-0.387	0.124	-0.056	0.275
1983	0.406	0.440	0.818	0.436	0.009	0.006	0.057	0.017	-0.388	0.124	-0.066	0.271
1984	0.397	0.376	0.858	0.498	0.009	0.005	0.059	0.019	-0.389	0.124	-0.060	0.271
1985	0.623	0.333	0.336	0.608	0.011	0.005	0.040	0.023	-0.395	0.124	-0.059	0.273
1986	0.581	0.307	0.087	0.728	0.011	0.005	0.031	0.027	-0.398	0.124	-0.047	0.277
1987	0.337	0.300	0.555	0.820	0.009	0.005	0.047	0.030	-0.354	0.124	-0.043	0.270
1988	0.223	0.308	0.645	0.912	0.008	0.005	0.050	0.033	-0.335	0.123	0.058	0.271
1989	0.057	0.302	0.727	0.929	0.007	0.005	0.052	0.034	-0.302	0.123	0.037	0.274
1990	0.172	0.309	0.809	0.949	0.008	0.005	0.057	0.035	-0.347	0.125	0.169	0.282
1991	0.036	0.298	0.946	0.971	0.007	0.005	0.061	0.035	-0.320	0.125	0.152	0.274
1992	-0.083	0.288	1.514	1.041	0.006	0.005	0.080	0.037	-0.320	0.125	0.159	0.276
1993	-0.097	0.275	1.800	1.140	0.006	0.005	0.089	0.041	-0.325	0.125	0.149	0.274
1994	-0.002	0.275	0.929	1.586	0.007	0.005	0.060	0.055	-0.309	0.124	0.156	0.286
1995	-0.046	0.261	1.410	1.784	0.006	0.005	0.076	0.061	-0.308	0.124	0.129	0.273
1996	-0.080	0.253	1.675	1.881	0.006	0.005	0.084	0.064	-0.305	0.124	0.116	0.272
1997	0.009	0.256	-0.664	2.251	0.007	0.005	0.008	0.076	-0.324	0.125	0.182	0.287
1998	-0.048	0.241	-0.088	3.178	0.006	0.005	0.027	0.106	-0.315	0.124	0.114	0.271
1999	-0.079	0.233	-0.453	4.442	0.006	0.005	0.015	0.146	-0.309	0.124	0.078	0.276
2000	-0.047	0.219	-1.902	4.333	0.006	0.004	-0.029	0.142	-0.350	0.125	0.049	0.275
2001	-0.060	0.206	-2.645	4.313	0.006	0.004	-0.052	0.141	-0.360	0.125	-0.016	0.277
2002	-0.086	0.211	-2.603	4.317	0.006	0.004	-0.050	0.141	-0.348	0.124	0.023	0.271
2003	-0.126	0.215	-4.313	5.199	0.006	0.005	-0.108	0.172	-0.325	0.124	0.038	0.273
2004	-0.150	0.215	-5.235	6.326	0.006	0.005	-0.139	0.211	-0.315	0.123	0.039	0.276
2005	-0.142	0.211	-4.701	6.169	0.006	0.005	-0.118	0.206	-0.336	0.124	0.056	0.274
2006	-0.155	0.209	-3.551	6.362	0.006	0.005	-0.077	0.213	-0.337	0.124	0.051	0.272
2007	-0.181	0.210	-3.992	9.066	0.006	0.005	-0.093	0.308	-0.322	0.123	0.059	0.277

Table B3. Results of the breakpoint analysis, with AICc and the relative probability (odds) against the Beverton-Holt stock-recruitment model being correct by breakpoint year. The model with no breakpoint is listed first in the table. The "best" model is shaded. Years are brood year.

Year	AICc	Odds
NA	29.7727	18.4149
1980	25.7843	2.5066
1981	24.5863	1.3770
1982	24.5910	1.3803
1983	24.1006	1.0801
1984	23.9464	1.0000
1985	24.8023	1.5341
1986	24.7628	1.5041
1987	27.9016	7.2254
1988	29.2177	13.9523
1989	31.7329	49.0694
1990	28.6093	10.2928
1991	30.6450	28.4827
1992	31.5624	45.0590
1993	31.6181	46.3324
1994	31.3514	40.5480
1995	31.7759	50.1358
1996	32.1970	61.8866
1997	30.0083	20.7162
1998	31.0013	34.0360
1999	31.4110	41.7743
2000	28.8322	11.5062
2001	28.1772	8.2927
2002	28.8375	11.5366
2003	30.5744	27.4948
2004	31.1698	37.0289
2005	29.6270	17.1211
2006	29.2277	14.0223
2007	30.1635	22.3878

Table B4. Parameter estimates and standard deviations for the Beverton-Holt stock-recruitment model with no breakpoint (first row) and the single breakpoint models (by year of breakpoint). The "best" model is shaded. Years are brood year.

Year	α_1	std.dev.	α_2	std.dev.	β_1	std.dev.	β_2	std.dev.	ln(σ)	std.dev.	tan(ρ)	std.dev.
			0.224	0.851			-3.290	1.684	-0.236	0.129	0.403	0.324
1980	-0.556	0.310	2.686	3.333	-10.91	35.202	0.094	3.500	-0.388	0.125	-0.146	0.282
1981	0.672	1.635	2.762	3.782	-3.736	2.500	0.203	3.952	-0.409	0.124	-0.052	0.296
1982	0.799	0.787	2.882	4.945	-3.551	1.225	0.326	5.129	-0.409	0.124	-0.045	0.282
1983	0.538	0.526	8.307	57.004	-3.945	0.992	5.768	57.013	-0.416	0.124	-0.068	0.275
1984	0.501	0.436	9.152	68.364	-4.003	0.889	6.604	68.368	-0.418	0.124	-0.064	0.273
1985	0.776	0.421	2.594	11.533	-3.580	0.785	0.026	11.994	-0.406	0.124	-0.051	0.275
1986	0.727	0.393	0.795	2.881	-3.643	0.777	-1.978	3.689	-0.405	0.124	-0.041	0.278
1987	0.482	0.385	8.354	122.464	-3.906	0.876	5.793	122.479	-0.364	0.124	-0.035	0.273
1988	0.394	0.421	8.228	111.591	-3.939	0.996	5.652	111.606	-0.344	0.123	0.079	0.274
1989	0.249	0.434	7.025	61.785	-4.023	1.107	4.410	61.814	-0.312	0.123	0.060	0.278
1990	0.370	0.452	7.051	52.894	-3.911	1.065	4.513	52.916	-0.354	0.125	0.187	0.288
1991	0.237	0.452	7.762	72.745	-4.018	1.157	5.185	72.760	-0.326	0.125	0.164	0.279
1992	0.084	0.433	7.678	54.671	-4.237	1.267	5.051	54.684	-0.311	0.124	0.178	0.279
1993	0.058	0.419	7.628	51.998	-4.281	1.277	4.996	52.011	-0.310	0.124	0.180	0.280
1994	0.206	0.450	5.852	54.545	-4.008	1.204	3.282	54.618	-0.313	0.125	0.199	0.288
1995	0.145	0.426	6.347	56.553	-4.097	1.219	3.763	56.599	-0.309	0.124	0.165	0.280
1996	0.100	0.411	6.545	58.063	-4.156	1.234	3.954	58.102	-0.304	0.124	0.132	0.280
1997	0.212	0.430	-0.690	2.493	-4.005	1.178	-4.849	13.254	-0.333	0.126	0.196	0.296
1998	0.130	0.391	0.233	9.064	-4.143	1.176	-2.668	13.428	-0.324	0.125	0.119	0.276
1999	0.094	0.380	-0.473	6.417	-4.193	1.186	-4.029	18.286	-0.318	0.124	0.081	0.281
2000	0.113	0.352	-1.011	0.284	-4.231	1.113	-9.764	109.299	-0.358	0.125	0.065	0.272
2001	0.098	0.336	-1.063	0.260	-4.258	1.083	-9.645	77.507	-0.368	0.125	0.012	0.272
2002	0.088	0.356	-1.074	0.349	-4.211	1.121	-8.571	46.119	-0.357	0.125	0.041	0.272
2003	0.087	0.401	-1.046	0.280	-4.085	1.186	-9.606	63.896	-0.331	0.124	0.073	0.275
2004	0.086	0.425	-1.051	0.334	-4.022	1.217	-8.858	47.684	-0.321	0.124	0.082	0.278
2005	0.089	0.411	-1.171	0.310	-4.033	1.179	-9.685	77.778	-0.344	0.124	0.081	0.277
2006	0.080	0.407	-1.248	0.398	-4.032	1.168	-8.833	63.349	-0.349	0.124	0.056	0.277
2007	0.082	0.440	-1.261	0.596	-3.954	1.211	-8.167	60.765	-0.336	0.124	0.075	0.281

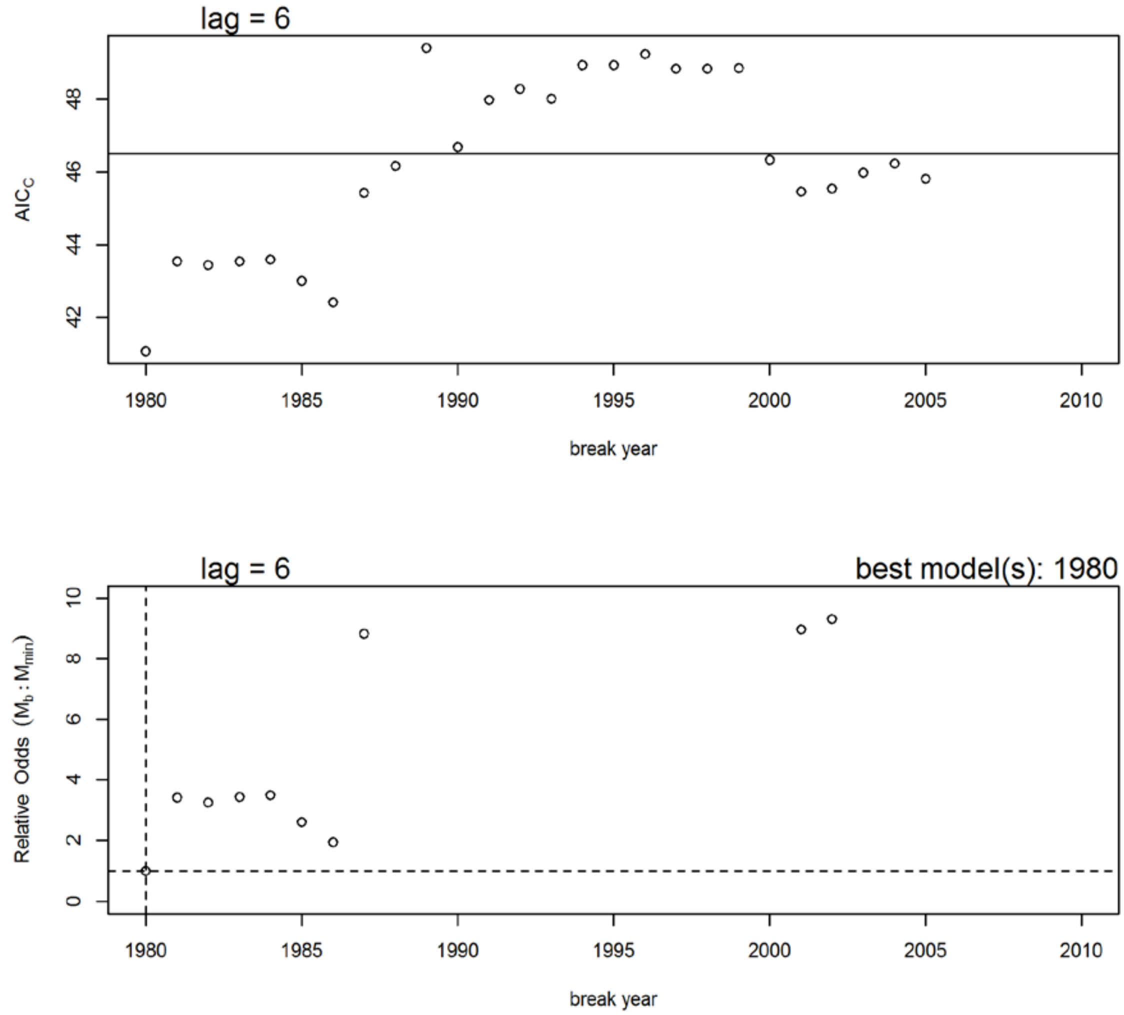


Figure B1. Results from the Ricker stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint model (horizontal solid line) relative to the model with the smallest AICc score. The dashed lines indicate the value for the model with the lowest AICc score. Not shown are 1-breakpoint models with high odds (>10) of being incorrect.

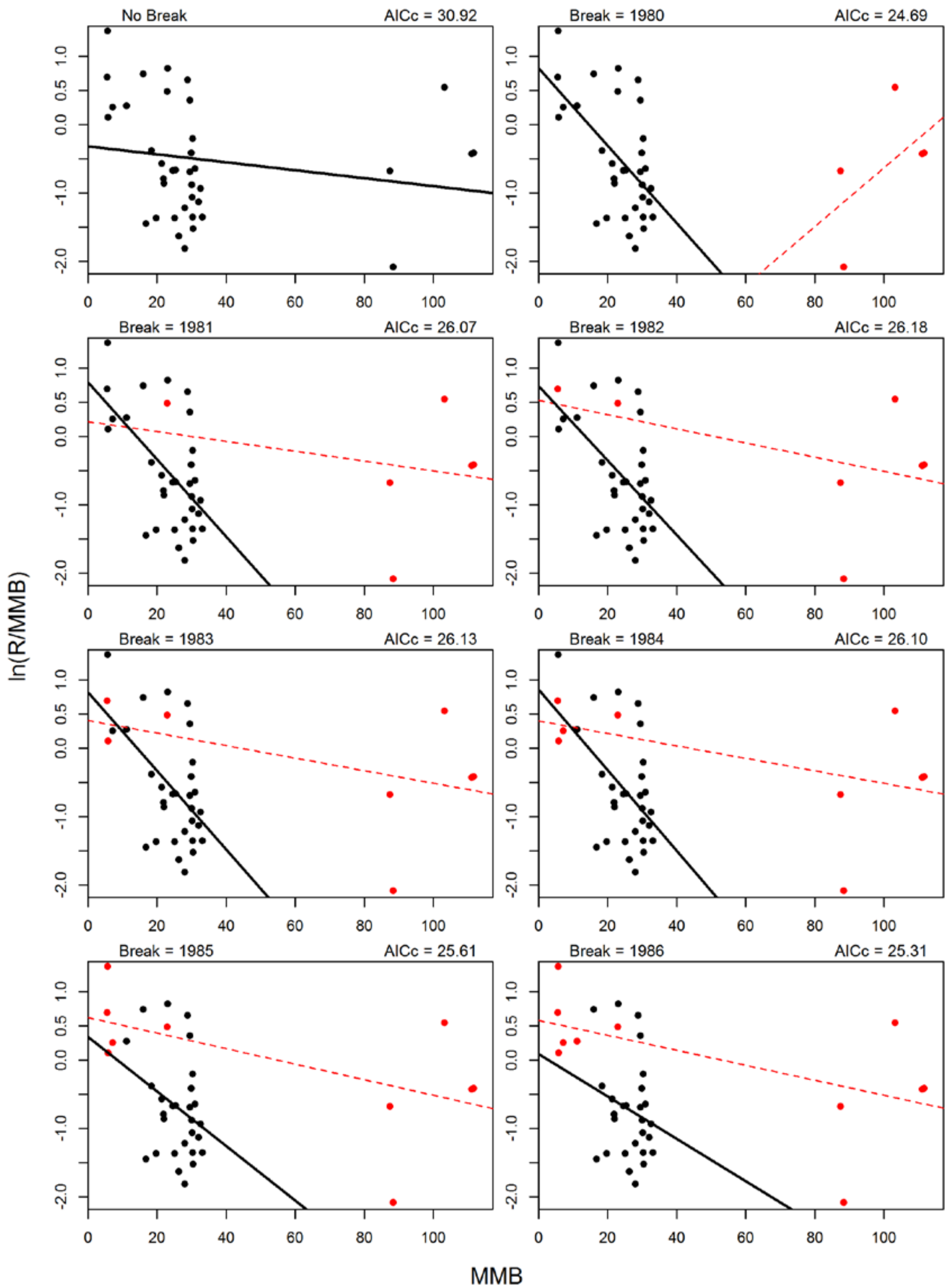
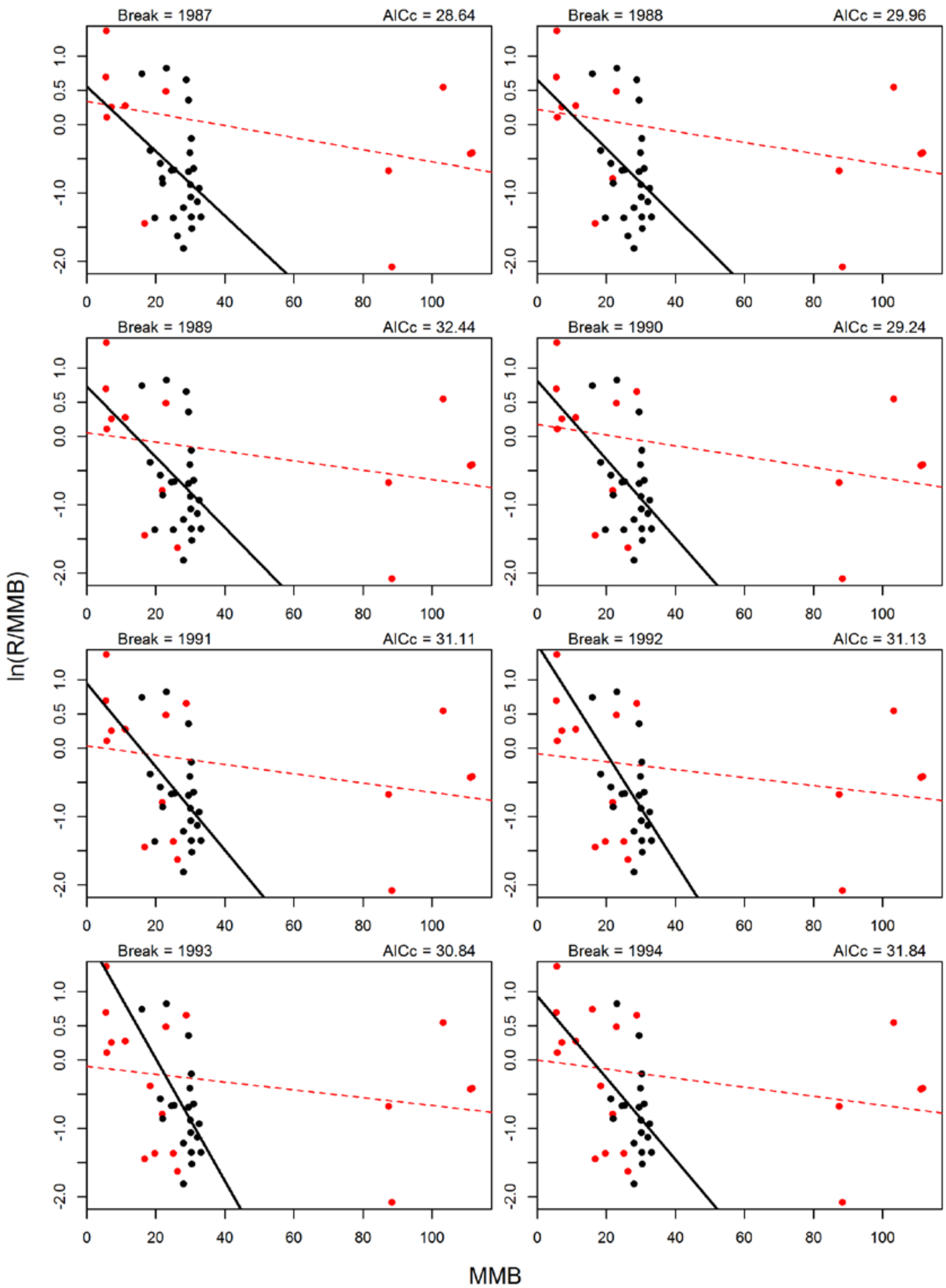


Figure B2. Fits for Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2007. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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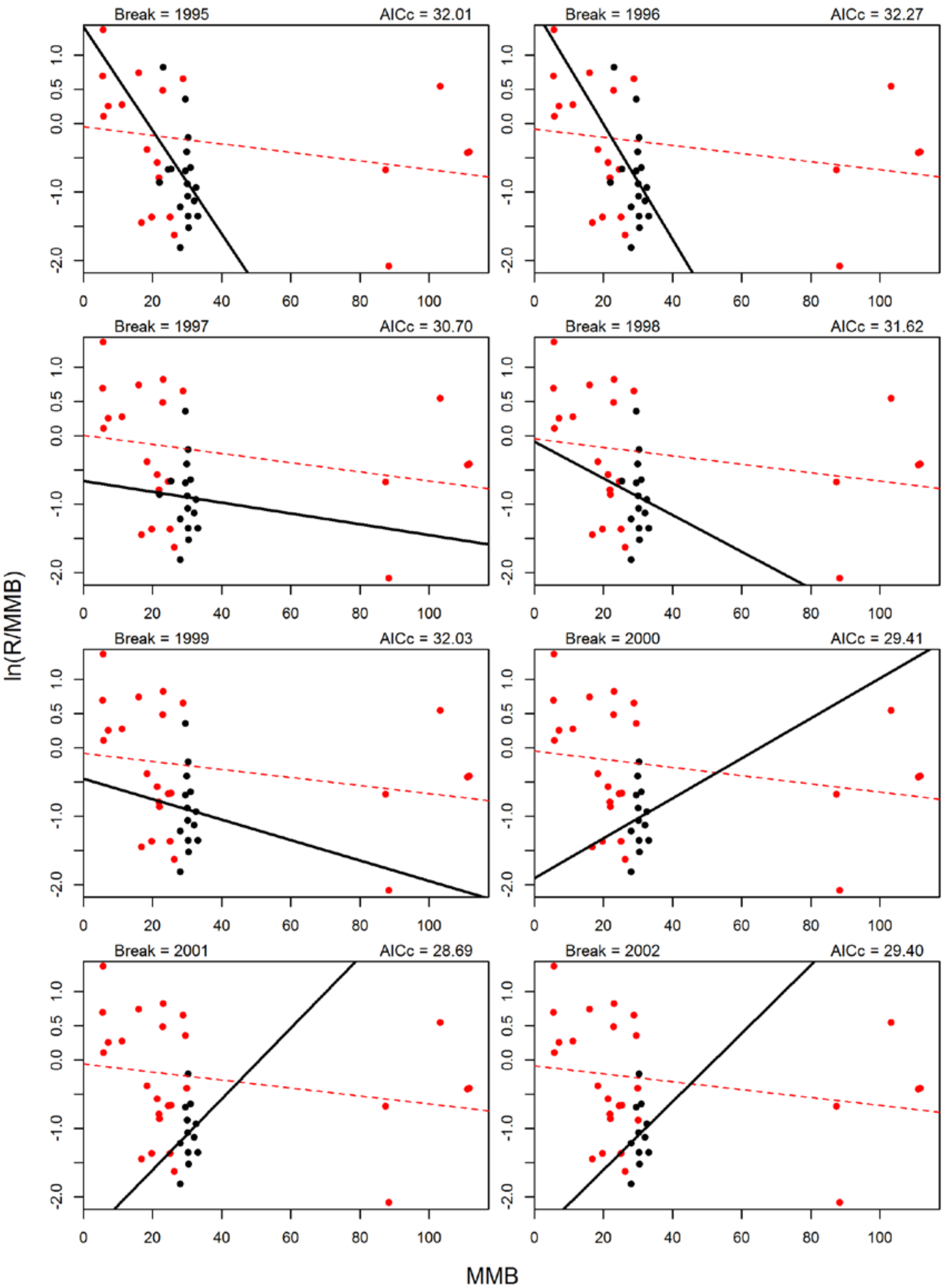

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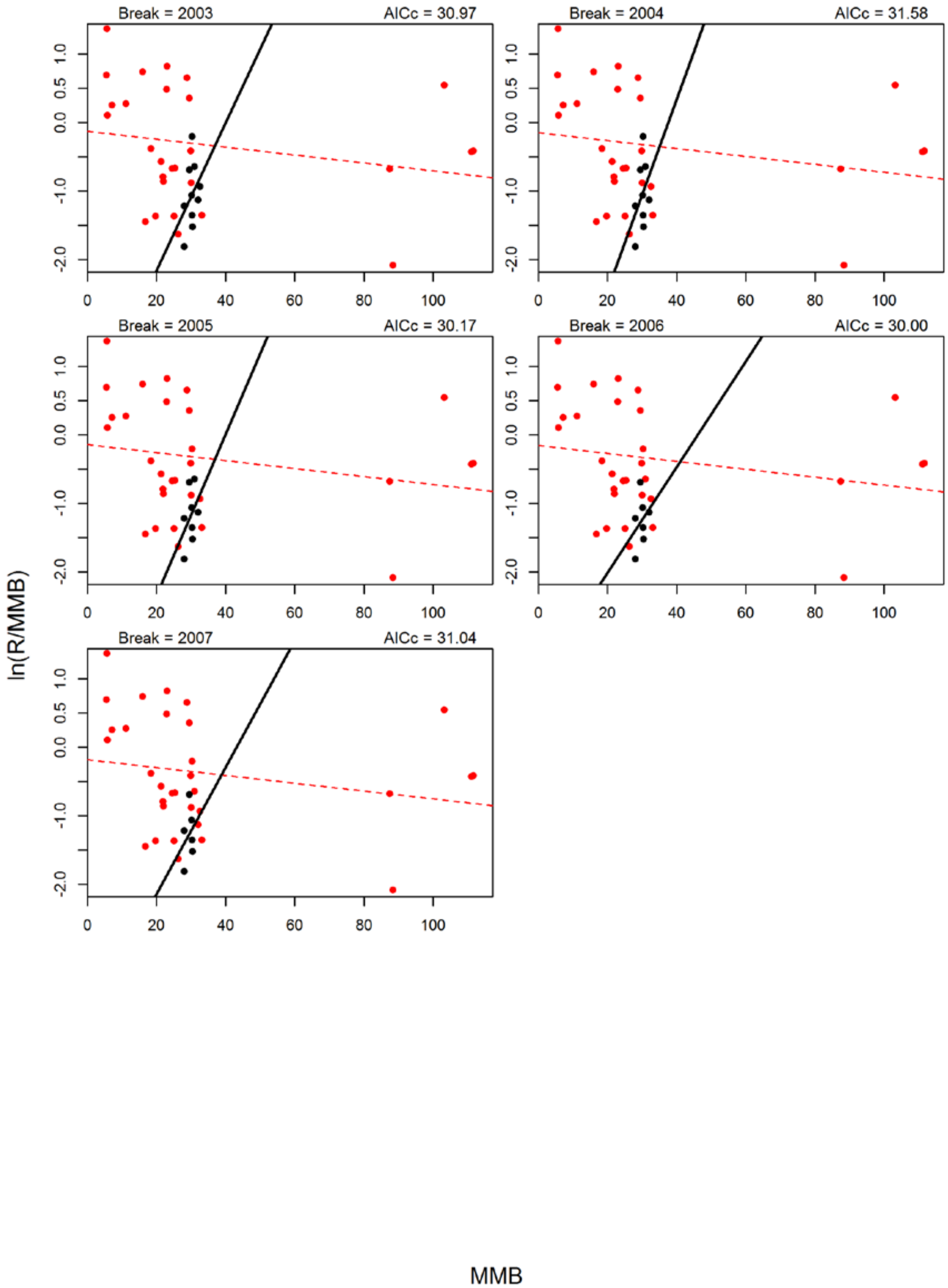

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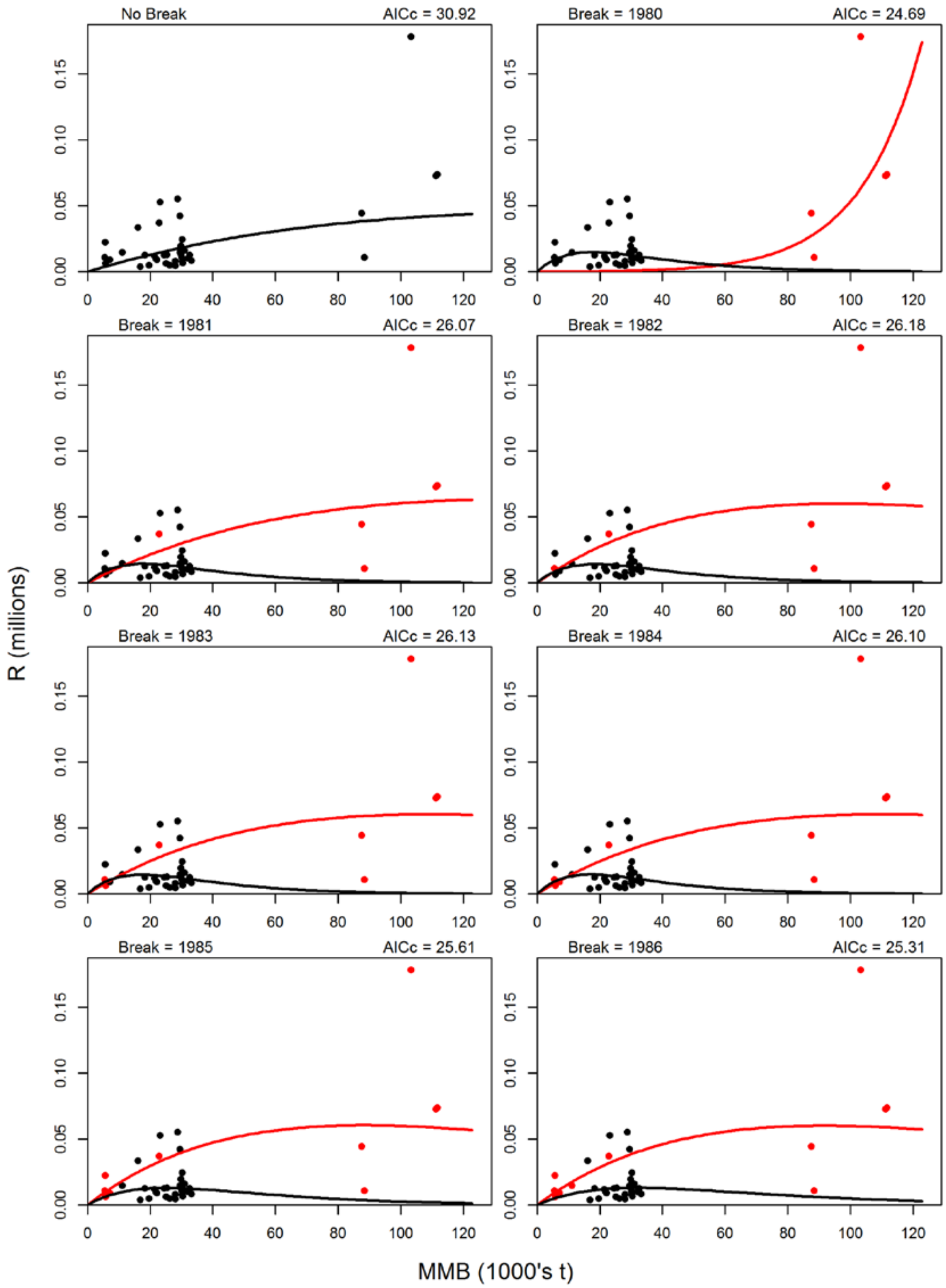
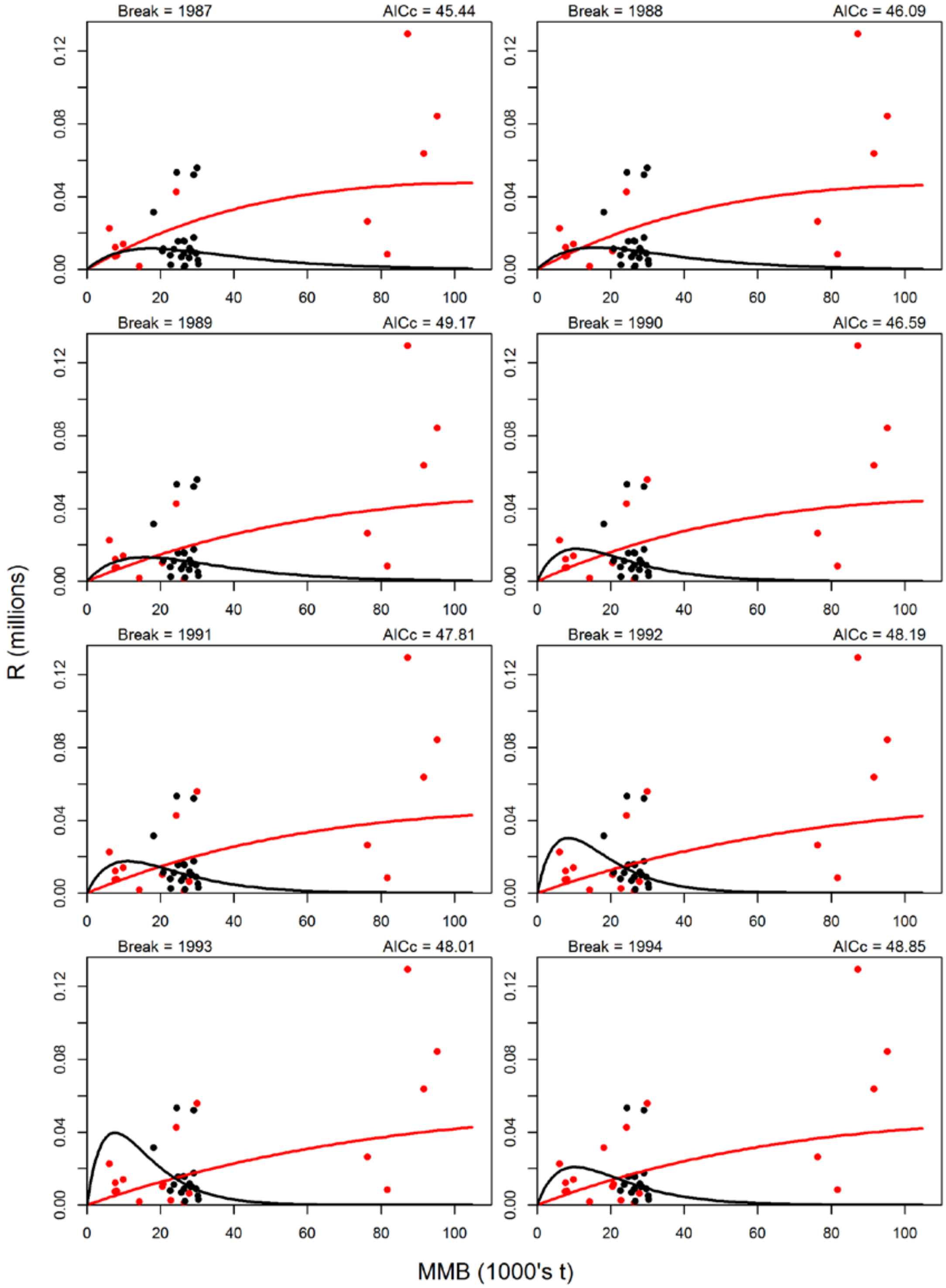


Figure B3. Fits on the arithmetic scale for Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2007. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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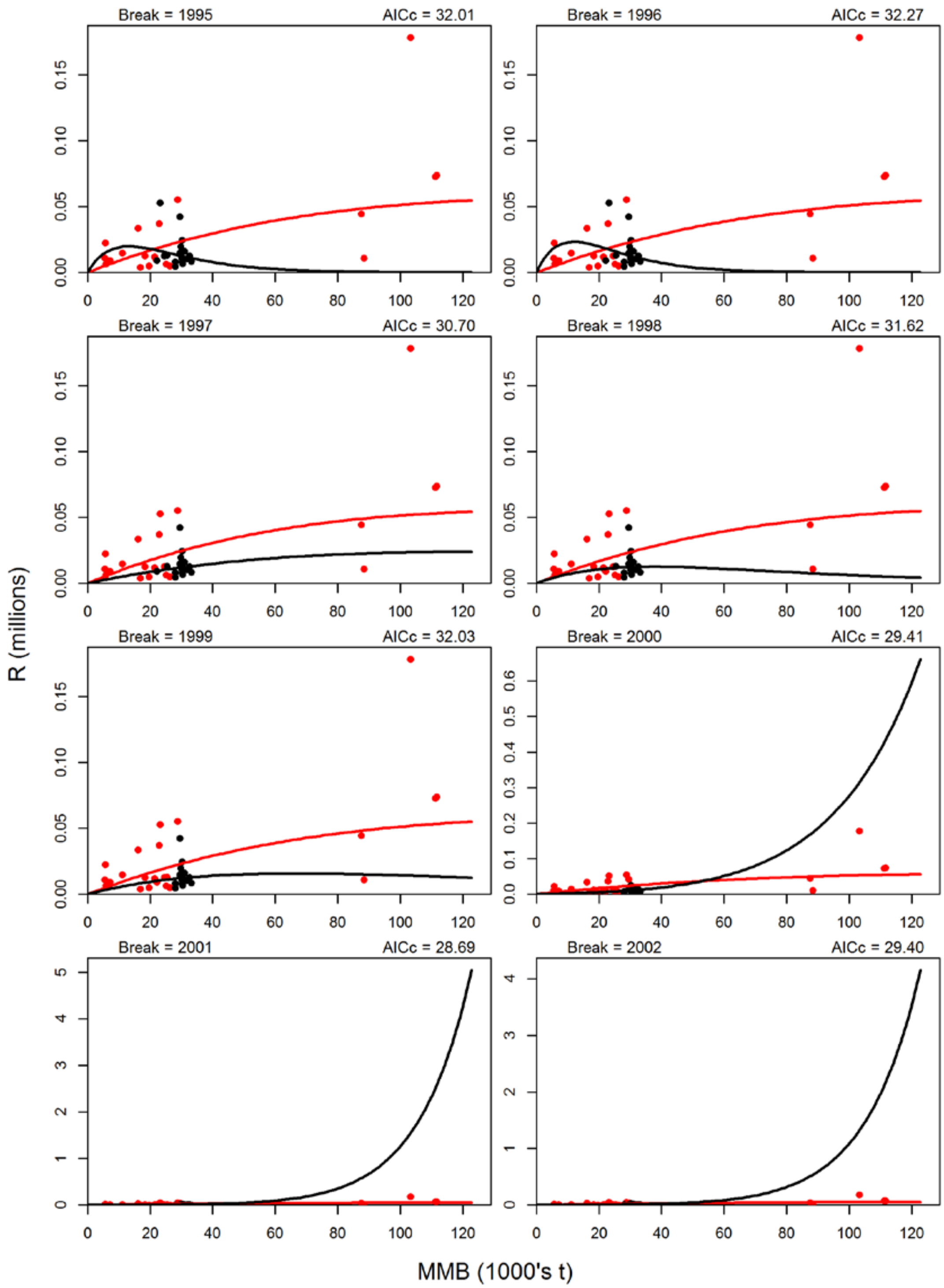

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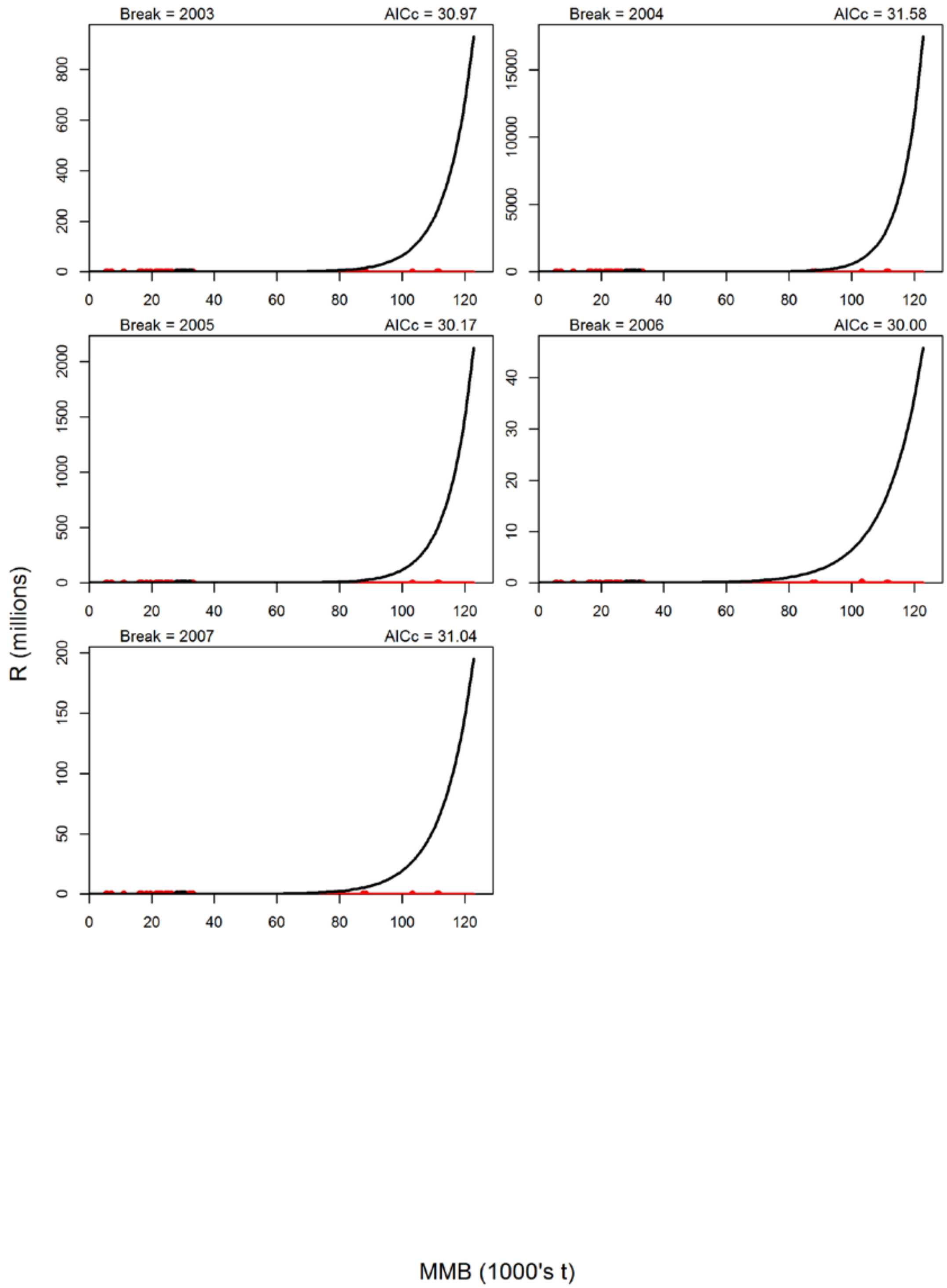

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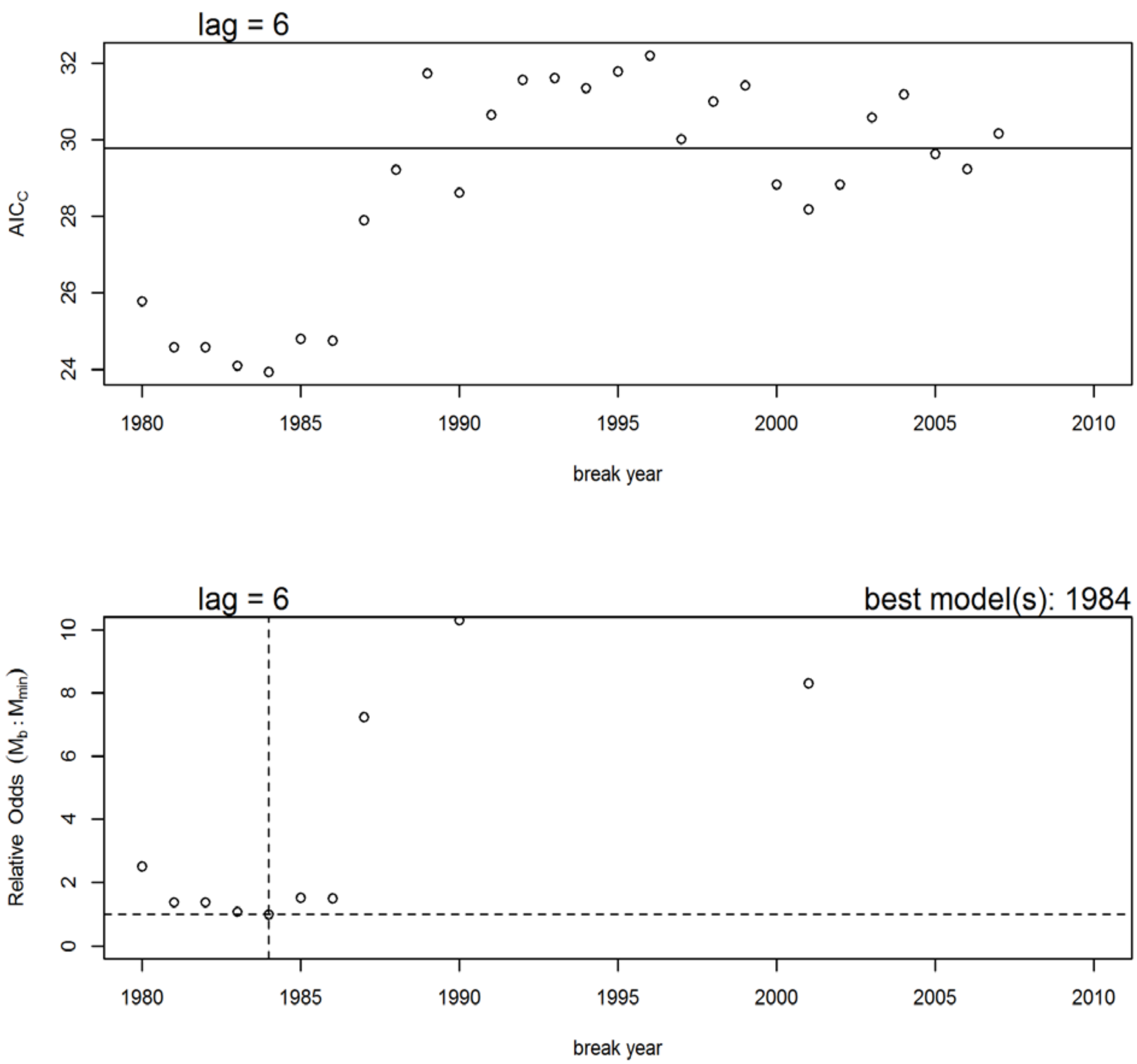


Figure B4. Results from the B-H stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint model (horizontal solid line) relative to the model with the smallest AICc score. The dashed lines indicate the value for the model with the lowest AICc score (breakpoint in 1984). Not shown are 1-breakpoint models with high odds (>10) of being incorrect.

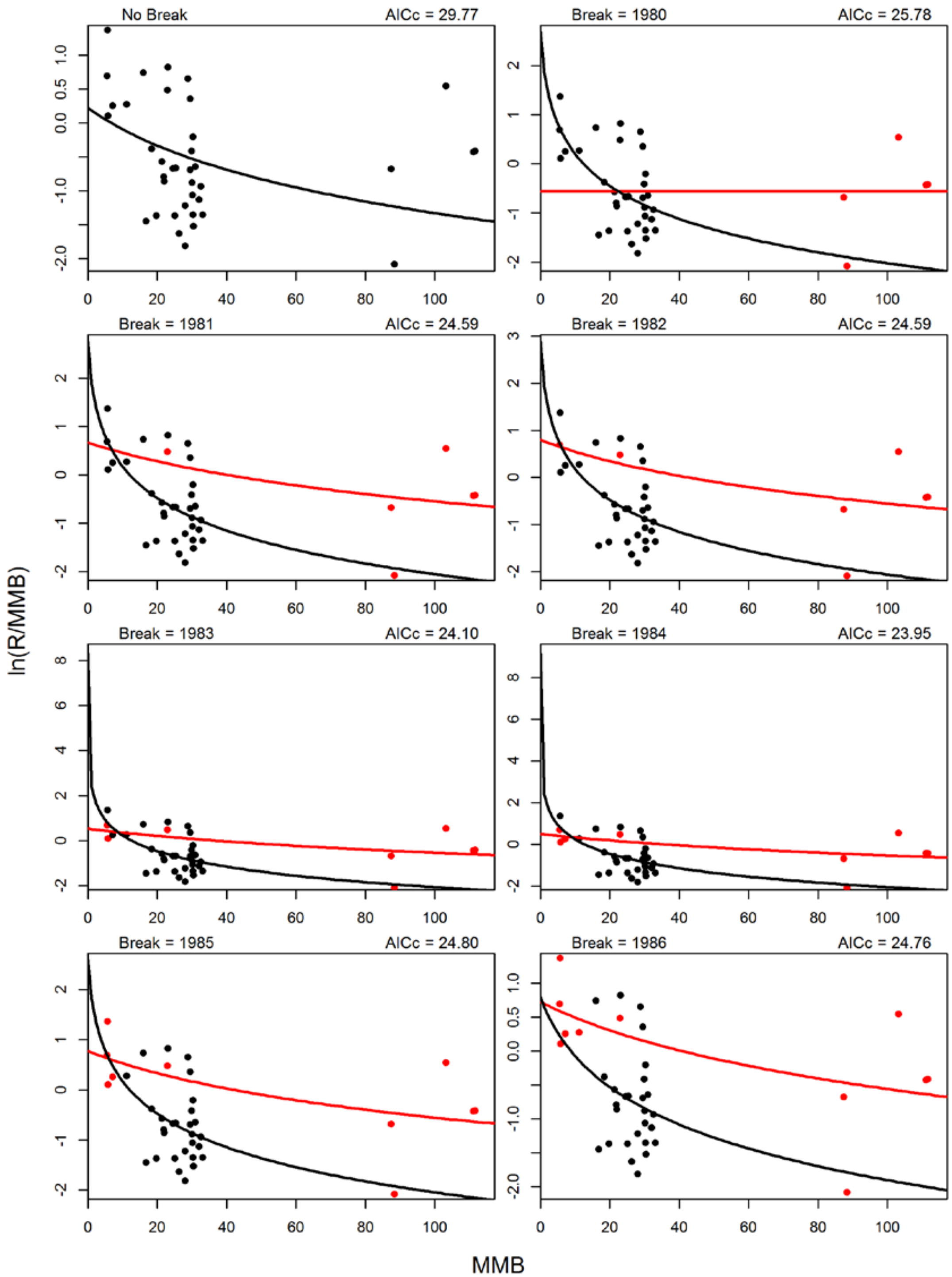
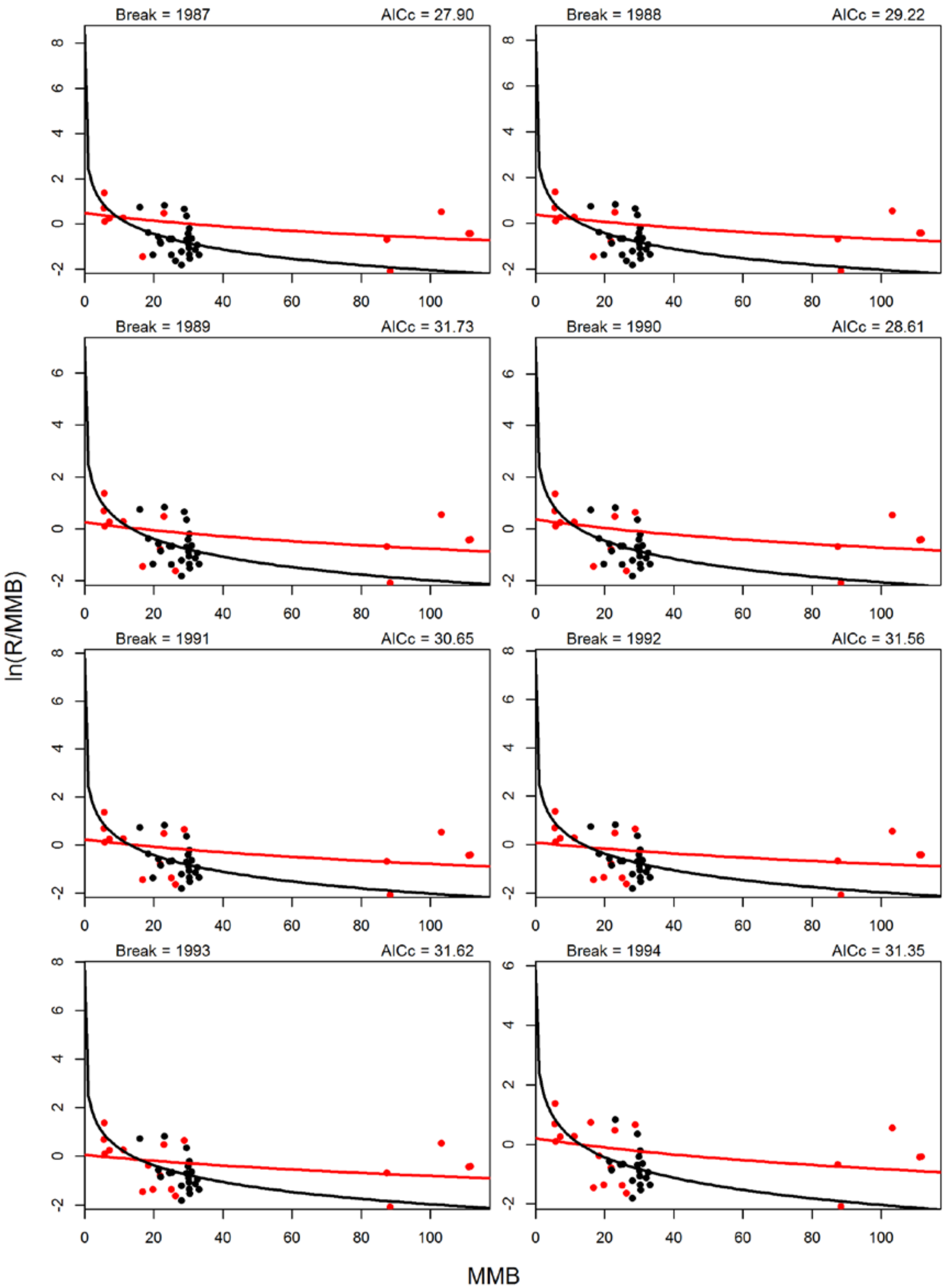


Figure B5. Fits for B-H models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2007. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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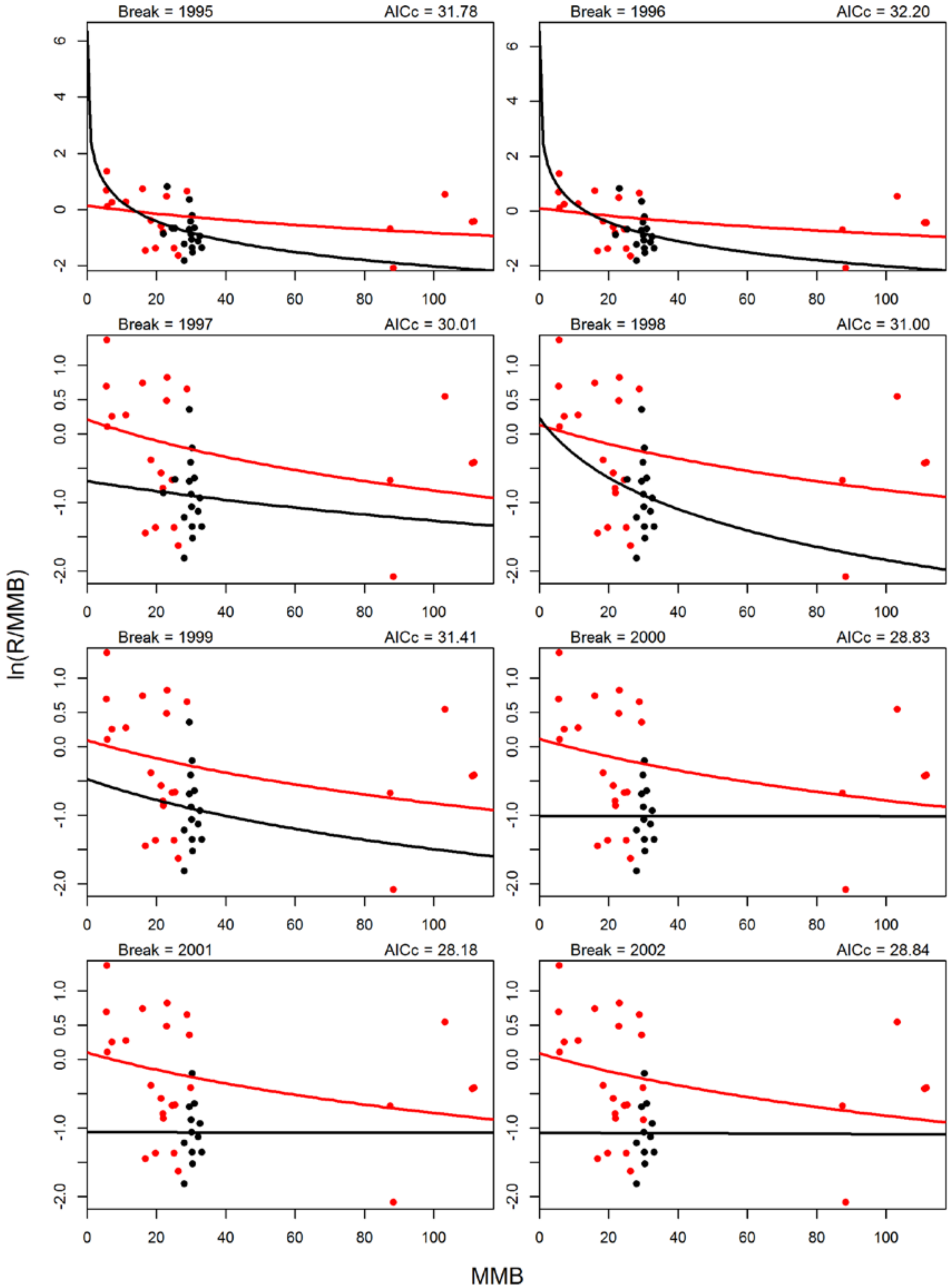

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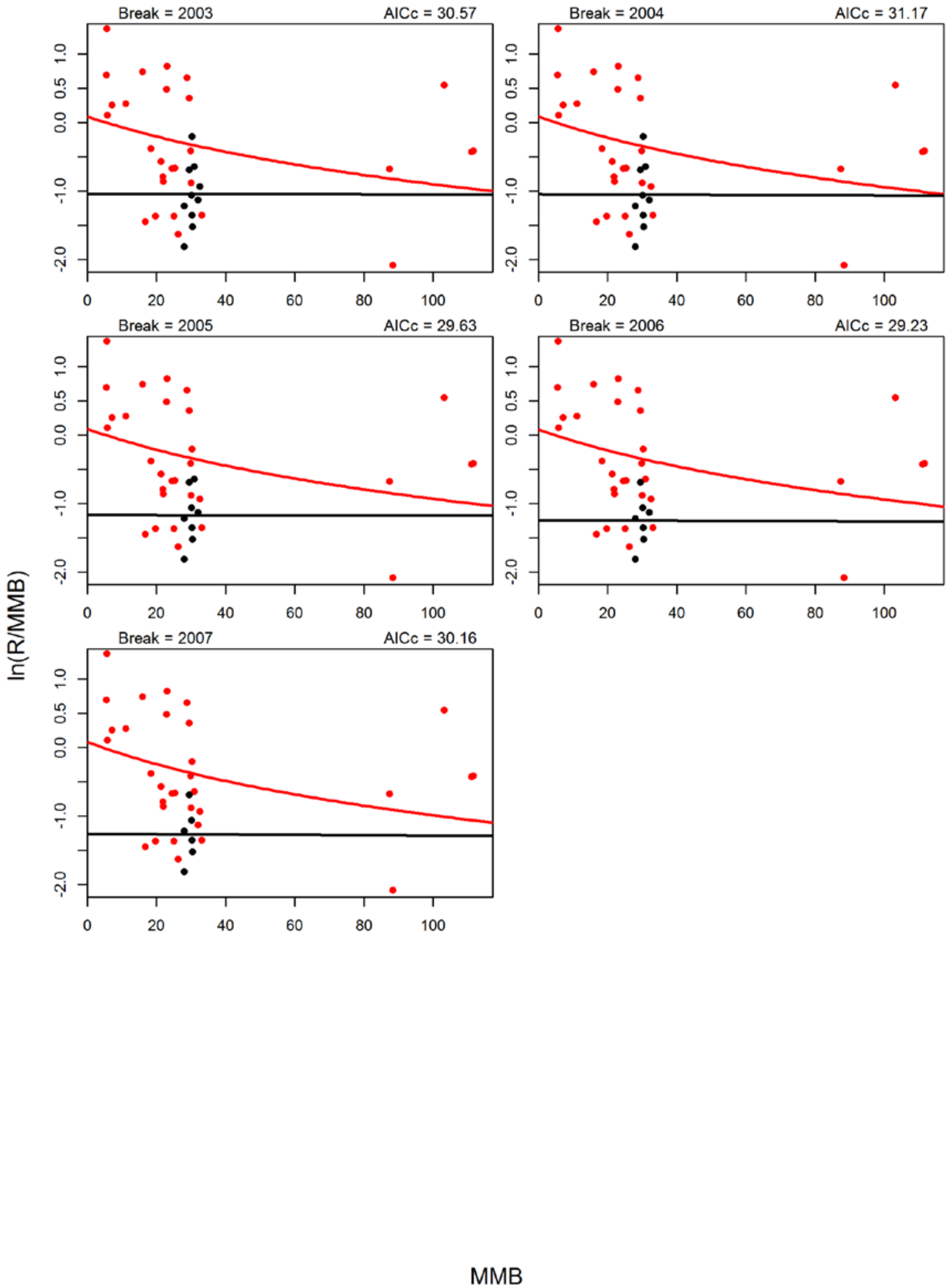

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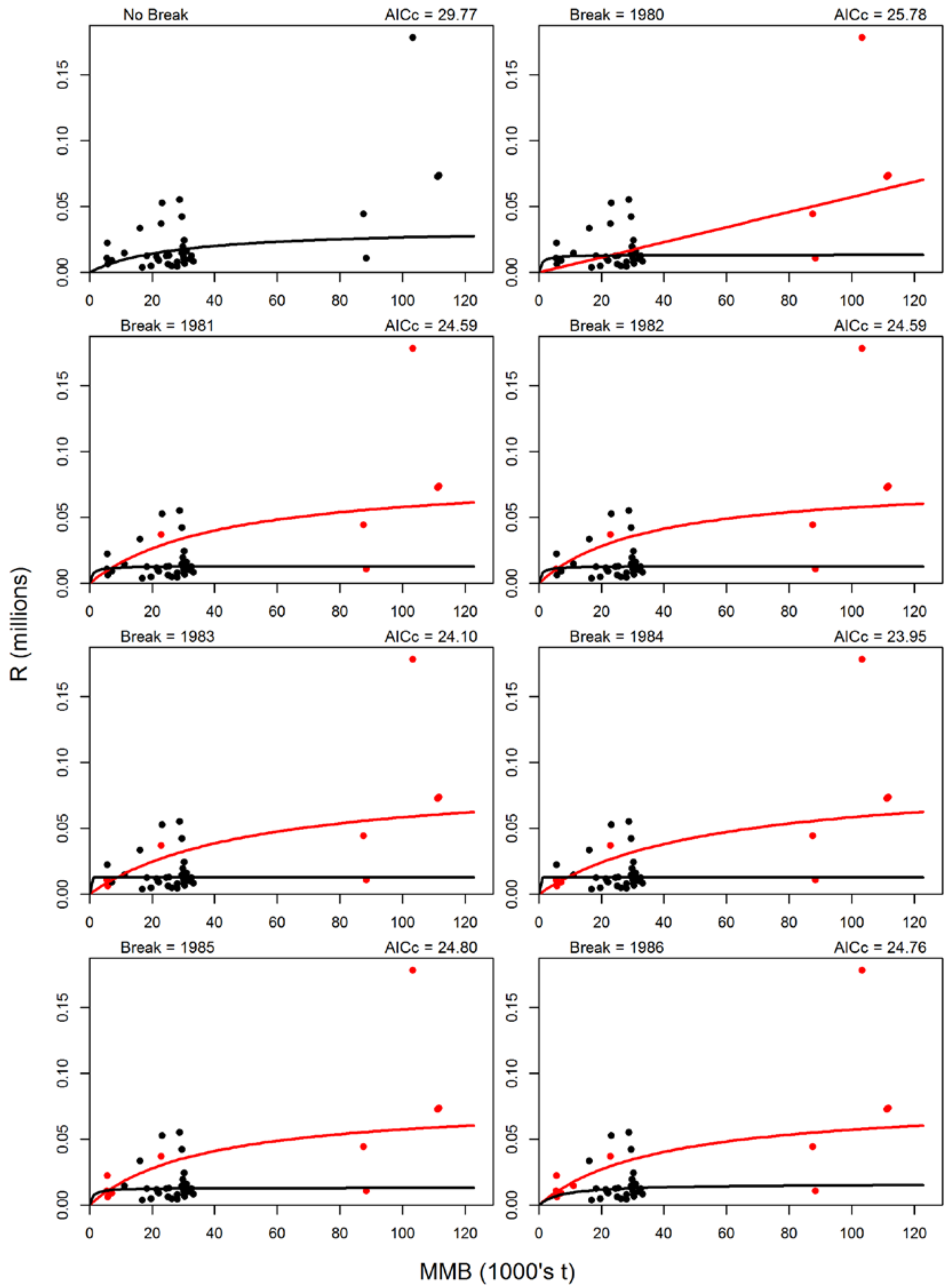


Figure B6. Fits on the arithmetic scale for B-H models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2007. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.

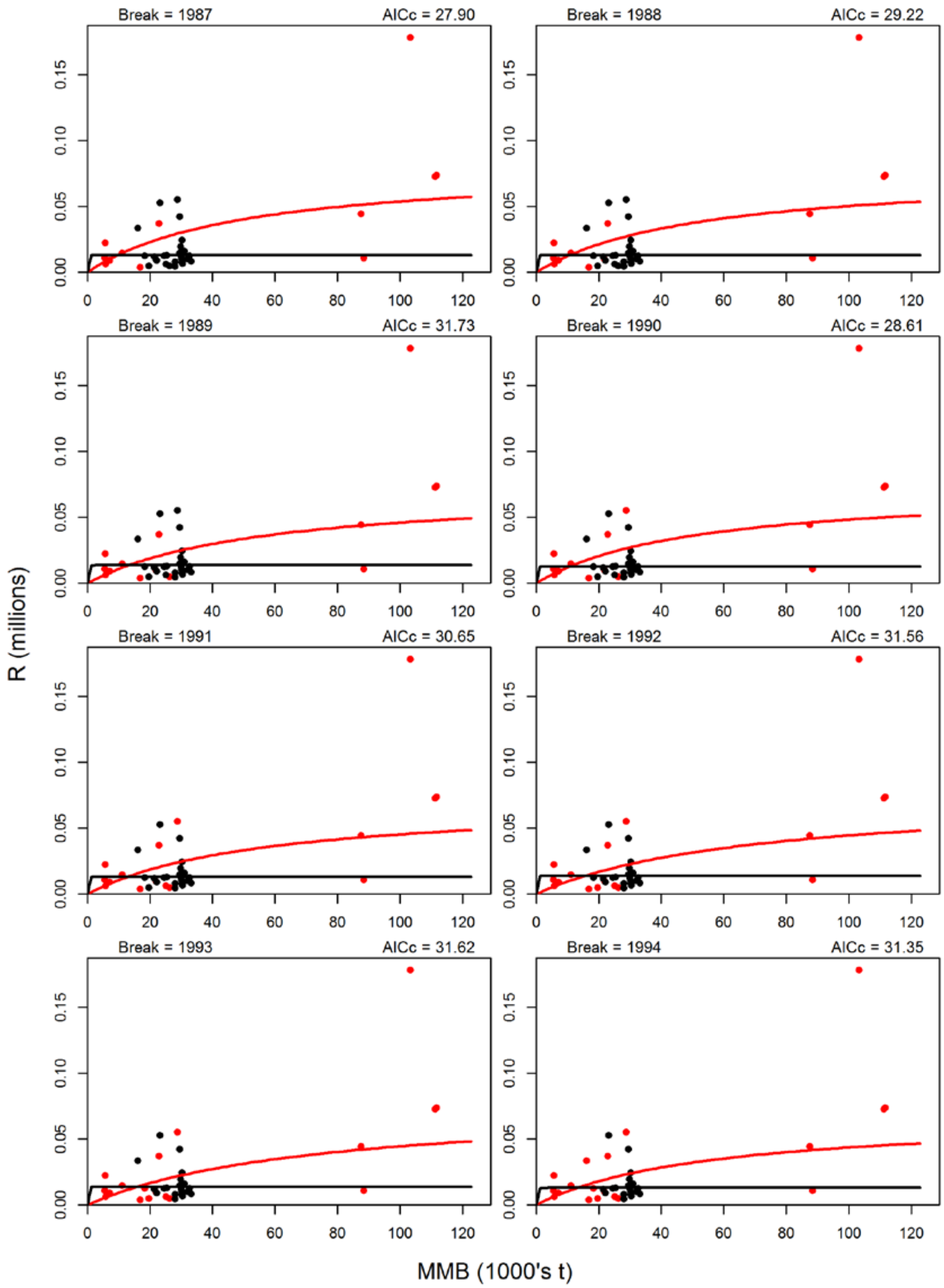
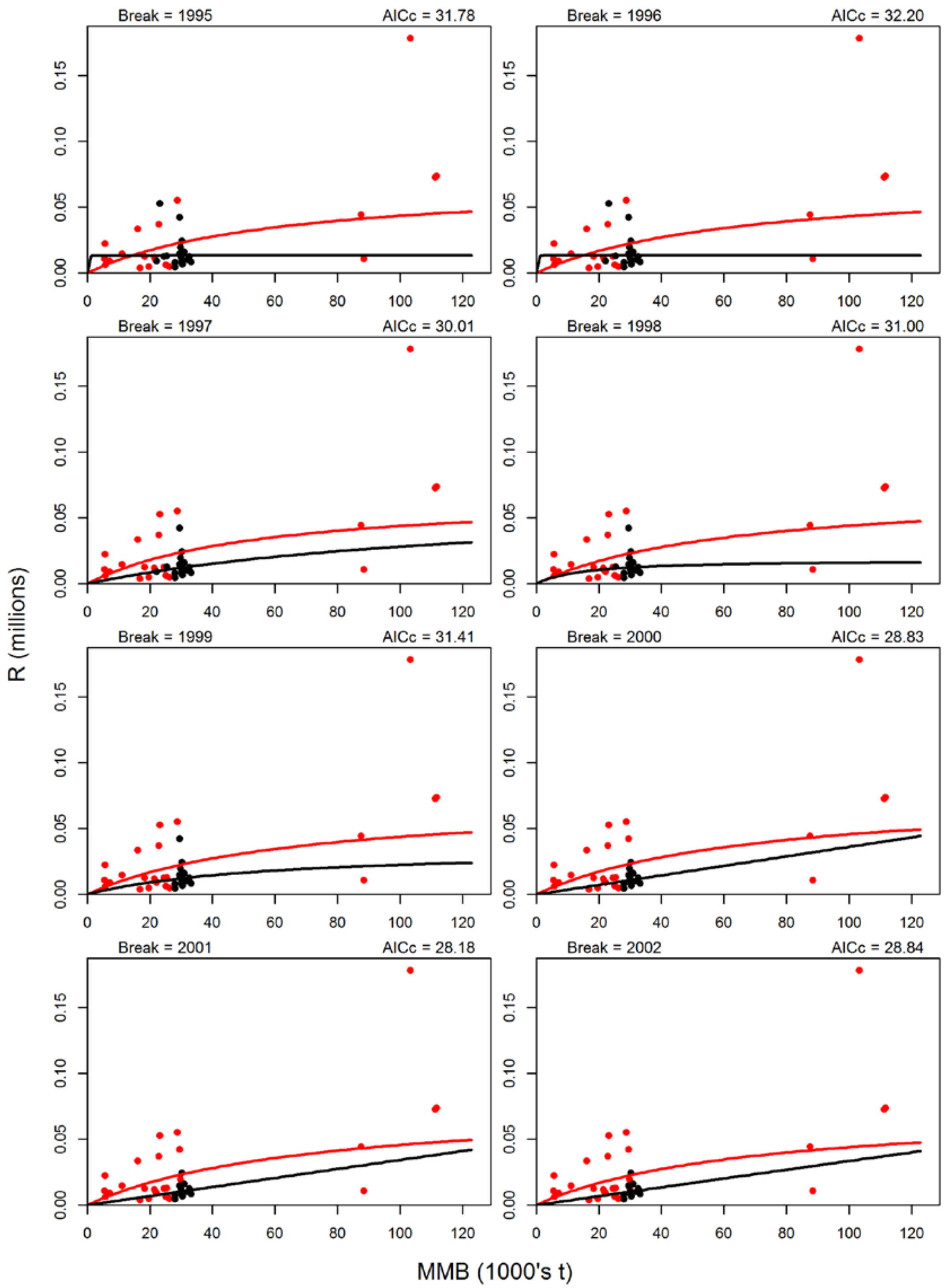


Figure B6. Continue.



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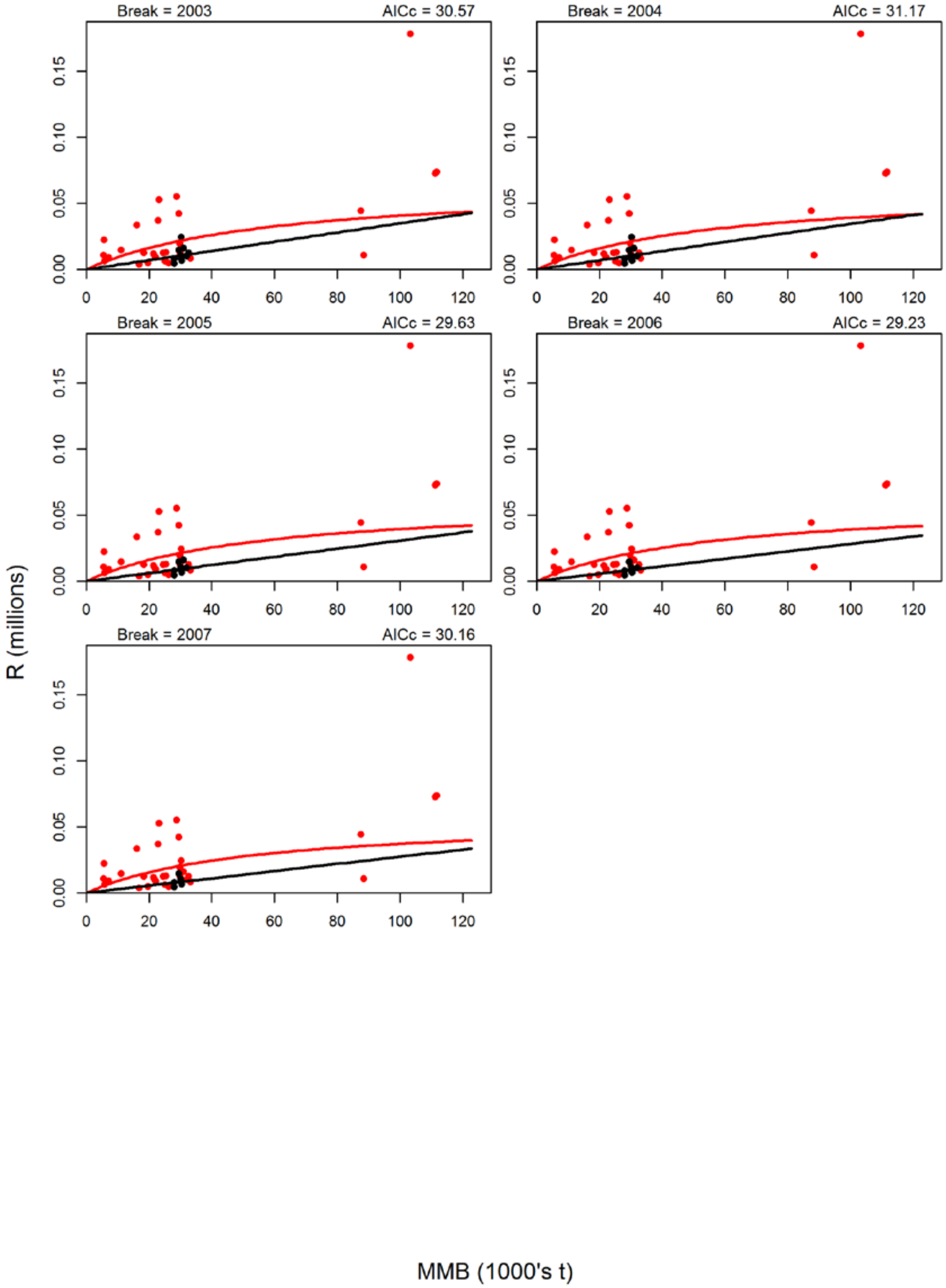

Figure B6. Continue.

Appendix C. Simple B0 Analysis

Ideally, a stock-recruitment relationship and impacts of environmental factors on recruitment are developed before doing B0 analysis. For Bristol Bay red king crab, there is hardly any relationship between estimated recruits and MMB (Figure 14a). The impacts of environmental factors on recruitment have not been quantified. We simply computed B0 values over time using the same recruitment time series estimated from the assessment model through setting all directed and bycatch fishing mortality to be zero. Figure C1 shows the time series of estimated B0, MMB with fishing, and ratios of MMB to B0 for model 18.0e. As expected, estimated B0 values change greatly over time.

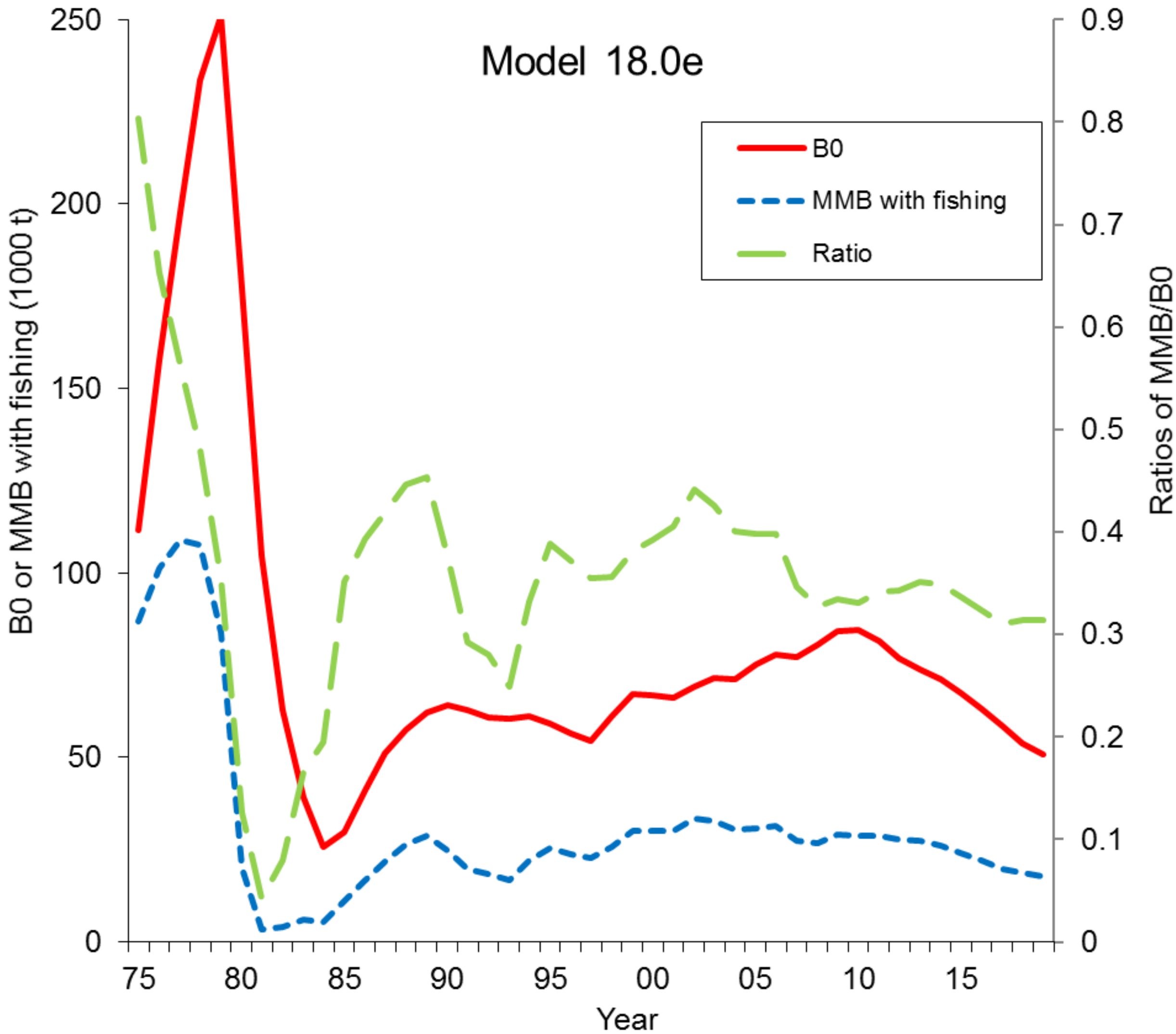

Figure C1. Estimated B0, MMB with fishing, and ratios of MMB/B0 from 1975 to 2019 for model 18.0e for Bristol Bay red king crab.

Appendix D. Control File for Model 19.0 (Gmacs)

```
##                                                  ##
## 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    0.2       -4      2    0.18    0.04      # 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)
   0.75      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

# 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)
```

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
————————————————————————————————————

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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 (males then females)
20 16
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
   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
## 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)

## ————————————————————————————————————————————————————————————————————————————##
## 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   2018  #4
   1     2    2   1      8.0      0.1   20    0      1    999    4     1975   2018  #4
   1     3    1   2     84.00      5    150    0      1    999    4     1975   2018
   1     4    2   2      4.0000    0.1   20    0      1    999    4     1975   2018
# Gear-2
   2     5    1   0    165.0       5    190    0      1    999    4     1975   2018
   2     6    2   0     15.0000    0.1   25    0      1    999    4     1975   2018
# Gear-3-
   3     7    1   1    115.0       5    190    0      1    999    4     1975   2018
   3     8    2   1     15.0      0.1   25    0      1    999    4     1975   2018
   3     9    1   2     95.0       5    190    0      1    999    4     1975   2018
   3    10    2   2      2.5      0.1   25    0      1    999    4     1975   2018
# Gear-4
   4    11    1   0    115.0       5    190    0      1    999    4     1975   2018
   4    12    2   0      9.0      0.1   25    0      1    999    4     1975   2018
# 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   2019  #5
   5    16    2   1     10.0       1     50    0      1    999    5     1982   2019  #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   2019  #5
   5    20    2   2      4.00     1.0    50    0      1    999    5     1982   2019  #5
# Gear-6
   6    21    1   1     75.0       1    180    0      1    999    5     1975   2019  # 5
   6    22    2   1      8.5       1     50    0      1    999    5     1975   2019  # 5
   6    23    1   2     85.0       1    180    0      1    999    5     1975   2019  # 5
   6    24    2   2     10.0       1     50    0      1    999    5     1975   2019  # 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   2018
  -1     28    2   1    2.5    1     20    0      1    999    4     2005   2018
  -1     29    1   2    591    1    999    0      1    999   -3     1975   2003
  -1     30    1   2    591    1    999    0      1    999   -3     2004   2018
# Gear-2
  -2     31    1   0    595    1    999    0      1    999   -3     1975   2018
# Gear-3
  -3     32    1   0    595    1    999    0      1    999   -3     1975   2018
# Gear-4
  -4     33    1   0    595    1    999    0      1    999   -3     1975   2018
# Gear-5
  -5     34    1   0    590    1    999    0      1    999   -3     1975   2019
# Gear-6
  -6     35    1   0    580    1    999    0      1    999   -3     1975   2019
## ------------------------------------------------------------------------------------ ##
# 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
  0.22313       0.0505     0.5     45.50     1      1   # Pot
  0.0183156       1.0     0.5     45.50     1     -1   # Trawl
  0.011109        1.0     0.5     45.50     1      1   # Tanner (-1 -5)
  0.011109        1.0     0.5     45.50     1     -1   # Fixed
  0.00            0.0    2.00     20.00    -1     -1   # NMFS trawl survey (0 catch)
  0.00            0.0    2.00     20.00    -1     -1   # BSFRF (0)
  2.95                                      # Upper bound value for male directed fishig mortality deviations
## ----------------------------------------------------------------------------------- ##
## ----------------------------------------------------------------------------------- ##
## 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)
0
## 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
```

```
4
## Year position of the knots (vector must be equal to the number of nodes)
1980 1985
1976 1980 1985 1994
# 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    ##
## ——————————————————————————————————————————— ##
 1.5342575      0        2         8      0
 0.000000     -2         2       -99      0
 0.262792      0         2         8     0
 1.780586      0         2         8     0
 9.262792      0         2         8    -3
 0.000000     -2         2       -99      0
## ——————————————————————————————————————————— ##
## ——————————————————————————————————————————— ##
## OTHER CONTROLS
## ——————————————————————————————————————————— ##
1975      # First rec_dev
2018      # last rec_dev
   2      # 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 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                  1
## EOF
9999
```

2019 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
10 September 2019

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 166°W 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 166° W and at 1,463,000 lbs (664 t) for the area east of 166° 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 166° W and at 8,480,000 lbs (3,829 t) for the area east of 166° W. On closing, 77.5% (2,329 t) of the TAC was taken in the western area while 99.6% (3,829 t) were taken in the eastern area. 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 166°W 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 166°W 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]).

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. 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 ~3,000 t for the 5-year period 2013/14-2017/18. Bycatch in the snow crab fishery in 2018/19 was 888 t. The groundfish fisheries have been the next major source of Tanner crab bycatch over the same five year time period, averaging 325 t. Bycatch in the groundfish fisheries in 2018/19 was 191 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 202 t over the 5-year time period. In 2018/19, this fishery accounted for only 74 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 using trawl gear 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 (M19F03), estimated MMB for 2018/19 was 79.5 thousand t (Table 47; Figure 61). MMB has been on a declining trend since 2014/15 when it peaked at 135.8 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). However, it is considerably below model-estimated historical levels in the late 1970s (1975-1980 average: 215.9 thousand t) before it declined through 1985.

4. Recruitment: trends and current levels relative to virgin or historic levels.
From the author’s preferred model (M19F03), the estimated total recruitment for 2018/19 (the number of crab entering the population on July 1) is 1,234.9 million crab (Table 50; Figure 59). Although this value is highly uncertain, it follows two years of similarly high estimates for 2016/17 and 2017/18 (647 and 677 million crab, respectively). The average 5-year recruitment prior to 2016/17 was only 108 million crab while the longterm (1982+) mean is 394 million crab.

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

(a) in 1000’s t.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2015/16	12.82	73.93	8.92	8.91	11.38	27.19	21.75
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		39.55				28.86	23.09

(b) in millions lbs.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2015/16	28.27	162.99	19.67	19.64	25.09	59.94	47.95
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				46.01	36.82
2019/20		87.18				63.62	50.89

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[A]	B_{MSY}[A]	Current MMB[A]	B/B_{MSY}[A]	F_{OFL}[A] (yr^{-1})	Years to define B_{MSY}[A]	Natural Mortality[A,B] (yr^{-1})
2015/16	3a	26.79	53.70	2.00	0.58	1982-2015	0.23
2016/17	3a	25.65	45.34	1.77	0.79	1982-2016	0.23
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

b) in millions lbs.

Year	Tier[A]	B_{MSY}[A]	Current MMB[A]	B/B_{MSY}[A]	F_{OFL}[A] (yr^{-1})	Years to define B_{MSY}[A]	Natural Mortality[A,B] (yr^{-1})
2015/16	3a	59.06	118.38	2.00	0.58	1982-2015	0.23
2016/17	3a	56.54	99.95	1.77	0.79	1982-2016	0.23
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

A—Calculated from the assessment reviewed by the Crab Plan Team in 20XX of 20XX/(XX+1) or based on the author's preferred model for 2019/20.
B—Nominal rate of natural mortality. Actual rates used in the assessment are estimated and may be different.

Current male spawning stock biomass (MMB), as projected for 2019/20, is estimated at 39.55 thousand t. B_{MSY} for this stock is calculated to be 41.07 thousand t, so MSST is 20.54 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 2018/19 was 1.90

thousand t, which was less than the OFL for 2017/18 (20.97 thousand t); consequently **overfishing did not occur**. The OFL for 2019/20 based on the author's preferred model (M19F03) is 28.86 thousand t. The ABC_{max} for 2019/20, based on the p^* ABC, is 28.79 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 23.09 thousand t.

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

A. Summary of Major Changes

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

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 has since been prosecuted in 2017/18 and 2018/19.

2. Changes to the input data
The following table summarizes data sources that have been updated for this assessment:

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

Updated data sources.

Description	Data types	Time frame	Notes	Source
NMFS EBS Bottom Trawl Survey	area-swept abundance, biomass	1975-2019	recalculated, new	NMFS
	size compositions	1975-2019	recalculated, new	
	male maturity data	2006+	new	
NMFS/BSFRF	molt-increment data	2015-17, 2019	same as 2017	NMFS, BSFRF
BSFRF SBS Bottom Trawl Survey	area-swept abundance, biomass	2013-17	new	BSFRF
	size compositions	2013-17	new	
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	updated, new	ADFG
	retained catch size compositions	2013/14-2018/19	updated, new	ADFG
	total catch (abundance, biomass)	1991/92-2017/18	revised, new	ADFG
	total catch size compositions	1991/92-2017/18	revised, new	ADFG
Snow Crab Fishery	historical effort	1978/79/1989/90	not updated	2018 assessment
	effort	1990/91-2018/19	revised, new	ADFG
	total bycatch (abundance, biomass)	1990/91-2018/19	revised, new	ADFG
	total bycatch size compositions	1990/91-2018/19	revised, new	ADFG
Bristol Bay Red King Crab Fishery	historical effort	1953/54-1989/90	not updated	2018 assessment
	effort	1990/91-2018/19	revised, new	ADFG
	total bycatch (abundance, biomass)	1990/91-2018/19	revised, new	ADFG
	total bycatch size compositions	1990/91-2018/19	revised, new	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)	1991/92-2017/18	revised, new	NMFS/AKFIN
	total bycatch size compositions	1991/92-2017/18	updated, new	

Changes of note include the incorporation of BSFRF bottom trawl survey data from the “side-by-side” (SBS) catchability studies jointly conducted with the NMFS EBS bottom trawl survey in 2013-2017, the addition of new molt increment (growth) data, and the use of revised estimates by ADFG of total catch/bycatch data from at-sea observer sampling in the crab fisheries. Otherwise, the changes consist of finalized catch data for 2017/18 and new catch data for 2018/19.

3. Changes to the assessment methodology.

Following a considerable development effort and substantial review by the CPT at the January 2017 Modeling Workshop and the May 2017 CPT Meeting, with additional review by the SSC at its February and June 2017 meetings, a new modeling “framework”, TCSAM02, was recommended by the CPT at its May 2017 meeting (and approved by the SSC at its June 2017 meeting) for use in the 2017/18 assessment. This framework was used again in 2018/19 and is the basis for this assessment. TCSAM02, while based on the previous assessment model (TCSAM2013), constitutes a completely rewritten code library for the Tanner crab assessment model. Results presented at the May 2017 CPT meeting demonstrated that TCSAM02 could be configured to exactly match results from the TCSAM2013 code, thus providing continuity with the old model code.

The 2017 assessment model (“B2b” in that assessment), built on the 2016 model by: 1) fitting EBS model-increment data inside the model to inform growth parameters, b) estimating separate retention functions for three time periods (pre-1997/98, 2005/06-2009/10, and 2013/14-2015/16), and c) estimating the asymptotic value for the fraction of male crab retained in the directed fishery (in the same three time periods as (b)), rather than assuming it was 1 (i.e., 100% retention at large sizes). This was also the model (with updated data for 2017/18, referred to in that assessment as “18AM17”) selected by the CPT and SSC for the 2018 assessment. This model is referred to here as “M19F00” as the base model scenario for this assessment.

The author-recommended model scenario proposed here, "M19F03", differs 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 fits the 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.

4. Changes to the assessment results
Revisions to the input crab fishery data used in the assessment model have had a large effect (almost 2x) on the estimated scale of the population, although the trends are very similar. Average recruitment (1982-present) was estimated at 224 million in last year's model, whereas it is estimated at 394 million in the author's preferred model this year. F_{MSY} is larger this year (1.18 yr^{-1} this year vs. 0.74 yr^{-1} last year), as is B_{MSY} (40.75 thousand t vs. 30.29 thousand t). The stock remains in Tier 3, but it is now classified as "3b" rather than "3a" (its classification last year) because the ratio of projected MMB to B_{MSY} is 0.95, i.e. less than 1. Last year the ratio was 1.19.

B. Responses to SSC and CPT Comments

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

June 2019 SSC Meeting
SSC Comment: The SSC reminded authors to use the model numbering protocols that allow the SSC to understand the year in which a particular version of the model was first introduced.
Response: The Tanner crab assessment has not fully implemented this suggestion. The 2018 assessment model was labeled 18AM17, which does not follow the guidelines. Here, that model is referred to as M19F00 ("00" designating the base model from which other scenarios proceed in the 2019 assessment, "F" denoting the "final" scenarios proposed in May). This also does not reflect the requested model numbering. However, the model numbering adopted herein should allow subsequent model numbering to follow the guidelines (so that the author's preferred model M19F03 would become 19.03 in the future).

May 2019 Crab Plan Team Meeting
No general comments.

October 2018 SSC Meeting
SSC Comment: The SSC reminded authors to use the model numbering protocols that allow the SSC to understand the year in which a particular version of the model was first introduced.
Response: Model numbering was consistent with this guideline for the model scenarios presented by the author to the CPT in September 2018. However, the CPT recommended a model based on the 2017 assessment which was labeled 18AM17 to designate the 2017 assessment model updated with 2018 data, which did not follow the guidelines.

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/
Response: The Tanner crab assessment does not yet use VAST-based estimates of survey biomass.

September 2018 Crab Plan Team Meeting
No general comments.

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

June 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).
Response: 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

The CPT accepted the author's recommended models for presentation in September 2019.
Response: The model runs with the recommended scenarios were run for this assessment, and the results are presented herein. The CPT (and assessment author) referred to these "final scenarios" as 19F.0, 19F.0a, 19F.1, 19F.2, 19F.3, 19F.4, and 19F.5. Here, they are referred to as M19F00, M19F00a, M19F01, M19F02, M19F03, M19F04, and M19F05 (which allowed for additional scenarios while maintaining folder/scenario order on computer disk).

CPT comment: compare the estimated selectivity to the ratio of NMFS to BSFRF numbers at length. Is estimated and empirical catchability/availability/selectivity the same? Does the empirical selectivity look logistic?"
Response: The model-estimated availability of Tanner crab to the survey gears in the side-by-side (SBS) study areas was compared to "empirical" estimates of availability using the ratio of numbers-at-size in the NMFS SBS datasets to those form the full NMFS EBS survey. The results are shown in Figure 53. While there are some similarities between the two sets, there are also substantial differences when conceptually they should be the same. Results for the empirical size-specific relative catchability (the ratio of NMFS to BSFRF estimated abundance at size) are shown in Figure 65, but are not compared directly to the estimated selectivity. The mean curves appear reasonably logistic, with approximate asymptotes of ~0.6 for males and ~0.4 for females. If the BSFRF surveys are regarded as providing estimates of absolute abundance (catchability=1 for all sizes), this would suggest fully-selected NMFS survey "q"'s are ~0.6 for males and ~0.4 for females--which are about 50% higher than the estimates (0.43 and 0.24, respectively) from the assessment model, but within the 95% confidence intervals for males (0.37-0.49) (but not females: 0.19-0.29).

CPT comment: show the fits to the BSFRF length composition data by year as well as in aggregate.
Response: These fits are shown in Appendix B.

CPT comment: check the bounds of parameters when estimating the BSFRF data.
Response: Fitting the BSFRF data results in no better, or worse, performance in terms of parameters hitting their bounds.

CPT comment: indicate whether or not Hessians were produced.
Response Hessians were produced for the "best" model runs for all scenarios and .std files were obtained.

CPT comment: Suggest rationale for chosen weighting for the second difference smoothing on the availability curve.
Response: The rationale for the selected weighting is that it reflects a preference toward a smoothly-varying function, reflecting an assumption that crab of similar sizes would tend to be found together with no abrupt dichotomies (which would justify a smaller smoothing weight) in spatial distribution with size. However, this assumption has not been examined in detail.

CPT comment: Compare trends in largest crab to fishing pressure and area occupied by stock.
Response: This is a good suggestion that, time permitting, will be addressed before the January 2020 CPT meeting.

CPT comment: Compare the maximum sizes seen in the fishery to the survey.
Response: Another good suggestion that, time permitting, will be addressed before the January 2020 CPT meeting.

CPT comment: Consider blocking for estimation of growth and probability of maturing.
Response: 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: Make incorporating chela height data in the assessment a priority because this might address changes in the probability of maturing over time
Response: Chela height data, in the form of male maturity ogives based on collections of chela heights since 2006, is incorporated in several model scenarios examined here, including the author-preferred scenario.

CPT comment: Provide retrospective analysis and calculate Mohn's rho for MMB
Response: Retrospective analyses for Tanner crab are complicated given the recent fishery closures and short time frames for molt increment and maturity ogive data. Time did not permit making retrospective analyses for the model scenarios considered herein. However, a retrospective analysis for the CPT-selected assessment model could be presented at the January 2020 CPT meeting.

October 2018 SSC Meeting
Comment: The SSC supports "the author's plans to investigate the sensitivity of the model to just a few early years of catch data".
Response: As described in Section 3.2, the apparent sensitivity of the model to changes in the early 1990s crab observer data was instead due to using erroneous input sample sizes for several years of fishery size composition data. After correcting these errors, the results using the revised crab fishery data are more reasonable, with less inflation of estimated population sizes. However, these sizes are still substantially larger than those obtained using the out-of-date fishery catch data. The author recommended adopting the revised crab fishery data, which was based on a painstaking reclassification of directed vs. incidental effort in the early Tanner and snow crab fisheries that more closely reflects current ADFG practices. Both the CPT and SSC concurred in May/June 2019 with this recommendation.

Comment: *"The SSC continues to recommend that the authors try to resolve the parameters on the bounds issue by either simplifying the model or experimenting with removing the bounds".*
Response: A number of formerly-estimated parameters related to the sex- and size-specific probability of undergoing the terminal molt to maturity have been eliminated because they were, unsurprisingly, estimated at their bounds (implying a probability of 0 for a terminal molt of very small immature crab or 1 for very large immature crab). This had no discernable effect on the MLE solution.

Comment: *"The author should justify fitting both abundance and biomass indices in the model or fit only one index".*
Response: The author sees no justification for fitting both abundance and biomass indices in the current model configuration and so will only include fits to one index (biomass) in the model optimization. Fits to the other index may provide a diagnostic capability.

Comment: *"The team looks forward to seeing the BSFRF work included in the future If the catchability study is to be used to inform selectivity and catchability estimates in the model, it could be as a prior instead of as fixed inputs".*
Response: After preliminary examination of this for the May 2019 CPT meeting, two model scenarios incorporating the BSFRF side-by-side (SBS) tow studies are considered in this assessment, using an approach similar to that used in the snow crab model. The use of the catchability study as a prior is an intriguing idea but would require substantial additional model development and remains to be explored. An alternative approach to the one applied here, which assumes that selectivity in the BSFRF studies is 1 and estimates availability curves that are applied to both the BSFRF and NMFS SBS simultaneously, is to

use the NMFS SBS data to estimate the availability curves outside the model using size-specific ratios between the NMFS SBS and full NMFS estimates of abundance-at-size. These could then be applied inside the model and would eliminate ~50 additional parameters per year of SBS data. However, issues associated with unobserved size ranges would need to be addressed.

September 2018 CPT Meeting
Comment: None

C. Introduction

1. Scientific name.
*Chionocoetes bairdi.*Tanner crab is one of five species in the genus *Chionoecetes* (Rathbun, 1924). The common name "Tanner crab" for *C. bairdi* (Williams et al. 1989) was recently modified to "southern Tanner crab" (McLaughlin et al. 2005). Prior to this change, the term "Tanner crab" had also been used to refer to other members of the genus, or the genus as a whole. Hereafter, the common name "Tanner crab" will be used in reference to "southern Tanner crab".

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

In the eastern Bering Sea (EBS), the Tanner crab distribution may be limited by water temperature (Somerton 1981a). The unit stock is that defined across the geographic range of the EBS continental shelf, and managed as a single unit (Fig. 1). *C. bairdi* is common in the southern half of Bristol Bay, around the Pribilof Islands, and along the shelf break, although males less than the industry-preferred size (>125 mm CW) and ovigerous and immature females of all sizes are distributed broadly from southern Bristol Bay northwest to St. Matthew Island (Rugolo and Turnock, 2011a). The southern range of the cold water congener the snow crab, *C. opilio*, in the EBS is near the Pribilof Islands (Turnock and Rugolo, 2011). The distributions of snow and Tanner crab overlap on the shelf from approximately 56° to 60°N, and in this area, the two species hybridize (Karinen and Hoopes 1971).

3. Evidence of stock structure
Tanner crabs in the EBS are considered to be a separate stock distinct from Tanner crabs in the eastern and western Aleutian Islands (NPFMC 1998). Somerton (1981b) suggests that clinal differences in some biological characteristics may exist across the range of the unit stock. These conclusions may be limited since terminal molt at maturity in this species was not recognized at the time of that analysis, nor was stock movement with ontogeny considered. Biological characteristics estimated based on comparisons of length frequency distributions across the range of the stock, or on modal length analysis over time may be confounded as a result.

Although the State of Alaska's (SOA) harvest strategy and management controls for this stock are different east and west of 166^{o}W, the unit stock of Tanner crab in the EBS appears to encompass both regions and comprises crab throughout the geographic range of the NMFS bottom trawl survey. Strong evidence is lacking that the EBS shelf is home to two distinct, non-intermixing, non-interbreeding stocks that should be assessed and managed separately (G. Johnson, presentation at the May 2019 CPT meeting).

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.

The Rugolo-Turnock classification approach is referred to herein as the "Rugolo-Turnock male maturity ogive". In this and previous assessments, the Rugolo-Turnock maturity ogive has been used to fix the proportions of immature and mature, new shell male crab in size composition data from the entire NMFS EBS bottom trawl survey dataset and to subsequently provide survey biomass estimates of abundance and biomass aggregated over all size classes. The NMFS survey datasets that use this approach to characterize male maturity outside the assessment model are identified here as "NMFS 0". The assessment model has used the resulting annual estimates of immature and new shell mature male crab abundance, biomass and size compositions as "data" to inform the model's estimates of population size and processes, including the probability of immature male crab within a given model size bin undergoing the terminal molt to maturity. This is somewhat circular in nature, and several model scenarios in this assessment fit directly to annual observed (i.e., classifying crab based on CH:CW ratios) proportions of new shell mature males to all new shell males by size bin without classifying new shell males as immature or mature outside the model.

g. Mortality

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

Rugolo and Turnock (2011a) examined empirical evidence for reliable estimates of oldest observed age for male Tanner crab. Unlike its congener the snow crab, information on longevity of the Tanner crab is lacking. They reasoned that longevity in a virgin population of Tanner crab would be analogous to that of the snow crab, where longevity would be at least 20 years, given the close analogues in population dynamic and life-history characteristics (Turnock and Rugolo 2011a). Employing 20 years as a proxy for longevity and assuming that this age represented the upper 98.5th percentile of the distribution of ages in an unexploited population, M was estimated to be 0.23 based on Hoenig's (1983) method. If 20 years was assumed to represent the 95% percentile of the distribution of ages in the unexploited stock, the estimate for M was 0.15. Rugolo and Turnock (2011a) adopted M=0.23 for both male and female Tanner because the value corresponded with the range estimated by Somerton (1981a), as well as the value used in the analysis to estimate new overfishing definitions underlying Amendment 24 to the Crab Fishery Management Plan (NPFMC 2007).

5. Brief summary of management history.

A complete summary of the management history is provided in the 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" (138 mm CW) throughout the Bering Sea District. The new regulations established different minimum size limits east and west of 166° W. The minimum size limit for the fishery to the east of 166°W is now 4.8" (122 mm CW) and that to the west is 4.4" (112 mm CW), where the size measurement includes the lateral spines. For economic reasons, fishers may adopt larger minimum sizes for retention of crab in both areas, and the SOA's harvest strategy and total allowable catch (TAC) calculations are based on assumed minimum preferred sizes that are larger than the legal minimums. In 2011, these minimum preferred sizes were set at 5.5" (140 mm CW) in the east and 5" (127 mm CW) in the west, including the lateral spines. In 2015, following a petition by the crab industry, the BOF revised the minimum preferred size for TAC calculations in the area east of 166° W longitude to 5" (127 mm CW), the same as that in the western area. These new "preferred" sizes were used to set the TAC for the 2015/16 fishery season.

In assessments prior to 2016, the term "legal males" was used to refer to male crab ≥ 138 mm CW (not including the lateral spines), although this was not strictly correct as it referred to the industry's "preferred" crab size in the east region, as well as to the minimum size in the east used in the SOA's harvest strategy for TAC setting. In subsequent assessments (and this one), the term "legal males" is used to refer to male crab 125 mm CW (the current minimum "preferred" size for both eastern and western areas used in the SOA's harvest strategy) and larger.

Landings of Tanner crab in the Japanese pot and tangle net fisheries were reported in the period 1965-1978, peaking at 19.95 thousand t in 1969. The Russian tangle net fishery was prosecuted during 1965-1971 with peak landings in 1969 at 7.08 thousand t. Both the Japanese and Russian Tanner crab fisheries were displaced by the domestic fishery by the late-1970s (Table 1; Figure 2). 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 3). Domestic US landings were first reported for Tanner crab in 1968 at 0.46 thousand t taken incidentally to the EBS red king crab fishery. Tanner crab was targeted thereafter by the domestic fleet and landings rose sharply in the early 1970s, reaching a high of 30.21 thousand t in 1977/78. Landings fell sharply after the peak in 1977/78 through the early 1980s, and domestic fishing was closed in 1985/86 and 1986/87 due to depressed stock status. In 1987/88, the fishery reopened and landings rose again in the late-1980s to a second peak in 1990/91 at 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; Figure 2). 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.

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 3). 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 mode of discard losses occurred in the early-1990s. In the early-1970s, the groundfish fisheries contributed significantly to total bycatch losses (although bycatch in the crab fisheries was undocumented at the time). From 1992/93 (when reliable crab fishery bycatch estimates are 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

For several years now, NMFS has annually provided a standardized version of the EBS bottom trawl survey for Tanner and other crab stocks for surveys from 1975 to the present. Similarly, estimates from the NMFS Regional Office for crab bycatch in the groundfish fisheries since 1990 have been provided by AKFIN. Standard procedure in this assessment has been to update all the data used in the assessment model based on these sources each year, so that the data used in the assessment remains consistent with the survey and groundfish bycatch data provided by NMFS and AKFIN (see below).

However, this was not done with the retained catch and bycatch data provided annually by ADFG due mainly to inconsistency between years in the formats in which the data were provided. More recently (starting in 2017), ADFG has provided datasets in more consistent formats, allowing development of stable R code to extract the data required for the assessment in a repeatable fashion, rather than doing it by hand or in "one-off" code for a particular assessment. Thus, prior to 2018 the corresponding data in the assessment tended to be added for the current and only updated for the previous year (if necessary). Following the 2017 assessment in the course of developing R code to extract the data to a format compatible with the assessment, it was noted that discrepancies had accrued primarily between the total catch biomass data used in the assessment and those provided by ADFG for fisheries conducted in the 1990s, although there were also some (much smaller) discrepancies later in the time series and in the retained catch data as well (Tables 4-7). The discrepancies in the total catch estimates in the 1990s were traced back to a substantial reclassification of directed fishing effort and at-sea observer sampling by Doug Pengilly in 2015 that primarily affected the expansion of sampled catch by at-sea observers to total catch estimates in the early 1990s; these had not been updated in the assessment (pending a review). The smaller discrepancies later in the time series may have been due to a change in the size-weight relationships used to calculate average catch weight when CPUE was expanded to total catch biomass. The main discrepancies in retained catch occurred in 2013/14 and 2014/15 and were the result of incidental retained catch of Tanner crab in the snow and BBRKC fisheries inadvertently not being aggregated into the values for the directed fishery provided to the assessment author (Table 8). For the 2018 assessment, the "current" crab fisheries data differed from "historical" data (i.e., used in the 2017 assessment) as summarized in the following table:

data type	years not updated	years updated
effort in the BBRKC fishery	1953/54-1989/90	1990/91 to present
effort in the snow crab fishery	1978/79-1989/90	1990/91 to present
retained catch abundance, biomass	1965/66-1996/97	2005/06 to present
retained catch size compositions	1980/81-1989/90	1990/91 to present
total catch abundance, biomass (all fisheries)	--	1990/91 to present
total catch size compositions (all fisheries)	--	1990/91 to present

Unfortunately, the CPT and SSC did not have the opportunity to approve the use of the "current" version of data from the crab fisheries prior to the 2018 assessment; thus, the 2018 assessment was based on the "historical" version, with the addition of 2017/18 data. However, the "current" version was reviewed by the CPT in May 2019 and approved for use in this assessment (to which the SSC concurred at the June 2019 Council meeting).

1. Summary of new information

ADFG provided revised values for retained catch abundance and biomass from fish ticket data for 2005/06-2017/18, with new values for 2018/19. This included a breakout of incidental retained Tanner crab catch in the snow crab and BBRKC fisheries; prior to the 2018/19 assessment only total retained catch (assumed taken in the directed fishery) had been provided. 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. Revised retained catch size composition data from "dockside" observer sampling in the directed fishery were provided by ADFG last year for 1989/90-2017/18 and updated by ADFG this year for 2013/14-2017/18, with new data for 2018/19.

Revised estimates of total Tanner crab catch and bycatch in the directed, snow crab, and BBRKC fisheries provided by ADFG for 1990/91-2017/18 were incorporated into the assessment. ADFG provided updated values for total catch in the crab fisheries for 2017/18 and new values for 2018/19.

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.

Swept-area abundance, biomass and size composition data from the 2019 NMFS EBS Bottom Trawl Survey were added to the assessment. Survey results for the assessment were calculated directly from the survey “crab haul” data files and station strata file to incorporate assessment criteria (e.g., excluding crab < 25 mm CW, aggregating crab > 185 mm CW into the upper-most size bin in size compositions) and facilitate comparisons across multiple areas and population categories.

Molt increment data from growth studies conducted in the EBS as cooperative research by NMFS and BSFRF are fit in the model scenarios included in this assessment, with new data from studies in 2017 and 2019 included in this assessment.

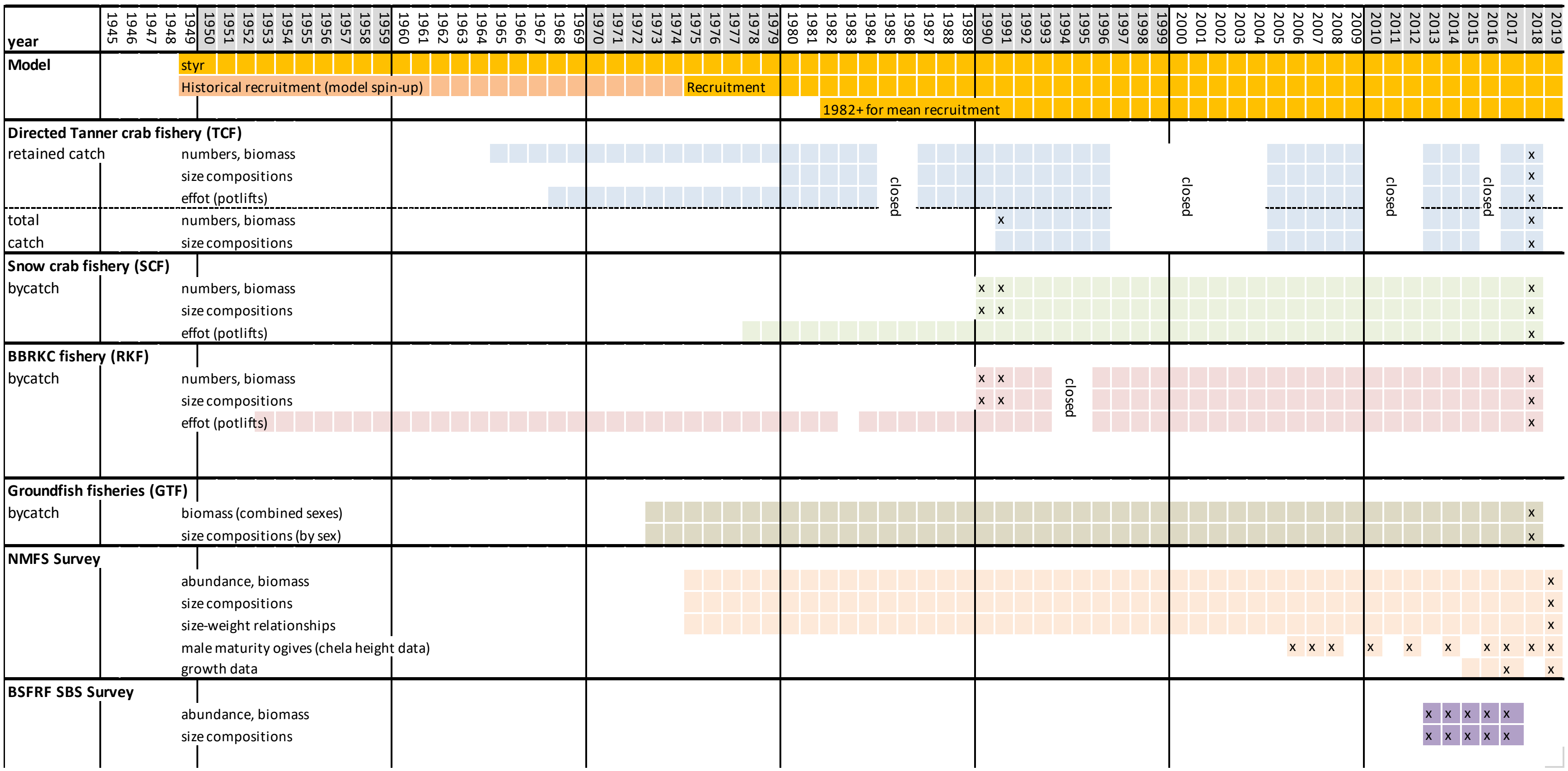
Annual male maturity ogives based on classification of male crab in the NMFS EBS bottom trawl survey using CH:CW ratios are fit in a number of the model scenarios considered in this assessment. Existing and new (2019) chela height data sets were analyzed to provide estimates of the fraction of new shell mature males to all new shell male crab by 10 mm size bin (J. Richar, NMFS, pers. comm.). Data from collections since 2006, when chela heights were first measured to 0.1 mm, are included in the assessment.

Finally, data for Tanner crab from the joint BSFRF-NMFS comparative catchability (“side-by-side”) studies in 2013-2017 are included in the assessment for the first time.

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

Description	Data types	Time frame	Notes	Source
NMFS EBS Bottom Trawl Survey	area-swept abundance, biomass	1975-2019	recalculated, new	NMFS
	size compositions	1975-2019	recalculated, new	
	male maturity data	2006+	new	
NMFS/BSFRF	molt-increment data	2015-17, 2019	same as 2017	NMFS, BSFRF
BSFRF SBS Bottom Trawl Survey	area-swept abundance, biomass	2013-17	new	BSFRF
	size compositions	2013-17	new	
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	updated, new	ADFG
	retained catch size compositions	2013/14-2018/19	updated, new	ADFG
	total catch (abundance, biomass)	1991/92-2017/18	revised, new	ADFG
	total catch size compositions	1991/92-2017/18	revised, new	ADFG
Snow Crab Fishery	historical effort	1978/79/1989/90	not updated	2018 assessment
	effort	1990/91-2018/19	revised, new	ADFG
	total bycatch (abundance, biomass)	1990/91-2018/19	revised, new	ADFG
	total bycatch size compositions	1990/91-2018/19	revised, new	ADFG
Bristol Bay Red King Crab Fishery	historical effort	1953/54-1989/90	not updated	2018 assessment
	effort	1990/91-2018/19	revised, new	ADFG
	total bycatch (abundance, biomass)	1990/91-2018/19	revised, new	ADFG
	total bycatch size compositions	1990/91-2018/19	revised, new	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)	1991/92-2017/18	revised, new	NMFS/AKFIN
	total bycatch size compositions	1991/92-2017/18	updated, new	

The following table summarizes the data coverage in the assessment model (color shading highlights different model time periods and data components):



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 2 and 3 by fishery year. More detailed information on retained catch in the directed domestic pot fishery is provided in Table 2, which lists total annual catches in numbers of crab and biomass (in lbs), as well as the SOA's Guideline Harvest Level (GHL) or Total Allowable Catch (TAC) , number of vessels participating in the directed fishery, and the fishery season. Information from the Community Development Quota (CDQ) is included in the totals starting in 2005/06.

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

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 3 and Figure 4 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. In previous assessments, estimates of "discards" were provided rather than estimates for "total catch", which allowed mortality associated with the handling process to be estimated outside the assessment model. While this generally remains true for bycatch in the groundfish and non-directed crab fisheries (most or all Tanner crab bycatch is discarded), "discard mortality" cannot be estimated outside the assessment model for males in the directed fishery.

Estimated bycatch mortality in the groundfish fisheries (without distinguishing gear type) was highest (~15,000 t) in the early 1970s, but was substantially reduced by1977 to ~2,000 t with the curtailment of foreign fishing fleets (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 a gradual decline until 2008, after which it has fluctuated annually below ~300 t to the present (150 t in 2018/19).

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 5 by fishery region and shell condition since the fishery re-opened in 2013/14. These appear to indicate a shift to retaining somewhat smaller minimum sizes since 2013/14, compared with 2005/06-2009/10 (Stockhausen, 2017). In fact, the BOF in 2014/15, in response to a petition by industry, 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.

Normalized total catch (retained + discards) size compositions from at-sea crab fishery observer sampling are presented by sex and fishery in Figures 6-11. 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 Figures 112-13 for 1991/92 to 2018/19. 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 in Figure 12).

Raw and input sample sizes (number of individuals measured) for the various fisheries are presented in Tables 9-13.

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 14-15, Figures14-15). 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 14). 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 currently at its lowest point (28,000 t) since 2000 (Table 14). 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 14). 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 15, Figure 15). 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 16, while estimates of area-swept biomass for the study areas are compared in Figure 17 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 18. 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 19), 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 19, 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 16. 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 Figures 20-22 for immature males, mature males, immature females, mature females and legal males. 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 23 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 166oW 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 17).

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 24) 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 25.

c. Size distribution at recruitment

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

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 have been made to the TCSAM computer code to improve code readability, computational speed, model output, and user friendliness without altering its underlying dynamics and overall framework. A detailed description of the 2013 model (TCSAM2013) is presented in Appendix 3 of the 2014 SAFE chapter (Stockhausen, 2014). Following the 2014 assessment, the model code was put under version control using "git" software and is publicly available for download from the GitHub website[2].

A new 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. The new 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 new frame work incorporates new data types (e.g., molt increment data, male maturity ogives), new survey data (e.g., the BSFRF surveys), and new fishery data (e.g., bycatch in the groundfish fisheries by gear type). The new model 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 Markov Chain Monte Carlo (MCMC) evaluation of a model's posterior probability distribution.

Most recently, the model code has been modified to allow fitting to molt increment observations, chela height data, and male maturity ogives. It has also been restructured to function in a management strategy evaluation (MSE) mode. The code for the TCSAM02 model framework is publicly available on GitHub[3].

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 A.

In brief, crab enter the modeled population as recruits following the size distribution in Figure 26. 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 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

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

[3] https://github.com/wStockhausen/wtsTCSAM02.git

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 function in a management strategy evaluation mode, with specific computational routes defined for use as an operational model and as an estimation model. Fits to annual male maturity ogives were incorporated into the model last year, but with the assumption that these data would be aggregated to the same size bins as used in the model and other data. Now, this requirement has been loosened and the model can now fit ogives given using any size bin width. Finally, the model now allows specification and estimation of "availability" functions, similar to selectivity functions, that reflect the size-specific fraction of a section of the population (defined by sex, maturity state and shell condition) that can be encountered within a specific survey collection. This was necessary to incorporate the BSFRF SBS data into the assessment framework because these collections, in contrast to the complete NMFS EBS bottom trawl survey, do not encompass the entire Tanner crab stock.

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 2018 assessment (Model 18AM17 from Stockhausen, 2018) provides the baseline model configuration for subsequent alternative model scenarios evaluated in this assessment. Here, the 2018 assessment model is designated "M19F00". The following tables provide a summary of the baseline model configuration, M19F00, for this assessment.

Model M19F00: 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 M19F00: 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 M19F00: Description of model likelihood components.

Component	Type	included in optimization	Distribution	Likelihood
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 "0" survey	abundance	no	lognormal	by sex
	biomass	yes	lognormal	by sex, for mature crab only
	size comp.s	yes	multinomial	by sex/maturity
	chela height data	no	--	--
NMFS "M" survey (males only, no maturity)	abundance	no	lognormal	all males
	biomass	no	lognormal	all males
	size comp.s	no	multinomial	all males
NMFS "F" survey (females only, w/ maturity)	abundance	no	lognormal	by maturity classification
	biomass	no	lognormal	by maturity classification
	size comp.s	no	multinomial	by maturity classification
growth data	EBS only	yes	gamma	by sex

The NMFS “0” survey refers to the “flavor” of the NMFS EBS bottom trawl survey data which has been fit in previous assessment models: maturity state (immature/mature) is determined outside the model for females based on morphological identification and for males on a size-dependent proportional basis using the Rugolo-Turnock maturity ogive. The NMFS “M” survey refers to a new, 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 “0” survey data configured as a separate data file to accompany the NMFS “M” survey data file.

As per CPT recommendation, the following model scenarios were evaluated as part of this assessment:

model scenario	number of parameters	objective function value	max gradient	Jitter runs	# runs converged to MLE	scenario description
M19F00	357	2,962.17	0.0004	--	--	2018 assessment model (18AM17)
M19F00a	357	3,025.43	0.0003	--	--	M19F00 with revised ADFG data for 1990+ crab fisheries
M19F01	363	3,368.11	0.0002	3,000	94	M19F00a updated for 2018/19 (base model for 2019)
M19F02	363	3,521.89	0.0004	--	--	M19F01 + 2006+ observed male maturity data
M19F03	343	3,467.75	0.0013	3,000	72	M19F02 - male maturity characterized by Rugolo/Turnock maturity ogive
M19F04	628	3,578.47	0.0004	3,000	7	M19F01 + 2013-2017 BSFRF/NMFS side-by-side data
M19F05	608	3,674.61	0.0004	3,000	5	M19F03 + 2013-2017 BSFRF/NMFS side-by-side data

As noted previously, M19F00 is the 2018 assessment model and data ("18AM17" in the 2018 assessment). For M19F00a, the "historical" crab fishery catch data is replaced with the "current" data provided by ADFG through 2017/18. This represents a bridging scenario to the 2019 assessment and allows a characterization of the effects of the changes in fishery data on model outcomes without the confounding effects of new data for 2018/19. M19F01 is M19F00a updated with 2018/19 data. It represents "business as usual" in terms of the development of the assessment model. M19F02 includes fits to the male maturity ogive data developed from 2006-onward chela height data collections during the NMFS EBS bottom trawl survey. It also, however, fits the male data in the NMFS "0" dataset with male maturity determined outside the assessment model using the Rugolo-Turnock maturity ogive. This is a bridging scenario that provides a transition to M19F03, which drops the fits to the male data in the NMFS "0" dataset and relies strictly on the male maturity ogive data (and the size composition data) to inform the model estimates of the size-specific probability of terminal molt for males. M19F04 constitutes a different development "fork" based on M19F01, and includes fits to the biomass and size composition data from 2013-2017 BSFRF and NMFS side-by-side studies. In this scenario, the BSFRF survey is assumed to be fully-selected across the size ranges in the model (> 25 mm CW) and thus provides estimates of absolute size-specific abundance within a given study area. Sex-specific "availability" functions are estimated in the model to relate the size-specific study-area abundance estimates to population abundance. The final scenario, M19F05, reflects a merging of the M19F01-M19F02-M19F03 fork with the M19F01-M19F04 fork.

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 as well in the table above. The total objective function values, however, cannot be directly compared between scenarios because each scenario fits different datasets. Convergence for the four scenarios under consideration for status determination and OFL-setting (M19F01, M19F03, M19F04, and M19F05) was evaluated using parameter jittering, with a total of 3,000 runs initiated for each scenario. Of these runs, generally a large number failed to converge at all and a smaller number converged to local minima smaller than the maximum likelihood (ML) solution. About 3% of the runs found the (presumed) ML solution in M19F01, about 2.4% for M19F03, and only about 0.2% in M19F04 and M19F05. In the interest of time and computing resources, the bridging scenarios were not jittered but instead were initialized using the final parameter estimates from the base scenario in the bridge.

M19F03 is the author's preferred model, as explained below.

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

The following table summarizes basic model results from the 2018 assessment model (M19F00) and the 6 scenarios considered here (results from the author's preferred model are highlighted):

Model Scenario	average recruitment millions	Final MMB 1000's t	B0 1000's t	Bmsy 1000's t	Fmsy	MSY 1000's t	Fofl	OFL 1000's t	projected MMB 1000's t	projected MMB / Bmsy
M19F00	223.63	66.64	86.55	30.29	0.74	12.75	0.74	20.87	35.95	1.19
M19F00a	284.28	82.05	94.24	32.99	0.89	14.58	0.89	27.90	41.52	1.26
M19F01	316.79	68.79	100.85	35.30	0.81	15.58	0.81	22.54	35.66	1.01
M19F02	367.48	71.54	105.59	36.96	1.11	17.89	1.03	24.75	34.63	0.94
M19F03	393.84	82.61	118.96	41.64	1.18	19.49	1.12	29.48	39.68	0.95
M19F04	377.28	74.03	106.76	37.37	0.87	16.87	0.87	24.87	37.50	1.00
M19F05	418.73	80.33	116.44	40.75	1.21	19.40	1.14	28.58	38.42	0.94

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

It was noted at the May 2018 CPT meeting that it was not biologically realistic that male Tanner crab less than 60 mm CW had undergone their terminal molt, although there were a few males collected in the NMFS EBS bottom trawl surveys below 60 mm CW that were classified as mature using the chela height data. It was similarly recognized that it was probably biologically unrealistic for female crab less than 40 mm CW to have undergone terminal molt. This actually resulted in simpler, but more realistic models, in scenarios where these constraints were implemented (scenarios M19F03 and M19F05).

A future avenue for exploration in this regard is to estimate the "availability" functions outside the model that are required to allow the SBS data to inform NMFS survey catchability, rather than estimating these functions inside the model. Because the availability functions are estimated in the model using a non-parametric approach to allow for an arbitrary, but smoothly-varying, shape, this adds 48 additional parameters per included SBS study (32 for the male availability function, 16 for the female one). Instead, the availability functions can be estimated outside the model using the size-specific ratios of the size composition data from each NMFS SBS dataset to the corresponding data from the full NMFS dataset, perhaps with a smoothing penalty applied to the resulting curve. In this respect, there would be no need to fit the NMFS SBS data within the model (as is done now) at all.

d. Convergence status and convergence criteria

As noted above, convergence in all non-bridging models was assessed by running each model 3,000 times with randomly-selected ("jittered") initial parameter values for each run. For each model, a number of these jitter runs failed, primarily because the initial values for the growth parameters resulted in the mean post-molt size being smaller than the pre-molt size. 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 would 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, many more runs converged to the final (presumably) ML solution for scenarios M19F01 and M19F03 than for M19F04 and M19F05, but this is not too surprising given the much larger number of estimated parameters for the latter two scenarios.

e. Sample sizes assumed for the compositional data

Input sample sizes used for compositional data are listed in Tables 9-13 for fishery-related size compositions. Input sample sizes for all survey size compositions were set to 200, which was also the maximum allowed for the fishery-related sample sizes. Otherwise, input sample sizes were scaled as described in Stockhausen (2014, Appendix 5):

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

where $\overline{SS}$ was the mean sample size for all males from dockside sampling in the directed fishery.

f. Parameter sensibility

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 Tables 18 and 19. 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. The logit-scale parameter describing the retention of male crab at large (asymptotic) sizes prior to 1997 was estimated at its upper bound (15) in all model scenarios. Because retention can only go as high as 1 on the arithmetic scale, and a logit-scale value of 15 corresponds to an arithmetic scale value of 0.9999997, this parameter should be fixed in future models. In a similar fashion, the logit-scale parameter describing the probability of terminal molt for males in the largest size bin (180+ mm CW) reached its bound of 15 in scenarios M19F00a, M19F01, M19F02, and M19F04 while that describing the probability of terminal molt for females in the smallest size bin (25-30 mm CW) reached its lower bound (-15). These were fixed in M19F03 and M19F05, based on assumptions of minimum and maximum sizes for immature crab at terminal molt, such that the corresponding probabilities of terminal molt in these size bins were 1 or 0.

Survey catchability parameters for the 1975-1981 time period (pQ[1] and pQ[3]) 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).

Estimates of parameter uncertainty, approximations calculated by inverting the model hessian and using the "delta" method, were obtained from each converged model's ADMB "std" file (Tables 20-33). Extremely large uncertainties were obtained for parameters related to the NMFS trawl survey selectivity for females after 1981 for all scenarios that estimated these parameters, unless the estimates hit one of the bounds (Table19). A number of other selectivity-related parameters, while not at one of their bounds, have large uncertainties associated with the estimates (e.g., the 95%-selected size for female bycatch in the BBRKC fishery, Table 31). These may reflect indeterminacy between the estimated capture rates for fully-selected crab and these parameters in determining the effective capture rates on large crab.

Unweighted negative log-likelihoods (NLLs) and their associated (weighted) components in the model objective function are compared for fits to data for the scenarios with 2018/19 data in Tables 34-36. Comparison of the unweighted versions gives some insight into the tradeoffs between fitting to different datasets in the model scenarios. For example, M19F03 doesn't actually fit the NMFS "0" dataset mature male biomass (i.e., the likelihood is not included in the objective function that is optimized) whereas M19F00 does, while the latter doesn't fit the NMFS "M" dataset biomass and the former does. The NLL for M19F00 from the NMFS "0" biomass is ~17 likelihood units better than that for M19F03 but the NLL for M19F03 is ~50 likelihood units better than that for M19F00. Another way of assessing model fit is to examine the average root mean square errors (RMSE) associated with differences between observed and predicted values (Table 38). In this regard, M19F03 fits NMFS "0" male size compositions (rmse=490.64) slightly worse than M19F01 (rmse=487.07) but fits the NMFS "M" size compositions better (185.98 vs. 195.51).

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

None of the model scenarios evaluated in this assessment were directly comparable using likelihood criteria because different combinations of datasets were fit in each scenario. Consequently, the criteria used to evaluate the alternative models were based primarily on: 1) goodness of fit (assessed using the unweighted NLLs and RMSEs for different datasets, even when the datasets were not included in the likelihood), 2) parameter sensibility, and 3) 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.

i. Evaluation of the model(s)

All scenarios fit their respective catch biomass data quite well (noting that different crab fishery data is fit in M19F00 and the other scenarios; Figures 27-30), although scenarios M19F01-M19F05 slightly underestimate total bycatch biomass in the groundfish fisheries from 1991-2013. The model fits to fishery size compositions are similar in quality to what has been obtained in previous assessments: not terrible, but not really great either. The fits to retained catch size compositions are the best overall and are essentially identical for all the scenarios excluding M19F00 (Appendix B, Figures 42-45). Some less good fits seem to be associated with a closure of one of the management areas (e.g., 2005, 2009, 2018). Fits to total catch size compositions in the directed fishery (Appendix B, Figures 46-51) are reasonably good (except for 1996, when sample sizes were very small) but continue to somewhat overestimate the catch of large males since 2013. Again, however, the fits are almost identical among the scenarios. The fits to the total catch size compositions from the snow crab fishery are somewhat worse, particularly in the early 1990s, than those for the directed fishery—to be expected given the differences in the numbers of crab sampled. Some slight differences can be seen among the scenarios in the fits to the total catch size compositions form the groundfish fisheries (Appendix B, Figures 58-67), but the fits themselves are not particularly good. Selectivity functions for the groundfish fisheries are estimated for three different time periods between 1973 and the present, but underlying changing in areas targeted and gear composition may occur on shorter time scales that contribute to the lack of fit. The fits to total catch in the BBRKC fishery (Appendix B, Figures 68-73) are the poorest, consistent with the low observer sample sizes for Tanner crab, particularly females, in this fishery. However, the disagreement between predicted and observed male compositions in the early 1990s is rather puzzling.

The fits to survey biomass (Figures 31-34) are somewhat poorer than those to fishery catch biomass, a not unexpected result because fitting to the fishery catch biomass data was weighted heavily (20x) in the model objective functions. The most notable differences among the fits are that scenarios M19F03 and M19F05 (which fit the male maturity ogive data) both follow the low female biomasses in the 1980's better than the other scenarios do. While all the scenarios estimate declining trends in mature survey biomass starting in 2014, all are biased somewhat high relative to the data.

In general, the predicted survey size compositions are remarkably similar among the scenarios (Appendix B, Figures 1-41), but scenarios that fit the male maturity ogive data (M19F02, M19F03, and M19F05) tend to estimate slightly higher proportions of "mature" (as categorized by the Rugolo-Turnock maturity ogive) males at smaller sizes, lower proportions of immature females at small sizes, and lower proportions of mature females at larger sizes, than occurs in the other scenarios. Somewhat surprisingly, the proportions for "immature" males are almost identical among the scenarios. The two scenarios that fit the SBS datasets also estimate almost identical size compositions which fit the observed ones fairly well for both the NMFS and BSFRF data. In particular, the models capture the recruitment event in 2017 well in both datasets, although it occurs much more strongly in the BSFRF dataset.

All the scenarios fit female growth equally well, but over-predict male molt increments at larger sizes, with M19F03 and M19F05 being the most biased (Figure 35). In contrast, M19F03 and M19F05 fit the male maturity ogive data better than the other scenarios, but all scenarios tend to underestimate the fraction mature in any size bin, although this is not true in all cases (Figure 36).

Estimated capture rates in the directed fishery (Figure 37) follow the same temporal patterns in all scenarios, with the largest peak in 1979 and a lesser peak in 1991 or 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 38-41) or retention functions (Figure 42), which are essentially identical (the differences between M19F00 and M19F00a in 1990 and 1991 are primarily due to changes in the underlying snow crab data).

Estimated capture rates in the snow crab (Figure 43) also exhibited similar temporal patterns. Scenarios M19F00 and M19F00a differ substantially in level due to changes in the underlying crab data, which changes the selectivity function estimated for the early 1990s, as well as differences in recruitment. The capture rates estimated in the other scenarios are much more similar to one another, and primarily reflect smaller differences in estimated recruitment. Estimated selectivity functions for these scenarios were almost identical for the three time periods in which they were estimated, with the only substantial difference being that the curves estimated in M19F04 and M19F05 for the pre-1997 time period were right-shifted to larger sizes by one or two size bins (Figure 44).

Estimated capture rates in the BBRKC fishery (Figure 45) exhibited similar temporal patterns among the scenarios, as well. Scenarios M19F00 and M19F00a were much more similar in level than was the case for the snow crab fishery because the underlying data was not substantially changed. The levels of the capture rates for females in scenarios M19F00a-M19F05 appear fairly variable, but the absolute scale is very small (on the order of 0.04 relative to 0.5 for the directed fishery) and the variability is primarily due to the small scale of the associated catches. The estimated selectivity functions (Figure 46) were also slightly different among the scenarios for females, while those for males were basically identical.

As with the other fisheries, estimated capture rates in the groundfish fisheries (Figure 47) exhibited similar temporal patterns in all scenarios but differed somewhat in absolute level. In addition, M19F00a exhibited substantially higher levels in the 1991-2012 time period than did scenarios M19F01-M19F05, which were all quite similar in level. Estimated male selectivity curves exhibited a fair amount of variation among scenarios during the 1997-2004 time period, while the selectivity curves for both males and females in the 2005+ period exhibited somewhat less variability and those in the pre-1997 period were essentially the same (Figure 48).

The change in the crab fishery data had fairly large effects on estimates of survey catchability and selectivity functions (Figures 49-51). Although estimated catchability was the same for scenarios M19F00 and M19F00a in the pre-1982 time period, the estimated size-at-50% selected for the male and female selectivity functions shifted substantially to larger sizes (more so for males than females) such that many more small and intermediate size crab were "invisible" to the survey during this time period. In the 1982+ time period, catchability was estimated to be smaller in M19F00a while the selectivity functions remained similar (the male function was slightly shifted toward larger sizes), with the result that crab of *all* sizes were effectively invisible to the survey in M19F00a. Survey catchability in the pre-1982 time period did not change in the M19F01-M19F05 scenarios, no did the male selectivity function, but the female selectivity function shifted to somewhat larger sizes in scenarios M19F03 and M19F05. Survey catchabilities did change in all of these scenarios in the 1982+ time period for both males and females, with the largest values estimated in M19F00a while the smallest value for females was estimated in M19F02 and the smallest for males in M19F03. In general, including the male maturity ogive data in the model fit decreased the catchability for both sexes. Selectivity for males in the pre-1982 time period was essentially unchanged among M19F01-M19F05 scenarios, while including the male maturity ogive data shifted female selectivity ~ 5 mm to larger sizes. The selectivity functions for both sexes differed among these scenarios for the 1982+ time period, shifting the 50%-selected size substantially to larger size for females in scenarios M19F03, M19F04, and M19F05 but only slightly to larger size for males.

Survey availability, estimated in scenarios M19F04 and M19F05 for the SBS datasets, were similar to one another (Figure 52). Curves for females were fairly similar for 2013-15, increasing with size, but different from those for 2016 and 2017, which decreased with size. For males, larger males in the 100-150 mm CW range tended to be most available to the survey. In 2013-15, small males were mostly unavailable while in 2016-17 the smallest were much more available while intermediate-sized males were relatively less available. It is possible to estimate empirical versions for the availability functions using the ratio of crab abundance in the NMFS SBS dataset to that in the NMFS "0" dataset by size bin. These empirical availability functions provide a check on the estimated versions. However, they do not particularly resemble the estimated versions (Figure 53), except for females in 2013.

Another effect of the revised crab fishery data is to slightly increase the estimated rate of M on mature mature females and to slightly decrease them on males, outside the 1980-84 "enhanced mortality" period when the effect is to increase the rates for both sexes (M19F00a compared with M19F00; Figure 54). Fitting the male maturity ogive data rather than mature male survey biomass based on the Rugolo-Turnock maturity ogive (M19F03, M19F05) results in a much reduced estimate of M on mature males in the enhanced mortality period while it is elevated for mature females.

The estimated probability of terminal molt by size is almost the same for all scenarios, but is shifted to smaller sizes by ~5 mm CW for the scenarios that fit the male maturity ogive data (scenarios M19F02, M19F03, and M19F05; Figure 55). Mean growth, as well, is similar across all scenarios for females while the scenarios that fit the male maturity ogive data yield slightly higher estimates of growth for males at large pre-molt sizes (Figure 56).

Estimated recruitment time series exhibit similar temporal patterns in all scenarios, but differ in overall scale, with the largest difference occurring between M19F00 (the 2018 assessment model) and M19F00a, the 2018 assessment model with the revised crab fishery data (Figures 57-58). The good news for the stock a few years in the future is that all the scenarios estimate recruitment during 2016-18 was much larger than during 2011-2015. The bad news is that all the scenarios estimated a declining trend in mature male and female biomass (MMB and MFB, evaluated on Feb. 15 for each year) over the past 4-5 years since a recent high in 2014 (or 2015, depending on scenario; Figures 59-60). Across the time series, the estimated trajectories for mature biomass also follow similar temporal trends but differ in scale. Unsurprisingly, similar trends were also estimated for the mature components of population biomass (evaluated on July 1 for each year; Figure 61). However, trends in immature biomass reflect the estimated recent recruitment trends and have been increasing in all scenarios for the past two years following a low point not seen since the early 1990s.

The author's preferred model, M19F03, fits all of the datasets reasonably well and includes fits to "observed" new shell male maturity ogives derived for years after 2005 when chela height data was collected in the NMFS EBS bottom trawl survey. It also drops the fits to immature/mature male categories created by applying the Rugolo-Turnock maturity ogive to male abundance and biomass by size outside the model. It does not fit the BSFRF SBS datasets, but doing so (i.e. M19F04, M19F05) does not seem to substantially change the estimates of catchability for the NMFS EBS bottom trawl survey or population quantities such as recruitment and mature biomass in the manner one would expect (higher estimates of catchability, lower estimates for population quantities). In addition, the manner in which "availability" is handled in the scenarios that fit the SBS data is somewhat problematic in terms of potential confounding between the ability to estimate availabilities for the BSFRF surveys and the ability to estimate catchabilities for the NMFS surveys. Finally, the estimated availability functions are somewhat inconsistent with empirical versions derived from the full NMFS survey and the NMFS SBS studies.

4. Results (best model(s))

Scenario M19F03 was selected as the author's preferred model for the 2019 assessment.

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

Input and effective sample sizes for size composition data fit in the model are listed in Tables 40-45 from the 2018 assessment model and scenario M19F03. 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 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 20-34.

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

Estimates for mature survey biomass, by sex, are listed in Table 46and for mature biomass at mating, by sex, in Table 47 for the 2018 assessment model and the author's preferred model, M19F03. 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 (see Tables 48 and 49, respectively).

iii. Recruitment time series

The estimated recruitment time series from the 2018 assessment and M19F03 are listed in Table 50.

iv. Time series of catch divided by biomass.

A comparison of catch divided by biomass (i.e., exploitation rate) from the 2017 assessment and 18C2a is listed in Table 51.

c. Graphs of estimates

Graphs of estimates from the preferred scenario, M19F03 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 curves for the directed fishery are shown in Figures 39-42, for the snow crab fishery in Figure 45, for the BBRKC fishery in Figure 47, and for the groundfish fisheries in Figure 49. Estimated retention curves are shown in Figure 43. Graphs of selectivity curves for the NMFS survey are shown Figure 51; graphs of estimated availability curves from the NMFS SBS studies are shown in Figure 53. Natural mortality estimates are shown in Figure 55, terminal molt probabilities are shown in Figure 56, and mean growth rates (molt increments) are shown in Figure 57.

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 38, 44, 46, and 48.

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 62. Mature male and female biomass trends (MMB and MFB) are shown in Figures 60 and 61.

iv. Estimated fishing mortality versus estimated spawning stock biomass

See Figure 65.

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

Not available.

e. Evaluation of the fit to the data:

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

Graphs of fits to observed catches are provided in Figure 26 for retained and total catch in the directed fishery and in Figures 27-29 for total catch in the snow crab, BBRKC, and groundfish fisheries. Fits to NMFS survey biomass are shown for mature crab and all males and females by maturity state in Figures 30 and 31, respectively. Fits to survey biomass in the SBS studies are shown in Figures 32 and 33.

ii. Graphs of model fits to survey numbers

Not available.

iii. Graphs of model fits to catch proportions by size class

See Appendix B for model fits to annual catch proportions by size class.

iv. Graphs of model fits to survey proportions by size class

See Appendix B for model fits to annual survey proportions by size class.

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

See Appendices C and D for marginal distributions of fits to the compositional data.

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

See Appendices C and D for plots of implied and input sample sizes. For the most part, the implied effective sample sizes tend to be substantially larger than the input values.

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

RMSEs for fits to various datasets are provided in Tables 37-39.

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.

Due to time constraints, quantile-quantile (q-q) plots and histograms of residuals were not completed for the 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).

Due to time constraints, retrospective analyses were not completed for the assessment.

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

Due to time constraints, an historical analysis was not completed for the assessment.

g. Uncertainty and sensitivity analyses

MCMC runs were completed for scenario M19F03 to explore model uncertainty. The model was run for four chains, which 10 million iterations each, with a burn-in period of 1,000,000 iterations and keeping results from every 1,000th iteration to reduce serial autocorrelation, which yielded 4000 samples per chain. Mixing appeared to be sufficient, but this can be difficult to evaluate. This run provides empirical posterior distributions for model parameters and selected derived quantities, including OFL-related quantities.

Time constraints (the MCMC run took several days to complete) did not allow a full exploration of the MCMC results. Summary results for the objective function and OFL-related quantities (Figure 62) indicates that they are reasonably well-behaved and normally-distributed, and do not exhibit unexpected correlation structures (e.g., F_{OFL} and F_{MSY} are expected to be highly correlated, so this is not cause for concern).

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 2018/19 was 20.87 thousand t while the total catch mortality was 1.90 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 2018/19. 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 63):

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* $F_{OFL} \leq F_{MSY}{}^{\dagger}$	

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 2019/20 require estimates of B = $MMB_{2019/20}$ (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 19). If the ratio is less than β, then the stock falls into Tier 3c and directed fishing must cease. In addition, if B is less than ½ $B_{35\%}$ (the minimum stock size threshold, MSST), the stock must be declared overfished and a rebuilding plan subsequently developed.

In 2015, the SOA's Board of Fish, under petition from the commercial Tanner crab fishing industry, changed the minimum preferred size for crab in the area east of 166°W longitude in calculations used for setting TACs from 138 mm CW (not including lateral spines) to 125 mm CW. The minimum preferred size in the area west of 166°W remained the same (125 mm CW). In assessments before 2017, an attempt was made to account for retention of slightly (10 mm CW) smaller crab in the directed fishery in the western area. Because the preferred size is now the same in both areas, the OFL is calculated assuming both selectivity (as previously) and retention (new) curves are the same in both areas.

In assessments before 2017, a separate "projection model" was used to determine OFL based on results from the assessment model. The estimated coefficient of variation for the estimate of final MMB was used to characterize model uncertainty and provided a calculational basis for determining an empirical probability density function (pdf) for OFL based on sampling final MMB from its assumed pdf. Since the transition to TCSAM02 in 2017, the OFL is calculated within the assessment model based on equilibrium calculations for F_{OFL} 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) incorporating full model uncertainty.

To calculate the F_{OFL}, the fishery capture rate for males in the directed fishery is adjusted until the longterm (equilibrium) MMB-at-mating is 35% of its unfished value. This calculation also depends on the assumed bycatch F's on Tanner crab in the snow crab, BBRKC and groundfish fisheries. As with last year, 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).

Selectivity curves in the bycatch fisheries were set using the average curves over the last 5 years for each fishery, the same approach as in previous assessments (Stockhausen 2017).

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+. This issue was revisited at the May 2018 CPT meeting with regard to the final year to be included in the calculation, but no definitive were made. Starting the average recruitment period in 1982 is consistent with a 5-6 year recruitment lag from 1976/77, when a well-known climate regime shift occurred in the EBS (Rodionov and Overland, 2005) that may have affected stock productivity. The value of $\bar{R}$ for this period from MCMC runs of the author's preferred model is 373.96 million. The estimates of average recruitment from the author's preferred model (M19F03), as well as all the other models based on the "current" ADFG fishery data, are substantially higher than from the 2018 assessment model (224 million; see Table 52). The value of B_{MSY}=$B_{35\%}$ for $\bar{R}$ is 41.07 thousand t, which is larger than that from the 2018 assessment (21.87 thousand t).

Once F_{OFL} is determined using the control rule (Figure 63), the (total catch) OFL can be calculated based on projecting the population forward one year assuming that $F = F_{OFL}$. In the absence of uncertainty, the OFL would then be the predicted total catch taken when fishing at $F = F_{OFL}$. When uncertainty (e.g. assessment uncertainty, variability in future recruitment) is taken into account, the OFL is taken as the median total catch when fishing at $F = F_{OFL}$.

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

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

where C is total catch (biomass), $F_{f,x,z}$ is the fishing mortality in fishery f on crab in size bin z by sex (x), $F_{.,x,z} = \sum_f F_{f,x,z}$ is the total fishing mortality by sex on crab in size bin z, $w_{x,z}$ is the mean weight of crab in size bin z by sex, M_x is the sex-specific rate of natural mortality, δt is the time from July 1 to the time of the fishery (0.625 yr), and $N_{x,z}$ is the numbers by sex in size bin z on July 1, 2019 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 2019/20 were calculated based on resulting model parameter values. This would be repeated a large number of times to approximate the distribution of OFL given the full model uncertainty. For this assessment, four chains of 10 million MCMC steps were generated, with the OFL and associated quantities calculated at each step. The chain was initialized from the converged model state using a "burn in" of 2,000,000 steps and subsequently thinned by a factor of 1,000 to reduce serial autocorrelation in the MCMC sampling. This resulted in about 20,000 MCMC samples with which to characterize the distribution of the OFL. **The median value**

of this distribution was taken as the OFL for 2019/20. The OFL for 2019/20 from the author's preferred model (Model M19F03) is 28.86 thousand t (Figure 64)**.**

The B_{MSY} proxy, $B_{35\%}$, from the author's preferred model is 41.07 thousand t, so MSST = 0.5 B_{MSY} = 20.54 thousand t. Because current projected B = 39.55 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 1965/66-2018/19 in Figure 65 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.

For the author's preferred scenario, M19F03, the P* ABC (ABC_{max}) is 28.79 thousand t while the 20% Buffer ABC is 23.09 thousand t. 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 23.09 thousand t**.

G. Rebuilding Analyses

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

H. Data Gaps and Research Priorities

Information on growth-per-molt has 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 is 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 166°W longitude should be explicitly represented in the assessment model should 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. There appears to be conflicting information from the NMFS and BSFRF SBS surveys regarding "availability" relative to the full NMFS survey, so estimating availability in the assessment model by fitting SBS data from both surveys (as was done here in Scenarios M19F04 and M19F05) may not be the best approach to incorporating the BSFRF surveys, which are assumed to provide absolute estimates of crab abundance within the area(s) in which the SBS surveys are conducted.

Development of a Gmacs version of the Tanner crab model is also a priority, but will await development of a Gmacs snow crab model.

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

J. Literature Cited

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Somerton, D. A. 1980. A computer technique for estimating the size of sexual maturity in crabs. Can. J. Fish. Aquat. Sci. 37:1488-1494.
Somerton, D. A. 1981a. Life history and population dynamics of two species of Tanner crab, *Chionoecetes bairdi* and *C. opilio*, in the eastern Bering Sea with implications for the management of the commercial harvest, PhD Thesis, University of Washington, 220 p.
Somerton, D. A. 1981b. Regional variation in the size at maturity of two species of Tanner Crab (*Chionoecetes bairdi* and *C. opilio*) in the eastern Bering Sea, and its use in defining management subareas. Canadian Journal of Fisheries and Aquatic Science. 38:163-174.
Somerton, D. A. and W. S. Meyers. 1983. Fecundity differences between primiparous and multiparous female Alaskan Tanner crab (*Chionoecetes bairdi*). Journal of Crustacean Biology. 3:183-186.
Somerton, D. A. and R. S. Otto. 1999. Net efficiency of a survey trawl for snow crab, *Chionoecetes opilio,* and Tanner crab, *C. bairdi.* Fish. Bull. 97:617-625.
Stevens, B. G. 2000. Moonlight madness and larval launch pads: tidal synchronization of Mound Formation and hatching by Tanner crab, *Chionoecetes bairdi*. Journal of Shellfish Research. 19:640-641.
Stockhausen, W., L. Rugolo and B. Turnock. 2013. 2013 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2013 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 342-478.
Stockhausen, W. 2014. 2014 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2014 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 324-545.
Stockhausen, W. 2015. 2015 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2015 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK.
Stockhausen, W. 2016. 2016 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2016 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK.
Stockhausen, W. 2017a. 2017 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2017 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK.
Stockhausen, W. 2017b. Tanner Crab Assessment Report for the May 2017 CPT Meeting. North Pacific Fishery Management Council. Anchorage, AK.
Stockhausen, W. 2018a. 2018 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2018 Final Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK.
Stockhausen, W. 2018b. Tanner Crab Assessment Report for the May 2018 CPT Meeting. North Pacific Fishery Management Council. Anchorage, AK.
Stone, R.P., M.M. Masuda and J.Clark. 2003. Growth of male Tanner crabs, *Chionoecetes bairdi,* in a Southeast Alaska Estuary. Draft document to Alaska Department of Fish and Game Headquarters. 36p.
Tamone, S. L., S. J. Taggart, A. G. Andrews, J. Mondragon, and J. K. Nielsen. 2007. The relationship between circulating ecdysteroids and chela allometry in male Tanner crabs: Evidence for a terminal molt in the genus *Chionoecetes*. J. Crust. Biol. 27:635-642.

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

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

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

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

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

Table captions

Figure captions

Tables

Table 1. Retained catch (males) in directed Tanner crab fisheries (1965/66-2000/01). Catch units are metric tons. Asterisks denote 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
1985*	0	0	0	0
1986*	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
1997*	0	0	0	0
1998*	0	0	0	0
1999*	0	0	0	0
2000*	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
2001*	0	0	0	0
2002*	0	0	0	0
2003*	0	0	0	0
2004*	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
2010*	1	0	0	1
2011*	2	0	0	2
2012*	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
2016*	1	0	0	1
2017	1,133	0	0	1,133
2018	1,107	0	0	1,107

Table 2. Retained catch (males) in the US domestic pot fishery. Information from the Community Development Quota (CDQ) fisheries is included in the table for fishery years 2005/06 to the present. Number of crabs caught and harvest includes deadloss. The "Fishery Year" YYYY/YY+1 runs from July 1, YYYY to June 30, YYYY+1. The 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

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
1985*	–	–	–	–	–	–	–	–	0.3992	0.3992
1986*	–	–	–	–	–	–	–	–	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
1997*	–	–	–	–	1.9637	0.0927	0.1601	0.0017	1.1800	3.3981
1998*	–	–	–	–	0.6559	0.0804	0.1152	0.0017	0.9350	1.7882
1999*	–	–	–	–	0.1318	0.0112	0.0751	0.0022	0.6306	0.8509
2000*	–	–	–	–	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
2001*	–	–	–	–	0.545308	0.020530	0.042200	0.000963	1.185191	1.794192
2002*	–	–	–	–	0.167178	0.013815	0.061253	0.001580	0.719068	0.962894
2003*	–	–	–	–	0.064743	0.007011	0.054937	0.001847	0.423801	0.552339
2004*	–	–	–	–	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
2010*	–	–	–	–	1.453261	0.009179	0.031920	0.000553	0.231367	1.726280
2011*	–	–	–	–	2.141349	0.013272	0.017470	0.000072	0.203984	2.376147
2012*	–	–	–	–	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
2016*	–	–	–	–	2.575704	0.016695	0.175692	0.004222	0.310121	3.082434
2017	1.362519	0.038489	–	–	1.081659	0.006841	0.183555	0.001433	0.167927	2.842423
2018	1.598424	0.034668	–	–	0.879726	0.008857	0.074017	0.000131	0.190972	2.786795

Table 4. Comparison of retained catch abundance and biomass used in the previous assessment ("historical") with "current" catch abundance and biomass. Only values since 2005 (highlighted in grey) have been changed.

	abundance (num. crab)		biomass (millions lbs)	
year	historical	current	historical	current
1965	1,558,362	1,558,362	4.24	4.24
1966	1,981,280	1,981,280	5.39	5.39
1967	11,032,652	11,032,652	29.98	29.98
1968	14,576,228	14,576,228	39.69	39.69
1969	22,394,986	22,394,986	60.60	60.60
1970	22,004,597	22,004,597	56.20	56.20
1971	17,820,914	17,820,914	45.66	45.66
1972	14,906,645	14,906,645	37.27	37.27
1973	12,000,825	12,000,825	28.72	28.72
1974	13,404,770	13,404,770	33.60	33.60
1975	15,603,036	15,603,036	38.92	38.92
1976	26,120,508	26,120,508	66.17	66.17
1977	26,821,995	26,821,995	78.32	78.32
1978	18,780,962	18,780,962	46.50	46.50
1979	16,805,611	16,805,611	41.90	41.90
1980	12,928,112	12,928,112	29.60	29.60
1981	4,830,980	4,830,980	11.00	11.00
1982	2,286,756	2,286,756	5.27	5.27
1983	516,877	516,877	1.21	1.21
1984	1,272,501	1,272,501	3.15	3.15
1987	957,318	957,318	2.20	2.20
1988	2,894,480	2,894,480	7.01	7.01
1989	10,672,607	10,672,607	24.50	24.50
1990	16,609,286	16,609,286	40.10	40.10
1991	12,924,102	12,924,102	31.80	31.80
1992	15,265,865	15,265,865	35.10	35.10
1993	7,236,054	7,236,054	16.90	16.90
1994	3,351,639	3,351,639	7.80	7.80
1995	1,881,525	1,881,525	4.23	4.23
1996	734,303	734,303	1.81	1.81
2005	443,865	443,977	0.95	0.95
2006	926,101	926,103	2.12	2.12
2007	927,164	927,164	2.11	2.11
2008	830,363	830,369	1.94	1.94
2009	485,963	485,963	1.33	1.33
2013	1,426,670	1,445,768	2.75	2.79
2014	7,442,931	7,522,844	13.58	13.70
2015	10,856,418	10,856,418	19.64	19.64
2017	1,340,394	1,340,394	2.50	2.50
2018	--	1,381,008	--	2.44

Table 5. Comparison of total catch biomass in the directed Tanner crab fisheries used in the previous assessment ("historical") with "current" catch biomass dataset. See text for details.

	biomass (millions lbs)			
	males		females	
year	historical	current	historical	current
1991	--	56.92	--	4.16
1992	48.71	81.59	2.21	3.76
1993	25.43	26.13	2.27	2.20
1994	14.70	16.13	2.80	1.86
1995	10.32	11.17	3.88	2.35
1996	2.07	0.66	0.10	0.12
2005	1.97	1.51	0.10	0.05
2006	5.14	3.77	0.78	0.27
2007	6.61	5.42	0.21	0.10
2008	2.89	2.86	0.03	0.02
2009	1.49	1.47	0.01	0.01
2013	3.60	3.70	0.05	0.05
2014	19.12	18.44	0.09	0.09
2015	26.35	26.96	0.13	0.13
2017	4.66	3.00	0.13	0.08
2018	--	3.52	--	0.08

Table 6. Comparison of Tanner crab bycatch biomass in the snow crab fisheries used in the previous assessment ("historical") with the "current" catch biomass dataset. See text for details.

	biomass (millions lbs)			
	males		females	
year	historical	current	historical	current
1990	--	15.61	--	0.23
1991	--	18.43	--	0.32
1992	56.79	5.48	3.94	0.36
1993	32.03	6.34	4.00	0.88
1994	15.71	2.97	2.80	0.43
1995	10.58	2.25	3.88	0.27
1996	1.84	4.32	0.51	0.26
1997	3.86	4.33	0.50	0.20
1998	4.38	1.45	0.39	0.18
1999	1.53	0.29	0.32	0.02
2000	0.32	0.69	0.05	0.01
2001	0.71	1.20	0.02	0.05
2002	1.23	0.37	0.08	0.03
2003	0.43	0.14	0.06	0.02
2004	0.17	0.30	0.03	0.09
2005	2.13	2.56	0.09	0.04
2006	3.22	3.37	0.37	0.19
2007	4.13	4.10	0.22	0.11
2008	2.47	2.43	0.11	0.05
2009	2.92	3.44	0.03	0.03
2010	2.96	3.20	0.03	0.02
2011	4.67	4.72	0.03	0.03
2012	2.62	3.45	0.02	0.02
2013	4.04	4.06	0.03	0.03
2014	11.87	11.75	0.11	0.11
2015	8.64	8.64	0.04	0.04
2016	5.68	5.68	0.04	0.04
2017	2.45	2.38	0.02	0.02
2018	--	1.94	--	0.02

Table 7. Comparison of Tanner crab bycatch biomass in the BBRKC fishery used in the previous assessment ("historical") with the "current" catch biomass dataset. See text for details.

	biomass (millions lbs)			
	males		females	
year	historical	current	historical	current
1990	--	8.21	--	0.08
1991	--	4.34	--	0.06
1992	2.62	2.90	0.06	0.04
1993	6.54	6.90	0.44	0.33
1996	0.06	0.60	0.01	0.01
1997	0.36	0.35	0.01	0.00
1998	0.26	0.25	0.01	0.00
1999	0.17	0.17	0.01	0.00
2000	0.15	0.15	0.01	0.00
2001	0.09	0.09	0.00	0.00
2002	0.14	0.14	0.01	0.00
2003	0.12	0.12	0.01	0.00
2004	0.11	0.11	0.01	0.00
2005	0.09	0.09	0.00	0.00
2006	0.06	0.07	0.01	0.00
2007	0.12	0.13	0.02	0.00
2008	0.59	0.62	0.01	0.01
2009	0.33	0.41	0.00	0.00
2010	0.07	0.07	0.00	0.00
2011	0.04	0.04	0.00	0.00
2012	0.09	0.09	0.00	0.00
2013	0.25	0.28	0.00	0.00
2014	0.65	0.67	0.00	0.00
2015	0.45	0.45	0.01	0.01
2016	0.39	0.39	0.01	0.01
2017	0.40	0.40	0.00	0.00
2018	--	0.16	--	0.00

Table 8. 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, and in 2016/17. 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	376,080	365,110	0	0	376,080	365,110	67,897	67,112	0	0
2006	333,508	320,187	583,650	633,937	917,158	954,124	7,115	6,784	1,830	1,883
2007	232,345	228,829	679,137	711,640	911,482	940,469	9,328	8,761	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

Table 9. Sample sizes for retained catch-at-size in the directed fishery. N = number of individuals. N` = scaled sample size used in assessment. The directed fishery was closed in 2016/17.

year	new + old shell	
	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
1992/93	125,193	200.0
1993/94	71,622	200.0
1994/95	27,658	200.0
1995/96	1,525	12.0
1996/97	4,430	34.8
2005/06	705	5.5
2006/07	2,940	23.1
2007/08	6,935	45.2
2008/09	3,490	27.4
2009/10	2,417	19.0
2013/14	4,760	35.8
2014/15	14,055	113.7
2015/16	24,420	190.3
2016/17	--	--
2017/18	3,470	27.3
2018/19	3,306	26.0

Table 10. Sample sizes for total catch-at-size in the directed fishery from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.

	N		N'	
year	males	females	males	females
1991/92	31,252	5,605	200.0	44.0
1992/93	54,836	8,755	200.0	68.8
1993/94	40,388	10,471	200.0	82.3
1994/95	5,792	2,132	45.5	16.7
1995/96	5,589	3,119	43.9	24.5
1996/97	352	168	2.8	1.3
2005/06	19,715	1,107	154.9	8.7
2006/07	24,226	4,432	190.3	34.8
2007/08	61,546	3,318	200.0	26.1
2008/09	29,166	646	200.0	5.1
2009/10	17,289	147	135.8	1.2
2013/14	17,291	710	135.8	5.6
2014/15	85,116	1,191	200.0	9.4
2015/16	119,843	1,622	200.0	12.8
2016/17	--	--	--	--
2017/18	18,785	1,721	147.6	13.5
2018/19	28,338	2,036	200.0	16.0

Table 11. Sample sizes for total bycatch-at-size in the snow crab fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.

year	N		N'	
	males	females	males	females
1990/91	14,032	478	110.2	3.8
1991/92	11,708	686	92.0	5.4
1992/93	6,280	859	49.3	6.7
1993/94	6,969	1,542	54.7	12.1
1994/95	2,982	1,523	23.4	12.0
1995/96	1,898	428	14.9	3.4
1996/97	3,265	662	25.6	5.2
1997/98	3,970	657	31.2	5.2
1998/99	1,911	324	15.0	2.5
1999/00	976	82	7.7	0.6
2000/01	1,237	74	9.7	0.6
2001/02	3,113	160	24.5	1.3
2002/03	982	118	7.7	0.9
2003/04	688	152	5.4	1.2
2004/05	833	707	6.5	5.6
2005/06	9,807	368	77.0	2.9
2006/07	10,391	1,256	81.6	9.9
2007/08	13,797	728	108.4	5.7
2008/09	8,455	722	66.4	5.7
2009/10	11,057	474	86.9	3.7
2010/11	12,073	250	94.8	2.0
2011/12	9,453	189	74.3	1.5
2012/13	11,004	270	86.4	2.1
2013/14	12,935	356	101.6	2.8
2014/15	24,878	804	195.4	6.3
2015/16	19,839	230	155.9	1.8
2016/17	16,369	262	128.6	2.1
2017/18	5,598	109	44.0	0.9
2018/19	6,145	233	48.3	1.8

Table 12. Sample sizes for total bycatch-at-size in the BBRKC fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.

year	N		N'	
	males	females	males	females
1990/91	1,580	43	12.4	0.3
1991/92	2,273	89	17.9	0.7
1992/93	2,056	105	16.2	0.8
1993/94	7,359	1,196	57.8	9.4
1997/98	1,030	41	8.1	0.3
1998/99	457	20	3.6	0.2
1999/00	207	14	1.6	0.1
2000/01	845	44	6.6	0.3
2001/02	456	39	3.6	0.3
2002/03	750	50	5.9	0.4
2003/04	555	46	4.4	0.4
2004/05	487	44	3.8	0.3
2005/06	983	70	7.7	0.5
2006/07	746	68	5.9	0.5
2007/08	1,360	89	10.7	0.7
2008/09	3,797	121	29.8	1.0
2009/10	2,871	70	22.6	0.5
2010/11	582	28	4.6	0.2
2011/12	323	4	2.5	0.0
2012/13	618	48	4.9	0.4
2013/14	2,110	60	16.6	0.5
2014/15	3,110	32	24.4	0.3
2015/16	2,175	186	17.1	1.5
2016/17	3,220	246	25.3	1.9
2017/18	3,782	86	29.7	0.7
2018/19	1,283	6	10.1	0.0

Table 13. Sample sizes for total catch-at-size in the groundfish fisheries, from groundfish observer sampling. N = number of individuals. N` = scaled sample size used in the assessment.

year	N		N'	
	males	females	males	females
1973/74	3,155	2,277	24.8	17.9
1974/75	2,492	1,600	19.6	12.6
1975/76	1,251	839	9.8	6.6
1976/77	6,950	6,683	54.6	52.5
1977/78	10,685	8,386	83.9	65.9
1978/79	18,596	13,665	146.1	107.4
1979/80	19,060	11,349	149.7	89.2
1980/81	12,806	5,917	100.6	46.5
1981/82	6,098	4,065	47.9	31.9
1982/83	13,439	8,006	105.6	62.9
1983/84	18,363	8,305	144.3	65.2
1984/85	27,403	13,771	200.0	108.2
1985/86	23,128	12,728	181.7	100.0
1986/87	14,860	7,626	116.7	59.9
1987/88	23,508	15,857	184.7	124.6
1988/89	10,586	7,126	83.2	56.0
1989/90	59,943	41,234	200.0	200.0
1990/91	23,545	11,212	185.0	88.1
1991/92	6,817	3,479	53.6	27.3
1992/93	3,128	1,175	24.6	9.2
1993/94	1,217	358	9.6	2.8
1994/95	3,628	1,820	28.5	14.3
1995/96	3,904	2,669	30.7	21.0
1996/97	8,306	3,400	65.3	26.7
1997/98	9,949	3,900	78.2	30.6
1998/99	12,105	4,440	95.1	34.9
1999/00	11,053	4,522	86.8	35.5
2000/01	12,895	3,087	101.3	24.3
2001/02	15,788	3,083	124.0	24.2
2002/03	15,401	3,249	121.0	25.5
2003/04	9,572	2,733	75.2	21.5
2004/05	13,844	4,460	108.8	35.0
2005/06	17,785	3,709	139.7	29.1
2006/07	15,903	3,047	124.9	23.9
2007/08	16,148	3,819	126.9	30.0
2008/09	26,171	4,235	200.0	33.3
2009/10	19,075	2,704	149.9	21.2
2010/11	15,131	2,275	118.9	17.9
2011/12	16,119	4,244	126.6	33.3
2012/13	12,987	3,083	102.0	24.2
2013/14	28,782	6,064	200.0	47.6
2014/15	39,119	4,212	200.0	33.1
2015/16	27,428	5,735	200.0	45.1
2016/17	18,313	4,299	143.9	33.8
2017/18	12,541	1,229	98.5	9.7
2018/19	7,004	1,227	55.0	9.6

Table 14. 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 14 (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 15. 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 15 (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 16. 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

Table16 (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 17. 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.

year	SCF all EBS	RKF 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 17 (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.

	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

Table 18.Non-selectivity parameters from all model scenarios that were estimated within 1% of bounds.

category	name	index	scenario	which?	bound	description
fisheries	pLgtRet[1]	1	M19F00	at upper bound	15	TCF: logit-scale max retention (pre-1997)
			M19F00a	at upper bound	15	TCF: logit-scale max retention (pre-1997)
			M19F01	at upper bound	15	TCF: logit-scale max retention (pre-1997)
			M19F02	at upper bound	15	TCF: logit-scale max retention (pre-1997)
			M19F03	at upper bound	15	TCF: logit-scale max retention (pre-1997)
			M19F04	at upper bound	15	TCF: logit-scale max retention (pre-1997)
			M19F05	at upper bound	15	TCF: logit-scale max retention (pre-1997)
population processes	pvLgtPrM2M[1]	32	M19F00	at upper bound	15	males (entire model period)
			M19F00a	at upper bound	15	males (entire model period)
			M19F01	at upper bound	15	males (entire model period)
			M19F02	at upper bound	15	males (entire model period)
			M19F04	at upper bound	15	males (entire model period)
	pvLgtPrM2M[2]	1	M19F00	at lower bound	-15	females (entire model period)
			M19F00a	at lower bound	-15	females (entire model period)
			M19F01	at lower bound	-15	females (entire model period)
			M19F02	at lower bound	-15	females (entire model period)
			M19F04	at lower bound	-15	females (entire model period)
surveys	pQ[1]	1	M19F00	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
			M19F00a	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
			M19F01	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
			M19F02	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
			M19F03	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
			M19F04	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
			M19F05	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
	pQ[3]	1	M19F00	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
			M19F00a	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
			M19F01	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
			M19F02	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
			M19F03	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
			M19F04	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
			M19F05	at lower bound	0.5	NMFS trawl survey: females, 1975-1981

Table 19.Selectivity-related parameters from all model scenarios estimated within 1% of bounds.

	name		scenario	which?	bound	description
selectivity	pS1[1]	1	M19F00a	at upper bound	90	z50 for NMFS survey selectivity (males, pre-1982)
			M19F01	at upper bound	90	z50 for NMFS survey selectivity (males, pre-1982)
			M19F02	at upper bound	90	z50 for NMFS survey selectivity (males, pre-1982)
			M19F03	at upper bound	90	z50 for NMFS survey selectivity (males, pre-1982)
			M19F04	at upper bound	90	z50 for NMFS survey selectivity (males, pre-1982)
			M19F05	at upper bound	90	z50 for NMFS survey selectivity (males, pre-1982)
	pS1[20]	1	M19F00	at lower bound	40	z50 for GF.AllGear selectivity (males, 1987-1996)
			M19F00a	at lower bound	40	z50 for GF.AllGear selectivity (males, 1987-1996)
			M19F01	at lower bound	40	z50 for GF.AllGear selectivity (males, 1987-1996)
			M19F02	at lower bound	40	z50 for GF.AllGear selectivity (males, 1987-1996)
			M19F03	at lower bound	40	z50 for GF.AllGear selectivity (males, 1987-1996)
			M19F04	at lower bound	40	z50 for GF.AllGear selectivity (males, 1987-1996)
			M19F05	at lower bound	40	z50 for GF.AllGear selectivity (males, 1987-1996)
	pS1[23]	1	M19F00	at upper bound	180	z95 for RKF selectivity (males, 1997-2004)
			M19F00a	at upper bound	180	z95 for RKF selectivity (males, 1997-2004)
			M19F01	at upper bound	180	z95 for RKF selectivity (males, 1997-2004)
			M19F02	at upper bound	180	z95 for RKF selectivity (males, 1997-2004)
			M19F03	at upper bound	180	z95 for RKF selectivity (males, 1997-2004)
			M19F04	at upper bound	180	z95 for RKF selectivity (males, 1997-2004)
			M19F05	at upper bound	180	z95 for RKF selectivity (males, 1997-2004)
	pS1[24]	1	M19F00	at upper bound	180	z95 for RKF selectivity (males, 2005+)
			M19F00a	at upper bound	180	z95 for RKF selectivity (males, 2005+)
			M19F01	at upper bound	180	z95 for RKF selectivity (males, 2005+)
			M19F02	at upper bound	180	z95 for RKF selectivity (males, 2005+)
			M19F03	at upper bound	180	z95 for RKF selectivity (males, 2005+)
			M19F04	at upper bound	180	z95 for RKF selectivity (males, 2005+)
			M19F05	at upper bound	180	z95 for RKF selectivity (males, 2005+)
	pS1[27]	1	M19F00	at upper bound	140	z95 for RKF selectivity (females, 2005+)
			M19F00a	at upper bound	140	z95 for RKF selectivity (females, 2005+)
			M19F01	at upper bound	140	z95 for RKF selectivity (females, 2005+)
			M19F02	at upper bound	140	z95 for RKF selectivity (females, 2005+)
			M19F03	at upper bound	140	z95 for RKF selectivity (females, 2005+)
			M19F04	at upper bound	140	z95 for RKF selectivity (females, 2005+)
			M19F05	at upper bound	140	z95 for RKF selectivity (females, 2005+)
	pS2[10]	1	M19F00a	at lower bound	0.1	ascending slope for SCF selectivity (males, pre-1997)
			M19F01	at lower bound	0.1	ascending slope for SCF selectivity (males, pre-1997)

Table 19 (cont.).Selectivity-related parameters from all model scenarios estimated within 1% of bounds.

name		model	which?	bound	description
		M19F02	at lower bound	0.1	ascending slope for SCF selectivity (males, pre-1997)
		M19F03	at lower bound	0.1	ascending slope for SCF selectivity (males, pre-1997)
		M19F04	at lower bound	0.1	ascending slope for SCF selectivity (males, pre-1997)
		M19F05	at lower bound	0.1	ascending slope for SCF selectivity (males, pre-1997)
pS2[2]	1	M19F01	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
		M19F02	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
		M19F03	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
		M19F04	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
		M19F05	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
pS2[4]	1	M19F00	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
		M19F00a	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
		M19F01	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
		M19F02	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
		M19F03	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
		M19F04	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
		M19F05	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
pS4[1]	1	M19F00	at upper bound	0.5	descending slope for SCF selectivity (males, pre-1997)
		M19F00a	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)
		M19F01	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)
		M19F02	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)
		M19F03	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)
		M19F04	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)
		M19F05	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)

Table 20. Estimated growth, natural mortality, and non-vector recruitment parameters for all model scenarios.

						M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
process	description	parameter		phase	scale	value	std dev	value	std dev	value	std dev	value	std dev	value	std dev	value	std dev	value	std dev
growth	both sexes	pGrBeta[1]	1	5	ARITHMETIC	8.116e − 01	0.12597	5.441e − 01	0.07594	5.822e − 01	0.06559	7.936e − 01	0.09799	9.035e − 01	0.11392	5.651e − 01	0.06168	9.061e − 01	0.11105
	females	pGrA[2]	1	4	ARITHMETIC	3.446e + 01	0.42304	3.389e + 01	0.35337	3.326e + 01	0.25176	3.367e + 01	0.29993	3.399e + 01	0.33574	3.320e + 01	0.24548	3.396e + 01	0.33400
		pGrB[2]	1	4	ARITHMETIC	1.151e + 02	0.84195	1.151e + 02	0.77050	1.152e + 02	0.59572	1.151e + 02	0.65401	1.149e + 02	0.64756	1.152e + 02	0.55714	1.149e + 02	0.61193
	males	pGrA[1]	1	4	ARITHMETIC	3.309e + 01	0.35045	3.268e + 01	0.26962	3.258e + 01	0.23545	3.235e + 01	0.26033	3.274e + 01	0.29222	3.245e + 01	0.23171	3.261e + 01	0.28179
		pGrB[1]	1	4	ARITHMETIC	1.670e + 02	1.07890	1.634e + 02	1.10110	1.612e + 02	1.02490	1.657e + 02	0.86298	1.666e + 02	0.92085	1.612e + 02	0.98847	1.670e + 02	0.94701
natural mortality	1980-1984 multiplier for mature females	pDM2[2]	1	4	ARITHMETIC	1.307e + 00	0.09981	1.440e + 00	0.10786	1.380e + 00	0.10693	1.353e + 00	0.10385	1.873e + 00	0.15471	1.356e + 00	0.10445	1.893e + 00	0.15211
	1980-1984 multiplier for mature males	pDM2[1]	1	4	ARITHMETIC	2.587e + 00	0.24183	2.843e + 00	0.25788	2.798e + 00	0.25750	2.620e + 00	0.22434	2.231e + 00	0.21496	2.720e + 00	0.24396	2.286e + 00	0.21422
	base ln-scale M	pM[1]	1	-1	LOG	−1.470e + 00	NA	−1.470e + 00	NA	−1.470e + 00	NA	−1.470e + 00	NA	−1.470e + 00	NA	−1.470e + 00	NA	−1.470e + 00	NA
	multiplier for immature crab	pDM1[1]	1	4	ARITHMETIC	1.002e + 00	0.05044	9.997e − 01	0.05066	9.901e − 01	0.05042	9.756e − 01	0.05022	9.839e − 01	0.05149	1.064e + 00	0.04820	1.048e + 00	0.04979
	multiplier for mature females	pDM1[3]	1	4	ARITHMETIC	1.386e + 00	0.03557	1.341e + 00	0.03710	1.328e + 00	0.03635	1.348e + 00	0.03688	1.316e + 00	0.03885	1.327e + 00	0.03567	1.327e + 00	0.03811
	multiplier for mature males	pDM1[2]	1	4	ARITHMETIC	1.152e + 00	0.03952	1.221e + 00	0.04087	1.230e + 00	0.03938	1.352e + 00	0.03742	1.292e + 00	0.04001	1.262e + 00	0.03864	1.318e + 00	0.03873
recruitment	current recruitment period	pLnR[2]	1	1	ARITHMETIC	5.138e + 00	0.07180	5.414e + 00	0.07889	5.484e + 00	0.08083	5.615e + 00	0.08148	5.691e + 00	0.08257	5.630e + 00	0.06936	5.740e + 00	0.06904
	fixed value	pRa[1]	1	-1	LOG	2.442e + 00	NA	2.442e + 00	NA	2.442e + 00	NA	2.442e + 00	NA	2.442e + 00	NA	2.442e + 00	NA	2.442e + 00	NA
		pRb[1]	1	-1	LOG	1.386e + 00	NA	1.386e + 00	NA	1.386e + 00	NA	1.386e + 00	NA	1.386e + 00	NA	1.386e + 00	NA	1.386e + 00	NA
	full model period	pRCV[1]	1	-1	LOG	−6.931e − 01	NA	−6.931e − 01	NA	−6.931e − 01	NA	−6.931e − 01	NA	−6.931e − 01	NA	−6.931e − 01	NA	−6.931e − 01	NA
		pRX[1]	1	-1	LOGIT	−1.110e − 16	NA	−1.110e − 16	NA	−1.110e − 16	NA	−1.110e − 16	NA	−1.110e − 16	NA	−1.110e − 16	NA	−1.110e − 16	NA
	historical recruitment period	pLnR[1]	1	1	ARITHMETIC	5.662e + 00	0.40017	6.039e + 00	0.38683	6.185e + 00	0.37589	6.251e + 00	0.39915	6.281e + 00	0.41654	6.315e + 00	0.37471	6.341e + 00	0.41554

Table 21. Historical recruitment devs estimates (1948-1974) for all model scenarios.

			M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
index			value	std dev	value	std dev	value	std dev	value	std dev	value	std dev	value	std dev	value	std dev
1	1	ARITHMETIC	−1.4120	1.4764	−1.2802	1.4628	−1.21227	1.4492	−1.21416	1.4817	−1.39338	1.5043	−1.19404	1.4508	−1.381738	1.5055
2	1	ARITHMETIC	−1.4120	1.3270	−1.2826	1.3122	−1.21620	1.2978	−1.21685	1.3320	−1.38912	1.3562	−1.19841	1.2993	−1.378240	1.3574
3	1	ARITHMETIC	−1.4105	1.1914	−1.2858	1.1758	−1.22223	1.1611	−1.22085	1.1953	−1.37960	1.2206	−1.20533	1.1624	−1.370257	1.2216
4	1	ARITHMETIC	−1.4057	1.0721	−1.2877	1.0561	−1.22784	1.0417	−1.22425	1.0745	−1.36341	1.0997	−1.21230	1.0428	−1.356370	1.1006
5	1	ARITHMETIC	−1.3949	0.9712	−1.2851	0.9552	−1.22960	0.9417	−1.22430	0.9714	−1.33850	0.9956	−1.21587	0.9423	−1.334528	0.9963
6	1	ARITHMETIC	−1.3746	0.8894	−1.2738	0.8738	−1.22273	0.8615	−1.21710	0.8872	−1.30189	0.9094	−1.21124	0.8616	−1.301728	0.9098
7	1	ARITHMETIC	−1.3393	0.8260	−1.2476	0.8107	−1.20041	0.7997	−1.19696	0.8213	−1.24913	0.8408	−1.19151	0.7994	−1.253493	0.8409
8	1	ARITHMETIC	−1.2817	0.7781	−1.1977	0.7631	−1.15263	0.7532	−1.15541	0.7712	−1.17347	0.7877	−1.14656	0.7525	−1.182986	0.7877
9	1	ARITHMETIC	−1.1899	0.7418	−1.1101	0.7266	−1.06393	0.7173	−1.07919	0.7330	−1.06415	0.7470	−1.06065	0.7164	−1.079357	0.7469
10	1	ARITHMETIC	−1.0453	0.7126	−0.9619	0.6970	−0.90858	0.6882	−0.94640	0.7028	−0.90325	0.7152	−0.90753	0.6871	−0.924438	0.7150
11	1	ARITHMETIC	−0.8151	0.6883	−0.7120	0.6736	−0.64015	0.6662	−0.71771	0.6798	−0.65848	0.6912	−0.63979	0.6654	−0.685503	0.6910
12	1	ARITHMETIC	−0.4383	0.6726	−0.2871	0.6623	−0.18242	0.6572	−0.32434	0.6683	−0.27087	0.6796	−0.18059	0.6566	−0.302887	0.6792
13	1	ARITHMETIC	0.1660	0.6670	0.3730	0.6568	0.50326	0.6510	0.29986	0.6641	0.32880	0.6782	0.50615	0.6503	0.293606	0.6774
14	1	ARITHMETIC	0.9679	0.6525	1.1497	0.6391	1.24659	0.6320	1.07202	0.6488	1.08913	0.6671	1.24599	0.6312	1.055489	0.6660
15	1	ARITHMETIC	1.6257	0.6254	1.6449	0.6127	1.65040	0.6070	1.62078	0.6236	1.67036	0.6444	1.64471	0.6067	1.646939	0.6433
16	1	ARITHMETIC	1.7976	0.6055	1.6724	0.6031	1.60834	0.6017	1.69296	0.6102	1.79168	0.6301	1.60010	0.6018	1.778654	0.6288
17	1	ARITHMETIC	1.6191	0.6125	1.4503	0.6111	1.36579	0.6077	1.47538	0.6164	1.61024	0.6355	1.35947	0.6078	1.604503	0.6347
18	1	ARITHMETIC	1.3692	0.6187	1.2196	0.6105	1.13831	0.6030	1.22210	0.6170	1.37666	0.6359	1.13637	0.6025	1.379250	0.6358
19	1	ARITHMETIC	1.2090	0.6091	1.0895	0.5948	1.01064	0.5864	1.05644	0.6040	1.22342	0.6216	1.01261	0.5853	1.238470	0.6212
20	1	ARITHMETIC	1.1875	0.5888	1.0640	0.5771	0.96832	0.5732	0.99256	0.5871	1.17131	0.6028	0.96827	0.5718	1.201936	0.6004
21	1	ARITHMETIC	1.2546	0.5708	1.0303	0.5654	0.89237	0.5599	0.95314	0.5733	1.13925	0.5929	0.87968	0.5582	1.179838	0.5890
22	1	ARITHMETIC	1.2263	0.5399	0.8766	0.5246	0.75151	0.5121	0.86630	0.5379	0.99302	0.5659	0.73357	0.5109	1.027757	0.5635
23	1	ARITHMETIC	1.0762	0.4826	0.8502	0.4642	0.72676	0.4560	0.80345	0.4809	0.77987	0.5114	0.70422	0.4560	0.797451	0.5113
24	1	ARITHMETIC	0.6695	0.4841	0.4802	0.4726	0.32334	0.4703	0.43006	0.4935	0.37588	0.5176	0.28941	0.4715	0.382385	0.5187
25	1	ARITHMETIC	0.2508	0.4985	0.1363	0.4876	0.06273	0.4829	0.09607	0.5049	−0.01844	0.5223	0.04545	0.4837	−0.006806	0.5232
26	1	ARITHMETIC	0.1002	0.4463	0.1744	0.4312	0.23064	0.4218	0.15639	0.4445	−0.04595	0.4561	0.23782	0.4209	−0.027946	0.4570

Table 22. Current recruitment devs estimates (1975-2019) for all model scenarios.

			M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
index			value	std dev	value	std dev	value	std dev	value	std dev	value	std dev	value	std dev	value	std dev
1	1	ARITHMETIC	1.325987	0.21947	1.26031	0.25829	1.1945	0.30320	1.15328	0.30225	0.86809	0.32553	1.11503	0.31661	0.873803	0.33236
2	1	ARITHMETIC	1.999511	0.14193	2.10527	0.14112	2.1559	0.14562	2.11267	0.15067	1.92607	0.15117	2.11699	0.14489	1.948271	0.15060
3	1	ARITHMETIC	1.741158	0.15634	1.79450	0.15903	1.7409	0.17475	1.74449	0.17805	1.64245	0.17117	1.67740	0.17631	1.647896	0.17221
4	1	ARITHMETIC	0.914330	0.25716	0.91906	0.26315	0.8178	0.29703	0.87446	0.30204	0.94441	0.26110	0.73860	0.30411	0.938347	0.26352
5	1	ARITHMETIC	0.060257	0.39606	0.15632	0.37163	0.1218	0.40566	0.07721	0.44154	−0.06675	0.43056	0.06231	0.41081	−0.073395	0.43698
6	1	ARITHMETIC	−0.436228	0.47983	−0.29754	0.43368	−0.2936	0.46888	−0.41781	0.53348	−0.57721	0.51730	−0.33556	0.47194	−0.565462	0.51549
7	1	ARITHMETIC	0.057849	0.25068	0.08108	0.25329	0.1607	0.25902	0.07293	0.27445	−0.10833	0.26401	0.11128	0.26485	−0.121861	0.26766
8	1	ARITHMETIC	−0.518498	0.33685	−0.40743	0.32326	−0.4401	0.36189	−0.54060	0.37438	−0.25303	0.24297	−0.45249	0.35993	−0.258598	0.24387
9	1	ARITHMETIC	1.068860	0.10832	1.06916	0.10705	1.1744	0.10699	1.09664	0.10918	0.84628	0.11017	1.15444	0.10700	0.837807	0.11057
10	1	ARITHMETIC	0.874922	0.14305	0.91568	0.13217	0.9568	0.13703	0.86325	0.14717	0.75097	0.14269	0.92987	0.13732	0.744673	0.14369
11	1	ARITHMETIC	1.172213	0.13044	0.85682	0.14854	0.7990	0.16062	0.93231	0.15232	0.95242	0.13655	0.76898	0.16024	0.962625	0.13501
12	1	ARITHMETIC	1.134704	0.13537	0.95193	0.13239	1.0451	0.12651	0.98791	0.14234	0.94857	0.14102	1.03449	0.12446	0.961474	0.14092
13	1	ARITHMETIC	1.127278	0.13076	0.94278	0.12646	0.8736	0.14097	0.97327	0.13736	0.98944	0.13308	0.83020	0.14230	0.993998	0.13253
14	1	ARITHMETIC	0.737460	0.15415	0.41544	0.15996	0.3241	0.17331	0.47560	0.17379	0.69924	0.15395	0.29543	0.17444	0.694339	0.15454
15	1	ARITHMETIC	0.004827	0.18563	−0.13141	0.18008	−0.1839	0.19135	−0.14532	0.20310	−0.17150	0.21099	−0.20957	0.19309	−0.187352	0.21377
16	1	ARITHMETIC	−1.180975	0.38180	−1.40841	0.40897	−1.5941	0.48663	−1.52964	0.50361	−1.32340	0.40960	−1.63103	0.49750	−1.339677	0.41479
17	1	ARITHMETIC	−1.404156	0.33220	−1.51656	0.33544	−1.5957	0.35933	−1.53360	0.36485	−1.42398	0.32064	−1.62032	0.36386	−1.435798	0.32304
18	1	ARITHMETIC	−1.526055	0.29294	−1.53753	0.28809	−1.5417	0.29511	−1.53361	0.30441	−1.39119	0.25789	−1.55755	0.29720	−1.397713	0.25815
19	1	ARITHMETIC	−1.529904	0.27300	−1.48781	0.27121	−1.4885	0.28543	−1.53198	0.29714	−1.48169	0.27427	−1.50814	0.28884	−1.500872	0.27647
20	1	ARITHMETIC	−1.259841	0.22362	−1.19852	0.22551	−1.1435	0.23061	−1.19402	0.23688	−1.25593	0.24584	−1.15282	0.23121	−1.269587	0.24563
21	1	ARITHMETIC	−1.004762	0.19234	−0.91708	0.19233	−0.8269	0.19186	−0.87836	0.19708	−0.72265	0.17359	−0.84062	0.19226	−0.740183	0.17330
22	1	ARITHMETIC	−1.078268	0.22288	−1.01880	0.22794	−1.0485	0.24793	−1.05749	0.24727	−1.01225	0.23320	−1.07560	0.25020	−1.036970	0.23392
23	1	ARITHMETIC	−0.008056	0.10696	0.05202	0.10829	0.1272	0.10884	0.11232	0.10896	0.02733	0.11155	0.11215	0.10864	0.009917	0.11119
24	1	ARITHMETIC	−0.920764	0.20125	−0.85936	0.20485	−0.8502	0.21716	−0.90117	0.22133	−0.84470	0.20866	−0.86471	0.21773	−0.860841	0.20859
25	1	ARITHMETIC	0.289723	0.10549	0.38974	0.10445	0.4616	0.10480	0.41001	0.10665	0.41959	0.10446	0.44562	0.10465	0.396694	0.10416
26	1	ARITHMETIC	−0.366276	0.20085	−0.29864	0.20562	−0.2978	0.21995	−0.34294	0.22357	−0.29201	0.21269	−0.30902	0.22019	−0.306770	0.21209
27	1	ARITHMETIC	0.815665	0.09646	0.86132	0.09686	0.9013	0.09881	0.90922	0.09894	0.93503	0.09762	0.89129	0.09891	0.914377	0.09759
28	1	ARITHMETIC	−0.324659	0.23741	−0.26477	0.23954	−0.2525	0.25385	−0.30239	0.26489	−0.24681	0.25659	−0.25004	0.25371	−0.252331	0.25580
29	1	ARITHMETIC	0.782948	0.11247	0.85807	0.10883	0.8867	0.11053	0.90219	0.11281	1.03049	0.10797	0.88050	0.11109	1.011588	0.10834
30	1	ARITHMETIC	0.754406	0.10830	0.72155	0.11167	0.6930	0.11698	0.76029	0.11716	0.84219	0.11706	0.69958	0.11696	0.839696	0.11671
31	1	ARITHMETIC	−0.561822	0.24624	−0.52333	0.24261	−0.6105	0.26630	−0.62183	0.28186	−0.46522	0.25987	−0.60852	0.26952	−0.477087	0.26272
32	1	ARITHMETIC	−0.827576	0.27219	−0.88981	0.29428	−0.9527	0.31647	−0.90211	0.31438	−0.84391	0.30278	−0.94964	0.32136	−0.845306	0.30424
33	1	ARITHMETIC	−1.079504	0.31525	−0.98223	0.31350	−0.9470	0.32000	−0.99731	0.33015	−0.97928	0.31748	−0.93565	0.32438	−0.983900	0.31895
34	1	ARITHMETIC	−0.651014	0.26285	−0.45404	0.25695	−0.3760	0.25660	−0.50319	0.26709	−0.50286	0.26369	−0.30953	0.25406	−0.506445	0.26382
35	1	ARITHMETIC	1.219595	0.10001	1.32960	0.09379	1.3675	0.09161	1.36945	0.09620	1.34668	0.10032	1.41816	0.08972	1.378909	0.09736
36	1	ARITHMETIC	1.079563	0.10839	1.00232	0.11536	0.8413	0.12839	0.96347	0.12734	1.07831	0.12005	0.81370	0.13253	1.059373	0.12192
37	1	ARITHMETIC	0.165279	0.17803	0.04304	0.18429	−0.1110	0.19518	−0.01554	0.19961	0.01705	0.19485	−0.01670	0.18271	0.052942	0.18644
38	1	ARITHMETIC	−1.429645	0.46100	−1.35238	0.43217	−1.5650	0.48335	−1.58832	0.52578	−1.55216	0.46028	−1.62522	0.50258	−1.629746	0.47288
39	1	ARITHMETIC	−0.447087	0.18059	−0.46539	0.18595	−0.5666	0.18716	−0.48835	0.18585	−0.53477	0.17530	−0.46516	0.15891	−0.459241	0.15041
40	1	ARITHMETIC	−0.834498	0.21397	−0.83214	0.21754	−1.0070	0.23089	−0.94203	0.23099	−1.01823	0.22108	−1.03765	0.21588	−1.077281	0.20752
41	1	ARITHMETIC	−1.244014	0.27292	−1.22138	0.27541	−1.3175	0.28034	−1.31779	0.28752	−1.30915	0.25684	−1.31331	0.24850	−1.357546	0.23090
42	1	ARITHMETIC	−0.893146	0.24196	−0.86516	0.24412	−0.8876	0.23938	−0.86864	0.23975	−0.92572	0.23069	−0.73199	0.18381	−0.840550	0.17699
43	1	ARITHMETIC	0.959708	0.14287	0.99193	0.14244	0.8948	0.13040	0.91736	0.13034	0.78189	0.12072	1.08909	0.11217	0.928495	0.10095
44	1	ARITHMETIC	1.240503	0.22169	1.21181	0.22408	0.8241	0.19598	0.86635	0.19511	0.82803	0.17921	0.91640	0.19794	0.823768	0.18082

Table 23. Logit-scale parameters for the probability of terminal molt for males for all model scenarios. The (arithmetic) probability of terminal molt was fixed at 0 for males less than 60 mm CW and at 1 for males greater than 145 mm CW in Scenarios M19F03 and M19F05.

scenario:	M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
size bin	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
27.5	-12.03	7.44	-12.06	7.42	-12.04	7.39	-12.48	7.59	--	--	-11.92	7.22	--	--
32.5	-10.85	5.62	-10.84	5.60	-10.82	5.57	-11.15	5.73	--	--	-10.70	5.43	--	--
37.5	-9.66	4.02	-9.62	4.00	-9.61	3.99	-9.82	4.11	--	--	-9.48	3.86	--	--
42.5	-8.48	2.68	-8.40	2.67	-8.39	2.66	-8.49	2.74	--	--	-8.27	2.56	--	--
47.5	-7.31	1.63	-7.19	1.61	-7.19	1.61	-7.17	1.64	--	--	-7.06	1.53	--	--
52.5	-6.16	0.91	-6.01	0.88	-6.01	0.88	-5.87	0.87	--	--	-5.89	0.84	--	--
57.5	-5.11	0.54	-4.92	0.52	-4.92	0.51	-4.65	0.46	--	--	-4.81	0.49	--	--
62.5	-4.49	0.36	-4.27	0.36	-4.24	0.35	-3.82	0.28	-2.91	0.28	-4.20	0.35	-2.95	0.28
67.5	-4.10	0.29	-3.95	0.29	-3.92	0.29	-3.48	0.22	-3.29	0.29	-3.98	0.29	-3.37	0.30
72.5	-3.46	0.22	-3.34	0.23	-3.39	0.22	-3.04	0.19	-2.86	0.25	-3.40	0.22	-2.86	0.25
77.5	-2.93	0.17	-2.71	0.17	-2.76	0.17	-2.50	0.14	-2.17	0.16	-2.68	0.17	-2.14	0.15
82.5	-2.50	0.14	-2.26	0.14	-2.24	0.14	-1.92	0.12	-1.66	0.14	-2.19	0.13	-1.67	0.13
87.5	-2.03	0.12	-1.90	0.12	-1.90	0.12	-1.53	0.10	-1.41	0.12	-1.91	0.11	-1.43	0.12
92.5	-1.44	0.11	-1.42	0.11	-1.48	0.10	-1.00	0.09	-0.86	0.11	-1.50	0.10	-0.86	0.10
97.5	-0.95	0.09	-0.95	0.10	-1.07	0.10	-0.57	0.08	-0.47	0.10	-1.07	0.10	-0.47	0.09
102.5	-0.68	0.09	-0.59	0.09	-0.67	0.09	-0.39	0.08	-0.32	0.10	-0.65	0.09	-0.34	0.09
107.5	-0.53	0.09	-0.47	0.09	-0.45	0.08	-0.23	0.08	-0.15	0.10	-0.41	0.08	-0.14	0.09
112.5	-0.06	0.10	-0.12	0.09	-0.15	0.09	0.20	0.09	0.30	0.11	-0.13	0.08	0.30	0.10
117.5	0.56	0.13	0.41	0.11	0.34	0.10	0.77	0.11	0.90	0.13	0.37	0.10	0.95	0.14
122.5	1.44	0.20	1.09	0.14	0.98	0.13	1.55	0.16	1.76	0.19	0.99	0.13	1.80	0.19
127.5	2.81	0.36	1.88	0.29	1.55	0.20	2.81	0.30	3.11	0.31	1.54	0.20	3.16	0.30
132.5	5.06	0.59	3.95	0.61	3.17	0.55	4.17	0.34	4.35	0.34	3.16	0.54	4.40	0.35
137.5	7.20	1.06	6.22	0.91	5.44	0.79	6.01	0.65	6.12	0.73	5.45	0.77	6.15	0.74
142.5	9.01	1.68	8.21	1.42	7.54	1.21	7.80	1.17	8.03	1.54	7.55	1.20	8.05	1.55
147.5	10.50	2.32	9.85	2.03	9.29	1.79	9.35	1.77	--	--	9.31	1.78	--	--
152.5	11.69	2.85	11.18	2.57	10.73	2.35	10.64	2.33	--	--	10.75	2.34	--	--
157.5	12.63	3.19	12.24	2.95	11.87	2.75	11.71	2.73	--	--	11.89	2.75	--	--
162.5	13.36	3.26	13.06	3.07	12.78	2.92	12.59	2.90	--	--	12.80	2.91	--	--
167.5	13.91	3.01	13.71	2.88	13.50	2.77	13.32	2.76	--	--	13.52	2.77	--	--
172.5	14.35	2.42	14.21	2.33	14.08	2.27	13.95	2.26	--	--	14.09	2.26	--	--
177.5	14.69	1.44	14.63	1.40	14.56	1.37	14.49	1.36	--	--	14.57	1.37	--	--
182.5	15.00	0.00	15.00	0.00	15.00	0.00	15.00	0.00	--	--	15.00	0.00	--	--

Table 24. Logit-scale parameters for the probability of terminal molt for females for all model scenarios. The (arithmetic) probability of terminal molt was fixed at 0 for females less than 50 mm CW in Scenarios M19F03 and M19F05 and at 1 for females greater than 105 mm CW for all scenarios.

scenario:	M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
size bin	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
27.5	-15.00	0.00	-15.00	0.00	-15.00	0.00	-15.00	0.00	--	--	-15.00	0.00	--	--
32.5	-13.77	0.78	-13.78	0.78	-13.79	0.78	-13.79	0.78	--	--	-13.81	0.78	--	--
37.5	-12.48	1.18	-12.50	1.18	-12.53	1.18	-12.52	1.18	--	--	-12.56	1.18	--	--
42.5	-11.09	1.29	-11.12	1.29	-11.15	1.28	-11.13	1.28	--	--	-11.20	1.28	--	--
47.5	-9.53	1.15	-9.56	1.15	-9.60	1.15	-9.58	1.15	--	--	-9.66	1.14	--	--
52.5	-7.76	0.86	-7.79	0.86	-7.83	0.86	-7.80	0.86	-6.82	0.99	-7.90	0.86	-6.89	1.00
57.5	-5.75	0.52	-5.78	0.53	-5.81	0.52	-5.78	0.52	-5.05	0.45	-5.88	0.52	-5.11	0.45
62.5	-3.58	0.24	-3.60	0.24	-3.63	0.24	-3.60	0.24	-3.34	0.21	-3.70	0.24	-3.39	0.20
67.5	-1.77	0.11	-1.78	0.11	-1.81	0.11	-1.78	0.11	-1.79	0.11	-1.87	0.11	-1.85	0.11
72.5	-0.43	0.09	-0.44	0.08	-0.48	0.08	-0.44	0.08	-0.51	0.09	-0.52	0.08	-0.54	0.09
77.5	0.31	0.09	0.28	0.09	0.24	0.08	0.29	0.09	0.22	0.09	0.26	0.08	0.27	0.09
82.5	0.59	0.10	0.59	0.10	0.56	0.09	0.59	0.10	0.55	0.10	0.55	0.09	0.56	0.09
87.5	1.28	0.16	1.23	0.15	1.20	0.14	1.26	0.15	1.18	0.14	1.03	0.12	1.04	0.12
92.5	2.58	0.35	2.36	0.29	2.36	0.27	2.53	0.31	2.26	0.25	2.08	0.22	2.12	0.22
97.5	4.03	0.67	3.61	0.50	3.67	0.49	3.96	0.60	3.48	0.47	3.50	0.41	3.53	0.43
102.5	5.52	1.27	4.91	0.99	5.03	1.00	5.42	1.18	4.78	0.99	5.02	0.87	5.06	0.93

Table 25. Log-scale NMFS survey catchability and selectivity parameters for all model scenarios.

				M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
name	label	phase	scale	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
pQ[1]	**NMFS trawl survey: males, 1975-1981**	5	LOG	-0.693	0.000	-0.693	0.000	-0.693	0.000	-0.693	0.000	-0.693	0.000	-0.693	0.000	-0.693	0.000
pQ[2]	**NMFS trawl survey: males, 1982+**	5	LOG	-0.450	0.054	-0.635	0.065	-0.708	0.063	-0.757	0.065	-0.848	0.069	-0.702	0.053	-0.766	0.055
pQ[3]	**NMFS trawl survey: females, 1975-1981**	5	LOG	-0.693	0.000	-0.693	0.000	-0.693	0.000	-0.693	0.000	-0.693	0.001	-0.693	0.000	-0.693	0.001
pQ[4]	**NMFS trawl survey: females, 1982+**	5	LOG	-0.922	0.073	-1.185	0.086	-1.268	0.084	-1.432	0.086	-1.437	0.105	-1.291	0.076	-1.357	0.099
pS1[1]	**z50 for NMFS survey selectivity (males, pre-1982)**	1	ARITHMETIC	52.441	2.125	90.000	0.001	90.000	0.000	90.000	0.000	90.000	0.000	90.000	0.000	90.000	0.000
pS1[2]	**z50 for NMFS survey selectivity (males, 1982+)**	1	ARITHMETIC	34.262	4.137	40.160	6.282	40.369	5.641	48.332	5.272	46.976	5.617	51.811	4.538	55.732	4.697
pS1[3]	**z50 for NMFS survey selectivity (females, pre-1982)**	1	ARITHMETIC	56.408	2.854	76.838	3.071	77.775	2.969	82.307	3.326	92.150	4.946	79.502	2.969	92.970	4.820
pS1[4]	**z50 for NMFS survey selectivity (females, 1982+)**	1	ARITHMETIC	-35.492	30.433	-33.961	30.933	-36.975	32.573	-47.549	41.643	-0.042	18.679	-4.632	15.305	18.651	14.067
pS2[1]	**z95-z50 for NMFS survey selectivity (males, pre-1982)**	1	ARITHMETIC	23.612	3.514	86.141	6.981	84.091	6.598	81.019	6.068	92.616	7.614	80.670	6.020	89.255	7.012
pS2[2]	**z95-z50 for NMFS survey selectivity (males, 1982+)**	1	ARITHMETIC	75.233	10.334	99.001	17.736	100.000	0.003	100.000	0.001	100.000	0.000	100.000	0.007	100.000	0.000
pS2[3]	**z95-z50 for NMFS survey selectivity (females, pre-1982)**	1	ARITHMETIC	40.090	5.841	59.809	6.261	59.360	5.973	65.786	6.834	68.015	8.994	60.215	5.987	67.834	8.860
pS2[4]	**z95-z50 for NMFS survey selectivity (females, 1982+)**	1	ARITHMETIC	100.000	0.002	100.000	0.002	100.000	0.002	100.000	0.003	100.000	0.001	100.000	0.001	100.000	0.000

Table 26. BSFRF SBS (side-by-side) male availability parameters for all model scenarios in which they were estimated.

	BSFRF availability (males, 2013)				BSFRF availability (males, 2014)				BSFRF availability (males, 2015)				BSFRF availability (males, 2016)				BSFRF availability (males, 2017)			
	M19F04		M19F05		M19F04		M19F05		M19F04		M19F05		M19F04		M19F05		M19F04		M19F05	
index	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
1	-3.297	0.615	-3.255	0.614	-3.608	0.708	-3.590	0.700	-3.084	0.588	-3.030	0.578	-0.591	0.477	-0.438	0.488	0.113	0.340	0.321	0.352
2	-3.463	0.509	-3.428	0.510	-3.558	0.569	-3.558	0.563	-3.057	0.465	-3.021	0.457	-0.848	0.390	-0.716	0.399	-0.433	0.298	-0.234	0.308
3	-3.606	0.443	-3.578	0.446	-3.505	0.466	-3.523	0.463	-3.032	0.381	-3.015	0.376	-1.082	0.344	-0.971	0.351	-0.901	0.292	-0.717	0.301
4	-3.709	0.407	-3.690	0.412	-3.445	0.401	-3.481	0.400	-3.002	0.331	-3.006	0.330	-1.271	0.326	-1.185	0.332	-1.204	0.299	-1.046	0.306
5	-3.764	0.388	-3.753	0.394	-3.374	0.366	-3.430	0.365	-2.970	0.308	-2.999	0.308	-1.400	0.324	-1.347	0.327	-1.356	0.311	-1.235	0.316
6	-3.764	0.375	-3.763	0.381	-3.292	0.347	-3.368	0.347	-2.932	0.298	-2.992	0.297	-1.458	0.326	-1.444	0.326	-1.394	0.326	-1.319	0.328
7	-3.713	0.363	-3.722	0.368	-3.205	0.334	-3.302	0.333	-2.872	0.292	-2.968	0.291	-1.440	0.327	-1.476	0.323	-1.347	0.342	-1.328	0.340
8	-3.618	0.349	-3.638	0.354	-3.107	0.320	-3.225	0.318	-2.775	0.287	-2.910	0.283	-1.350	0.327	-1.443	0.318	-1.241	0.357	-1.283	0.350
9	-3.476	0.334	-3.505	0.339	-2.987	0.302	-3.125	0.300	-2.632	0.279	-2.803	0.274	-1.193	0.326	-1.346	0.312	-1.091	0.369	-1.197	0.356
10	-3.283	0.321	-3.320	0.326	-2.829	0.283	-2.984	0.280	-2.446	0.267	-2.647	0.262	-0.974	0.323	-1.189	0.305	-0.907	0.379	-1.076	0.360
11	-3.048	0.310	-3.092	0.316	-2.623	0.263	-2.794	0.260	-2.242	0.254	-2.465	0.248	-0.706	0.321	-0.979	0.297	-0.699	0.386	-0.925	0.360
12	-2.792	0.304	-2.843	0.309	-2.367	0.245	-2.551	0.241	-2.061	0.241	-2.298	0.235	-0.415	0.321	-0.740	0.292	-0.471	0.392	-0.749	0.360
13	-2.529	0.303	-2.589	0.307	-2.083	0.232	-2.276	0.227	-1.924	0.230	-2.164	0.224	-0.125	0.322	-0.485	0.290	-0.228	0.396	-0.544	0.358
14	-2.244	0.306	-2.315	0.310	-1.774	0.224	-1.969	0.217	-1.828	0.222	-2.060	0.215	0.141	0.325	-0.235	0.291	0.023	0.398	-0.317	0.356
15	-1.899	0.312	-1.979	0.315	-1.437	0.218	-1.625	0.211	-1.756	0.215	-1.965	0.208	0.362	0.327	-0.002	0.292	0.270	0.396	-0.074	0.353
16	-1.484	0.320	-1.574	0.322	-1.097	0.216	-1.267	0.208	-1.684	0.209	-1.858	0.204	0.527	0.326	0.199	0.292	0.498	0.390	0.170	0.348
17	-1.044	0.327	-1.143	0.329	-0.824	0.216	-0.977	0.208	-1.605	0.203	-1.745	0.199	0.624	0.320	0.348	0.290	0.689	0.380	0.391	0.341
18	-0.668	0.334	-0.776	0.337	-0.660	0.219	-0.806	0.210	-1.557	0.199	-1.672	0.195	0.642	0.309	0.422	0.283	0.820	0.366	0.563	0.333
19	-0.445	0.343	-0.560	0.345	-0.618	0.224	-0.763	0.215	-1.540	0.197	-1.637	0.193	0.573	0.295	0.411	0.274	0.877	0.350	0.669	0.323
20	-0.419	0.353	-0.533	0.355	-0.648	0.230	-0.797	0.220	-1.540	0.196	-1.623	0.192	0.413	0.280	0.305	0.265	0.850	0.332	0.696	0.311
21	-0.566	0.362	-0.671	0.364	-0.683	0.234	-0.836	0.222	-1.514	0.195	-1.586	0.192	0.174	0.265	0.116	0.256	0.734	0.315	0.637	0.300
22	-0.807	0.367	-0.895	0.368	-0.693	0.234	-0.851	0.223	-1.453	0.193	-1.516	0.191	-0.119	0.252	-0.134	0.247	0.533	0.302	0.492	0.293
23	-1.086	0.368	-1.155	0.370	-0.670	0.233	-0.835	0.222	-1.395	0.193	-1.454	0.191	-0.451	0.245	-0.432	0.244	0.258	0.300	0.271	0.297
24	-1.385	0.374	-1.432	0.376	-0.655	0.236	-0.831	0.224	-1.369	0.196	-1.430	0.194	-0.814	0.256	-0.768	0.256	-0.073	0.318	-0.010	0.320
25	-1.703	0.395	-1.731	0.397	-0.672	0.249	-0.862	0.236	-1.391	0.206	-1.458	0.203	-1.198	0.296	-1.132	0.294	-0.441	0.368	-0.332	0.372
26	-2.037	0.445	-2.044	0.447	-0.735	0.283	-0.941	0.268	-1.461	0.231	-1.538	0.227	-1.589	0.371	-1.507	0.366	-0.831	0.453	-0.678	0.458
27	-2.381	0.530	-2.369	0.532	-0.831	0.347	-1.055	0.328	-1.576	0.281	-1.664	0.276	-1.987	0.481	-1.889	0.473	-1.230	0.573	-1.035	0.576
28	-2.730	0.650	-2.698	0.652	-0.941	0.444	-1.183	0.421	-1.726	0.364	-1.825	0.357	-2.388	0.624	-2.276	0.612	-1.633	0.725	-1.397	0.725
29	-3.080	0.803	-3.029	0.803	-1.055	0.572	-1.315	0.546	-1.886	0.482	-1.999	0.472	-2.792	0.794	-2.666	0.779	-2.038	0.904	-1.761	0.902
30	-3.431	0.983	-3.360	0.983	-1.171	0.730	-1.450	0.700	-2.049	0.630	-2.175	0.618	-3.195	0.987	-3.055	0.969	-2.442	1.106	-2.125	1.101
31	-3.782	1.187	-3.692	1.186	-1.288	0.913	-1.586	0.880	-2.213	0.805	-2.353	0.790	-3.599	1.202	-3.445	1.181	-2.847	1.329	-2.489	1.321
32	-4.132	1.411	-4.024	1.409	-1.406	1.118	-1.722	1.081	-2.377	1.002	-2.531	0.985	-4.002	1.434	-3.835	1.411	-3.252	1.569	-2.853	1.560

Table 27. BSFRF SBS (side-by-side) female availability parameters for all model scenarios. in which they were estimated.

	BSFRF availability (females, 2013)				BSFRF availability (females, 2014)				BSFRF availability (females, 2015)				BSFRF availability (females, 2016)				BSFRF availability (females, 2017)			
	M19F04		M19F05		M19F04		M19F05		M19F04		M19F05		M19F04		M19F05		M19F04		M19F05	
index	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
1	-3.376	0.599	-3.272	0.597	-4.290	0.862	-4.211	0.860	-3.616	0.647	-3.543	0.642	-0.314	0.558	-0.156	0.572	0.798	0.434	1.001	0.450
2	-3.735	0.510	-3.640	0.509	-4.212	0.720	-4.146	0.718	-3.681	0.545	-3.621	0.542	-0.674	0.472	-0.531	0.483	0.328	0.377	0.526	0.390
3	-4.061	0.458	-3.974	0.457	-4.132	0.608	-4.079	0.607	-3.748	0.477	-3.701	0.474	-1.014	0.416	-0.886	0.424	-0.093	0.351	0.094	0.362
4	-4.327	0.429	-4.250	0.429	-4.053	0.524	-4.014	0.522	-3.810	0.434	-3.778	0.431	-1.300	0.377	-1.190	0.382	-0.393	0.335	-0.228	0.344
5	-4.508	0.409	-4.442	0.409	-3.987	0.460	-3.962	0.458	-3.863	0.404	-3.848	0.402	-1.529	0.346	-1.441	0.349	-0.564	0.321	-0.427	0.327
6	-4.586	0.389	-4.532	0.389	-3.940	0.408	-3.930	0.406	-3.900	0.379	-3.903	0.377	-1.688	0.318	-1.625	0.318	-0.627	0.309	-0.525	0.313
7	-4.542	0.363	-4.503	0.362	-3.904	0.362	-3.909	0.359	-3.919	0.354	-3.940	0.352	-1.769	0.290	-1.734	0.289	-0.611	0.300	-0.548	0.300
8	-4.367	0.331	-4.344	0.330	-3.864	0.317	-3.886	0.314	-3.903	0.327	-3.942	0.325	-1.774	0.263	-1.770	0.260	-0.547	0.292	-0.524	0.290
9	-4.050	0.296	-4.045	0.295	-3.791	0.274	-3.833	0.271	-3.828	0.301	-3.884	0.299	-1.707	0.241	-1.734	0.237	-0.464	0.286	-0.481	0.281
10	-3.579	0.262	-3.595	0.261	-3.657	0.239	-3.721	0.236	-3.682	0.278	-3.754	0.277	-1.573	0.226	-1.632	0.222	-0.389	0.281	-0.447	0.275
11	-2.960	0.237	-3.002	0.237	-3.438	0.216	-3.530	0.213	-3.472	0.264	-3.563	0.263	-1.407	0.220	-1.497	0.216	-0.356	0.280	-0.455	0.272
12	-2.217	0.231	-2.291	0.230	-3.133	0.207	-3.255	0.205	-3.218	0.259	-3.331	0.258	-1.276	0.222	-1.398	0.217	-0.393	0.287	-0.534	0.275
13	-1.385	0.249	-1.499	0.248	-2.731	0.210	-2.891	0.207	-2.930	0.262	-3.069	0.260	-1.200	0.231	-1.355	0.224	-0.497	0.306	-0.679	0.290
14	-0.494	0.297	-0.652	0.294	-2.242	0.223	-2.444	0.219	-2.589	0.269	-2.759	0.267	-1.166	0.250	-1.353	0.240	-0.650	0.346	-0.874	0.325
15	0.440	0.375	0.236	0.372	-1.672	0.253	-1.921	0.246	-2.172	0.286	-2.378	0.281	-1.158	0.290	-1.380	0.276	-0.833	0.417	-1.100	0.391
16	1.389	0.486	1.138	0.483	-1.048	0.313	-1.352	0.300	-1.696	0.322	-1.943	0.313	-1.156	0.364	-1.414	0.345	-1.032	0.525	-1.340	0.494
17	2.340	0.629	2.042	0.626	-0.410	0.413	-0.772	0.393	-1.195	0.392	-1.488	0.378	-1.156	0.476	-1.450	0.452	-1.235	0.666	-1.586	0.631
18	3.292	0.800	2.946	0.797	0.227	0.550	-0.197	0.526	-0.693	0.501	-1.034	0.481	-1.156	0.622	-1.488	0.595	-1.439	0.837	-1.833	0.799
19	4.243	0.994	3.849	0.991	0.863	0.719	0.376	0.691	-0.188	0.645	-0.579	0.619	-1.155	0.796	-1.525	0.766	-1.643	1.032	-2.080	0.991
20	5.195	1.209	4.753	1.206	1.500	0.912	0.949	0.881	0.317	0.818	-0.124	0.788	-1.155	0.994	-1.563	0.961	-1.847	1.248	-2.327	1.205
21	6.146	1.442	5.656	1.439	2.136	1.126	1.523	1.092	0.822	1.015	0.332	0.981	-1.155	1.212	-1.600	1.176	-2.051	1.483	-2.574	1.438

Table 28. Mean capture rate, selectivity and retention parameter estimates for the directed fishery (TCF) for all model scenarios.

				M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
name	label	index	phase	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
pDC2[1]	TCF: female offset	1	1	-2.351	0.300	-1.968	0.269	-2.002	0.265	-2.121	0.260	-2.202	0.225	-2.242	0.224	-2.365	0.209
pLgtRet[1]	TCF: logit-scale max retention (pre-1997)	1	3	14.999	2.211	14.999	4.414	14.999	4.355	14.999	4.757	14.999	5.155	14.999	4.336	14.999	4.561
pLgtRet[2]	TCF: logit-scale max retention (2005-2009)	1	3	2.101	1.305	14.210	996.790	14.919	337.810	14.863	526.220	14.993	39.551	14.868	479.580	14.928	322.800
pLgtRet[3]	TCF: logit-scale max retention (2013+)	1	3	4.031	2.222	14.633	619.480	14.990	45.731	14.980	78.614	14.987	57.716	14.977	88.452	14.984	66.741
pLnC[1]	TCF: base capture rate, pre-1965 (=0.05)	1	-1	-2.996	0.000	-2.996	0.000	-2.996	0.000	-2.996	0.000	-2.996	0.000	-2.996	0.000	-2.996	0.000
pLnC[2]	TCF: base capture rate, 1965+	1	1	-1.418	0.083	-1.580	0.085	-1.679	0.083	-1.634	0.083	-1.818	0.086	-1.678	0.081	-1.767	0.082
pDevsS1[1]	ln(z50 devs) for TCF selectivity (males, 1991+)	1	2	0.037	0.018	0.086	0.011	0.100	0.012	0.092	0.011	0.090	0.010	0.099	0.012	0.090	0.010
		2	2	0.124	0.012	0.040	0.011	0.050	0.011	0.044	0.010	0.038	0.010	0.049	0.011	0.041	0.010
		3	2	0.107	0.014	0.118	0.013	0.130	0.014	0.121	0.013	0.112	0.012	0.128	0.013	0.113	0.012
		4	2	0.088	0.021	0.070	0.018	0.081	0.018	0.075	0.017	0.066	0.017	0.079	0.018	0.068	0.017
		5	2	0.001	0.027	-0.002	0.026	0.002	0.027	0.009	0.025	0.005	0.024	0.001	0.026	0.008	0.023
		6	2	0.130	0.040	0.153	0.038	0.167	0.038	0.161	0.037	0.161	0.036	0.164	0.038	0.159	0.035
		7	2	-0.079	0.017	-0.076	0.016	-0.067	0.016	-0.064	0.015	-0.061	0.015	-0.066	0.016	-0.062	0.015
		8	2	-0.087	0.018	-0.080	0.016	-0.068	0.016	-0.067	0.015	-0.062	0.015	-0.066	0.016	-0.062	0.015
		9	2	-0.124	0.016	-0.122	0.015	-0.114	0.015	-0.108	0.014	-0.103	0.014	-0.113	0.015	-0.103	0.014
		10	2	0.019	0.014	0.018	0.014	0.029	0.013	0.027	0.013	0.030	0.013	0.029	0.013	0.029	0.013
		11	2	0.189	0.016	0.189	0.015	0.198	0.015	0.192	0.014	0.195	0.014	0.197	0.015	0.193	0.014
		12	2	-0.040	0.017	-0.035	0.015	-0.027	0.015	-0.022	0.015	-0.020	0.015	-0.025	0.015	-0.020	0.015
		13	2	-0.100	0.014	-0.096	0.013	-0.083	0.012	-0.085	0.012	-0.085	0.012	-0.082	0.012	-0.086	0.012
		14	2	-0.138	0.016	-0.142	0.014	-0.128	0.013	-0.124	0.013	-0.124	0.013	-0.126	0.013	-0.124	0.013
		15	2	-0.125	0.021	-0.122	0.019	-0.113	0.019	-0.103	0.017	-0.098	0.017	-0.112	0.019	-0.099	0.017
		16	2					-0.157	0.017	-0.147	0.016	-0.145	0.016	-0.156	0.017	-0.146	0.016
pS1[28]	z50 for TCF retention (2005-2009)	1	1	138.799	1.573	137.700	0.303	137.716	0.337	137.711	0.331	137.711	0.329	137.716	0.348	137.711	0.328
pS1[29]	z50 for TCF retention (2013+)	1	1	125.230	0.725	125.170	0.566	125.216	0.544	125.269	0.539	125.254	0.538	125.189	0.543	125.249	0.538
pS1[5]	z50 for TCF retention (pre-1991)	1	1	138.043	0.420	138.527	0.448	138.635	0.452	138.545	0.441	138.638	0.446	138.591	0.444	138.577	0.438
pS1[6]	z50 for TCF retention (1991-1996)	1	1	137.483	0.250	138.337	0.331	138.378	0.340	138.418	0.347	138.475	0.357	138.380	0.339	138.438	0.352
pS1[8]	ln(z50) for TCF selectivity (males)	1	1	4.858	0.008	4.865	0.008	4.857	0.007	4.860	0.007	4.859	0.007	4.859	0.007	4.860	0.007
pS1[9]	z50 for TCF selectivity (females)	1	1	96.441	2.583	96.842	2.621	96.722	2.641	96.719	2.600	95.205	2.202	94.863	2.164	94.174	1.986
pS2[28]	slope for TCF retention (2005-2009)	1	1	0.865	0.634	2.000	0.507	2.000	0.649	2.000	0.628	2.000	0.618	1.999	0.691	2.000	0.614
pS2[29]	slope for TCF retention (2013+)	1	1	0.563	0.115	0.568	0.108	0.570	0.104	0.563	0.100	0.565	0.100	0.575	0.105	0.567	0.101
pS2[5]	slope for TCF retention (pre-1991)	1	1	0.687	0.125	0.686	0.118	0.687	0.115	0.678	0.115	0.689	0.116	0.692	0.116	0.694	0.117
pS2[6]	slope for TCF retention (1997+)	1	1	0.954	0.190	0.937	0.222	0.933	0.222	0.920	0.217	0.908	0.212	0.931	0.221	0.918	0.217
pS2[7]	slope for TCF selectivity (males, pre-1997)	1	1	0.118	0.006	0.112	0.006	0.110	0.006	0.114	0.006	0.116	0.006	0.111	0.006	0.117	0.006
pS2[8]	slope for TCF selectivity (males, 1997+)	1	1	0.155	0.008	0.156	0.008	0.158	0.008	0.160	0.007	0.159	0.007	0.158	0.007	0.159	0.007
pS2[9]	slope for TCF selectivity (females)	1	1	0.185	0.019	0.184	0.018	0.179	0.017	0.179	0.017	0.184	0.017	0.189	0.018	0.191	0.018

Table 29. Log-scale male capture rate dev parameter estimates for the directed fishery (TCF) for all model scenarios.

	M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
year	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
1965	-0.548	0.463	-0.569	0.459	-0.588	0.456	-0.561	0.459	-0.494	0.460	-0.590	0.456	-0.501	0.460
1966	-0.773	0.369	-0.775	0.365	-0.785	0.362	-0.769	0.364	-0.724	0.365	-0.786	0.362	-0.729	0.365
1967	0.449	0.336	0.460	0.329	0.459	0.325	0.466	0.328	0.494	0.327	0.459	0.324	0.492	0.328
1968	0.294	0.315	0.322	0.308	0.333	0.304	0.330	0.306	0.353	0.307	0.334	0.304	0.350	0.308
1969	0.474	0.304	0.504	0.298	0.518	0.294	0.514	0.295	0.532	0.296	0.517	0.295	0.528	0.298
1970	0.332	0.303	0.356	0.295	0.369	0.290	0.370	0.290	0.375	0.291	0.366	0.291	0.370	0.294
1971	0.138	0.293	0.159	0.283	0.172	0.277	0.182	0.276	0.169	0.276	0.168	0.277	0.160	0.280
1972	-0.033	0.261	-0.005	0.251	0.016	0.244	0.036	0.245	0.001	0.242	0.010	0.244	-0.015	0.246
1973	-0.281	0.199	-0.227	0.193	-0.191	0.188	-0.161	0.191	-0.220	0.185	-0.197	0.188	-0.247	0.187
1974	-0.094	0.136	0.002	0.136	0.055	0.134	0.090	0.137	0.008	0.130	0.052	0.133	-0.028	0.130
1975	0.130	0.103	0.271	0.108	0.340	0.106	0.373	0.109	0.281	0.104	0.340	0.105	0.240	0.102
1976	0.908	0.096	1.064	0.103	1.142	0.103	1.187	0.105	1.085	0.101	1.148	0.100	1.046	0.098
1977	1.711	0.113	1.812	0.124	1.885	0.123	2.007	0.131	1.827	0.117	1.901	0.121	1.797	0.115
1978	2.041	0.150	1.966	0.166	2.017	0.161	2.250	0.175	1.996	0.152	2.042	0.159	1.980	0.151
1979	2.818	0.229	2.383	0.225	2.407	0.205	2.703	0.229	2.488	0.220	2.443	0.201	2.483	0.223
1980	2.015	0.178	2.066	0.172	2.242	0.175	2.133	0.167	2.073	0.162	2.290	0.175	2.071	0.161
1981	0.207	0.112	0.357	0.116	0.534	0.119	0.353	0.110	0.390	0.108	0.565	0.118	0.386	0.108
1982	-0.791	0.123	-0.750	0.123	-0.667	0.123	-0.705	0.122	-0.641	0.122	-0.652	0.123	-0.637	0.122
1983	-1.796	0.244	-1.801	0.245	-1.768	0.246	-1.733	0.248	-1.708	0.248	-1.760	0.246	-1.692	0.249
1984	-0.779	0.174	-0.771	0.176	-0.759	0.175	-0.675	0.176	-0.715	0.176	-0.752	0.175	-0.680	0.177
1987	-1.338	0.208	-1.271	0.211	-1.230	0.211	-1.189	0.211	-1.120	0.213	-1.214	0.212	-1.116	0.214
1988	-0.527	0.105	-0.407	0.105	-0.336	0.103	-0.361	0.103	-0.224	0.103	-0.320	0.103	-0.224	0.104
1989	0.669	0.081	0.772	0.078	0.820	0.076	0.821	0.077	0.998	0.077	0.832	0.076	0.999	0.078
1990	1.347	0.087	1.498	0.082	1.529	0.079	1.519	0.081	1.669	0.082	1.540	0.079	1.680	0.082
1991	1.352	0.105	1.762	0.118	1.823	0.119	1.742	0.116	1.826	0.115	1.835	0.119	1.852	0.116
1992	2.049	0.142	1.933	0.115	1.938	0.113	1.856	0.110	1.875	0.108	1.944	0.112	1.910	0.109
1993	1.442	0.147	1.576	0.143	1.594	0.144	1.491	0.140	1.428	0.136	1.596	0.143	1.470	0.135
1994	0.932	0.193	0.800	0.160	0.794	0.160	0.748	0.157	0.696	0.150	0.790	0.158	0.743	0.150
1995	0.340	0.178	0.222	0.166	0.168	0.161	0.219	0.166	0.204	0.161	0.163	0.158	0.251	0.161
1996	0.055	0.378	-0.370	0.409	-0.381	0.411	-0.356	0.407	-0.381	0.402	-0.383	0.409	-0.339	0.402
2005	-2.086	0.189	-2.210	0.206	-2.172	0.206	-2.208	0.206	-2.159	0.207	-2.173	0.206	-2.156	0.207
2006	-1.490	0.123	-1.715	0.138	-1.660	0.137	-1.704	0.137	-1.650	0.137	-1.660	0.137	-1.645	0.137
2007	-1.473	0.110	-1.653	0.119	-1.614	0.117	-1.652	0.117	-1.618	0.117	-1.625	0.116	-1.617	0.117
2008	-1.826	0.154	-1.819	0.155	-1.743	0.154	-1.800	0.154	-1.786	0.154	-1.746	0.154	-1.782	0.154
2009	-1.198	0.265	-1.147	0.263	-1.049	0.264	-1.125	0.258	-1.091	0.260	-1.046	0.265	-1.087	0.260
2013	-1.821	0.136	-1.705	0.137	-1.621	0.135	-1.652	0.136	-1.647	0.136	-1.638	0.135	-1.656	0.136
2014	-0.623	0.089	-0.581	0.093	-0.463	0.090	-0.558	0.088	-0.546	0.087	-0.503	0.089	-0.568	0.087
2015	-0.363	0.088	-0.359	0.090	-0.249	0.087	-0.309	0.085	-0.278	0.084	-0.300	0.085	-0.295	0.084
2017	-1.864	0.125	-2.151	0.143	-2.042	0.140	-2.037	0.141	-1.983	0.141	-2.097	0.139	-1.995	0.140
2018	--	--	--	--	-1.836	0.135	-1.833	0.135	-1.784	0.134	-1.894	0.133	-1.798	0.133

Table 30. Comparison of mean capture rate, ln-scale capture rate devs, and selectivity parameter estimates for the snow crab fishery (SCF) for all model scenarios.

				M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
name	label	index	phase	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
pDC2[2]	SCF: female offset	1	2	-1.749	0.150	-3.361	0.619	-3.388	0.621	-3.521	0.622	-3.394	0.616	-3.403	0.618	-3.415	0.611
pDevsLnC[2]	SCF: 1992+	1	2	1.945	0.091	0.572	0.105	0.586	0.105	0.571	0.105	0.512	0.104	0.583	0.105	0.516	0.104
		2	2	1.641	0.093	0.897	0.098	0.904	0.098	0.889	0.098	0.807	0.097	0.900	0.097	0.816	0.097
		3	2	1.241	0.097	0.331	0.181	0.330	0.180	0.332	0.181	0.242	0.179	0.325	0.180	0.255	0.179
		4	2	1.170	0.104	0.290	0.237	0.285	0.236	0.303	0.238	0.199	0.234	0.280	0.237	0.218	0.234
		5	2	-0.271	0.244	1.203	0.144	1.194	0.143	1.229	0.144	1.099	0.140	1.194	0.142	1.123	0.140
		6	2	0.784	0.211	0.919	0.160	0.895	0.163	0.909	0.162	0.901	0.161	0.915	0.160	0.912	0.159
		7	2	0.999	0.203	-0.136	0.354	-0.147	0.352	-0.122	0.351	-0.134	0.351	-0.133	0.353	-0.123	0.351
		8	2	-0.035	0.336	-0.995	0.551	-1.000	0.548	-0.976	0.550	-0.982	0.548	-0.991	0.551	-0.975	0.549
		9	2	-0.982	0.513	-0.731	0.495	-0.733	0.493	-0.717	0.491	-0.718	0.492	-0.724	0.496	-0.711	0.492
		10	2	-0.834	0.441	-0.447	0.384	-0.448	0.382	-0.447	0.379	-0.419	0.384	-0.437	0.384	-0.413	0.384
		11	2	-0.614	0.358	-1.148	0.497	-1.155	0.495	-1.152	0.493	-1.115	0.500	-1.148	0.496	-1.112	0.500
		12	2	-1.311	0.453	-1.422	0.497	-1.426	0.496	-1.428	0.494	-1.390	0.501	-1.420	0.497	-1.389	0.500
		13	2	-1.652	0.465	-1.470	0.467	-1.472	0.467	-1.476	0.465	-1.435	0.470	-1.466	0.467	-1.435	0.469
		14	2	-0.540	0.229	-0.107	0.205	-0.109	0.204	-0.118	0.204	-0.079	0.204	-0.090	0.204	-0.076	0.204
		15	2	-0.251	0.170	0.041	0.164	0.030	0.163	0.030	0.163	0.069	0.163	0.046	0.163	0.070	0.163
		16	2	-0.144	0.145	0.136	0.142	0.138	0.141	0.116	0.141	0.124	0.141	0.151	0.141	0.124	0.140
		17	2	-0.729	0.202	-0.490	0.207	-0.483	0.207	-0.499	0.206	-0.494	0.206	-0.473	0.206	-0.495	0.206
		18	2	-0.504	0.181	-0.105	0.160	-0.107	0.159	-0.103	0.159	-0.085	0.159	-0.102	0.159	-0.087	0.159
		19	2	-0.330	0.181	-0.017	0.170	-0.022	0.169	-0.001	0.169	0.014	0.169	-0.017	0.169	0.013	0.169
		20	2	0.256	0.136	0.530	0.130	0.531	0.129	0.559	0.129	0.568	0.128	0.537	0.129	0.568	0.128
		21	2	-0.386	0.200	0.189	0.163	0.210	0.162	0.212	0.162	0.215	0.161	0.210	0.161	0.206	0.161
		22	2	-0.269	0.148	0.081	0.144	0.130	0.143	0.089	0.143	0.101	0.142	0.121	0.142	0.082	0.142
		23	2	0.646	0.099	0.953	0.093	1.005	0.091	0.971	0.091	1.005	0.089	0.986	0.090	0.984	0.088
		24	2	0.423	0.107	0.702	0.100	0.753	0.098	0.729	0.098	0.773	0.096	0.728	0.097	0.754	0.096
		25	2	0.202	0.125	0.463	0.119	0.514	0.117	0.502	0.117	0.548	0.115	0.483	0.116	0.530	0.115
		26	2	-0.457	0.208	-0.240	0.216	-0.182	0.217	-0.187	0.216	-0.148	0.217	-0.210	0.216	-0.163	0.216
		27	2					-0.221	0.258	-0.215	0.258	-0.177	0.260	-0.248	0.257	-0.189	0.259
pLnC[3]	SCF: base capture rate, pre-1978 (=0.01)	1	-2	-4.605	0.000	-4.605	0.000	-4.605	0.000	-4.605	0.000	-4.605	0.000	-4.605	0.000	-4.605	0.000
pLnC[4]	SCF: base capture rate, 1992+	1	2	-2.862	0.102	-3.428	0.123	-3.505	0.124	-3.526	0.122	-3.732	0.116	-3.557	0.113	-3.693	0.106
pS1[10]	ascending z50 for SCF selectivity (males, pre-1997)	1	2	87.648	1.558	113.170	2.039	113.617	1.991	115.440	1.911	113.499	1.864	113.489	1.947	113.866	1.836
pS1[11]	ascending z50 for SCF selectivity (males, 1997-2004)	1	2	95.647	3.832	94.504	3.036	94.623	3.059	95.940	3.096	95.758	3.008	94.609	2.975	95.734	2.961
pS1[12]	ascending z50 for SCF selectivity (males, 2005+)	1	2	105.452	1.410	105.556	1.188	105.657	1.180	106.572	1.149	106.295	1.103	105.846	1.165	106.315	1.097
pS1[13]	ascending z50 for SCF selectivity (females, pre-1997)	1	2	70.333	4.978	74.138	4.872	74.155	4.844	74.154	4.851	73.422	4.650	74.086	4.752	73.547	4.635
pS1[14]	ascending z50 for SCF selectivity (females, 1997-2004)	1	2	76.365	4.529	76.921	4.483	76.928	4.439	76.865	4.458	76.348	4.447	76.990	4.394	76.484	4.427
pS1[15]	ascending z50 for SCF selectivity (females, 2005+)	1	2	84.942	5.484	81.126	4.013	80.715	4.017	80.706	4.030	79.972	3.937	80.666	3.847	80.056	3.826
pS2[10]	ascending slope for SCF selectivity (males, pre-1997)	1	2	0.376	0.131	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000
pS2[11]	ascending slope for SCF selectivity (males, 1997-2004)	1	2	0.209	0.064	0.224	0.065	0.225	0.066	0.209	0.056	0.211	0.056	0.227	0.066	0.212	0.056
pS2[12]	ascending slope for SCF selectivity (males, 2005+)	1	2	0.175	0.015	0.182	0.013	0.181	0.013	0.180	0.013	0.182	0.013	0.180	0.013	0.182	0.013
pS2[13]	slope for SCF selectivity (females, pre-1997)	1	2	0.221	0.127	0.162	0.065	0.163	0.065	0.162	0.065	0.170	0.068	0.164	0.064	0.170	0.066
pS2[14]	slope for SCF selectivity (females, 1997-2004)	1	2	0.263	0.128	0.257	0.119	0.259	0.119	0.259	0.120	0.264	0.126	0.259	0.117	0.262	0.123
pS2[15]	slope for SCF selectivity (females, 2005+)	1	2	0.157	0.049	0.193	0.057	0.190	0.055	0.190	0.055	0.193	0.058	0.193	0.054	0.194	0.056
pS4[1]	descending slope for SCF selectivity (males, pre-1997)	1	2	0.500	0.001	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000	0.100	0.000
pS4[2]	descending slope for SCF selectivity (males, 1997-2004)	1	2	0.126	0.081	0.164	0.093	0.157	0.090	0.167	0.103	0.168	0.103	0.164	0.096	0.171	0.107
pS4[3]	descending slope for SCF selectivity (males, 2005+)	1	2	0.182	0.024	0.191	0.024	0.189	0.023	0.193	0.025	0.196	0.025	0.192	0.024	0.197	0.025

Table 31. Comparison of mean capture rate, ln-scale capture rate devs, and selectivity parameters estimates for the BBRKC fishery (RKF) for all model scenarios.

				M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
name	label	index	phase	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
pDC2[4]	**RKF: female offset**	1	2	-0.834	3.018	-1.153	3.735	-1.278	3.713	-1.430	3.589	-1.832	2.062	-1.686	2.318	-1.950	1.864
pDevsLnC[4]	**RKF: 1992+**	1	2	0.845	0.275	0.565	0.191	0.548	0.190	0.522	0.189	0.466	0.185	0.548	0.190	0.474	0.185
		2	2	2.220	0.213	1.589	0.129	1.566	0.126	1.539	0.125	1.433	0.121	1.564	0.125	1.447	0.122
		3	2	-0.044	0.381	0.162	0.344	0.120	0.338	0.143	0.346	0.088	0.330	0.121	0.338	0.105	0.333
		4	2	0.010	0.396	0.294	0.425	0.260	0.418	0.268	0.424	0.282	0.421	0.265	0.419	0.287	0.424
		5	2	-0.012	0.392	0.256	0.425	0.227	0.419	0.236	0.424	0.255	0.424	0.233	0.421	0.258	0.426
		6	2	-0.028	0.389	0.219	0.419	0.194	0.415	0.202	0.419	0.222	0.419	0.200	0.417	0.224	0.421
		7	2	-0.035	0.387	0.195	0.412	0.173	0.409	0.179	0.412	0.196	0.412	0.178	0.411	0.197	0.413
		8	2	-0.052	0.381	0.145	0.398	0.129	0.397	0.128	0.397	0.145	0.397	0.135	0.398	0.145	0.398
		9	2	-0.060	0.376	0.098	0.379	0.089	0.380	0.082	0.378	0.106	0.381	0.095	0.382	0.106	0.382
		10	2	-0.083	0.368	0.027	0.361	0.019	0.362	0.015	0.361	0.041	0.364	0.024	0.363	0.041	0.365
		11	2	-0.126	0.355	-0.070	0.341	-0.069	0.343	-0.076	0.342	-0.053	0.344	-0.064	0.344	-0.053	0.344
		12	2	-0.161	0.345	-0.146	0.323	-0.140	0.326	-0.146	0.325	-0.128	0.326	-0.132	0.327	-0.127	0.326
		13	2	-0.218	0.333	-0.250	0.306	-0.236	0.310	-0.247	0.309	-0.233	0.309	-0.227	0.311	-0.233	0.309
		14	2	-0.229	0.326	-0.292	0.296	-0.280	0.299	-0.284	0.299	-0.278	0.299	-0.274	0.300	-0.277	0.299
		15	2	-0.125	0.319	-0.191	0.282	-0.167	0.287	-0.184	0.285	-0.195	0.282	-0.161	0.287	-0.195	0.282
		16	2	-0.236	0.314	-0.320	0.278	-0.295	0.282	-0.298	0.282	-0.306	0.280	-0.291	0.282	-0.306	0.280
		17	2	-0.280	0.318	-0.399	0.285	-0.385	0.288	-0.362	0.291	-0.361	0.290	-0.383	0.288	-0.360	0.290
		18	2	-0.239	0.328	-0.323	0.296	-0.312	0.299	-0.277	0.304	-0.274	0.304	-0.310	0.299	-0.272	0.304
		19	2	-0.196	0.336	-0.235	0.307	-0.221	0.310	-0.190	0.316	-0.189	0.314	-0.218	0.311	-0.188	0.314
		20	2	-0.189	0.329	-0.193	0.303	-0.160	0.309	-0.166	0.309	-0.174	0.306	-0.161	0.309	-0.181	0.305
		21	2	-0.139	0.311	-0.188	0.278	-0.125	0.288	-0.167	0.282	-0.175	0.280	-0.134	0.286	-0.188	0.278
		22	2	-0.233	0.307	-0.345	0.273	-0.280	0.281	-0.304	0.278	-0.302	0.277	-0.297	0.279	-0.312	0.276
		23	2	-0.221	0.314	-0.343	0.277	-0.280	0.285	-0.279	0.285	-0.266	0.286	-0.299	0.282	-0.274	0.285
		24	2	-0.168	0.327	-0.255	0.288	-0.193	0.296	-0.174	0.299	-0.156	0.301	-0.212	0.293	-0.164	0.299
		25	2					-0.183	0.313	-0.162	0.317	-0.145	0.319	-0.200	0.310	-0.152	0.318
pLnC[7]	**RKF: base capture rate, pre-1953 (=0.02)**	1	-2	-3.912	0.000	-3.912	0.000	-3.912	0.000	-3.912	0.000	-3.912	0.000	-3.912	0.000	-3.912	0.000
pLnC[8]	**RKF: base capture rate, 1992+**	1	2	-4.012	0.159	-3.595	0.117	-3.663	0.118	-3.626	0.120	-3.758	0.120	-3.665	0.115	-3.702	0.115
pS1[22]	**z95 for RKF selectivity (males, pre-1997)**	1	3	157.784	6.506	151.838	4.156	152.477	4.147	152.695	4.047	151.025	4.078	152.312	4.110	151.034	4.047
pS1[23]	**z95 for RKF selectivity (males, 1997-2004)**	1	3	180.000	0.005	180.000	0.001	180.000	0.001	180.000	0.001	180.000	0.001	180.000	0.001	180.000	0.001
pS1[24]	**z95 for RKF selectivity (males, 2005+)**	1	3	180.000	0.000	180.000	0.000	180.000	0.000	180.000	0.000	180.000	0.000	180.000	0.000	180.000	0.000
pS1[25]	**z95 for RKF selectivity (females, pre-1997)**	1	3	121.870	39.215	125.661	42.789	125.322	41.346	125.189	40.260	118.660	23.645	119.762	27.833	116.967	22.375
pS1[26]	**z95 for RKF selectivity (females, 1997-2004)**	1	3	122.103	56.686	123.545	50.295	124.984	56.212	125.454	57.613	121.229	48.066	120.998	50.369	119.121	45.518
pS1[27]	**z95 for RKF selectivity (females, 2005+)**	1	3	140.000	0.037	140.000	0.034	140.000	0.036	140.000	0.035	140.000	0.103	140.000	0.040	140.000	0.107
pS2[22]	**ln(z95-z50) for RKF selectivity (males, pre-1997)**	1	3	3.070	0.163	2.930	0.134	2.943	0.133	2.931	0.129	2.914	0.133	2.935	0.132	2.908	0.133
pS2[23]	**ln(z95-z50) for RKF selectivity (males, 1997-2004)**	1	3	3.550	0.086	3.458	0.074	3.452	0.074	3.439	0.072	3.433	0.072	3.447	0.073	3.431	0.071
pS2[24]	**ln(z95-z50) for RKF selectivity (males, 2005+)**	1	3	3.516	0.041	3.435	0.038	3.428	0.036	3.413	0.035	3.408	0.035	3.418	0.036	3.405	0.035
pS2[25]	**ln(z95-z50) for RKF selectivity (males, pre-1997)**	1	3	2.789	0.697	2.830	0.607	2.825	0.599	2.823	0.590	2.743	0.529	2.759	0.565	2.719	0.544
pS2[26]	**ln(z95-z50) for RKF selectivity (males, 1997-2004)**	1	3	2.859	0.909	2.866	0.781	2.883	0.795	2.892	0.799	2.865	0.860	2.849	0.872	2.840	0.895
pS2[27]	**ln(z95-z50) for RKF selectivity (males, 2005+)**	1	3	2.985	0.212	2.970	0.205	2.971	0.204	2.972	0.204	3.026	0.201	2.999	0.203	3.039	0.201

Table 32. Comparison of mean capture rate and selectivity parameters estimates for the groundfish fisheries (GTF).

		M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
name	label	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
pDC2[3]	GTF: female offset	-0.957	0.072	-0.981	0.087	-1.081	0.079	-1.231	0.081	-1.002	0.083	-1.137	0.078	-1.048	0.082
pLnC[6]	GTF: base capture rate, ALL YEARS	-4.408	0.067	-4.611	0.073	-4.830	0.066	-4.804	0.068	-4.992	0.069	-4.843	0.060	-4.948	0.061
pS1[16]	z50 for GF.AllGear selectivity (males, pre-1987)	55.070	1.852	57.435	2.141	59.312	2.273	61.798	2.619	57.543	2.499	60.814	2.316	59.036	2.555
pS1[17]	z50 for GF.AllGear selectivity (males, 1987-1996)	59.005	4.849	60.873	6.670	68.343	6.466	78.079	6.766	68.399	5.326	71.569	6.318	70.533	5.218
pS1[18]	z50 for GF.AllGear selectivity (males, 1997+)	80.710	2.123	86.047	2.398	87.470	2.298	93.086	2.404	92.847	2.489	89.264	2.235	93.451	2.401
pS1[19]	z50 for GF.AllGear selectivity (males, pre-1987)	41.206	1.659	41.987	1.914	41.429	1.744	40.562	1.645	41.453	1.663	41.795	1.711	41.970	1.654
pS1[20]	z50 for GF.AllGear selectivity (males, 1987-1996)	40.000	0.000	40.000	0.000	40.000	0.000	40.000	0.000	40.000	0.000	40.000	0.000	40.000	0.002
pS1[21]	z50 for GF.AllGear selectivity (males, 1997+)	76.232	2.497	79.614	2.733	77.468	2.549	78.569	2.695	85.086	3.036	77.762	2.492	84.499	2.955
pS2[16]	slope for GF.AllGear selectivity (males, pre-1987)	0.104	0.010	0.094	0.009	0.088	0.008	0.084	0.008	0.093	0.010	0.087	0.008	0.091	0.009
pS2[17]	slope for GF.AllGear selectivity (males, 1987-1996)	0.057	0.012	0.049	0.013	0.041	0.007	0.037	0.005	0.046	0.007	0.040	0.006	0.046	0.006
pS2[18]	slope for GF.AllGear selectivity (males, 1997+)	0.075	0.004	0.069	0.004	0.067	0.003	0.063	0.003	0.061	0.003	0.068	0.003	0.062	0.003
pS2[19]	slope for GF.AllGear selectivity (females, pre-1987)	0.137	0.022	0.124	0.021	0.130	0.021	0.139	0.022	0.138	0.020	0.130	0.020	0.138	0.020
pS2[20]	slope for GF.AllGear selectivity (females, 1987-1996)	0.185	0.038	0.189	0.038	0.184	0.039	0.182	0.039	0.168	0.038	0.182	0.039	0.167	0.038
pS2[21]	slope for GF.AllGear selectivity (females, 1997+)	0.073	0.006	0.070	0.005	0.073	0.005	0.071	0.005	0.063	0.005	0.075	0.005	0.064	0.005

Table 33. Log-scale capture rate dev parameter estimates for the groundfish fisheries (GTF) for all model scenarios.

scenario:	M19F00		M19F00a		M19F01		M19F02		M19F03		M19F04		M19F05	
year	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err	value	std err
1973	1.312	0.098	1.352	0.099	1.524	0.092	1.496	0.097	1.428	0.097	1.519	0.091	1.397	0.097
1974	1.703	0.077	1.764	0.081	1.945	0.073	1.916	0.076	1.853	0.077	1.943	0.071	1.819	0.075
1975	0.856	0.072	0.924	0.077	1.110	0.069	1.081	0.071	1.036	0.072	1.111	0.066	1.002	0.069
1976	0.319	0.079	0.376	0.084	0.562	0.077	0.542	0.078	0.519	0.080	0.565	0.074	0.487	0.077
1977	0.009	0.100	0.033	0.104	0.217	0.098	0.210	0.099	0.203	0.100	0.223	0.097	0.175	0.098
1978	-0.254	0.130	-0.270	0.134	-0.085	0.130	-0.087	0.130	-0.070	0.131	-0.075	0.129	-0.094	0.130
1979	0.369	0.098	0.289	0.101	0.482	0.094	0.467	0.095	0.520	0.095	0.497	0.092	0.497	0.093
1980	-0.009	0.126	-0.094	0.126	0.099	0.121	0.063	0.121	0.132	0.121	0.115	0.120	0.118	0.120
1981	-0.201	0.158	-0.276	0.158	-0.103	0.156	-0.129	0.156	-0.058	0.156	-0.089	0.155	-0.059	0.156
1982	-0.969	0.353	-1.029	0.350	-0.893	0.357	-0.895	0.358	-0.836	0.361	-0.883	0.358	-0.826	0.362
1983	-0.418	0.302	-0.457	0.300	-0.328	0.303	-0.306	0.305	-0.260	0.306	-0.320	0.303	-0.239	0.307
1984	-0.203	0.326	-0.211	0.325	-0.093	0.329	-0.056	0.331	-0.030	0.334	-0.088	0.329	-0.001	0.336
1985	-0.615	0.425	-0.605	0.423	-0.495	0.434	-0.462	0.435	-0.452	0.446	-0.489	0.433	-0.432	0.450
1986	-0.461	0.321	-0.439	0.318	-0.308	0.323	-0.295	0.321	-0.254	0.331	-0.303	0.322	-0.243	0.332
1987	-0.659	0.319	-0.606	0.319	-0.421	0.325	-0.381	0.324	-0.363	0.329	-0.407	0.325	-0.356	0.330
1988	-1.066	0.363	-0.997	0.364	-0.818	0.375	-0.796	0.374	-0.769	0.379	-0.806	0.375	-0.768	0.380
1989	-0.874	0.295	-0.782	0.295	-0.594	0.300	-0.584	0.299	-0.560	0.301	-0.583	0.300	-0.562	0.301
1990	-0.532	0.231	-0.448	0.233	-0.250	0.235	-0.258	0.234	-0.252	0.233	-0.240	0.235	-0.254	0.233
1991	0.569	0.104	0.630	0.108	0.518	0.070	0.477	0.071	0.405	0.069	0.524	0.070	0.406	0.069
1992	0.869	0.097	0.893	0.101	0.798	0.067	0.752	0.069	0.666	0.066	0.803	0.067	0.670	0.066
1993	0.704	0.134	0.668	0.136	0.431	0.082	0.391	0.084	0.291	0.082	0.435	0.082	0.300	0.082
1994	1.168	0.117	1.072	0.120	0.952	0.071	0.927	0.073	0.821	0.071	0.956	0.071	0.833	0.071
1995	1.155	0.150	1.015	0.152	0.886	0.080	0.881	0.081	0.758	0.080	0.889	0.079	0.773	0.079
1996	1.440	0.145	1.287	0.147	1.002	0.083	1.012	0.084	0.877	0.083	1.006	0.082	0.896	0.082
1997	1.415	0.190	1.311	0.190	1.429	0.079	1.459	0.080	1.445	0.080	1.447	0.079	1.463	0.080
1998	1.186	0.252	1.110	0.250	1.321	0.089	1.360	0.090	1.348	0.089	1.340	0.089	1.367	0.089
1999	0.740	0.370	0.684	0.367	0.689	0.136	0.729	0.137	0.729	0.136	0.709	0.136	0.748	0.136
2000	0.816	0.308	0.785	0.312	0.674	0.127	0.711	0.128	0.729	0.127	0.694	0.127	0.747	0.127
2001	1.129	0.197	1.129	0.199	0.801	0.100	0.832	0.101	0.863	0.100	0.819	0.100	0.879	0.100
2002	0.455	0.304	0.459	0.308	0.073	0.159	0.104	0.160	0.140	0.160	0.088	0.159	0.155	0.159
2003	-0.162	0.418	-0.157	0.425	-0.318	0.190	-0.293	0.190	-0.267	0.190	-0.305	0.189	-0.253	0.190
2004	0.001	0.310	0.026	0.314	-0.011	0.127	0.003	0.128	0.025	0.127	-0.002	0.127	0.036	0.127
2005	-0.246	0.323	-0.213	0.327	-0.367	0.155	-0.359	0.156	-0.343	0.156	-0.361	0.155	-0.333	0.156
2006	-0.232	0.285	-0.204	0.288	-0.386	0.148	-0.385	0.149	-0.378	0.149	-0.383	0.148	-0.370	0.149
2007	-0.344	0.287	-0.316	0.290	-0.110	0.116	-0.116	0.116	-0.116	0.116	-0.112	0.115	-0.110	0.116
2008	-0.593	0.333	-0.572	0.337	-0.434	0.155	-0.440	0.155	-0.439	0.155	-0.441	0.154	-0.436	0.155
2009	-0.780	0.394	-0.776	0.398	-0.821	0.223	-0.817	0.223	-0.812	0.223	-0.834	0.222	-0.811	0.223
2010	-0.900	0.455	-0.904	0.459	-1.113	0.294	-1.101	0.294	-1.100	0.294	-1.125	0.293	-1.098	0.294
2011	-0.905	0.476	-0.895	0.482	-0.682	0.204	-0.667	0.205	-0.662	0.204	-0.696	0.204	-0.664	0.204
2012	-1.074	0.486	-1.032	0.495	-1.234	0.295	-1.232	0.295	-1.219	0.295	-1.251	0.294	-1.226	0.295
2013	-0.944	0.405	-0.877	0.413	-0.863	0.201	-0.881	0.201	-0.858	0.201	-0.888	0.200	-0.871	0.201
2014	-0.908	0.366	-0.850	0.371	-0.811	0.193	-0.841	0.194	-0.809	0.193	-0.844	0.193	-0.824	0.193
2015	-0.953	0.399	-0.922	0.401	-0.946	0.244	-0.974	0.244	-0.938	0.244	-0.985	0.243	-0.952	0.244
2016	-0.891	0.428	-0.873	0.430	-0.800	0.253	-0.818	0.253	-0.782	0.253	-0.843	0.252	-0.794	0.253
2017	-1.021	0.496	-1.003	0.499	-1.213	0.374	-1.222	0.375	-1.186	0.377	-1.259	0.371	-1.201	0.376
2018	0.000	0.000	0.000	0.000	-1.015	0.346	-1.019	0.347	-0.976	0.349	-1.071	0.343	-0.995	0.348

Table 34. (Unweighted) negative log-likelihoods and (weighted) objective function values for fishery-related data components from the model scenarios. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: BBRKC fishery; GTF: groundfish fisheries.

				NLLs					Objective function values				
fleet	catch.type	data.type	x	M19F01	M19F02	M19F03	M19F04	M19F05	M19F01	M19F02	M19F03	M19F04	M19F05
GTF	total catch	abundance	all sexes	0.15	0.15	0.16	0.15	0.16	2.99	3.03	3.19	3.04	3.23
		biomass	all sexes	1.24	1.28	1.48	1.26	1.49	24.71	25.60	29.69	25.11	29.78
		n.at.z	female	293.88	293.59	274.46	290.59	273.66	293.88	293.59	274.46	290.59	273.66
			male	288.00	294.90	285.09	291.02	287.46	288.00	294.90	285.09	291.02	287.46
RKF	total catch	abundance	female	21,939.76	25,053.62	28,472.19	18,960.49	30,238.99	0.00	0.00	0.00	0.00	0.00
			male	8,919.09	8,498.83	8,786.52	8,885.16	8,754.89	0.00	0.00	0.00	0.00	0.00
		biomass	female	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.07	0.07	0.07
			male	1.20	1.23	1.36	1.22	1.36	23.99	24.60	27.22	24.34	27.28
		n.at.z	female	3.16	3.16	3.06	3.24	3.13	3.16	3.16	3.06	3.24	3.13
			male	75.34	72.80	74.43	75.72	75.27	75.34	72.80	74.43	75.72	75.27
SCF	total catch	abundance	female	267.01	271.11	367.66	280.76	363.74	0.00	0.00	0.00	0.00	0.00
			male	100.24	101.77	96.25	98.78	96.11	0.00	0.00	0.00	0.00	0.00
		biomass	female	0.10	0.10	0.10	0.10	0.10	1.92	1.92	1.92	1.92	1.92
			male	1.12	1.04	0.89	1.12	0.89	22.35	20.89	17.75	22.37	17.76
		n.at.z	female	15.07	15.10	15.69	15.88	16.30	15.07	15.10	15.69	15.88	16.30
			male	133.09	129.50	124.76	132.85	125.92	133.09	129.50	124.76	132.85	125.92
TCF	retained cat	abundance	female	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			male	226.68	224.71	218.46	227.25	219.40	0.00	0.00	0.00	0.00	0.00
		biomass	female	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			male	0.44	0.41	0.37	0.44	0.39	8.75	8.19	7.35	8.72	7.74
		n.at.z	male	54.24	54.37	51.98	54.69	52.92	54.24	54.37	51.98	54.69	52.92
	total catch	abundance	female	13,346.33	13,369.84	17,446.24	13,835.53	15,990.44	0.00	0.00	0.00	0.00	0.00
			male	10.78	10.19	9.31	10.65	9.37	0.00	0.00	0.00	0.00	0.00
		biomass	female	0.53	0.50	0.50	0.53	0.50	10.63	10.07	9.96	10.65	9.92
			male	0.21	0.20	0.19	0.21	0.19	4.19	3.99	3.77	4.18	3.80
		n.at.z	female	18.19	18.11	18.16	17.86	17.97	18.19	18.11	18.16	17.86	17.97
			male	89.01	88.69	88.13	87.57	87.80	89.01	88.69	88.13	87.57	87.80

Table 35. (Unweighted) negative log-likelihoods and (weighted) objective function values for survey-related data components from the model scenarios. Rows consisting of all zero values indicate a data component which was not included in any of the models. Blank cells indicate a data component (row) that was not included in the associated scenario (column).

			NLLs					Objective function values				
fleet	catch.type	data.type	M19F01	M19F02	M19F03	M19F04	M19F05	M19F01	M19F02	M19F03	M19F04	M19F05
NMFS 0	index catch	abundance	838.19	792.09	757.00	818.86	748.14	0.00	0.00	0.00	0.00	0.00
		biomass	250.88	234.17	267.37	251.37	264.97	250.88	234.17	0.00	251.37	0.00
		n.at.z	991.65	982.94	1,126.75	993.77	1,135.21	991.65	982.94	0.00	993.77	0.00
NMFS F	index catch	abundance	388.10	372.88	329.04	383.67	328.60	0.00	0.00	0.00	0.00	0.00
		biomass	320.69	307.61	278.83	324.17	278.68	0.00	0.00	278.83	0.00	278.68
		n.at.z	336.03	338.50	343.70	334.71	347.17	0.00	0.00	343.70	0.00	347.17
NMFS M	index catch	abundance	289.94	261.72	240.01	280.35	234.33	0.00	0.00	0.00	0.00	0.00
		biomass	151.12	131.45	141.07	147.12	136.47	0.00	0.00	141.07	0.00	136.47
		n.at.z	465.57	460.96	449.00	466.11	455.33	0.00	0.00	449.00	0.00	455.33
SBS BSFRF females	index catch	abundance				9.12	7.70				0.00	0.00
		biomass				2.86	2.88				2.86	2.88
		n.at.z				45.54	45.09				45.54	45.09
SBS BSFRF males	index catch	abundance				10.44	8.65				0.00	0.00
		biomass				1.99	2.24				1.99	2.24
		n.at.z				48.87	48.93				48.87	48.93
SBS NMFS females	index catch	abundance				7.92	8.40				0.00	0.00
		biomass				9.72	9.86				9.72	9.86
		n.at.z				23.26	22.53				23.26	22.53
SBS NMFS males	index catch	abundance				2.91	3.76				0.00	0.00
		biomass				3.67	4.62				3.67	4.62
		n.at.z				30.00	30.15				30.00	30.15

Table 36. (Unweighted) negative log-likelihoods and (weighted) objective function values for fits to growth (molt increment) and male maturity ogive data components from the model scenarios.

	NLLs					objective function values				
category	M19F01	M19F02	M19F03	M19F04	M19F05	M19F01	M19F02	M19F03	M19F04	M19F05
growth data	493.63	524.81	539.86	490.63	540.15	493.63	524.81	539.86	490.63	540.15
maturity ogive data	215.21	116.53	95.42	210.40	95.61	0.00	116.53	95.42	0.00	95.61

Table 37. Root mean square errors (RMSE) for fishery-related data components from the model scenarios. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: BBRKC fishery; GTF: groundfish fisheries. Rows consisting of all zero values indicate a data component which was not included in any of the models.

fleet	catch.type	data.type	x	M19F01	M19F02	M19F03	M19F04	M19F05
GTF	total catch	**abundance**	all sexes	0.10	0.10	0.11	0.10	0.11
		biomass	all sexes	0.23	0.24	0.25	0.23	0.25
		n.at.z	female	371.61	384.39	388.75	372.54	391.04
			male	373.16	358.55	369.45	371.28	366.79
RKF	total catch	**abundance**	female	40.31	43.08	45.92	37.48	47.33
			male	25.70	25.09	25.51	25.65	25.47
		biomass	female	0.02	0.02	0.02	0.02	0.02
			male	0.30	0.30	0.32	0.30	0.32
		n.at.z	female	48.67	48.79	54.10	48.20	52.53
			male	56.41	56.51	55.96	56.25	55.74
SCF	total catch	**abundance**	female	4.29	4.32	5.04	4.40	5.01
			male	2.63	2.65	2.58	2.61	2.57
		biomass	female	0.08	0.08	0.08	0.08	0.08
			male	0.28	0.27	0.25	0.28	0.25
		n.at.z	female	54.82	55.60	54.83	50.76	51.28
			male	227.18	232.72	235.32	224.44	235.23
TCF	retained catch	**abundance**	female	0.00	0.00	0.00	0.00	0.00
			male	3.37	3.35	3.30	3.37	3.31
		biomass	female	0.00	0.00	0.00	0.00	0.00
			male	0.15	0.14	0.14	0.15	0.14
		n.at.z	male	355.25	367.67	384.72	354.36	381.60
	total catch	**abundance**	female	40.84	40.88	46.70	41.59	44.71
			male	1.16	1.13	1.08	1.15	1.08
		biomass	female	0.26	0.25	0.25	0.26	0.25
			male	0.16	0.16	0.15	0.16	0.15
		n.at.z	female	182.37	188.63	208.21	194.75	231.22
			male	499.38	511.41	513.56	514.17	520.01

Table 38. Average root mean square errors (RMSE) for survey-related data components from the model scenarios. Rows consisting of all zero values indicate a data component which was not included in any of the models. Blank cells indicate a data component (row) that was not included in the likelihood in the associated scenario (column).

fleet	catch.type	data.type	x	M19F01	M19F02	M19F03	M19F04	M19F05
NMFS 0	index catch	**abundance**	female	2.92	2.86	2.69	2.90	2.69
			male	3.12	2.99	3.05	3.06	3.02
		biomass	female	2.32	2.29	2.30	2.34	2.31
			male	2.40	2.27	2.56	2.38	2.54
		n.at.z	female	373.93	385.98	356.45	364.22	344.26
			male	487.07	499.49	490.64	477.53	480.54
NMFS F	index catch	**abundance**	female	2.92	2.86	2.69	2.90	2.69
			male	0.00	0.00	0.00	0.00	0.00
		biomass	female	2.65	2.60	2.48	2.66	2.48
			male	0.00	0.00	0.00	0.00	0.00
		n.at.z	female	125.86	125.69	136.02	125.48	133.02
NMFS M	index catch	**abundance**	female	0.00	0.00	0.00	0.00	0.00
			male	3.59	3.41	3.27	3.53	3.23
		biomass	female	0.00	0.00	0.00	0.00	0.00
			male	2.59	2.42	2.50	2.56	2.46
		n.at.z	male	195.51	188.89	185.98	192.03	183.02
SBS BSFRF females	index catch	**abundance**	female				1.31	1.23
			male				0.00	0.00
		biomass	female				0.76	0.75
			male				0.00	0.00
		n.at.z	female				44.41	46.72
SBS BSFRF males	index catch	**abundance**	female				0.00	0.00
			male				2.04	1.86
		biomass	female				0.00	0.00
			male				0.89	0.95
		n.at.z	male				191.47	198.80
SBS NMFS females	index catch	**abundance**	female				1.17	1.22
			male				0.00	0.00
		biomass	female				1.25	1.28
			male				0.00	0.00
		n.at.z	female				48.92	53.02
SBS NMFS males	index catch	**abundance**	female				0.00	0.00
			male				1.08	1.23
		biomass	female				0.00	0.00
			male				1.21	1.36
		n.at.z	male				316.65	303.44

Table 39. Root mean square errors (RMSE) for fits to growth (molt increment) and male maturity ogive data components from the model scenarios.

category	M19F01	M19F02	M19F03	M19F04	M19F05
growth data	0.42	0.42	0.43	0.42	0.43
maturity ogive data	2.51	1.92	1.77	2.48	1.80

Table 40. Effective sample sizes used for NMFS 0 EBS trawl survey size composition data for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach. Note that, while effective N's were calculated for this dataset in MF1903, it was not included in the model objective function (the weight in the likelihood was set to 0). Input sample sizes were set at 200.

Sum of val	**Column Labels**	
year	**M19F00**	**M19F03**
1975	700.312702	479.8666701
1976	835.8906704	679.480725
1977	874.9223597	775.5274286
1978	892.441064	1415.818871
1979	1130.270061	802.0601696
1980	1441.838602	1103.810405
1981	1138.908258	723.7818753
1982	518.8477363	480.801695
1983	1067.859284	866.8946961
1984	572.9407661	790.9737623
1985	326.2645986	386.0794348
1986	676.7917083	818.0047904
1987	789.3102243	1520.471983
1988	1107.233577	1722.63342
1989	2579.165029	1673.448147
1990	2756.786708	2063.757876
1991	3162.992353	1499.878515
1992	2697.685485	2936.358538
1993	1972.898268	1429.015184
1994	1603.111983	1219.109801
1995	1758.283681	1208.444231
1996	1935.626324	1479.261951
1997	1891.598819	1523.133367
1998	2046.203568	1345.547918
1999	1158.80325	1541.437445
2000	1589.385175	2628.510003
2001	2168.1765	1789.809452
2002	1943.798287	2242.190544
2003	1488.112154	2703.663841
2004	978.9173627	1103.316885
2005	3262.607163	4249.657685
2006	1505.176736	2452.948118
2007	1294.785121	1506.294676
2008	2318.550309	2770.433117
2009	1414.661594	2372.096875
2010	12011.00017	4232.237577
2011	1806.553577	2278.879216
2012	1476.147611	1820.248354
2013	2662.685394	2493.220045
2014	1191.826672	1135.930166
2015	2445.230566	1933.403136
2016	1168.110952	1004.934831
2017	1151.365149	1026.282821
2018	2277.011147	1905.751709
2019		4102.775173

Table 41. Effective sample sizes used for retained catch size composition data from the directed fishery for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	M19F00		M19F03	
year	effective N	input ss	effective N	input ss
1980	24.8	97.8	24.8	104.6
1981	1466.9	83.1	476.1	88.9
1982	1992.2	99.3	1097.8	106.2
1983	52.4	12.3	55.6	13.2
1984	426.3	18.7	203.8	20.0
1988	128.0	91.0	142.5	97.3
1989	1429.7	30.3	413.9	32.4
1990	256.1	200.0	242.1	200.0
1991	144.3	200.0	903.1	200.0
1992	99.0	200.0	313.2	200.0
1993	131.3	200.0	599.2	200.0
1994	145.3	200.0	273.7	200.0
1995	175.6	11.2	307.6	12.0
1996	172.8	32.6	1951.4	34.8
2005	14.4	5.2	18.3	5.5
2006	301.0	21.6	120.6	23.1
2007	1641.2	51.0	224.3	45.2
2008	972.8	25.6	402.8	27.4
2009	128.9	17.8	126.5	19.0
2013	770.9	35.0	581.1	35.8
2014	219.2	103.3	285.1	113.7
2015	164.3	200.0	263.6	190.3
2017	104.0	25.5	132.4	27.3
2018			73.8	26.0

Table 42. Effective sample sizes used for total catch size composition data from the directed fishery for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	M19F00				M19F03			
	female		male		female		male	
year	effective N	input ss	effective N	input ss	effective N	input ss	effective N	input ss
1991	421.1	41.2	1343.4	200.0	245.5	44.0	499.5	200.0
1992	555.0	64.3	121.7	200.0	1450.9	68.8	363.3	200.0
1993	307.9	76.9	267.9	200.0	232.8	82.3	270.1	200.0
1994	62.7	15.7	549.0	42.6	81.4	16.7	1044.4	45.5
1995	100.7	22.9	310.4	41.1	136.0	24.5	285.2	43.9
1996	249.3	2.5	31.3	5.0	171.1	1.3	22.3	2.8
2005	41.7	8.1	99.4	144.9	48.2	8.7	118.1	154.9
2006	442.5	32.6	285.3	178.0	341.9	34.8	330.7	190.3
2007	302.4	24.4	394.4	200.0	231.5	26.1	560.6	200.0
2008	46.3	4.7	1149.5	200.0	45.1	5.1	1250.6	200.0
2009	23.6	1.1	162.5	127.0	21.5	1.2	168.1	135.8
2013	59.7	5.2	1475.0	127.0	44.7	5.6	2528.6	135.8
2014	175.6	8.8	210.5	200.0	126.6	9.4	248.3	200.0
2015	75.3	11.9	133.0	200.0	81.9	12.8	189.4	200.0
2017	52.1	12.6	168.4	138.0	58.5	13.5	243.4	147.6
2018					13.7	16.0	94.3	200.0

Table 43. Effective sample sizes used for bycatch size composition data from the snow crab fishery for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	M19F00				M19F03			
	female		male		female		male	
year	effective N	input ss	effective N	input ss	effective N	input ss	effective N	input ss
1990					38.9	3.8	42.9	110.2
1991					22.7	5.4	86.1	92.0
1992	18.3	6.3	186.3	46.1	24.0	6.7	29.7	49.3
1993	30.7	11.3	117.4	51.2	38.0	12.1	28.6	54.7
1994	40.7	11.2	37.3	21.9	30.0	12.0	13.9	23.4
1995	42.1	3.1	86.7	13.9	40.5	3.4	26.2	14.9
1996	46.2	4.9	289.1	24.0	73.2	5.2	104.5	25.6
1997	111.8	4.8	449.8	29.2	106.4	5.2	390.0	31.2
1998	21.5	2.4	1131.3	14.0	21.7	2.5	546.4	15.0
1999	30.3	0.6	132.8	7.2	32.1	0.6	128.9	7.7
2000	30.6	0.5	285.3	9.1	34.3	0.6	253.4	9.7
2001	121.8	1.2	565.8	22.9	132.8	1.3	436.8	24.5
2002	45.6	0.9	59.8	7.2	47.2	0.9	66.1	7.7
2003	45.1	1.1	110.1	5.1	45.7	1.2	130.5	5.4
2004	30.7	5.2	23.1	6.2	30.5	5.6	23.7	6.5
2005	154.2	2.7	123.0	72.0	75.2	2.9	134.4	77.0
2006	49.9	9.2	76.5	76.4	30.4	9.9	77.1	81.6
2007	44.2	5.3	384.9	101.4	27.3	5.7	421.7	108.4
2008	15.0	5.3	97.0	62.1	20.2	5.7	102.0	66.4
2009	21.2	3.5	470.9	81.2	33.1	3.7	449.5	86.9
2010	76.4	1.8	382.8	88.7	91.7	2.0	279.0	94.8
2011	62.1	1.4	228.2	69.5	58.9	1.5	183.2	74.3
2012	47.3	1.4	209.1	53.9	78.5	2.1	153.3	86.4
2013	203.9	2.6	248.0	95.0	117.9	2.8	216.7	101.6
2014	67.5	5.9	532.0	182.8	141.0	6.3	402.6	195.4
2015	107.8	1.7	520.2	146.5	56.6	1.8	354.9	155.9
2016	112.9	1.7	468.7	142.8	28.9	2.1	844.4	128.6
2017	63.6	0.8	709.0	41.1	96.2	0.9	491.4	44.0
2018					16.2	1.8	406.7	48.3

Table 44. Effective sample sizes used for bycatch size composition data from the BBRKC fishery for the 2018 assessment model (M19F00) and the author's preferred model (M19F03. Effective sample sizes were estimated using the McAllister-Ianelli approach.

	M19F00				M19F03			
	female		male		female		male	
year	effective N	input ss	effective N	input ss	effective N	input ss	effective N	input ss
1990					42.5	0.3	12.6	12.4
1991					91.0	0.7	16.0	17.9
1992	83.1	0.8	33.2	15.1	82.5	0.8	23.1	16.2
1993	275.0	8.8	32.9	54.1	319.6	9.4	24.5	57.8
1996	3.4	0.0	12.6	0.8				
1997	25.2	0.3	19.6	7.6	27.8	0.3	27.4	8.1
1998	21.0	0.1	55.7	3.4	21.6	0.2	83.0	3.6
1999	17.5	0.1	51.2	1.5	18.3	0.1	41.9	1.6
2000	40.5	0.3	134.6	6.2	41.1	0.3	92.2	6.6
2001	51.1	0.3	113.6	3.4	50.0	0.3	69.8	3.6
2002	35.5	0.4	87.3	5.5	36.7	0.4	60.3	5.9
2003	53.3	0.3	58.2	4.1	52.7	0.4	42.5	4.4
2004	20.3	0.3	31.5	3.6	21.0	0.3	24.4	3.8
2005	12.6	0.5	44.3	7.2	14.1	0.6	34.5	7.7
2006	23.8	0.6	22.6	5.9	28.4	0.5	19.0	5.9
2007	102.5	0.7	91.4	10.3	91.7	0.7	71.7	10.7
2008	91.8	0.9	62.5	27.9	108.5	1.0	81.2	29.8
2009	109.0	0.5	19.3	24.9	116.8	0.6	22.5	22.6
2010	35.9	0.2	51.3	4.4	52.2	0.2	43.1	4.6
2011	6.0	0.0	68.6	2.5	5.8	0.0	50.9	2.5
2012	6.9	0.4	66.0	4.5	7.2	0.4	48.6	4.9
2013	9.7	0.4	86.1	15.5	9.6	0.5	110.8	16.6
2014	19.3	0.2	155.1	22.9	19.8	0.3	169.1	24.4
2015	86.3	1.3	195.1	16.1	89.9	1.5	119.9	17.1
2016	18.9	1.8	25.1	22.5	19.6	1.9	21.4	25.3
2017	34.0	0.6	76.0	27.8	32.7	0.7	55.7	29.7
2018					5.5	0.0	89.1	10.1

Table 45. Effective sample sizes used for bycatch size composition data from the groundfish fisheries for the 2018 assessment model (M19F00) and the author's preferred model (M19F03). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	M19F00				M19F03			
	female		male		female		male	
year	effective N	input ss	effective N	input ss	effective N	input ss	effective N	input ss
1973	226.8	39.9	357.5	39.9	220.4	39.9	269.0	39.9
1974	209.7	30.1	726.4	30.1	220.2	30.1	470.6	30.1
1975	195.0	15.4	334.1	15.4	230.7	15.4	254.9	15.4
1976	107.3	100.2	178.4	100.2	114.1	100.2	125.7	100.2
1977	327.3	140.1	233.1	140.1	312.4	140.1	210.2	140.1
1978	193.1	237.1	249.6	237.1	175.7	237.1	239.9	237.1
1979	889.5	223.5	594.2	223.5	776.5	223.5	763.7	223.5
1980	419.3	137.6	1045.8	137.6	817.6	137.6	704.2	137.6
1981	56.1	74.7	1050.0	74.7	67.3	74.7	791.0	74.7
1982	62.1	157.6	529.6	157.6	90.6	157.6	509.7	157.6
1983	134.6	196.0	345.6	196.0	293.9	196.0	401.5	196.0
1984	235.0	301.2	354.6	301.2	482.9	301.2	679.8	301.2
1985	278.0	263.5	169.9	263.5	274.3	263.5	239.7	263.5
1986	193.5	165.2	281.7	165.2	155.0	165.2	405.1	165.2
1987	671.1	289.3	266.3	289.3	718.7	289.3	282.6	289.3
1988	224.1	130.2	404.9	130.2	218.5	130.2	339.5	130.2
1989	595.1	400.0	810.5	400.0	906.0	400.0	747.2	400.0
1990	308.5	255.4	997.0	255.4	349.5	255.4	953.5	255.4
1991	186.1	75.7	330.4	75.7	213.5	80.9	316.1	80.9
1992	63.6	31.6	177.7	31.6	68.4	33.8	166.4	33.8
1993	93.8	11.6	77.8	11.6	108.2	12.4	72.8	12.4
1994	429.9	40.0	238.3	40.0	442.7	42.8	236.5	42.8
1995	60.2	48.3	58.2	48.3	65.5	51.6	52.2	51.6
1996	597.2	86.0	176.8	86.0	512.7	92.0	158.0	92.0
1997	184.6	101.8	49.5	101.8	137.2	108.8	43.0	108.8
1998	303.0	121.6	119.1	121.6	182.3	130.0	93.1	130.0
1999	1011.6	114.4	441.8	114.4	569.3	122.4	288.5	122.4
2000	899.8	117.4	556.9	117.4	638.7	125.6	338.9	125.6
2001	1246.6	138.7	775.7	138.7	1297.3	148.2	523.1	148.2
2002	891.3	137.0	429.6	137.0	736.2	146.5	391.5	146.5
2003	300.1	90.4	196.9	90.4	307.9	96.7	196.2	96.7
2004	30.3	134.5	110.2	134.5	32.8	143.8	119.3	143.8
2005	1814.9	157.9	1545.9	157.9	1652.0	168.9	1226.6	168.9
2006	134.6	139.2	182.0	139.2	151.8	148.9	197.8	148.9
2007	106.0	146.7	187.6	146.7	117.7	156.9	199.2	156.9
2008	164.5	223.4	184.2	223.4	182.4	233.3	172.7	233.3
2009	536.6	160.0	313.3	160.0	524.9	171.1	345.8	171.1
2010	2097.5	127.9	628.5	127.9	1362.2	136.7	719.2	136.7
2011	66.8	149.6	83.2	149.6	61.7	160.0	71.3	160.0
2012	102.6	118.1	412.4	118.1	112.1	126.2	426.6	126.2
2013	433.7	244.6	359.5	244.6	567.0	247.6	314.9	247.6
2014	794.9	231.0	1037.7	231.0	741.6	233.1	1105.9	233.1
2015	203.2	242.1	219.3	242.1	250.8	245.1	232.4	245.1
2016	56.9	166.2	229.2	166.2	57.4	177.6	244.0	177.6
2017	173.8	98.6	80.6	98.6	149.8	108.2	75.1	108.2
2018					214.1	64.7	279.5	64.7

Table 46. Comparison of fits to mature survey biomass by sex (in 1000's t) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03).

	M19F00				M19F03			
	female		male		female		male	
year	observed	predicted	observed	predicted	observed	predicted	observed	predicted
1975	72.4	102.8	540.9	333.2	72.4	91.5	540.9	381.9
1976	68.7	91.6	283.3	295.7	68.7	80.3	283.3	328.2
1977	91.6	82.8	249.8	241.9	91.6	70.6	249.8	261.2
1978	58.3	80.2	176.2	192.1	58.3	64.8	176.2	201.2
1979	42.5	84.2	82.7	183.6	42.5	65.2	82.7	187.0
1980	141.1	87.3	239.3	186.2	141.1	68.5	239.3	201.0
1981	86.7	77.5	130.2	156.7	86.7	56.4	130.2	180.4
1982	130.0	56.1	117.5	160.0	130.0	43.7	117.5	161.6
1983	43.1	43.9	67.9	117.2	43.1	31.7	67.9	120.2
1984	32.1	35.4	56.3	83.5	32.1	23.8	56.3	85.0
1985	12.1	31.4	26.8	65.2	12.1	20.5	26.8	65.0
1986	9.4	33.5	34.9	81.9	9.4	23.9	34.9	77.6
1987	25.3	38.0	70.1	108.6	25.3	28.7	70.1	98.2
1988	60.9	42.4	160.2	139.6	60.9	33.5	160.2	122.5
1989	50.6	45.6	226.1	165.9	50.6	37.0	226.1	143.3
1990	85.2	46.2	230.3	172.2	85.2	38.8	230.3	151.2
1991	96.5	43.5	258.4	153.9	96.5	38.0	258.4	144.0
1992	54.4	37.7	233.1	132.8	54.4	34.5	233.1	134.1
1993	24.3	30.1	135.3	99.0	24.3	29.0	135.3	108.8
1994	20.9	23.2	92.2	72.9	20.9	23.3	92.2	86.7
1995	25.8	17.9	67.7	53.9	25.8	18.6	67.7	67.4
1996	20.6	14.1	58.3	40.7	20.6	15.1	58.3	53.3
1997	8.2	11.8	25.9	34.7	8.2	13.0	25.9	44.9
1998	6.5	10.5	25.9	32.0	6.5	11.7	25.9	40.0
1999	10.5	10.4	34.5	32.2	10.5	11.6	34.5	39.4
2000	10.7	11.0	40.2	35.9	10.7	12.2	40.2	42.1
2001	15.4	12.7	47.9	43.4	15.4	13.9	47.9	48.3
2002	14.4	14.4	46.4	51.8	14.4	15.7	46.4	56.3
2003	21.5	17.0	62.4	62.7	21.5	18.7	62.4	67.7
2004	13.5	20.2	65.9	77.0	13.5	22.3	65.9	82.4
2005	33.5	22.7	108.9	92.9	33.5	25.3	108.9	98.7
2006	43.1	24.5	169.4	106.8	43.1	27.9	169.4	114.2
2007	32.5	25.5	173.7	117.0	32.5	29.4	173.7	127.1
2008	26.2	24.6	150.0	124.6	26.2	28.8	150.0	135.2
2009	19.5	22.9	85.6	122.2	19.5	27.0	85.6	130.3
2010	14.7	21.8	88.1	110.2	14.7	25.3	88.1	115.4
2011	21.2	22.4	105.9	101.8	21.2	25.2	105.9	104.6
2012	36.4	25.5	122.3	105.2	36.4	27.8	122.3	107.7
2013	42.1	29.4	170.4	126.9	42.1	31.5	170.4	128.6
2014	32.2	30.1	191.3	150.1	32.2	32.2	191.3	148.9
2015	24.1	26.9	137.2	144.4	24.1	29.0	137.2	142.2
2016	16.4	22.5	131.2	118.1	16.4	24.4	131.2	116.2
2017	15.6	19.8	104.5	102.7	15.6	20.9	104.5	97.4
2018	14.9	19.0	86.8	90.4	14.9	19.0	86.8	82.8
2019					14.6	19.7	48.8	75.0

Table 47. Comparison of estimates of mature biomass-at-mating by sex (in 1000's t) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03).

	M19F00		M19F03				M19F00		M19F03	
year	female	male	female	male		year	female	male	female	male
1948	0	0	0	0		1981	62.61178291	75.56595728	82.26932357	131.5457245
1949	0	0	0	0		1982	51.87527796	70.87388133	63.4376148	120.0710505
1950	0.029290529	0.010148921	0.052876667	0.032672463		1983	39.72084346	54.03546272	44.82566346	91.63937955
1951	0.248247159	0.137859662	0.426265689	0.358680293		1984	29.98144143	35.0648082	31.06340546	60.86077393
1952	1.009797269	0.996117696	1.729951628	2.05994497		1985	25.60570341	33.03218917	27.90313734	55.15366568
1953	2.27389353	3.799354119	4.034889901	6.798217159		1986	26.02824674	39.80612176	31.91702343	64.05134402
1954	3.530051511	8.111411502	6.516424806	13.71206184		1987	29.57524959	52.15248396	39.27885587	80.65351304
1955	4.505292273	11.95069256	8.572618804	19.91123245		1988	34.25326965	69.06617841	47.76469389	102.1912584
1956	5.23017135	14.86119389	10.17885791	24.64490259		1989	38.49425689	75.18367028	55.51587713	112.8729649
1957	5.78636166	17.08319575	11.47760673	28.32425004		1990	40.93261177	69.26230859	61.27541543	111.8311327
1958	6.245965522	18.83845512	12.60903413	31.34932668		1991	40.45010837	66.70096787	63.29311168	116.5835973
1959	6.678762971	20.34192753	13.71131601	34.10406971		1992	36.03354495	57.41112499	59.78533715	108.7895289
1960	7.166650145	21.80054365	14.95040896	36.96211501		1993	29.65188903	49.3061425	51.56526726	100.0945072
1961	7.836129047	23.456348	16.58795884	40.38361165		1994	23.0563003	39.76180942	41.6729754	83.5553754
1962	8.952929857	25.7583941	19.17276358	45.27954043		1995	17.59936166	29.9848262	32.93880923	65.64733696
1963	11.20855208	29.68301023	24.08692299	53.71943121		1996	13.60743973	24.14996006	26.2383916	52.55986347
1964	16.36886723	37.82739217	34.63784649	71.00574611		1997	10.89988773	20.4377007	21.53158493	43.25608304
1965	27.65874111	55.00374857	56.44912529	107.3336525		1998	9.235893888	18.20281208	18.67026921	37.79694288
1966	47.58206403	93.89734099	93.53874708	180.1369655		1999	8.542129551	17.98680288	17.4372762	36.17624799
1967	72.62268113	148.279836	139.8721418	279.6484942		2000	8.83666402	19.51660887	17.74578088	37.62178453
1968	93.82954052	214.5323711	180.3751698	388.7986146		2001	9.692410669	23.12988283	19.18716563	42.12837696
1969	104.9105219	255.7631836	203.5673987	456.8869593		2002	11.02624145	28.07170871	21.7207241	49.14444027
1970	107.109204	271.41282	210.1384986	481.6364664		2003	12.9610676	34.12756344	25.48135684	58.66512211
1971	105.2731072	271.6575832	207.2362958	478.9748353		2004	15.62280239	42.27234237	30.63971212	71.66628579
1972	103.0811121	267.6417929	200.5408889	464.2391531		2005	18.32526828	51.63285385	36.34643336	86.95724602
1973	100.1838676	261.581255	190.297984	440.9478977		2006	20.8324607	60.09081306	42.1541279	102.2607715
1974	95.18617647	246.8464928	175.7955327	402.2135648		2007	23.30097298	67.36561163	47.78906901	116.9103724
1975	87.98656329	230.3186616	158.2999936	358.4925464		2008	23.64643945	76.38178815	49.26304162	130.6858117
1976	77.82978018	188.5578534	137.8142501	289.4207129		2009	21.09129729	76.86605777	44.74294322	128.1643334
1977	67.70984017	130.9737959	118.1804075	209.8222867		2010	17.86953558	68.49052925	38.25400266	111.6231267
1978	63.0060915	96.16056729	106.342965	163.6950948		2011	16.63246429	59.23689734	35.08159051	95.47813585
1979	65.72347908	74.32736881	107.0998424	142.6686239		2012	19.85647861	57.81165696	39.75256727	94.20587388
1980	67.71303871	70.16135116	98.82641083	131.1216495		2013	25.76424691	70.26742291	49.64969507	114.7756218
						2014	28.58151286	83.75361085	54.83740078	135.7892866
						2015	26.38078068	82.0122724	51.08625555	131.8573143
						2016	22.15777388	75.99847076	43.11401688	117.1288802
						2017	18.40263189	64.09196727	35.57943126	96.36555861
						2018			29.66231471	79.45494853

Table 48. Estimated population size (millions) for females on July 1 of year. from the author's preferred model, Model M19F03.
<<Table too large: available online in the zip file "TannerCrab.PopSizeStructure.csvs.zip".>>

Table 49. Estimated population size (millions) for males on July 1 of year. from the author's preferred mode, Model M19F03.
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Table 50. Comparison of estimates of recruitment (in millions) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03).

year	M19F00	M19F03		year	M19F00	M19F03
1948	70.09251687	132.6537449		1981	101.416713	229.8722417
1949	70.09557738	133.2203853		1982	496.0095549	690.0962537
1950	70.19921793	134.4944439		1983	408.5677129	627.3626472
1951	70.53781202	136.6898133		1984	550.0166431	767.3734676
1952	71.30143949	140.1373441		1985	529.7681206	764.4249404
1953	72.76979101	145.363002		1986	525.8487112	796.315064
1954	75.37788738	153.237184		1987	356.0941501	595.7349193
1955	79.85259349	165.2823008		1988	171.1538503	249.3996718
1956	87.52520379	184.3743392		1989	52.28767878	78.81849366
1957	101.1405733	216.5609486		1990	41.82858297	71.27724516
1958	127.3271887	276.6196651		1991	37.02824035	73.65268281
1959	185.5896413	407.587403		1992	36.8859791	67.27971079
1960	339.6142312	742.4221286		1993	48.32235441	84.32008419
1961	757.2893156	1588.034161		1994	62.36311147	143.7247786
1962	1462.061345	2839.791915		1995	57.94345627	107.5877226
1963	1736.132801	3206.061429		1996	168.9628999	304.259962
1964	1452.379666	2674.087231		1997	67.82772625	127.2116239
1965	1131.170889	2117.061574		1998	227.5701775	450.4022196
1966	963.730419	1816.266851		1999	118.091505	221.0847323
1967	943.2576586	1724.0517		2000	385.0604766	754.1423021
1968	1008.697227	1669.653411		2001	123.1097967	231.3054485
1969	980.6227068	1442.516104		2002	372.6665098	829.6787085
1970	843.9469644	1165.600708		2003	362.1799899	687.2774432
1971	561.9043515	778.2159348		2004	97.11673458	185.9225205
1972	369.6842268	524.6240813		2005	74.45238686	127.3120944
1973	318.0087047	510.3866376		2006	57.8718913	111.1939148
1974	641.4445935	705.3119393		2007	88.82972036	179.0548001
1975	1257.959539	2031.682265		2008	576.7044896	1138.228615
1976	971.5504765	1529.970097		2009	501.346918	870.3214169
1977	424.9897994	761.2503091		2010	200.9415568	301.1484309
1978	180.9087231	276.9401217		2011	40.77585148	62.70194572
1979	110.113046	166.2250105		2012	108.9237585	173.4310903
1980	180.4735272	265.6626468		2013	73.93881264	106.9458916
				2014	49.09325854	79.9499305
				2015	69.72714155	117.3112392
				2016	444.7192575	647.0591576
				2017	588.8895622	677.6176162
				2018		1234.937393

Table 51. Comparison of exploitation rates (i.e., catch divided by biomass) from the 2018 assessment model (M19F00) and the author's preferred model (M19F03).

year	M19F00	M19F03		year	M19F00	M19F03
1949	0.001622787	0.000851594		1981	0.046786646	0.026757506
1950	0.002688423	0.001373949		1982	0.025203452	0.014146239
1951	0.004152346	0.00210409		1983	0.013099622	0.007026487
1952	0.006247527	0.003273033		1984	0.026017138	0.015184677
1953	0.009322445	0.00529258		1985	0.015433162	0.005593393
1954	0.01260007	0.007679072		1986	0.019326482	0.007141423
1955	0.014753304	0.009385377		1987	0.031682959	0.013068075
1956	0.015980555	0.010368409		1988	0.040555945	0.020050353
1957	0.016287354	0.010527445		1989	0.091529287	0.054189398
1958	0.016548995	0.010701976		1990	0.152834055	0.091491752
1959	0.016393883	0.0105286		1991	0.14575004	0.075020873
1960	0.01602232	0.010226125		1992	0.173127894	0.095630499
1961	0.015550666	0.009976282		1993	0.130835171	0.054998198
1962	0.014008919	0.009008863		1994	0.098005158	0.038802861
1963	0.01190419	0.007751795		1995	0.085254294	0.031793233
1964	0.010409007	0.006771504		1996	0.047280956	0.019457438
1965	0.015993162	0.009020895		1997	0.033563022	0.01697017
1966	0.015931948	0.009115647		1998	0.031137612	0.01149889
1967	0.043643679	0.025403963		1999	0.01512733	0.005898124
1968	0.048268751	0.028737808		2000	0.012987827	0.006044593
1969	0.063683821	0.038160681		2001	0.016821106	0.006725774
1970	0.059569187	0.035828691		2002	0.010714727	0.003631334
1971	0.050880748	0.030686751		2003	0.006018027	0.002625986
1972	0.045502754	0.028496504		2004	0.006466766	0.003153082
1973	0.055554121	0.035566735		2005	0.012287384	0.006120349
1974	0.074143668	0.048631197		2006	0.018752949	0.008653291
1975	0.064643017	0.04403133		2007	0.020865591	0.010646254
1976	0.100923862	0.070635583		2008	0.014201418	0.007946933
1977	0.140735249	0.098008396		2009	0.012001593	0.006769104
1978	0.118938682	0.075778039		2010	0.006272852	0.00328305
1979	0.152736347	0.085590706		2011	0.007820264	0.004469626
1980	0.093896849	0.05814116		2012	0.004964941	0.00300838
				2013	0.015086706	0.008840832
				2014	0.052987808	0.031389129
				2015	0.072375017	0.044605374
				2016	0.009963209	0.005834419
				2017	0.020021174	0.010205414
				2018		0.01100967

Table 52. 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. Results from the author's preferred model (M19F03) are highlighted in green.

Model Scenario	average recruitment millions	Final MMB 1000's t	B0 1000's t	Bmsy 1000's t	Fmsy	MSY 1000's t	Fofl	OFL 1000's t	projected MMB 1000's t	projected MMB / Bmsy
M19F00	223.63	66.64	86.55	30.29	0.74	12.75	0.74	20.87	35.95	1.19
M19F00a	284.28	82.05	94.24	32.99	0.89	14.58	0.89	27.90	41.52	1.26
M19F01	316.79	68.79	100.85	35.30	0.81	15.58	0.81	22.54	35.66	1.01
M19F02	367.48	71.54	105.59	36.96	1.11	17.89	1.03	24.75	34.63	0.94
M19F03	393.84	82.61	118.96	41.64	1.18	19.49	1.12	29.48	39.68	0.95
M19F04	377.28	74.03	106.76	37.37	0.87	16.87	0.87	24.87	37.50	1.00
M19F05	418.73	80.33	116.44	40.75	1.21	19.40	1.14	28.58	38.42	0.94

Figures

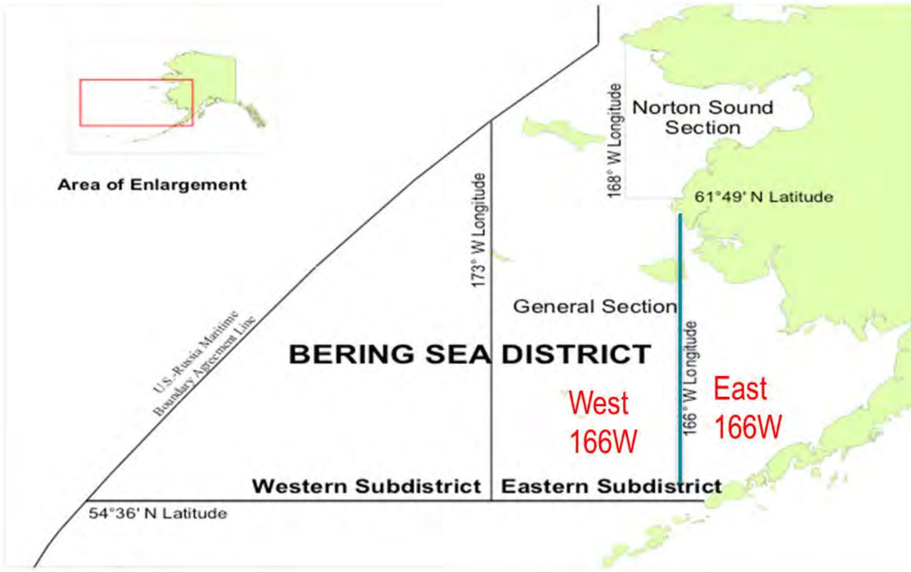
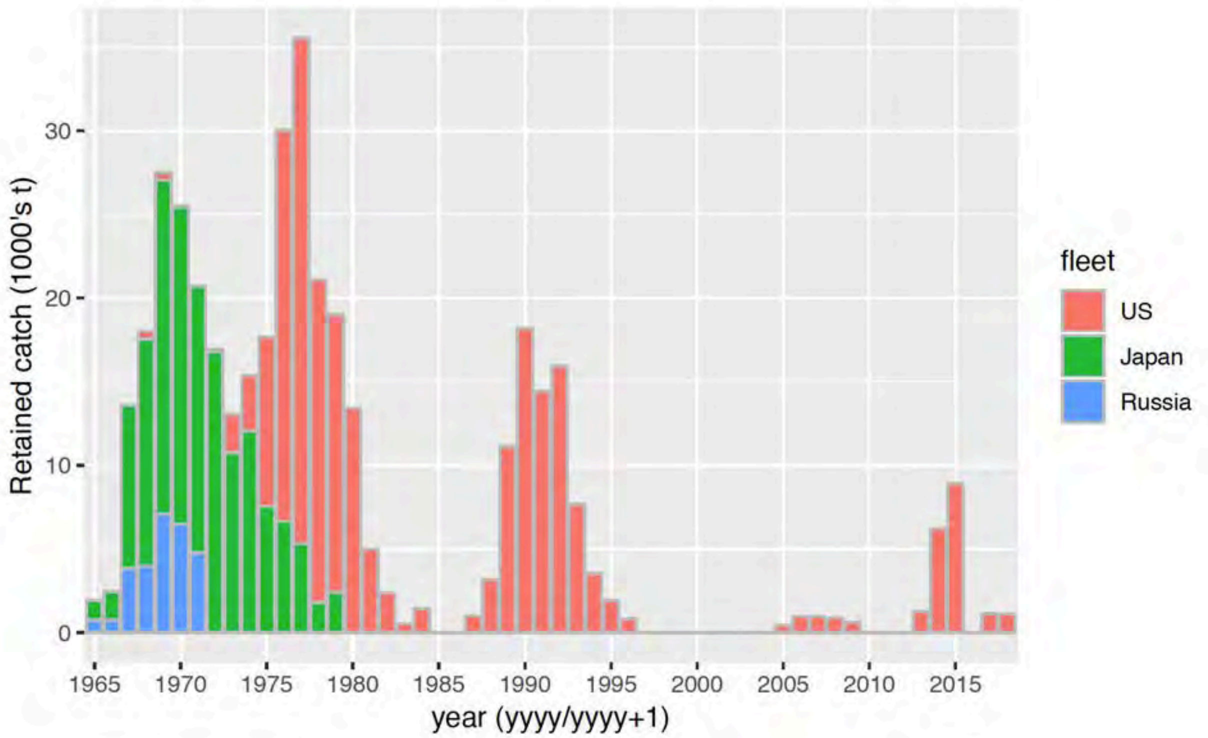


Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008).



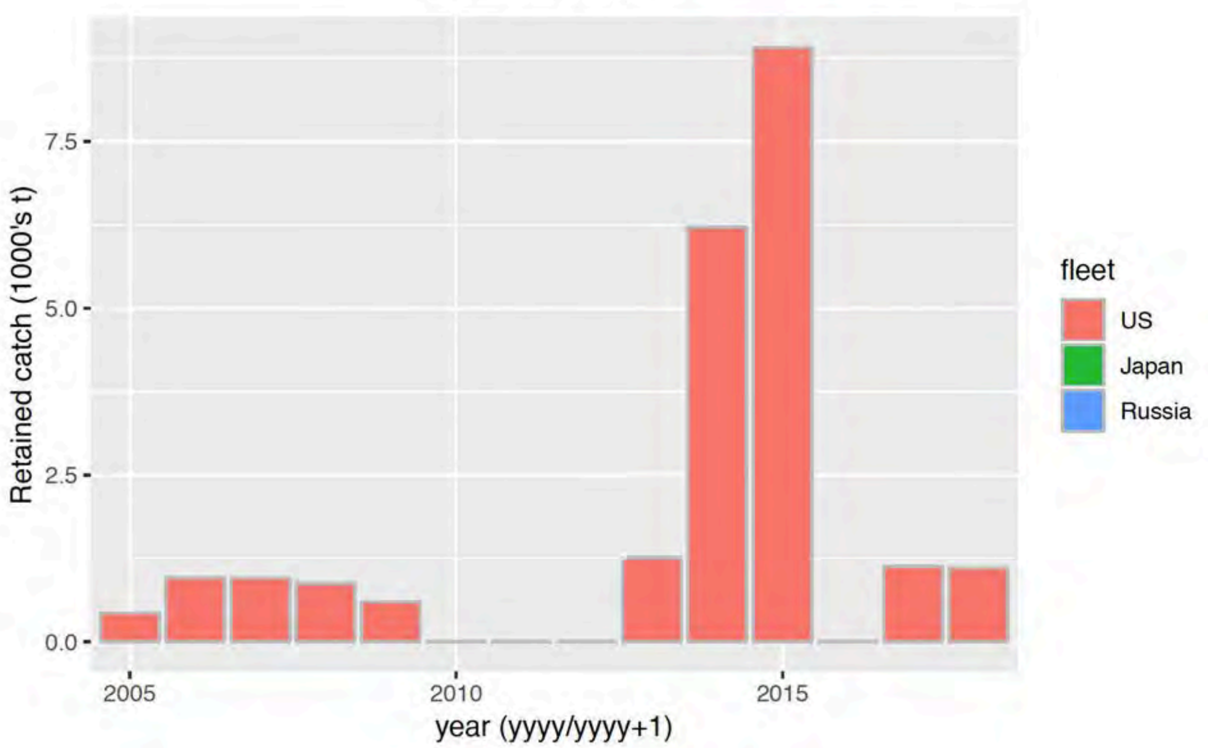


Figure 2. Upper: retained catch (males, 1000's t) in the directed fisheries (US pot fishery [green bars], Russian tangle net fishery [red bars], and Japanese tangle net fisheries [blue bars]) for Tanner crab since 1965/66. Lower: Retained catch (males, 1000's t) in directed fishery since 2001/02. The directed fishery was closed from 1996/97 to 2004/05, from 2010/11 to 2012/13, and in 2016/17.

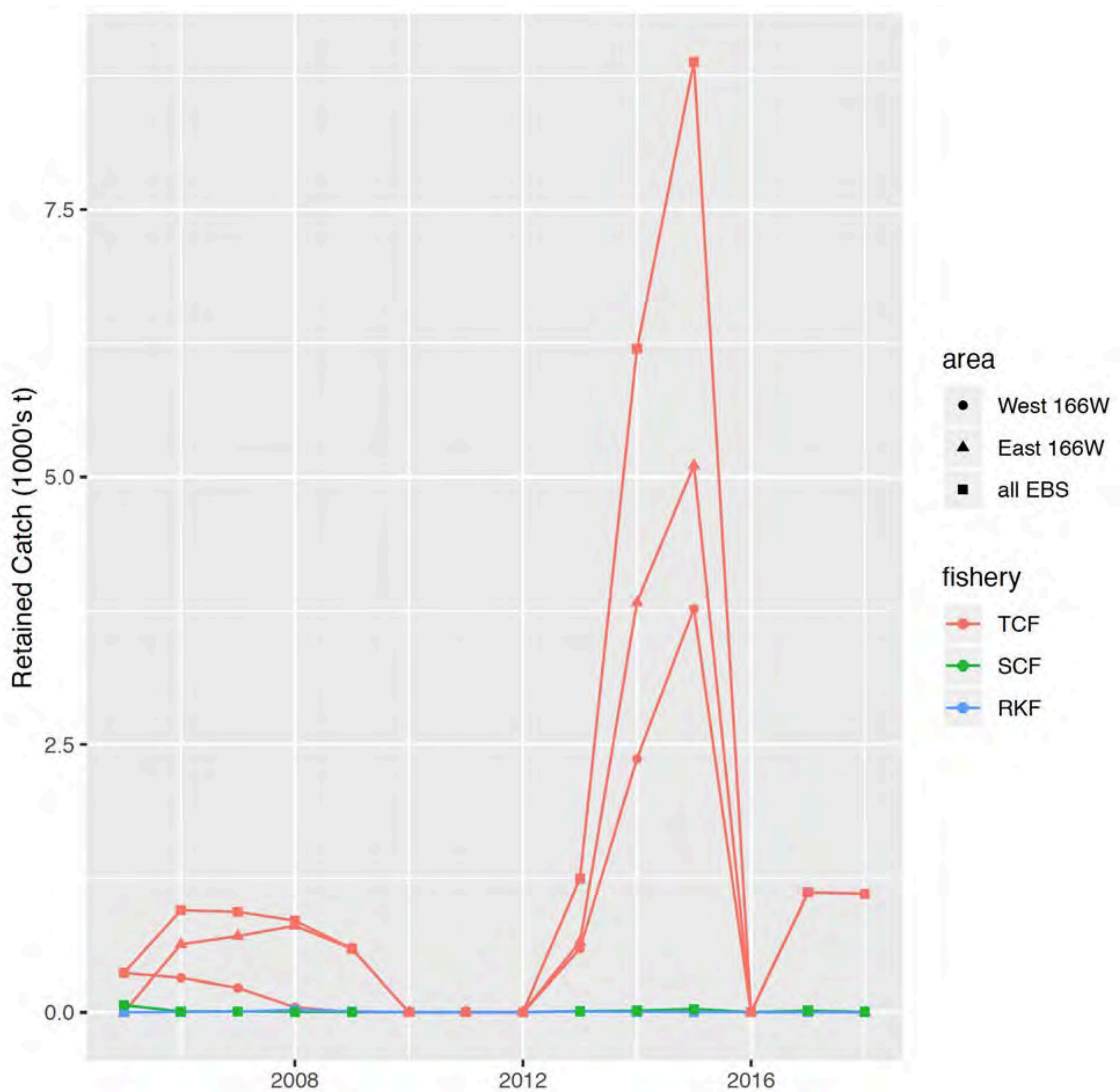


Figure 3. Time series of retained catch biomass (1000’s t) in the directed Tanner crab (TCF: red; eastern area: triangles; western area: circles; all EBS: squares), snow crab (SCF: green), and BBRKC (RFF: blue) fisheries since 2005. The directed fishery was closed from 2010/11 to 2012/13, and in 2016/17. Legal-sized Tanner crab can be incidentally-retained in the snow crab and BBRKC fisheries up to a cap of 5% the target catch.

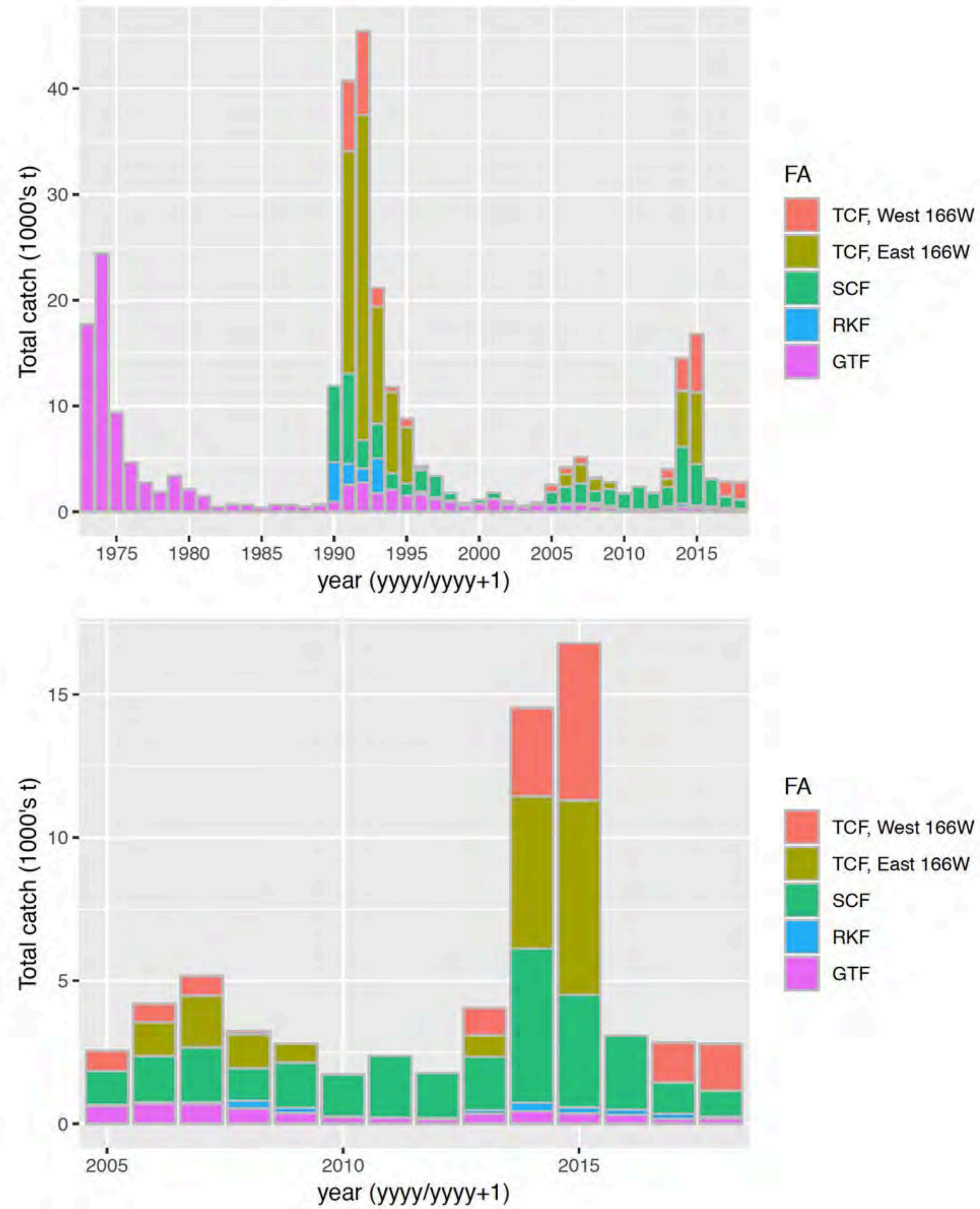


Figure 4. Upper: total catch (retained + discards) of Tanner crab (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Bycatch reporting began in 1973 for the groundfish fisheries and in 1992 for the crab fisheries. Lower: detail since 2005.

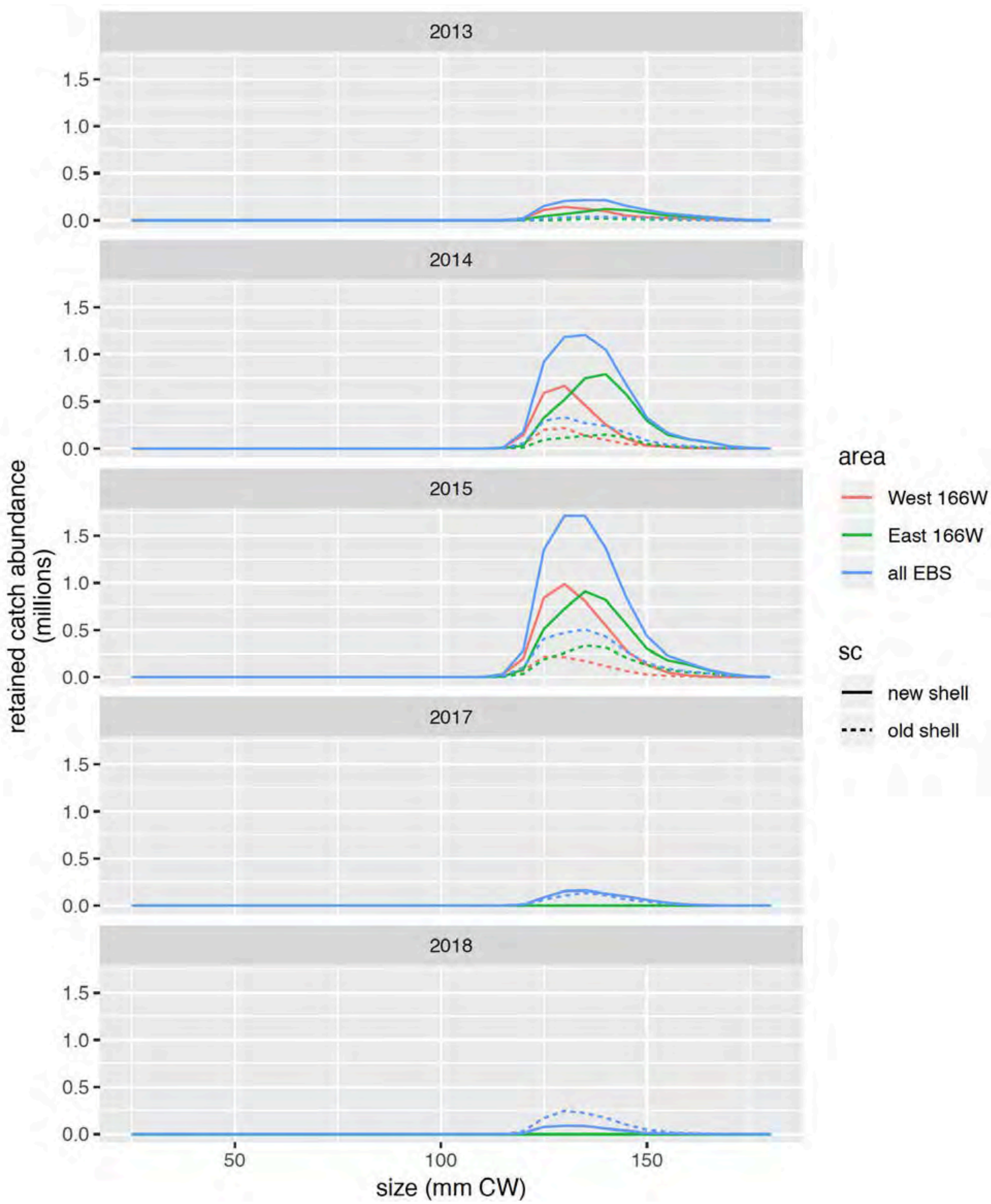


Figure 5. Retained catch size compositions in the directed Tanner crab fisheries since the fishery re-opened in 2013/14 (red: western area, green: eastern area; blue: all EBS).

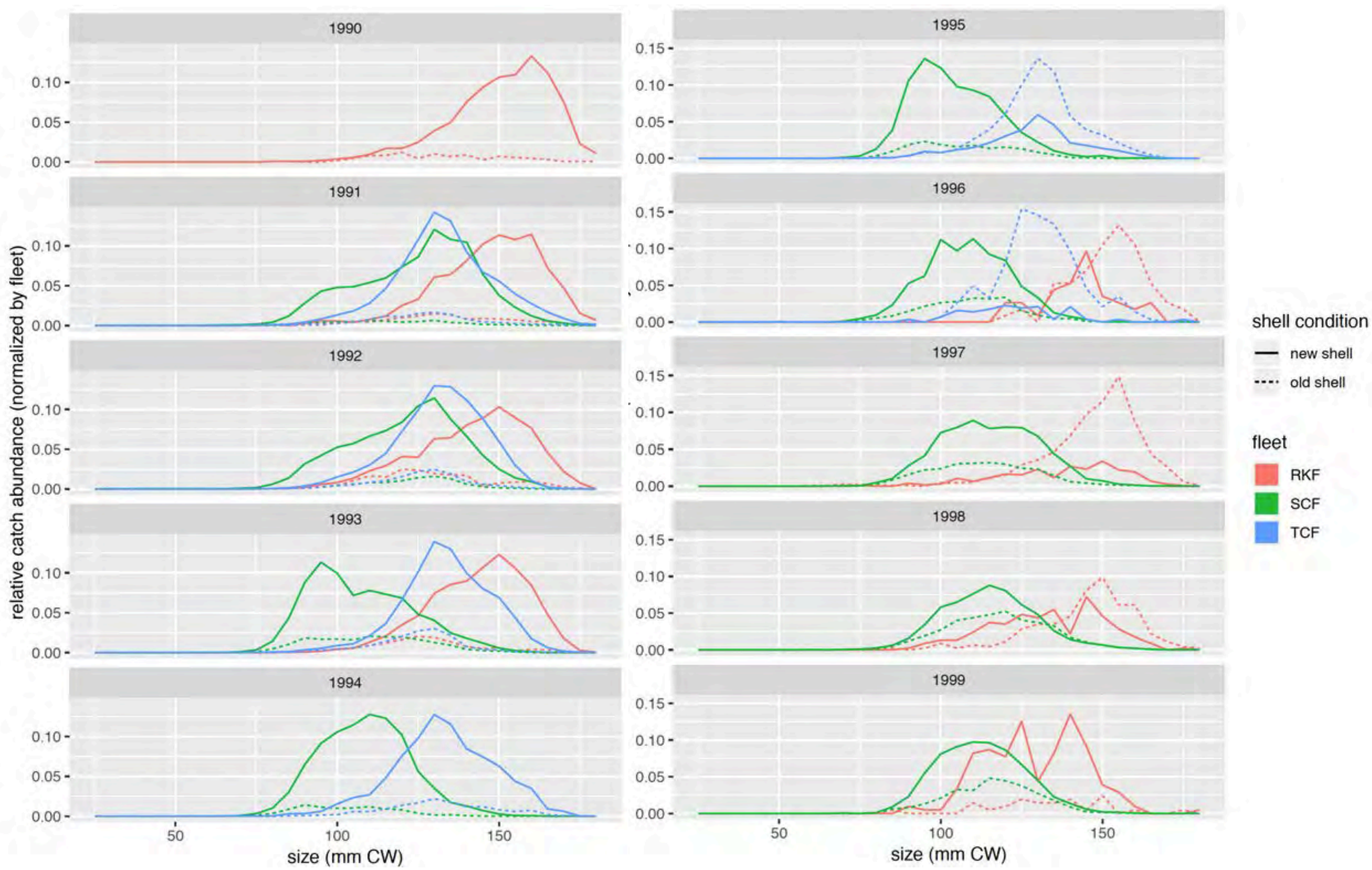


Figure 6. Total catch (retained + discards) size compositions for males, normalized by fleet, during 1990/91-1999/2000 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab).

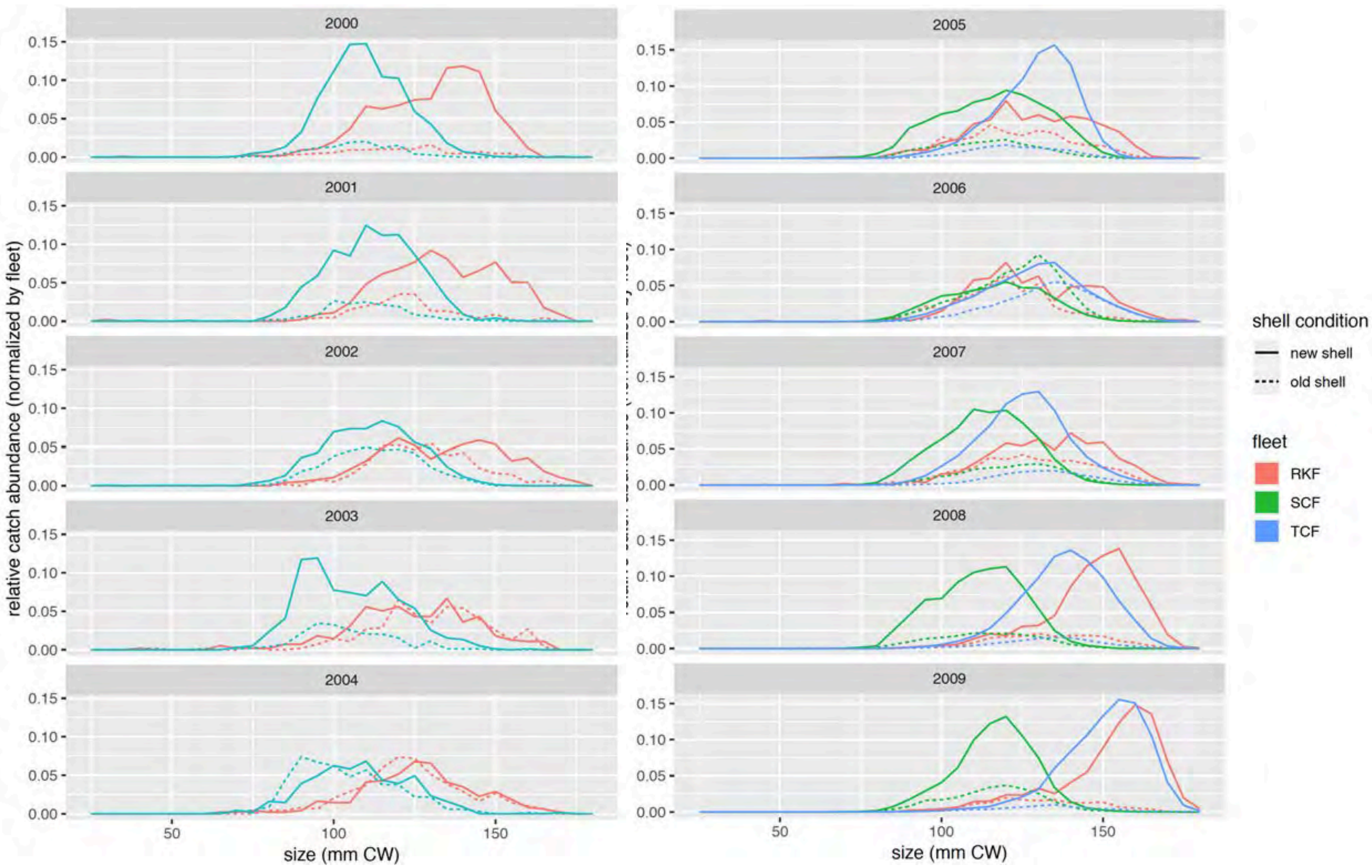


Figure 7. Total catch (retained + discards) size compositions for males, normalized by fleet, during 2000/01-2009/10 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab). The directed fishery was closed in 2000/01-2004/05 and was open only in the western area in 2005/06 and in the eastern area in 2009/10.

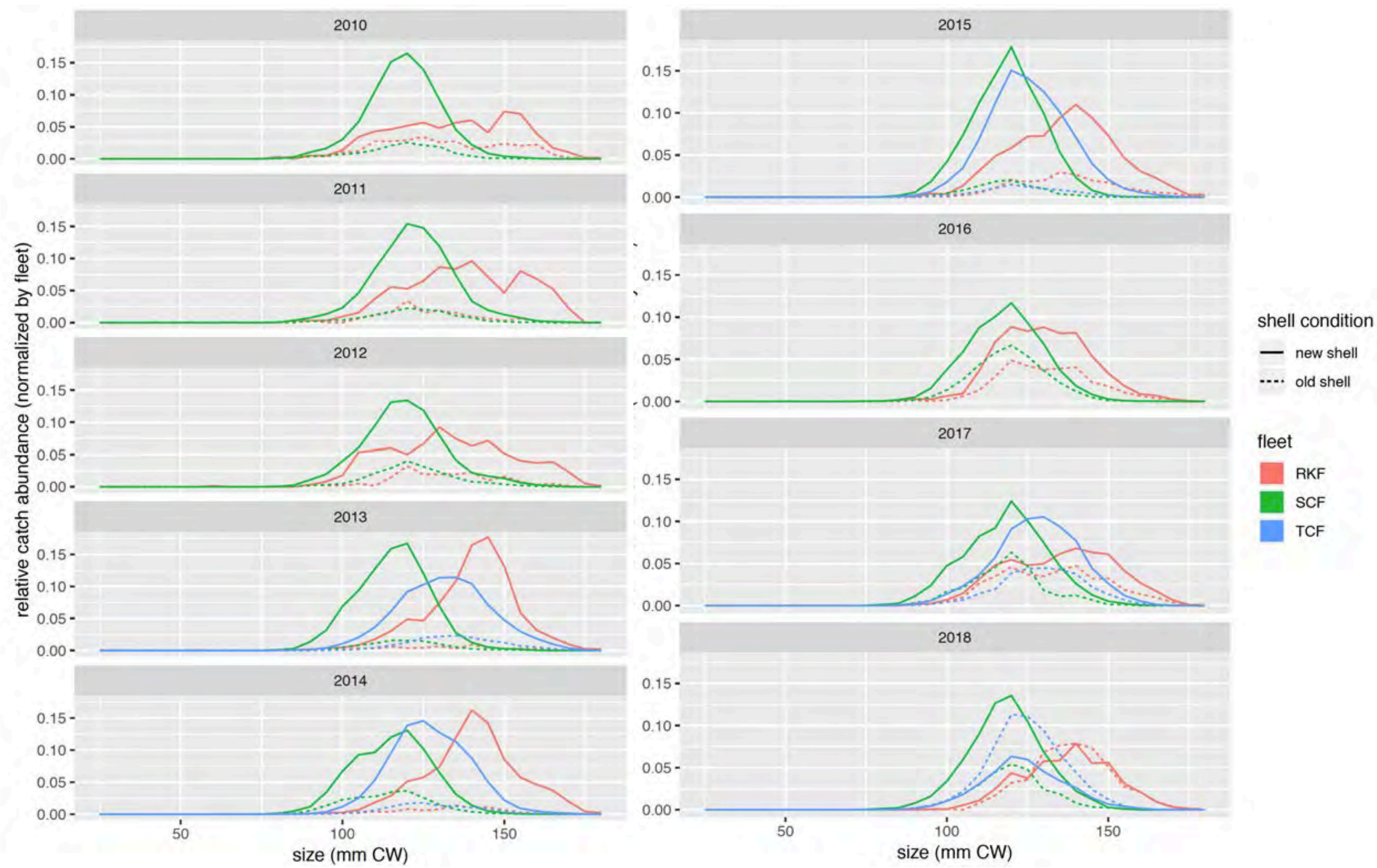


Figure 8. Total catch (retained + discards) size compositions for males, normalized by fleet, during 2010/11-2018/19 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab). The directed fishery was closed in 2010/11-2012/13 and 206/17, and was open only in the western area in 2017/18 and 2018/19.

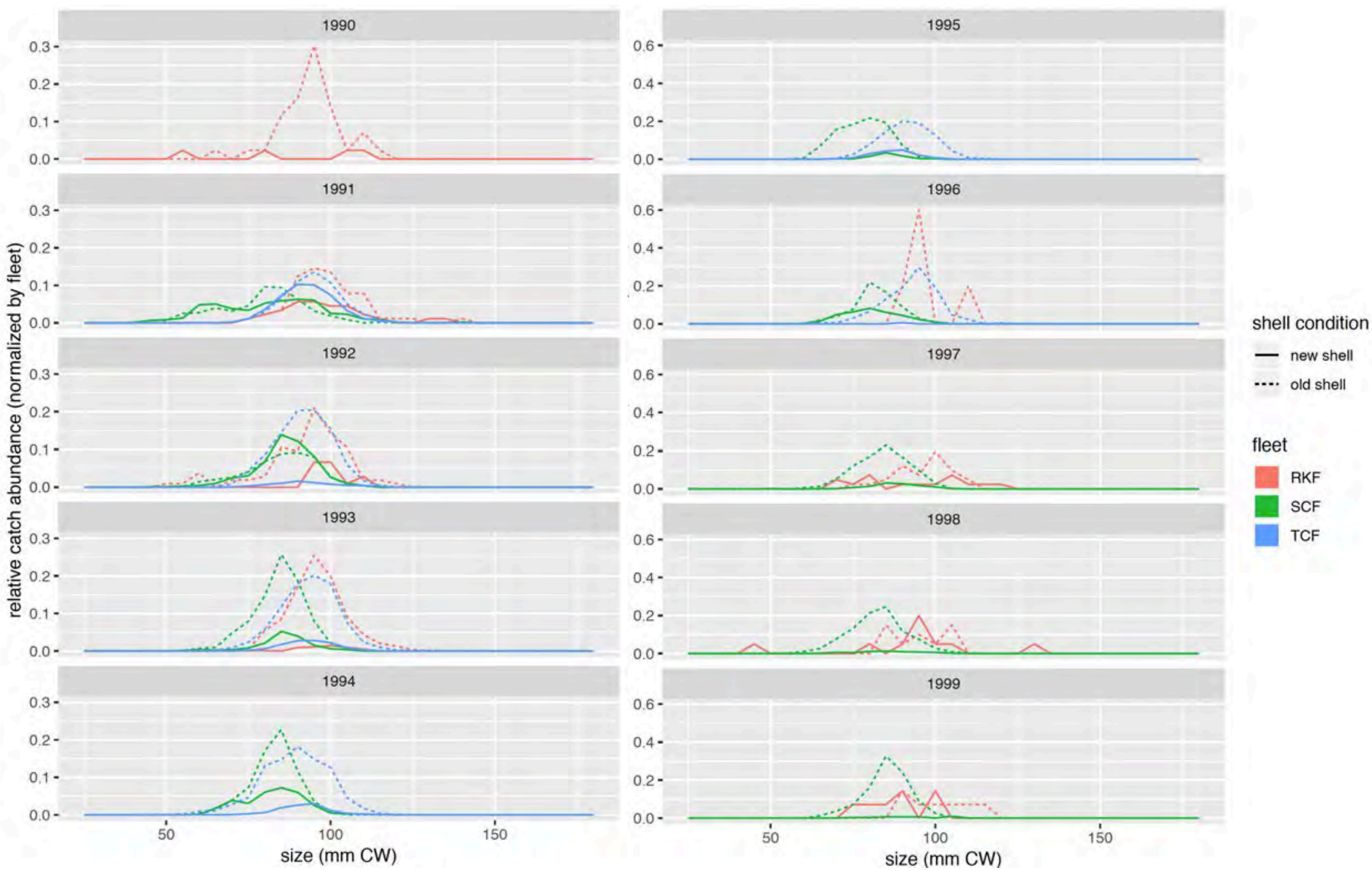


Figure 9. Bycatch size compositions for females, normalized by fleet, during 1990/91-1999/2000 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab).

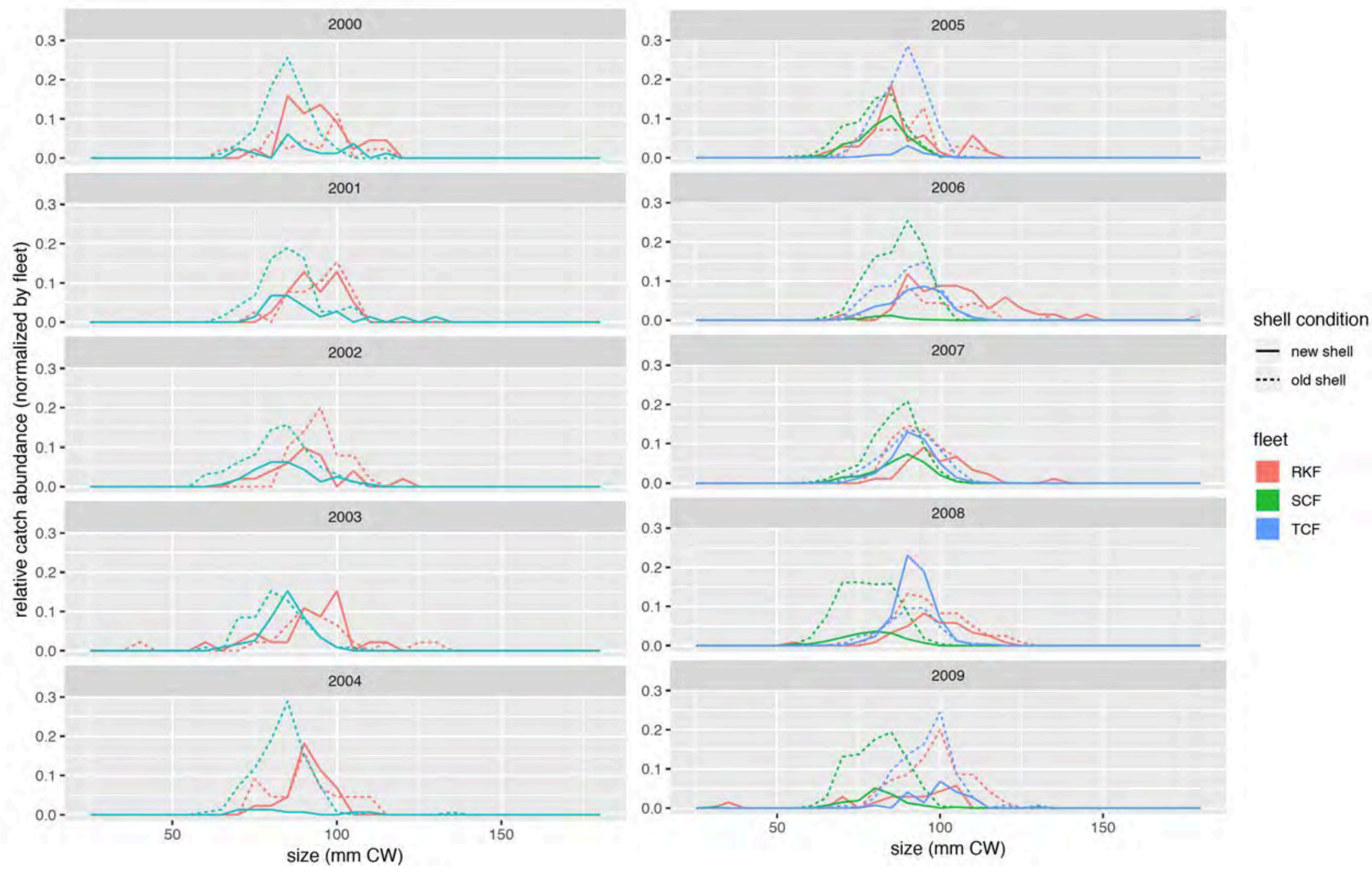


Figure 10. Bycatch size compositions for females, normalized by fleet, during 2000/01-2009/10 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab).

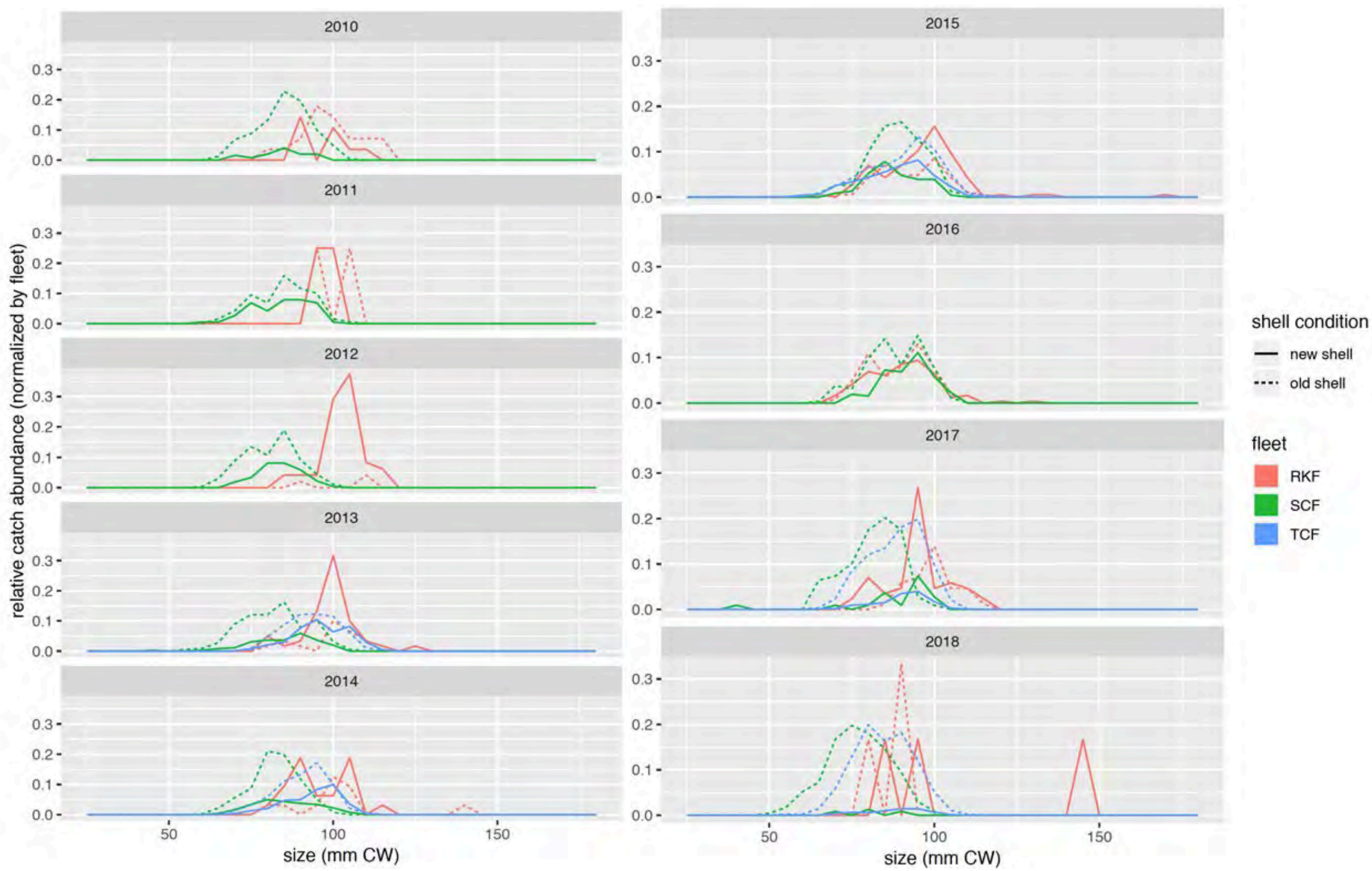


Figure 11. Bycatch size compositions for females, normalized by fleet, during 2010/11-2018/19 in the directed Tanner crab (aggregated across areas, TCF: blue), snow crab (SCF: green), and BBRKC (RKF: red) fisheries (solid line: new shell crab; dotted line: old shell crab).

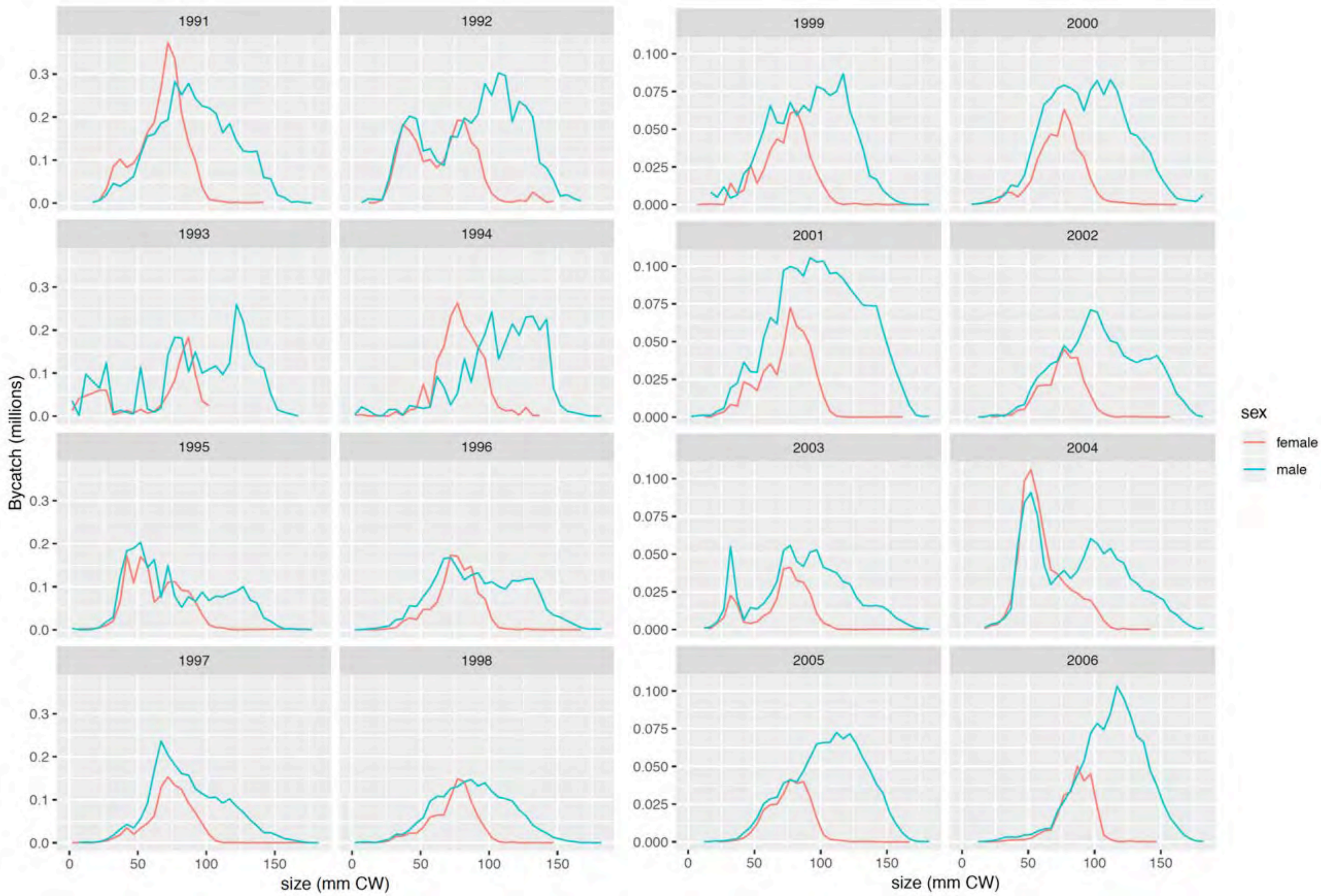


Figure 12. Annual bycatch size compositions in the groundfish fisheries by sex, expanded to total bycatch, during 1991/92-2006/07. Red lines: females; green lines: males.

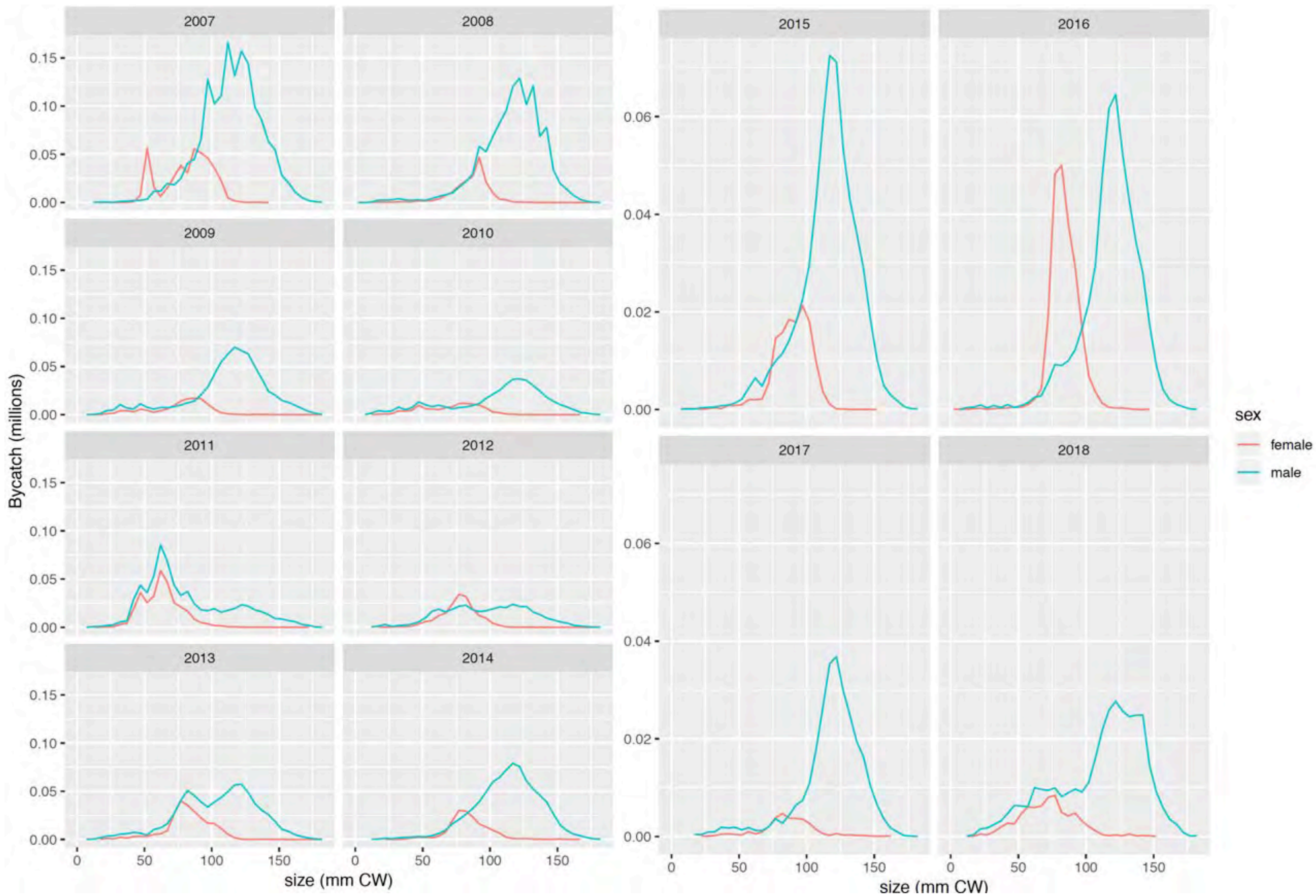


Figure 13. Annual bycatch size compositions in the groundfish fisheries by sex, expanded to total bycatch, during 2007/08-2018/19. Red lines: females; green lines: males.

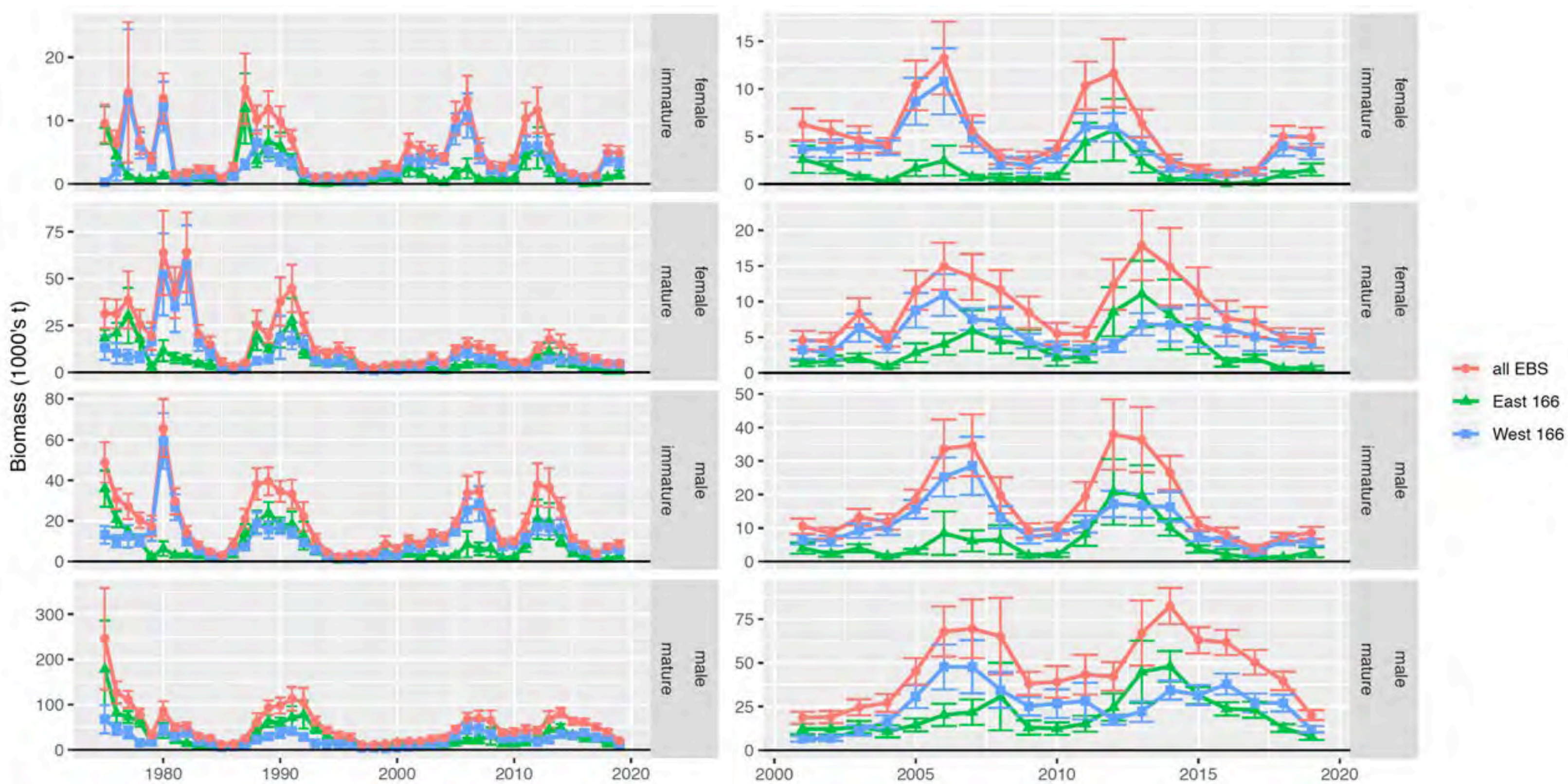


Figure 14. Annual estimates of area-swept biomass from the NMFS EBS bottom trawl survey, by sex, maturity state, and management area. Red lines: total biomass; green lines: biomass in the eastern area; blue: biomass in the western area.

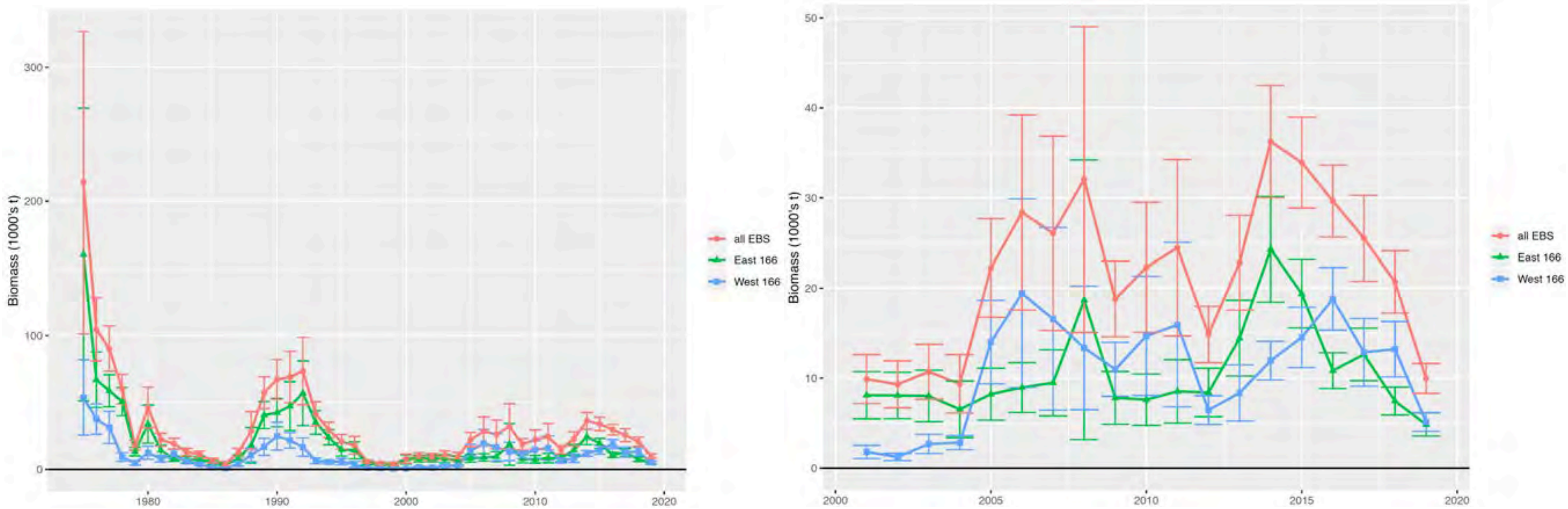


Figure 15. Annual estimates of area-swept biomass from the NMFS EBS bottom trawl survey for preferred-size (>125 mm CW) legal males . Red lines: total biomass; green lines: biomass in the eastern area; blue: biomass in the western area.

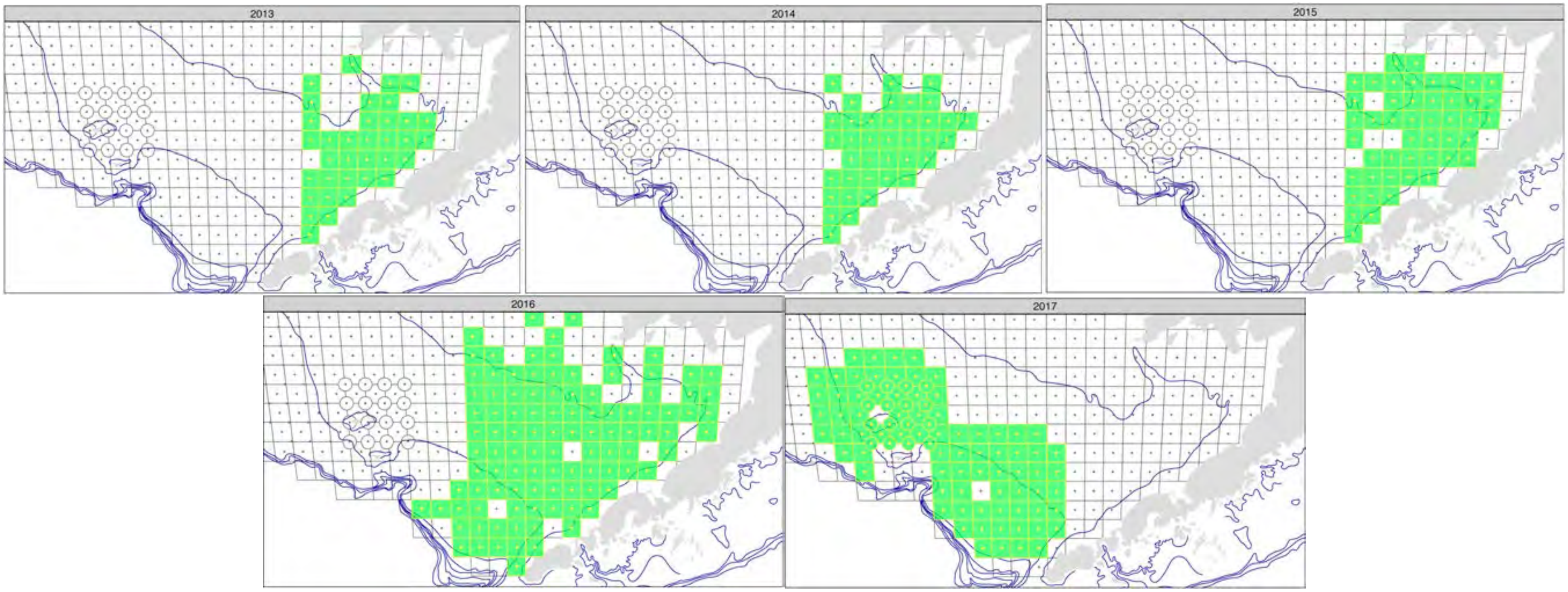


Figure 16. Spatial footprints (stations occupied in green) during the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2017. Squares and circles represent stations in the standard NMFS EBS bottom trawl survey (which extends beyond the area shown in the maps).

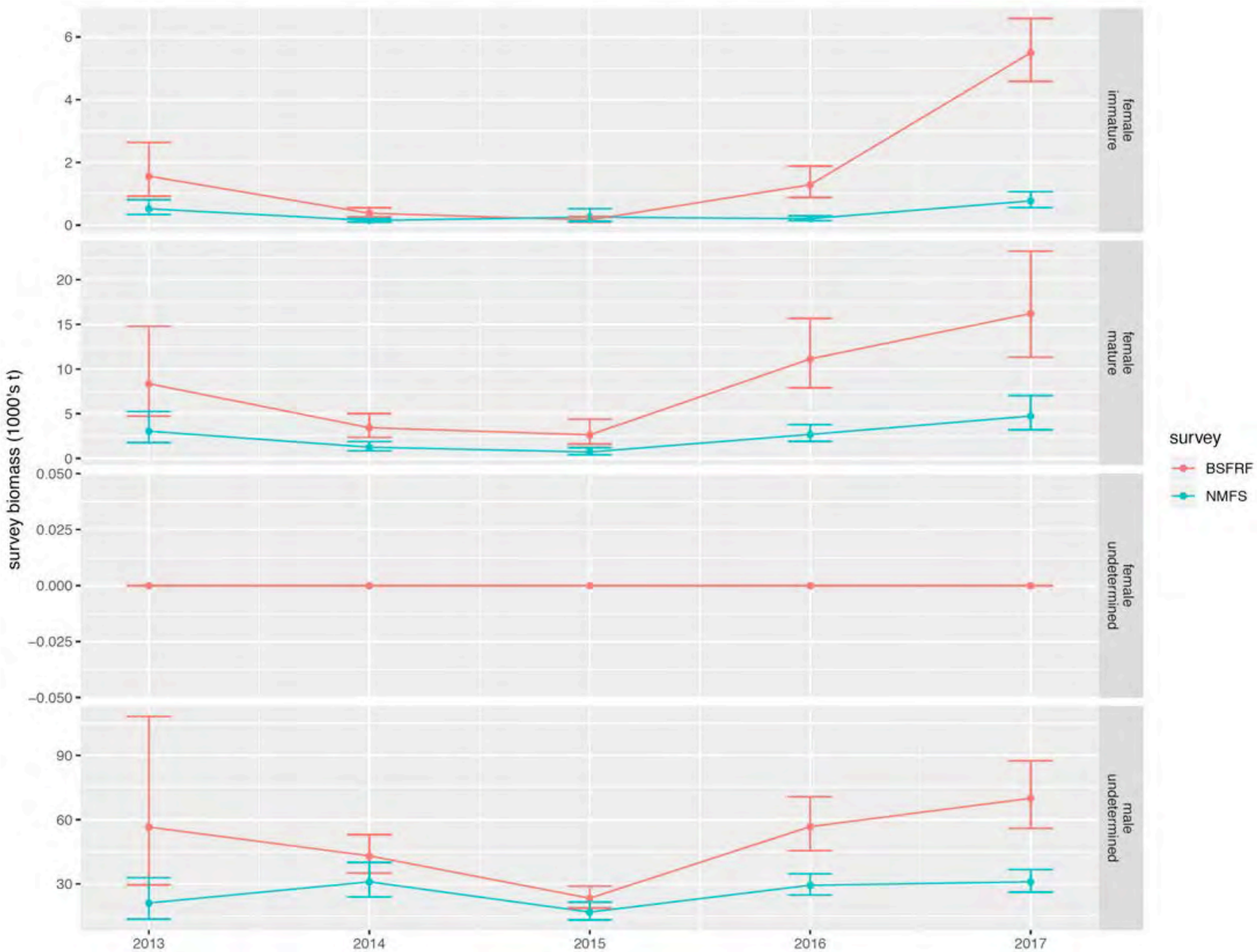


Figure 17. Annual estimates of area-swept biomass from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2017. The SBS studies had different spatial footprints each year, so annual changes in biomass do not necessarily reflect underlying population trends. Red lines: BSFRF; green lines: NMFS.

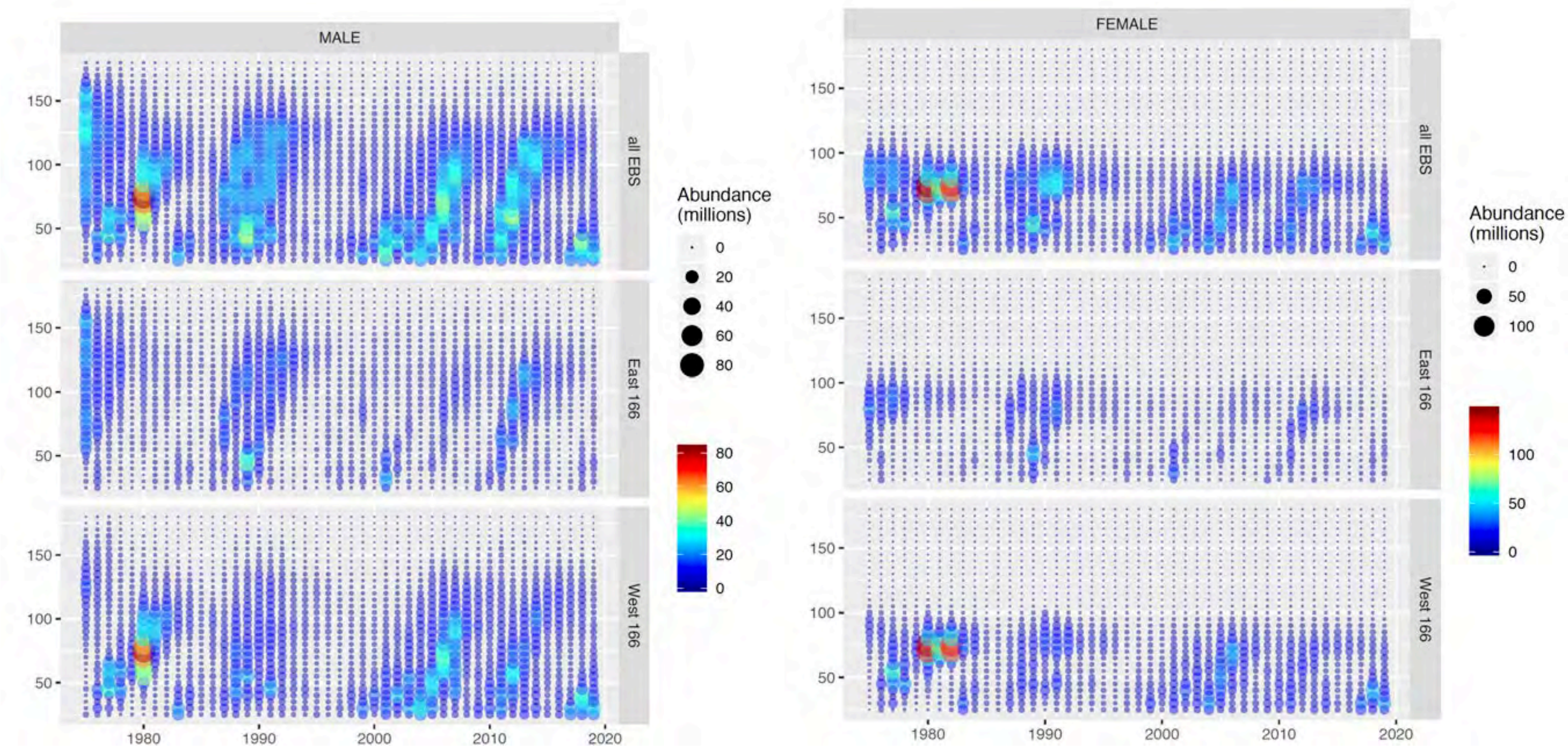


Figure 18. Size compositions from the NMFS EBS bottom trawl survey for 1975-2019.

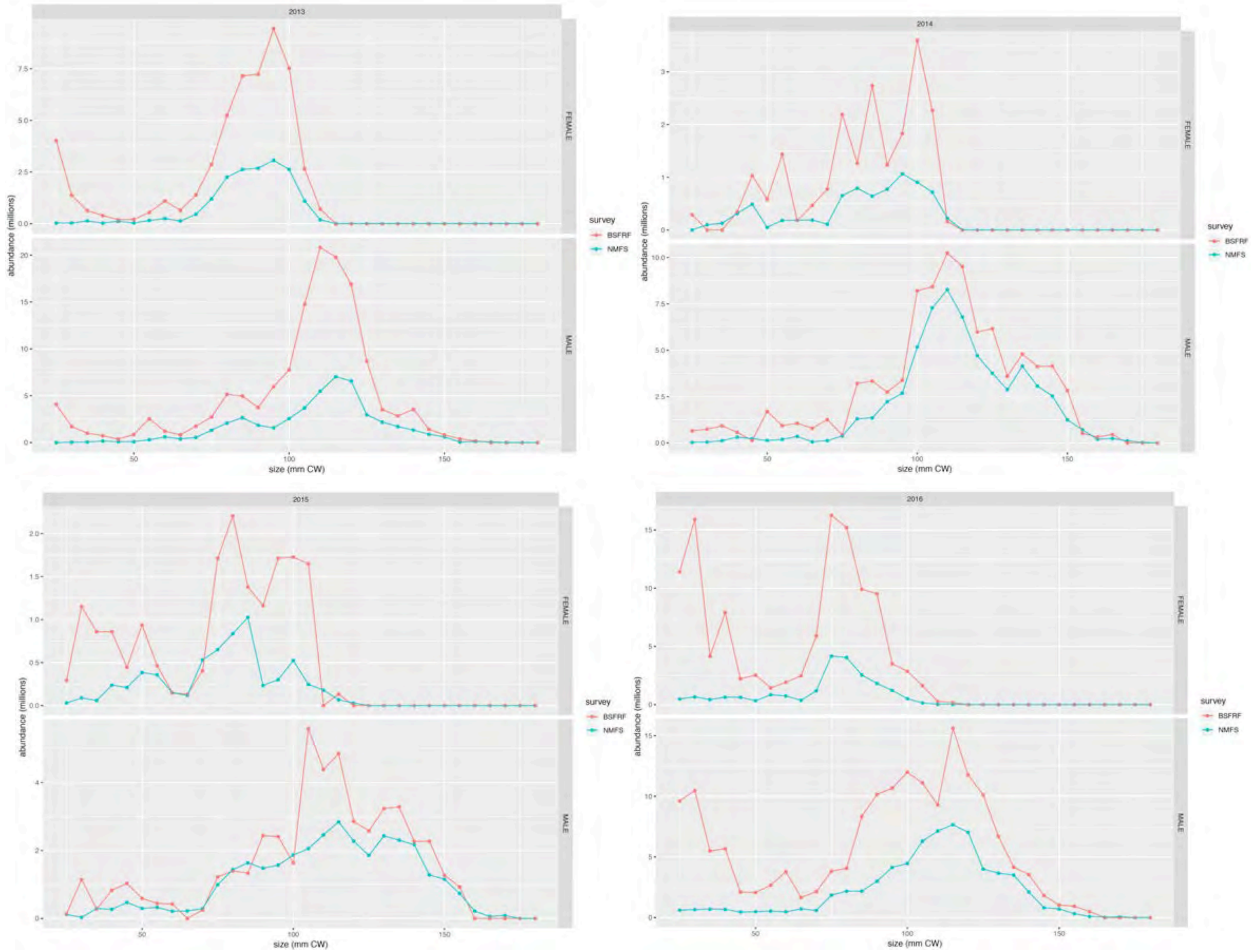


Figure 19. Annual size compositions of area-swept abundance by sex from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2013-2015. Red lines: BSFRF; green lines: NMFS.

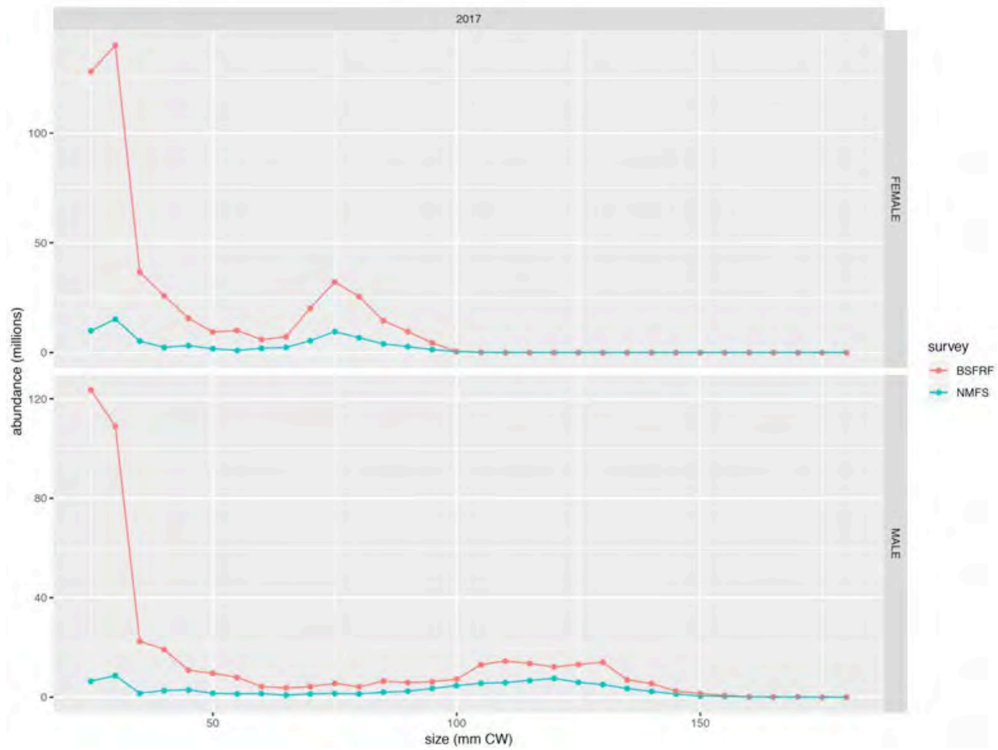


Figure 19 (cont.). Annual size compositions of area-swept abundance by sex from the BSFRF-NMFS cooperative side-by-side (SBS) catchability studies in 2017. Red lines: BSFRF; green lines: NMFS

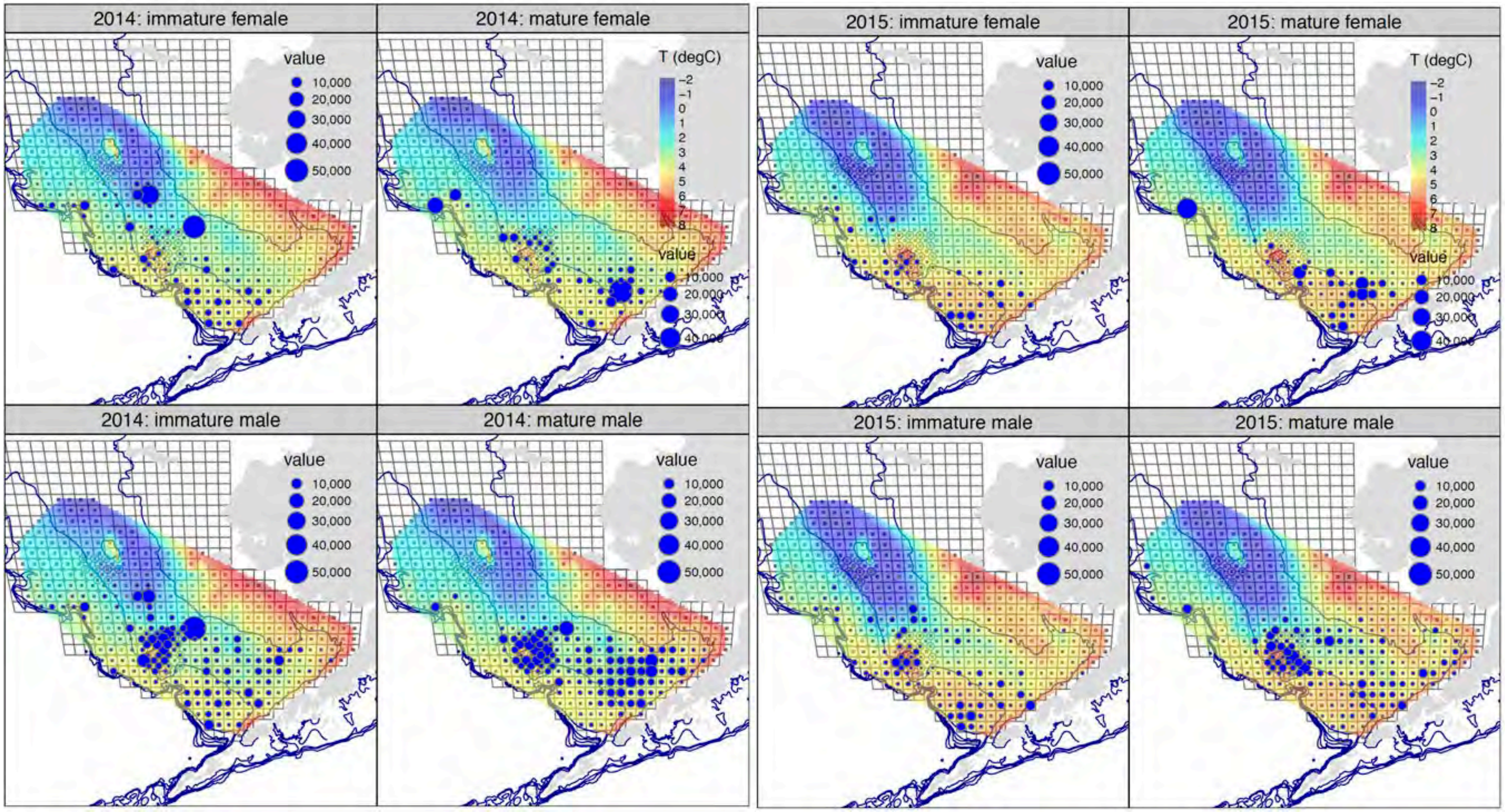


Figure 20. Annual estimates of area-swept abundance (blue circles) from the NMFS EBS bottom trawl survey, by sex and maturity state for 2014 and 2015. Local abundance scales with symbol area. The background "heatmap" represents bottom water temperatures at the time of the survey.

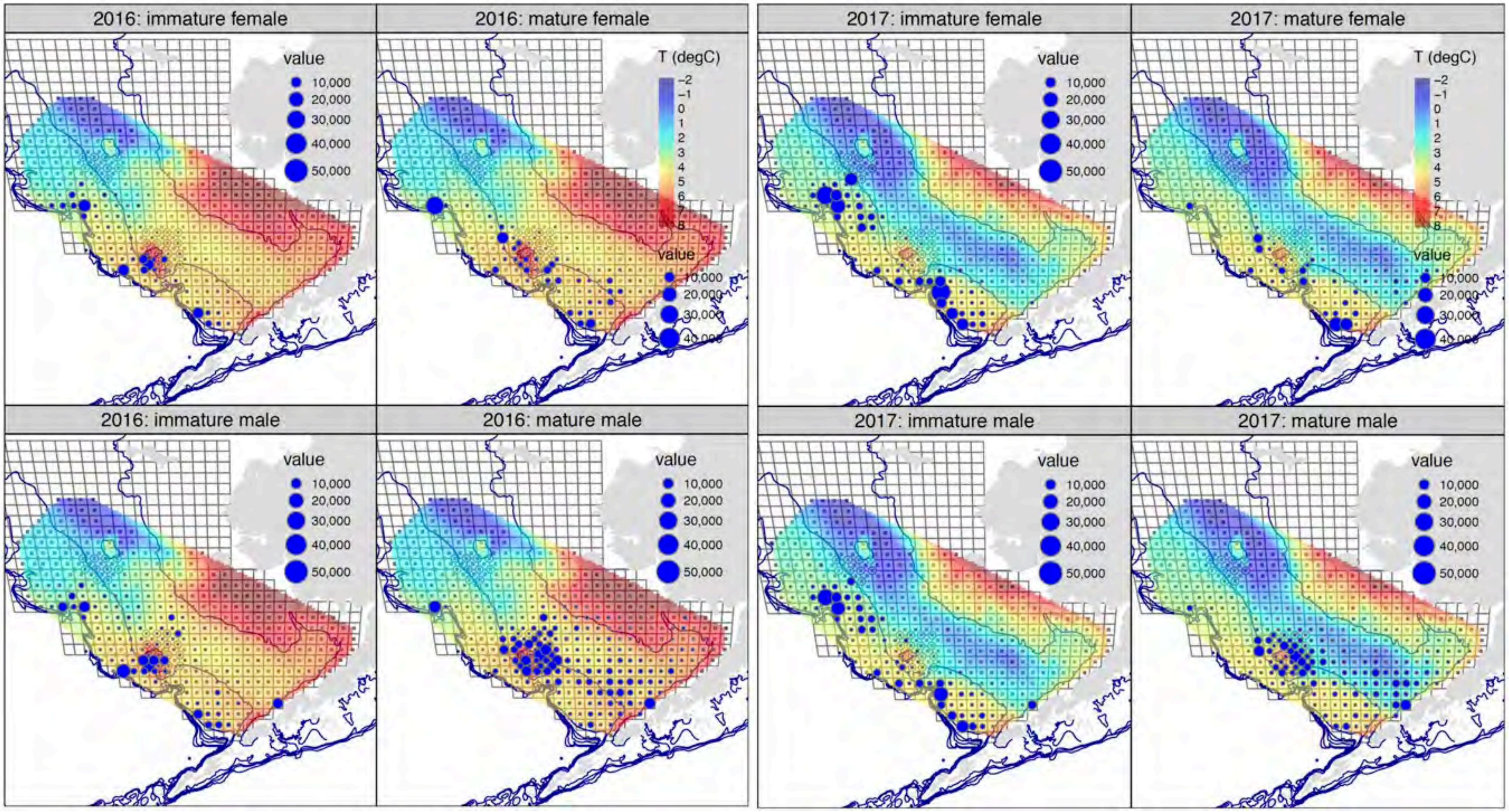


Figure 21. Annual estimates of area-swept abundance (blue circles) from the NMFS EBS bottom trawl survey, by sex and maturity state for 2016 and 2017. Local abundance scales with symbol area. The background "heatmap" represents bottom water temperatures at the time of the survey.

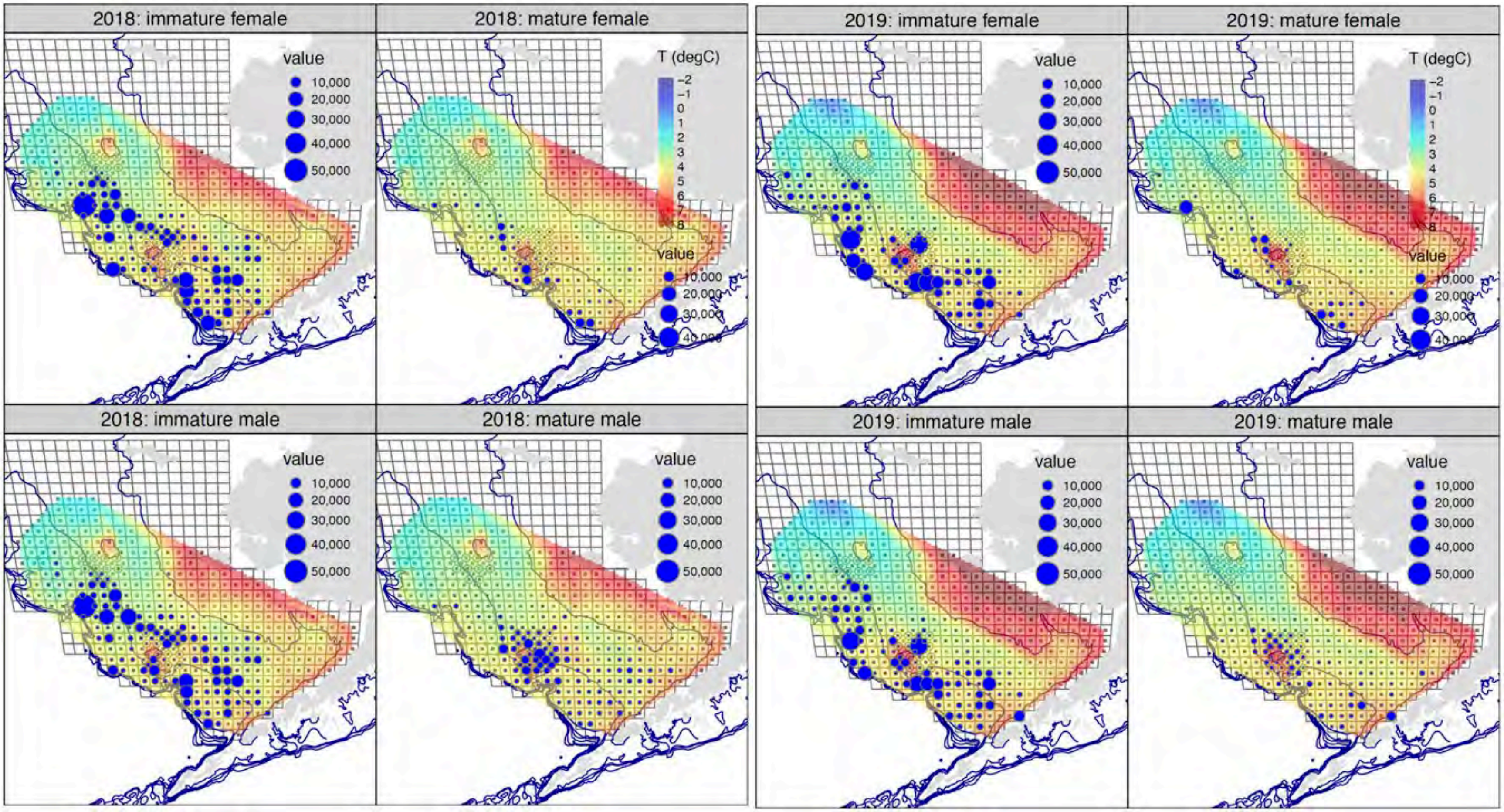


Figure 22. Annual estimates of area-swept abundance (blue circles) from the NMFS EBS bottom trawl survey, by sex and maturity state for 2018 and 2019. Local abundance scales with symbol area. The background "heatmap" represents bottom water temperatures at the time of the survey.

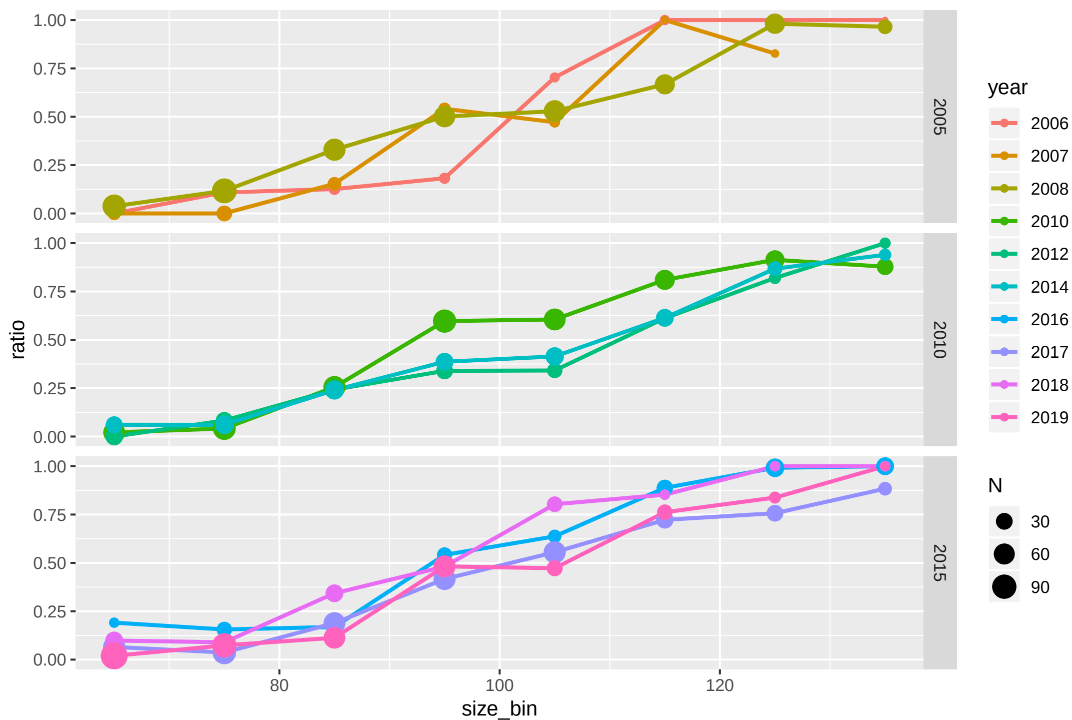


Figure 23. Male maturity ogives (the fraction of new shell mature males, relative to all new shell males) as determined from chela height:carapace width ratios from the NMFS EBS bottom trawl survey for years when chela heights were collected with 0.1 mm precision..

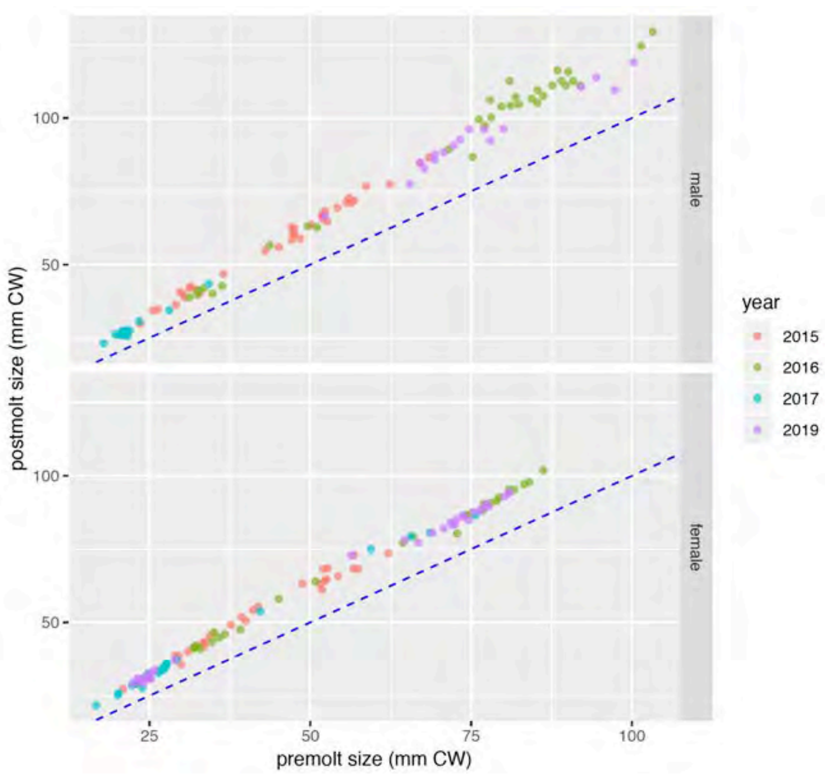


Figure 24. Molt increment data collected collaboratively by NMFS, BSFRF, and ADFG.

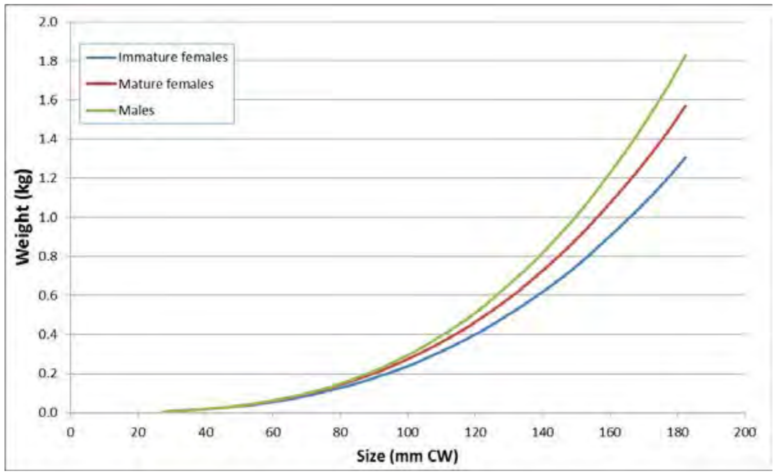


Figure 25. Size-weight relationships developed from NMFS EBS summer trawl survey data.

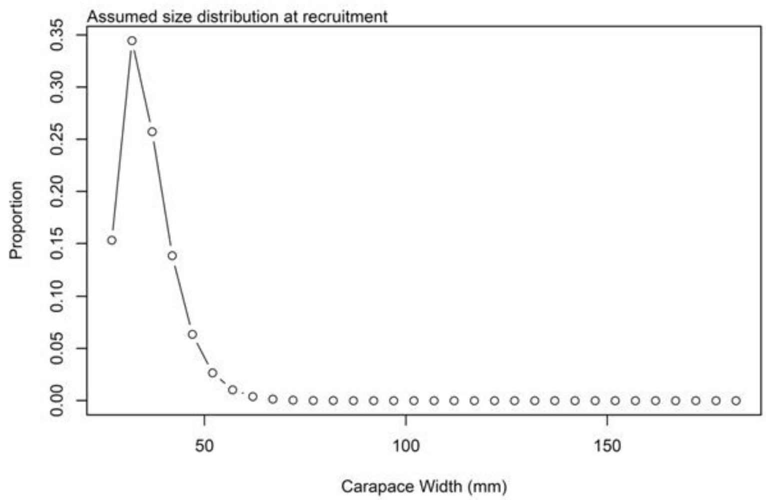


Figure 26. Assumed size distribution for recruits entering the population.

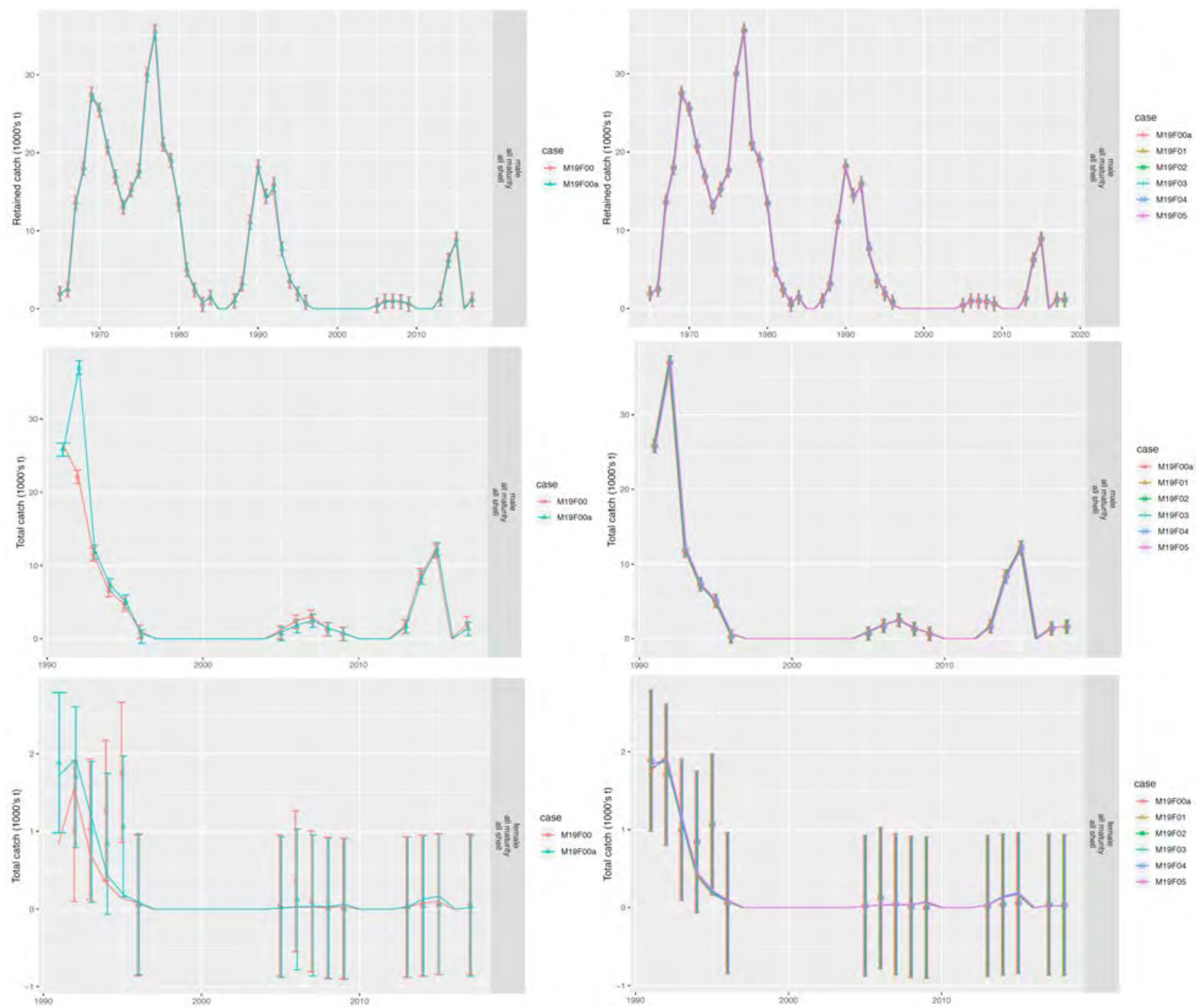


Figure 27. Fits to retained and total catch biomass in the directed fishery from all model scenarios.

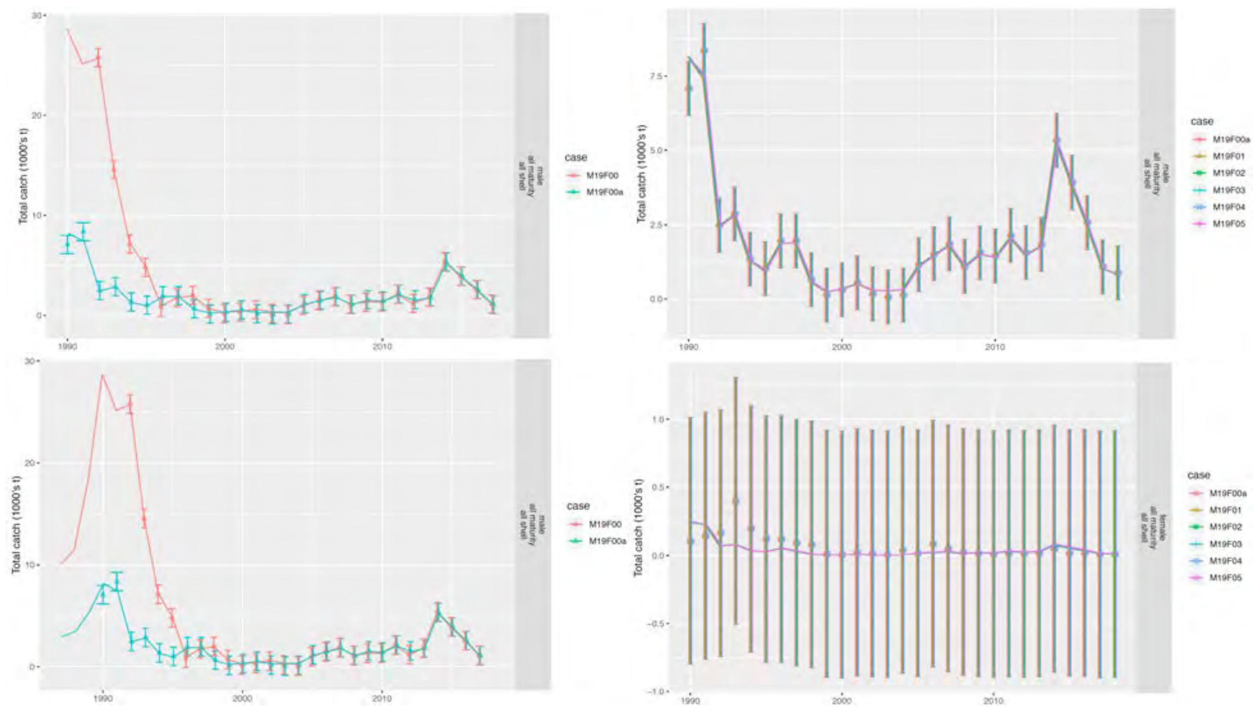


Figure 28. Fits to total catch biomass in the snow crab fishery from all scenarios.

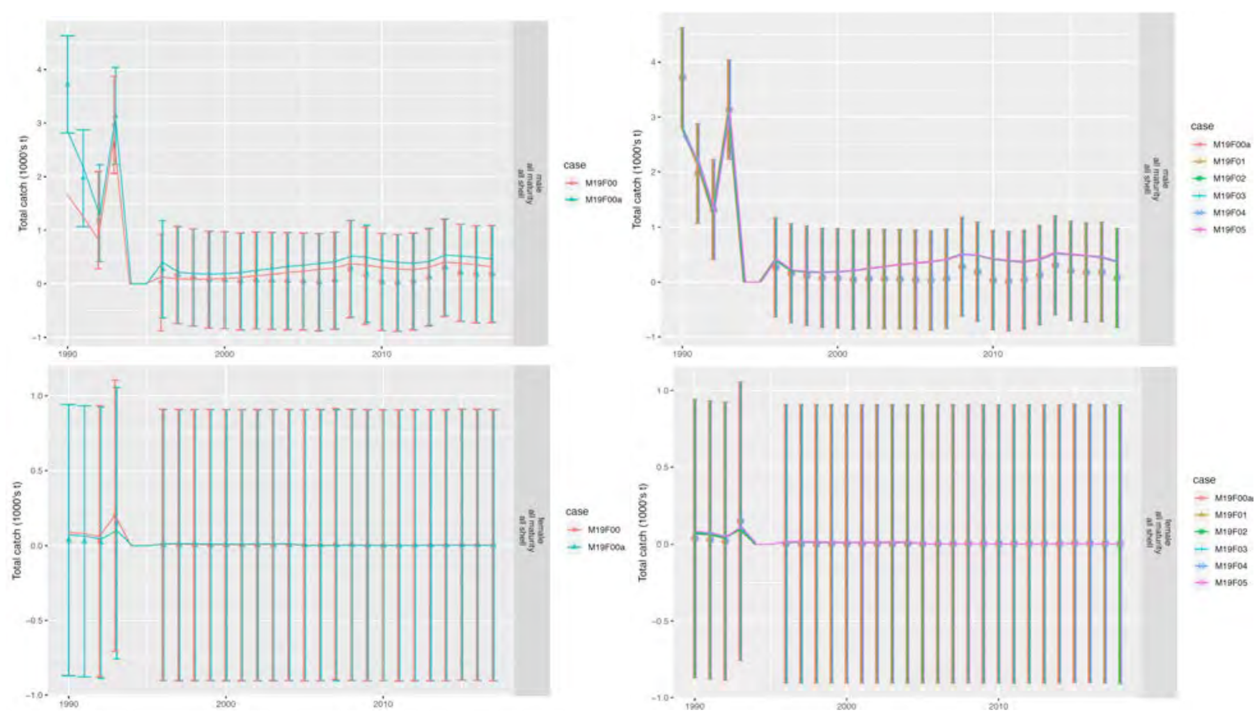
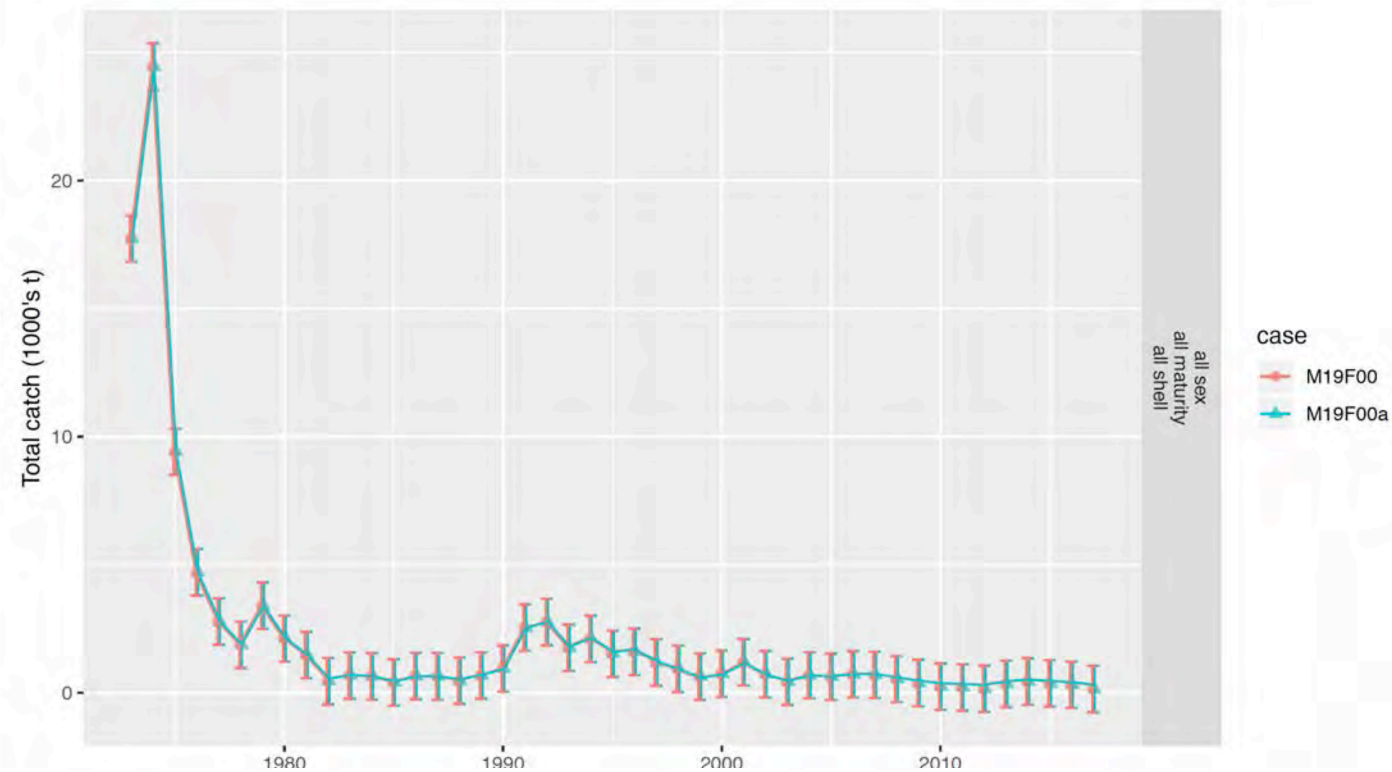


Figure 29. Fits to total catch biomass in the BBRKC fishery from all scenarios.



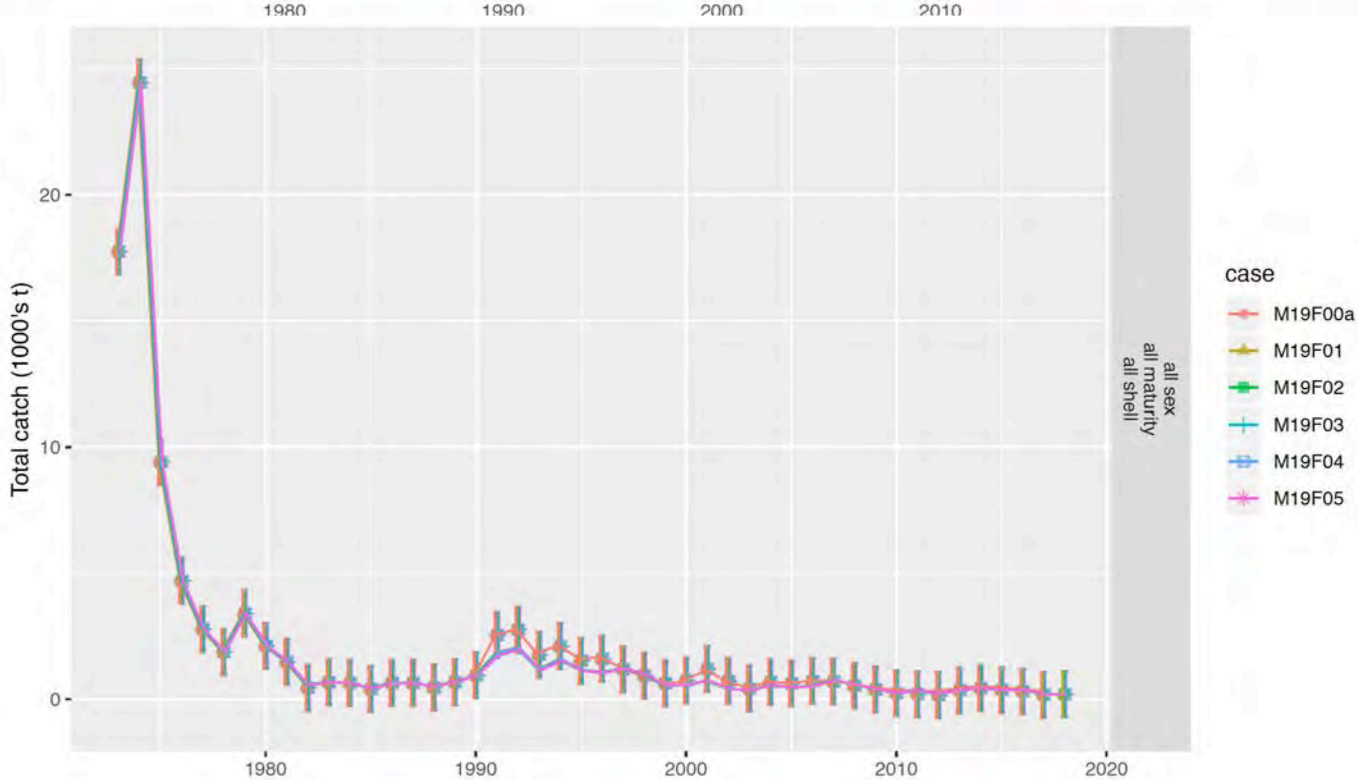


Figure 30. Fits to total catch biomass in the groundfish fisheries for all scenarios.

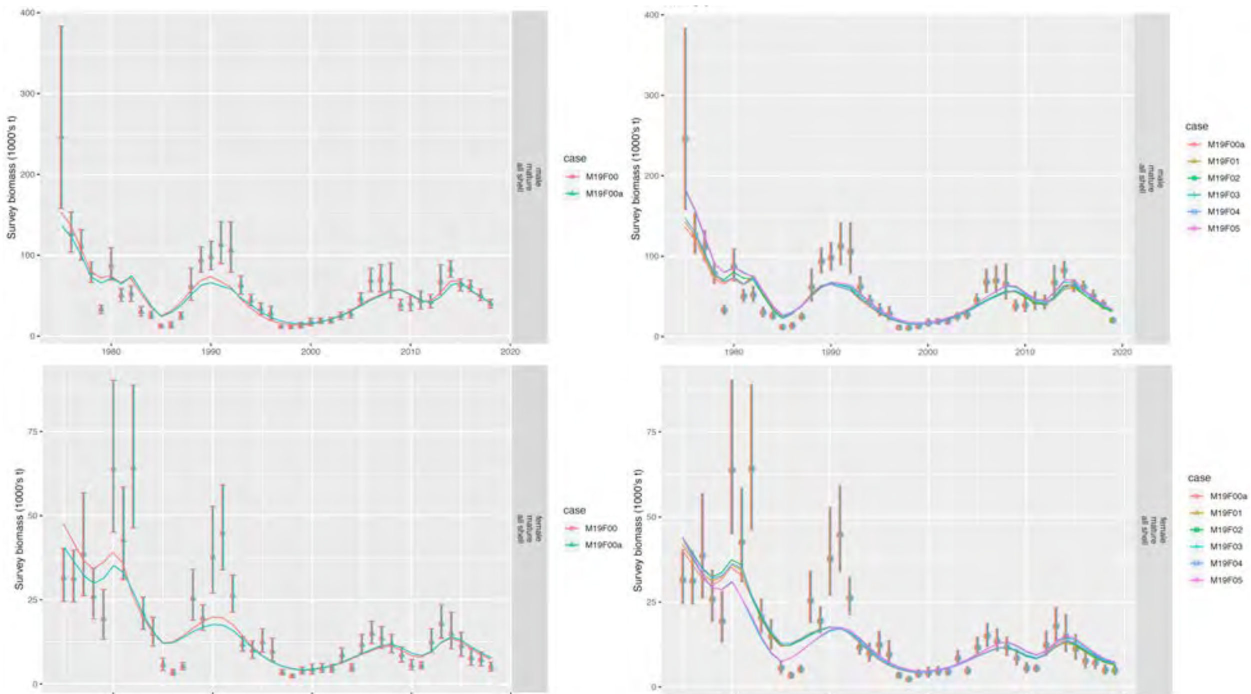


Figure 31. Fits to mature biomass from the NMFS "0" EBS bottom trawl survey data for all. Note that scenarios M19F03 and M19F05 do not include the mature male component in the likelihood (they fit total male biomass) and fit both mature and immature biomass for females.

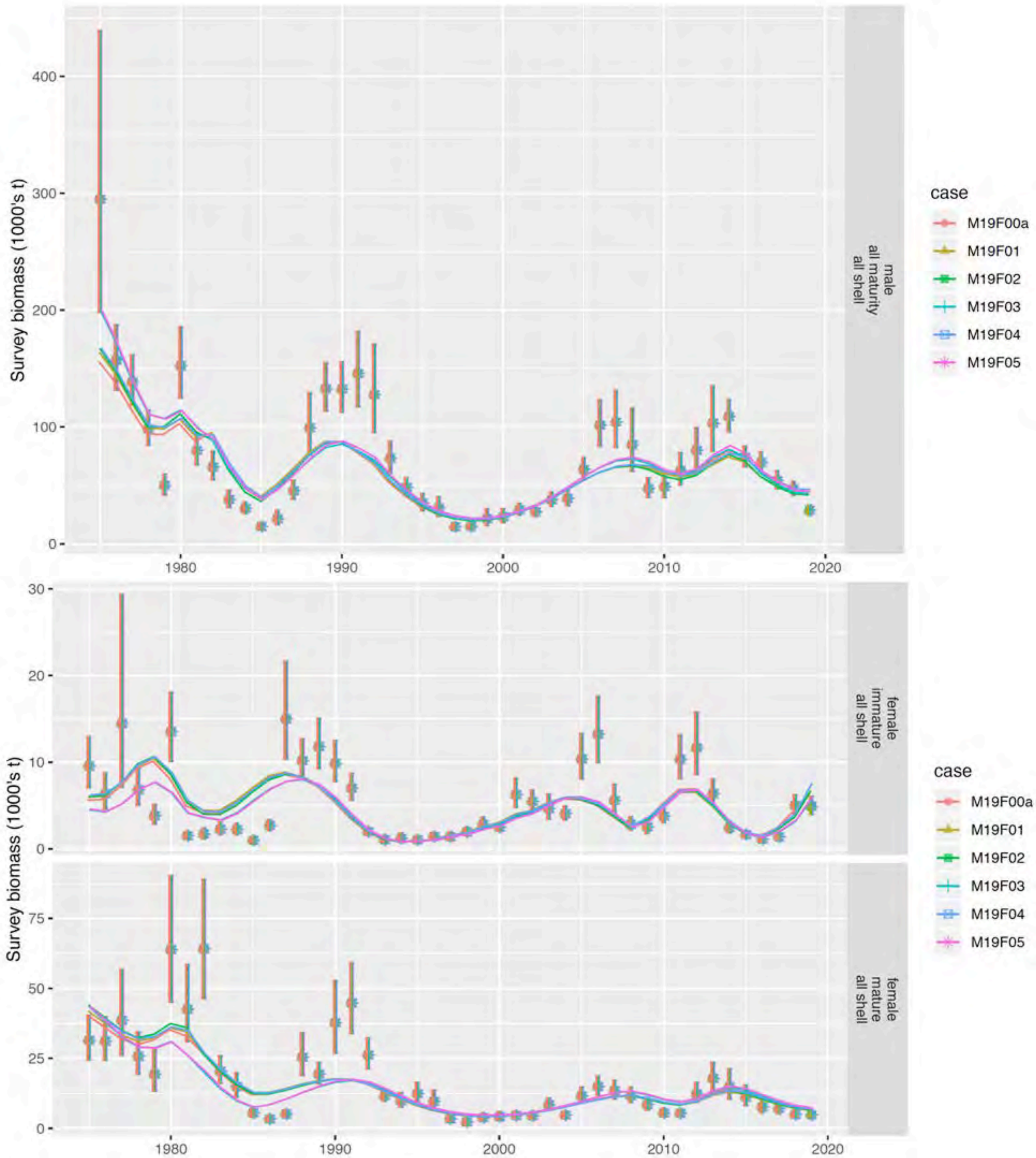


Figure 32. Fits to mature biomass from the NMFS "M" and NMFS "F" EBS bottom trawl survey data for scenarios M19F00a, M19F01, M19F02, M19F02, M19F03, M19F04, and M19F05. Note that only scenarios M19F03 and M19F05 include these data components in the model objective function.

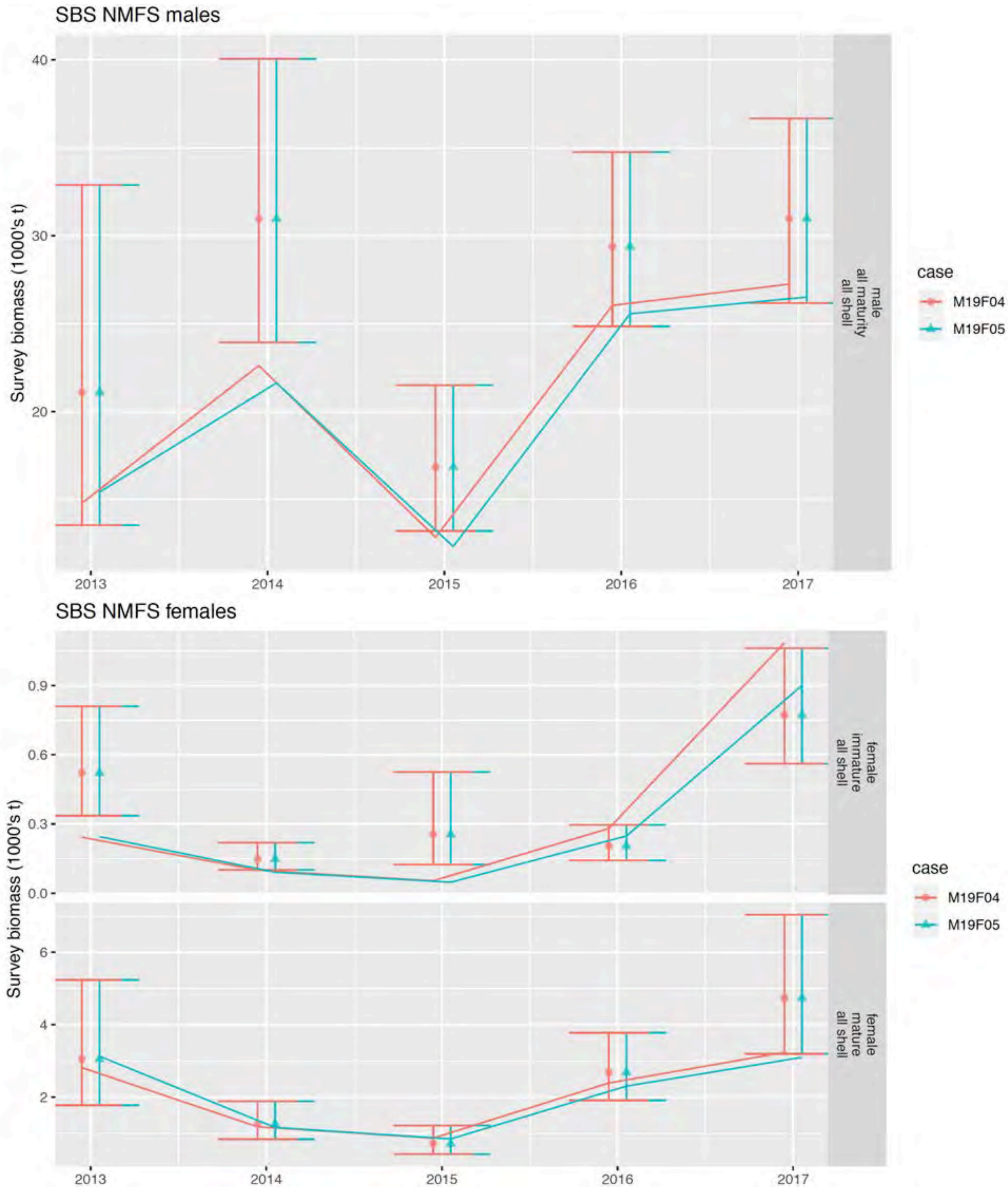


Figure 33. Fits to survey biomass from the NMFS SBS bottom trawl survey data for scenarios M19F04 and M19F05.

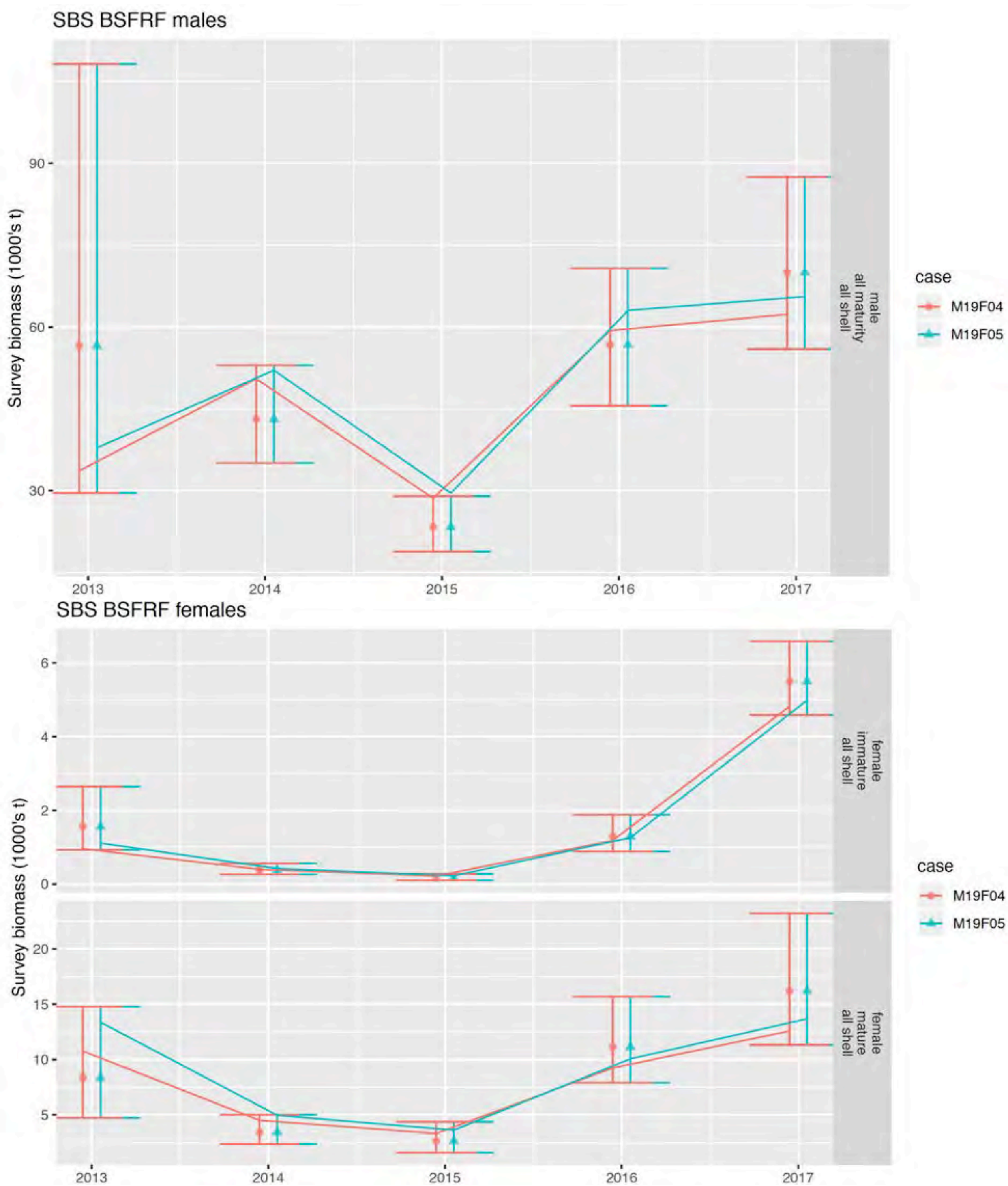


Figure 34. Fits to survey biomass from the BSFRF SBS bottom trawl survey data for scenarios M19F04 and M19F05.

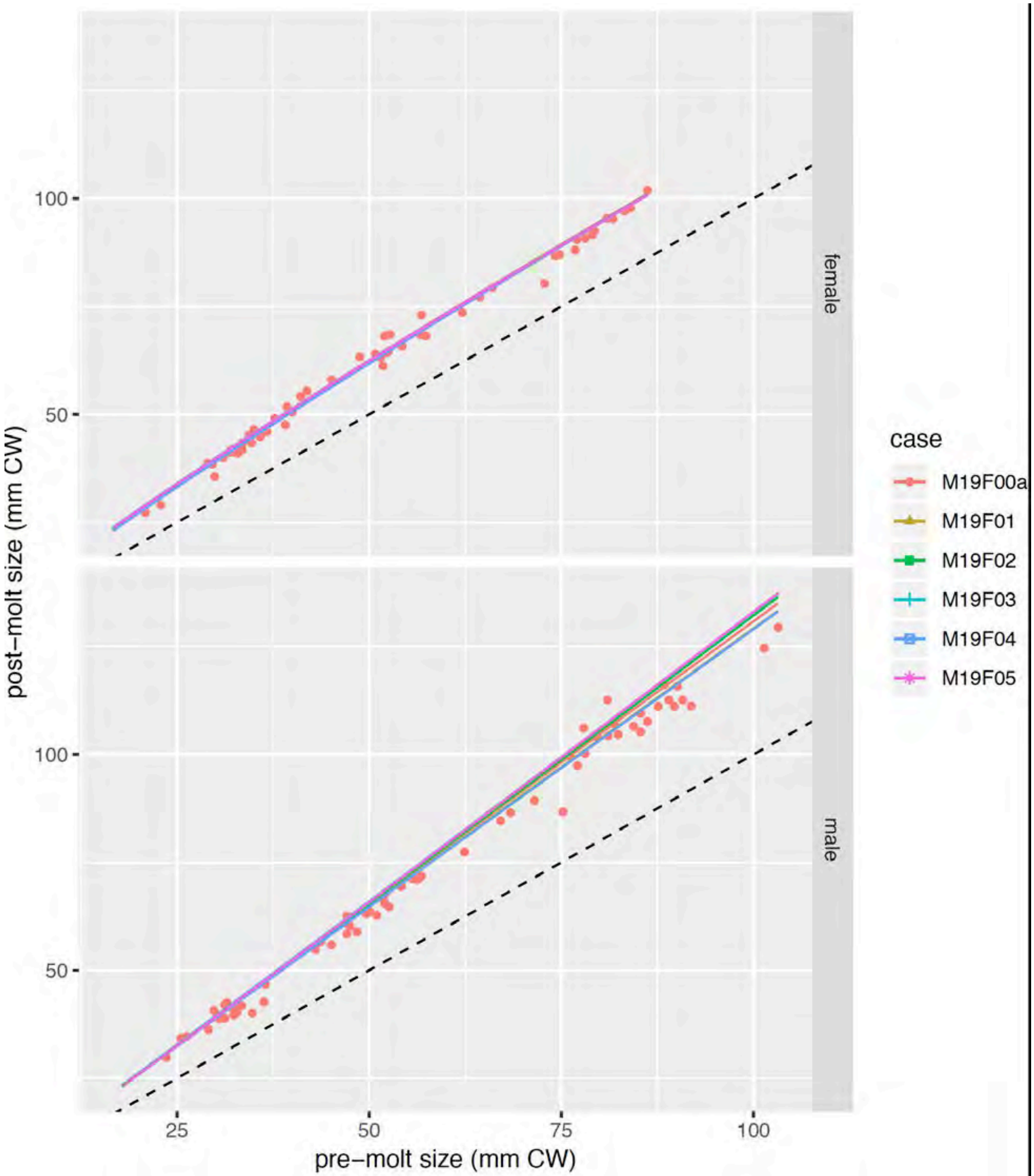


Figure 35. Fits to molt increment data for scenarios M19F00a, M19F01, M19F02, M19F02, M19F03, M19F04, and M19F05.

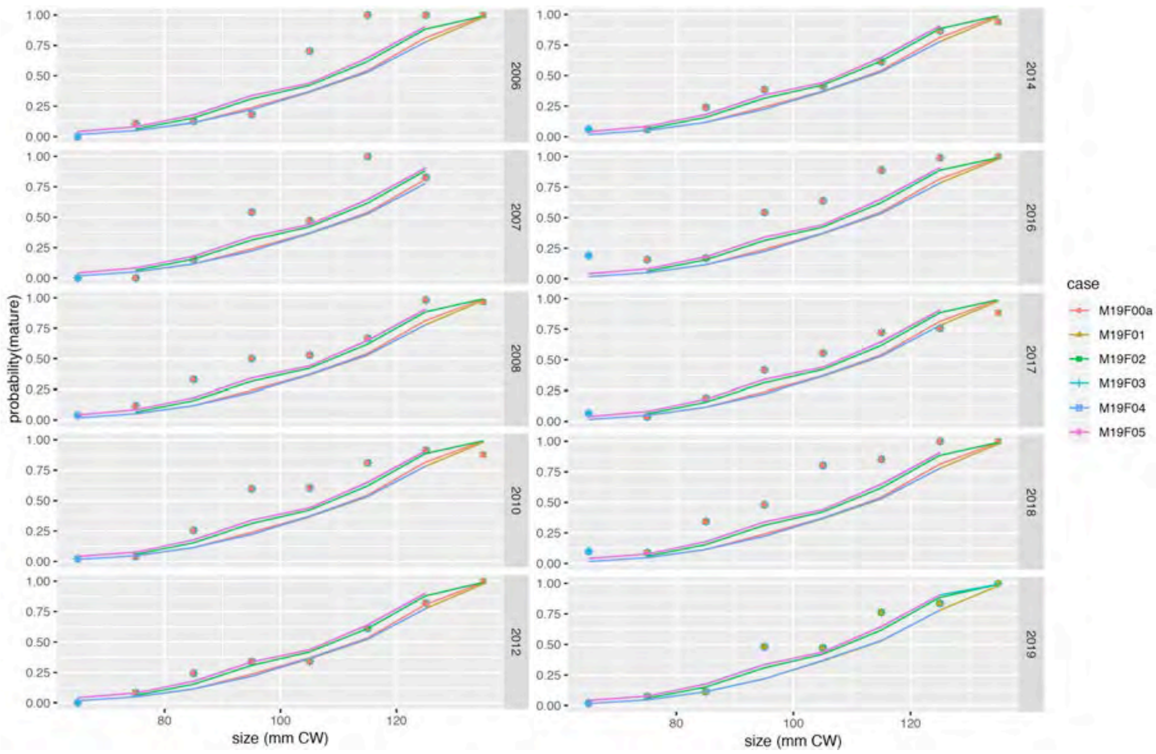


Figure 36. Fits to male maturity ogive data for scenarios M19F00a, M19F01, M19F02, M19F02, M19F03, M19F04, and M19F05. Note that only scenarios M1902, M19F03, and M19F05 include the data in the likelihood.

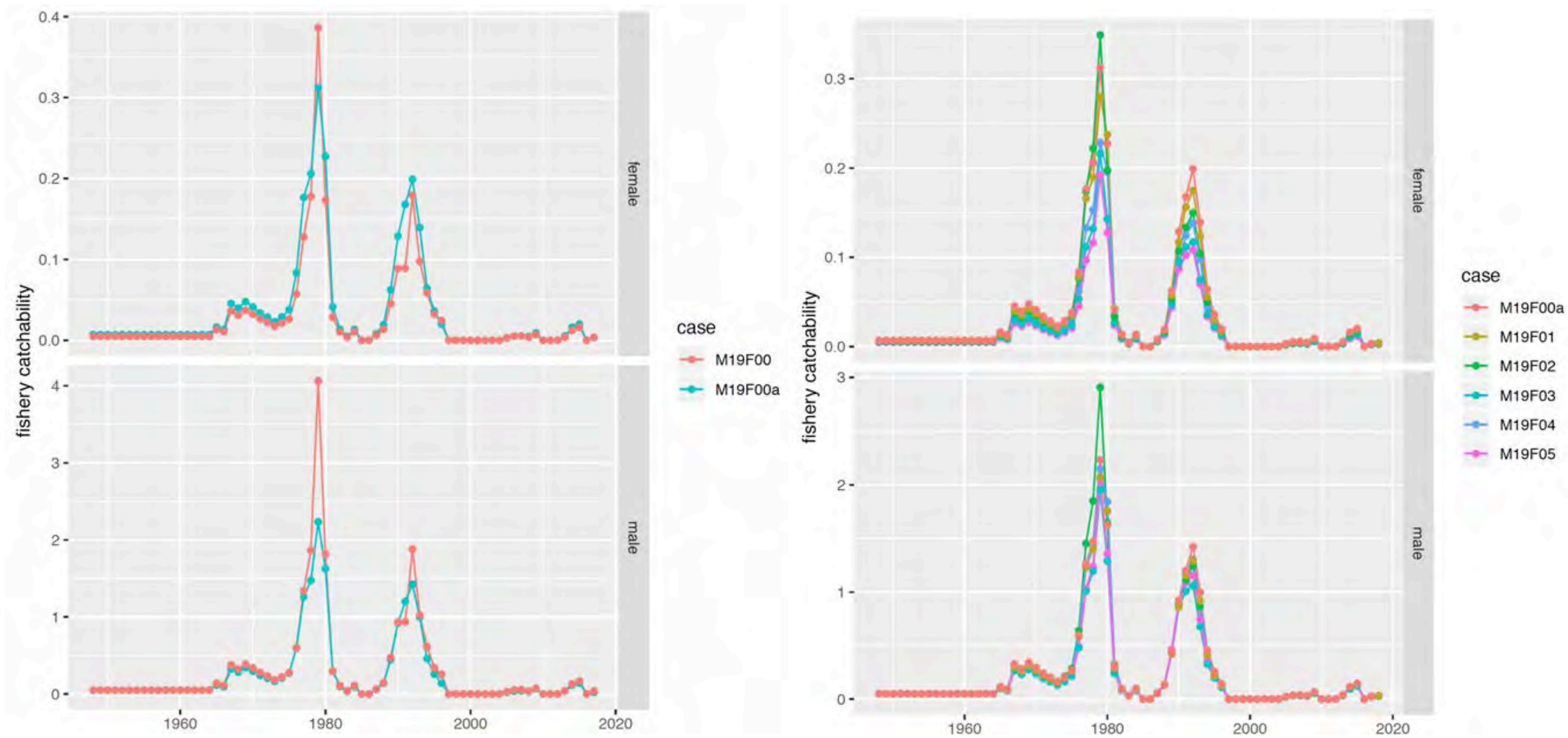


Figure 37. Directed fishery catchability (capture rates) from all model scenarios.

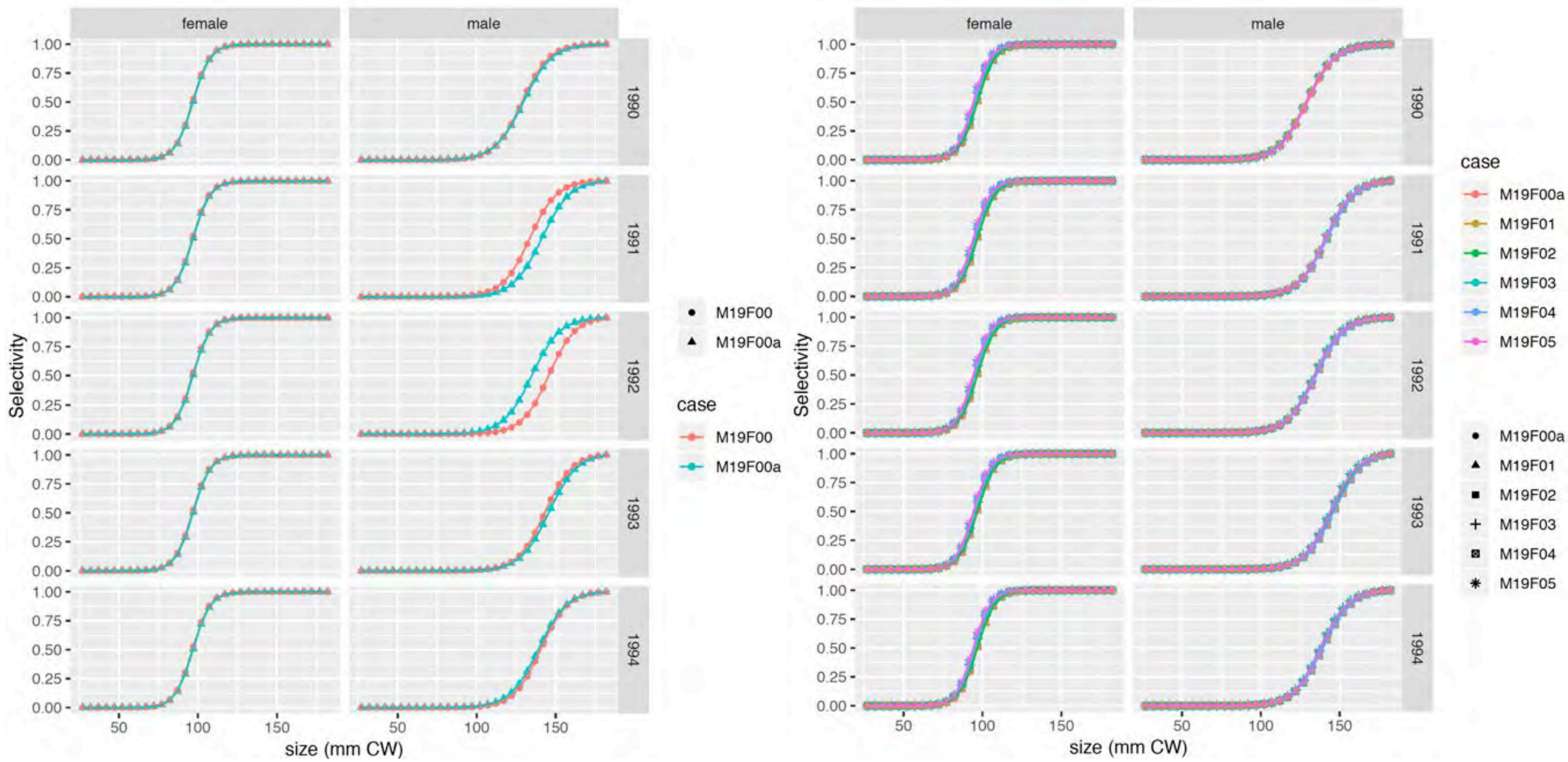


Figure 38. Directed fishery selectivity curves from all scenarios for the pre-1991 time period and 1991-1994. The 50%-selected parameter varies annually for 1991+.

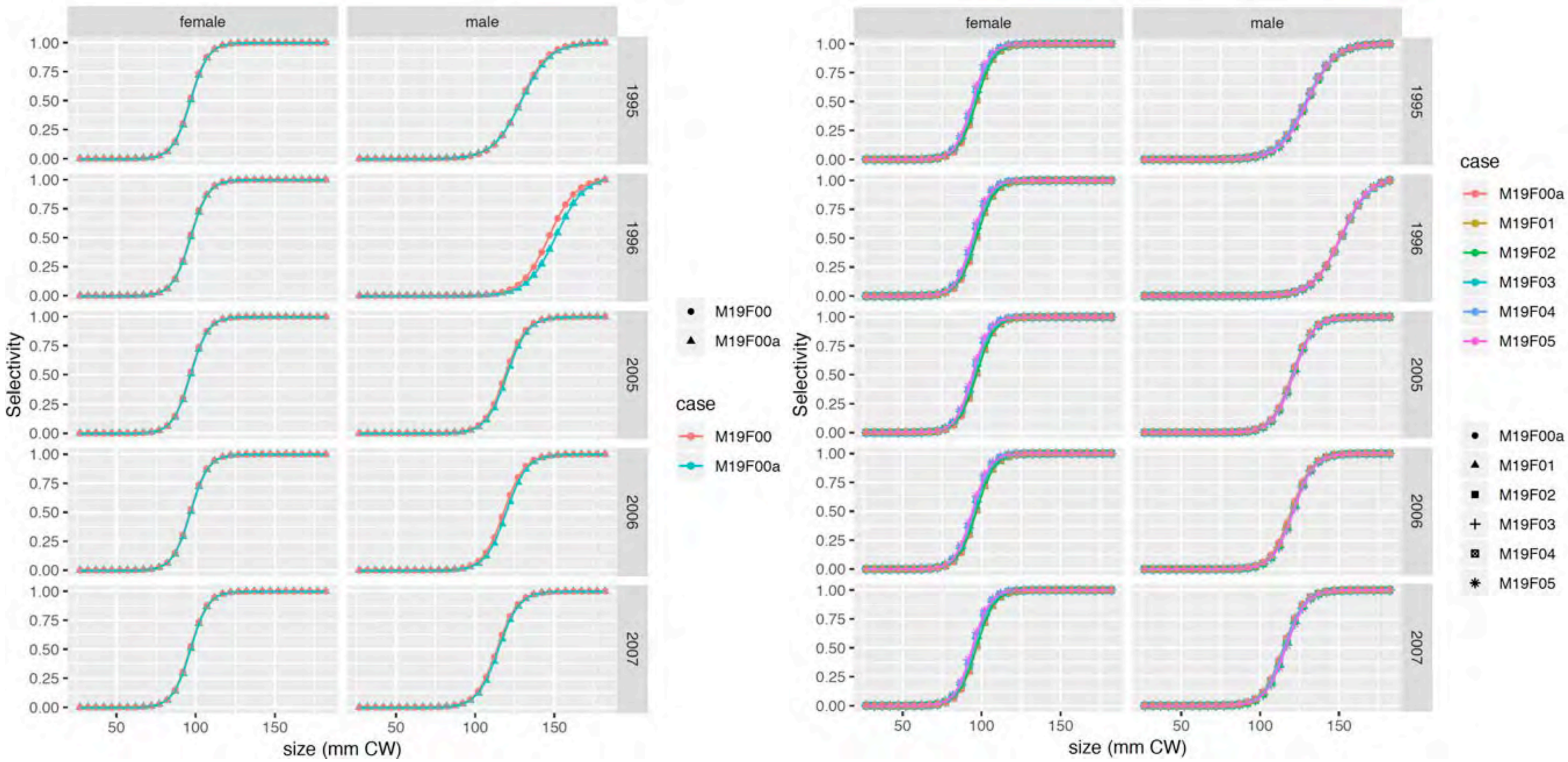


Figure 39. Directed fishery selectivity curves from all scenarios for 1995-1996 and 2005-2007. The 50%-selected parameter varies annually for 1991+.

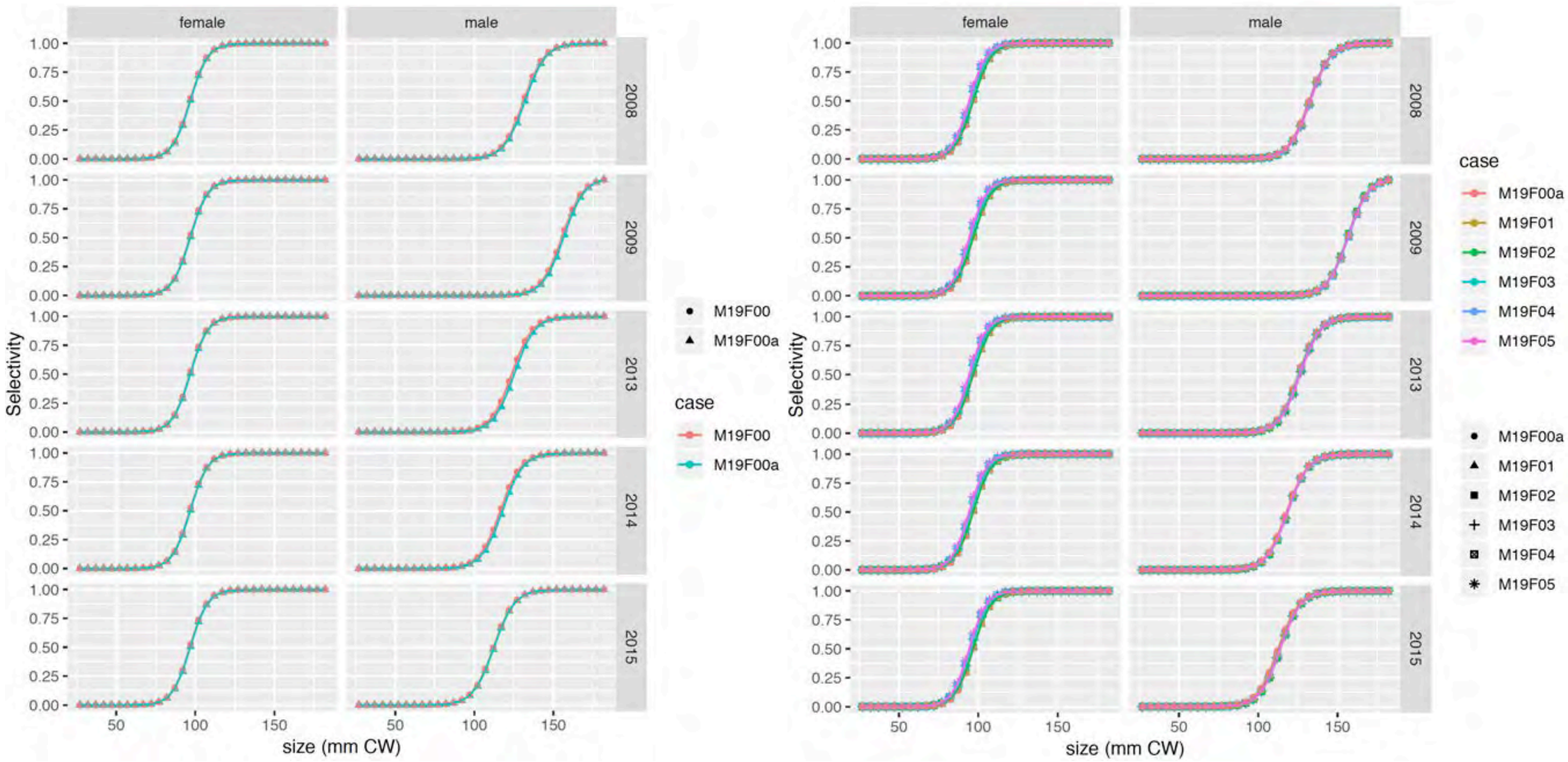
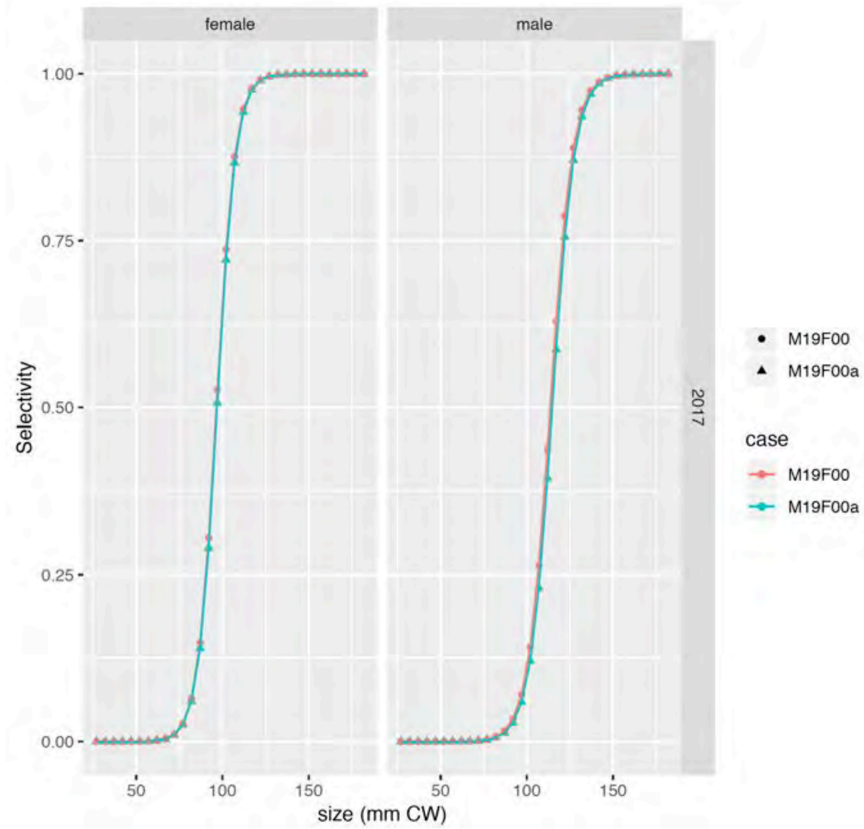


Figure 40. Directed fishery selectivity curves from all scenarios for 2008-2009 and 2013-2015. The 50%-selected parameter varies annually for 1991+.



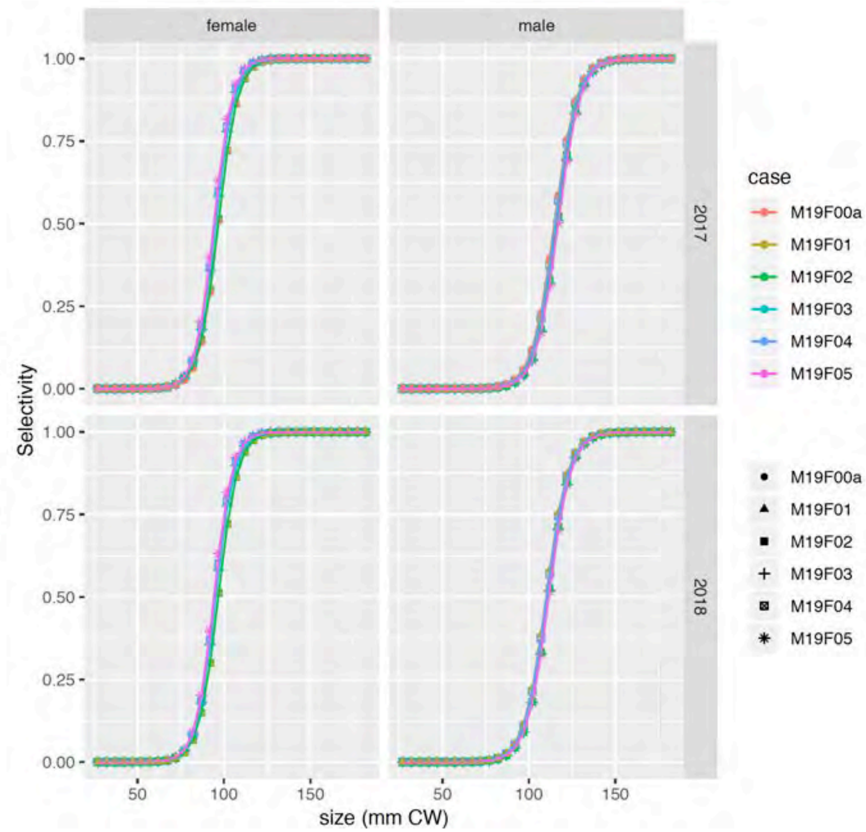


Figure 41. Directed fishery selectivity curves from all scenarios for 2008-2009 and 2013-2015. The 50%-selected parameter varies annually for 1991+.

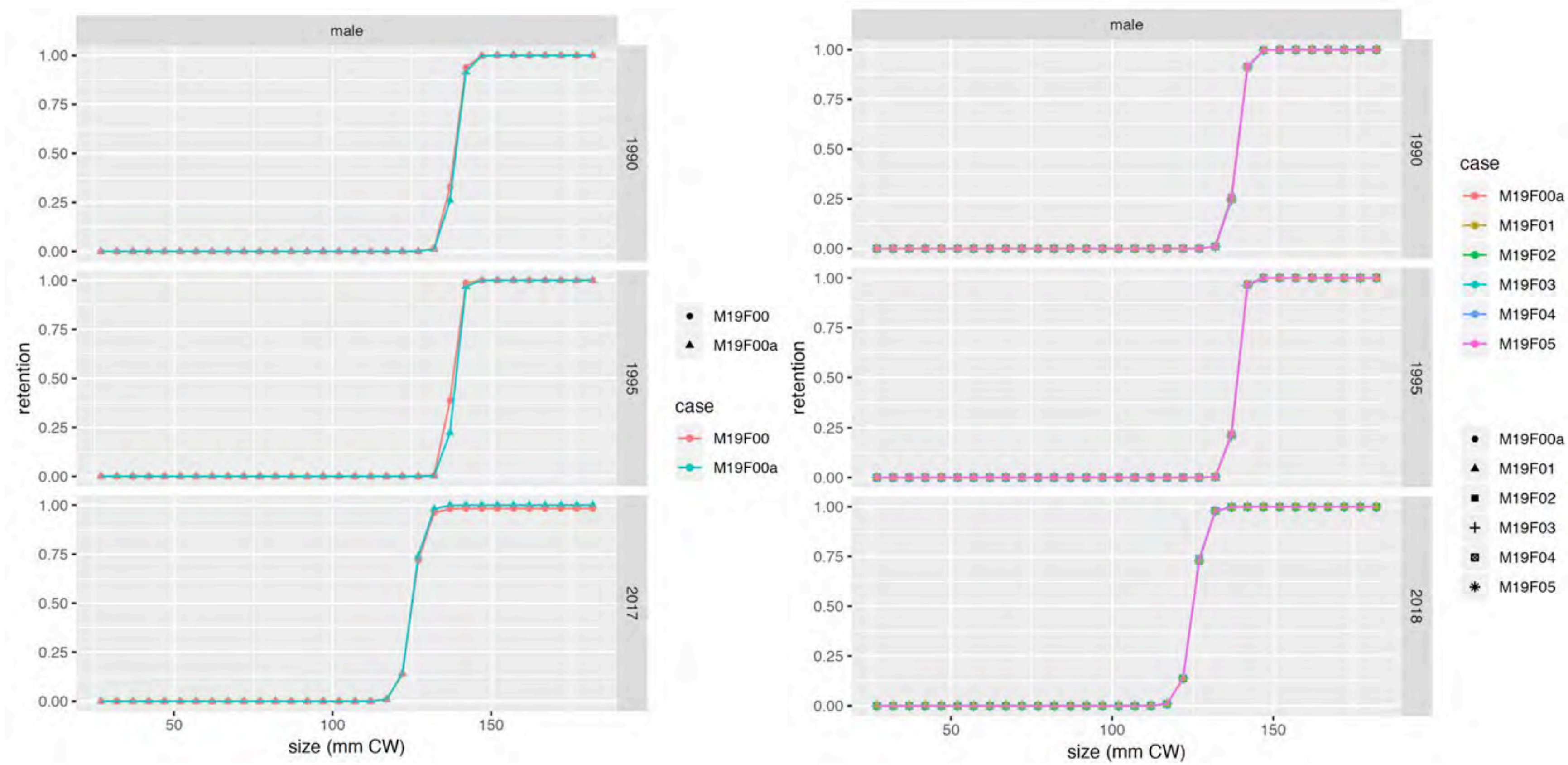
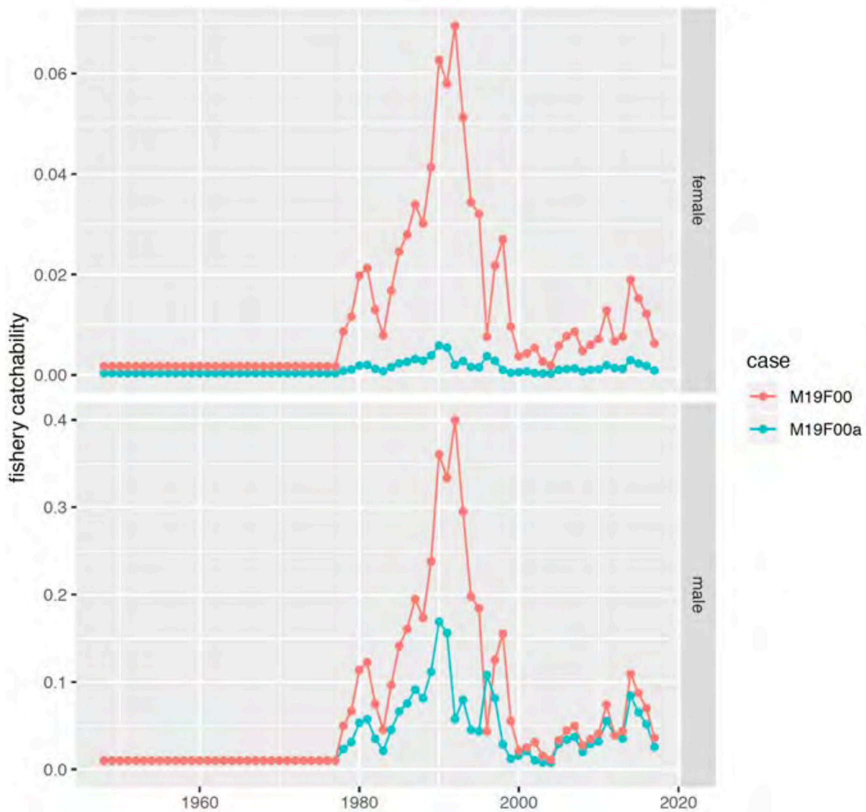


Figure 42. Directed fishery retention curves from all scenarios for the pre-1991, 1991-1996, and post-2004 time periods



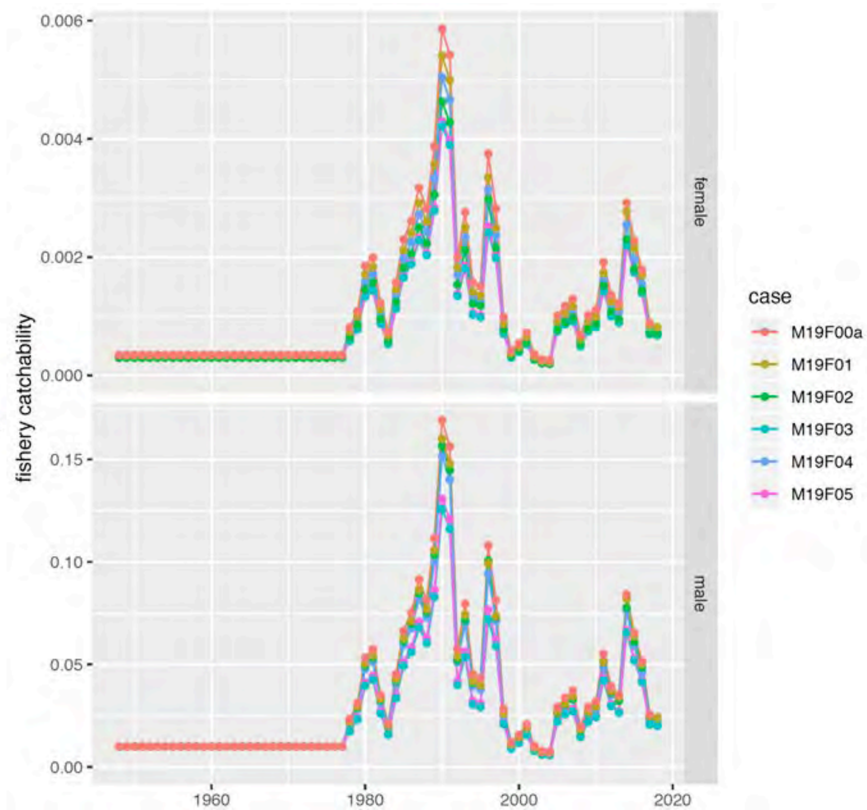


Figure 43. Snow crab fishery catchability (capture rates) from all scenarios.

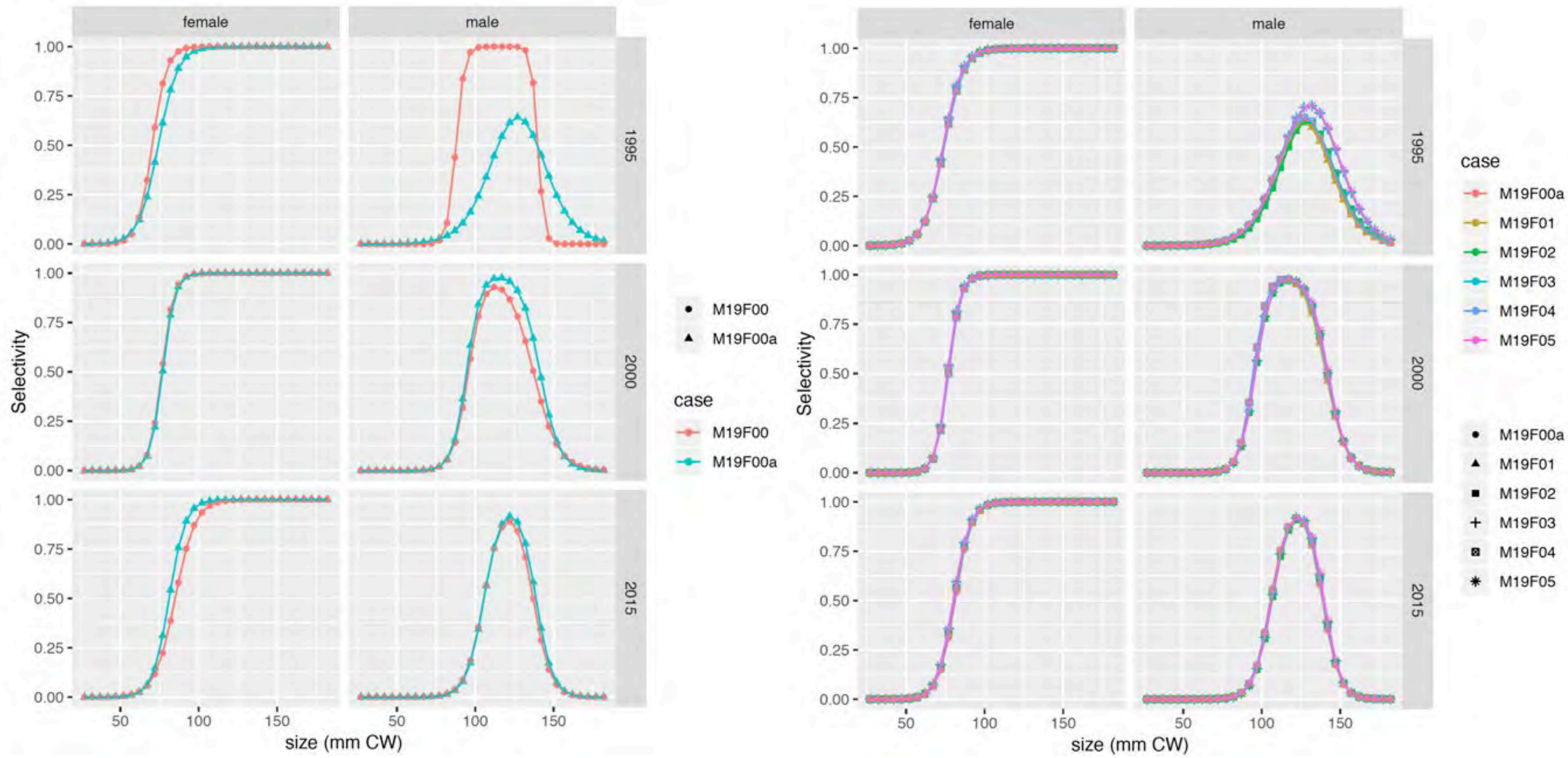


Figure 44. Snow crab fishery selectivity curves from all scenarios for 3 time periods: pre-1997, 1997-2004, 2005+.

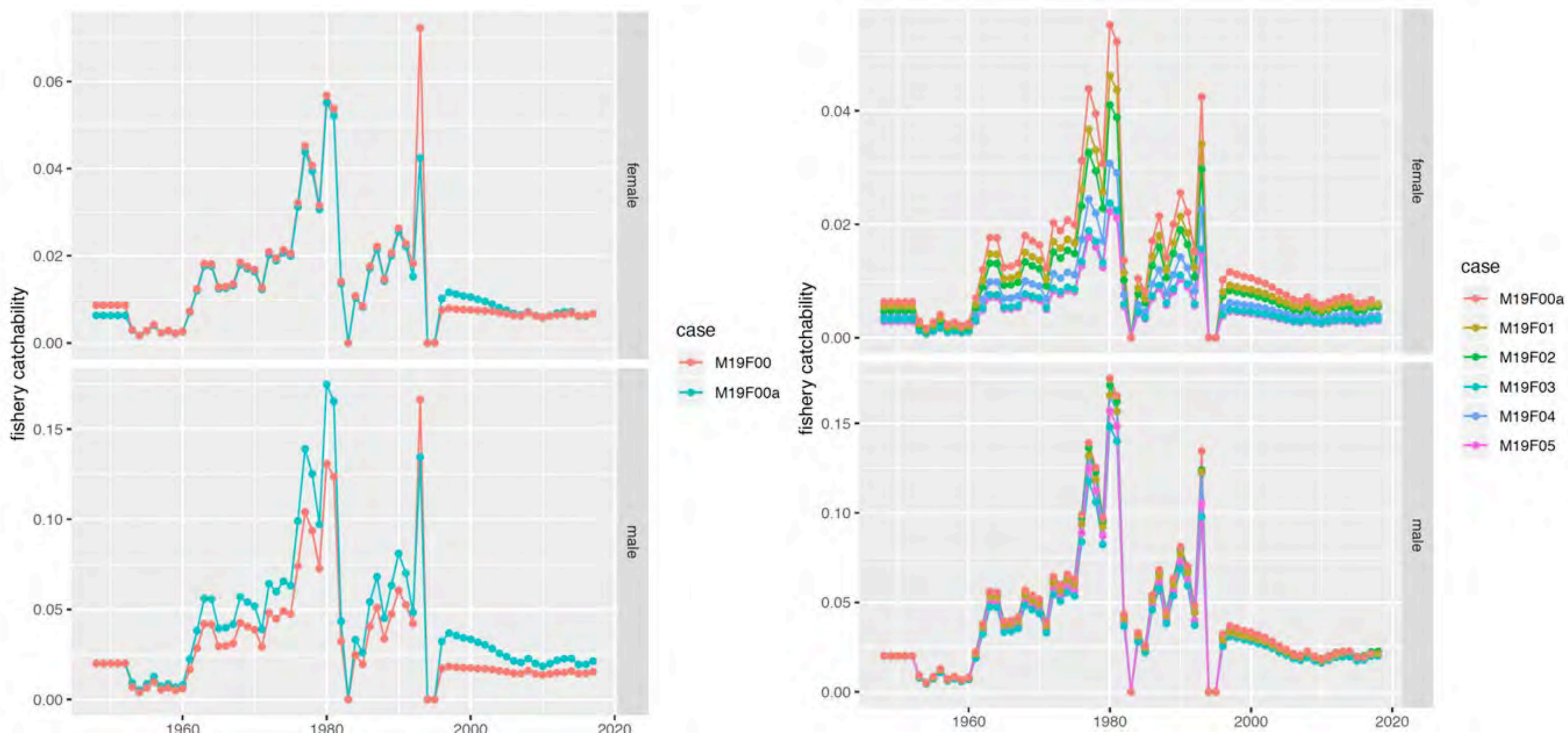


Figure 45. BBRKC fishery catchability (capture rates) from all scenarios.

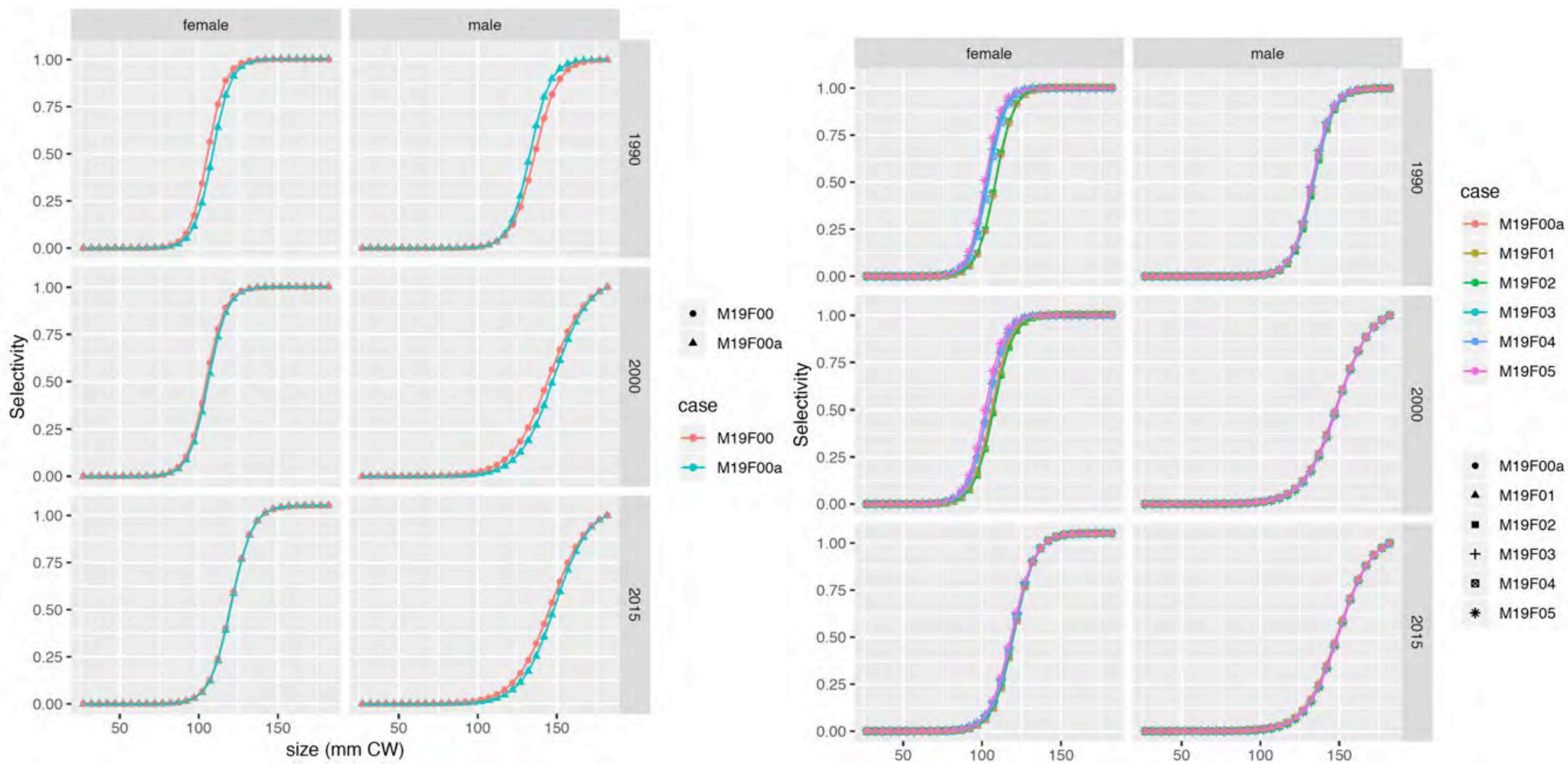


Figure 46. BBRKC fishery selectivity curves from all scenarios for 3 time periods: pre-1997, 1997-2004, 2005+.

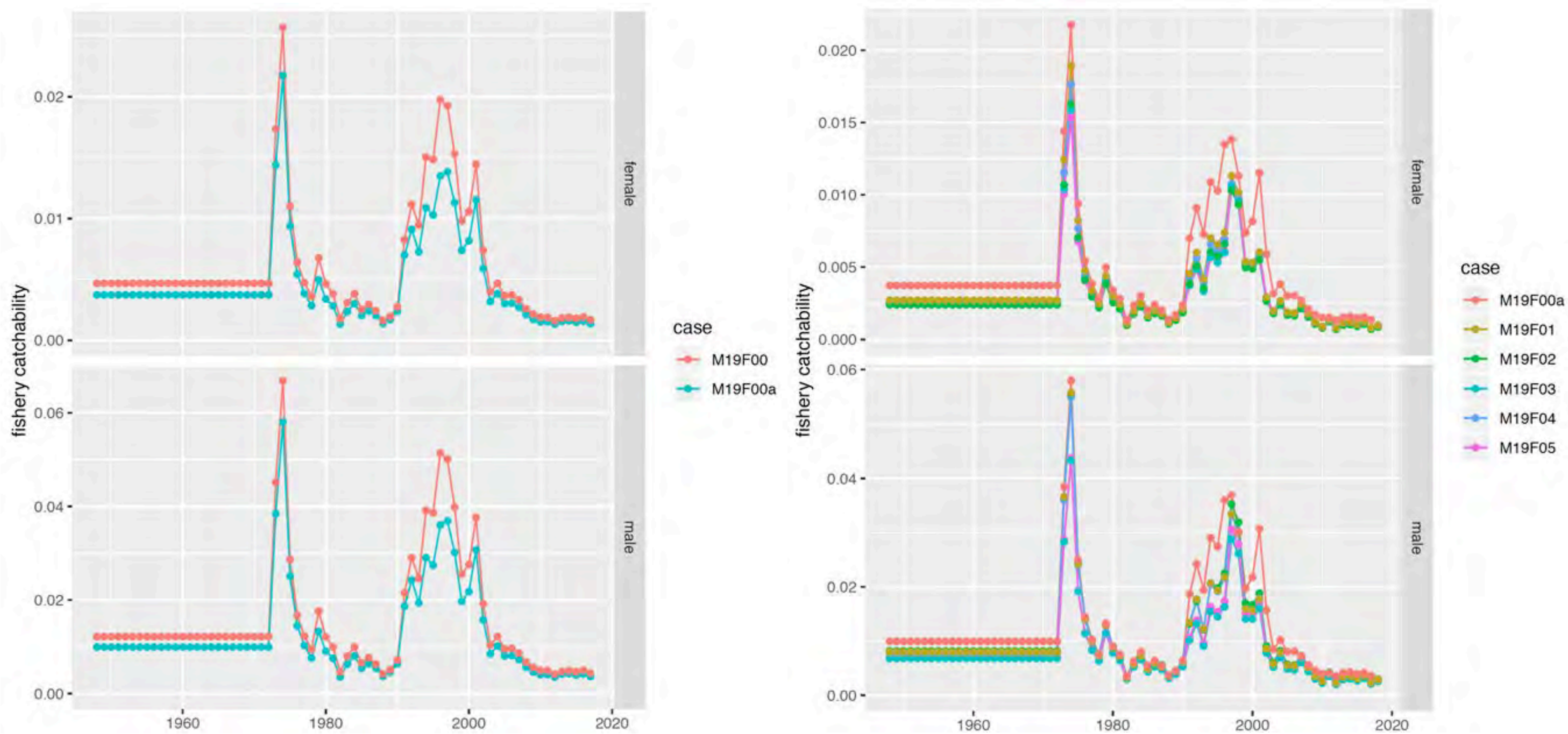
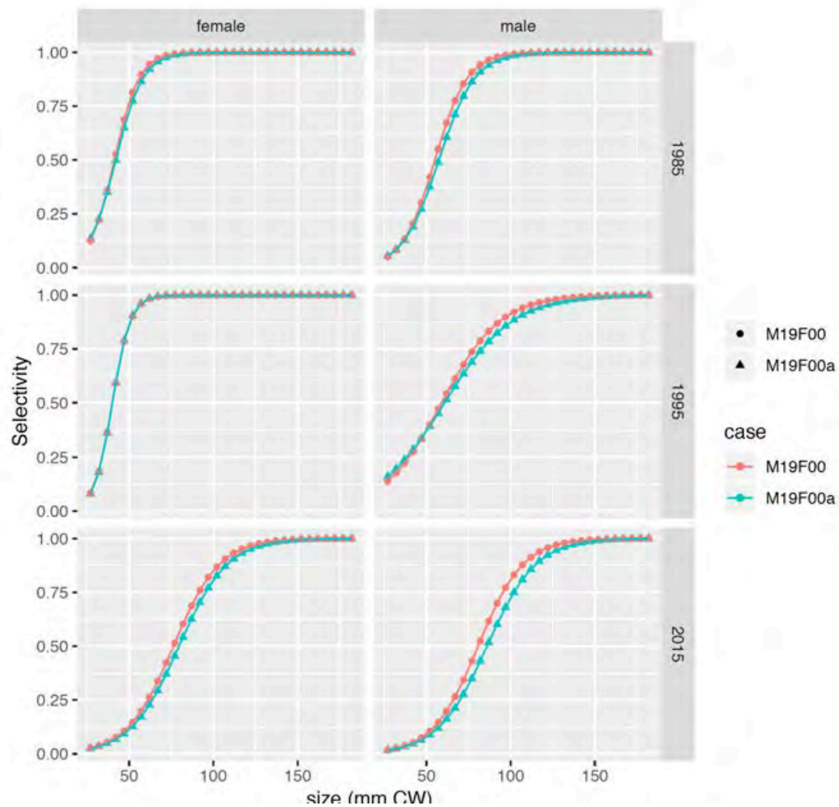


Figure 47. Catchability (capture rates) in the groundfish fisheries from all scenarios.



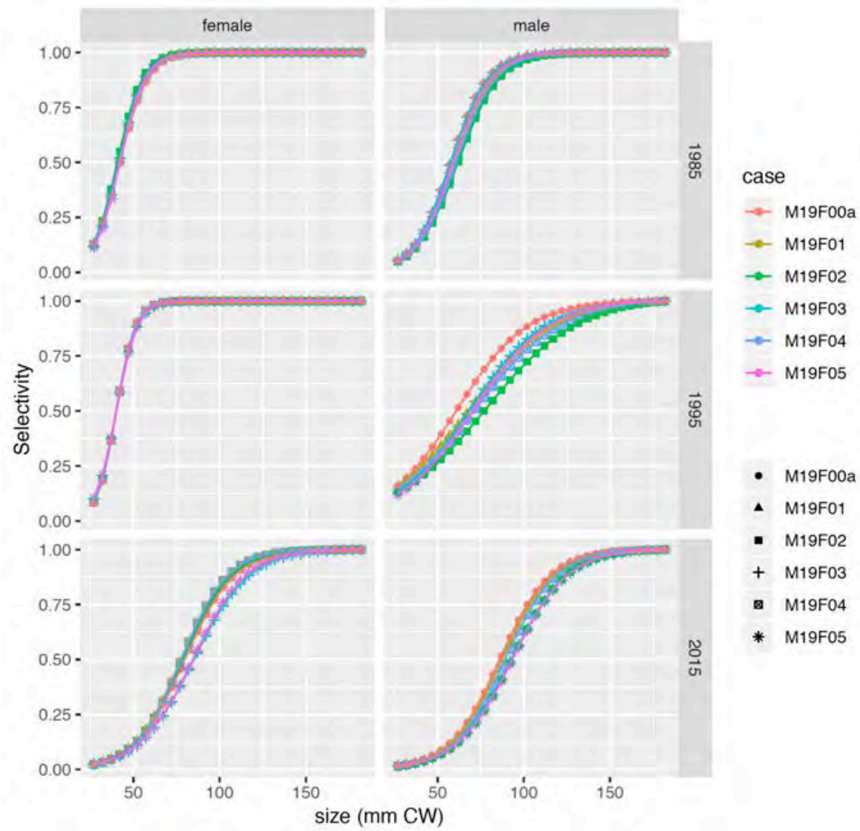
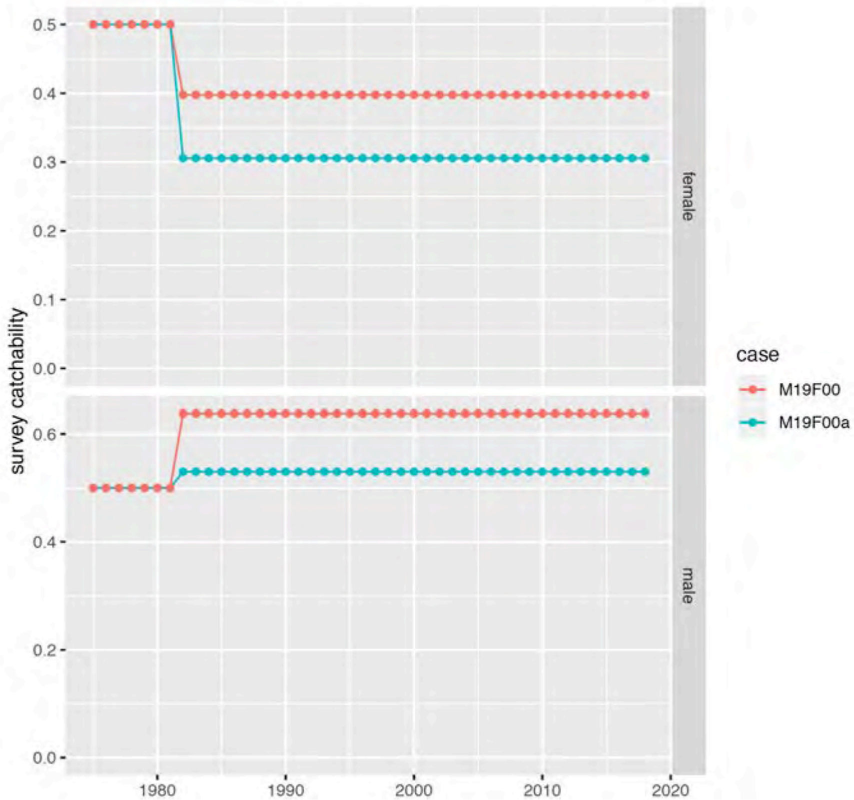


Figure 48. Groundfish fisheries selectivity curves from all scenarios estimated for 3 time periods: pre-1987, 1987-1996, 1997+.



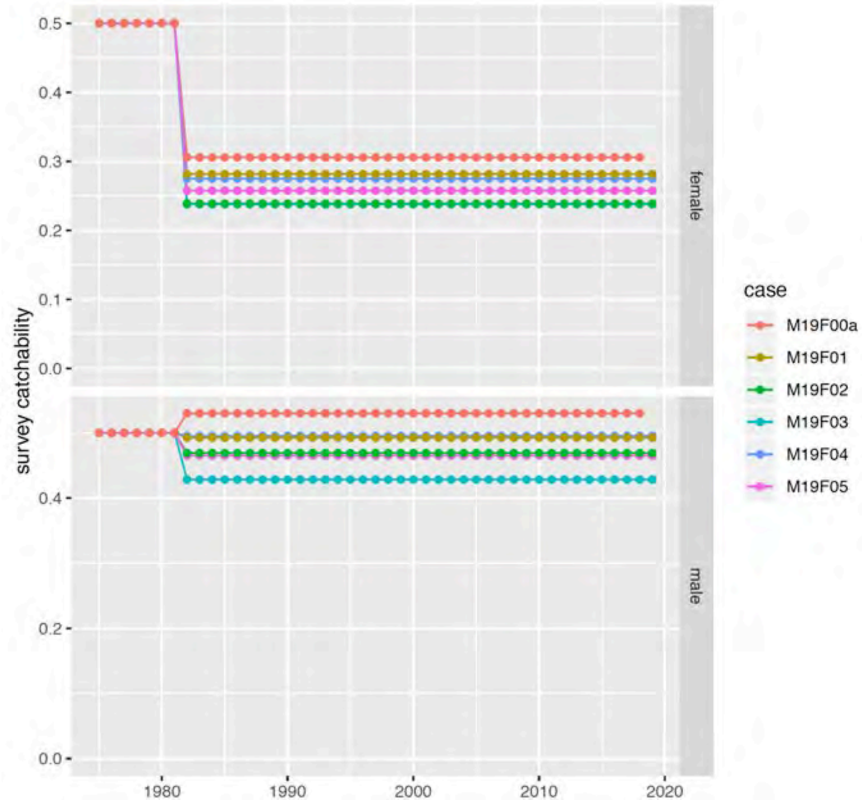
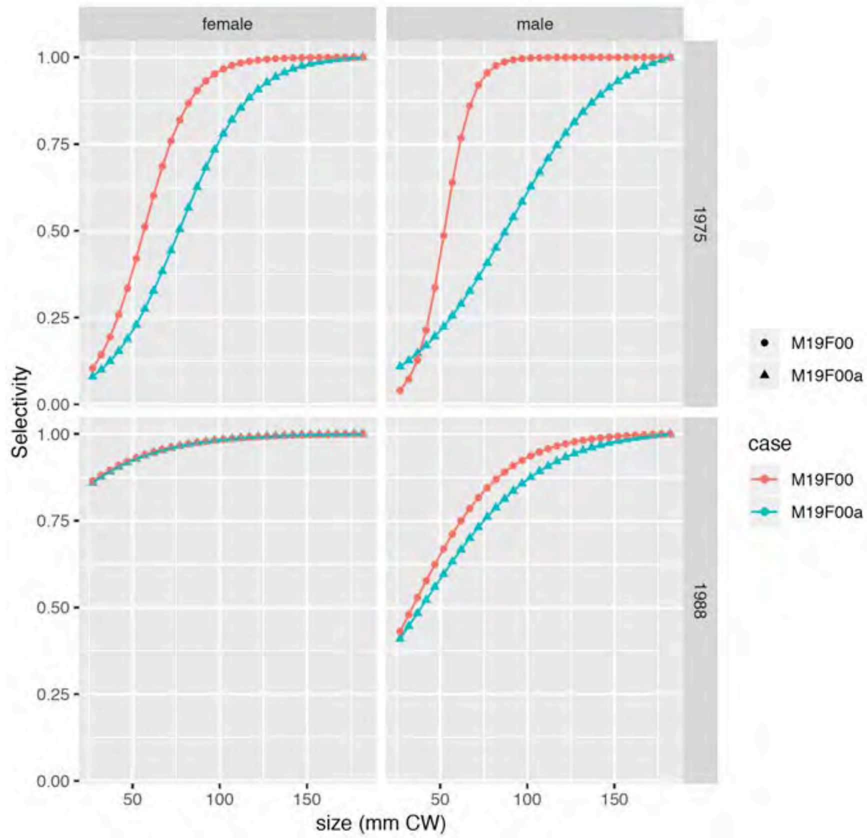


Figure 49. NMFS “0” survey catchabilities for all scenarios for the 1975-1981 and 1982+ time periods.



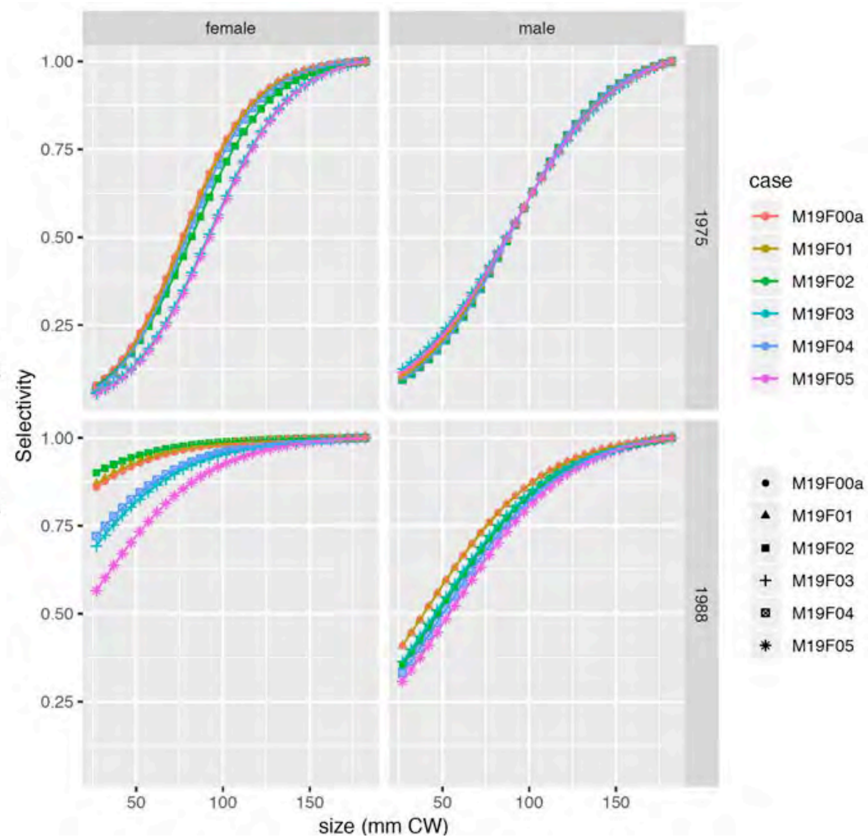


Figure 50. NMFS "0" survey selectivity functions for all scenarios for the 1975-1981 and 1982+ time periods.

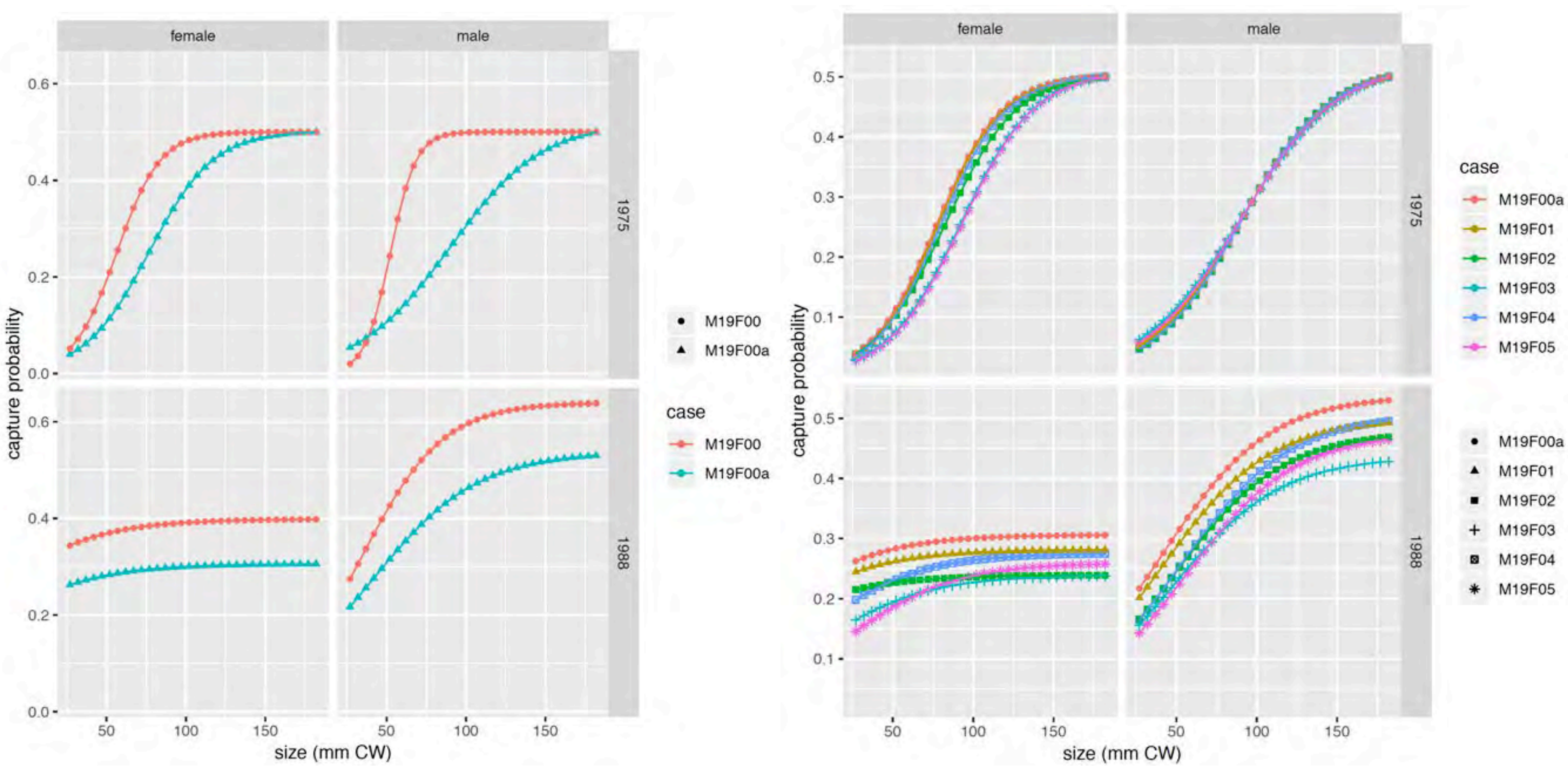


Figure 51. NMFS “0” survey capture probabilities (i.e., catchability *x* selectivity) for all scenarios for the 1975-1981 and 1982+ time periods.

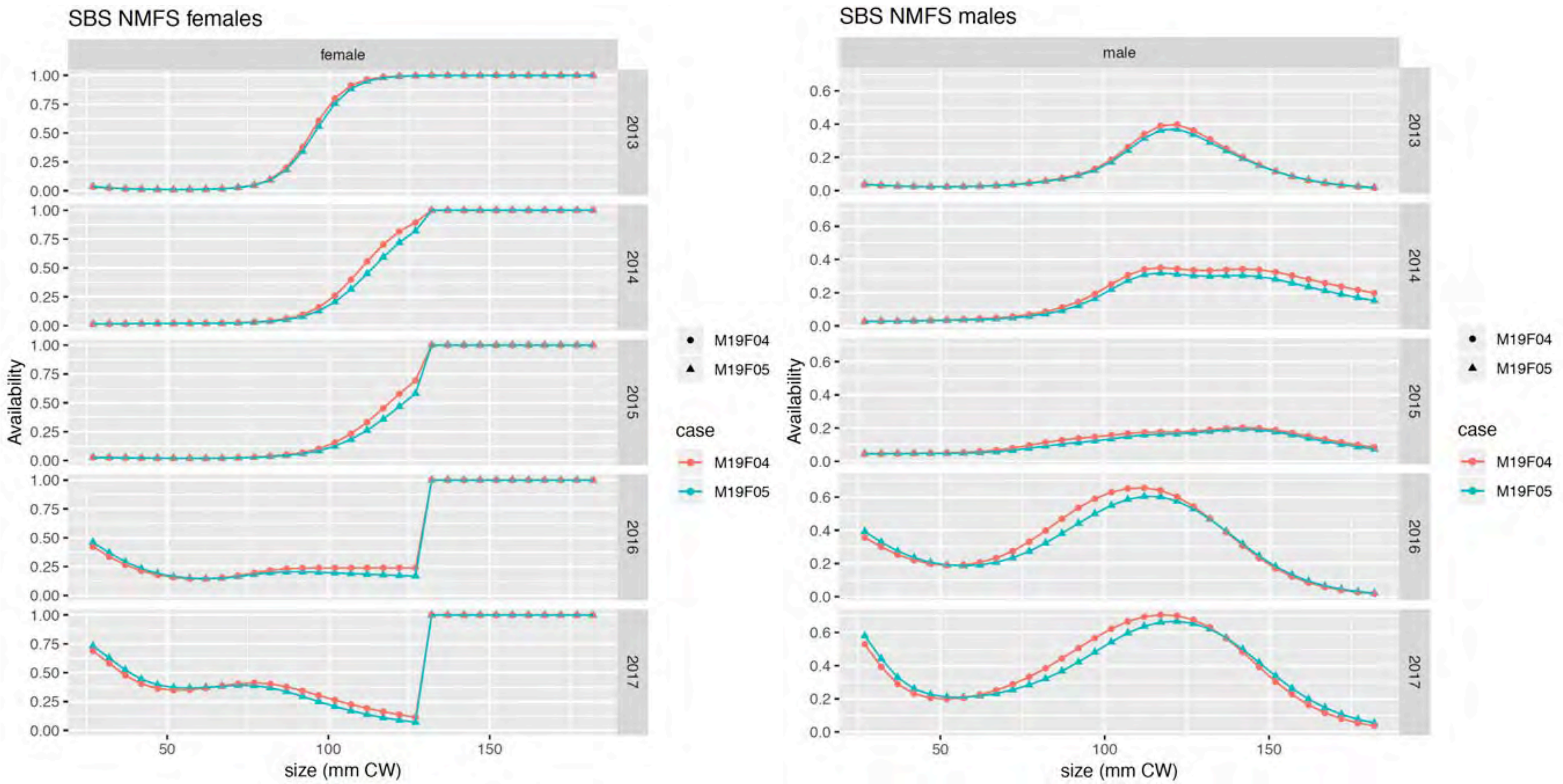


Figure 52. Survey availabilities from scenarios M19F04 and M19F05 for the 2013-2017 SBS studies.

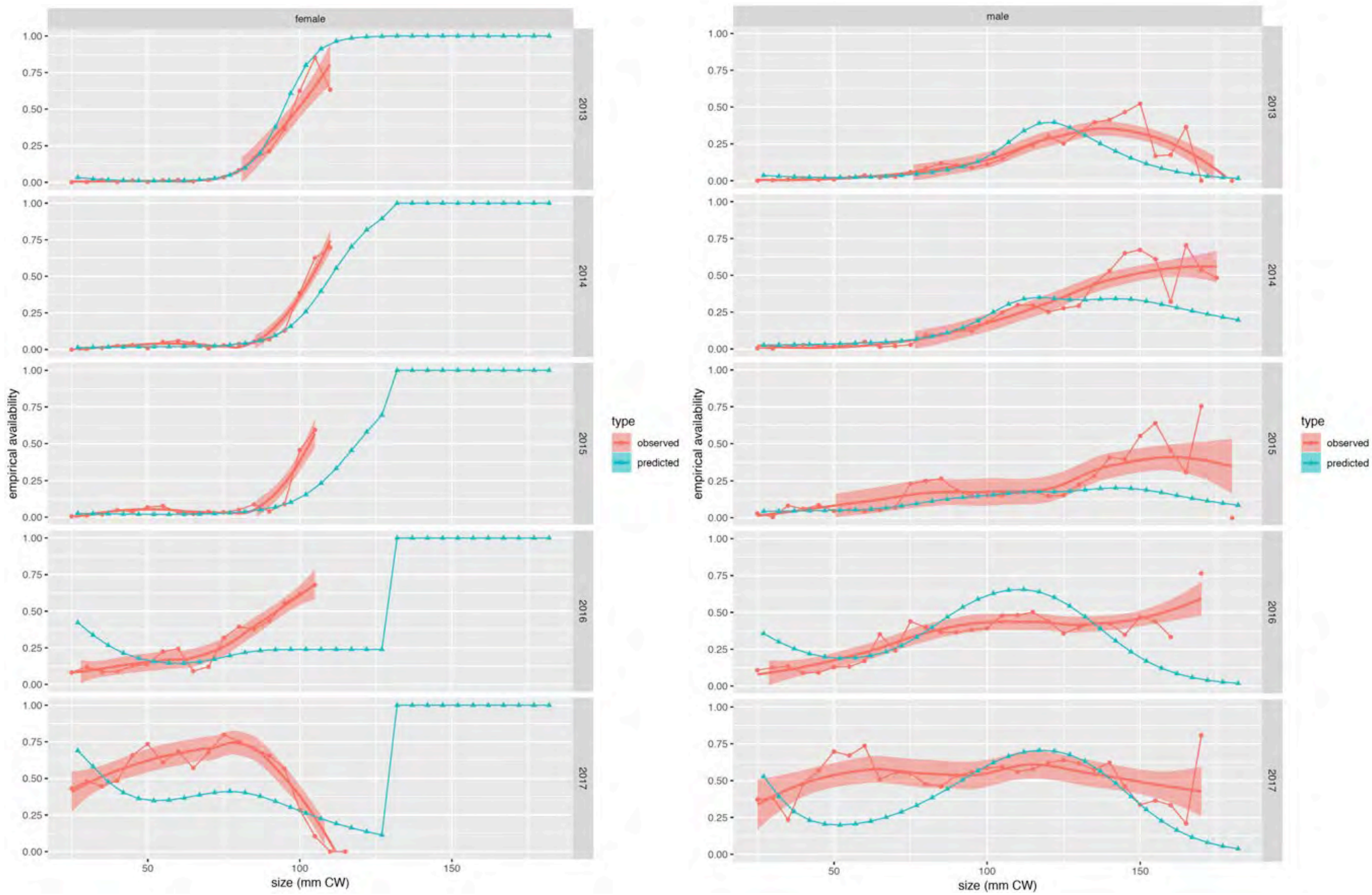


Figure 53. Comparison of empirical "observed" and predicted availability in the 2013-2017 SBS studies from scenario M19F04. The "observed" availability is the ratio of abundance in the NMFS SBS survey to that in the full NMFS survey by size bin. Observed: red points, lines. Red fills are from loess smoothing of the observed availability. Predicted: green points, lines.

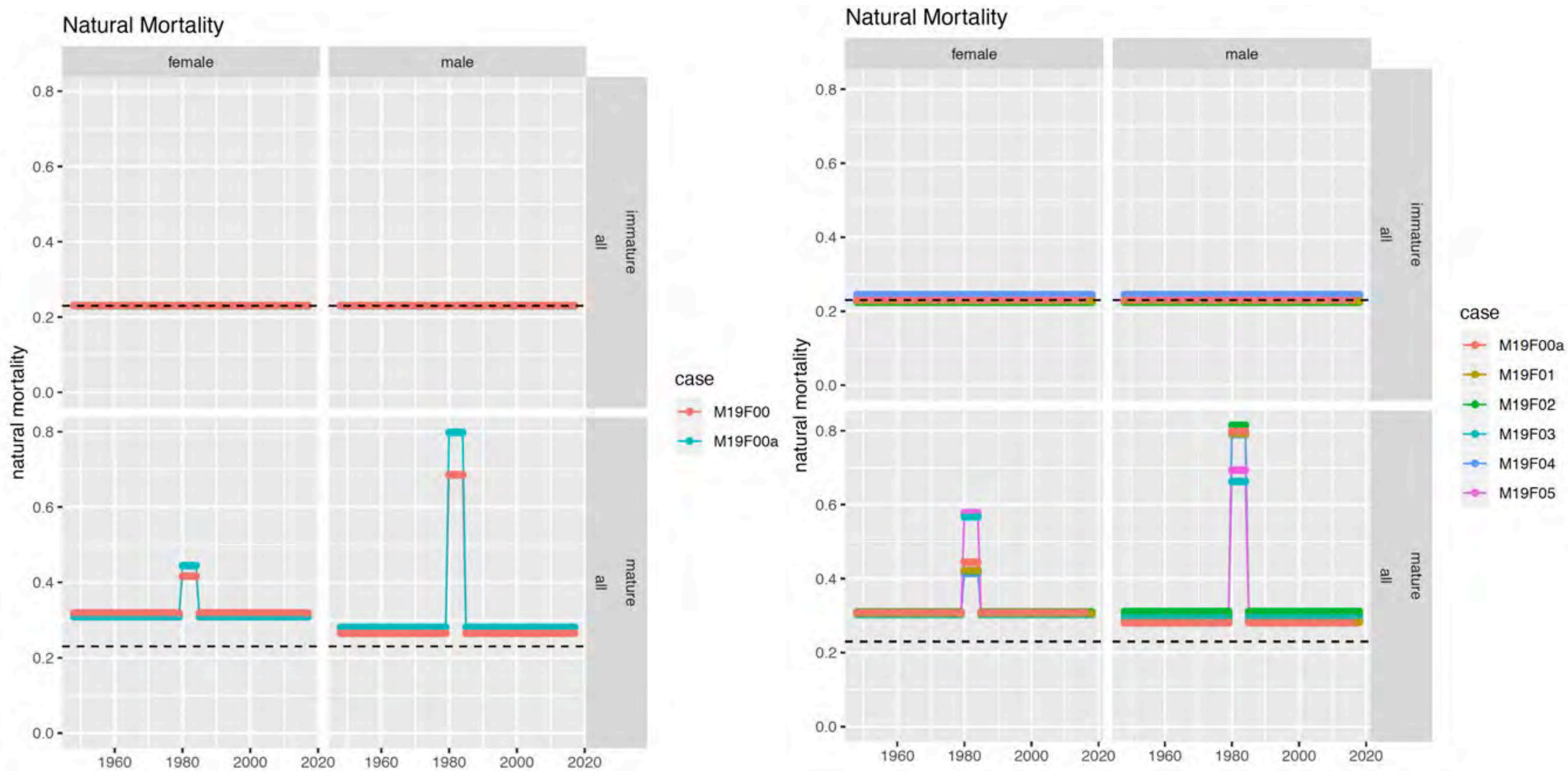
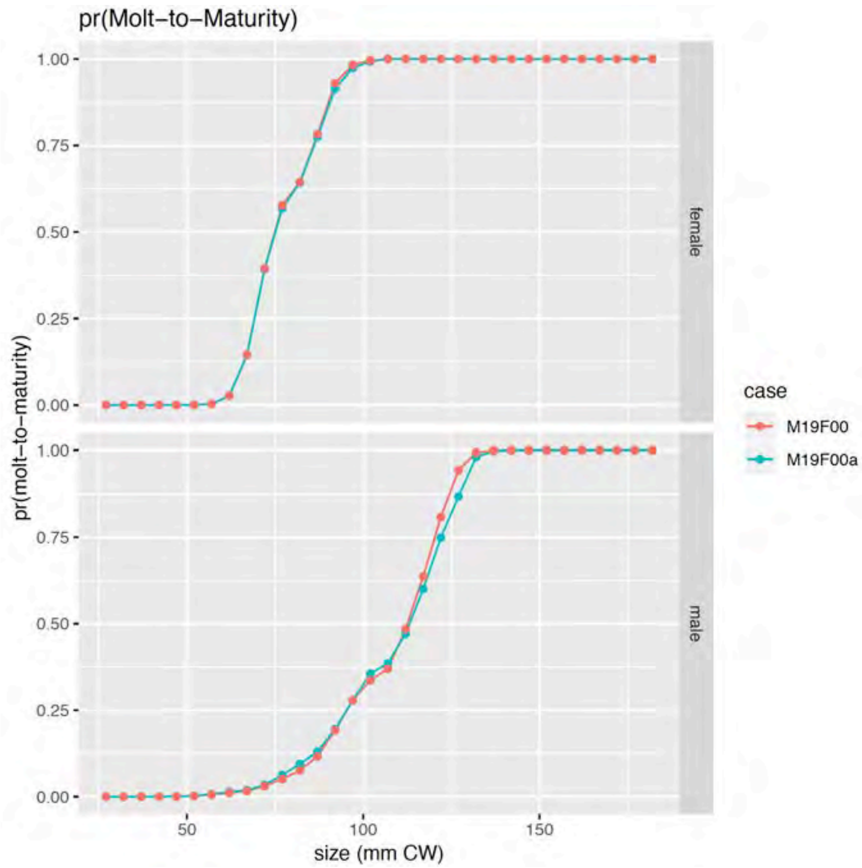


Figure 54. Estimates of natural mortality from all scenarios.



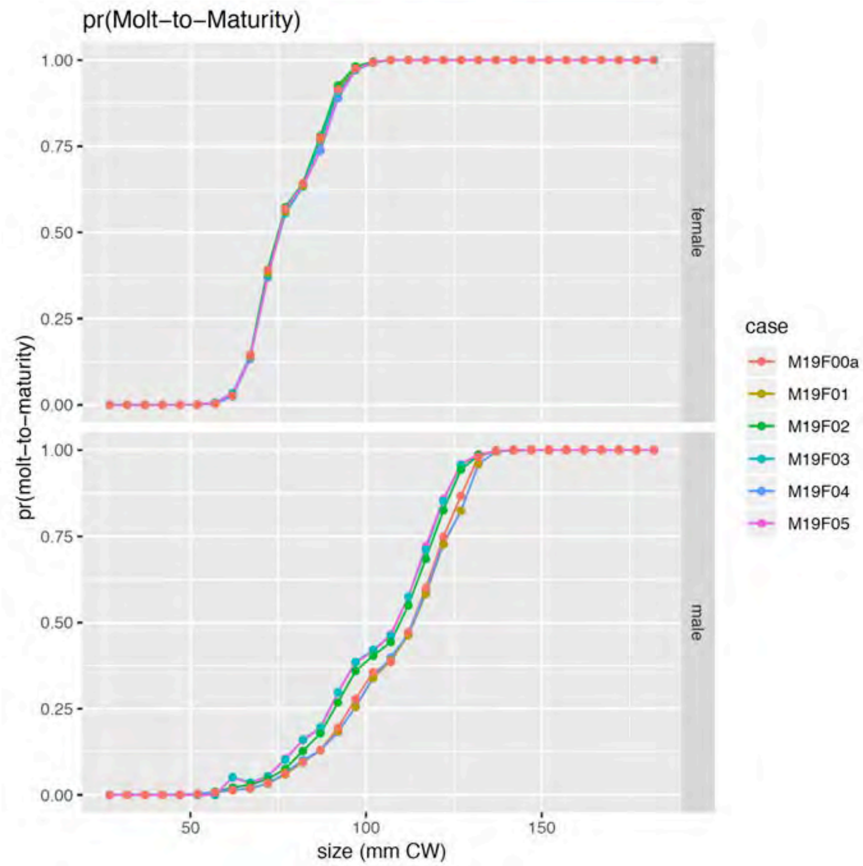


Figure 55. Estimates of the probability of terminal molt from all scenarios.

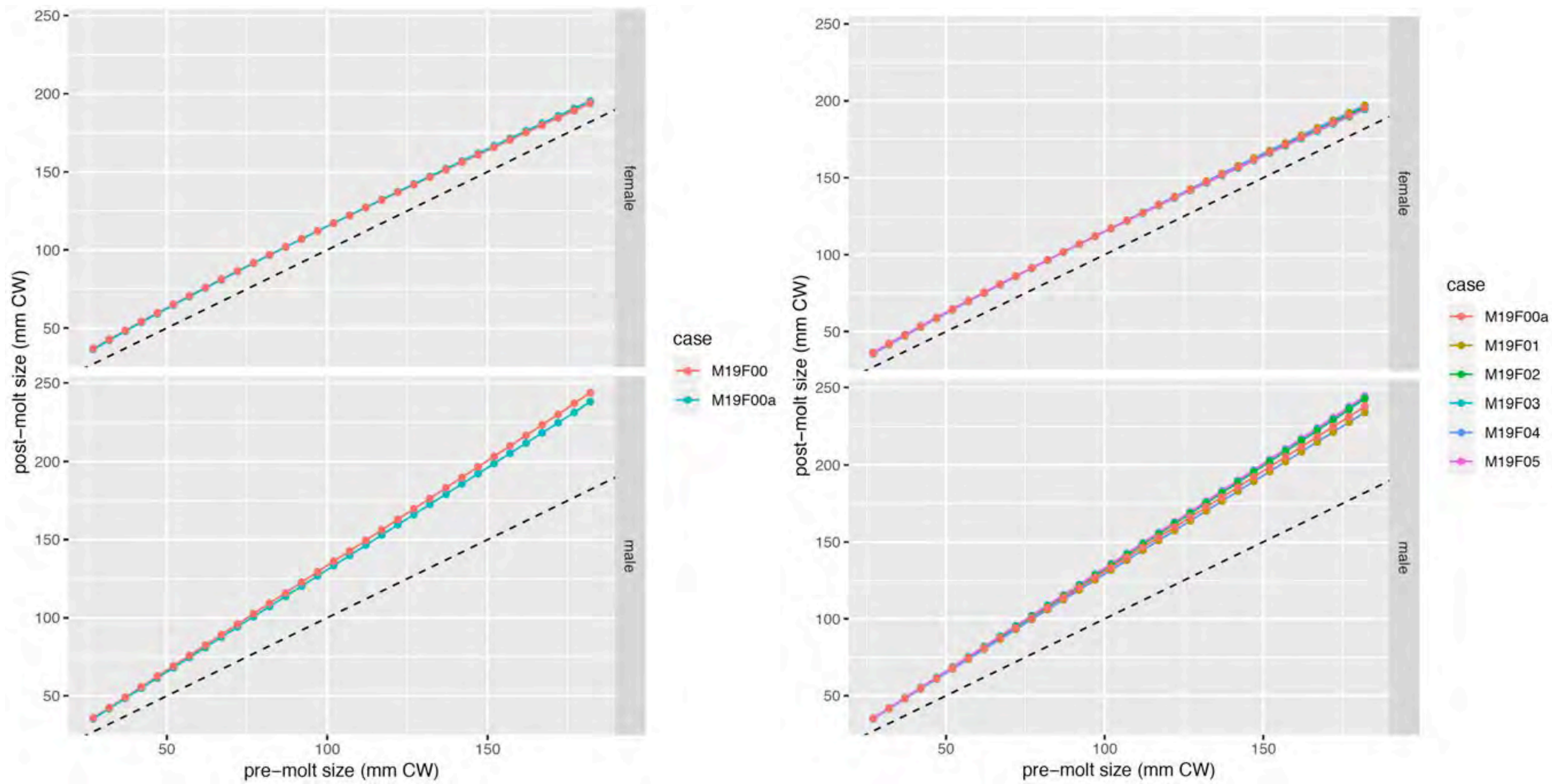
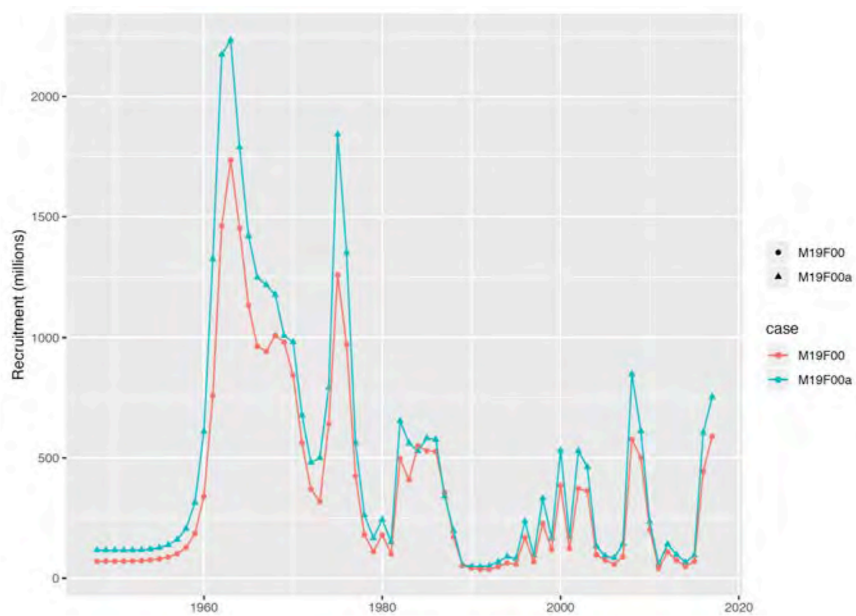


Figure 56. Estimates of mean growth from all scenarios. Dashed line is 1:1.



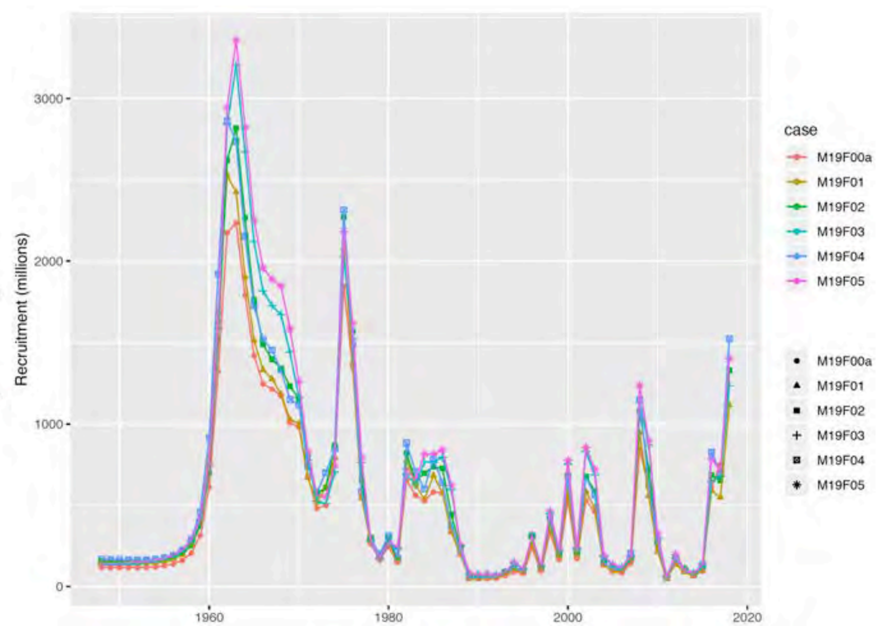
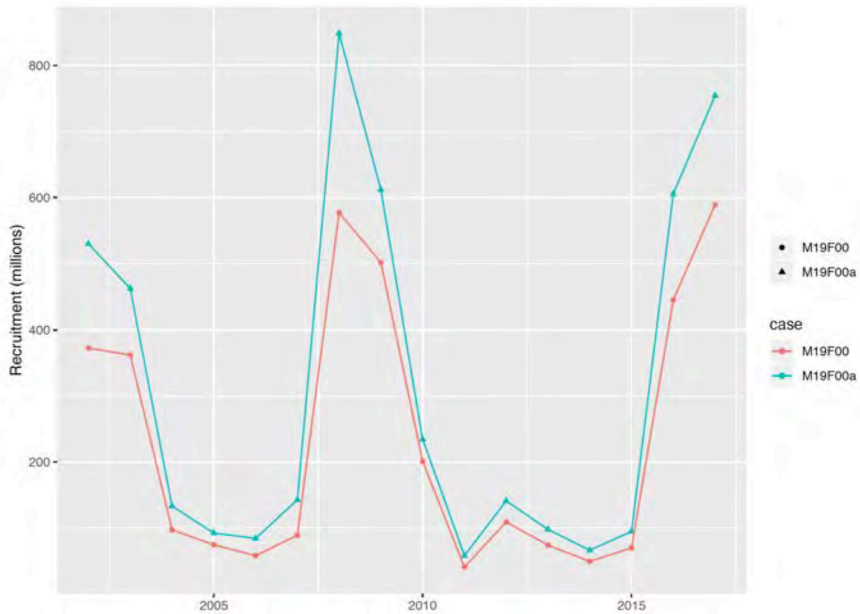


Figure 57. Estimated recruitment time series from all scenarios.



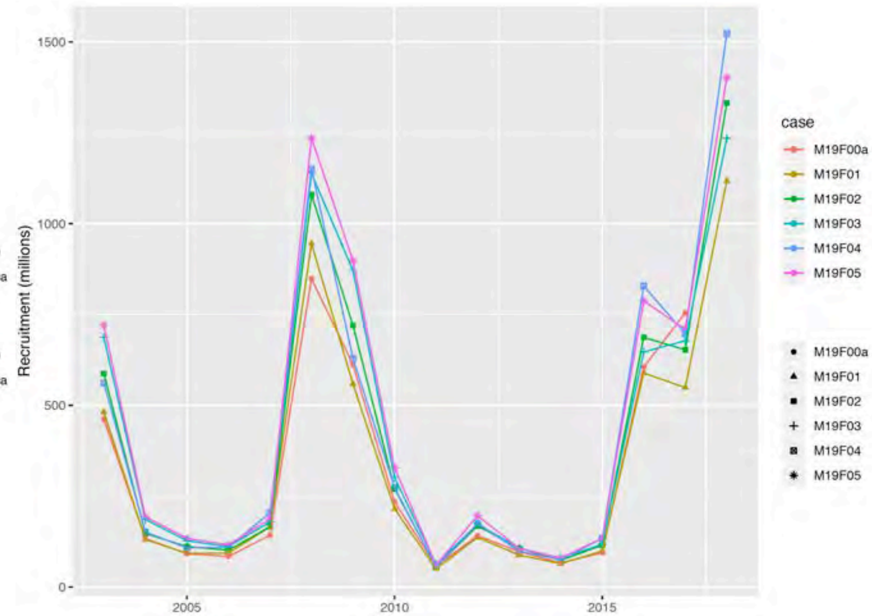


Figure 58. Estimated recent recruitment time series from all scenarios.

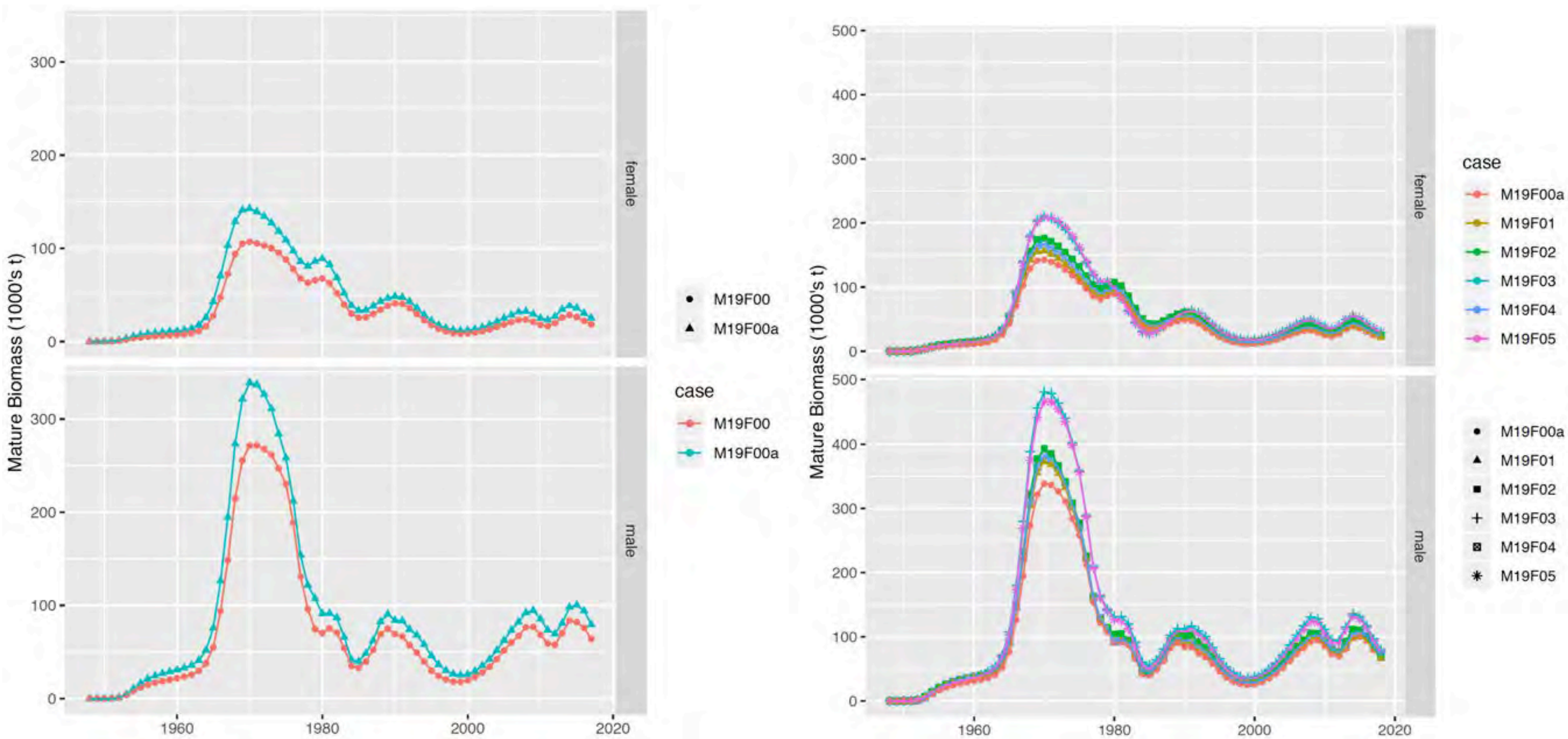


Figure 59. Estimated (Feb. 15) mature biomass time series from all scenarios.

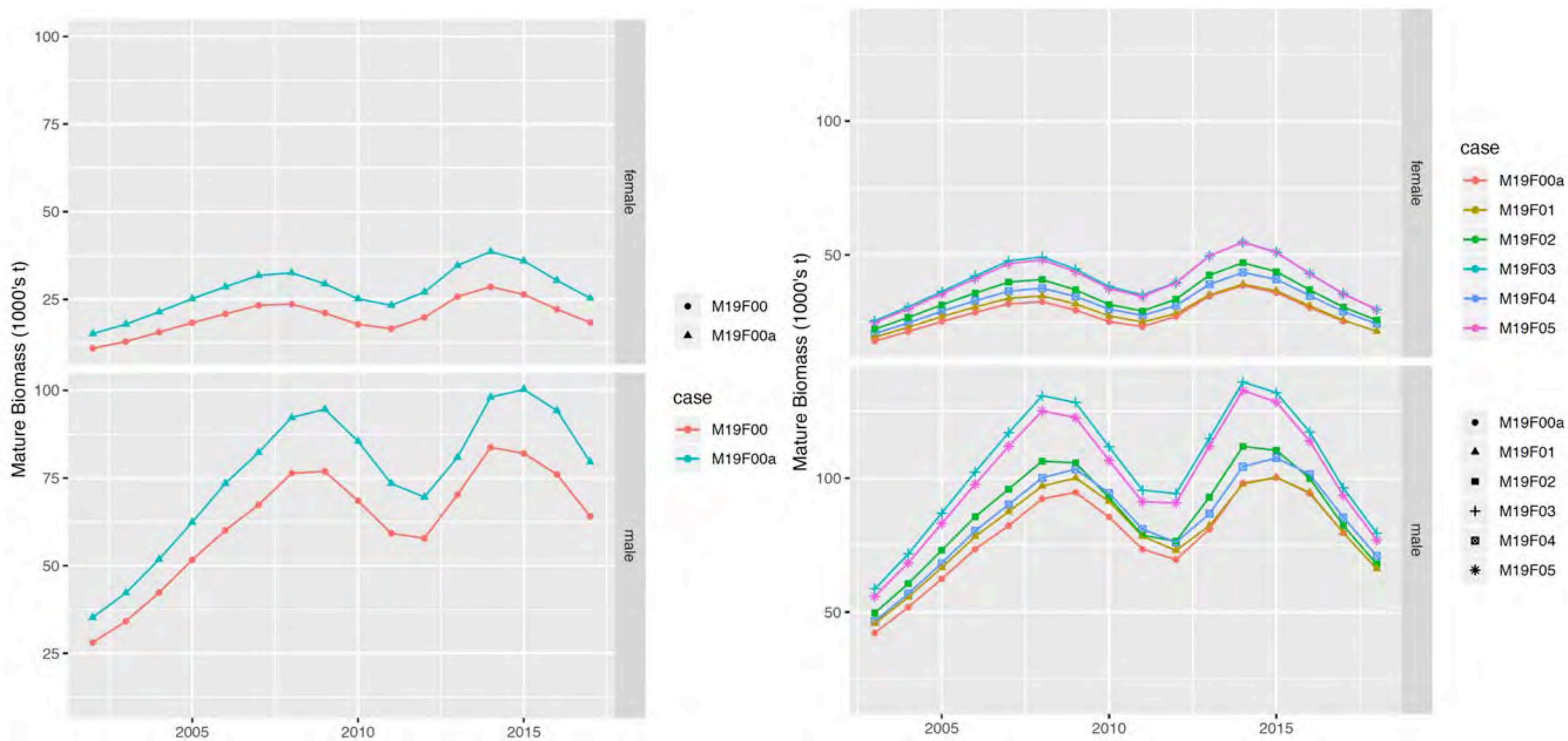


Figure 60. Estimated recent (Feb. 15) mature biomass time series from all scenarios.

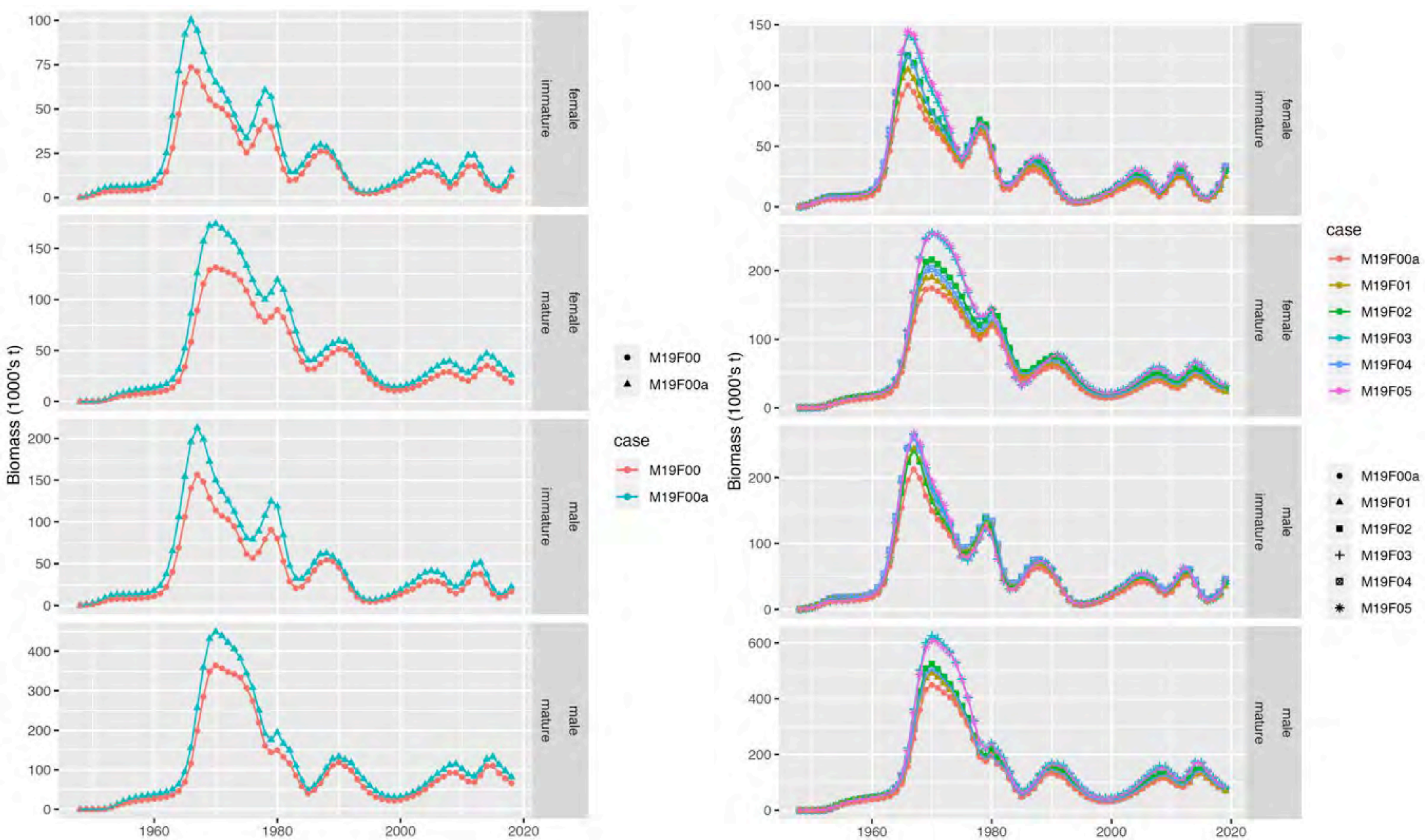


Figure 61. Estimated (July 1) biomass time series by population category for all scenarios.

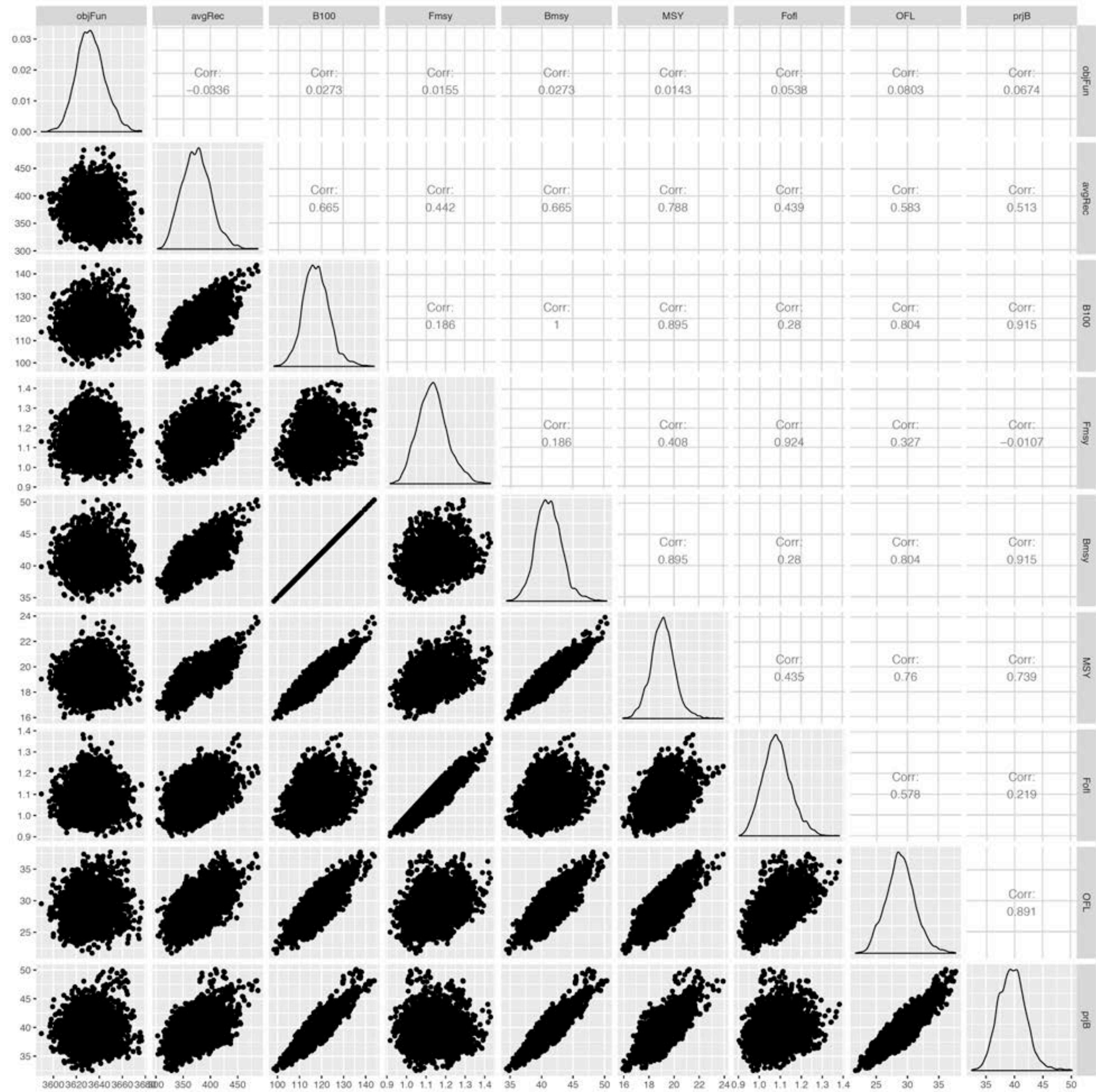


Figure 62. MCMC results from scenario M19F03, the author's preferred model, for OFL-related quantities.

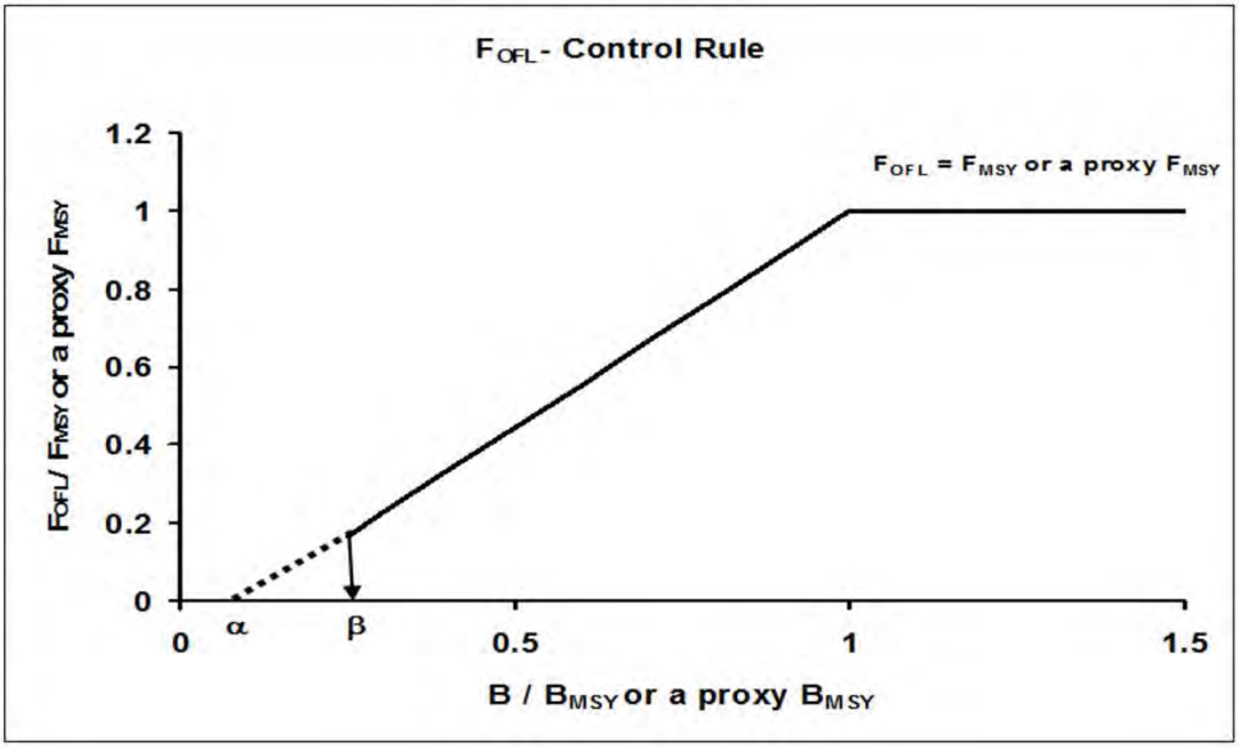


Figure 63. The F_{OFL} harvest control rule.

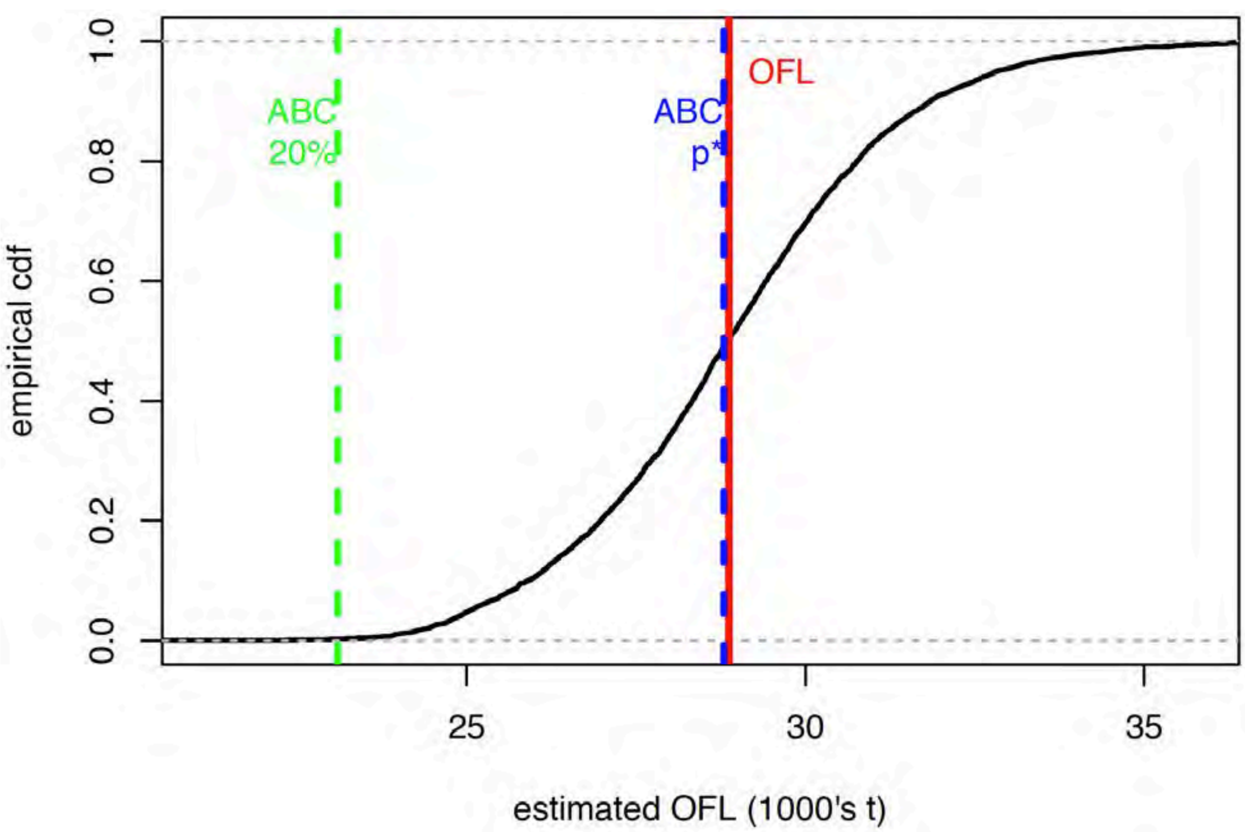


Figure 64. The OFL and ABC from the author's preferred model, scenario M19F03.

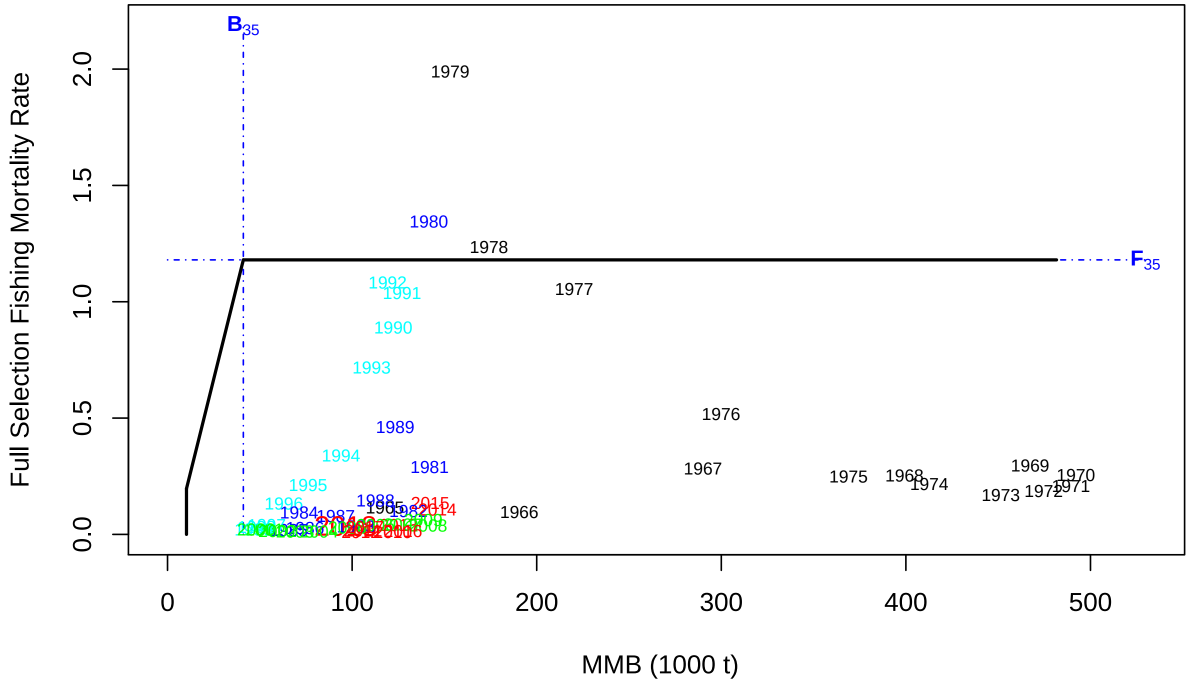


Figure 65. Quad plot for the author's preferred model, scenario M19F03.

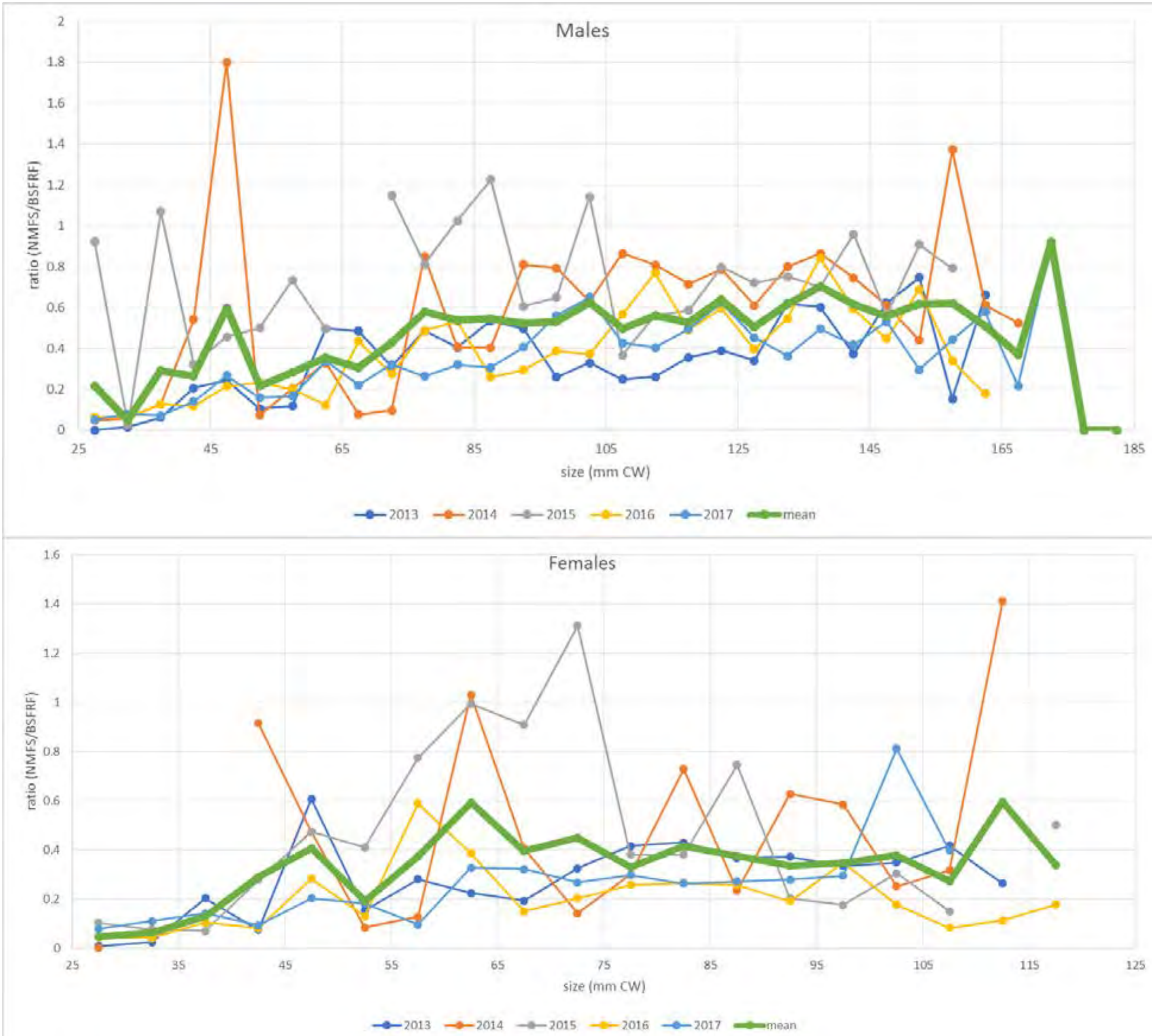


Figure 66. The ratio of estimated abundance by size from the NMFS and BSFRF side-by-side catchability studies. The heavy green line is the size-specific mean over the 5 years. These represent simple empirical estimates of the size-specific catchability of the NMFS survey gear relative to the BSFRF gear. If the BSFRF survey gear is assumed to capture all crab within the area swept, these curves represent empirical estimates of the size-specific NMFS survey gear catchability (i.e., fully selected catchability [q] *x* selectivity).

Appendix A:
Description of the Tanner Crab Stock Assessment Model, Version 2

September, 2019

Introduction

The "TCSAM02" (Tanner Crab Stock Assessment Model, version 2) modeling framework was developed "from scratch" to eliminate many of the constraints imposed on potential future assessment models by TCSAM2013, the previous assessment model framework (Stockhausen, 2016). Like TCSAM2013, TCSAM02 uses AD Model Builder libraries as the basis for model optimization using a maximum likelihood (or Bayesian) approach. The model code for TCSAM02 is available on GitHub (the 2019 assessment model code is available at "201909CPTdoRetro"). TCSAM02 was first used for the Tanner crab assessment in 2017 (Stockhausen, 2017) and will be used until a transition is made to Gmacs (the Generalized Model for Alaska Crab Stocks). Gmacs is intended to be used for all crab stock assessments conducted for the North Pacific Fisheries Management Council (NPFMC), including both lithodid (king crab) and *Chionoecetes* (Tanner and snow crab) stocks, while TCSAM02 is specific to *Chionoecetes* biology (i.e., terminal molt).

TCSAM02 is referred to here as a "modeling framework" because, somewhat similar to Stock Synthesis (Methot and Wetzel, 2013), model structure and parameters are defined "on-the-fly" using control files—rather than editing and re-compiling the underlying code. In particular, the number of fisheries and surveys, as well as their associated data types (abundance, biomass, and /or size compositions) and the number and types of time blocks defined for every model parameter, are defined using control files in TCSAM02 and have not been pre-determined. Priors can be placed on any model parameter. New data types (e.g., growth data) can also be included in the model optimization that could not be fit with TCSAM2013. Additionally, status determination and OFL calculations can be done directly within a TCSAM02 model run, rather having to run a separate "projection model".

Model Description

A. General population dynamics

TCSAM02 is a stage/size-based population dynamics model. Population abundance at the start (July 1) of year *y* in the model, $n_{y,x,m,s,z}$, is characterized by sex *x* (male, female), maturity state *m* (immature, mature), shell condition *s* (new shell, old shell), and size *z* (carapace width, CW). Changes in abundance due to natural mortality, molting and growth, maturation, shell aging, fishing mortality and recruitment are tracked on an annual basis. Because the principal crab fisheries occur during the winter, the model year runs from July 1 to June 30 of the following calendar year.

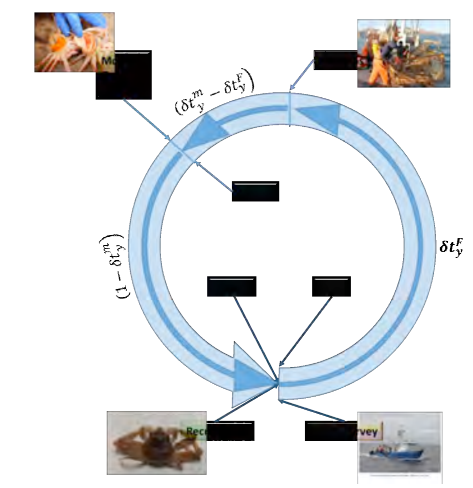


Fig. 1. Timing of annual events in TCSAM02 when fisheries occur before molting/growth/mating.

The order of calculation steps to project population abundance from year *y* to *y*+1 depends on the assumed timing of the fisheries (δt_y^F) relative to molting/growth/mating (δt_y^m) in year *y*. The steps when the fisheries occur before molting/growth/mating ($\delta t_y^F \leq \delta t_y^m$) are outlined below first (Steps A1.1-A1.4), followed by the steps when molting/growth/mating occurs after the fisheries ($\delta t_y^m < \delta t_y^F$; Steps A2.1-A2.4).

A1. Calculation sequence when $\boldsymbol{\delta t_y^F \leq \delta t_y^m}$

Step A1.1: Survival prior to fisheries

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

$n_{y,x,m,s,z}^1 = e^{-M_{y,x,m,s,z} \cdot \delta t_y^F} \cdot n_{y,x,m,s,z}$	A1.1

where *M* represents the annual rate of natural mortality in year *y* on crab classified as *x*, *m*, *s*, *z*.

Step A1.2: Prosecution of the fisheries

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

$n_{y,x,m,s,z}^2 = e^{-F_{y,x,m,s,z}^T} \cdot n_{y,x,m,s,z}^1$	A1.2

where $F_{y,x,m,s,z}^T$ represents the total fishing mortality (over all fisheries) on crab classified as *x*, *m*, *s*, *z* in year *y*.

Step A1.3: Survival after fisheries to time of molting/growth/mating

Natural mortality is again applied to the population from just after the fisheries to the time just before molting/growth/mating occurs for year *y* at δt_y^m (generally Feb. 15). The numbers surviving to δt_y^m in year *y* are given by:

$n_{y,x,m,s,z}^3 = e^{-M_{y,x,m,s,z} \cdot (\delta t_y^m - \delta t_y^F)} \cdot n_{y,x,m,s,z}^2$	A1.3

where, as above, *M* represents the annual rate of natural mortality in year *y* on crab classified as *x*, *m*, *s*, *z*.

Step A1.4: Molting, growth, and maturation
The changes in population structure due to molting, growth and maturation of immature (new shell) crab, as well as the change in shell condition for mature new shell (MAT, NS) crab to mature old shell (MAT, OS) crab due to aging, are given by:

$n^4_{y,x,MAT,NS,z} = \phi_{y,x,z} \cdot \sum_{z'} \Theta_{y,x,z,z'} \cdot n^3_{y,x,IMM,NS,z'}$	A1.4a
$n^4_{y,x,IMM,NS,z} = (1 - \phi_{y,x,z}) \cdot \sum_{z'} \Theta_{y,x,z,z'} \cdot n^3_{y,x,IMM,NS,z'}$	A1.4b
$n^4_{y,x,MAT,OS,z} = n^3_{y,x,MAT,OS,z} + n^3_{y,x,MAT,NS,z}$	A1.4c

where $\Theta_{y,x,z,z'}$ is the growth transition matrix in year *y* for an immature new shell (IMM, NS) crab of sex *x* and pre-molt size *z'* to post-molt size *z* and $\phi_{y,x,z}$ is the probability that a just-molted crab of sex *x* and post-molt size *z* has undergone its terminal molt to maturity (MAT). All crab that molted remain new shell (NS) crab. Additionally, all mature crab that underwent terminal molt to maturity the previous year are assumed to change shell condition from new shell to old shell (A1.4c). Note that the numbers of immature old shell (IMM, OS) crab are identically zero in the current model because immature crab are assumed to molt each year until they undergo the terminal molt to maturity; consequently, the "missing" equation for *m=IMM*, *s=OS* is unnecessary.

Step A1.5: Survival to end of year, recruitment, and update to start of next year
Finally, the population abundance at the start of year *y*+1, due to natural mortality on crab from just after the time of molting/growth/mating in year *y* until the end of the model year (June 30) and recruitment ($R_{y,x,z}$) at the end of year *y* of immature new shell (IMM, NS) crab by sex *x* and size *z*, is given by:

$n_{y+1,x,m,s,z} = \begin{cases} e^{-M_{y,x,IMM,NS,z} \cdot (1-\delta t^m_y)} \cdot n^4_{y,x,IMM,NS,z} + R_{y,x,z} & m = IMM, s = NS \\ e^{-M_{y,x,m,s,z} \cdot (1-\delta t^m_y)} \cdot n^4_{y,x,m,s,z} & otherwise \end{cases}$	A1.5

A2. Calculation sequence when $\delta t^m_y < \delta t^F_y$

Step A2.1: Survival prior to molting/growth/mating
As in the previous sequence, natural mortality is first applied to the population from the start of the model year (July 1), but this time until just prior to molting/growth/mating in year *y* at δt^m_y (generally Feb. 15). The numbers surviving at δt^m_y in year *y* are given by:

$n^1_{y,x,m,s,z} = e^{-M_{y,x,m,s,z} \cdot \delta t^m_y} \cdot n_{y,x,m,s,z}$	A2.1

where *M* represents the annual rate of natural mortality in year *y* on crab classified as *x*, *m*, *s*, *z*.

Step A2.2: Molting, growth, and maturation
The changes in population structure due to molting, growth and maturation of immature new shell (IMM, NS) crab, as well as the change in shell condition for mature new shell (MAT, NS) crab to mature old shell (MAT, OS) crab due to aging, are given by:

$n^2_{y,x,MAT,NS,z} = \phi_{y,x,z} \cdot \sum_{z'} \Theta_{y,x,z,z'} \cdot n^1_{y,x,IMM,NS,z'}$	A2.2a
$n^2_{y,x,IMM,NS,z} = (1 - \phi_{y,x,z}) \cdot \sum_{z'} \Theta_{y,x,z,z'} \cdot n^1_{y,x,IMM,NS,z'}$	A2.2b
$n^2_{y,x,MAT,OS,z} = n^1_{y,x,MAT,OS,z} + n^1_{y,x,MAT,NS,z}$	A2.2c

where $\Theta_{y,x,z,z'}$ is the growth transition matrix in year *y* for an immature new shell (IMM, NS) crab of sex *x* and pre-molt size *z'* to post-molt size *z* and $\phi_{y,x,z}$ is the probability that a just-molted crab of sex *x* and post-molt size *z* has undergone its terminal molt to maturity. Additionally, mature new shell (MAT, NS) crab that underwent their terminal molt to maturity the previous year are assumed to change shell condition from new shell to old shell (A2.2c). Again, the numbers of immature old shell crab are identically zero because immature crab are assumed to molt each year until they undergo the terminal molt to maturity.

Step A2.3: Survival after molting/growth/mating to prosecution of fisheries
Natural mortality is again applied to the population from just after molting/growth/mating to the time at which the fisheries occur for year *y* (at δt^F_y). The numbers surviving at δt^F_y in year *y* are then given by:

$n^3_{y,x,m,s,z} = e^{-M_{y,x,m,s,z} \cdot (\delta t^F_y - \delta t^m_y)} \cdot n^2_{y,x,m,s,z}$	A2.3

where, as above, *M* represents the annual rate of natural mortality in year *y* on crab classified as *x*, *m*, *s*, *z*.

Step A2.4: Prosecution of the fisheries
The directed fishery and bycatch fisheries are modeled as pulse fisheries occurring at δt^F_y in year *y*. The numbers that remain after the fisheries are prosecuted are given by:

$n^4_{y,x,m,s,z} = e^{-F^T_{y,x,m,s,z}} \cdot n^3_{y,x,m,s,z}$	A2.4

where $F^T_{y,x,m,s,z}$ represents the total fishing mortality (over all fisheries) on crab classified as *x*, *m*, *s*, *z* in year *y*.

Step A2.5: Survival to end of year, recruitment, and update to start of next year
Finally, population abundance at the start of year *y*+1 due to natural mortality on crab from just after prosecution of the fisheries in year *y* until the end of the model year (June 30) and recruitment of immature new (IMM, NS) shell crab at the end of year *y* ($R_{y,x,z}$) and are given by:

$n_{y+1,x,m,s,z} = \begin{cases} e^{-M_{y,x,IMM,NS,z} \cdot (1-\delta t^F_y)} \cdot n^4_{y,x,IMM,NS,z} + R_{y,x,z} & m = IMM, s = NS \\ e^{-M_{y,x,m,s,z} \cdot (1-\delta t^F_y)} \cdot n^4_{y,x,m,s,z} & otherwise \end{cases}$	A2.5

B. Parameter specification

Because parameterization of many model processes (e.g., natural mortality, fishing mortality) in TCSAM02 is fairly flexible, it is worthwhile discussing how model processes and their associated parameters are configured in TCSAM02 before discussing details of the model processes themselves. Each type of model process has a set of (potentially estimable) model parameters and other information associated with it, but different "elements" of a model process can be defined that apply, for example, to different segments of the population and/or during different time blocks. In turn, several "elements" of a model parameter associated with a model process may also be defined (and applied to different elements of the process). At least one combination of model parameters and other information associated with a model process must be defined—i.e., one process element must be defined.

Model processes and parameters are configured in a "ModelParametersInfo" file, one of the three control files required for a model run (the others are the "ModelConfiguration" file and the "ModelOptions" file). As an example of the model processes and parameter specification syntax, Text Box 1 presents the part of a "ModelParametersInfo" file concerned with specifying fishing processes in the directed Tanner crab fishery.

In Text Box 1, the keyword "fisheries" identifies the model process in question. The first section, following the "PARAMETER_COMBINATIONS" keyword (up to the first set of triple blue dots), specifies the indices associated with fishing process parameters (pHM, pLnC, pDC1, pDC2, pDC3, pDC4, pDevsLnC, pLnEffX, pLgtRet), selectivity and retention functions (idxSelFcn, idxRetFcn), and effort averaging time period (effAvgID) that apply to a single fishing process element. In this example, the indices for the selectivity and retention functions, as well as those for the effort averaging time period, constitute the "other information" specified for each fishing process element. Each fishing process element in turn applies to a specific fishery (FISHERY=1 indicates the directed fishery, in this case), time block (specified by YEAR_BLOCK), and components of the model population (specified by SEX, MATURITY STATE, and SHELL CONDITION). Using indices to identify which parameters and selectivity and retention functions apply to a given combination of fishery/time block/sex/maturity state/shell condition allows one to "share" individual parameters and selectivity and retention functions across different fishery/time block/sex/maturity state/shell condition combinations.

The second section (following the "PARAMETERS" keyword) determines the characteristics for each of the fishing process parameters, organized by parameter name (note: the parameters associated with the different selectivity and retention functions are specified in a different section of the ModelParametersInfo file). Here, each parameter name corresponds to an ADMB "param_init_bounded_number_vector" in the model code—the exception being pDevsLnC, which corresponds to an ADMB "param_init_bounded_vector_vector".

Each row under a "non-devs" parameter name in the fisheries section (e.g., pLnC) specifies the index used to associate an element of the parameter with the fishing processes defined in the PARAMETER_COMBINATIONS section, as well as characteristics of the element in the associated ADMB number_vector (upper and lower bounds, initial value, and initial estimation phase), various flags for initialization ("jitter", "resample"), definition of an associated prior probability distribution, and a label. Each row under a "devs" parameter name (e.g., pDevsLnC) specifies much the same information for the associated ADMB devs vector, with the "read" flag replacing the "initial value" entry. If "read?" is TRUE, then a vector of initial values is read from the file after all "info" rows for the devs parameter have been read. The “jitter” flag (if set to TRUE) provides the ability to change the initial value for an element of a non-devs parameter using a randomly selected value based on the element’s upper and lower bounds. For a devs parameter, an element with jitter set to TRUE is initialized using a vector of randomly-generated numbers (subject to being a devs vector within the upper and lower bounds). The “resample” flag was intended to specify an alternative method to providing randomly-generated initial values (based on an element’s prior probability distribution, rather than its upper and lower bounds), but this has not yet been fully implemented.

Some model processes apply only to specific segments of the population (e.g., growth only applies to immature, new shell crab). In general, though, a model process element can be defined to apply to any segment of the population (by specifying SEX, MATURITY STATE, and SHELL CONDITION appropriately) and range of years (by specifying YEAR_BLOCK). In turn, an element of a parameter may be “shared” across multiple processes by specifying the element’s index in multiple rows of a PARAMETERS_COMBINATION block.

```
#------------------------------
# Fishery parameters
#------------------------------
fisheries #process name
PARAMETER_COMBINATIONS
42  #number of rows defining parameter combinations for all fisheries
#Directed Tanner Crab Fishery (TCF)
#                                          |MATURITY|SHELL|                                |pDevs| pLn | pLgt| idx  | idx  |  eff  |
#id  FISHERY  YEAR_BLOCK             SEX    | STATE  |COND |  pHM  pLnC  pDC1  pDC2  pDC3  pDC4 | LnC | EffX| Ret |SelFcn|RetFcn|  AvgID |  label
1       1     [-1:1964]              MALE      ALL     ALL     1     1     0     0    0     0      0     0     0     9      5       0    TCF:_M_T1
2       1     [1965:1984;1987:1990]  MALE      ALL     ALL     1     2     0     0    0     0      1     0     0     9      5       0    TCF:_M_T2
3       1     [1991:1996]            MALE      ALL     ALL     1     2     0     0    0     0      1     0     0    10      6       0    TCF:_M_T3
4       1     [2005:2009]            MALE      ALL     ALL     1     2     0     0    0     0      1     0     1    11      7       0    TCF:_M_T4
5       1     [2013:-1]              MALE      ALL     ALL     1     2     0     0    0     0      1     0     1    12      8       0    TCF:_M_T5
6       1     [-1:1964]              FEMALE    ALL     ALL     1     1     0     1    0     0      0     0     0    13      0       0    TCF:_F_T1
7       1     [1965:1984;1987:1996]  FEMALE    ALL     ALL     1     2     0     1    0     0      1     0     0    13      0       0    TCF:_F_T2
8       1     [2005:2009;2013:-1]    FEMALE    ALL     ALL     1     2     0     1    0     0      1     0     0    14      0       0    TCF:_F_T3
…
PARAMETERS
pHM #handling mortality (0-1)
3   #number of parameters
#   |   limits    |        | initial | start |          |-       priors          -|
#id |lower   upper|jitter?| value   | phase |resample?| wgt| type| params| consts| label
1      0       1    OFF     0.321      -1       OFF      1   none   none     none    handling_mortality_for_crab_pot_fisheries
…
pLnC #base (ln-scale) capture rate (mature males)
9    #number of parameters
#   |   limits    |        |  initial    | start |          |-       priors          -|
#id |lower   upper|jitter?|   value     | phase |resample?| wgt| type| params| consts| label
 1    -15     15     OFF    -2.995732274    -1       OFF      1   none  none    none      TCF:_base_capture_rate,_pre-1965_(=0.05)
 2    -15     15     ON     -1.164816291     1       OFF      1   none  none    none      TCF:_base_capture_rate,_1965+
…
pDC1 #main temporal ln-scale capture rate offset
0    #number of parameters
pDC2 #ln-scale capture rate offset for female crabs
6    #number of parameters
#   |   limits    |        |  initial    | start |          |-       priors           -|
#id |lower  upper |jitter?|   value     | phase |resample?|  wgt  type  params  consts| label
1    -5.0    5.0     ON    -2.058610432    1       OFF       1.0  none   none    none   TCF:_female_offset
…
pDevsLnC #annual ln-scale capture rate deviations
6        #number of parameter vectors
#   | index  |           index                  |       |   limits     |          |initial |start |          |-      priors              -|
#id |  type  |           block                  | read? |lower   upper | jitter?| value  |phase |resample?|  wgt | type | params | consts |label
 1     YEAR   [1965:1984;1987:1996;2005:2009;2013:-1]  FALSE   -15     15       ON       0       1      OFF       2.0  normal    0 1     none    TCF:_T2345
…
```

Text Box 1. Abbreviated example of process and parameter specifications in a “ModelParametersInfo” file for fishing mortality in TCSAM02. Only parameter combinations and parameters relevant to the directed fishery are shown. Input values are in black text, comments are in green, triple blue dots indicate additional input lines not shown.

C. Model processes: natural mortality

The natural mortality rate applied to crab of sex *x*, maturity state *m*, shell condition *s*, and size *z* in year *y*, $M_{y,x,m,s,z}$, can be specified using one of two parameterizations. The first parameterization option uses a ln-scale parameterization with an option to include an inverse- size dependence using Lorenzen's approach:

$lnM_{y,x,m,s} = \mu^0_{y,x,m,s} + \sum_{i=1}^{4} \delta\mu^i_{y,x,m,s}$	C.1a
$M_{y,x,m,s,z} = \begin{cases} \exp(lnM_{y,x,m,s}) & if\ Lorenzen\ option\ is\ not\ selected \\ \exp(lnM_{y,x,m,s}) \cdot \frac{z_{base}}{z} & if\ Lorenzen\ option\ is\ selected \end{cases}$	C.1b C.1c

where the μ^0 and the $\delta\mu^i$'s are (potentially) estimable parameters defined for time block *T*, sex *S* (MALE, FEMALE, or ANY), maturity *M* (IMMATURE, MATURE, or ANY), and shell condition *S* (NEWSHELL, OLDSHELL, or ANY), and $\{y,x,m,s\}$ falls into the set $\{T,X,M,S\}$. In Eq. C.1c, z_{base} denotes the specified reference size (mm CW) for the inverse-size dependence.

The second parameterization option uses an arithmetic parameterization in order to provide backward compatibility with the 2016 assessment model based on TCSAM2013. In TCSAM2013, the natural mortality rate $M_{y,x,m,s,z}$ was parameterized using:

$M_{y,x,m=IMM,s,z} = M^{base} \cdot \delta M_{IMM}$	C.2a
$M_{y,x,m=MAT,s,z} = \begin{cases} M^{base} \cdot \delta M_{x,MAT} & otherwise \\ M^{base} \cdot \delta M_{x,MAT} \cdot \delta M^T_{x,MAT} & 1980 \leq y \leq 1984 \end{cases}$	C.2b

where M^{base} was a fixed value (0.23 yr^{-1}), δM_{IMM} was a multiplicative factor applied for all immature crab, the $\delta M_{x,MAT}$ were sex-specific multiplicative factors for mature crab, and the $\delta M^T_{x,MAT}$ were additional sex-specific multiplicative factors for mature crab during the 1980-1984 time block (which has been identified as a period of enhanced natural mortality on mature crab, the mechanisms for which are not understood). While it would be possible to replicate Eq.s C.2a and C.2b using ln-scale parameters, TCSAM2013 also placed informative arithmetic-scale priors on some of these parameters—and this could not be duplicated on the ln-scale. Consequently, the second option uses the following parameterization, where the parameters (and associated priors) are defined on the arithmetic-scale:

$lnM_{y,x,m,s} = \ln[\mu^0_{y,x,m,s}] + \sum_{i=1}^{4} \ln[\delta\mu^i_{y,x,m,s}]$	C.3a

A system of equations identical to C.2a-b can be achieved under the following assignments:

$\mu^0_{\{y,x,m,s\} \in \{T=ALL,X=ALL,M=ALL,S=ALL\}} = M^{base}$	C.4a
$\delta\mu^1_{\{y,x,m,s\} \in \{T=ALL,X=ALL,M=IMM,S=ALL\}} = \delta M_{IMM}$	C.4e
$\delta\mu^1_{\{y,x,m,s\} \in \{T=ALL,X=x,M=MAT,S=ALL\}} = \delta M_{x,MAT}$	C.4f
$\delta\mu^2_{\{y,x,m,s\} \in \{T=1980-1984,X=x,M=MAT,S=ALL\}} = \delta M^T_{x,MAT}$	C.4g

where unassigned $\delta\mu^{i}_{y,x,m,s}$ are set equal to 1. Pending further model testing using alternative model configurations, the TCSAM2013 option is standard.

It is worth noting explicitly that, given the number of potential parameters above that could be used, extreme care must be taken when defining a model to achieve a set of parameters that are not confounded and are, at least potentially, estimable.

D. Model processes: growth

Because Tanner crab are assumed to undergo a terminal molt to maturity, in TCSAM02 only immature crab experience growth. Annual growth of immature crab is implemented as using two options, the first based on a formulation used in Gmacs and the second (mainly for purposes of backward compatibility) based on that used in TCSAM2013. In TCSAM02, growth can vary by time block and sex, so it is expressed by sex-specific transition matrices for time block *t*, $\Theta_{t,x,z,z'}$, that specify the probability that crab of sex *x* in pre-molt size bin z' grow to post-molt size bin z at molting.

In the Gmacs-like approach (the standard approach as of May, 2017), the sex-specific growth matrices are given by:

$\Theta_{t,x,z,z'} = c_{t,x,z'} \cdot \int_{z-bin/2}^{+bin/2} \Gamma\left(\frac{z'' - \bar{z}_{t,x,z'}}{\beta_{t,x}}\right) dz''$	Sex-specific (*x*) transition matrix for growth from pre-molt z' to post-molt z, with $z \geq z'$	D.1a
$c_{t,x,z'} = \left[\int_{z'}^{\infty} \Gamma\left(\frac{z'' - \bar{z}_{t,x,z'}}{\beta_{t,x}}\right) dz''\right]^{-1}$	Normalization constant so $1 = \sum_{z} \Theta_{t,x,z,z'}$	D.1b
$\bar{z}_{t,x,z'} = e^{a_{t,x}} \cdot z'^{b_{t,x}}$	Mean size after molt, given pre-molt size z'	D.1c

where the integral represents a cumulative gamma distribution across the post-molt (z) size bin. This approach may have better numerical stability properties than the TCSAM2013 approach below.

The TCSAM2013 approach is an approximation to the Gmacs approach, where the sex-specific growth matrices $\Theta_{t,x,z,z'}$ are given by

$\Theta_{t,x,z,z'} = c_{t,x,z'} \cdot \Delta_{z,z'}{}^{\alpha_{t,x,z'}-1} \cdot e^{-\frac{\Delta_{z,z'}}{\beta_{t,x}}}$	Sex-specific (*x*) transition matrix for growth from pre-molt z' to post-molt z, with $z \geq z'$	D.2a
$c_{t,x,z'} = \left[\sum_{z'} \Delta_{z,z'}{}^{\alpha_{t,x,z'}-1} \cdot e^{-\frac{\Delta_{z,z'}}{\beta_{t,x}}}\right]^{-1}$	Normalization constant so $1 = \sum_{z} \Theta_{t,x,z,z'}$	D.2b
$\Delta_{z,z'} = z - z'$	Actual growth increment	D.2c
$\alpha_{t,x,z'} = [\bar{z}_{t,x,z'} - z']/\beta_{t,x}$	Mean molt increment, scaled by $\beta_{t,x}$	D.2d
$\bar{z}_{t,x,z'} = e^{a_{t,x}} \cdot z'^{b_{t,x}}$	Mean size after molt, given pre-molt size z'	D.2e

In both approaches, the $a_{t,x}$, $b_{t,x}$, and $\beta_{t,x}$ are arithmetic-scale parameters with imposed bounds. $\Theta_{t,x,z,z'}$ is used to update the numbers-at-size for immature crab, $n_{y,x,z}$, from pre-molt size z' to post-molt size z using:

$n^{+}_{y,x,z} = \sum_{z'} \Theta_{t,x,z,z'} \cdot n_{y,x,z'}$	numbers at size of immature crab after growth	D.3

where y falls within time block t (see also Eq.s A1.4a-b and A2.2a-b).

Priors using normal distributions are imposed on $a_{t,x}$ and $b_{t,x}$ in TCSAM2013, with the values of the hyper-parameters hard-wired in the model code. While priors may be defined for the associated parameters here, these are identified by the user in the model input files and are not hard-wired in the model code.

E. Model processes: maturity (terminal molt)

Maturation of immature crab in TCSAM02 is based on a similar approach to that taken in TCSAM2013, except that the sex- and size-specific probabilities of terminal molt for immature crab, $\phi_{t,x,z}$ (where size z is post-molt size), can vary by time block. After molting and growth, the numbers of (new shell) crab at post-molt size z remaining immature, $n^{+}_{y,x,IMM,NS,z}$, and those maturing, $n^{+}_{x,MAT,NS,z}$, are given by:

$n^{+}_{y,x,IMM,NS,z} = (1 - \phi_{t,x,z}) \cdot n_{y,x,IMM,NS,z}$ $n^{+}_{y,x,MAT,NS,z} = \phi_{t,x,z} \cdot n_{y,x,IMM,NS,z}$	crab remaining immature crab maturing (terminal molt)	E.1a E.1b

where y falls in time block t and $n_{y,x,IMM,NS,z}$ is the number of immature, new shell crab of sex x at post-molt size z.

The sex- and size-specific probabilities of terminal molt, $\phi_{t,x,z}$, are related to logit-scale model parameters $p^{mat}_{t,x,z}$ by:

$\phi_{t,FEM,z} = \begin{cases} \dfrac{1}{1+e^{p^{mat}_{t,FEM,z}}} & z \le z^{mat}_{t,FEM} \\ 1 & z > z^{mat}_{t,FEM} \end{cases}$	female probabilities of maturing at post-molt size z	E.2a
$\phi_{t,MALE,z} = \begin{cases} \dfrac{1}{1+e^{p^{mat}_{t,MALE,z}}} & z \le z^{mat}_{t,MALE} \\ 1 & z > z^{mat}_{t,MALE} \end{cases}$	male probabilities of maturing at post-molt size z	E.2b

where the $z^{mat}_{t,x}$ are constants specifying the minimum pre-molt size at which to assume all immature crab will mature upon molting. The $z^{mat}_{t,x}$ are used here pedagogically; in actuality, the user specifies the *number* of logit-scale parameters to estimate (one per size bin starting with the first bin) for each sex, and this determines the $z^{mat}_{t,x}$ used above. This parameterization is similar to that implemented in TCSAM2013 for the 2016 assessment model.

Second difference penalties are applied to the parameter estimates in TCSAM2013's objective function to promote relatively smooth changes in these parameters with size. Similar penalties (smoothness, non-decreasing) can be applied in TCSAM02.

F. Model processes: recruitment

Recruitment in TCSAM02 consists of immature new shell crab entering the population at the end of the model year (June 30). Recruitment in TCSAM02 has a similar functional form to that used in TCSAM2013, except that the sex ratio at recruitment is not fixed at 1:1 and multiple time blocks can be specified. In TCSAM2013, two time blocks were defined: "historical" (model start to 1974) and "current" (1975-present), with "current" recruitment starting in the first year of NMFS survey data. In TCSAM02, recruitment in year y of immature new shell crab of sex x at size z is specified as

$R_{y,x,z} = \dot{R}_y \cdot \ddot{R}_{y,x} \cdot \dddot{R}_{y,z}$	recruitment of immature, new shell crab by sex and size bin	F.1

where $\dot{R}_y$ represents total recruitment in year *y* and $\ddot{R}_{y,x}$ represents the fraction of sex *x* crab recruiting, and $\dddot{R}_{y,z}$ is the size distribution of recruits, which is assumed identical for males and females.

Total recruitment in year *y*, $\dot{R}_y$, is parameterized as

$\dot{R}_y = e^{pLnR_t + \delta R_{t,y}} \quad y \in t$	total recruitment in year *y*	F.2

where *y* falls within time block *t*, $pLnR_t$ is the ln-scale mean recruitment parameter for *t*, and $\delta R_{t,y}$ is an element of a "devs" parameter vector for *t* (constrained such that the elements of the vector sum to zero over the time block).

The fraction of crab recruiting as sex *x* in year *y* in time block *t* is parameterized using the logistic model

$\ddot{R}_{y,x} = \begin{cases} \dfrac{1}{1+e^{pLgtRx_t}} & x = MALE \\ 1 - \ddot{R}_{y,MALE} & x = FEMALE \end{cases} \quad y \in t$	sex-specific fraction recruiting in year *y*	F.3

where $pLgtRx_t$ is a logit-scale parameter determining the sex ratio in time block *t*.

The size distribution for recruits in time block *t*, $\dddot{R}_{t,z}$, is assumed to be a gamma distribution and is parameterized as

$\dddot{R}_{t,z} = c^{-1} \cdot \Delta_z^{\frac{\alpha_t}{\beta_t}-1} \cdot e^{-\frac{\Delta_z}{\beta_t}}$	size distribution of recruiting crab	F.4
$c_t = \sum_z \Delta_z^{\frac{\alpha_t}{\beta_t}-1} \cdot e^{-\frac{\Delta_z}{\beta_t}}$	normalization constant so that $1 = \sum_z \dddot{R}_{t,z}$	F.5
$\Delta_z = z + \delta z/2 - z_{min}$	offset from minimum size bin	F.6
$\alpha_t = e^{pLnRa_t}$	gamma distribution location parameter	F.7
$\beta_t = e^{pLnRb_t}$	gamma distribution shape parameter	F.8

where $pLnRa_t$ and $pLnRb_t$ are the ln-scale location and shape parameters and the constant δz is the size bin spacing.

A final time-blocked parameter, $pLnRCV_t$, is associated with the recruitment process representing the ln-scale coefficient of variation (cv) in recruitment variability in time block *t*. These parameters are used to apply priors on the recruitment "devs" in the model likelihood function.

G. Selectivity and retention functions

Selectivity and retention functions in TCSAM02 are specified independently from the fisheries and surveys to which they are subsequently applied. This allows a single selectivity function to be "shared" among multiple fisheries and/or surveys, as well as among multiple time block/sex/maturity state/shell condition categories, if so desired.

Currently, the following functions are available for use as selectivity or retention curves in a model:

$S_z = \{1+e^{-\beta\cdot(z-z_{50})}\}^{-1}$	standard logistic	G.1
$S_z = \{1+e^{-\beta\cdot(z-\exp(lnZ_{50}))}\}^{-1}$	logistic w/ alternative parameterization	G.2
$S_z = \left\{1+e^{-\ln(19)\cdot\frac{(z-z_{50})}{\Delta z_{95-50}}}\right\}^{-1}$	logistic w/ alternative parameterization	G.3
$S_z = \left\{1+e^{-\ln(19)\cdot\frac{(z-z_{50})}{\exp(ln\Delta z_{95-50})}}\right\}^{-1}$	logistic w/ alternative parameterization	G.4
$S_z = \left\{1+e^{-\ln(19)\cdot\frac{(z-\exp(lnZ_{50}))}{\exp(ln\Delta z_{95-50})}}\right\}^{-1}$	logistic w/ alternative parameterization	G.5
$S_z = \frac{1}{1+e^{-\beta_a\cdot(z-z_{a50})}}\cdot\frac{1}{1+e^{\beta_d\cdot(z-z_{d50})}}$	double logistic	G.6
$S_z = \frac{1}{1+e^{-\ln(19)\cdot\frac{(z-z_{a50})}{\Delta z_{a(95-50)}}}}\cdot\frac{1}{1+e^{\ln(19)\cdot\frac{(z-z_{d50})}{\Delta z_{d(95-50)}}}}$	double logistic with alt. parameterization	G.7
$S_z = \frac{1}{1+e^{-\ln(19)\cdot\frac{(z-z_{a50})}{\exp(ln\Delta z_{a(95-50)})}}}\cdot\frac{1}{1+e^{\ln(19)\cdot\frac{(z-z_{d50})}{\exp(ln\Delta z_{d(95-50)})}}}$ $where\ z_{d50} = [z_{a50}+\exp(ln\Delta z_{a(95-50)})+\exp(ln\Delta z_{d(95-50)})]$	double logistic with alt. parameterization	G.8
$S_z = \frac{1}{1+e^{-\ln(19)\cdot\frac{(z-\exp(lnz_{a50}))}{\exp(ln\Delta z_{a(95-50)})}}}\cdot\frac{1}{1+e^{\ln(19)\cdot\frac{(z-z_{d50})}{\exp(ln\Delta z_{d(95-50)})}}}$ $where\ z_{d50} = [\exp(lnz_{a50})+\exp(ln\Delta z_{a(95-50)})+\exp(ln\Delta z_{d(95-50)})]$	double logistic with alt. parameterization	G.9
$S_z = \frac{1}{1+e^{-\beta_a\cdot(z-z_{a50})}}\cdot\frac{1}{1+e^{\beta_d\cdot(z-[z_{a50}+\exp(lnZ_{d50-a50})])}}$	double logistic with alt. parameterization	G.10

A double normal selectivity function (requiring 6 parameters to specify) has also been implemented as an alternative to the double logistic functions. In the above functions, all symbols (e.g., β, z_{50}, Δz_{95-50}) represent parameter values, except "*z*" which represents crab size.

Selectivity parameters are defined independently of the functions themselves, and subsequently assigned. It is thus possible to "share" parameters across multiple functions. The "parameters" used in selectivity functions are further divided into mean parameters across a time block and annual deviations within a time block. To accommodate the 6-parameter double normal equation, six "mean" parameter sets (*pS1*, *pS2*,…, *pS6*) and six associated sets of "devs" parameter vectors (*pDevsS1*, *pDevsS2*,…, *pDevsS6*) are defined to specify the parameterization of individual selectivity/retention functions. Thus, for example, z_{50} in eq. F1 is actually expressed as $z_{50,y} = \bar{z}_{50} + \delta z_{50,y}$ in terms of model parameters *pS1* and *pDevsS1*$_y$, where $\bar{z}_{50} = pS1$ is the mean size-at-50%-selected over the time period and $\delta z_{50,y} = pDevsS1_y$ is the annual deviation.

Finally, three different options to normalize individual selectivity curves are provided: 1) no normalization, 2) specifying a fully-selected size, and 3) re-scaling such that the maximum value of the re-scaled function is 1. A normalization option must be specified in the model input files for each defined selectivity/retention curve.

H. Fisheries

Unlike TCSAM2013, which explicitly models 4 fisheries that catch Tanner crab (one as a directed fishery, three as bycatch), there is no constraint in TCSAM02 on the number of fisheries that can be incorporated in the model. All fisheries are modeled as "pulse" fisheries occurring at the same time.

TCSAM02 uses the Gmacs approach to modeling fishing mortality (also implemented in TCSAM2013). The total (retained + discards) fishing mortality rate, $F_{f,y,x,m,s,z}$, in fishery *f* during year *y* on crab in state *x*, *m*, *s*, and *z* (i.e., sex, maturity state, shell condition, and size) is related to the associated fishery capture rate $\phi_{f,y,x,m,s,z}$ by

$F_{f,y,x,m,s,z} = \left[h_{f,t} \cdot \left(1 - \rho_{f,y,x,m,s,z}\right) + \rho_{f,y,x,m,s,z}\right] \cdot \phi_{f,y,x,m,s,z}$	fishing mortality rate	H.1

where $h_{f,t}$ is the handling (discard) mortality for fishery *f* in time block t (which includes year *y*) and $\rho_{f,y,x,m,s,z}$ is the fraction of crabs in state *x*, *m*, *s*, *z* that were caught and retained (i.e., the retention function). The retention function is assumed to be identically 0 for females in a directed fishery and for both sexes in a bycatch fishery.

In TCSAM2013, the same retention function (in each of two time blocks) was applied to male crab regardless of maturity state or shell condition. Additionally, full retention of large males was assumed, such that the retention function essentially reached 1 at large sizes. In TCSAM02, different retention functions can be applied based on maturity state and/or shell condition, and "max retention" is now an (potentially) estimable logit-scale parameter. Thus, in TCSAM02, the retention function $\rho_{f,y,x,m,s,z}$ is given by

$\rho_{f,y,x,m,s,z} = \frac{1}{1 + e^{\rho_{f,t,x,m,s}}} \cdot R_{f,y,x,m,s,z}$	retention function	H.2

where *f* corresponds to the directed fishery, *y* is in time block *t*, *x*=MALE, $\rho_{f,t,x,m,s}$ is the corresponding logit-scale "max retention" parameter, and $R_{f,y,x,m,s,z}$ is the associated selectivity/retention curve.

If $n_{y,x,m,s,z}$ is the number of crab classified as *x*, *m*, *s*, *z* in year *y* just prior to the prosecution of the fisheries, then

$c_{f,y,x,m,s,z} = \frac{\phi_{f,y,x,m,s,z}}{F^T_{y,x,m,s,z}} \cdot \left[1 - e^{-F^T_{y,x,m,s,z}}\right] \cdot n_{y,x,m,s,z}$	number of crab captured	H.3

is the number of crab classified in that state that were *captured* by fishery *f*, where $F^T_{y,x,m,s,z} = \sum_f F_{f,y,x,m,s,z}$ represents the total (across all fisheries) fishing mortality on those crab. The number of crab retained in fishery *f* classified as *x*, *m*, *s*, *z* in year *y* is given by

$r_{f,y,x,m,s,z} = \frac{\rho_{f,y,x,m,s,z} \cdot \phi_{f,y,x,m,s,z}}{F^T_{y,x,m,s,z}} \cdot \left[1 - e^{-F^T_{y,x,m,s,z}}\right] \cdot n_{y,x,m,s,z}$	number of retained crab	H.4

while the number of discarded crab, $d_{f,y,x,m,s,z}$, is given by

$d_{f,y,x,m,s,z} = \frac{(1-\rho_{f,y,x,m,s,z}) \cdot \phi_{f,y,x,m,s,z}}{F^T_{y,x,m,s,z}} \cdot \left[1 - e^{-F^T_{y,x,m,s,z}}\right] \cdot n_{y,x,m,s,z}$	number of discarded crab	H.5

and the discard mortality, $dm_{f,y,x,m,s,z}$, is

$dm_{f,y,x,m,s,z} = \frac{h_{f,y} \cdot (1-\rho_{f,y,x,m,s,z}) \cdot \phi_{f,y,x,m,s,z}}{F^T_{y,x,m,s,z}} \cdot \left[1 - e^{-F^T_{y,x,m,s,z}}\right] \cdot n_{y,x,m,s,z}$	discard mortality (numbers)	H.6

The capture rate $\phi_{f,y,x,m,s,z}$ (*not* the fishing mortality rate $F_{f,y,x,m,s,z}$) is modeled as a function separable into separate year and size components such that

$\phi_{f,y,x,m,s,z} = \phi_{f,y,x,m,s} \cdot S_{f,y,x,m,s,z}$	fishing capture rate	H.7

where $\phi_{f,y,x,m,s}$ is the fully-selected capture rate in year *y* and $S_{f,y,x,m,s,z}$ is the size-specific selectivity.

The fully-selected capture rate $\phi_{f,y,x,m,s}$ for *y* in time block *t* is parameterized in the following manner:

$\phi_{f,y,x,m,s} = \exp\left(lnC_{f,t,x,m,s} + pDevsC_{f,y,x,m,s}\right)$	H.8

where the $pDevsC_{f,y,x,m,s}$ are elements for year *y* in time block *t* of a "devs" vectors representing annual variations from the ln-scale mean fully-selected capture rate $lnC_{f,t,x,m,s}$. The latter is expressed in terms of model parameters as

$lnC_{f,t,x,m,s} = pLnC_{f,t,x,m,s} + \sum_{i=1}^{4} \delta C^i_{f,t,x,m,s}$	H.9

where the $pLnC_{f,t,x,m,s}$ is the mean ln-scale capture rate (e.g., for mature males) and the $\delta C^i_{f,t,x,m,s}$ are ln-scale offsets.

I. Surveys

If $n_{y,x,m,s,z}$ is the number of crab classified as *x*, *m*, *s*, *z* in year *y* just prior to the prosecution of a survey, then the survey abundance, $a_{v,y,x,m,s,z}$, of crab classified in that state by survey *v* is given by

$_{v,y,x,m,s,z} = q_{v,y,x,m,s,z} \cdot n_{y,x,m,s,z}$	survey abundance	I.1

where $q_{v,y,x,m,s,z}$ is the size-specific survey catchability on this component of the population.

The survey catchability $q_{v,y,x,m,s,z}$ is decomposed in the usual fashion into separate time block and size components such that, for *y* in time block *t*:

$q_{v,y,x,m,s,z} = q_{v,t,x,m,s} \cdot S_{v,t,x,m,s,z} \cdot A_{v,t,x,m,s,z}$	survey catchability	I.2

where $q_{v,t,x,m,s}$ is the fully-selected catchability in time block *t*, $S_{v,t,x,m,s,z}$ is the size-specific survey selectivity, and $A_{v,t,x,m,s,z}$ is the size-specific availability of the population to the survey. If the survey covers the complete stock area (as the standard NMFS EBS bottom trawl is assumed to do for Tanner crab), then $A_{v,t,x,m,s,z} \equiv 1$. However, if the survey does not cover the complete stock, as is the case with the BSFRF/NMFS side-by-side catchability studies, then $A_{v,t,x,m,s,z}$ needs to be estimated or assumed.

The fully-selected catchability $q_{v,t,x,m,s}$ is parameterized in a fashion similar to that for fully-selected fishery capture rates (except that annual "devs" are not included) in the following manner:

$q_{v,t,x,m,s} = \exp\left(pLnQ_{v,t,x,m,s} + \sum_{i=1}^{4} \delta Q^{i}_{v,t,x,m,s}\right)$	I.3

where the $pLnQ_{v,t,x,m,s}$ is the mean ln-scale catchability (e.g., for mature males) and the $\delta Q^{i}_{v,t,x,m,s}$ are ln-scale offsets.

J. Model fitting: objective function equations

The TCSAM02 model is fit by minimizing an objective function, $\mathcal{O}$, with additive components consisting of: 1) negative log-likelihood functions based on specified prior probability distributions associated with user-specified model parameters, and 2) several negative log-likelihood functions based on input data components, of the form:

$\mathcal{O} = -2\sum_{p} \lambda_p \cdot \ln(\wp_p) - 2\sum_{l} \lambda_l \cdot \ln(\mathcal{L}_l)$	model objective function	J.1

where $\wp_p$ represents the pth prior probability function, $\mathcal{L}_l$ represents the lth likelihood function, and the λ's represent user-adjustable weights for each component.

Prior Probability Functions

Prior probability functions can be associated with each model parameter or parameter vector by the user in the model input files (see Section L below for examples on specifying priors).

Likelihood Functions

The likelihood components included in the model's objective function are based on normalized size frequencies and time series of abundance or biomass from fishery or survey data. Survey data optionally consists of abundance and/or biomass time series for males, females, and/or all crab (with associated survey cv's), as well as size frequencies by sex, maturity state, and shell condition. Fishery data consists of similar data types for optional retained, discard, and total catch components.

Size frequency components

Likelihood components involving size frequencies are based on multinomial sampling:

$\ln(\mathcal{L}) = \sum_{y} n_{y,c} \cdot \sum_{z} \left\{p^{obs}_{y,c,z} \cdot \ln\left(p^{mod}_{y,c,z} + \delta\right) - p^{obs}_{y,c,z} \cdot \ln\left(p^{obs}_{y,c,z} + \delta\right)\right\}$	multinomial log-likelihood	J.2

where the y's are years for which data exists, "c" indicates the population component classifiers (i.e., sex, maturity state, shell condition) the size frequency refers to, $n_{y,c}$ is the classifier-specific effective sample size for year y, $p^{obs}_{y,c,z}$ is the observed size composition in size bin z (i.e., the size frequency normalized to sum to 1 across size bins for each year), $p^{mod}_{y,c,z}$ is the corresponding model-estimated size composition, and δ is a small constant. The manner in which the observed and estimated size frequencies for each data component are aggregated (e.g., over shell condition) prior to normalization is specified by the user in the model input files. Data can be entered in input files at less-aggregated levels of than will be used in the model; it will be aggregated in the model to the requested level before fitting occurs.

Aggregated abundance/biomass components
Likelihood components involving aggregated (over size, at least) abundance and or biomass time series can be computed using one of three potential likelihood functions: the normal, the lognormal, and the "norm2". The likelihood function used for each data component is user-specified in the model input files.

The ln-scale normal likelihood function is

$\ln(\mathcal{L}^N)_c = -\frac{1}{2}\sum_y \left\{\frac{\left[a_{y,c}^{obs} - a_{y,c}^{mod}\right]^2}{\sigma_{y,c}^2}\right\}$	normal log-likelihood	J.3

where $a_{y,c}^{obs}$ is the observed abundance/biomass value in year *y* for aggregation level *c*, $a_{y,c}^{mod}$ is the associated model estimate, and $\sigma_{y,c}^2$ is the variance associated with the observation.

The ln-scale lognormal likelihood function is

$\ln(\mathcal{L}^{LN})_c = -\frac{1}{2}\sum_y \left\{\frac{\left[ln\left(a_{y,c}^{obs} + \delta\right) - ln\left(a_{y,c}^{mod} + \delta\right)\right]^2}{\sigma_{y,c}^2}\right\}$	lognormal log-likelihood	J.4

where $a_{y,c}^{obs}$ is the observed abundance/biomass value in year *y* for aggregation level *c*, $a_{y,c}^{mod}$ is the associated model estimate, and $\sigma_{y,c}^2$ is the ln-scale variance associated with the observation.

For consistency with TCSAM2013, a third type, the "norm2", may also be specified

$\ln(\mathcal{L}^{N2})_x = -\frac{1}{2}\sum_y \left[a_{y,x}^{obs} - a_{y,x}^{mod}\right]^2$	"norm2" log-likelihood	J.5

This is equivalent to specifying a normal log-likelihood with $\sigma_{y,x}^2 \equiv 1.0$. This is the standard likelihood function applied in TCSAM2013 to fishery catch time series.

Growth data
Growth (molt increment) data can be fit as part of a TCSAM02 model. Multiple datasets can be fit at the same time. The likelihood for each dataset (L_d) is based on the same gamma distribution used in the growth model:

$\mathrm{L}_d = -\sum_{i \in d} ln\left\{\Gamma\left(\frac{\tilde{z}_i - \bar{z}_{y_i,x_i,z_i}}{\beta_{y_i,x_i}}\right)\right\}$	gamma log-likelihood	J.6

where z_i and $\tilde{z}_i$ are the pre-molt and post-molt sizes for individual *i* (of sex x_i collected in year y_i) in dataset *d*, respectively, $\bar{z}_{y_i,x_i,z_i}$ is the predicted mean post-molt size for individual *i*, and β_{y_i,x_i} is the scale factor for the gamma distribution corresponding to individual *i*.

Maturity ogive data
Annual maturity ogive data, the observed proportions-at-size of mature crab in a given year, can also be fit as part of a TCSAM02 model. This data consists of proportions of mature crab observed within a size bin, as well as the total number of observations for that size bin. The proportions are assumed to represent the fraction of new shell mature crab (i.e., having gone through terminal molt within the previous growth season) to all new shell crab within the size bin in that year. Multiple datasets can be fit at the same time. The likelihood for each observation is based on a binomial distribution with sample size equal to the

number of observations within the corresponding size bin, so the likelihood for each dataset (L_m) is given by:

$L_m = \sum_{y,z} n_{y,z} \cdot \{p_{y,z}^{obs} \cdot \ln(p_{y,z}^{mod} + \delta) + (1 - p_{y,z}^{obs}) \cdot \ln(1 - p_{y,z}^{mod} + \delta)\}$	binomial log-likelihood	J.7

where y is a year, z is a size bin, $n_{y,z}$ is the total number of classified crab in size bin z in year y, $p_{y,z}^{obs}$ is the observed ratio of mature, new shell males to total new shell males in size bin z in year y, $p_{y,z}^{obs}$ is the corresponding model-predicted ratio, and δ is a small constant to prevent trying to calculate ln(0).

Effort data
In both TCSAM2013 and TCSAM02, fishery-specific effort data is used to predict annual fully-selected fishery capture rates for Tanner crab bycatch in the snow crab and Bristol Bay red king crab fisheries in the period before at-sea observer data is available (i.e., prior to 1991), based on the assumed relationship

$$F_{f,y} = q_f \cdot E_{f,y}$$

where $F_{f,y}$ is the fully-selected capture rate in fishery f in year y, q_f is the estimated catchability in fishery f, and $E_{f,y}$ is the reported annual, fishery-specific effort (in pots). In TCAM2013, the fishery q's are estimated directly from the ratio of fishery mean F to mean E over the time period (t_f) when at-sea observer data is available from which to estimate the $F_{f,y}$'s as parameters:

$$q_f = \frac{\sum_{y \in t_f} F_{f,y}}{\sum_{y \in t_f} E_{f,y}}.$$

Note that, in this formulation, the fishery q's are not parameters (i.e., estimated via maximizing the likelihood) in the model. In TCSAM2013, the time period over which q is estimated for each fishery is hard-wired. This approach is also available as an option in TCSAM02, although different time periods for the averaging can be specified in the model options file.

A second approach to effort extrapolation in which the fishery q's are fully-fledged parameters estimated as part of maximizing the likelihood is provided in TCSAM02 as an option, as well. In this case, the effort data is assumed to have a lognormal error distribution and the following negative log-likelihood components are included in the overall model objective function:

$$L_f = \sum_y \frac{\left(\ln(E_{f,y} + \delta) - \ln\left(\frac{F_{f,y}}{q_f} + \delta\right)\right)^2}{2 \cdot \sigma_f^2}$$

where σ_f^2 is the assumed ln-scale variance associated with the effort data and δ is a small value so that the arguments of the ln functions do not go to zero.

Aggregation fitting levels
A number of different ways to aggregate input data and model estimates prior to fitting likelihood functions have been implemented in TCSAM02. These include:

Abundance/Biomass	Size Conpositions	
by	by	extended by
total	total	x
x		x, m
x, mature only	x	--
x, m		m
x, s		s
x, m, s	x, m	--
		s
	x, s	
	x, m, s	

where x, m, s refer to sex, maturity state and shell condition and missing levels are aggregated over. For size compositions that are "extended by" x, m, s, or $\{x, m\}$, this involves appending the size compositions corresponding to each combination of "extended by" factor levels, renormalizing the extended composition to sum to 1, and then fitting the extended composition using a multinomial likelihood.

K. Devs vectors

For TCSAM02 to accommodate arbitrary numbers of fisheries and time blocks, it is necessary to be able to define arbitrary numbers of "devs" vectors. This is currently not possible using the ADMB C++ libraries, so TCSAM02 uses an alternative implementation of devs vectors from that implemented in ADMB. For the 2017 assessment, an n-element "devs" vector was implemented using an n-element bounded parameter vector. with the final element of the "devs" vector defined as $-\sum_{n-1} v_i$, where v_i was the ith value of the parameter (or devs) vector, so that the sum over all elements of the devs vector was identically 0. Penalties were placed on the final element of the devs vector to ensure it was bounded in the same manner as the parameter vector. However, this approach was problematic when initializing the model with the values for the n-1 elements that defined the n-element devs vector, the value of the n-th element ($-\sum_{n-1} v_i$) was not guaranteed to satisfy the bounds placed on the vector. Thus, this approach was revised to allow specification of all n element values (the $v_n = -\sum_{n-1} v_i$ constraint was removed) while the likelihood penalty was changed to ensure the sum of the elements was 0. The new approach also has the advantage that it more closely follows the one used in ADMB to define "devs" vectors. Test runs with both approaches showed no effect on convergence to the MLE solution.

L. Priors for model parameters

A prior probability distribution can be specified for any element of model parameter. The following distributions are available for use as priors:

indicator	**parameters**	**constants**	**description**
none	none	none	no prior applied
ar1_normal	μ, σ	none	random walk with normal deviates
cauchy	x_0, γ	none	Cauchy pdf
chisquare	υ	none	χ^2 pdf
constant	min, max	none	uniform pdf
exponential		none	exponential pdf
gamma	r, μ	none	gamma pdf
invchisquare	υ	none	inverse χ^2 pdf

invgamma	r, μ	none	inverse gamma pdf
invgaussian	$\mu,$	none	inverse Gaussian pdf
lognormal	median, CV	none	lognormal pdf
logscale_normal	median, CV	none	normal pdf on ln-scale
normal	μ, σ	none	normal pdf
scaled_invchisquare	υ, s	none	inverse χ^2 scaled pdf
scaledCV_invchisquare	υ, CV	none	inverse χ^2 pdf, scaled by CV
t	υ	none	t distribution
truncated_normal	μ, σ	min, max	truncated normal pdf

M. Parameters and other information determined outside the model

Several nominal model parameters are not estimated in the model, rather they are fixed to values determined outside the model. These include Tanner crab handling mortality rates for discards in the crab fisheries (32.1%), the groundfish trawl fisheries (80%), and the groundfish pot fisheries (50%), as well the base rate for natural mortality (0.23 yr^{-1}). Sex- and maturity-state-specific parameters for individual weight-at-size have also been determined outside the model, based on fits to data collected on the NMFS EBS bottom trawl survey (Daly et al., 2016). Weight-at-size, $w_{x,m,z}$, is given by

$$w_{x,m,z} = a_{x,m} \cdot z^{b_{x,m}}$$

where

sex	**maturity state**	$a_{x,m}$	$b_{x,m}$
male	all states	0.000270	3.022134
female	immature	0.000562	2.816928
	mature	0.000441	2.898686

and size is in mm CW and weight is in kg.

N. OFL calculations and stock status determination

Overfishing level (OFL) calculations and stock status determination for Tanner crab are based on Tier 3 considerations for crab stocks as defined by the North Pacific Fishery Management Council (NPFMC; NPFMC 2016). Tier 3 considerations require life history information such as natural mortality rates, growth, and maturity but use proxies based on a spawner-per-recruit approach for F_{MSY}, B_{MSY}, and MSY because there is no reliable stock-recruit relationship. Equilibrium recruitment is assumed to be equal to the average recruitment over a selected time period (1982-present for Tanner crab). For Tier 3 stocks, the proxy for B_{MSY} is defined as 35% of longterm (equilibrium) mature male biomass (MMB) for the unfished stock (B_0). The proxy F_{MSY} for Tier 3 stocks is then the directed fishing mortality rate that results in $B_{35\%}$ (i.e., $F_{35\%}$), while the MSY proxy is the longterm total (retained plus discard) catch mortality resulting from fishing at F_{MSY}. The OFL calculation for the upcoming year is based on a sloping

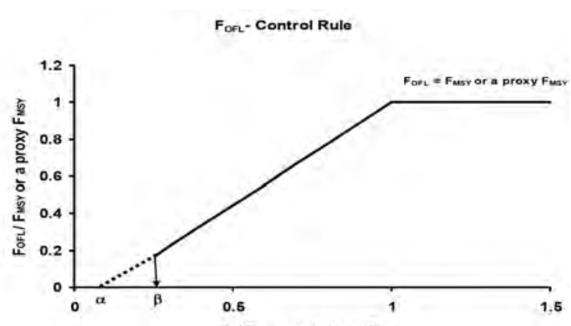


Fig. 2. The F_{OFL} harvest control rule.

harvest control rule for F_{OFL} (Fig. 2), the directed fishing mortality rate that results in the OFL. If the "current" MMB (projected to Feb. 15 of the upcoming year under the F_{OFL}) is above B_{MSY} ($B_{35\%}$), then F_{OFL}=F_{MSY}=$F_{35\%}$. If the current MMB is between $\beta \cdot B_{MSY}$–and B_{MSY}, then F_{OFL} is determined from the slope of the control rule. In either of these cases, the OFL is simply the projected total catch mortality under directed fishing at F_{OFL}. If current MMB is less than $\beta \cdot B_{MSY}$, then no directed fishing is allowed (F_{OFL}=0) and the OFL is set to provide for stock rebuilding with bycatch in non-directed fisheries. Note that if current MMB is less than B_{MSY}, then the process of determining F_{OFL} is generally an iterative one.

Stock status is determined by comparing "current" MMB with the Minimum Stock Size Threshold (MSST), which is defined as $0.5x B_{MSY}$: if "current" MMB is below the MSST, then the stock is overfished—otherwise, it is not overfished.

N.1 Equilibrium conditions

Both OFL calculations and stock status determination utilize equilibrium considerations, both equilibrium under unfished conditions (to determine B_0 and $B_{35\%}$) and under fished conditions (to determine $F_{35\%}$). For Tier 3 stocks, because there is no reliable stock-recruit relationship, analytical solutions can be found for equilibrium conditions for any fishing mortality conditions. These solutions are described below (the notation differs somewhat from that used in previous sections).

N.1.1 Population states

The Tanner crab population on July 1 can be characterized by abundance-at-size in four population states:

in– immature new shell crab
io– immature old shell crab
mn – mature new shell crab
mo – mature old shell crab

where each of these states represents a vector of abundance-at-size (i.e., a vector subscripted by size).

N.1.2 Population processes

The following processes then describe the dynamics of the population over a year:

S_1 – survival from start of year to time of molting/growth of immature crab, possibly including fishing mortality (a diagonal matrix)
S_2 – survival after time of molting/growth of immature crab to end of year, possibly including fishing mortality (a diagonal matrix)
Φ – probability of an immature crab molting (pr(molt|z), where z is pre-molt size; a diagonal matrix) (pr(molt|z) is assumed to be 1 in TCSAM02).
Θ – probability that a molt was terminal (pr(molt to maturity|z, molt), where z is post-molt size; a diagonal matrix)
T – size transition matrix (a non-diagonal matrix)
1 – identity matrix
R –number of recruits by size (a vector)

The matrices above are doubly–subscripted, and R is singly-subscripted, by size. Additionally, the matrices above (except for the identity matrix) can also be subscripted by population state (*in*, *io*, *mn*, *mo*) for generality. For example, survival of immature crab may differ between those that molted and those that skipped.

N.1.3 Population dynamics

The following equations then describe the development of the population from the beginning of one year to the beginning of the next:

$$in^{+} = R + S_{2in} \cdot \{(1 - \Theta_{in}) \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \cdot in + T_{io} \cdot (1 - \Theta_{io}) \cdot \Phi_{io} \cdot S_{1io} \cdot io\}^{-} \qquad \text{(N.1)}$$
$$io^{+} = S_{2io} \cdot \{(1 - \Phi_{in}) \cdot S_{1in} \cdot in + (1 - \Phi_{io}) \cdot S_{1io} \cdot io\}^{-} \qquad \text{(N.2)}$$
$$mn^{+} = S_{2mn} \cdot \{\Theta_{in} \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \cdot in + \Theta_{io} \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \cdot io\}^{-} \qquad \text{(N.3)}$$
$$mo^{+} = S_{2mo} \cdot \{S_{1mn} \cdot mn + S_{1mo} \cdot mo\}^{-} \qquad \text{(N.4)}$$

where "+" indicates year+1 and all recruits (*R*) are assumed to be new shell.

N.1.4 Equilibrium equations

The equations reflecting equilibrium conditions (i.e., $in^{+} = in$, etc.) are simply:

$$in = R + S_{2in} \cdot \{(1 - \Theta_{in}) \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \cdot in + (1 - \Theta_{io}) \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \cdot io\}^{-} \qquad \text{(N.5)}$$
$$io = S_{2io} \cdot \{(1 - \Phi_{in}) \cdot S_{1in} \cdot in + (1 - \Phi_{io}) \cdot S_{1io} \cdot io\}^{-} \qquad \text{(N.6)}$$
$$mn = S_{2mn} \cdot \{\Theta_{in} \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \cdot in + \Theta_{io} \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \cdot io\}^{-} \qquad \text{(N.7)}$$
$$mo = S_{2mo} \cdot \{S_{1mn} \cdot mn + S_{1mo} \cdot mo\}^{-} \qquad \text{(N.8)}$$

where *R* above is now the equilibrium (longterm average) number of recruits-at-size vector.

N.1.5 Equilibrium solution

The equilibrium solution can be obtained by rewriting the above equilibrium equations as:

$$in = R + A \cdot in + B \cdot io^{-} \qquad \text{(N.9)}$$
$$io = C \cdot in + D \cdot io^{-} \qquad \text{(N.10)}$$
$$mn = E \cdot in + F \cdot io^{-} \qquad \text{(N.11)}$$
$$mo = G \cdot mn + H \cdot mo^{-} \qquad \text{(N.12)}$$

where *A*, *B*, *C*, *D*, *E*, *F*, *G*, and *H* are square matrices. Solving for *io* in terms of *in* in eq. 10, one obtains

$$io = \{1 - D\}^{-1} \cdot C \cdot in^{-} \qquad \text{(N.13)}$$

Plugging eq. 13 into 9 and solving for *in* yields

$$in = \{1 - A - B \cdot [1 - D]^{-1} \cdot C\}^{-1} \cdot R^{-} \qquad \text{(N.14)}$$

Equations 13 for *io* and 14 for *in* can simply be plugged into eq. 11 to yield *mn:*

$$mn = E \cdot in + F \cdot io^{-} \qquad \text{(N.15)}$$

while eq. 12 can then be solved for *mo*, yielding:

$$mo = \{1 - H\}^{-1} \cdot G \cdot mn^{-} \qquad \text{(N.16)}$$

where (for completeness):

$$A = S_{2in} \cdot (1 - \Theta_{in}) \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in^{-}} \qquad \text{(N.17)}$$
$$B = S_{2in} \cdot (1 - \Theta_{io}) \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io^{-}} \qquad \text{(N.18)}$$
$$C = S_{2io} \cdot (1 - \Phi_{in}) \cdot S_{1in^{-}} \qquad \text{(N.19)}$$
$$D = S_{2io} \cdot (1 - \Phi_{io}) \cdot S_{1io^{-}} \qquad \text{(N.20)}$$
$$E = S_{2mn} \cdot \Theta_{in} \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in^{-}} \qquad \text{(N.21)}$$

$$F = S_{2mn} \cdot \Theta_{io} \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \tag{N.22}$$
$$G = S_{2mo} \cdot S_{1mn} \tag{N.23}$$
$$H = S_{2mo} \cdot S_{1mo} \tag{N.24}$$

Note that Θ, the size-specific conditional probability of a molt being the terminal molt-to-maturity, is defined above on the basis of post-molt, not pre-molt, size. This implies that whether or not a molt is terminal depends on the size a crab grows into, not the size it at which it molted. An alternative approach would be to assume that the conditional probability of terminal molt is determined by pre-molt size. This would result in an alternative set of equations, but these can be easily obtained from the ones above by simply reversing the order of the terms involving T and Θ (e.g., the term $(1 - \Theta_{in}) \cdot T_{in}$ becomes $T_{in} \cdot (1 - \Theta_{in})$).

N.2 OFL calculations

Because a number of the calculations involved in determining the OFL are iterative in nature, the OFL calculations do not involve automatically-differentiated (AD) variables. Additionally, they are only done after model convergence or when evaluating an MCMC chain. The steps involved in calculating the OFL are outlined as follows:

1. The initial population numbers-at-sex/maturity state/shell condition/size for the upcoming year are copied to a non-AD array.
2. Mean recruitment is estimated over a pre-determined time frame (currently 1982-present).
3. The arrays associated with all population rates in the final year are copied to non-AD arrays for use in the upcoming year.
4. Calculate the average selectivity and retention functions for all fisheries over the most recent 5-year period.
5. Determine the average maximum capture rates for all fisheries over the most recent 5-year period.
6. Using the equilibrium equations, calculate B_0 for unfished stock (B35% = 0.35*B_0).
7. Using the equilibrium equations, iterate on the maximum capture rate for males in the directed fishery to find the one ($F_{35\%}$) that results in the equilibrium MMB = $B_{35\%}$.
8. Calculate "current" MMB under directed fishing at F=$F_{35\%}$ by projecting initial population (1) to Feb. 15.
    a. If current MMB > $B_{35\%}$, F_{OFL} = $F_{35\%}$. The associated total catch mortality is OFL.
    b. Otherwise
        i. set directed F based on the harvest control rule and the ratio of the calculated current MMB to $B_{35\%}$
        ii. recalculate current MMB
        iii. iterate i-iii until current MMB doesn't change between iterations. Then $F_{OFL} = F$ ($< F_{35\%}$) and the OFL is the associated total (retained plus discard) catch mortality.

References

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Methot, R.D. and C.R. Wetzel. 2013. Stock synthesis: A biological and statistical framework for fish stock assessment and fishery management. Fish. Res. 142: 86-99.

NPFMC. 2016. Introduction. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2016 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 1-40.

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

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

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

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

Stockhausen, W.T. 2014. 2014 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2014 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 324-545.

Stockhausen, W.T. 2015. 2015 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2015 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 293-440.

Stockhausen, W.T. 2016. 2016 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands: 2016 Crab SAFE. North Pacific Fishery Management Council. Anchorage, AK. pp. 251-446.

Model Comparisons: Fits to Size Composition Data – M19F00a vs M19F01 vs M19F02 vs M19F03 vs M19F04 vs M19F05

William Stockhausen

07 September, 2019

Contents

Model fits to size compositions, by year

Fits to the size composition data available to the model(s) are presented in this section as line plots by year. Not all of the fits presented are necessarily included in the parameter optimization for each model; some fits to datasets for a particular model may be included for comparison purposes with other models which include those data in their optimization. The reader should consult the main assessment document to determine which fits are included in the optimization for any particular model.

Survey size compositions

Figure 1: Comparison of observed and predicted male, immature, all shell survey size comps for NMFS 0. Page 1 of 5.

Figure 2: Comparison of observed and predicted male, immature, all shell survey size comps for NMFS 0. Page 2 of 5.

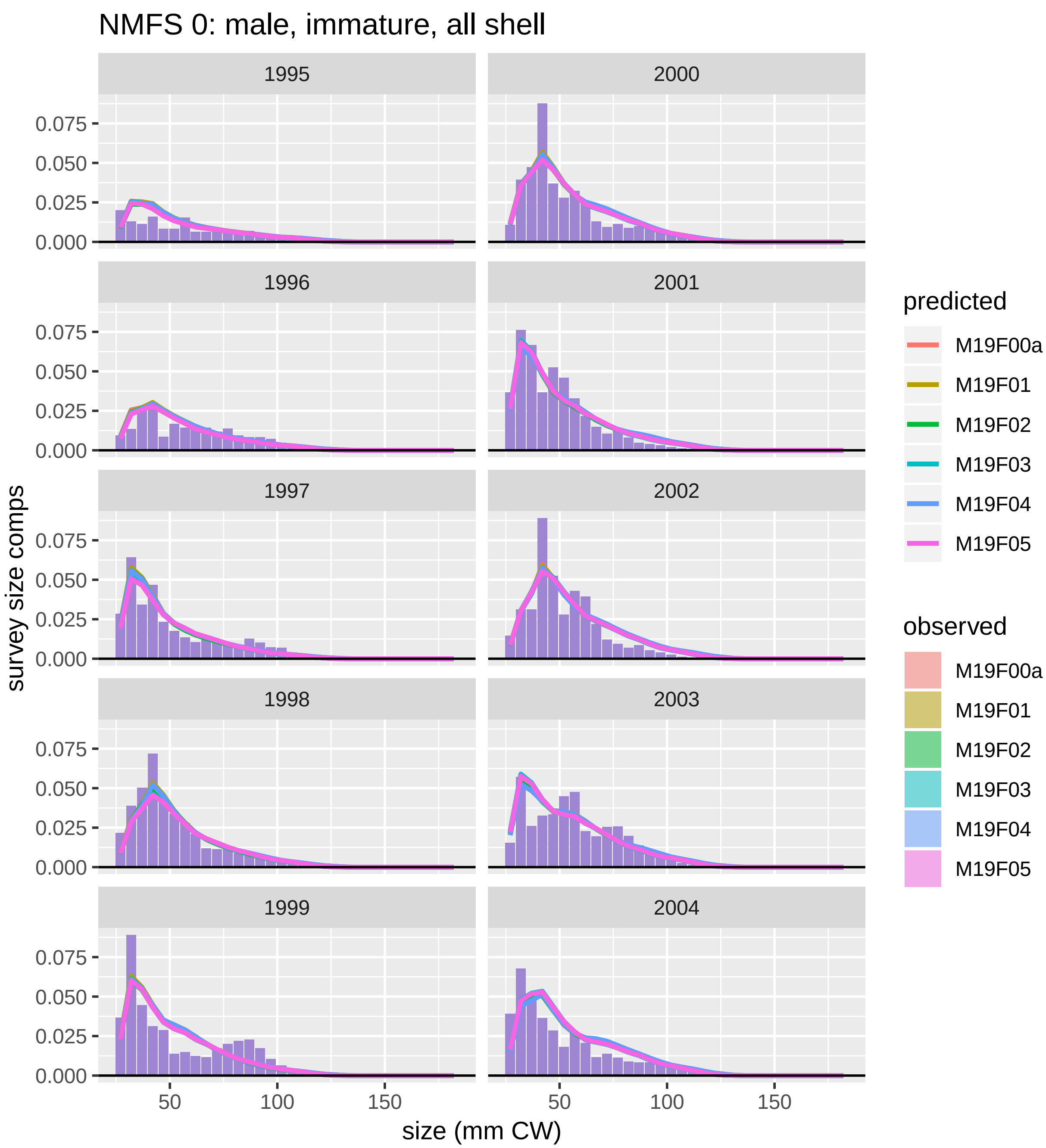


Figure 3: Comparison of observed and predicted male, immature, all shell survey size comps for NMFS 0. Page 3 of 5.

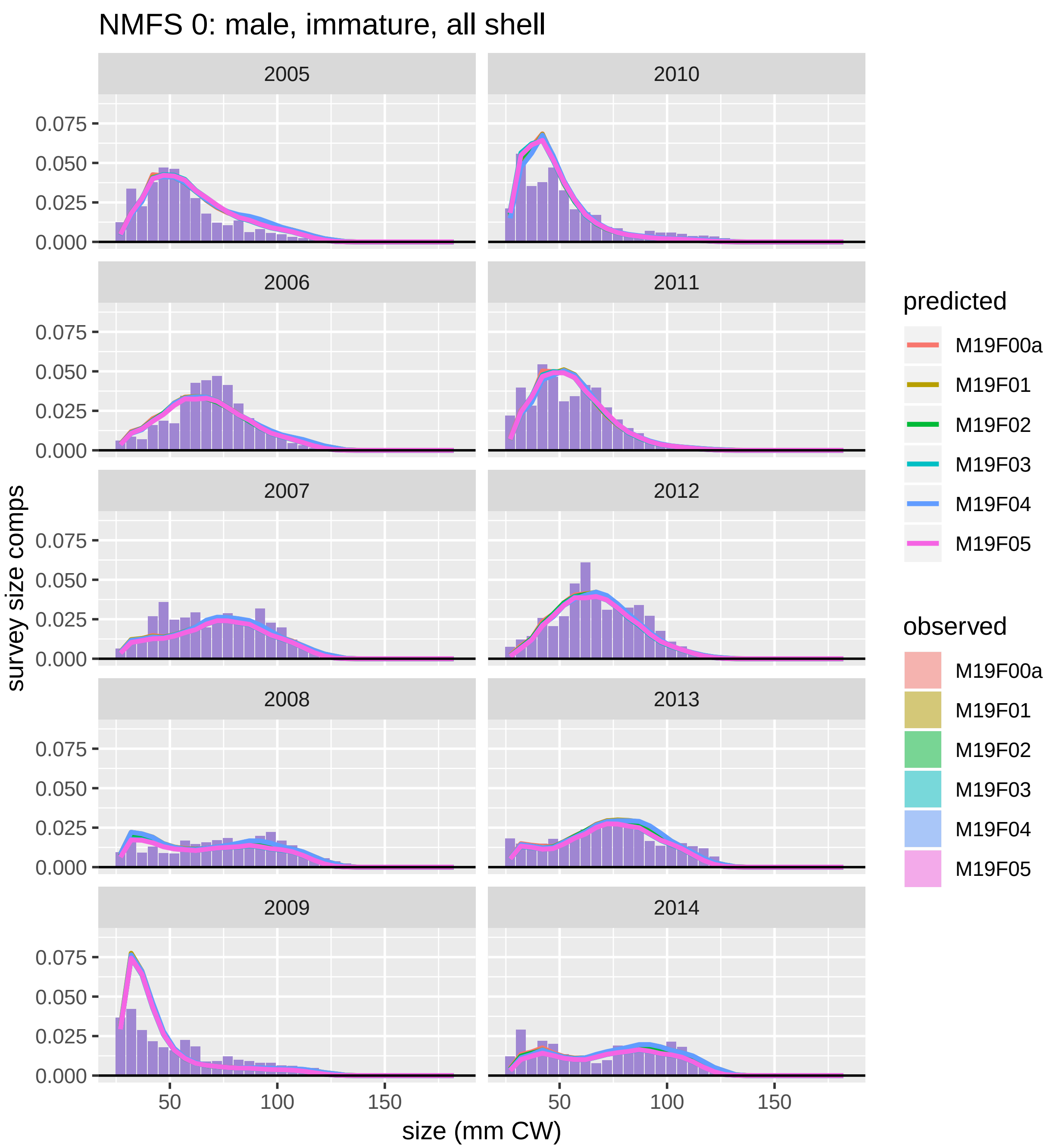


Figure 4: Comparison of observed and predicted male, immature, all shell survey size comps for NMFS 0. Page 4 of 5.

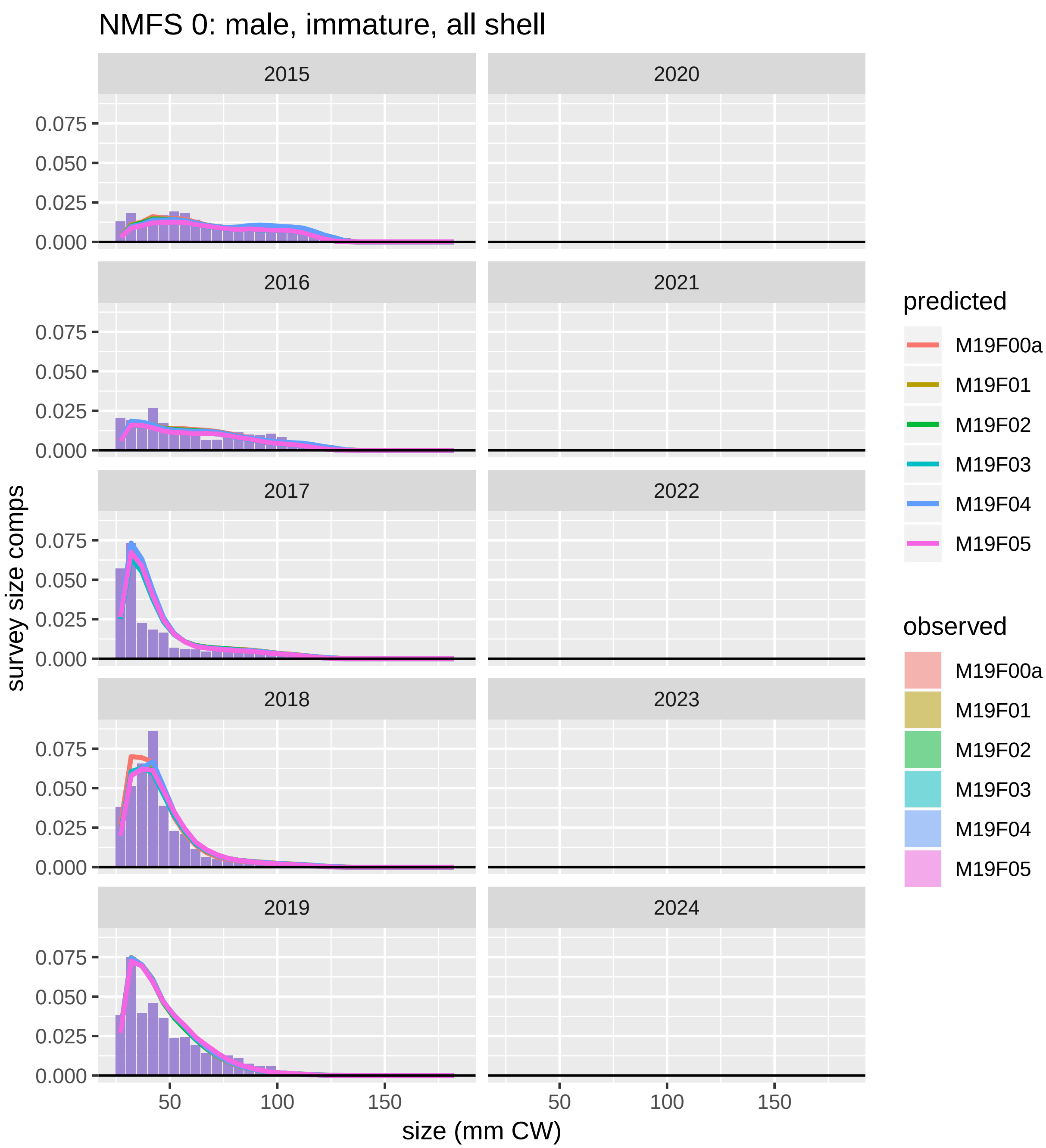


Figure 5: Comparison of observed and predicted male, immature, all shell survey size comps for NMFS 0. Page 5 of 5.

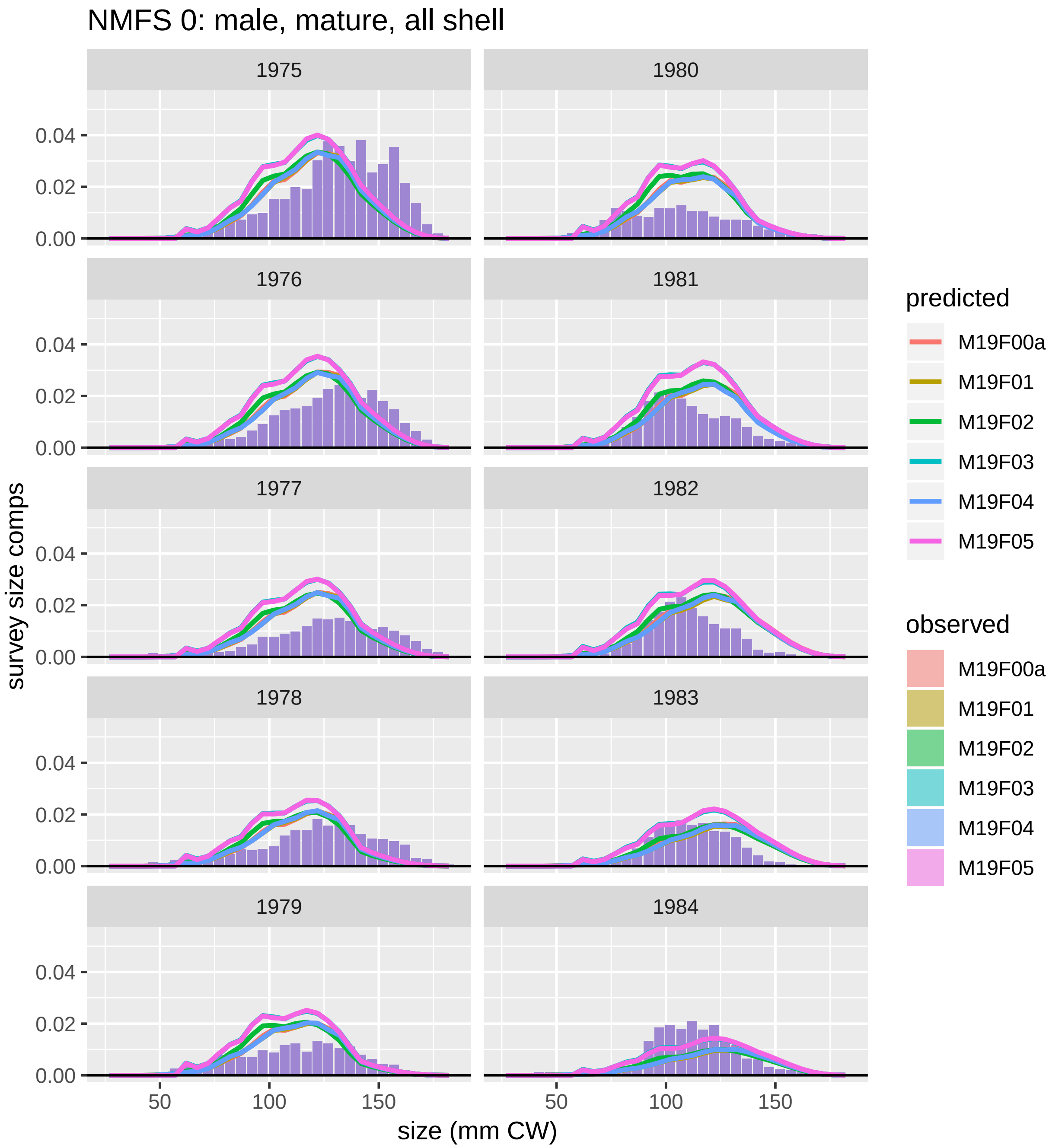


Figure 6: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS 0. Page 1 of 5.

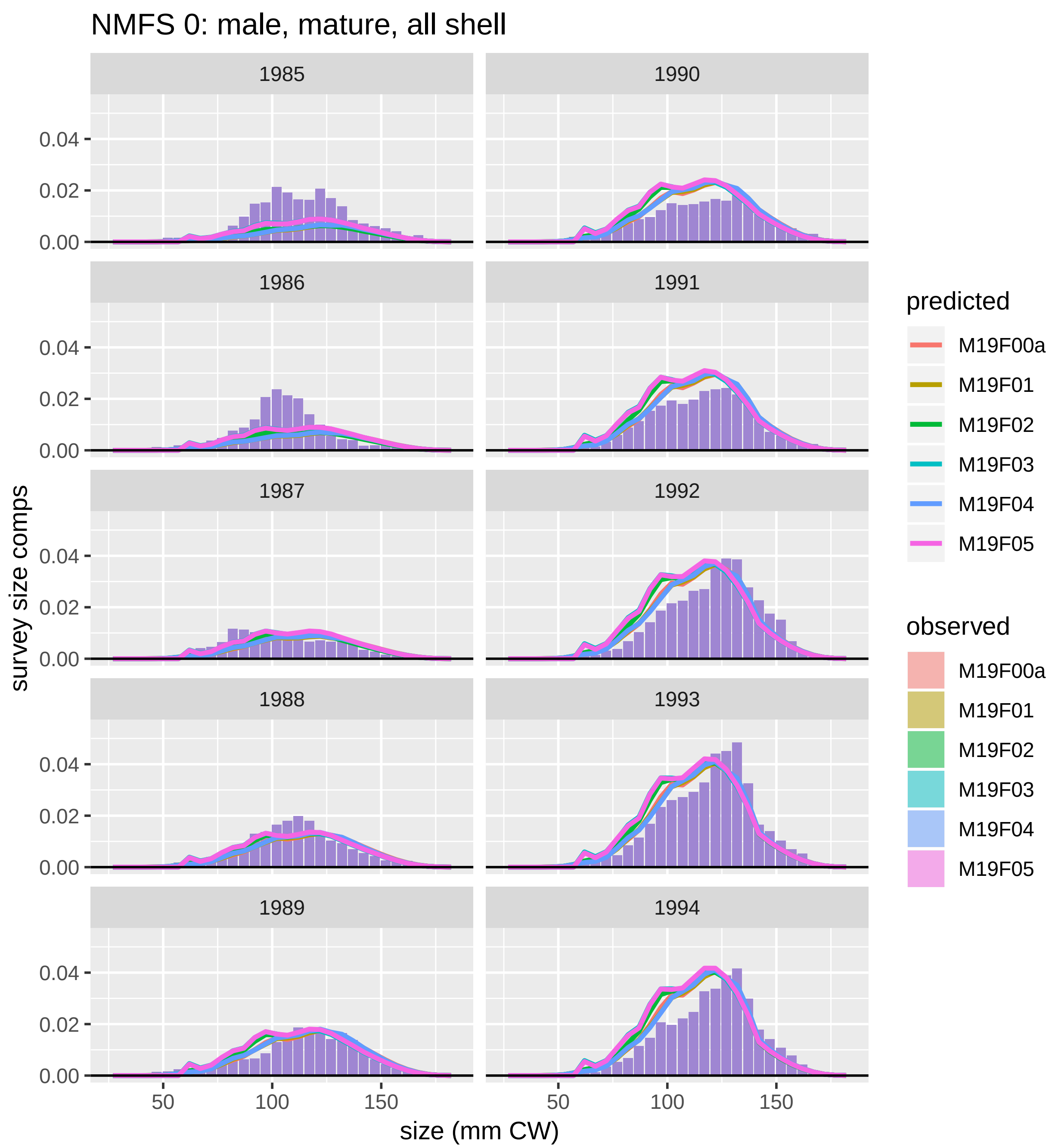


Figure 7: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS 0. Page 2 of 5.

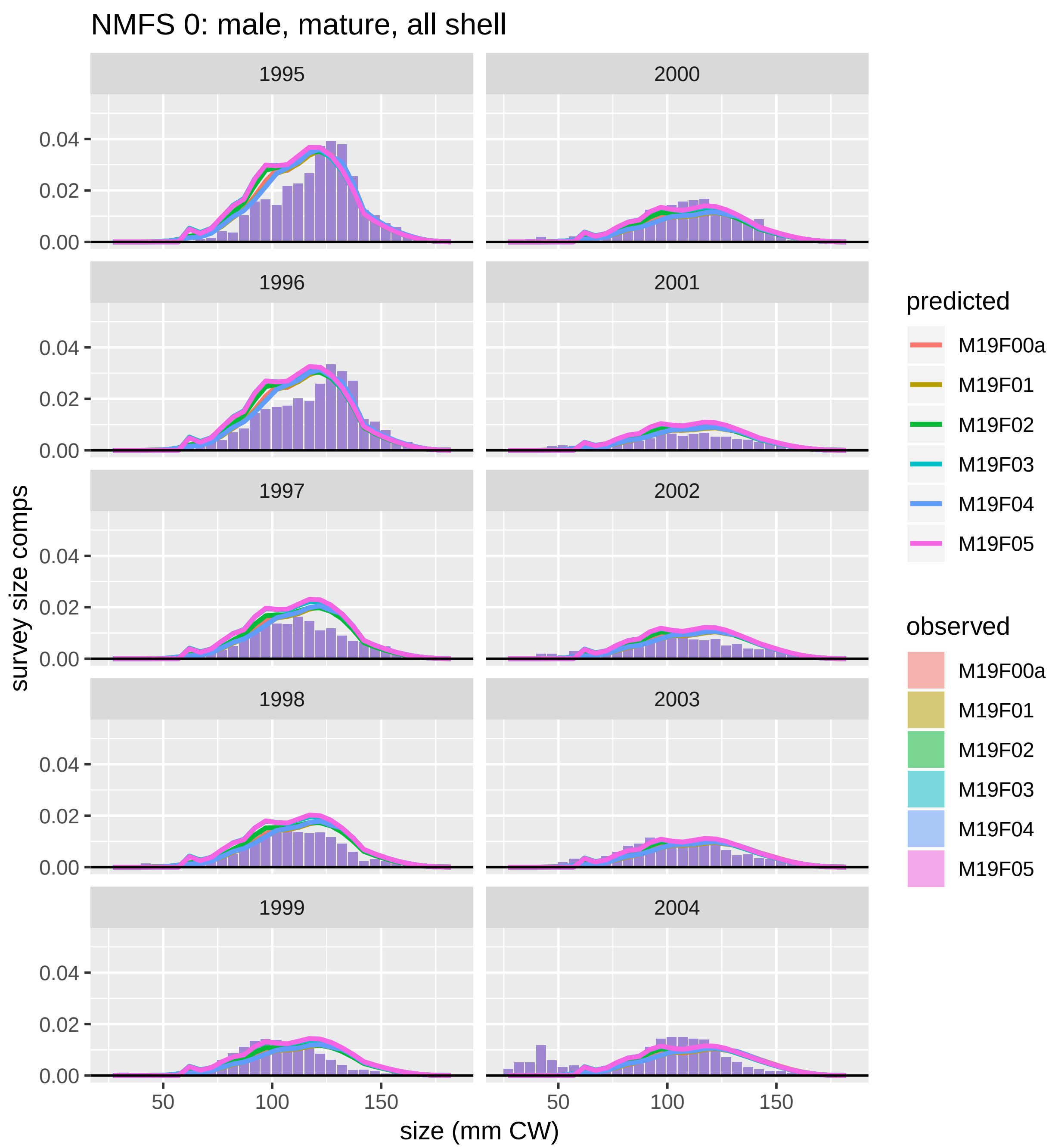


Figure 8: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS 0. Page 3 of 5.

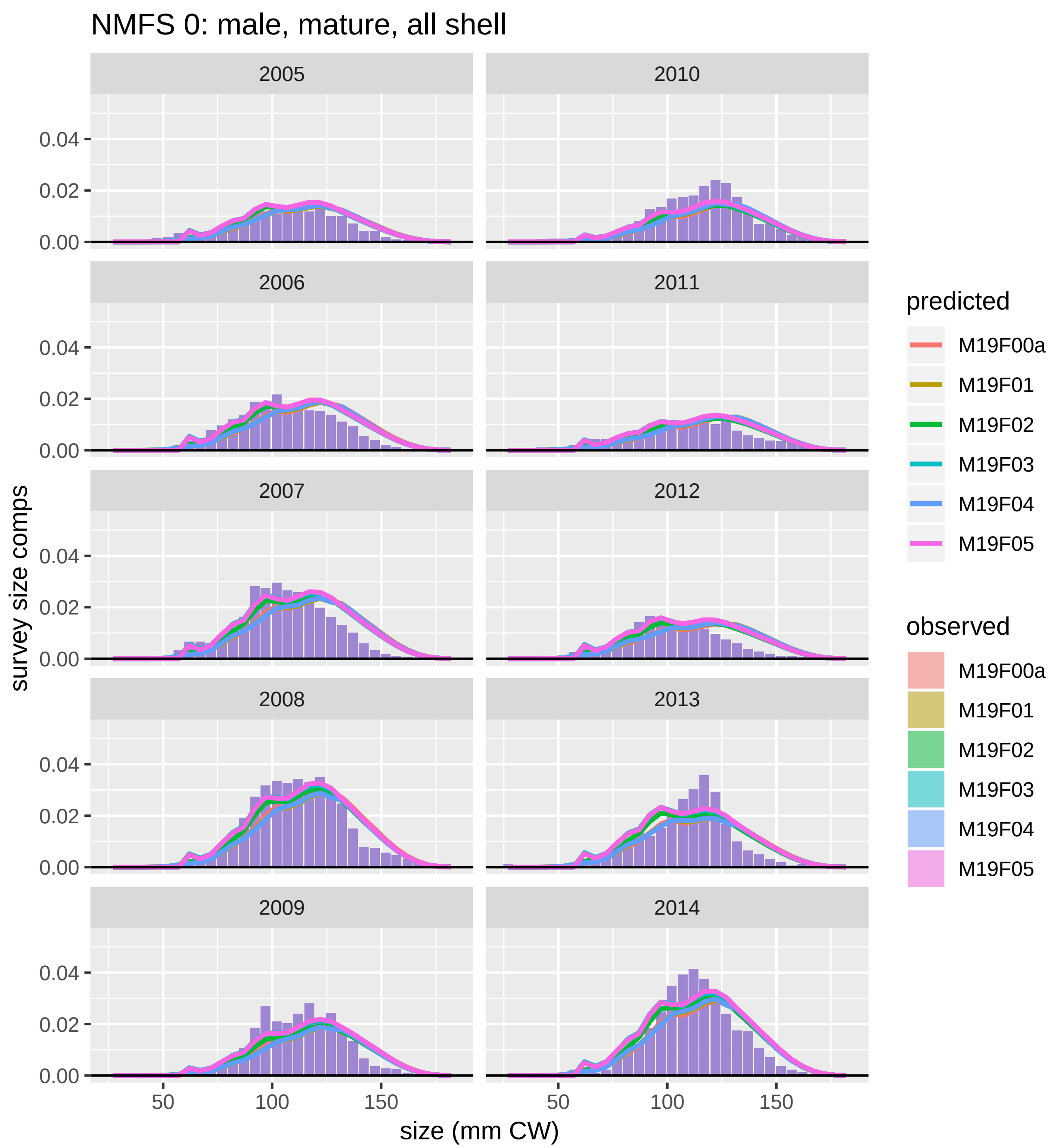


Figure 9: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS 0. Page 4 of 5.

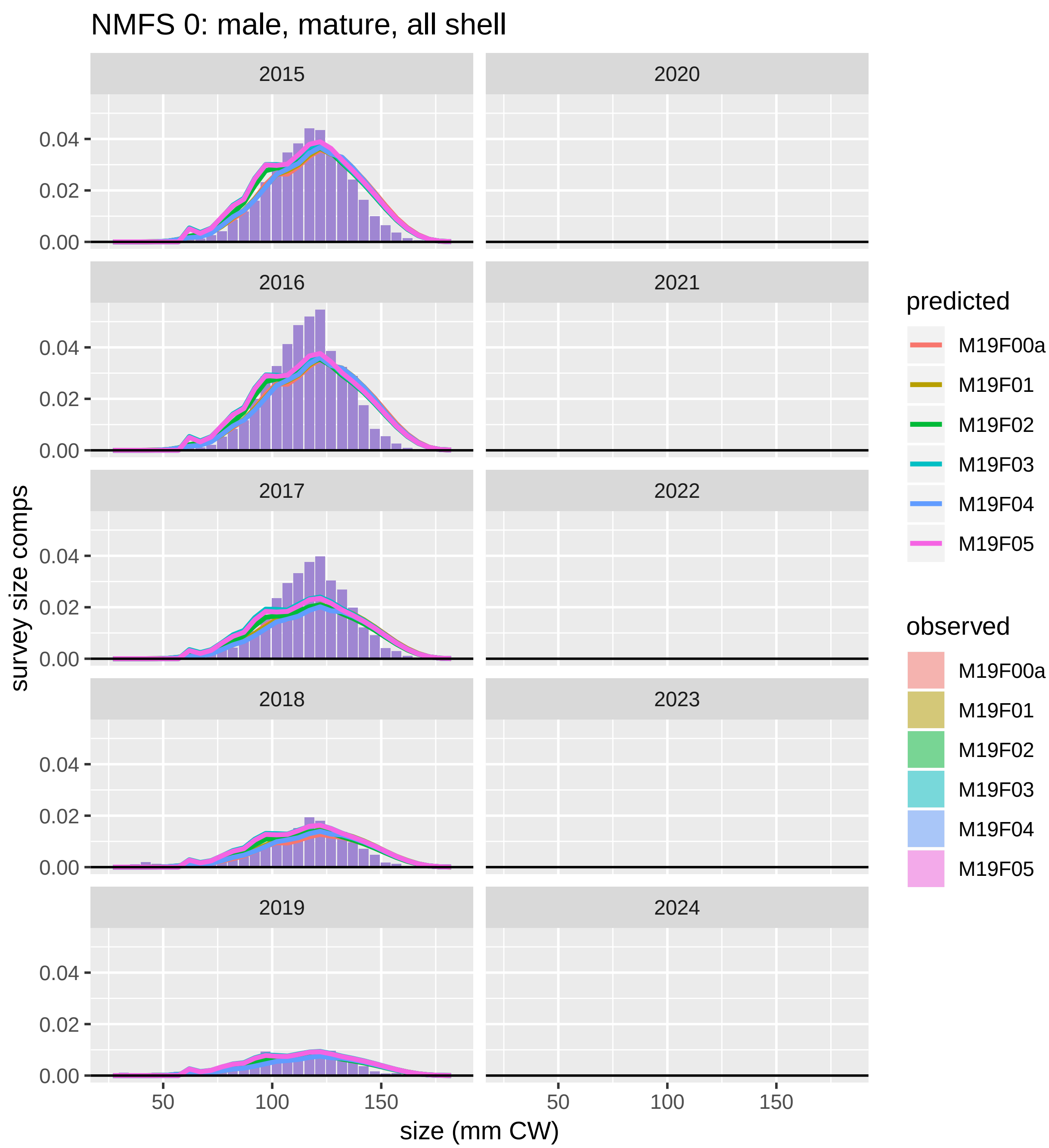


Figure 10: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS 0. Page 5 of 5.

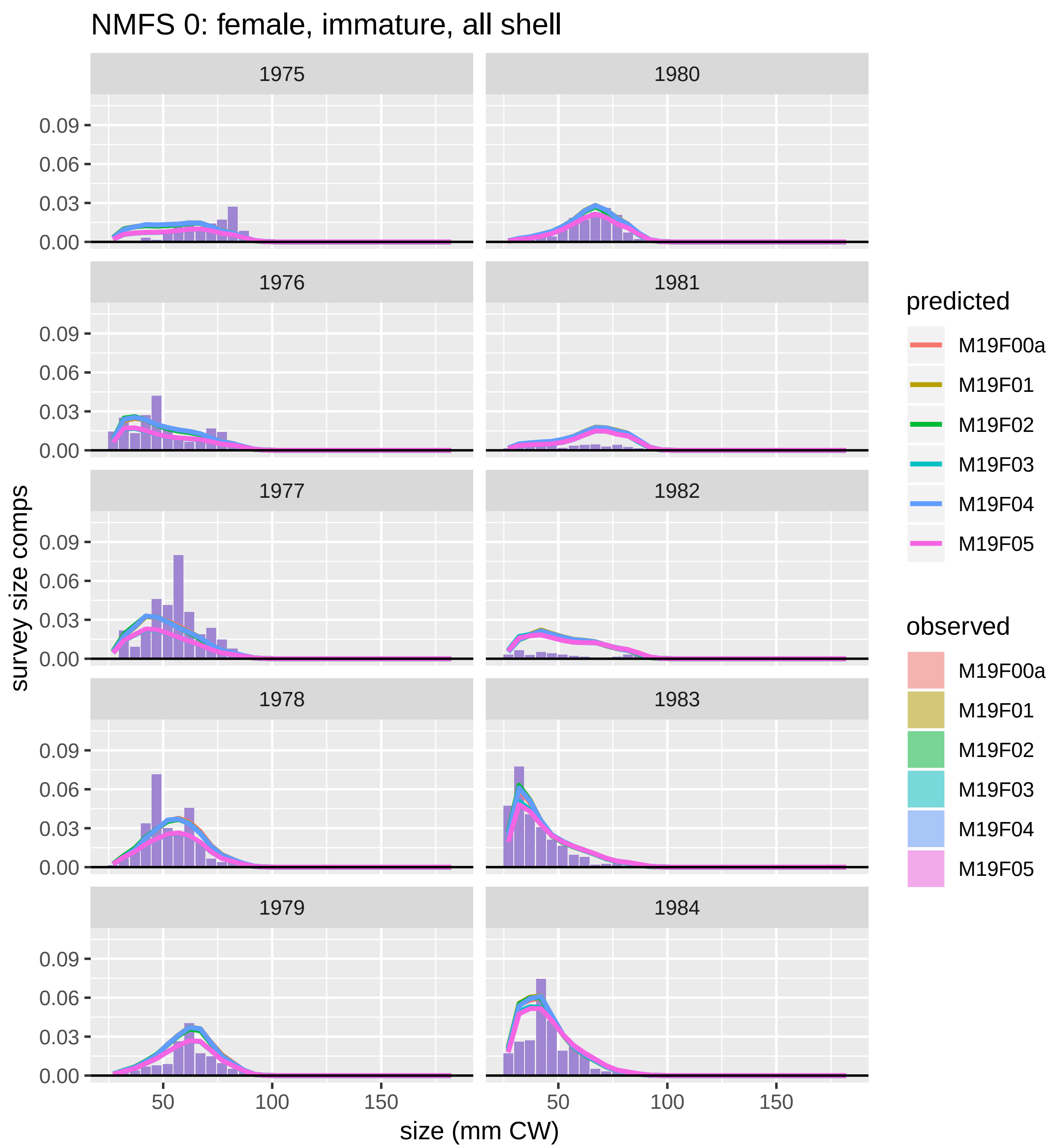


Figure 11: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS 0. Page 1 of 5.

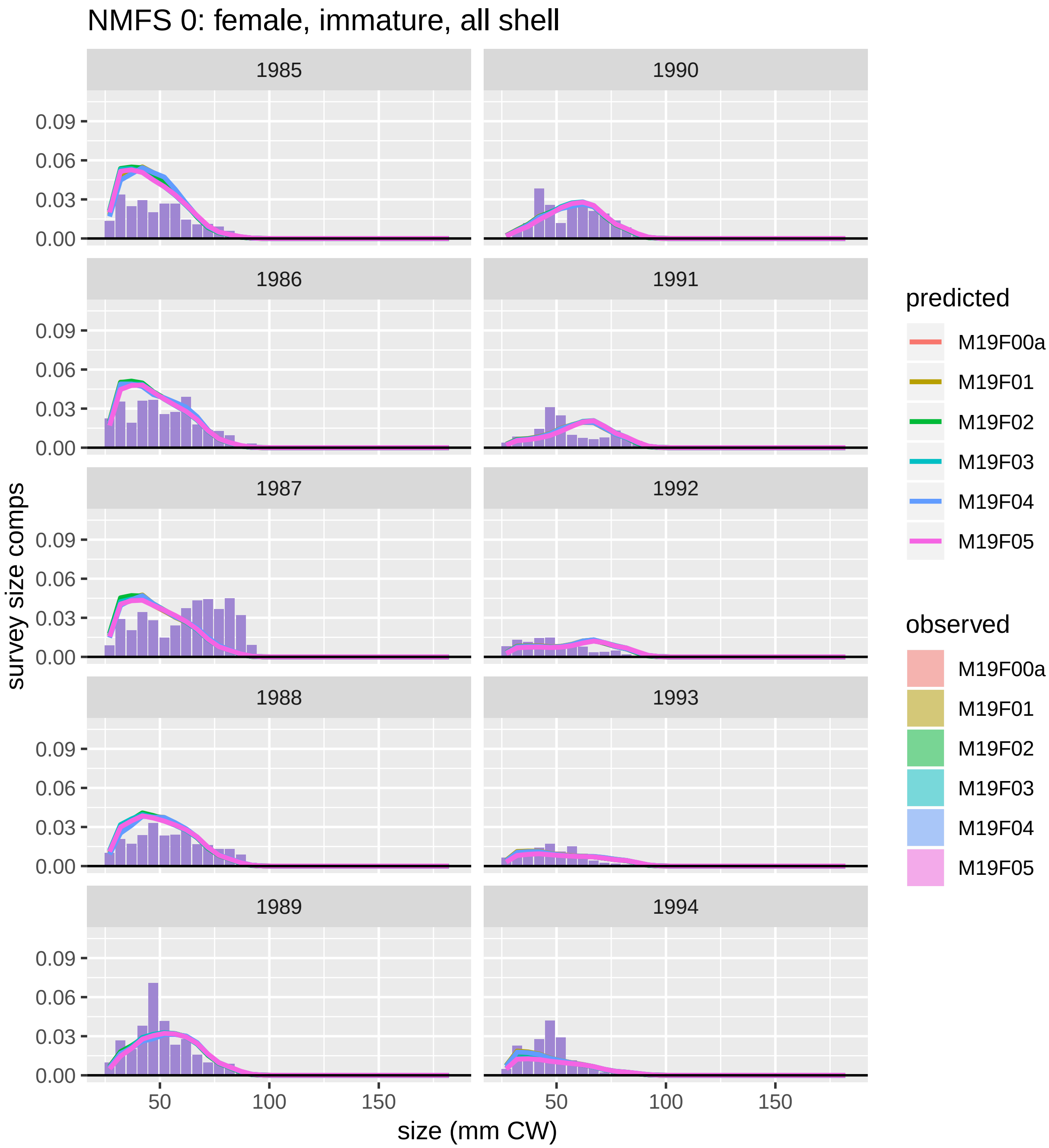


Figure 12: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS 0. Page 2 of 5.

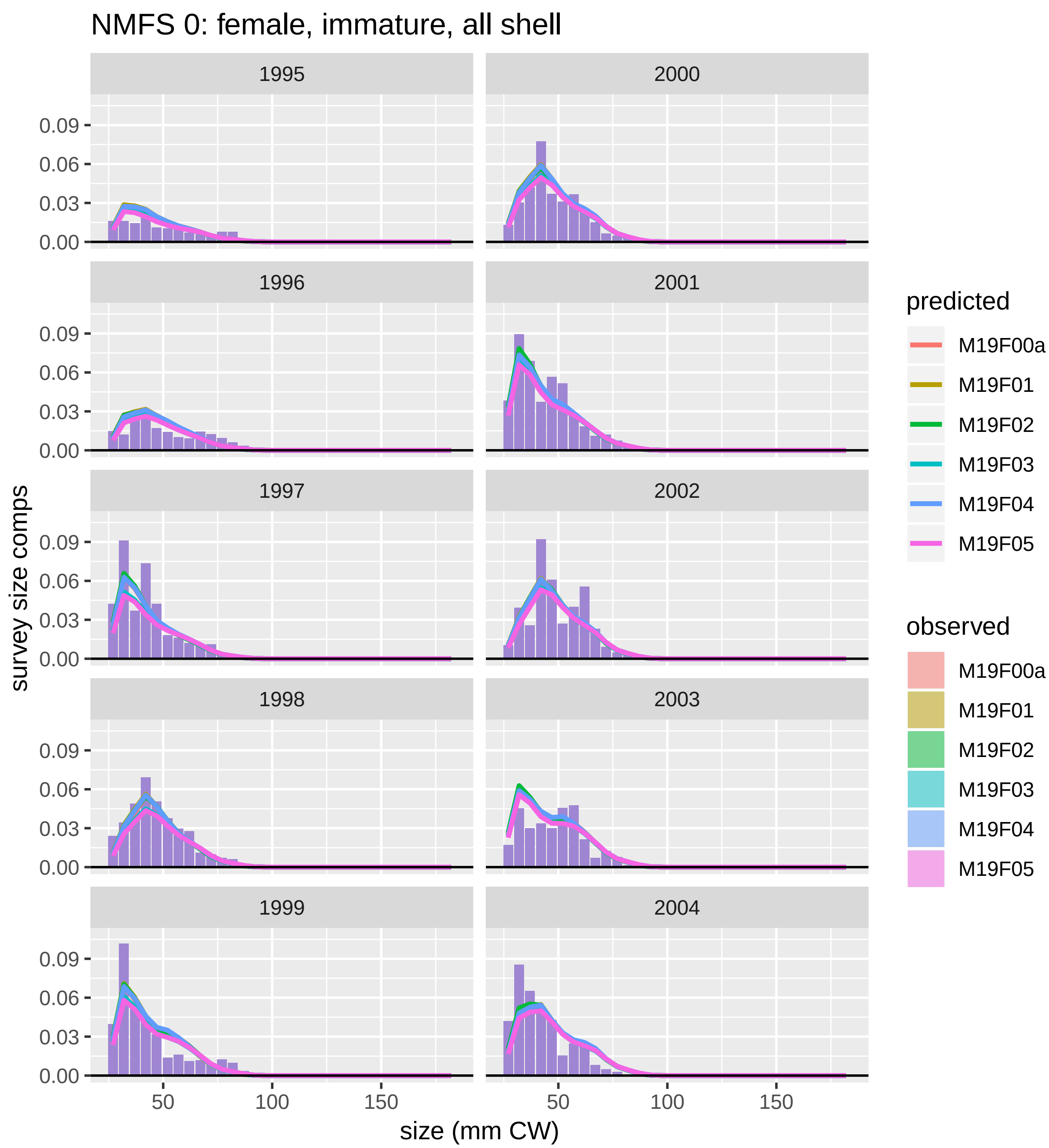


Figure 13: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS 0. Page 3 of 5.

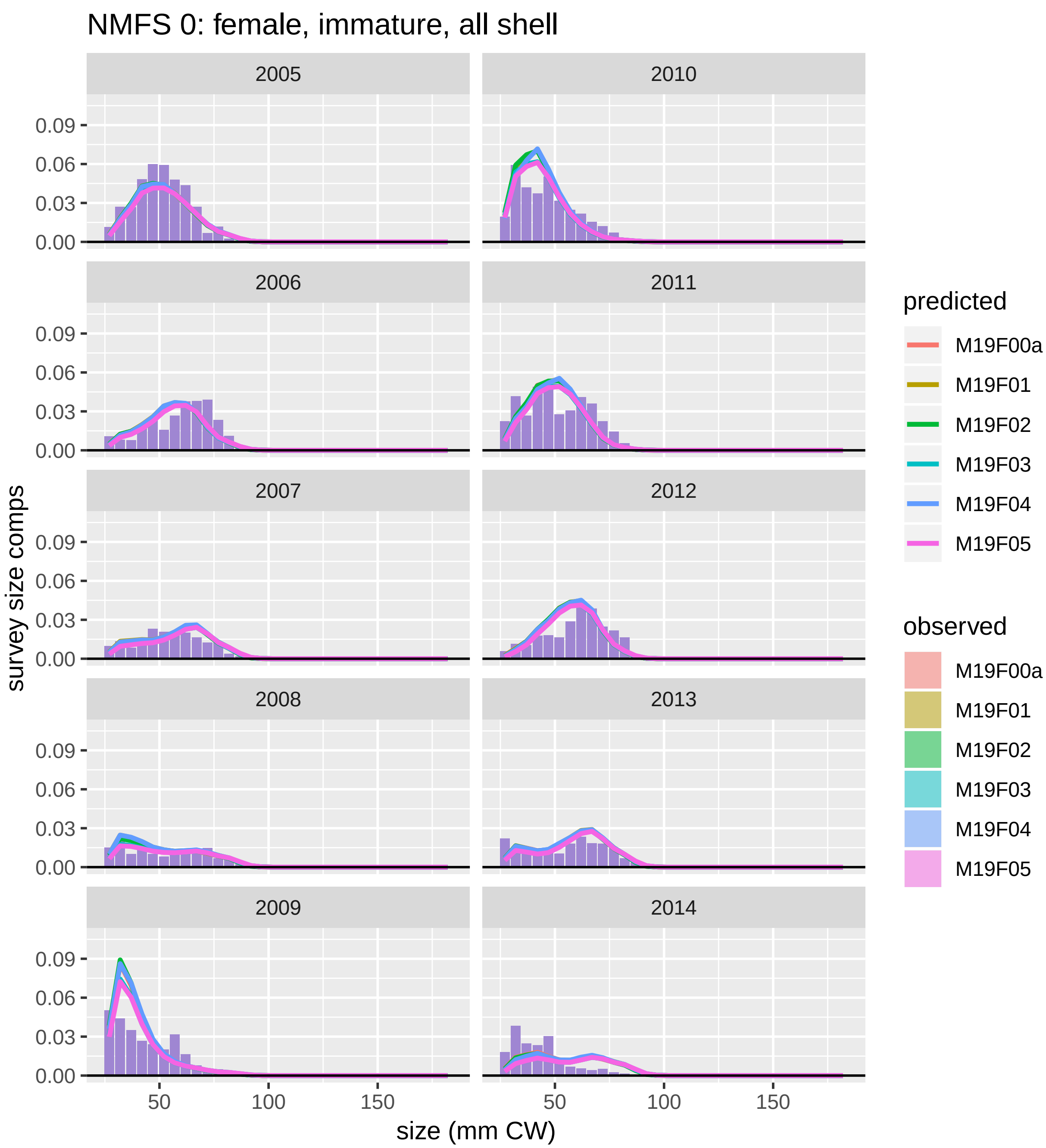


Figure 14: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS 0. Page 4 of 5.

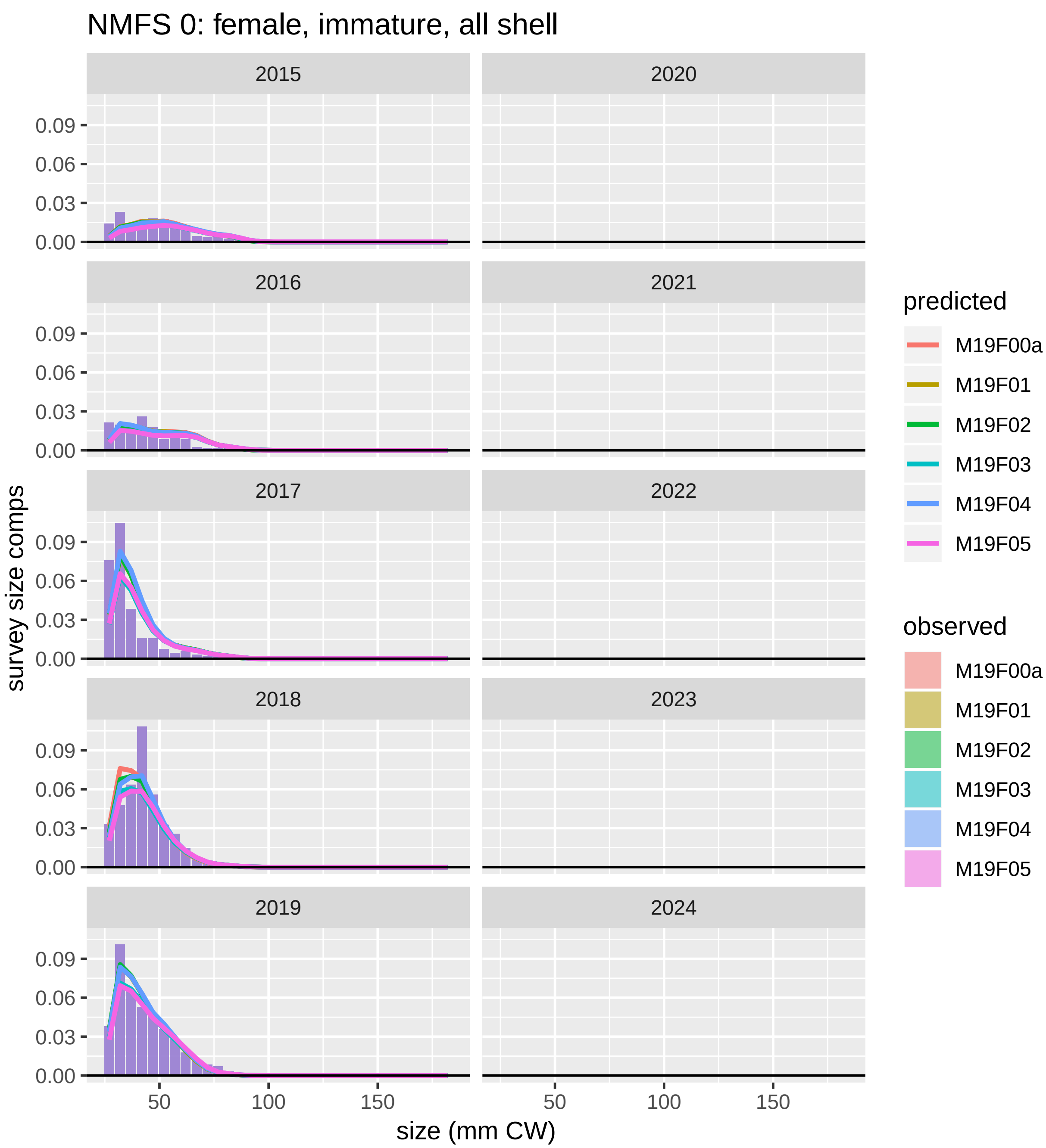


Figure 15: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS 0. Page 5 of 5.

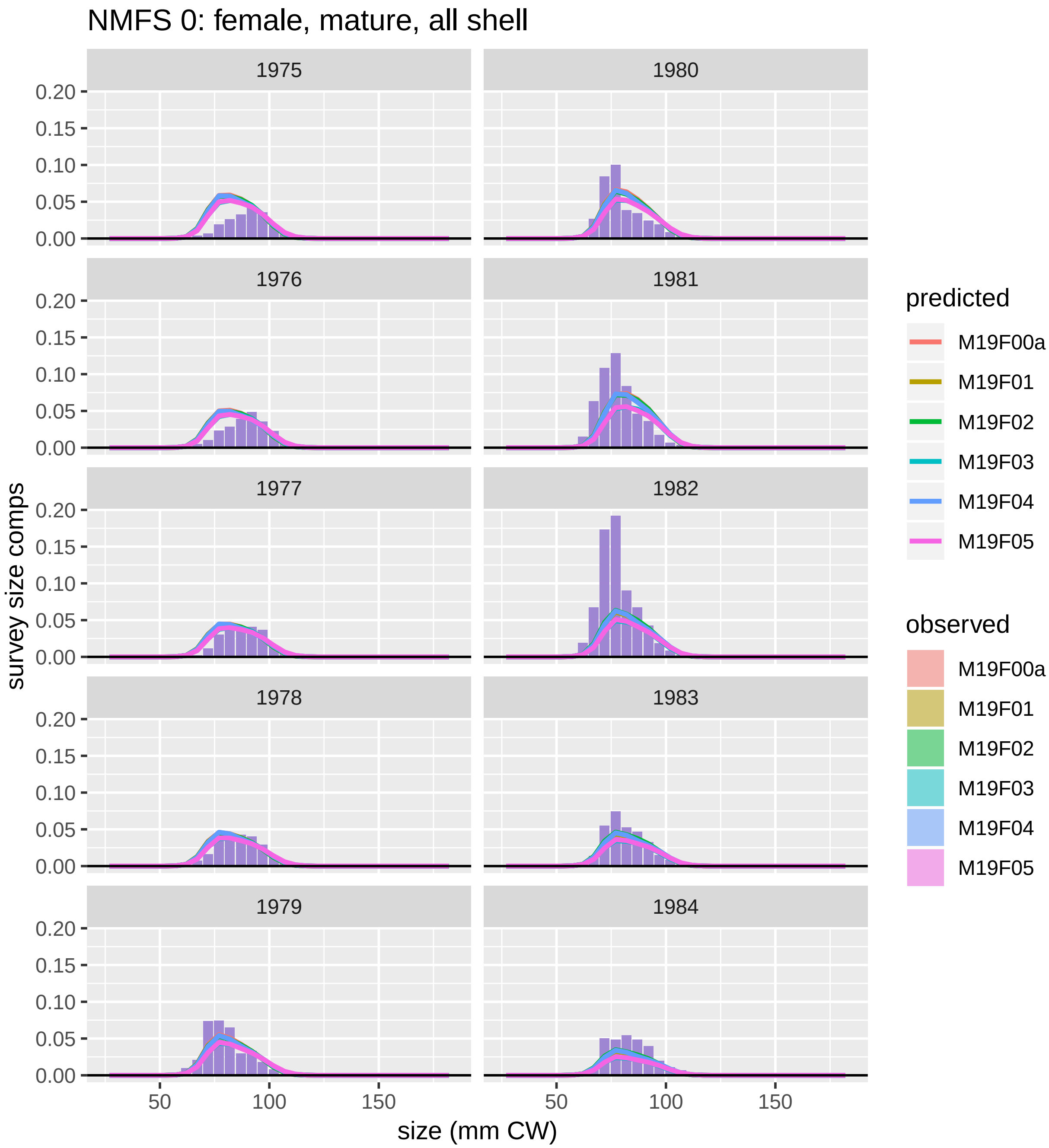


Figure 16: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS 0. Page 1 of 5.

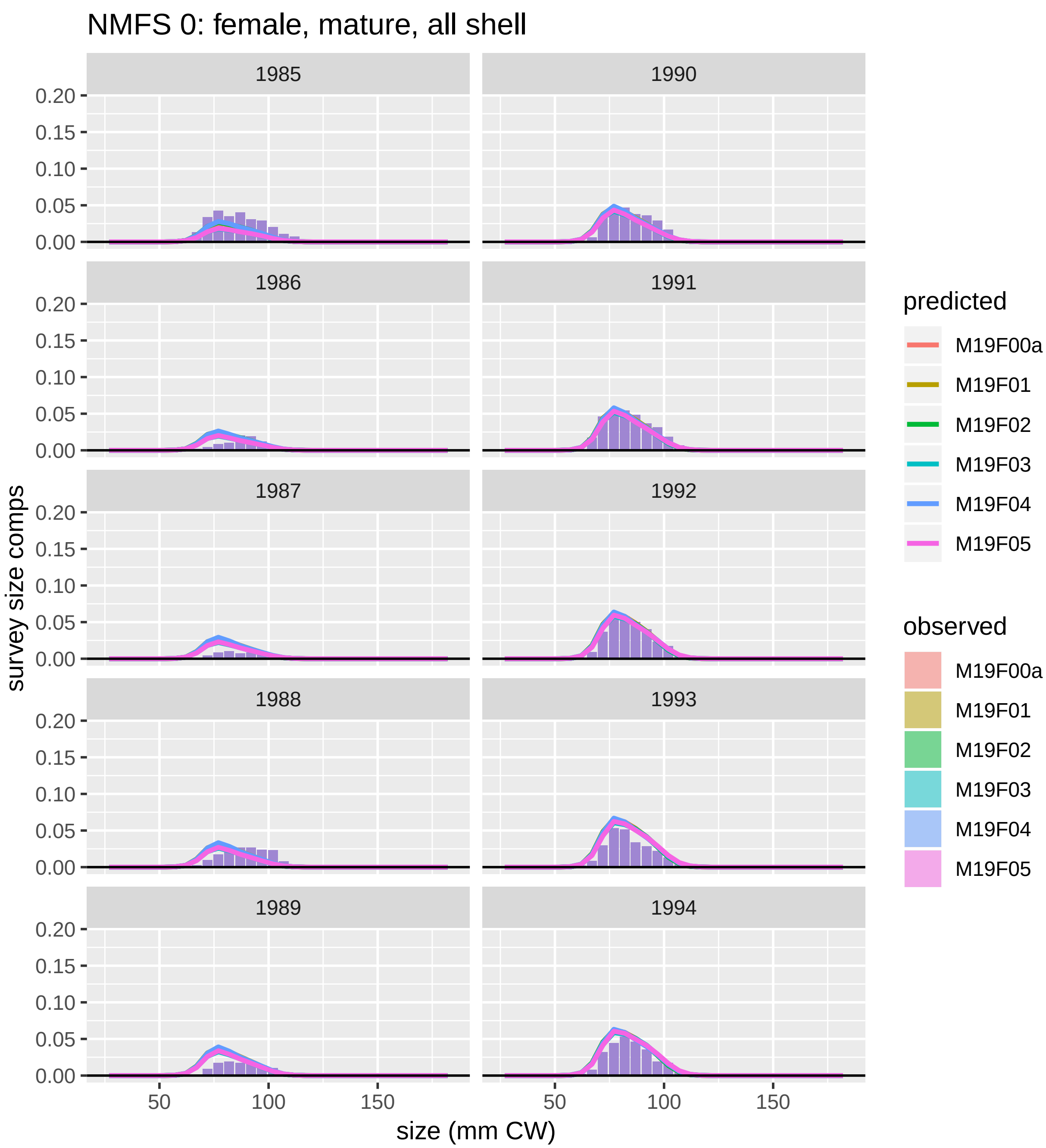


Figure 17: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS 0. Page 2 of 5.

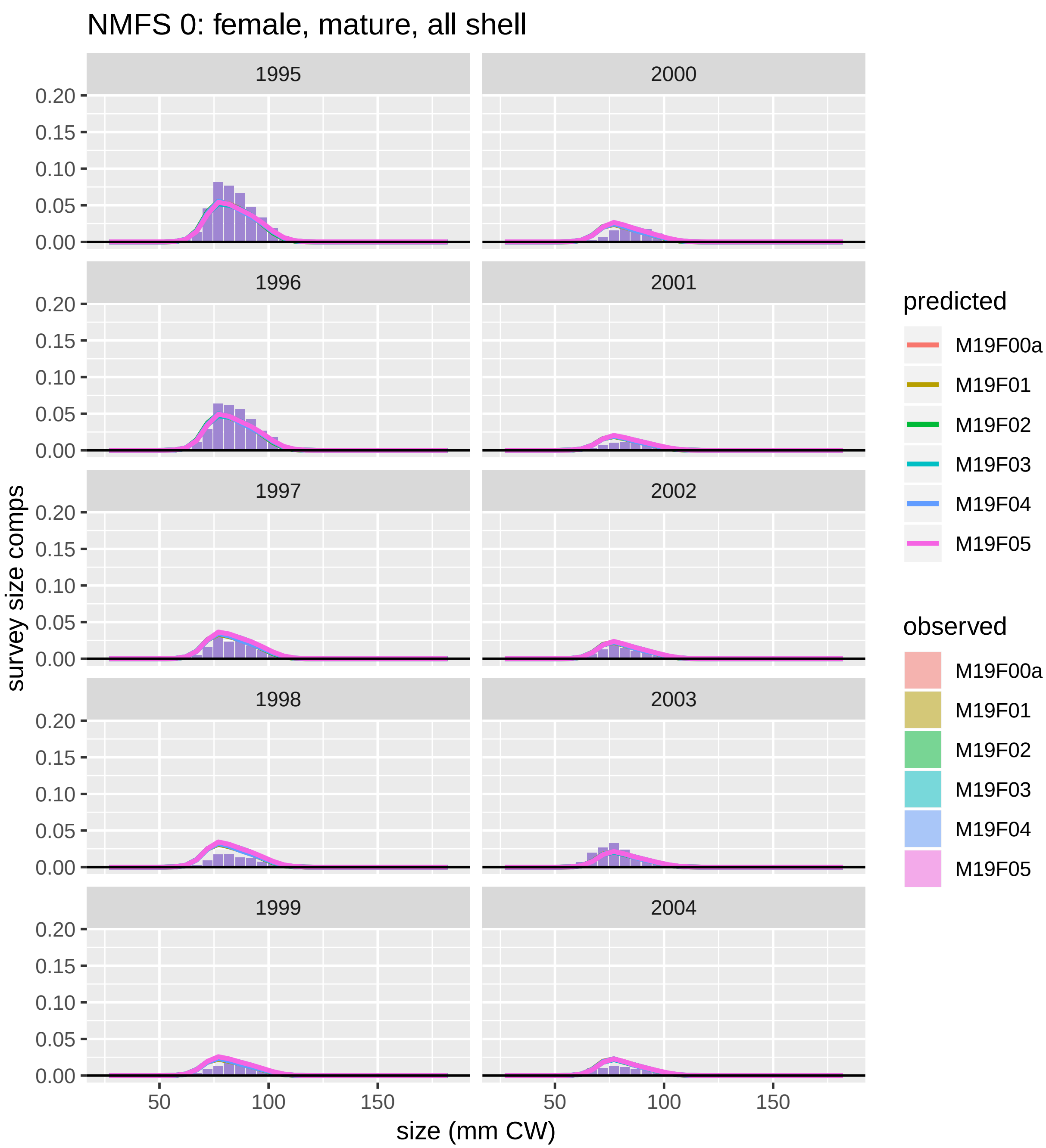


Figure 18: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS 0. Page 3 of 5.

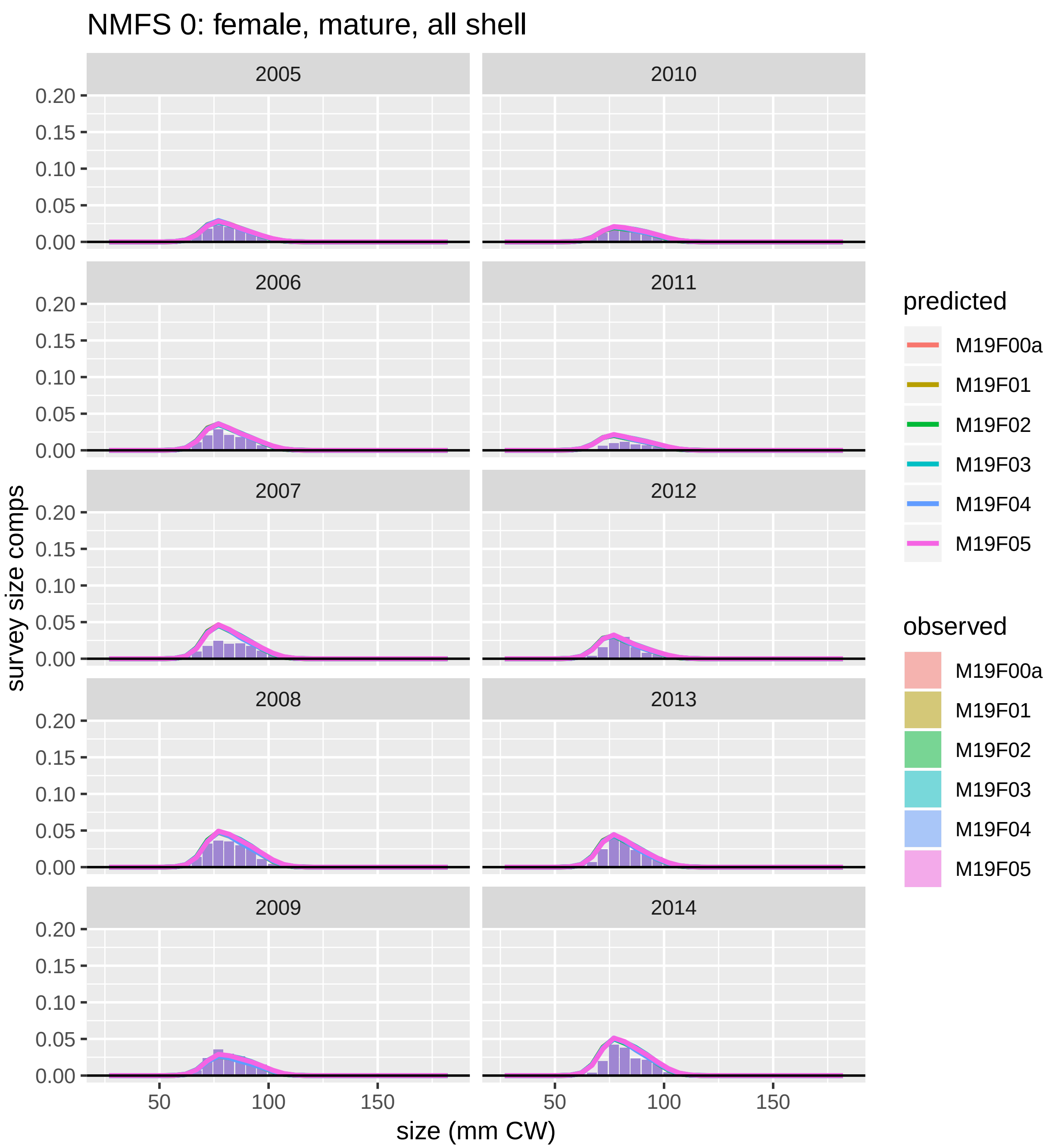


Figure 19: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS 0. Page 4 of 5.

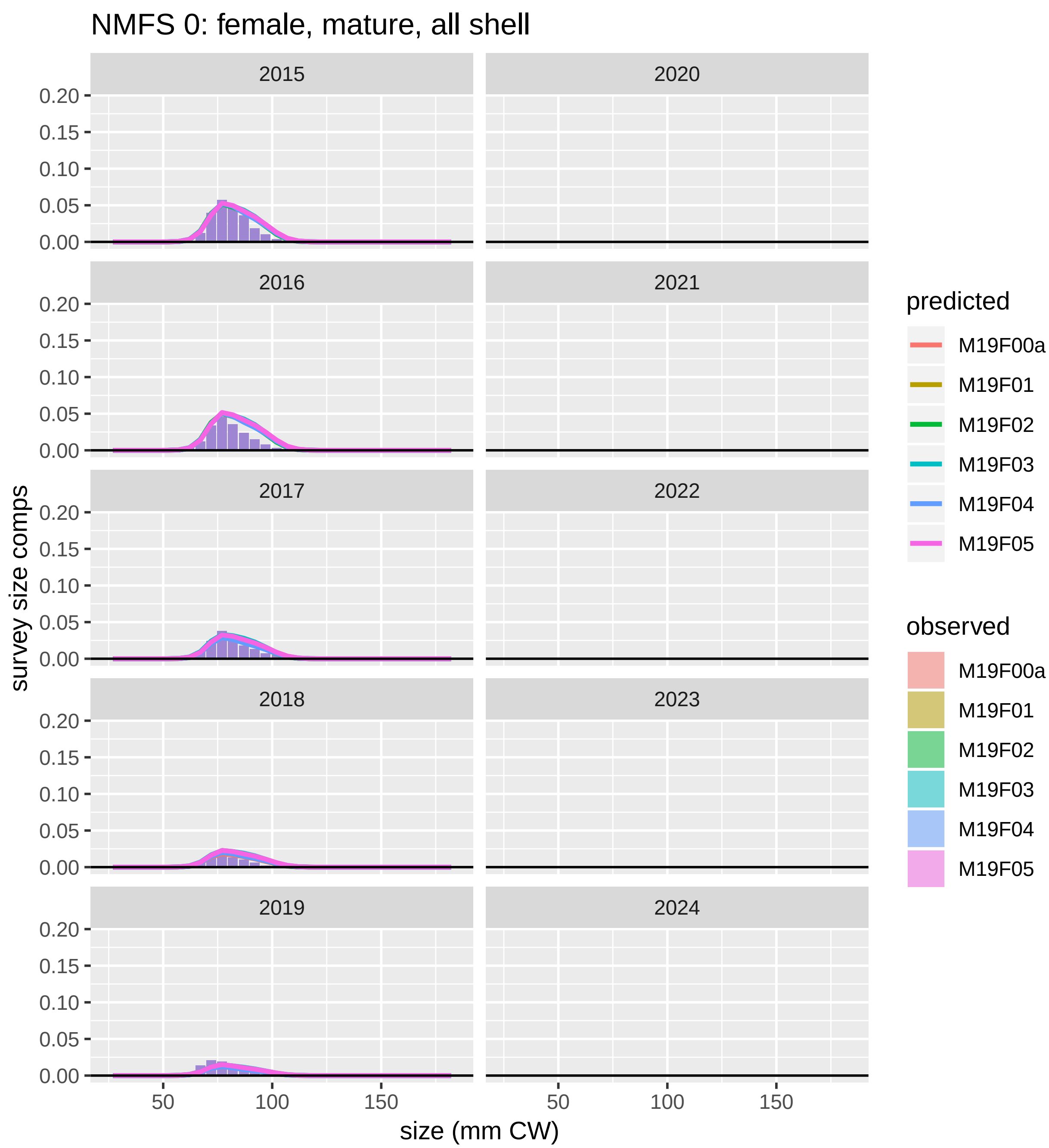


Figure 20: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS 0. Page 5 of 5.

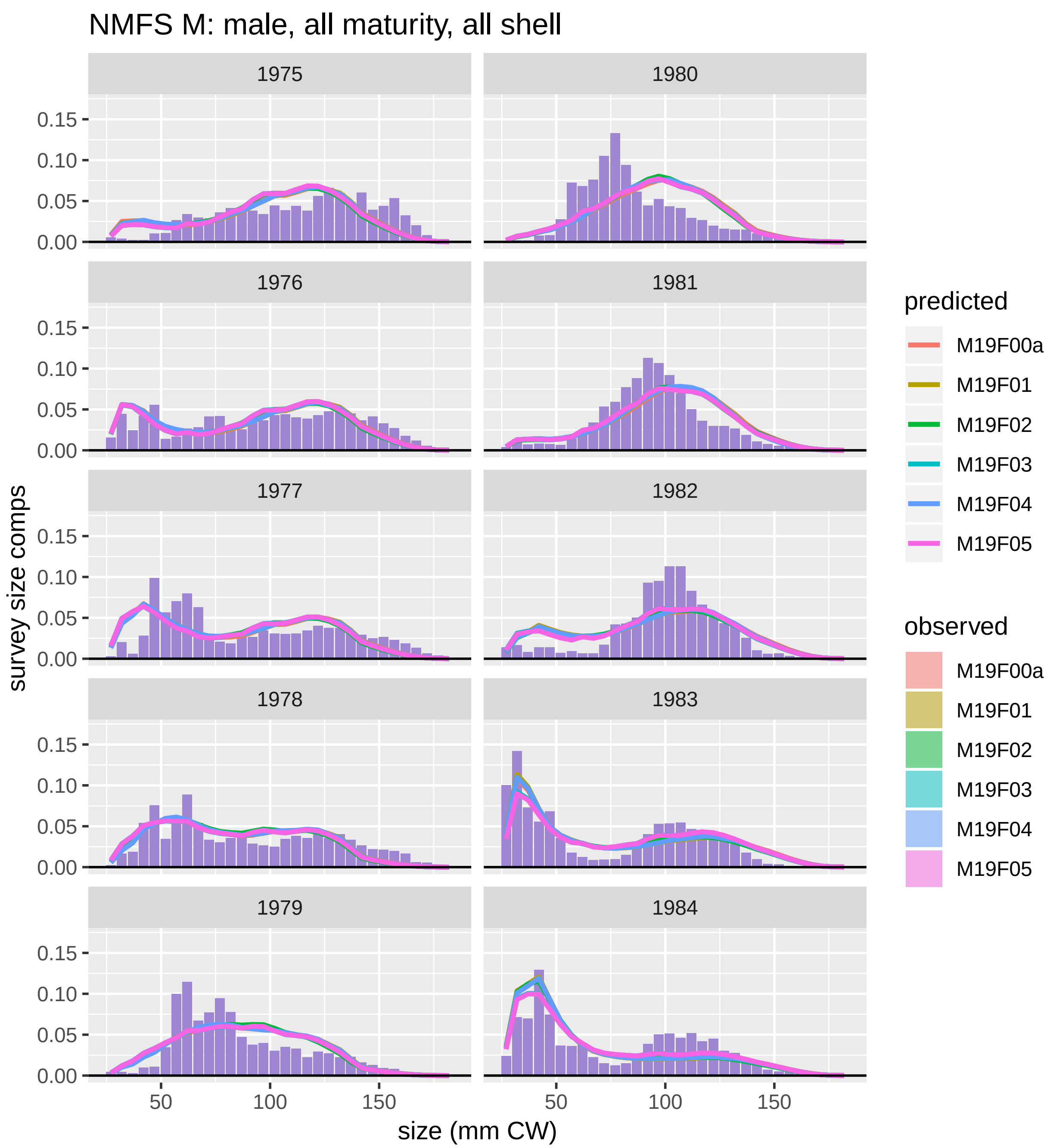


Figure 21: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 1 of 5.

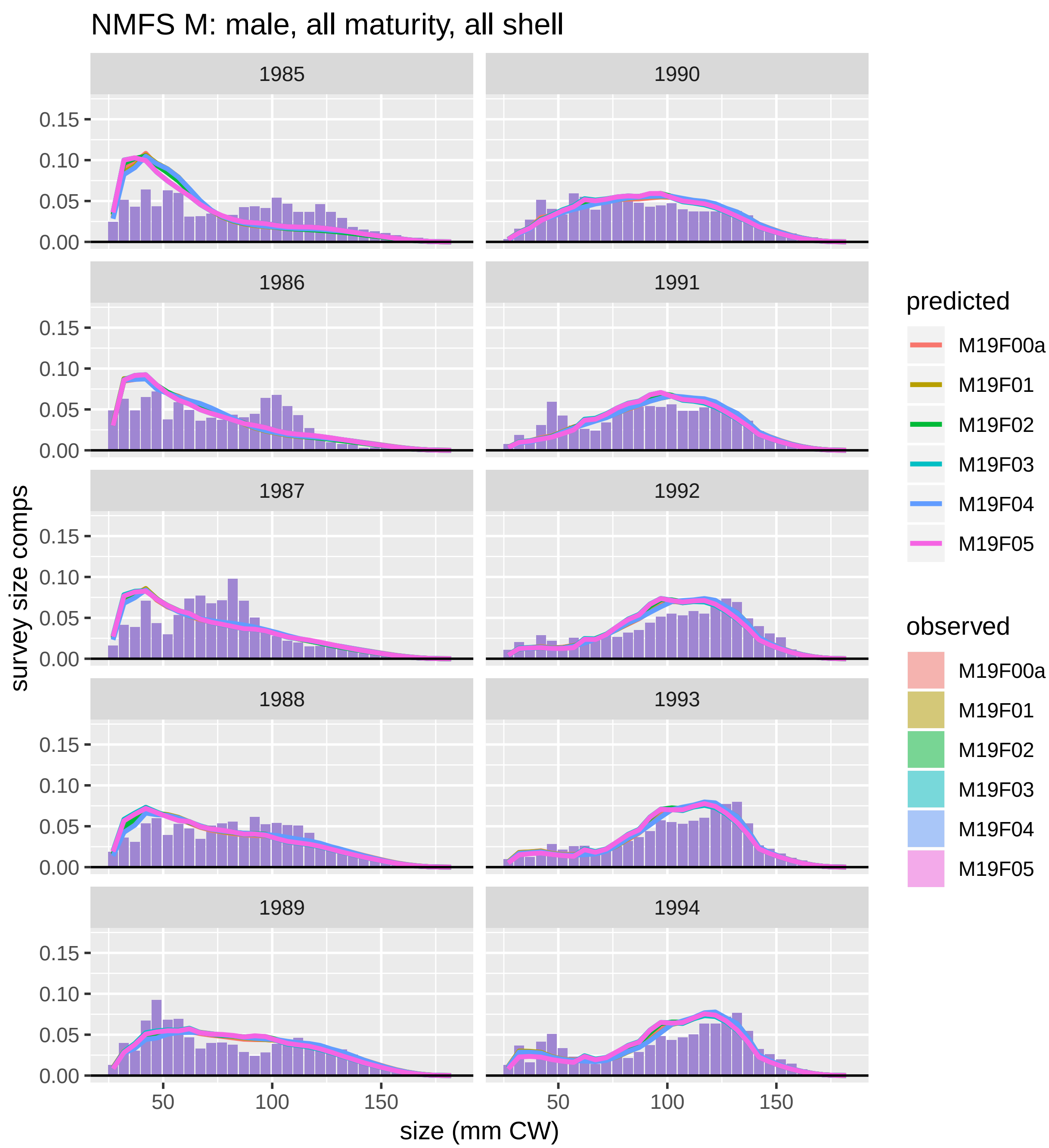


Figure 22: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 2 of 5.

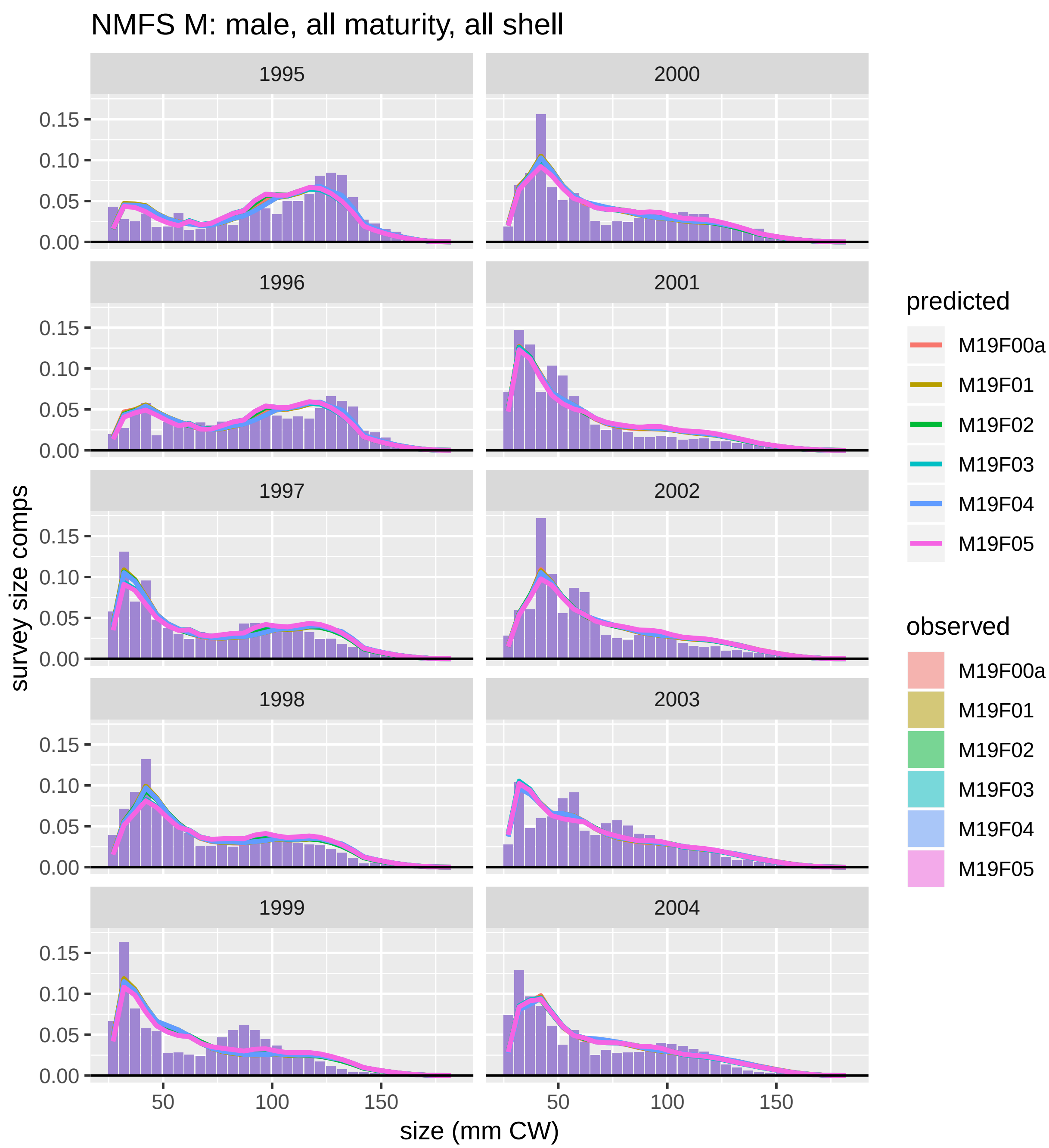


Figure 23: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 3 of 5.

Figure 24: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 4 of 5.

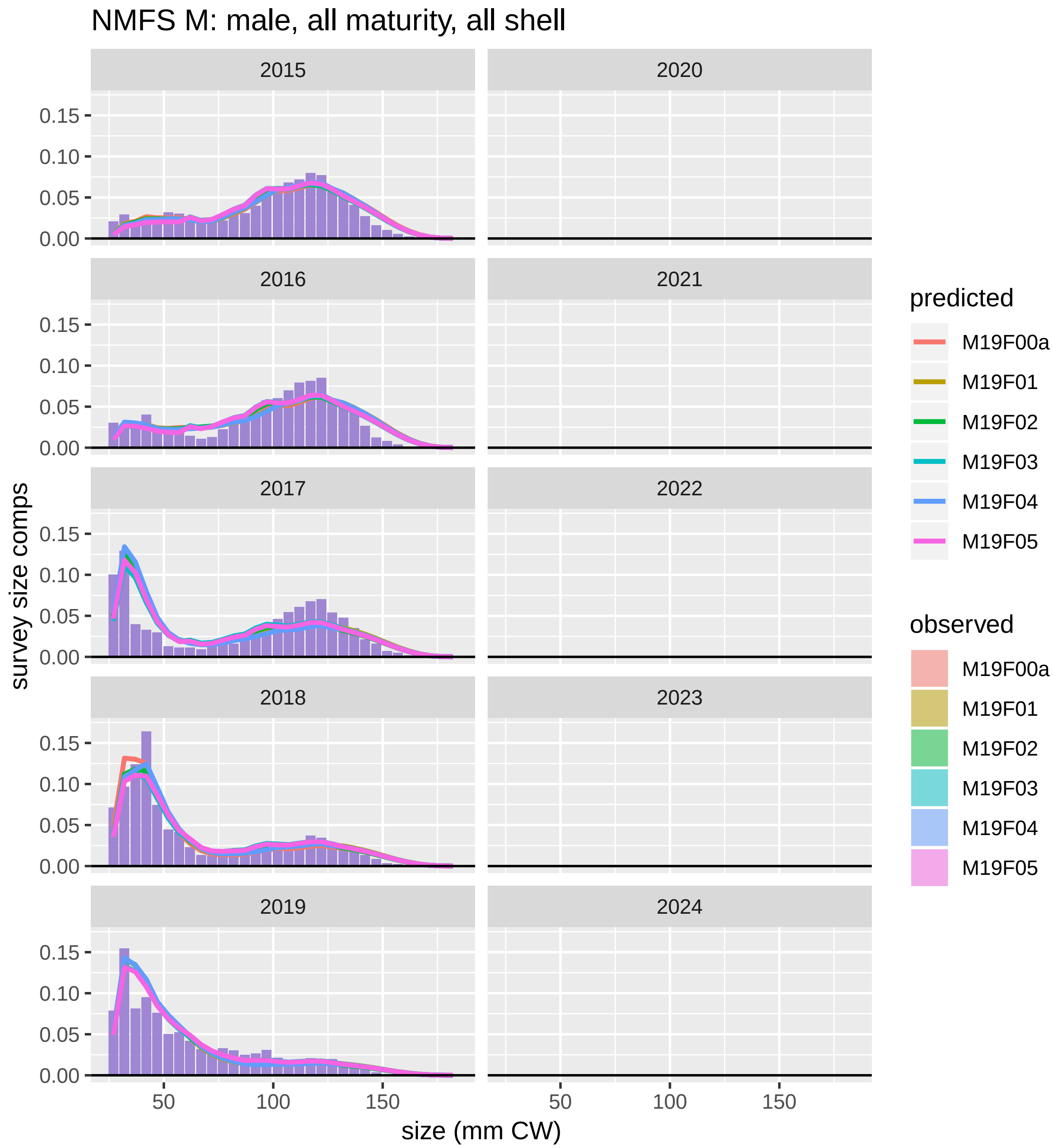


Figure 25: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS M. Page 5 of 5.

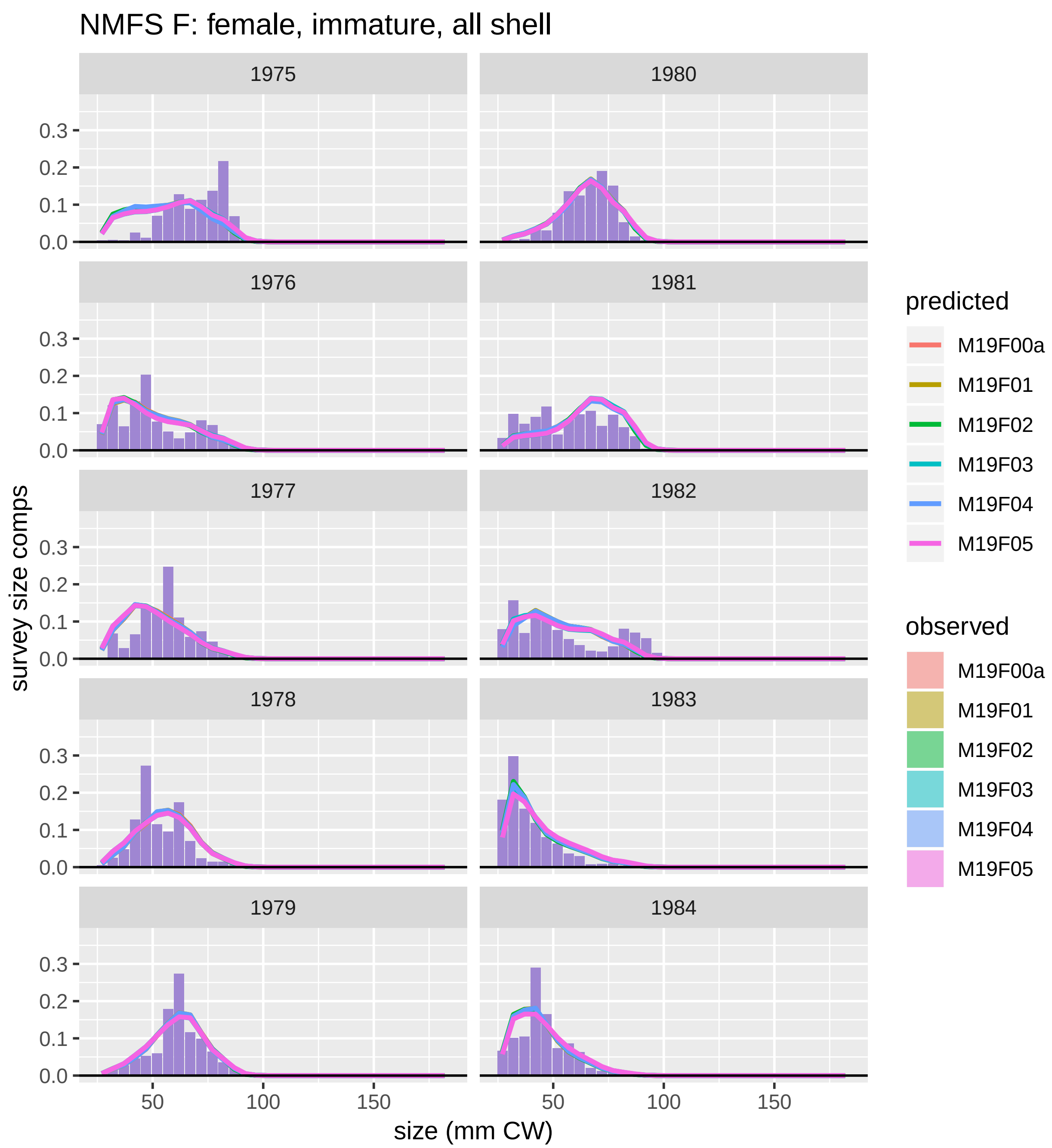


Figure 26: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 1 of 5.

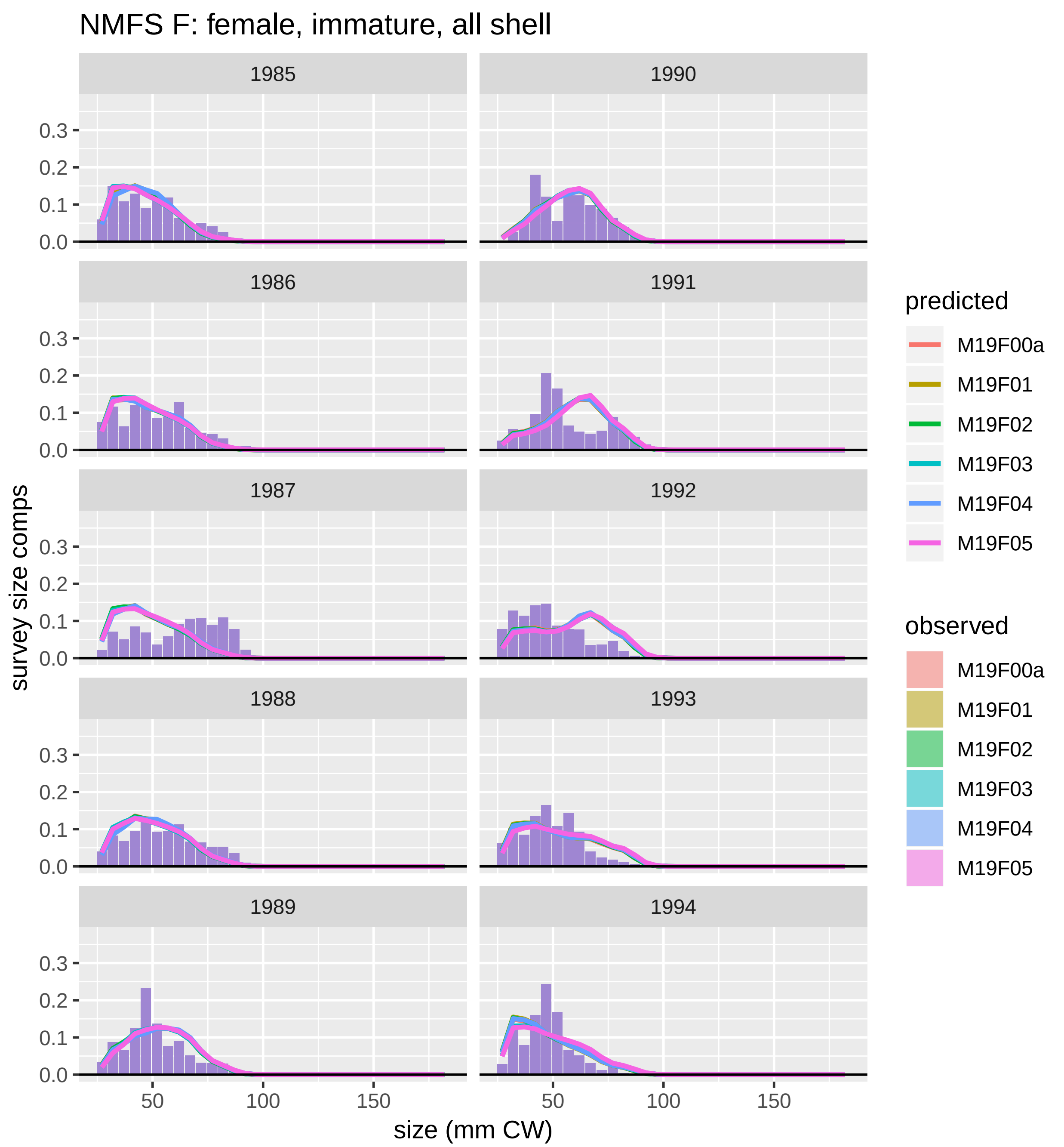


Figure 27: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 2 of 5.

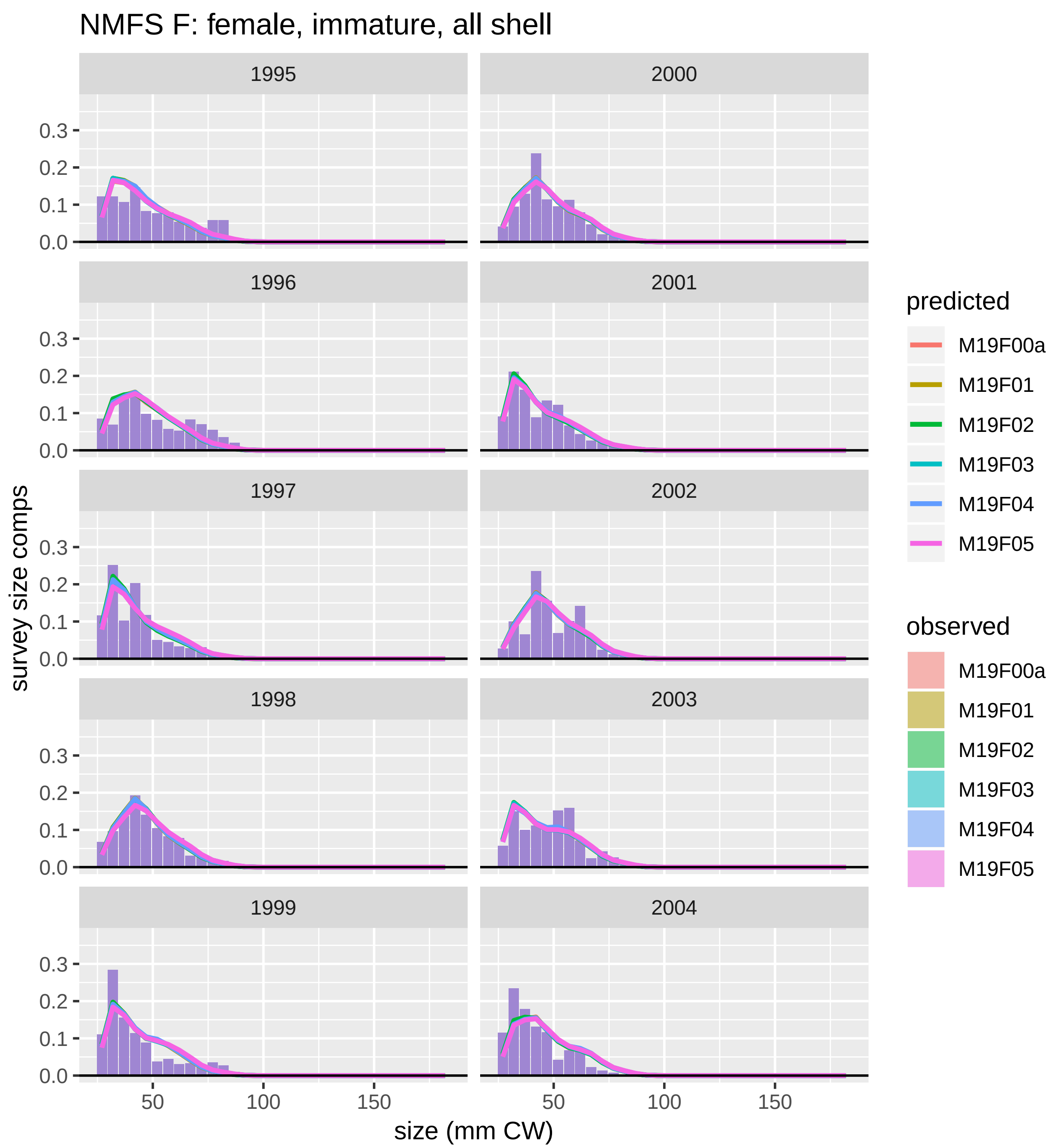


Figure 28: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 3 of 5.

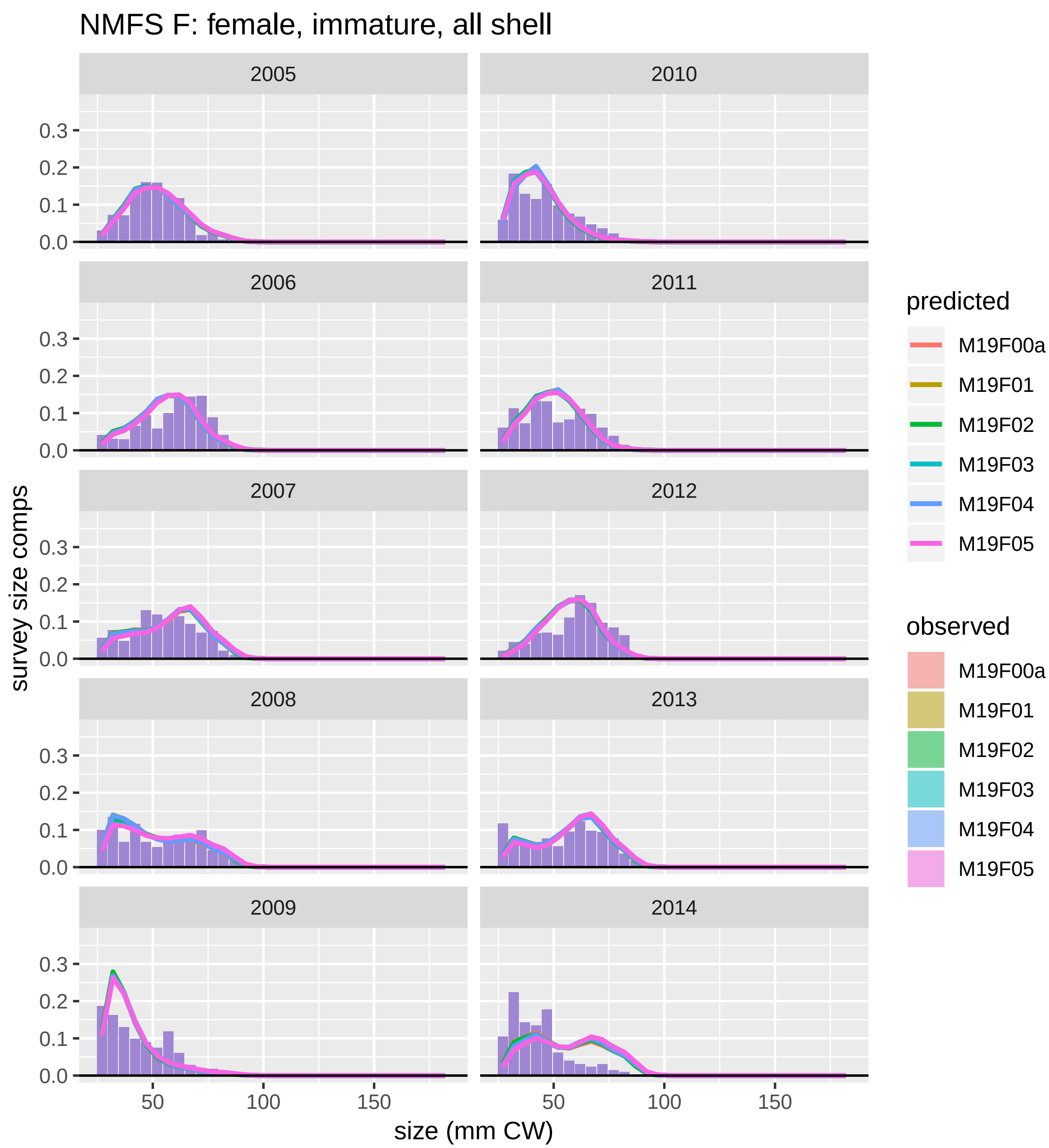


Figure 29: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 4 of 5.

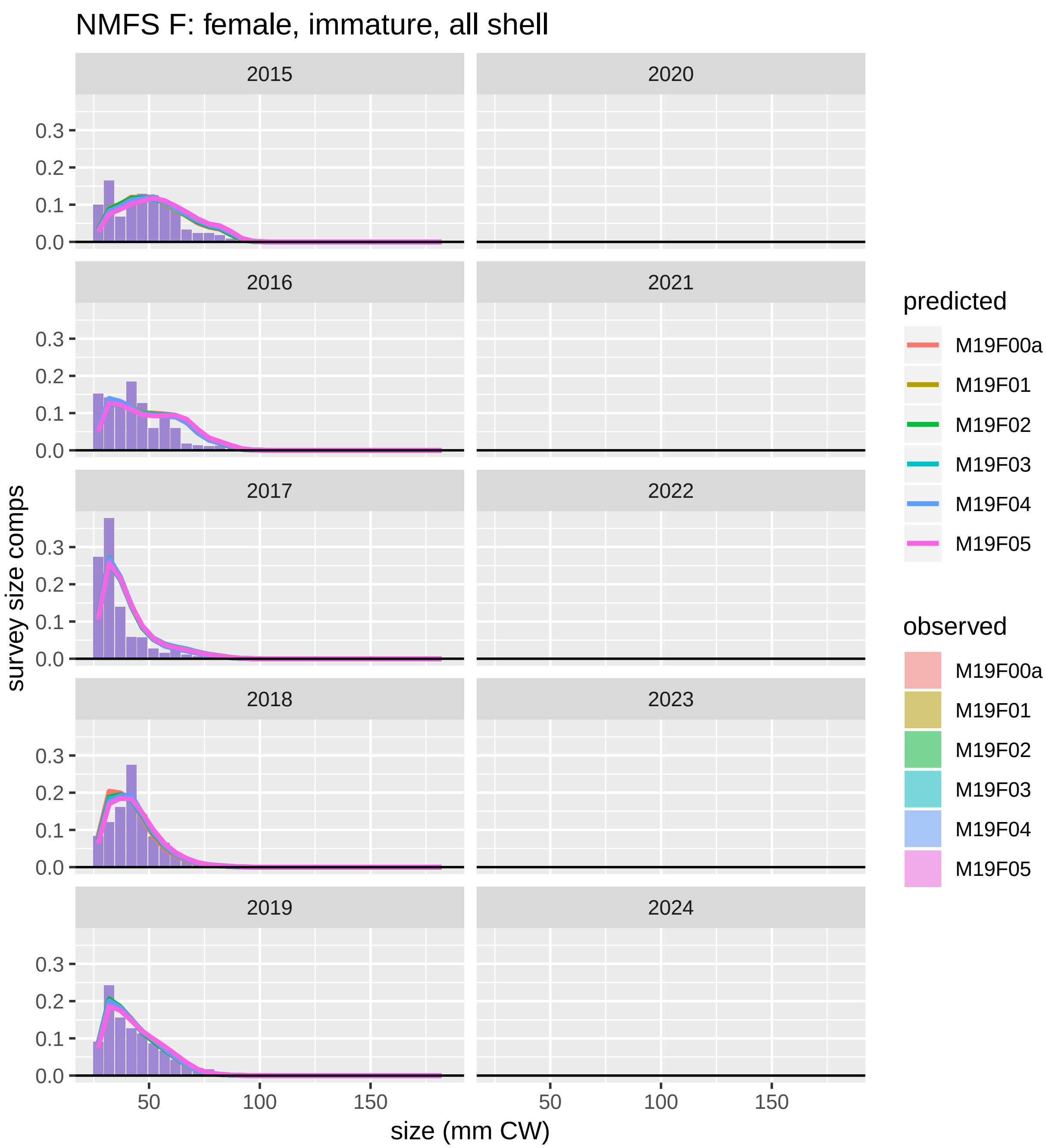


Figure 30: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS F. Page 5 of 5.

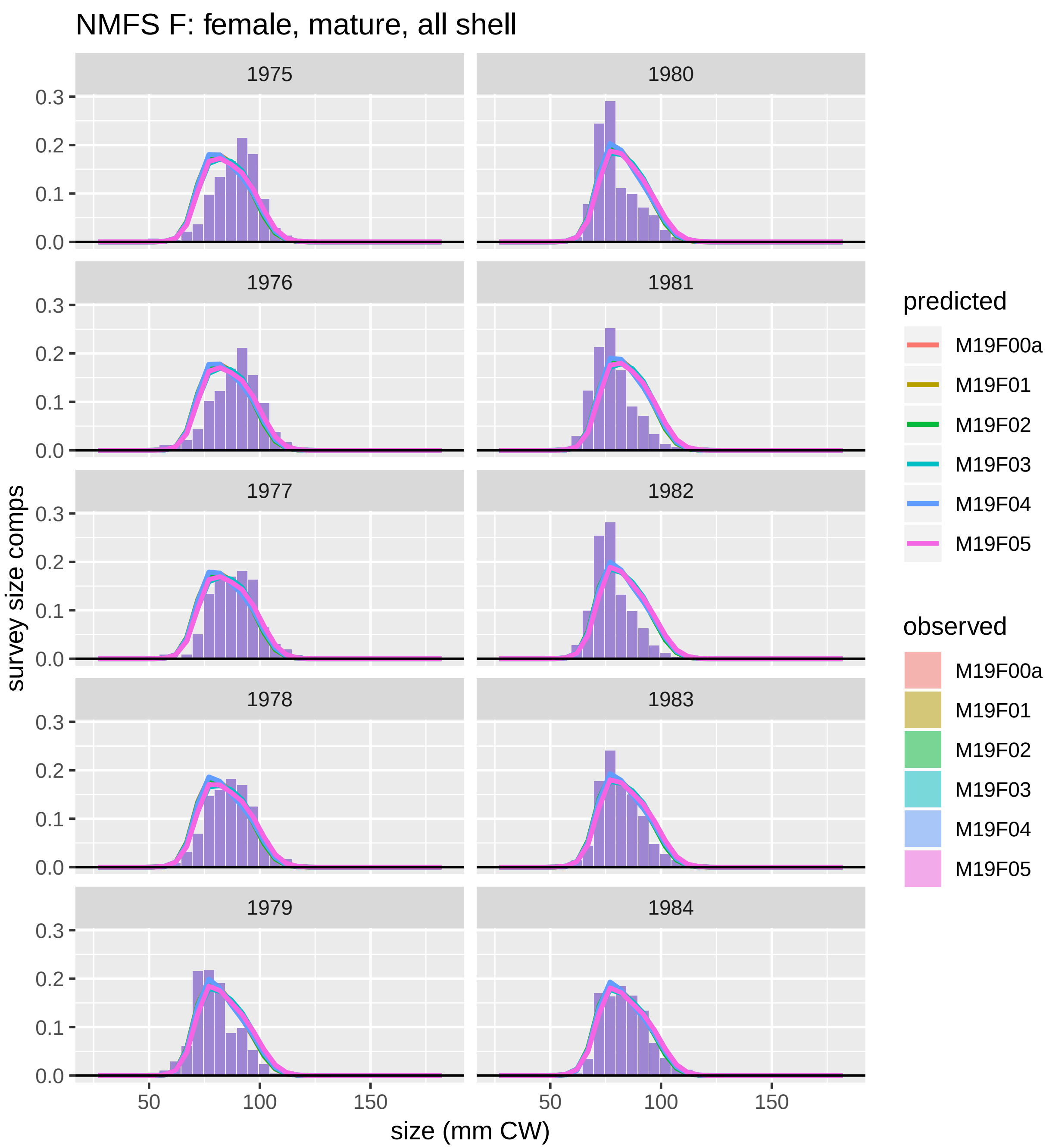


Figure 31: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 1 of 5.

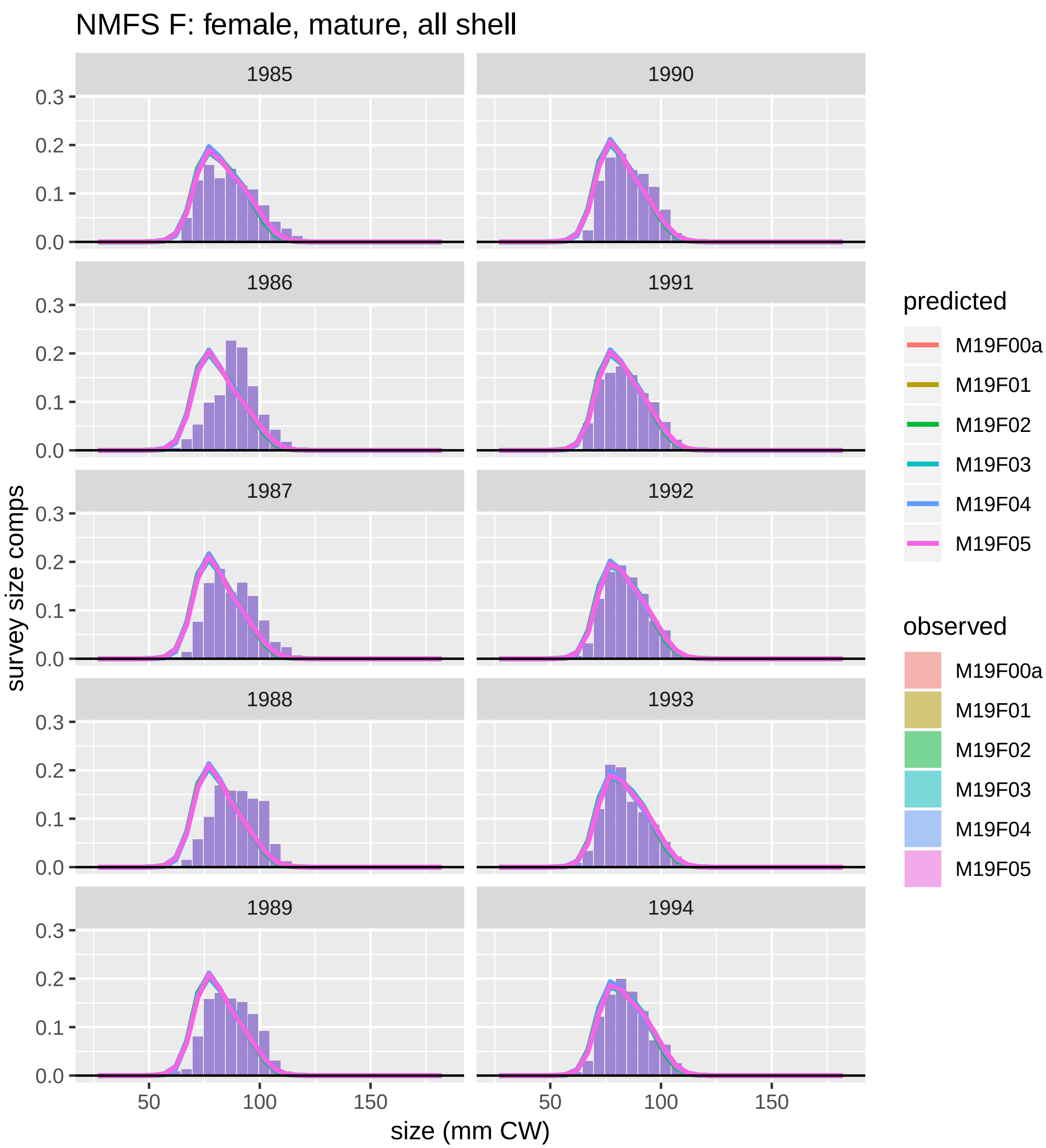


Figure 32: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 2 of 5.

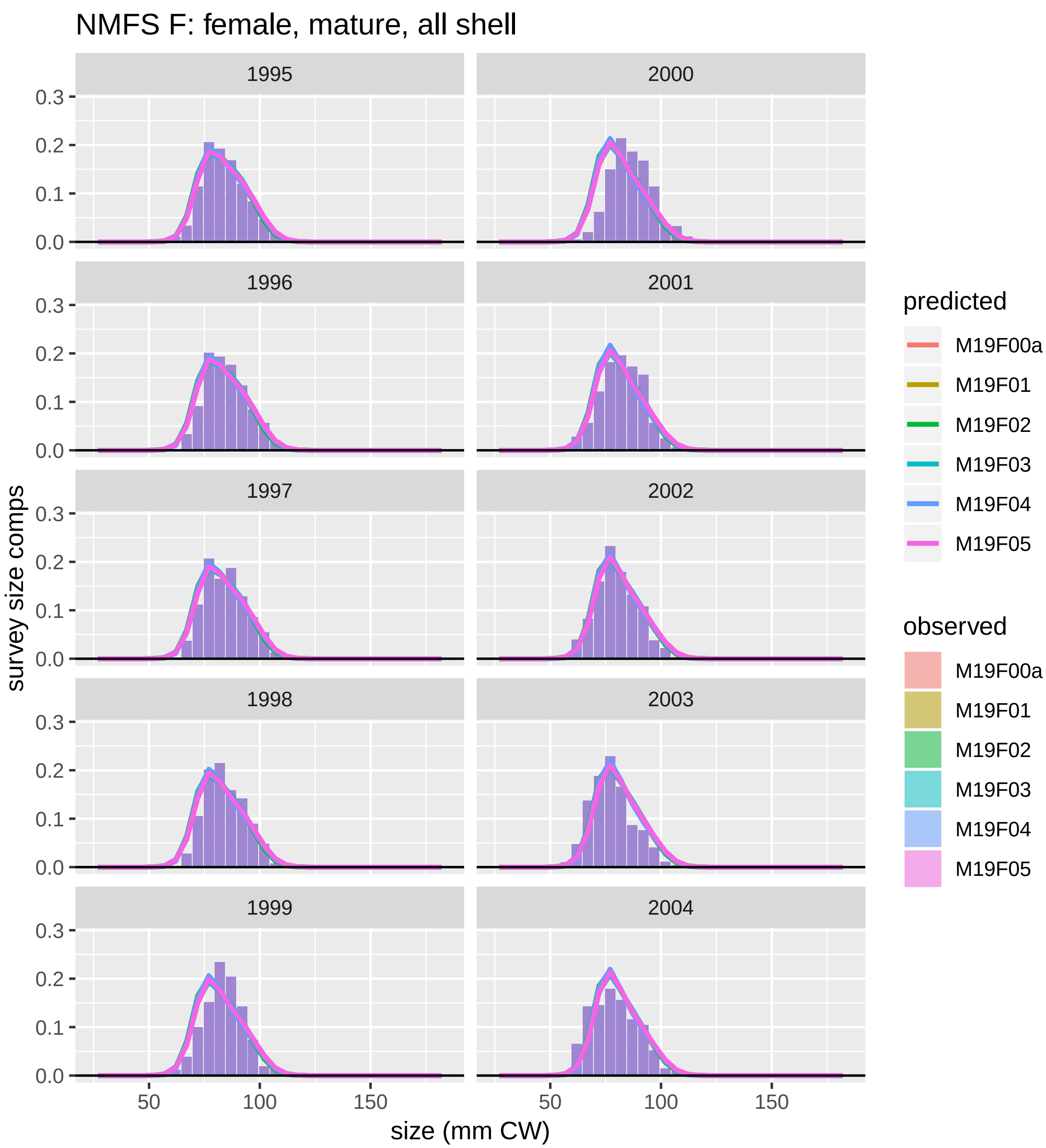


Figure 33: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 3 of 5.

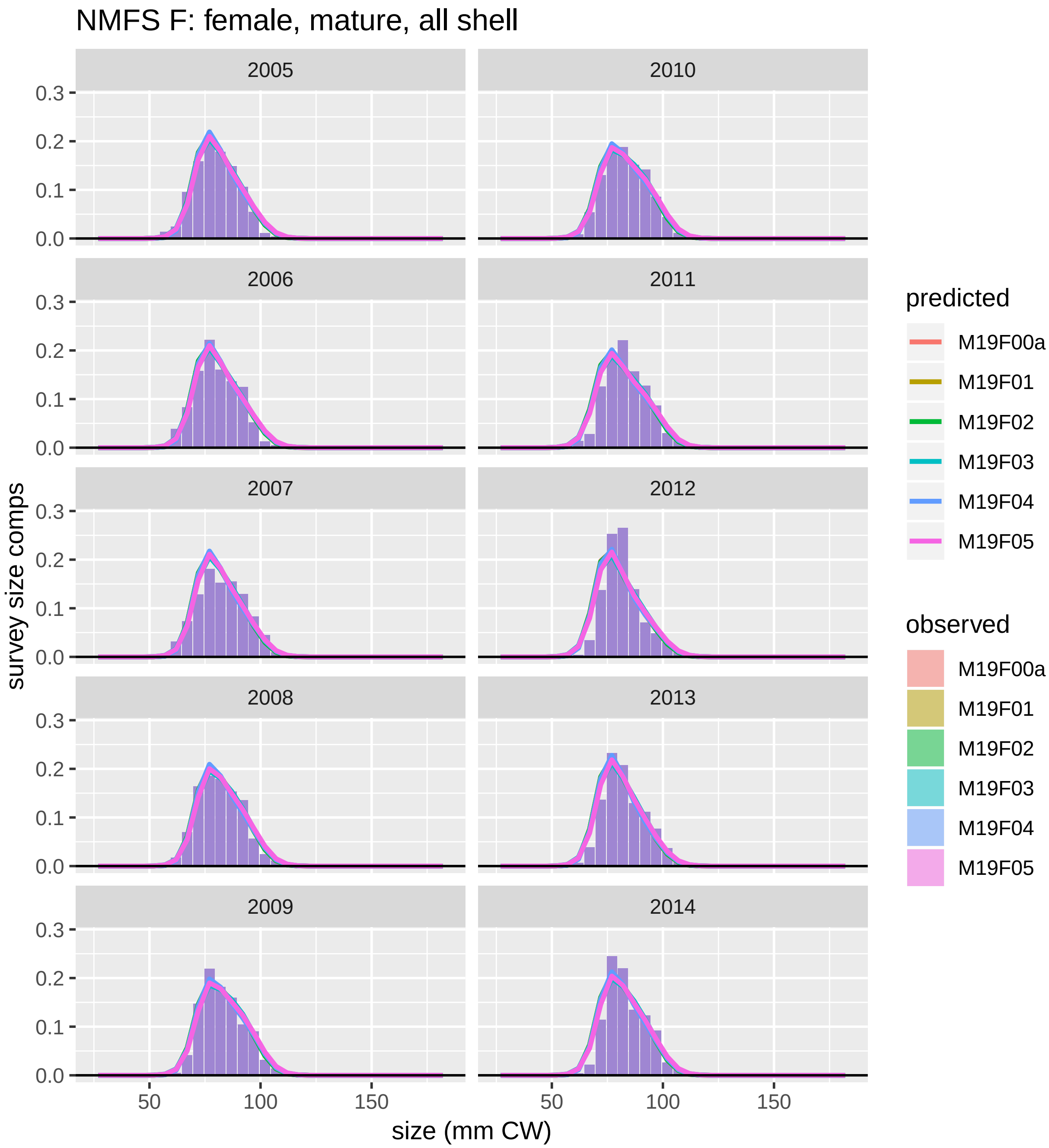


Figure 34: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 4 of 5.

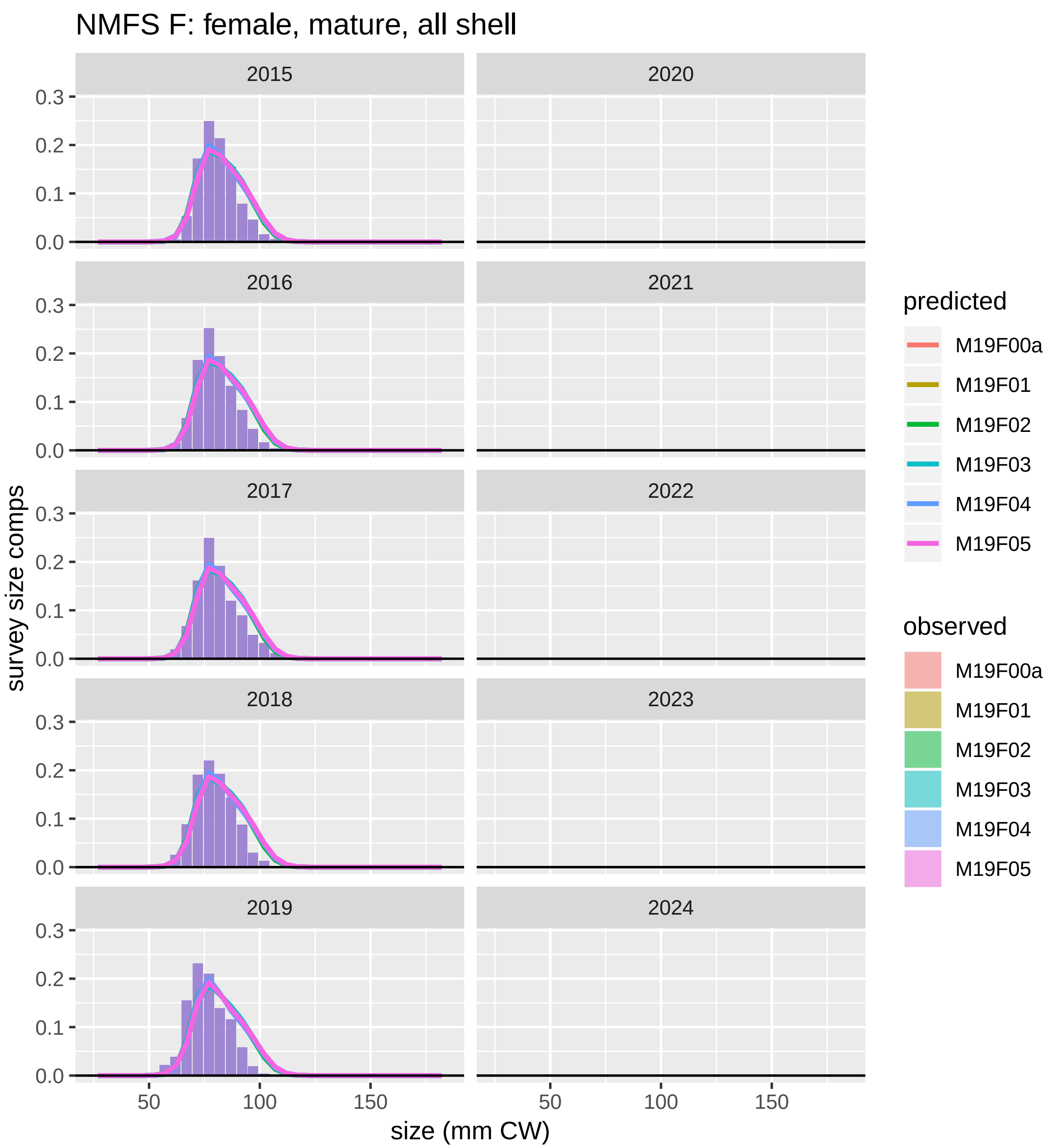


Figure 35: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS F. Page 5 of 5.

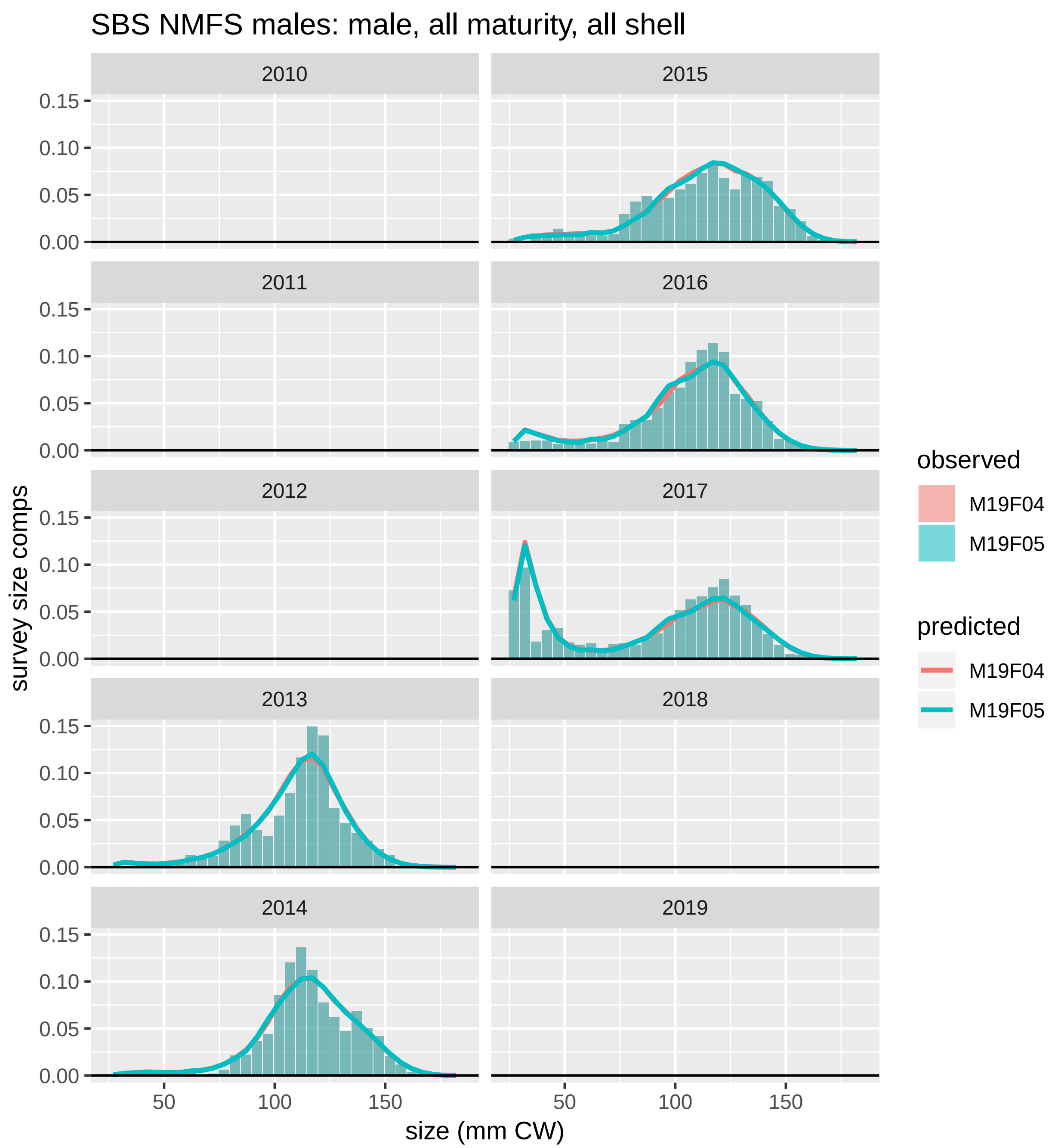


Figure 36: Comparison of observed and predicted male, all maturity, all shell survey size comps for SBS NMFS males. Page 1 of 1.

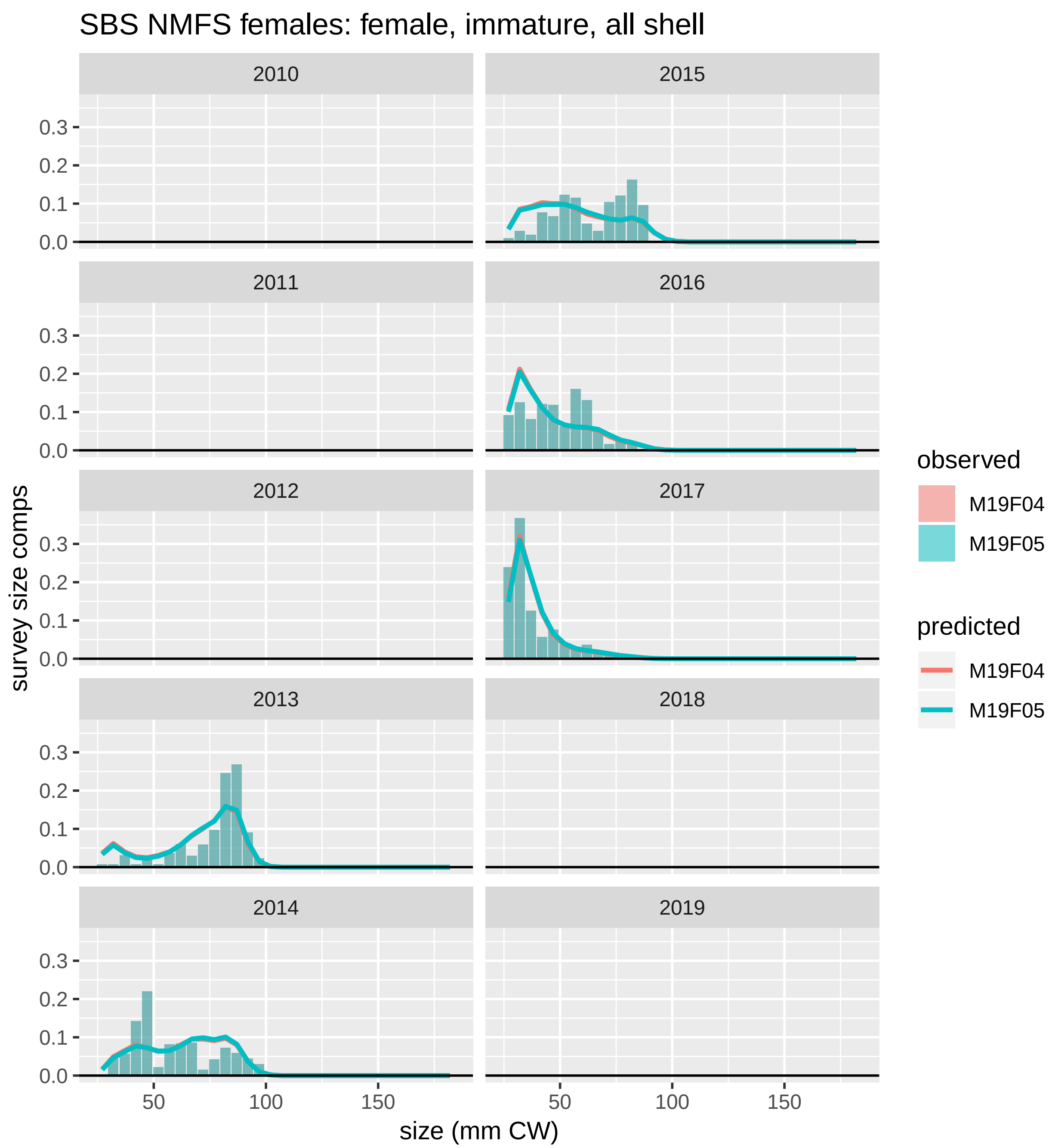


Figure 37: Comparison of observed and predicted female, immature, all shell survey size comps for SBS NMFS females. Page 1 of 1.

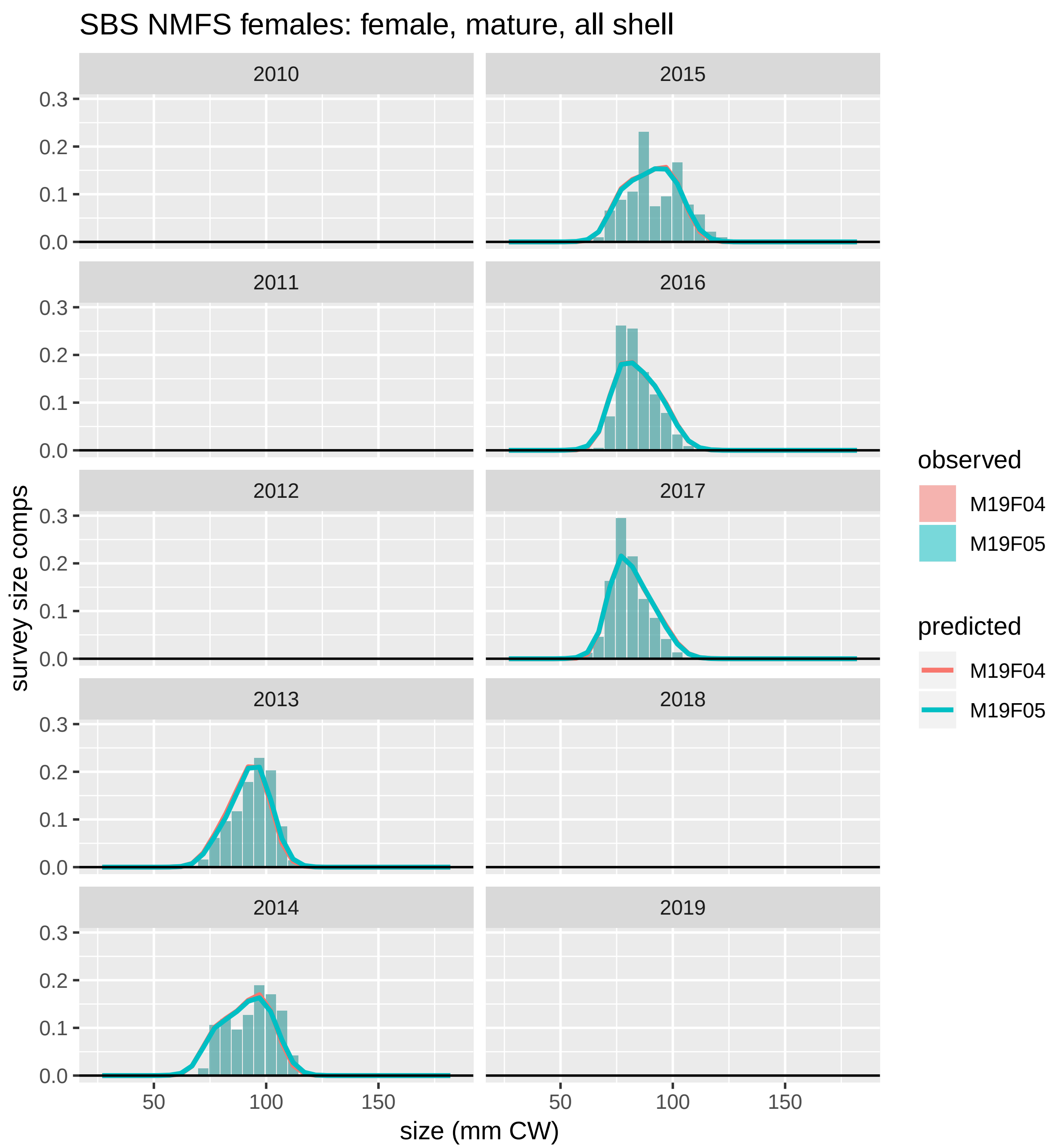


Figure 38: Comparison of observed and predicted female, mature, all shell survey size comps for SBS NMFS females. Page 1 of 1.

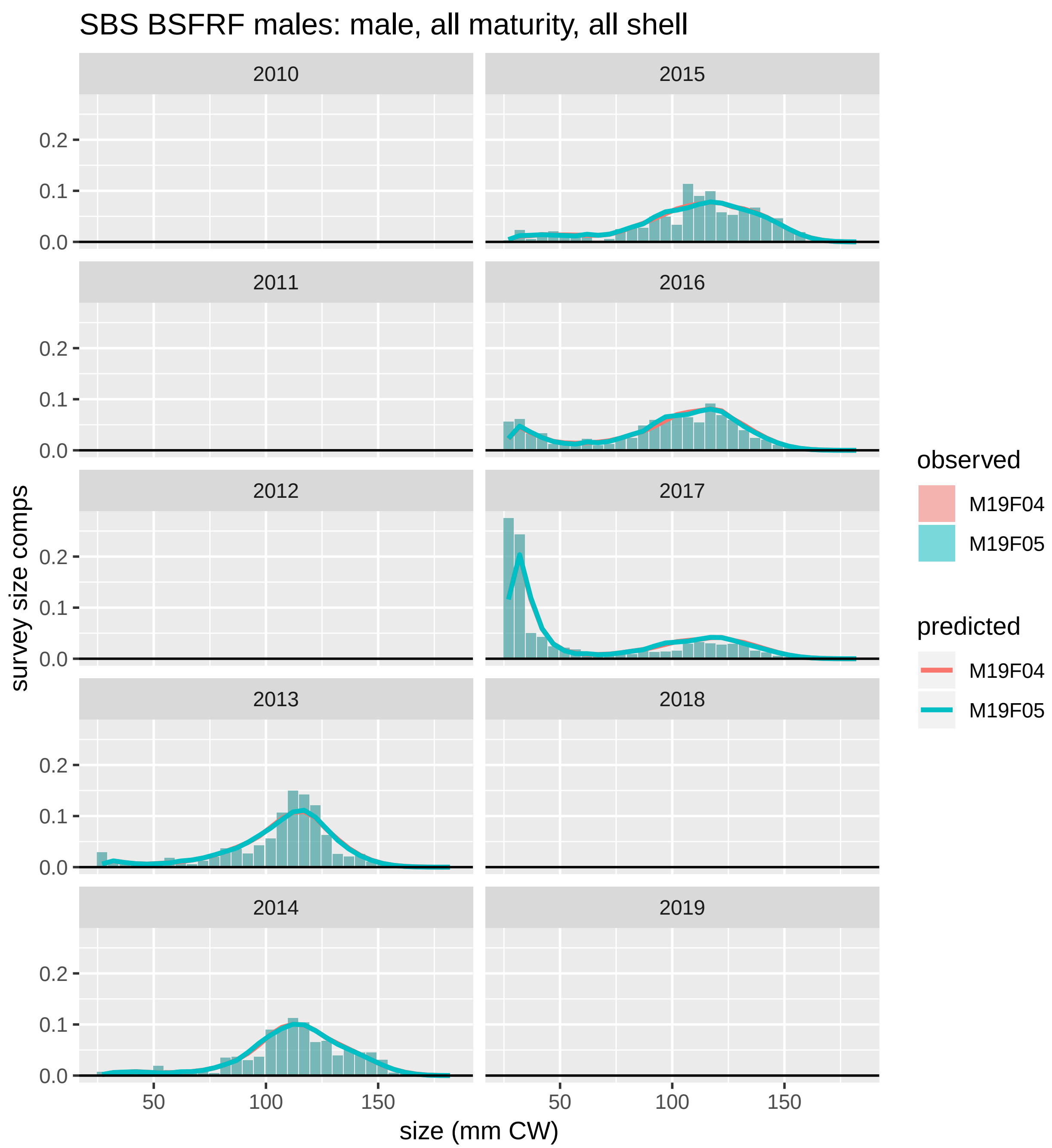


Figure 39: Comparison of observed and predicted male, all maturity, all shell survey size comps for SBS BSFRF males. Page 1 of 1.

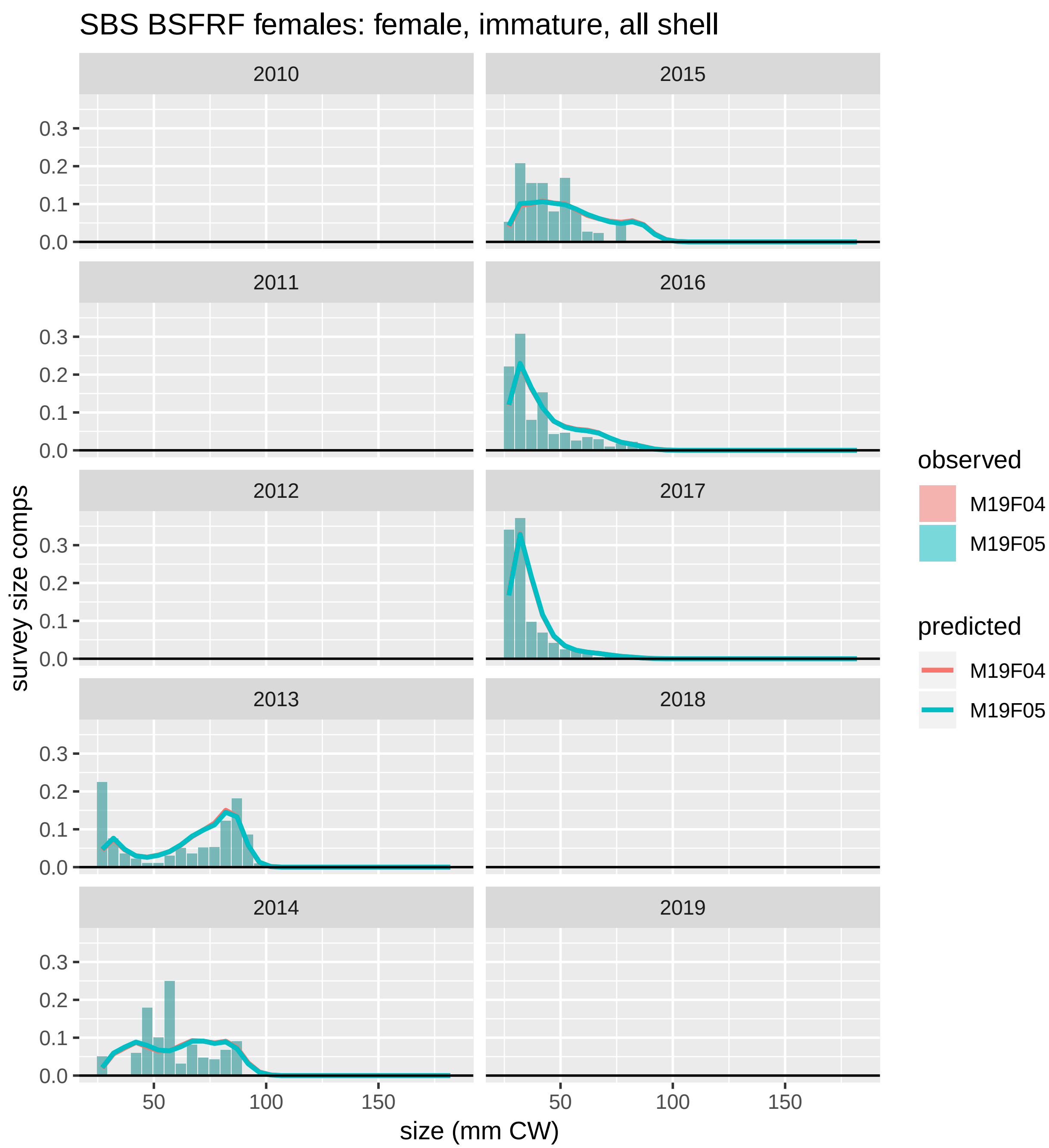


Figure 40: Comparison of observed and predicted female, immature, all shell survey size comps for SBS BSFRF females. Page 1 of 1.

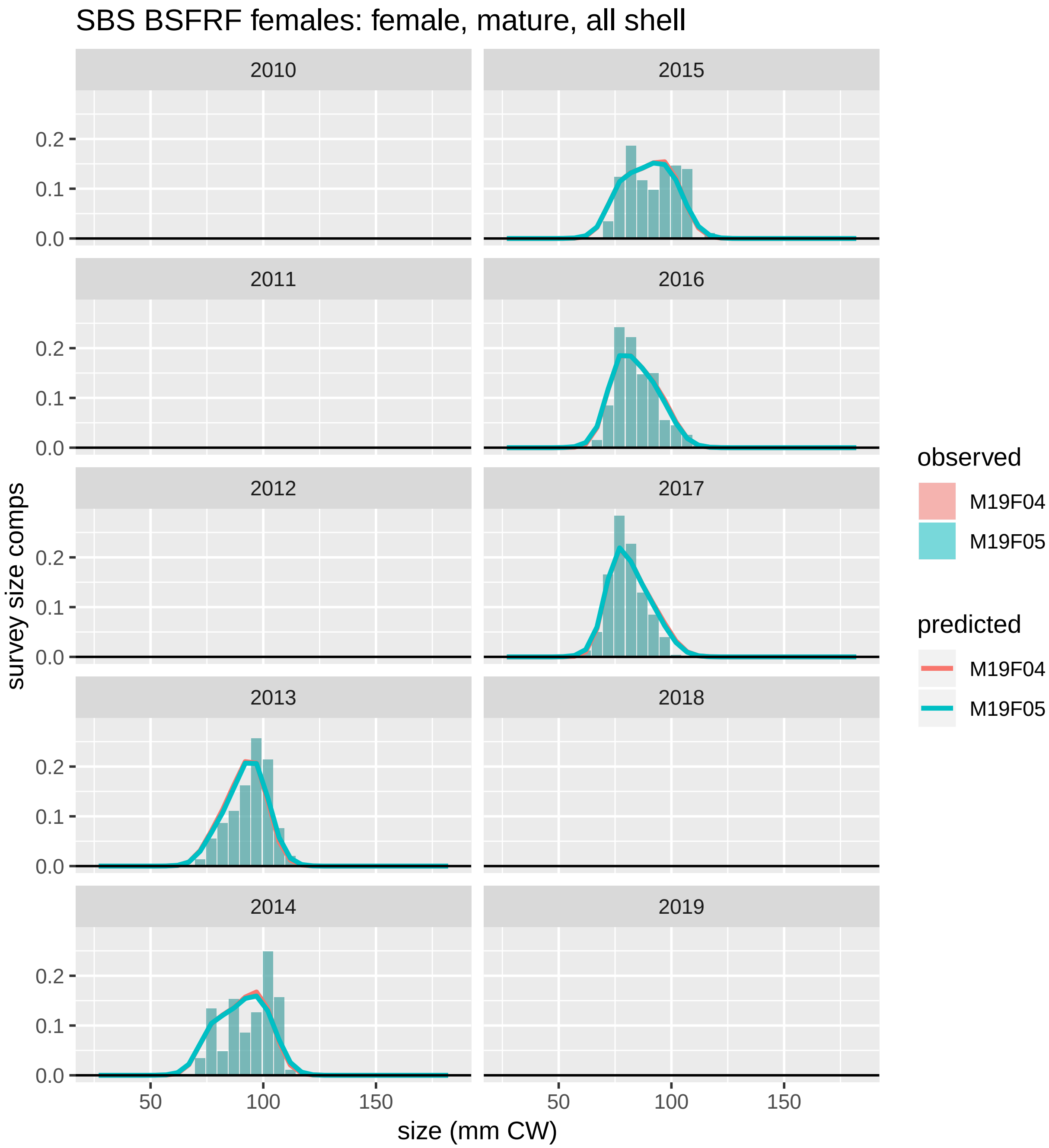


Figure 41: Comparison of observed and predicted female, mature, all shell survey size comps for SBS BSFRF females. Page 1 of 1.

Fishery retained catch size compositions

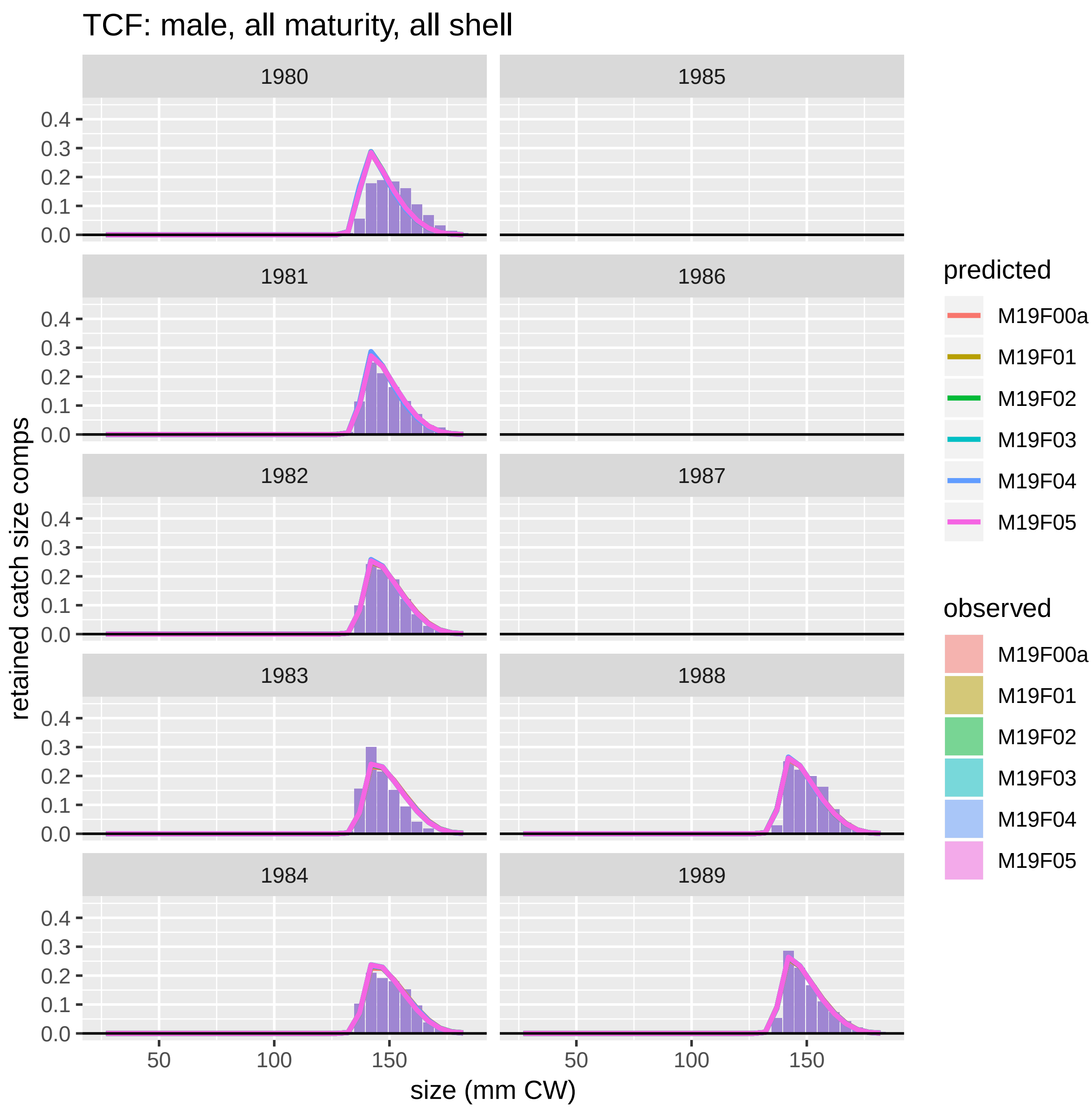


Figure 42: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 1 of 4.

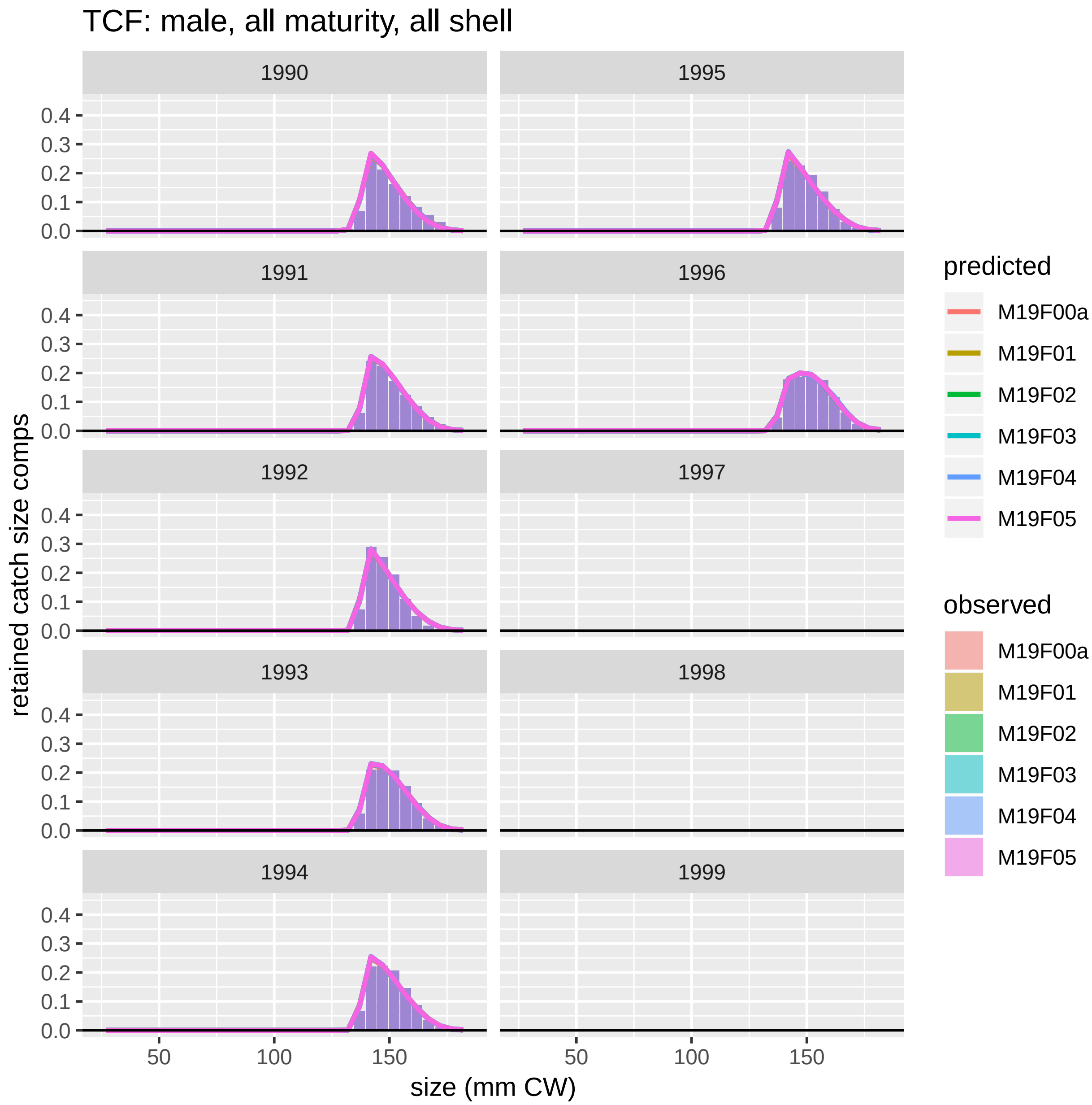


Figure 43: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 2 of 4.

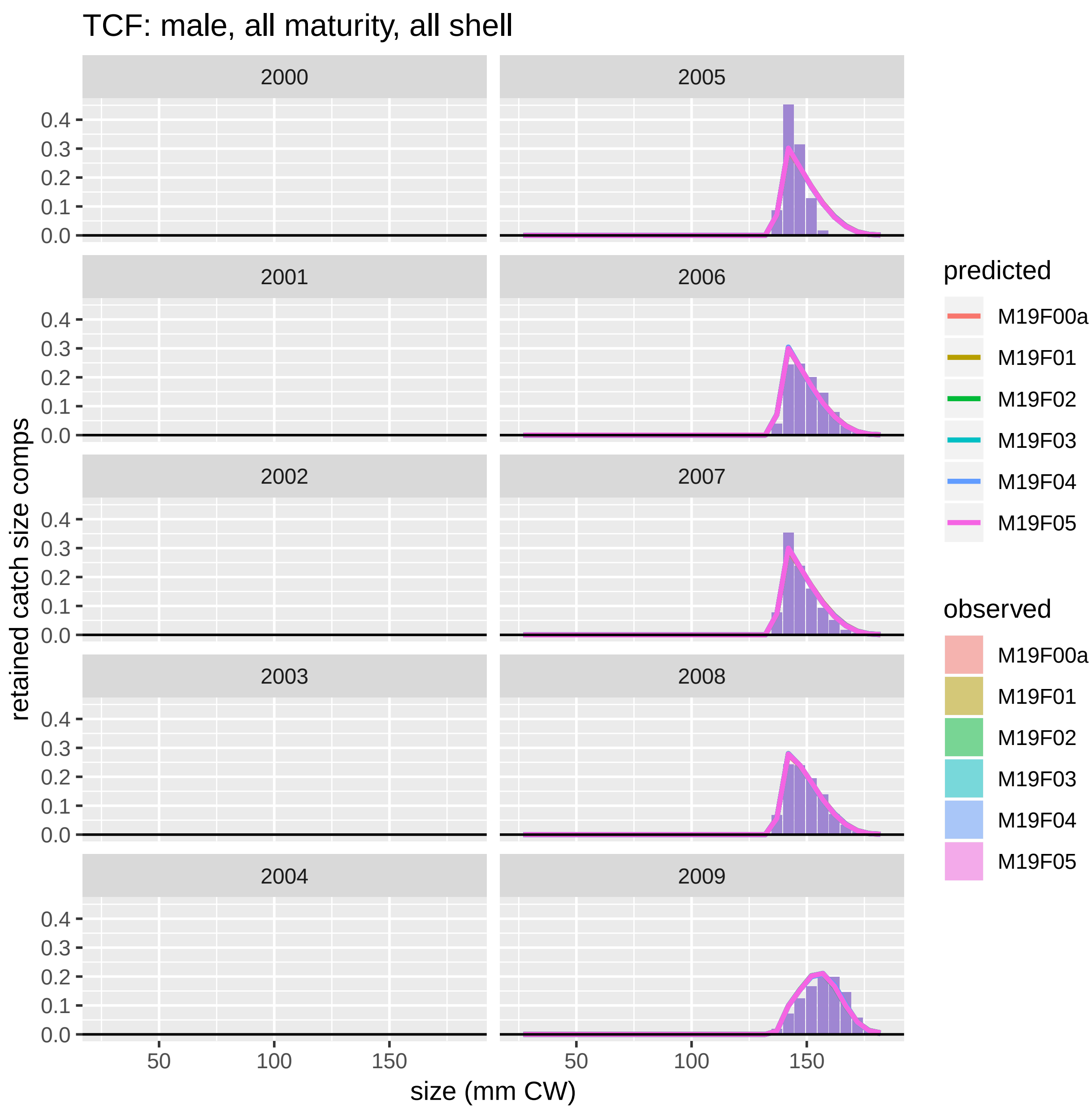


Figure 44: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 3 of 4.

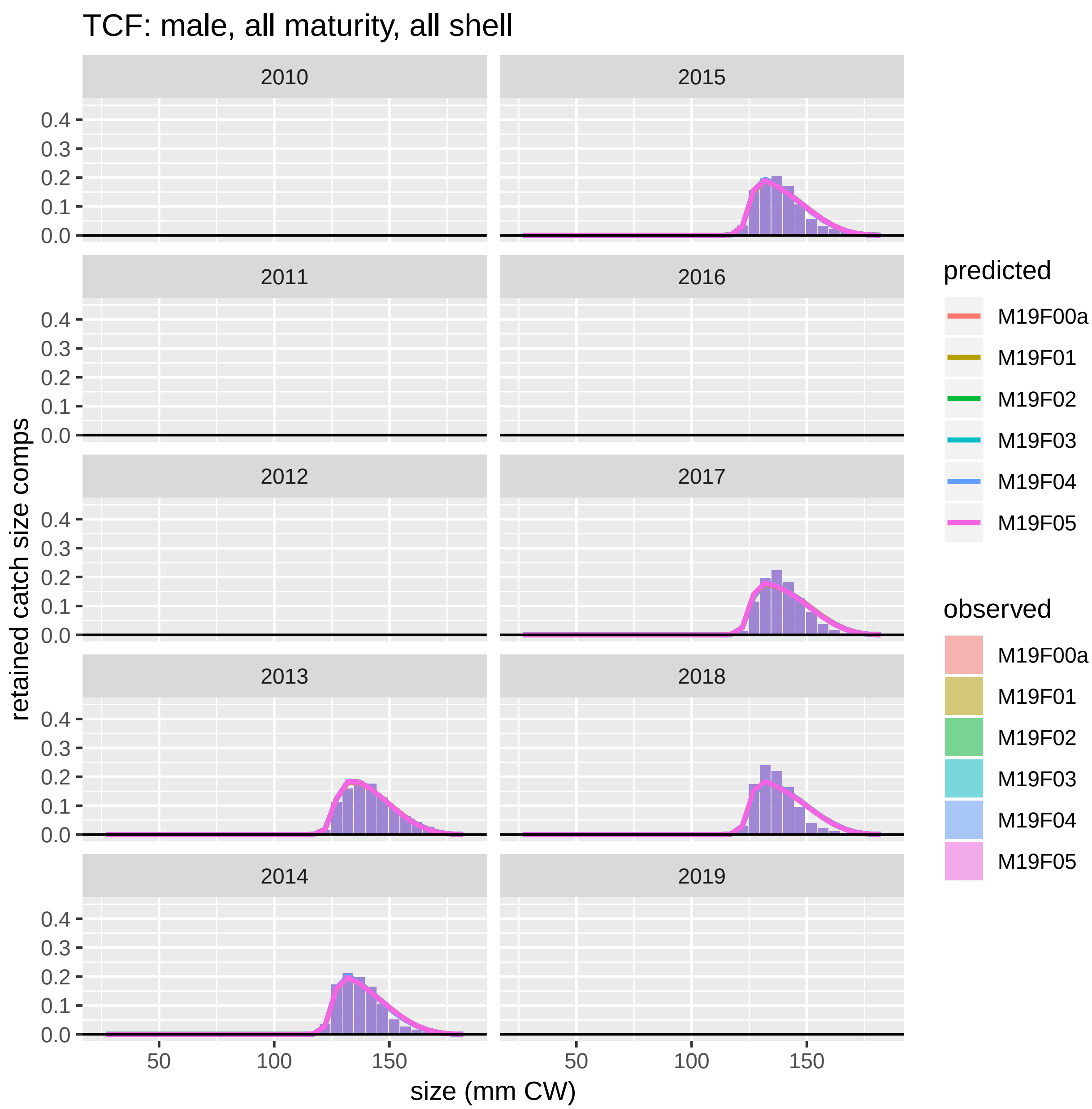


Figure 45: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 4 of 4.

Fishery total catch size compositions

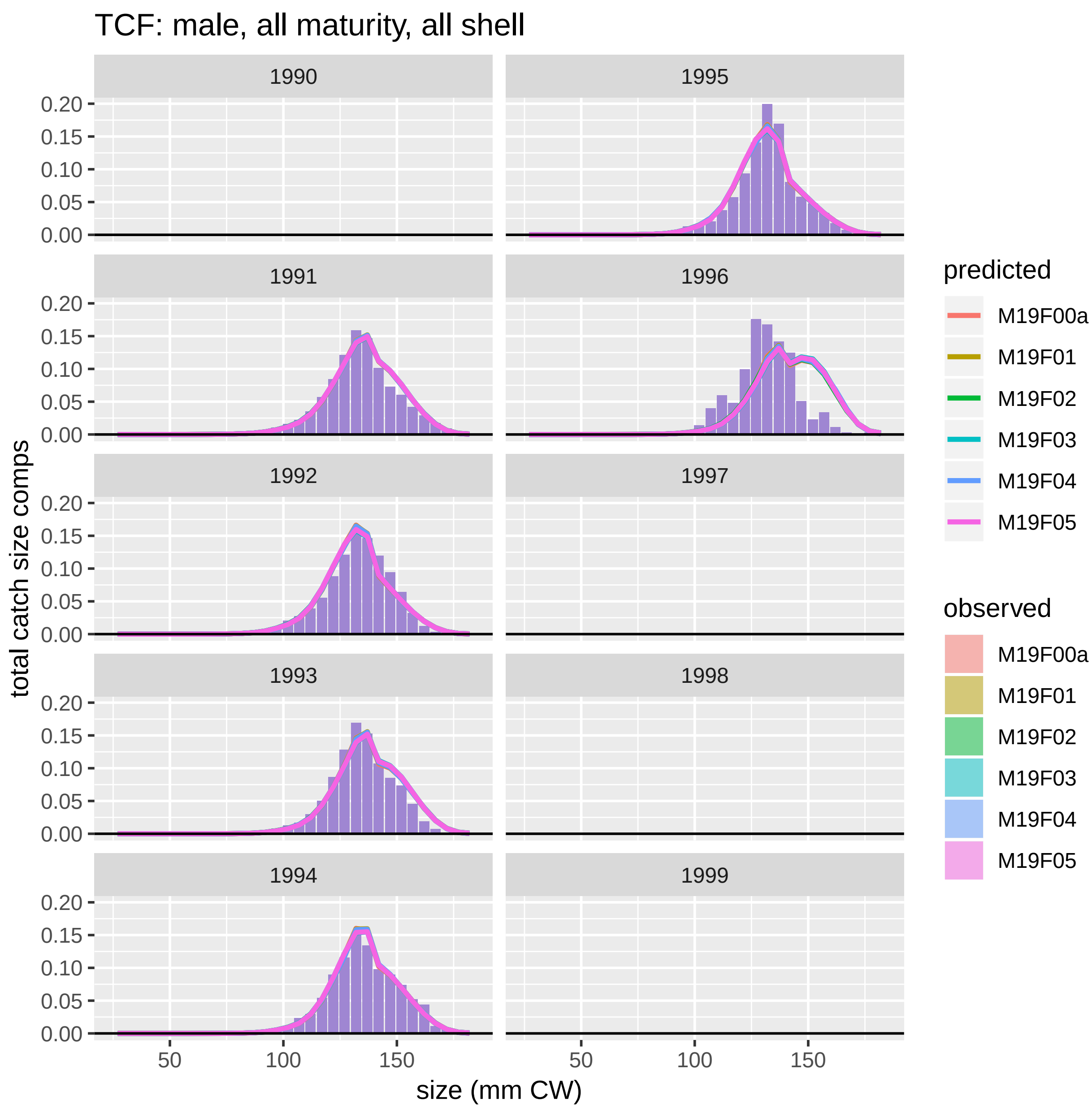


Figure 46: Comparison of observed and predicted male, all maturity, all shell total catch size comps for TCF. Page 1 of 3.

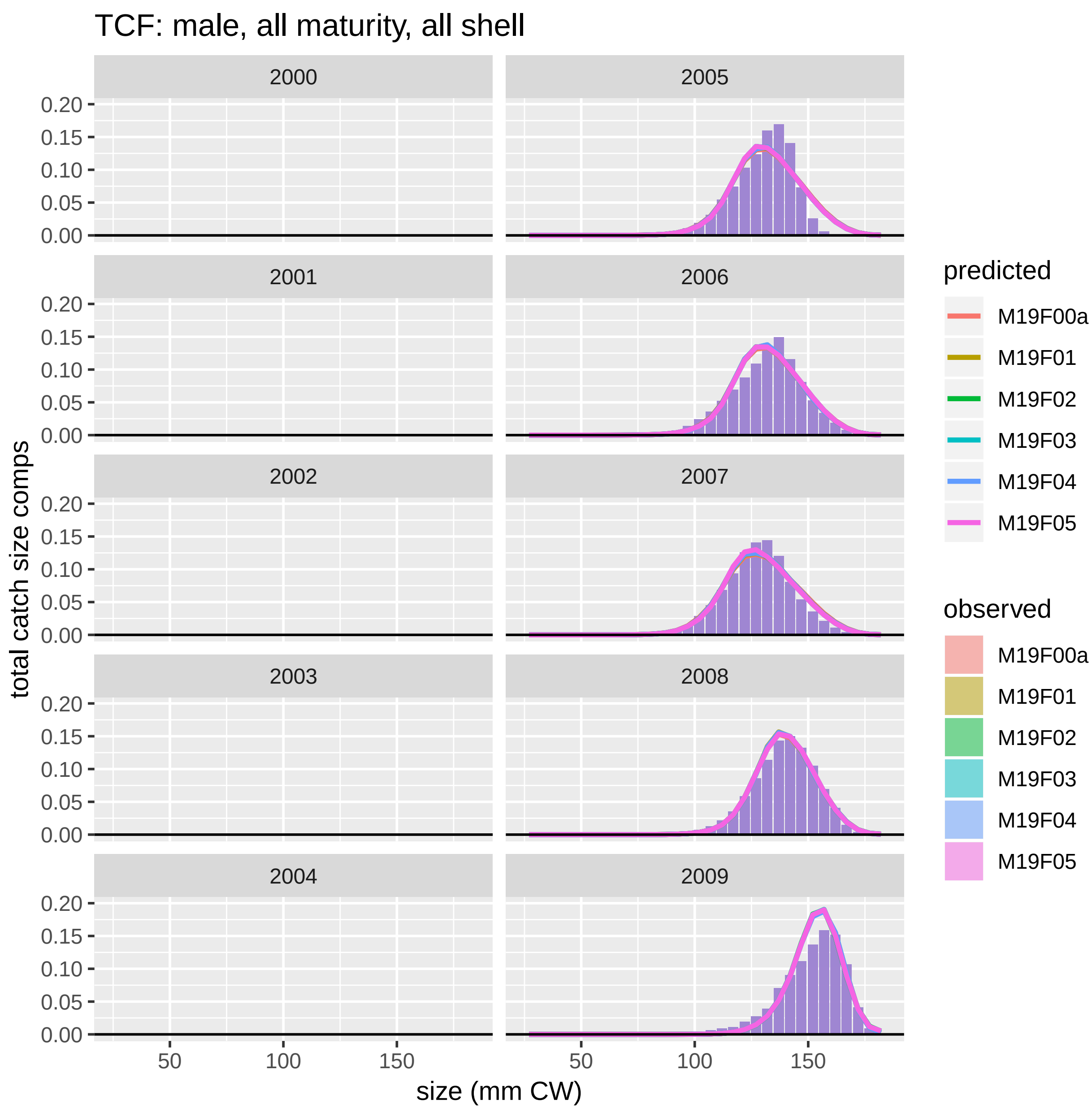


Figure 47: Comparison of observed and predicted male, all maturity, all shell total catch size comps for TCF. Page 2 of 3.

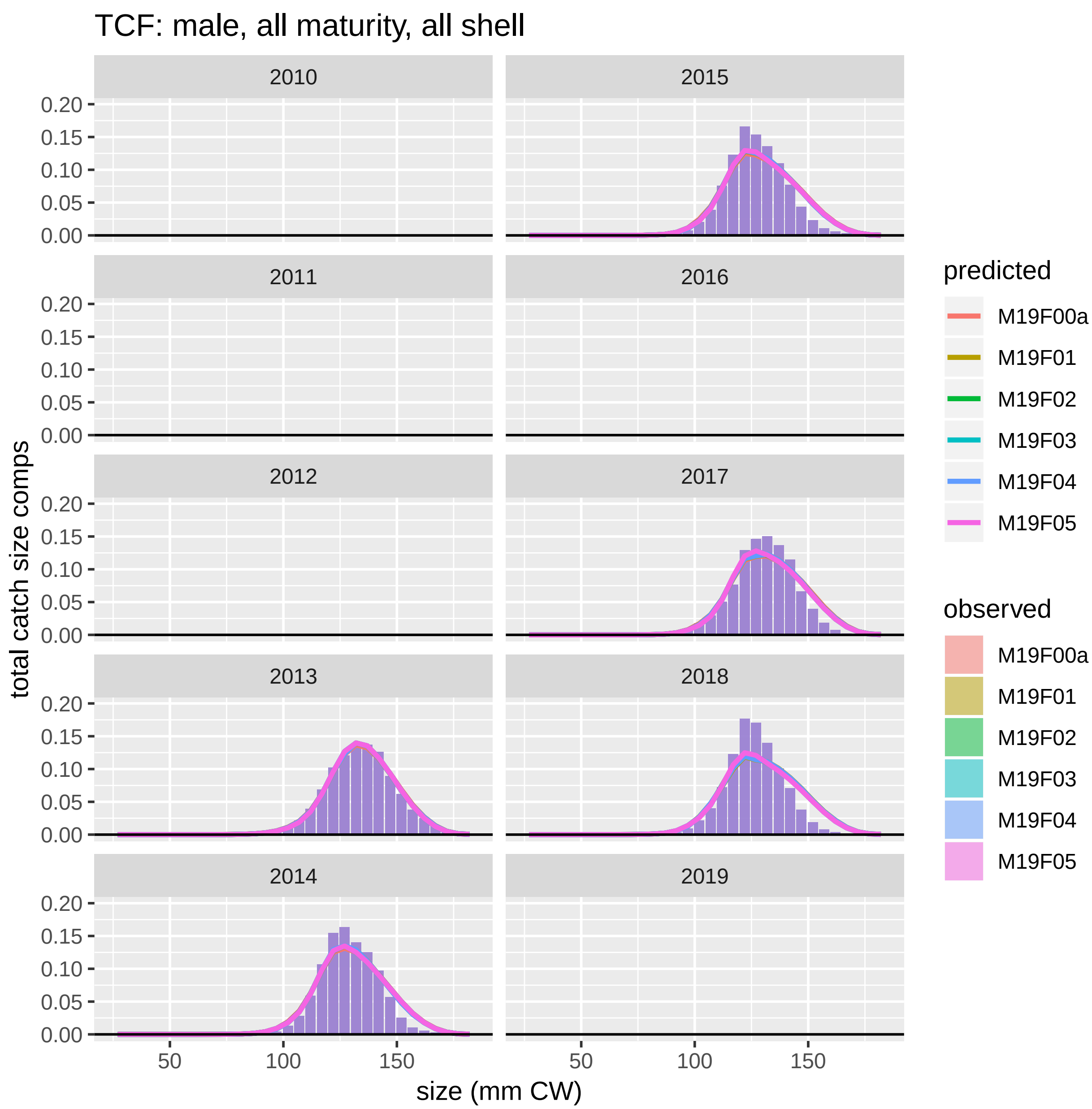


Figure 48: Comparison of observed and predicted male, all maturity, all shell total catch size comps for TCF. Page 3 of 3.

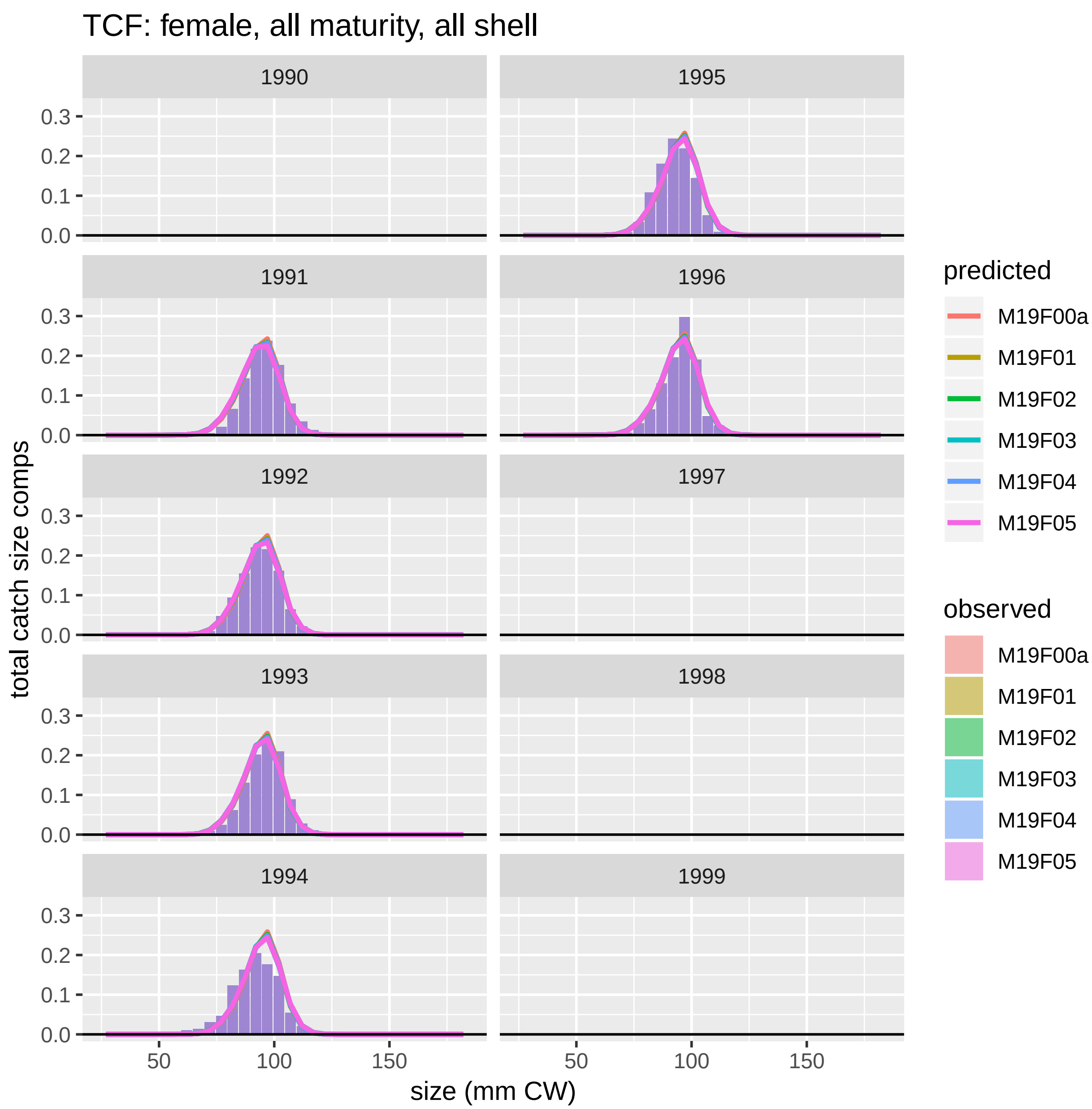


Figure 49: Comparison of observed and predicted female, all maturity, all shell total catch size comps for TCF. Page 1 of 3.

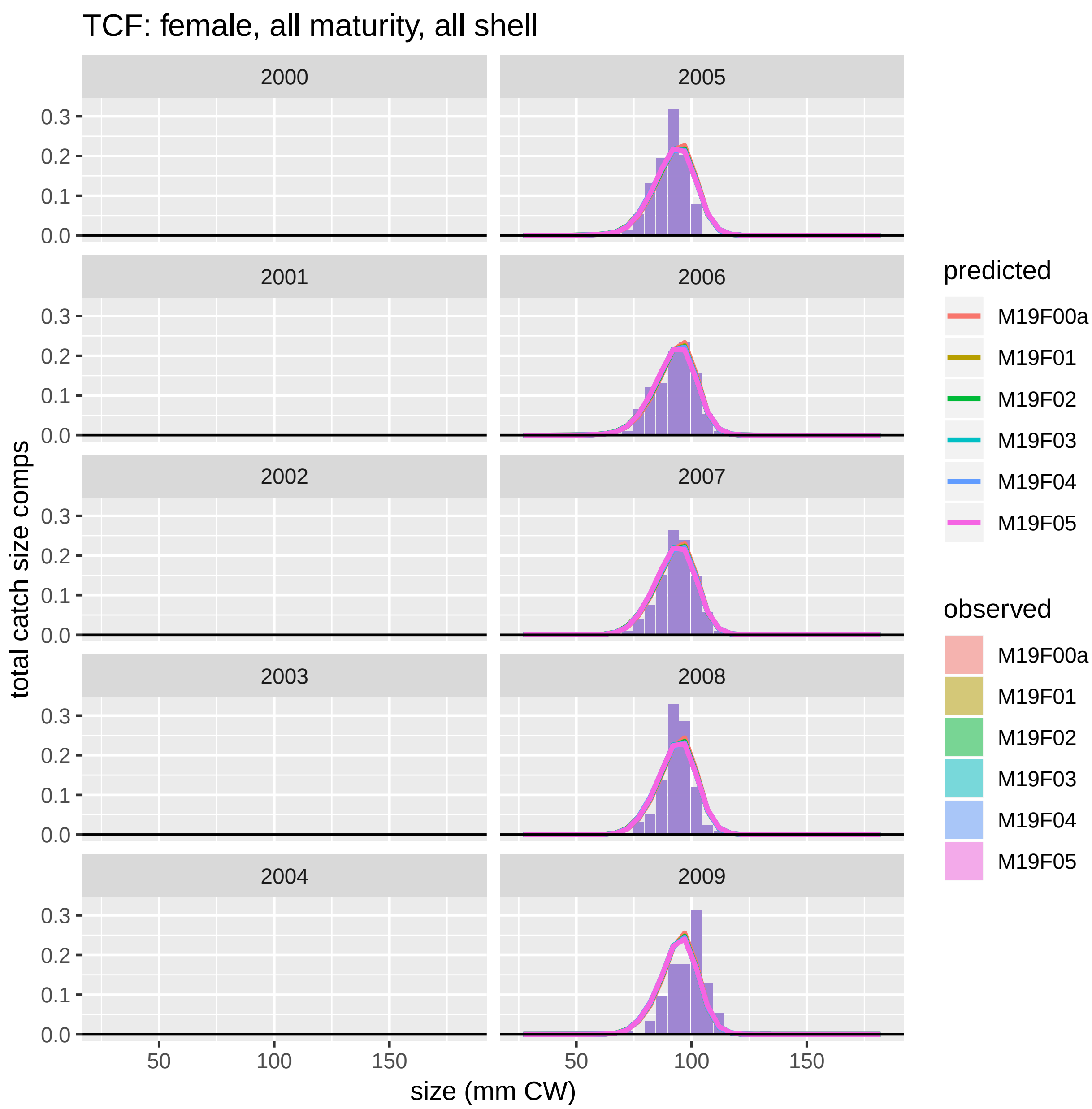


Figure 50: Comparison of observed and predicted female, all maturity, all shell total catch size comps for TCF. Page 2 of 3.

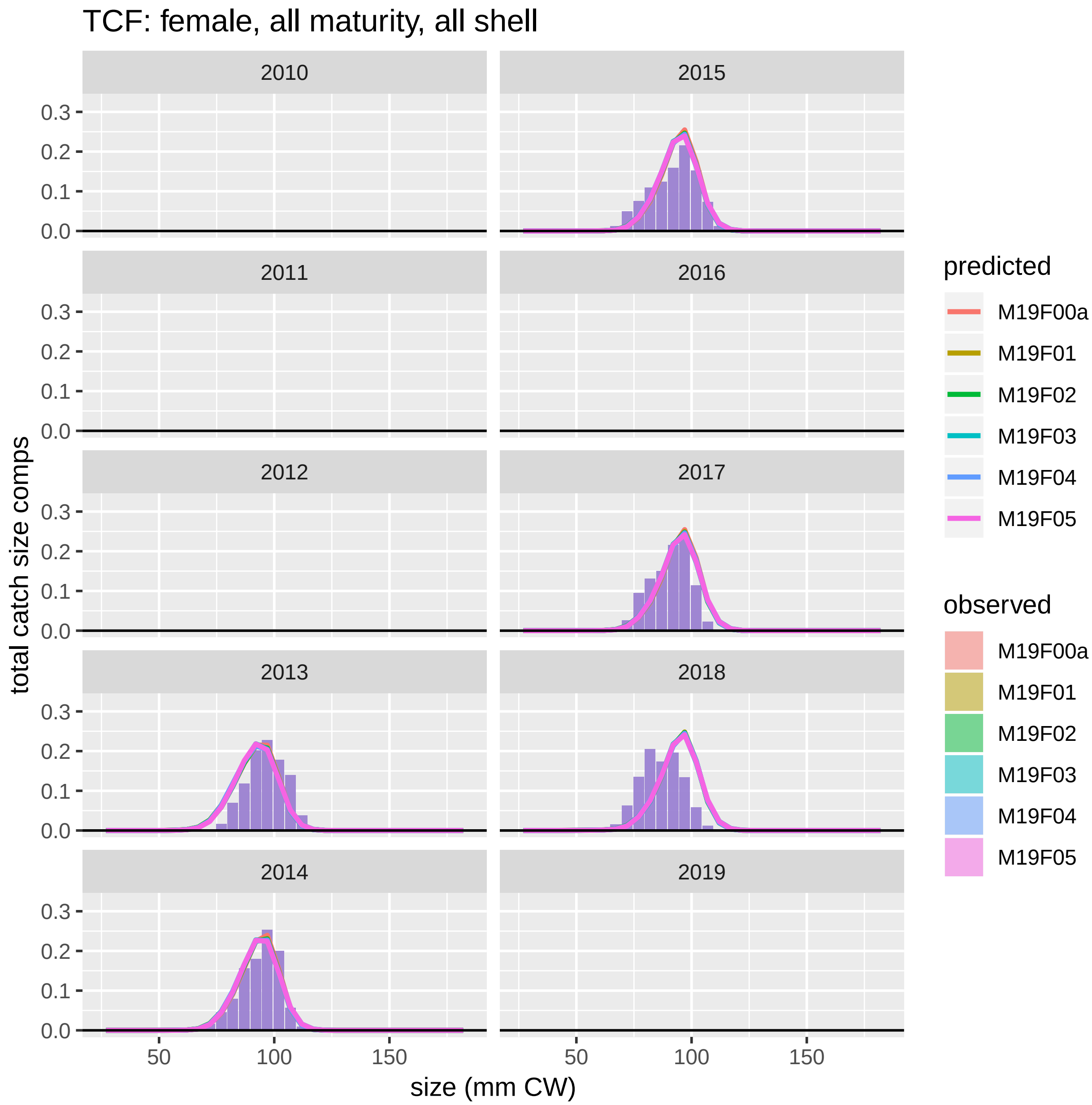


Figure 51: Comparison of observed and predicted female, all maturity, all shell total catch size comps for TCF. Page 3 of 3.

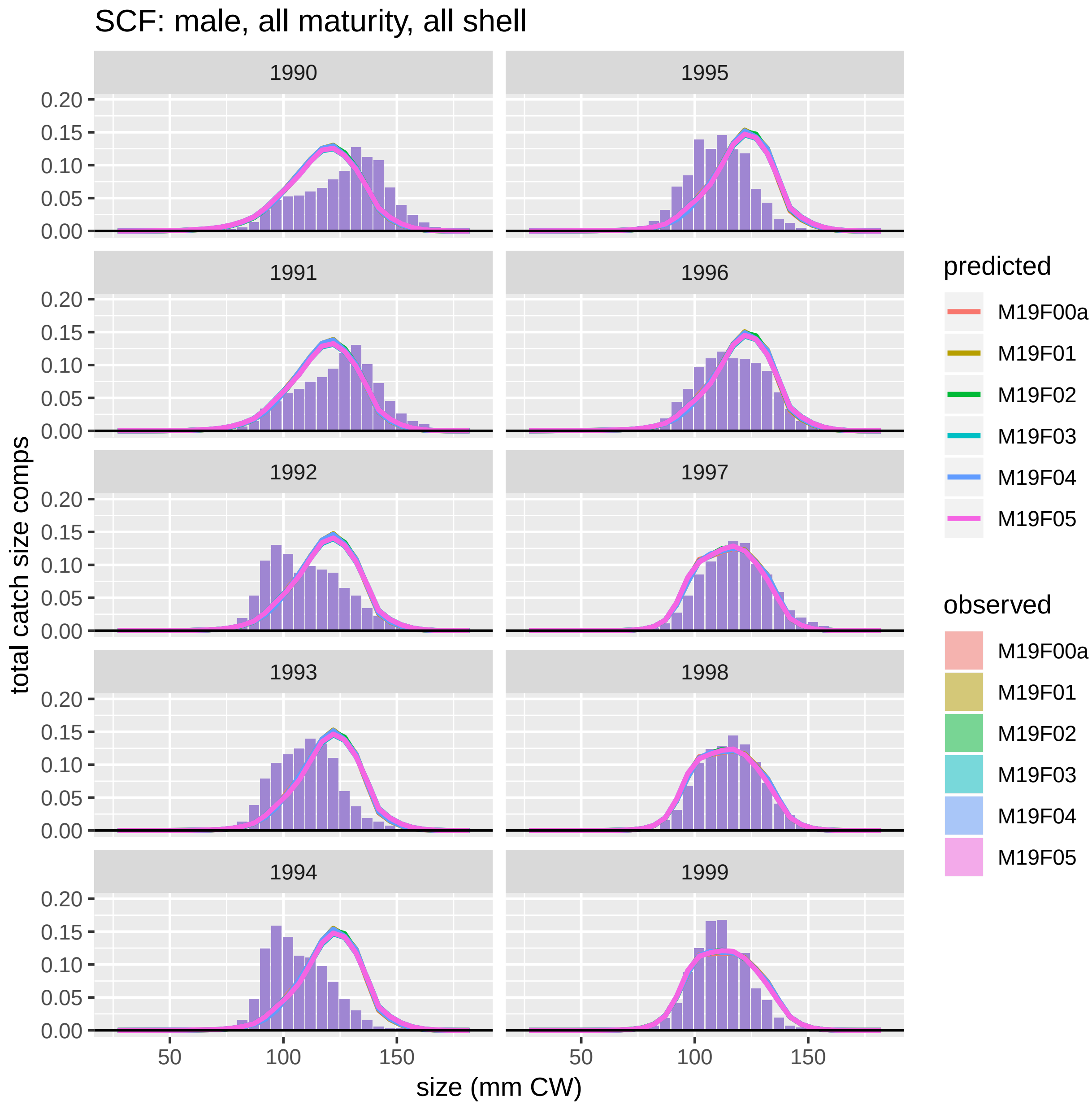


Figure 52: Comparison of observed and predicted male, all maturity, all shell total catch size comps for SCF. Page 1 of 3.

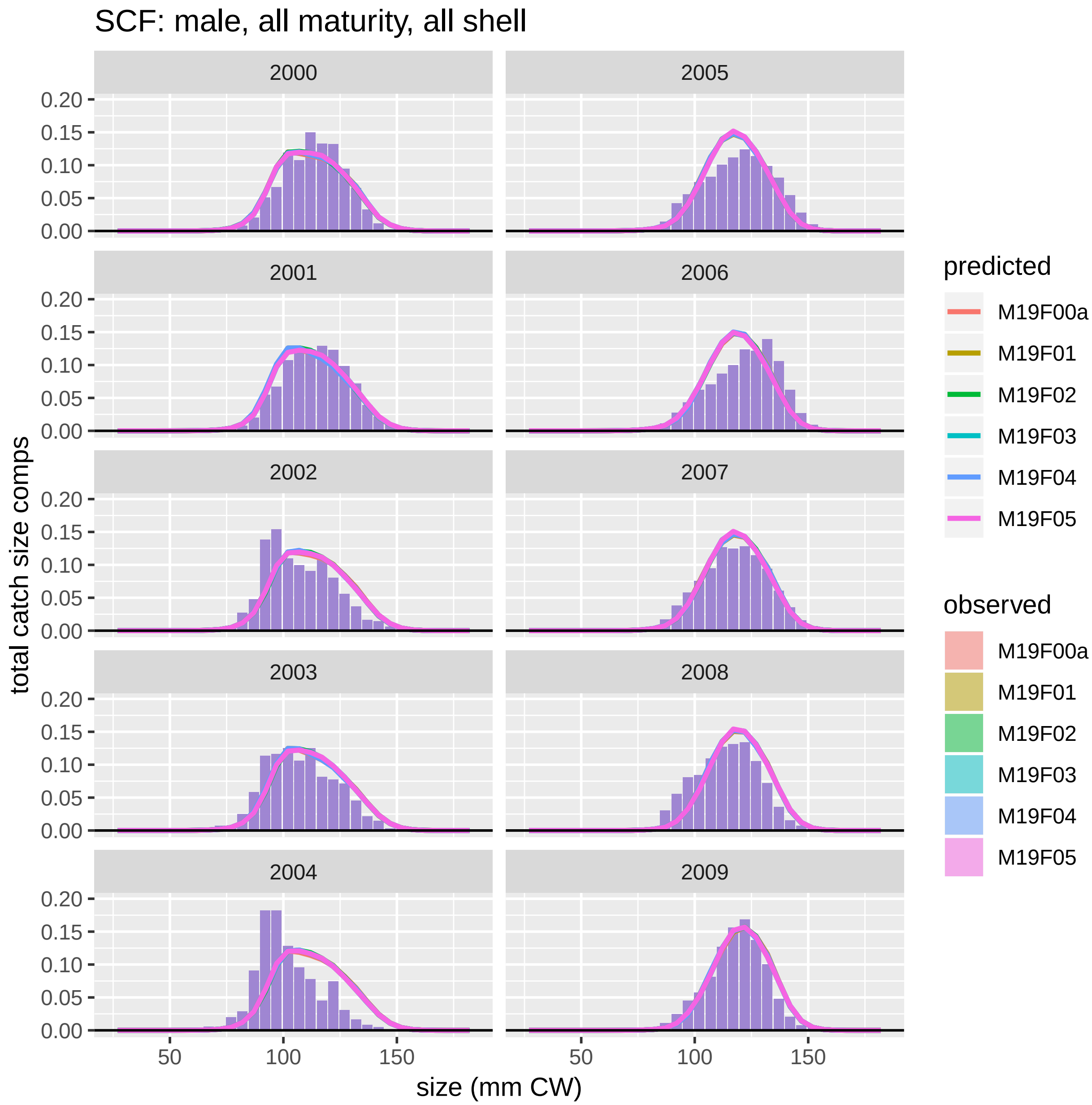


Figure 53: Comparison of observed and predicted male, all maturity, all shell total catch size comps for SCF. Page 2 of 3.

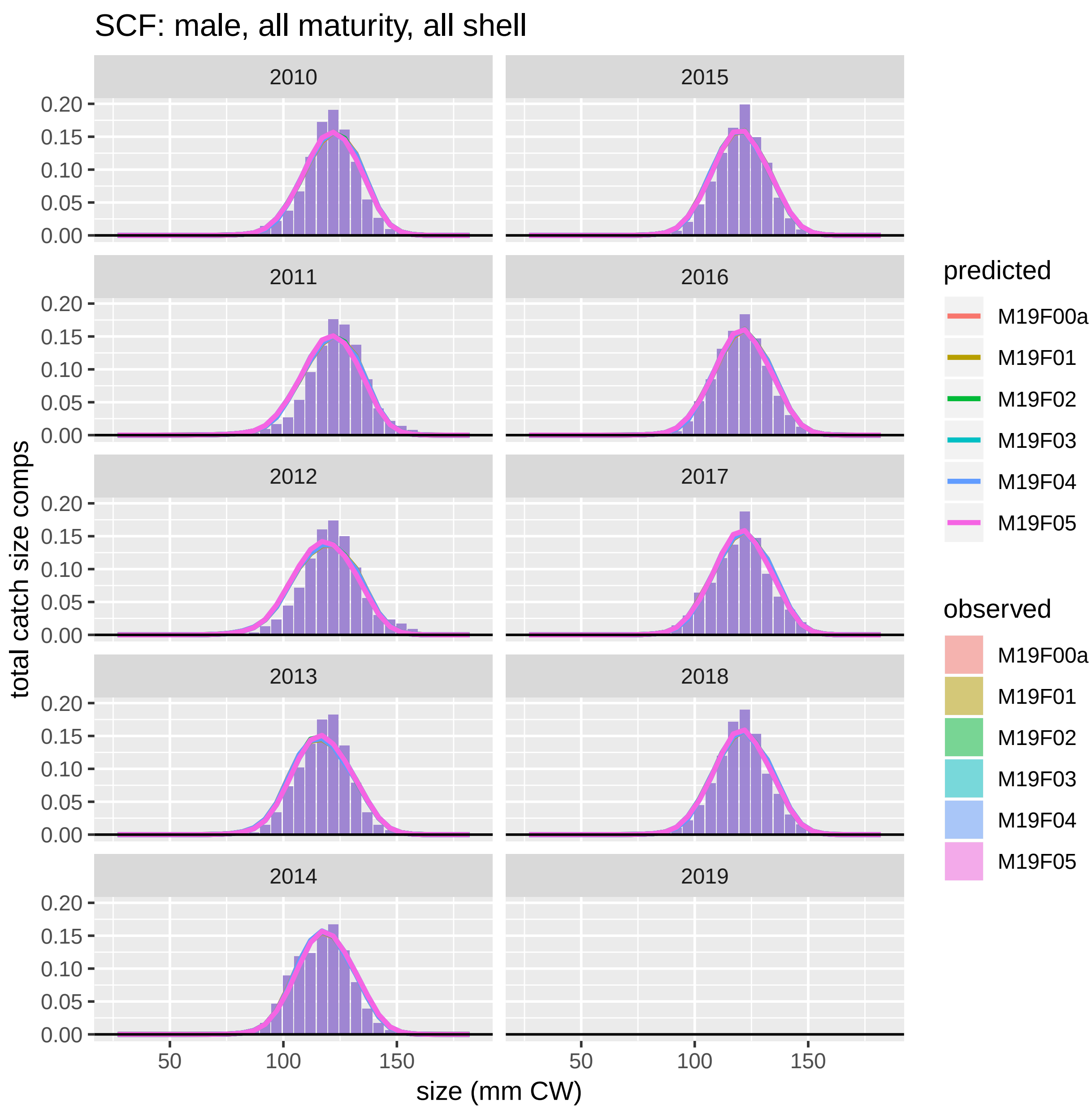


Figure 54: Comparison of observed and predicted male, all maturity, all shell total catch size comps for SCF. Page 3 of 3.

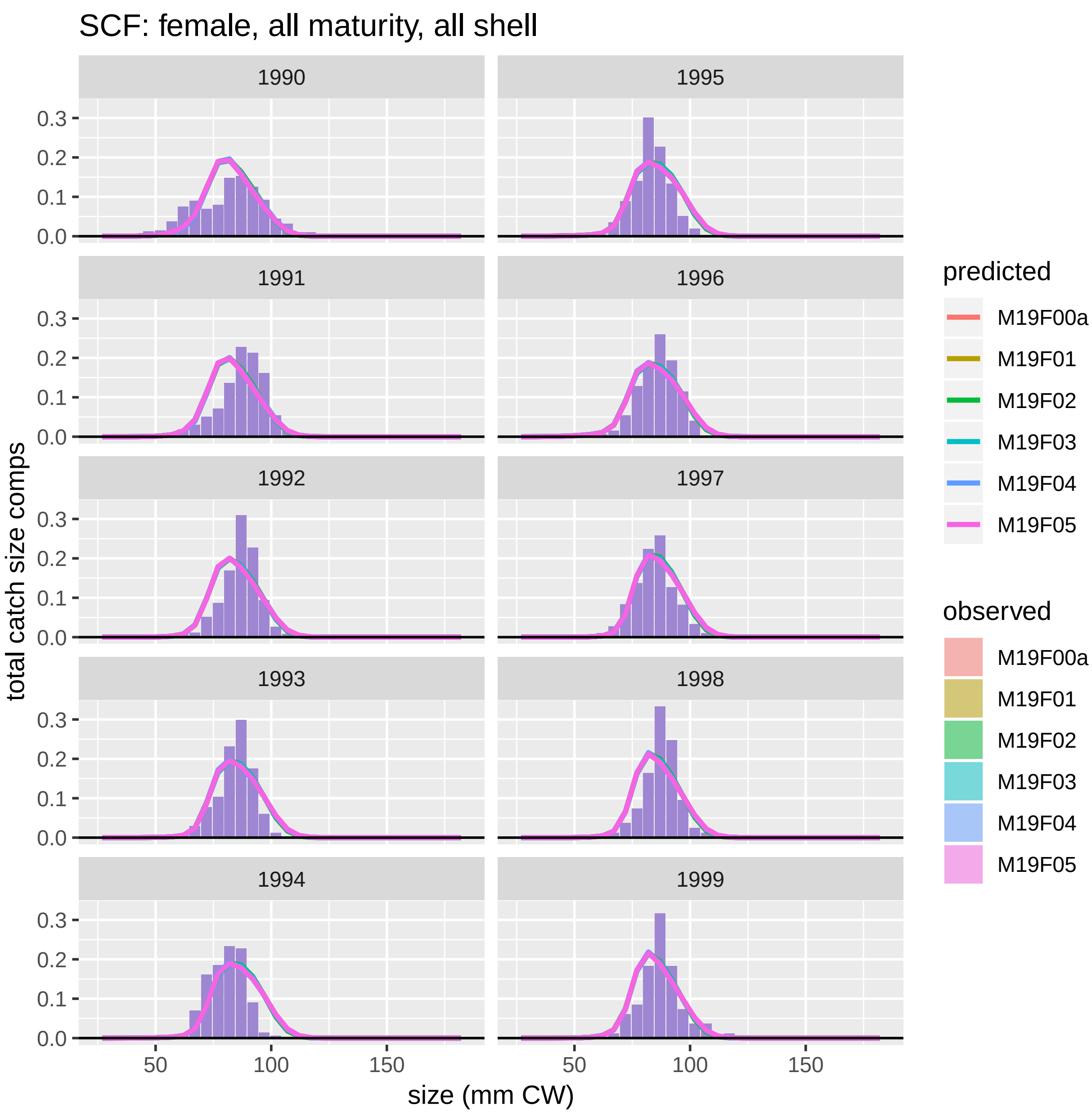


Figure 55: Comparison of observed and predicted female, all maturity, all shell total catch size comps for SCF. Page 1 of 3.

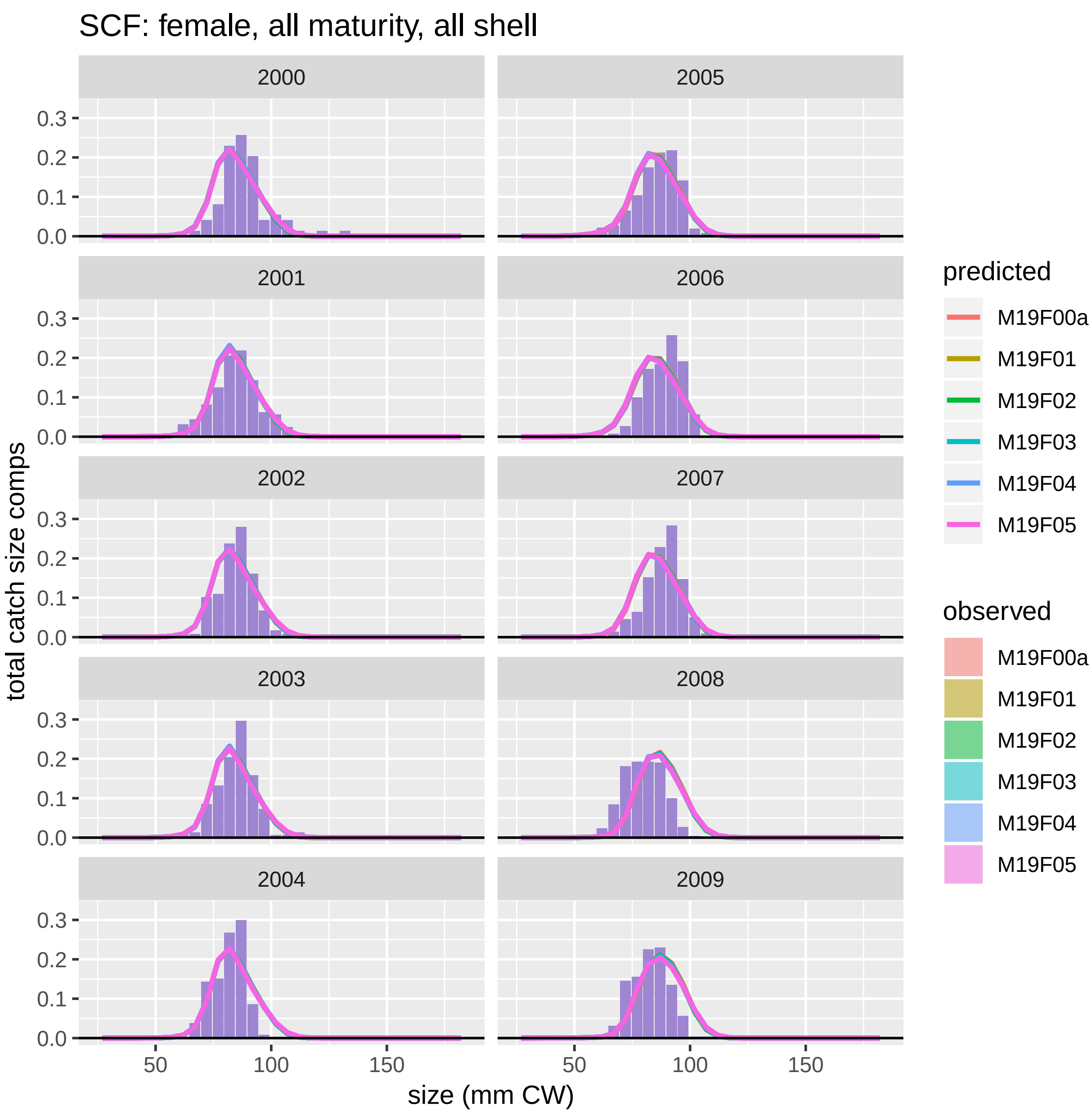


Figure 56: Comparison of observed and predicted female, all maturity, all shell total catch size comps for SCF. Page 2 of 3.

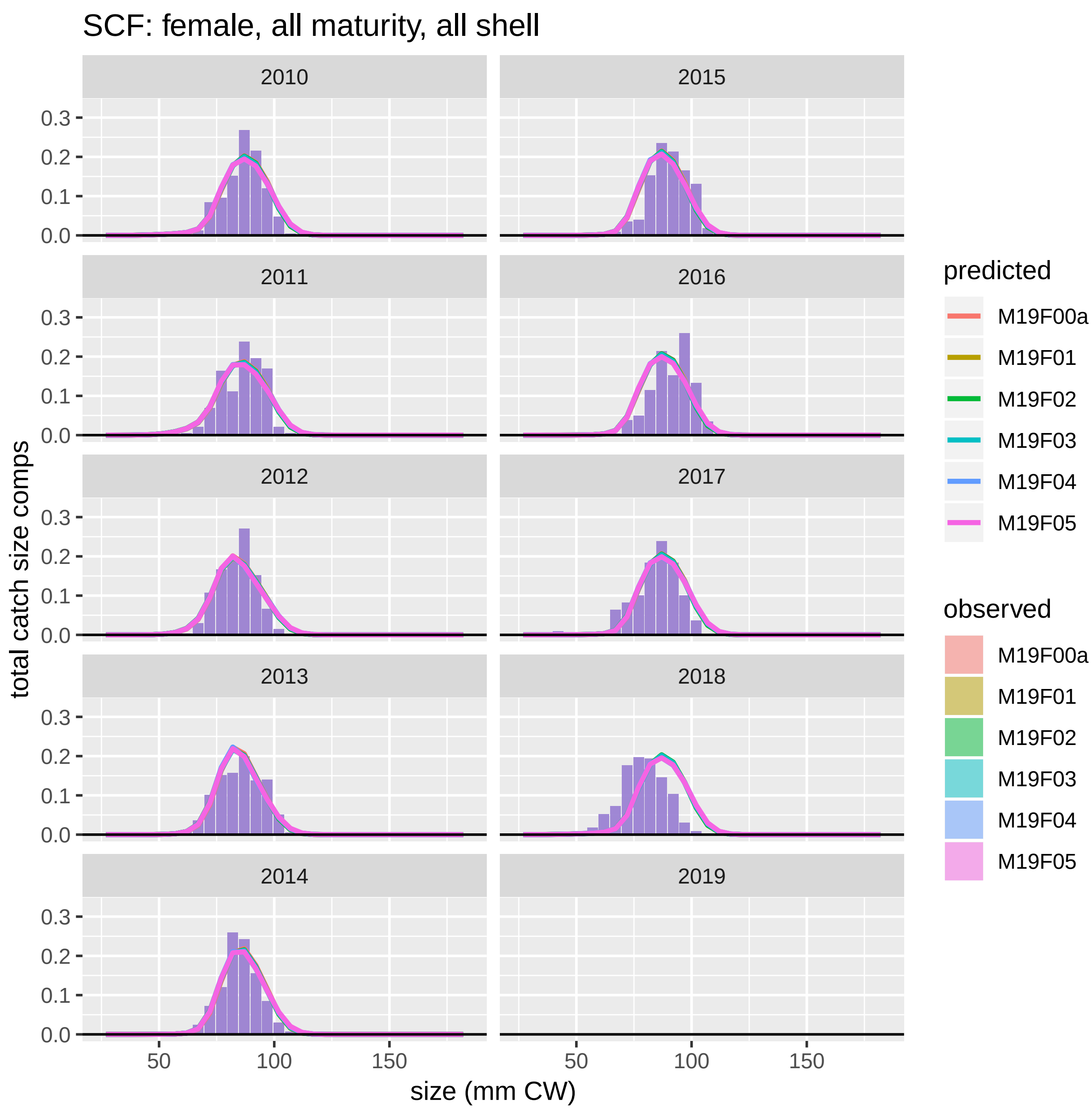


Figure 57: Comparison of observed and predicted female, all maturity, all shell total catch size comps for SCF. Page 3 of 3.

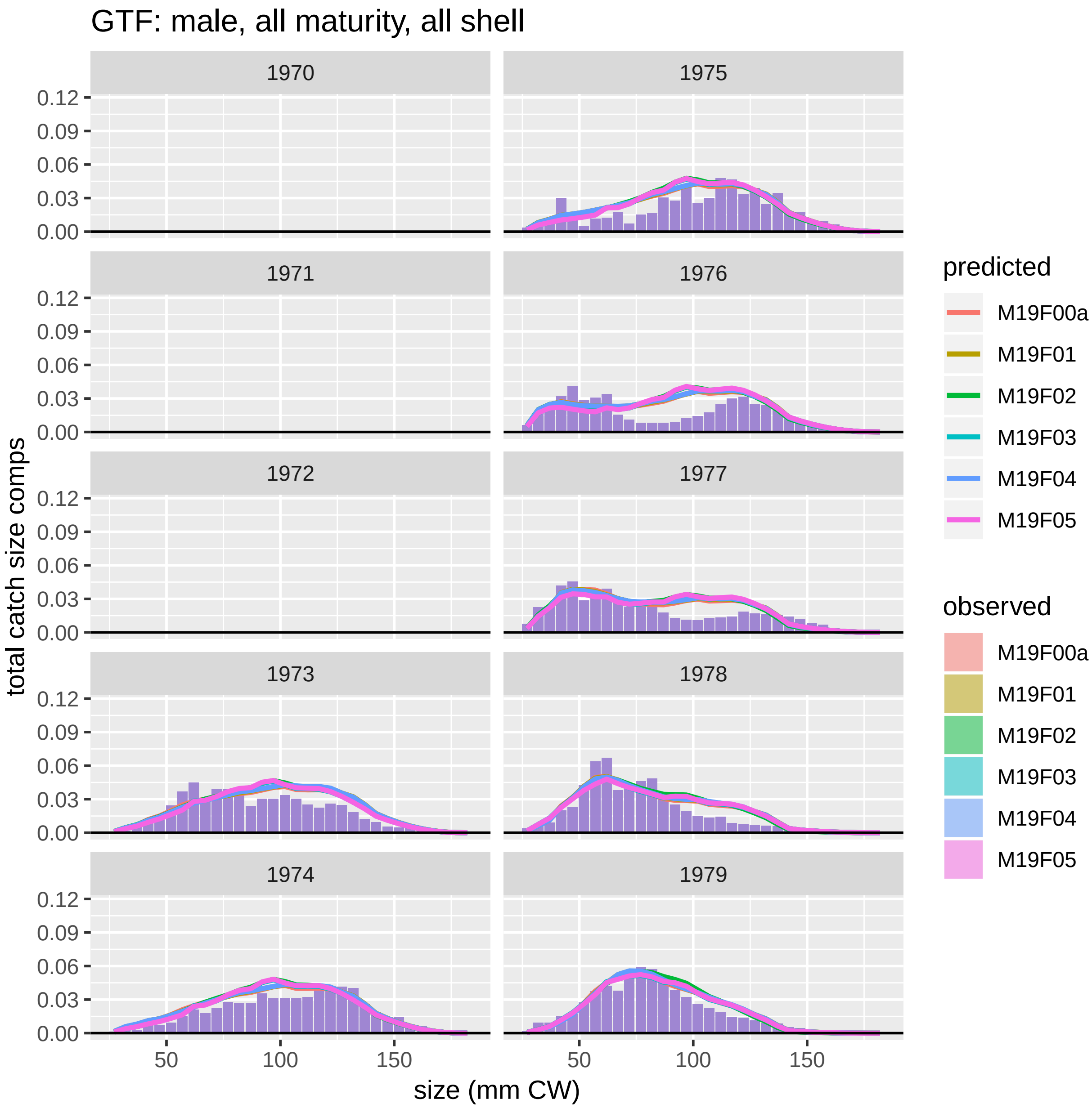


Figure 58: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 1 of 5.

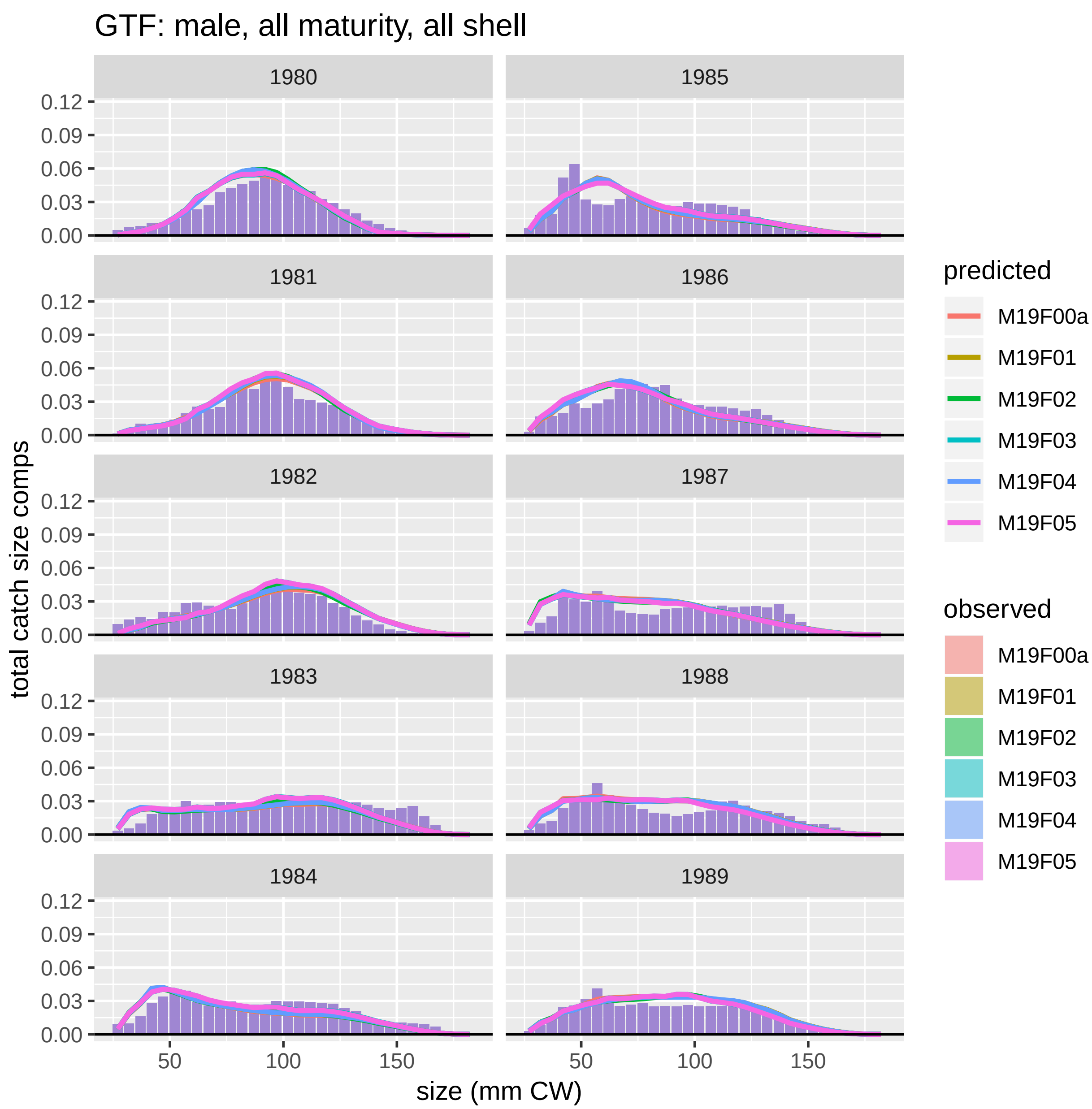


Figure 59: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 2 of 5.

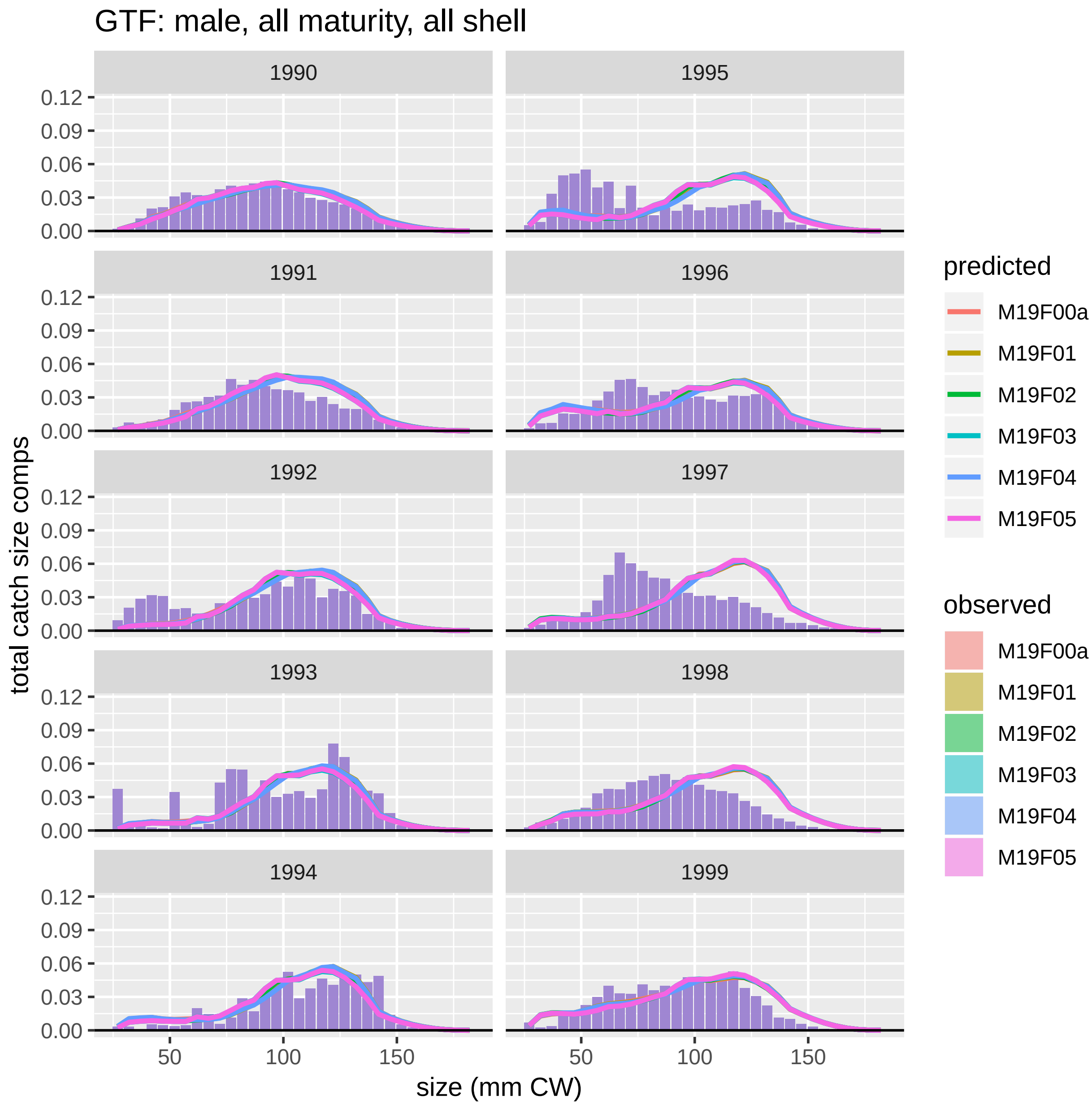


Figure 60: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 3 of 5.

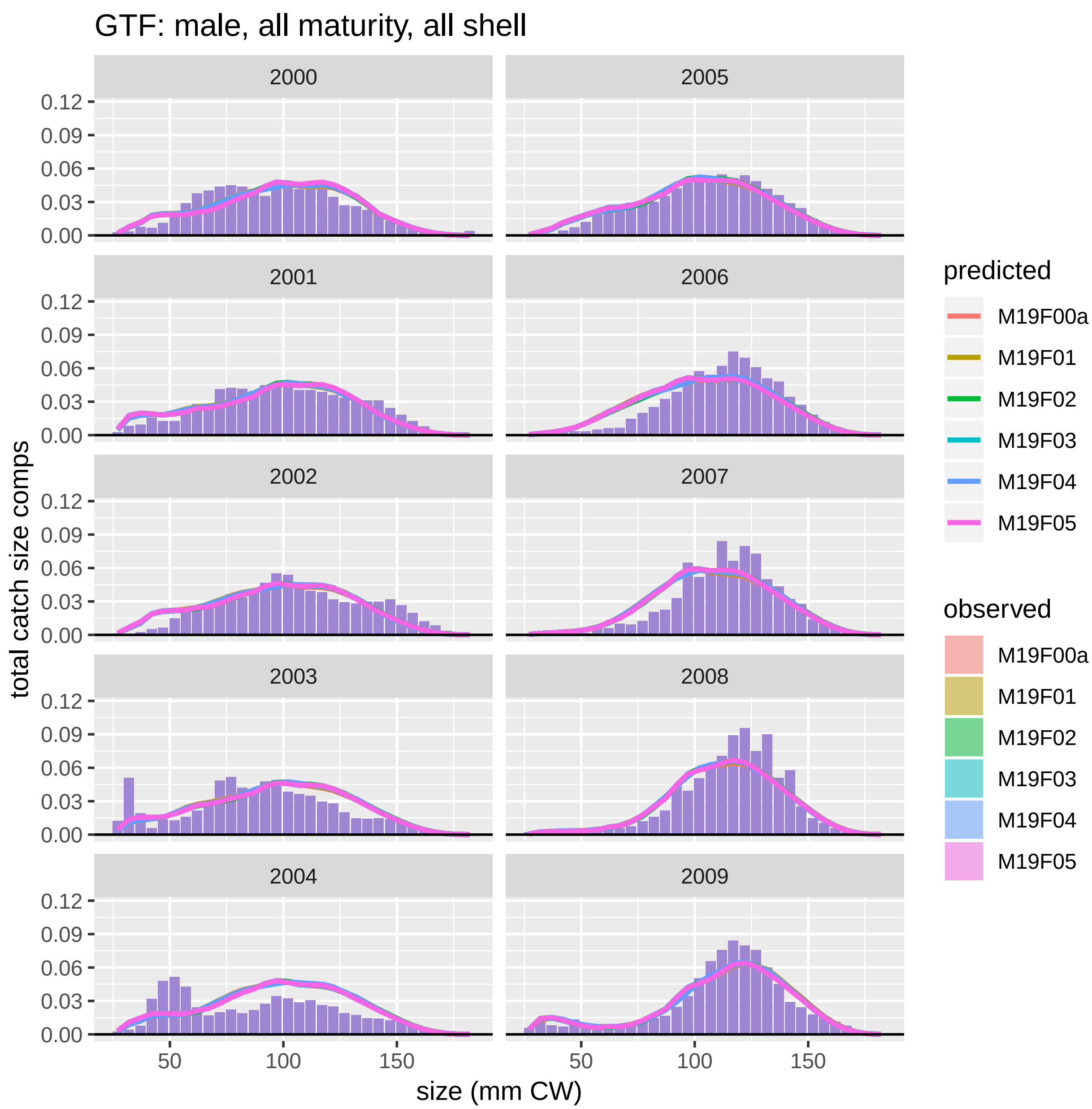


Figure 61: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 4 of 5.

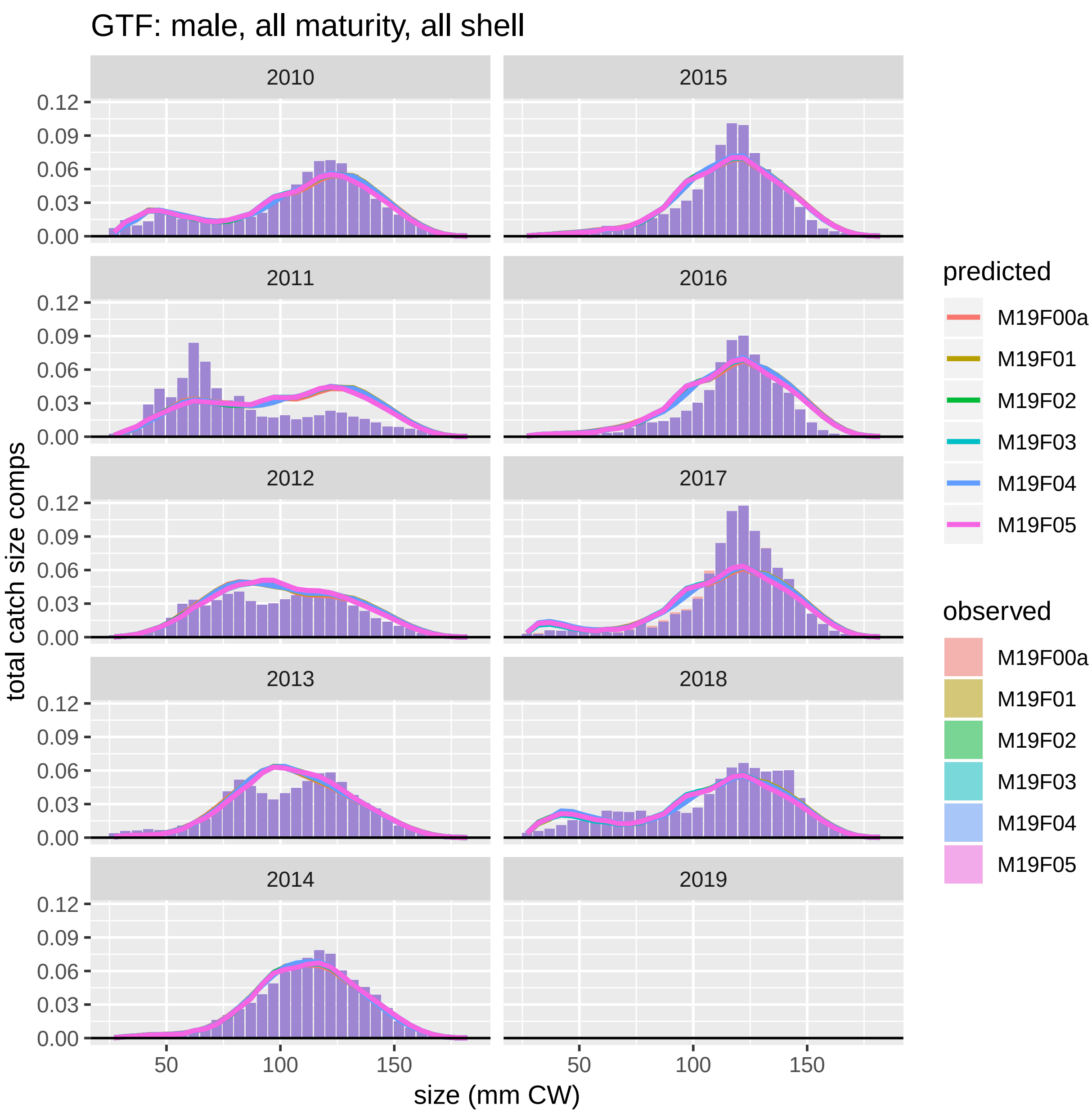


Figure 62: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 5 of 5.

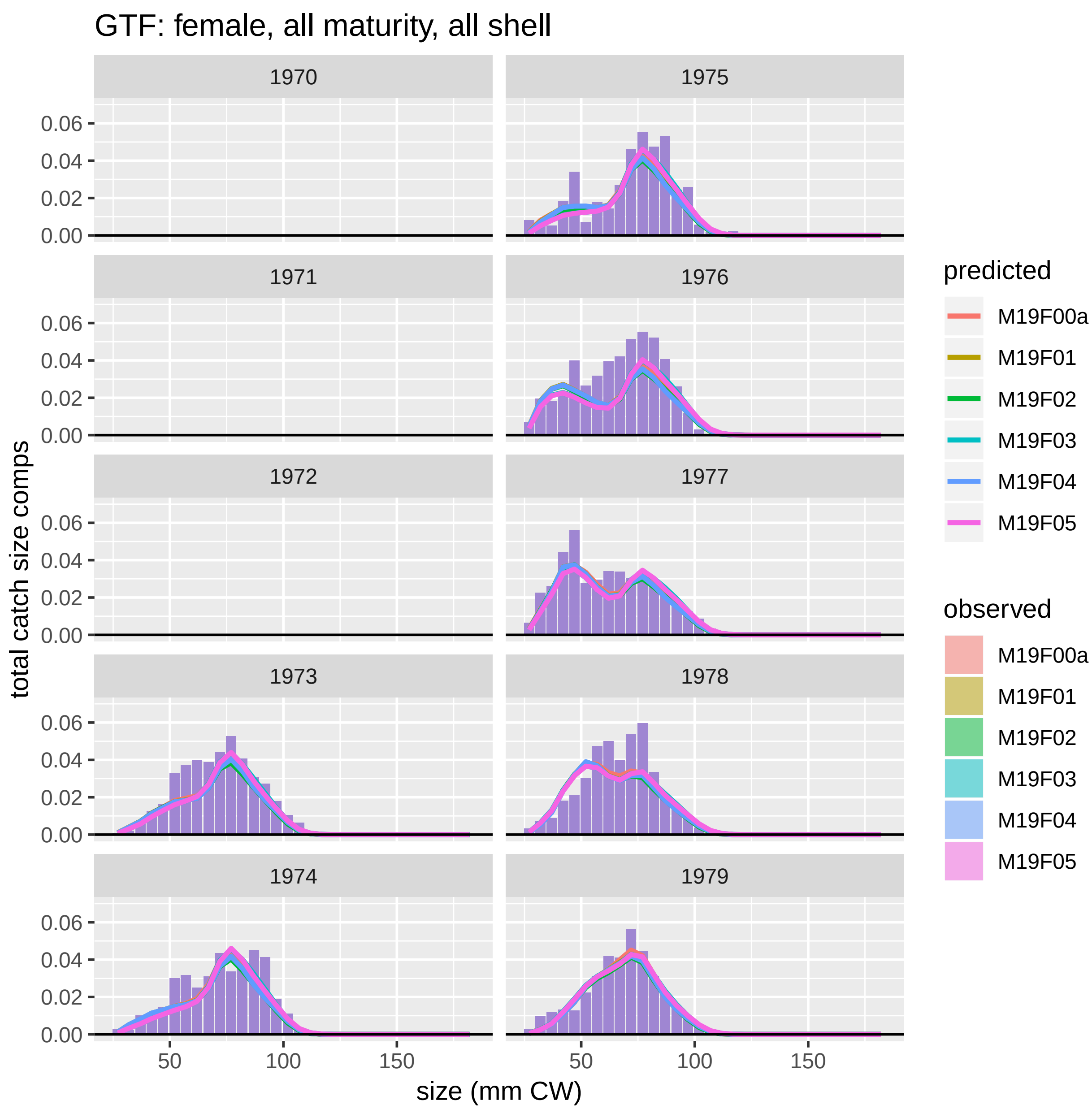


Figure 63: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 1 of 5.

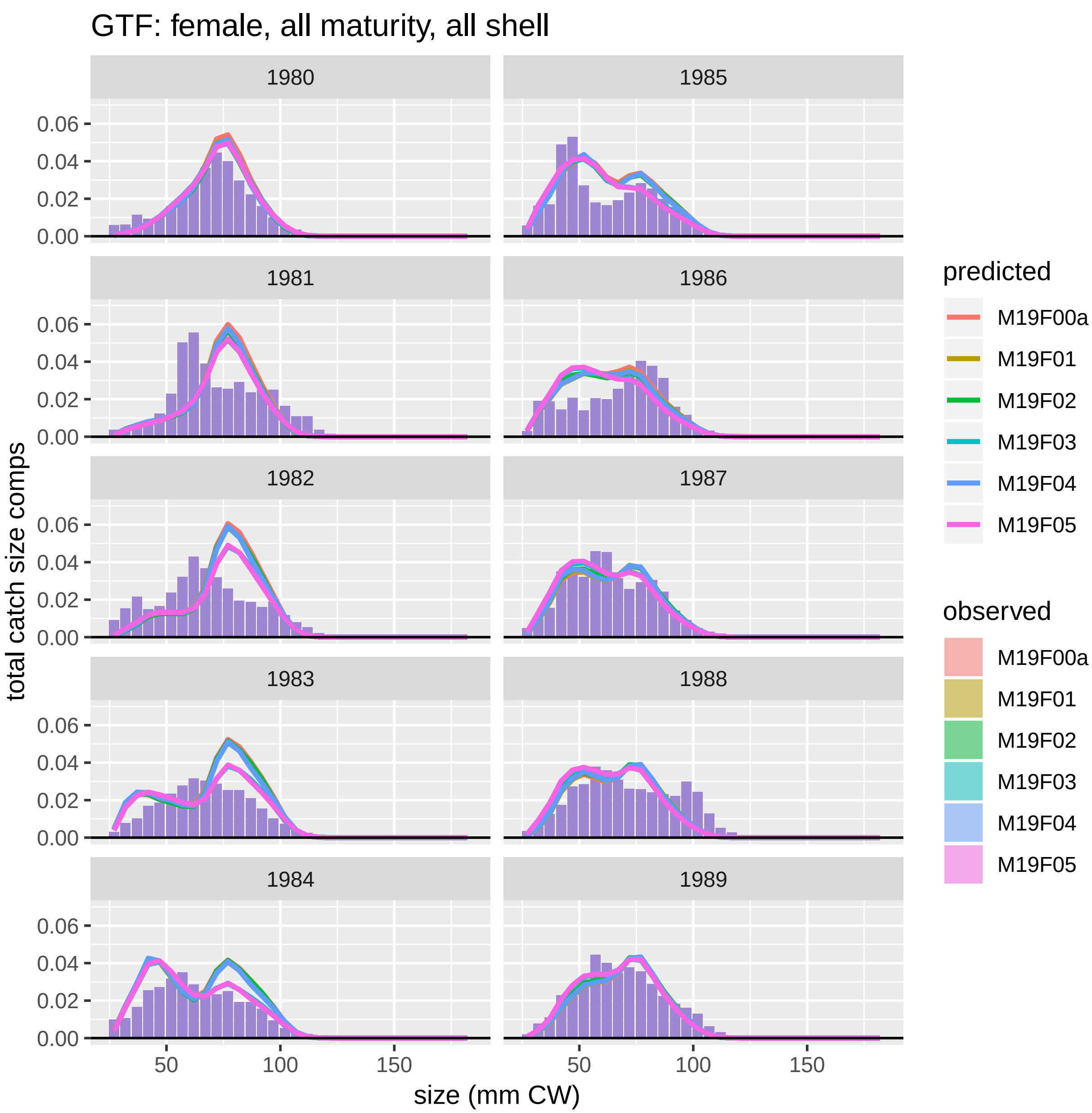


Figure 64: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 2 of 5.

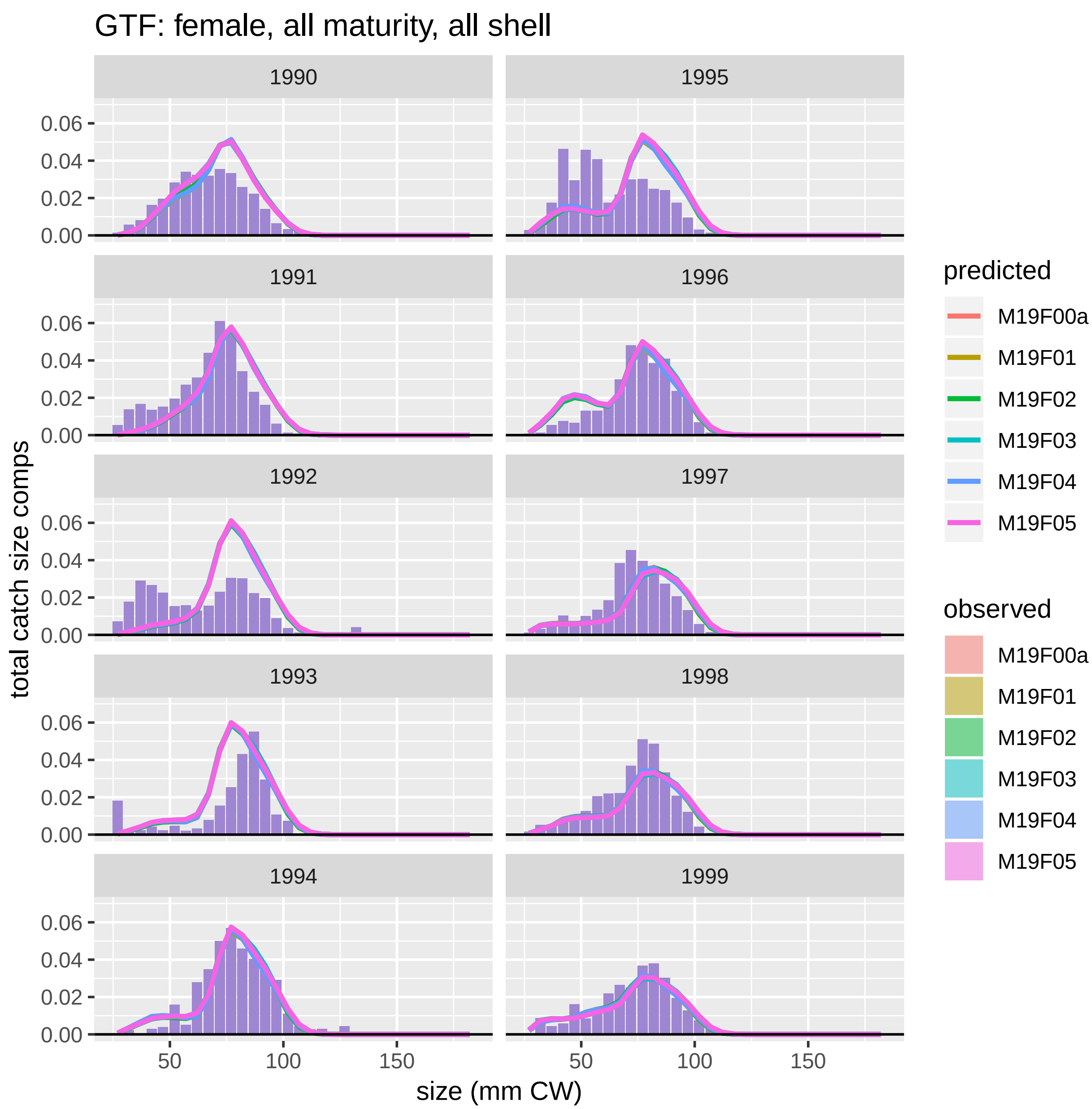


Figure 65: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 3 of 5.

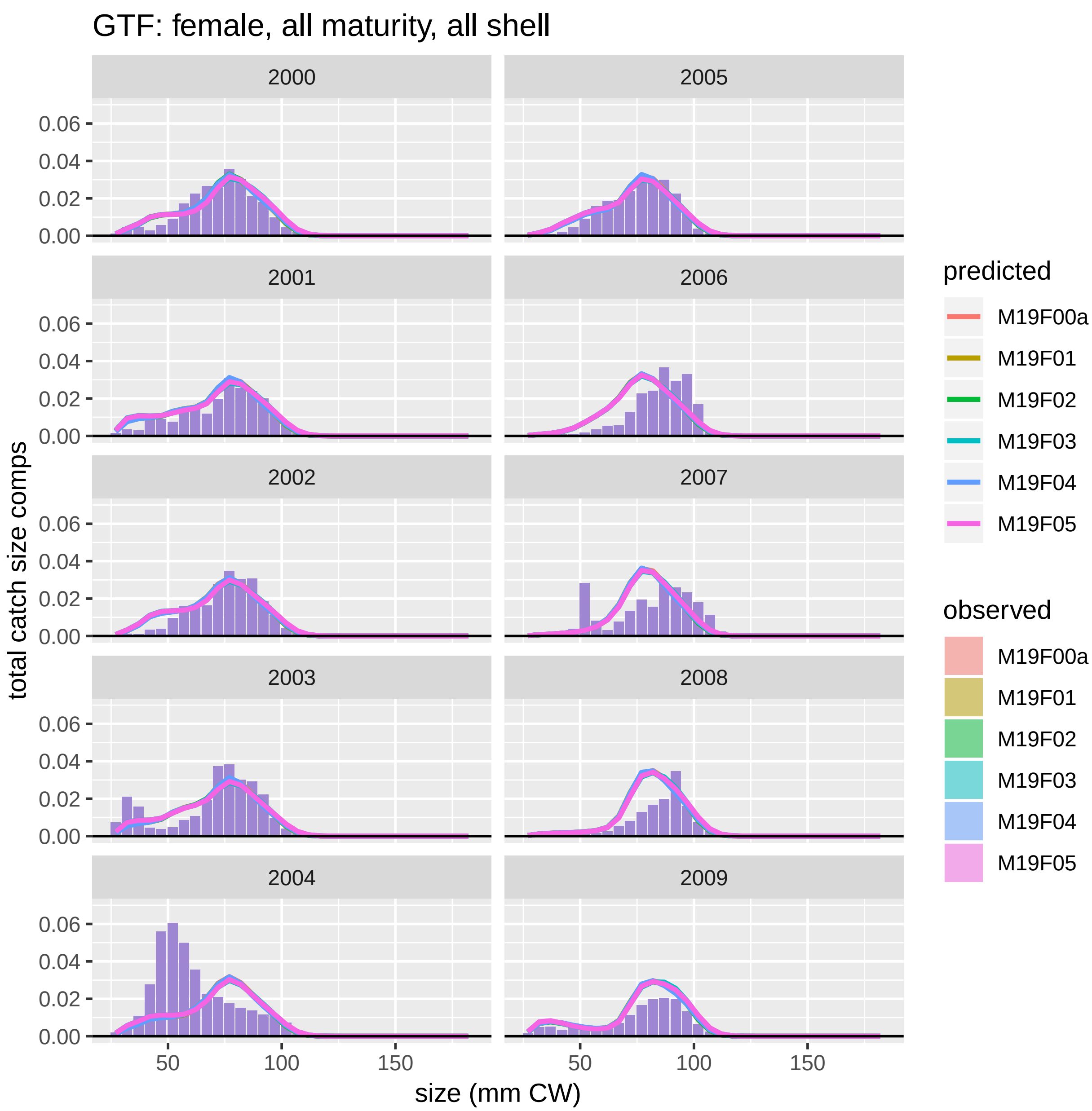


Figure 66: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 4 of 5.

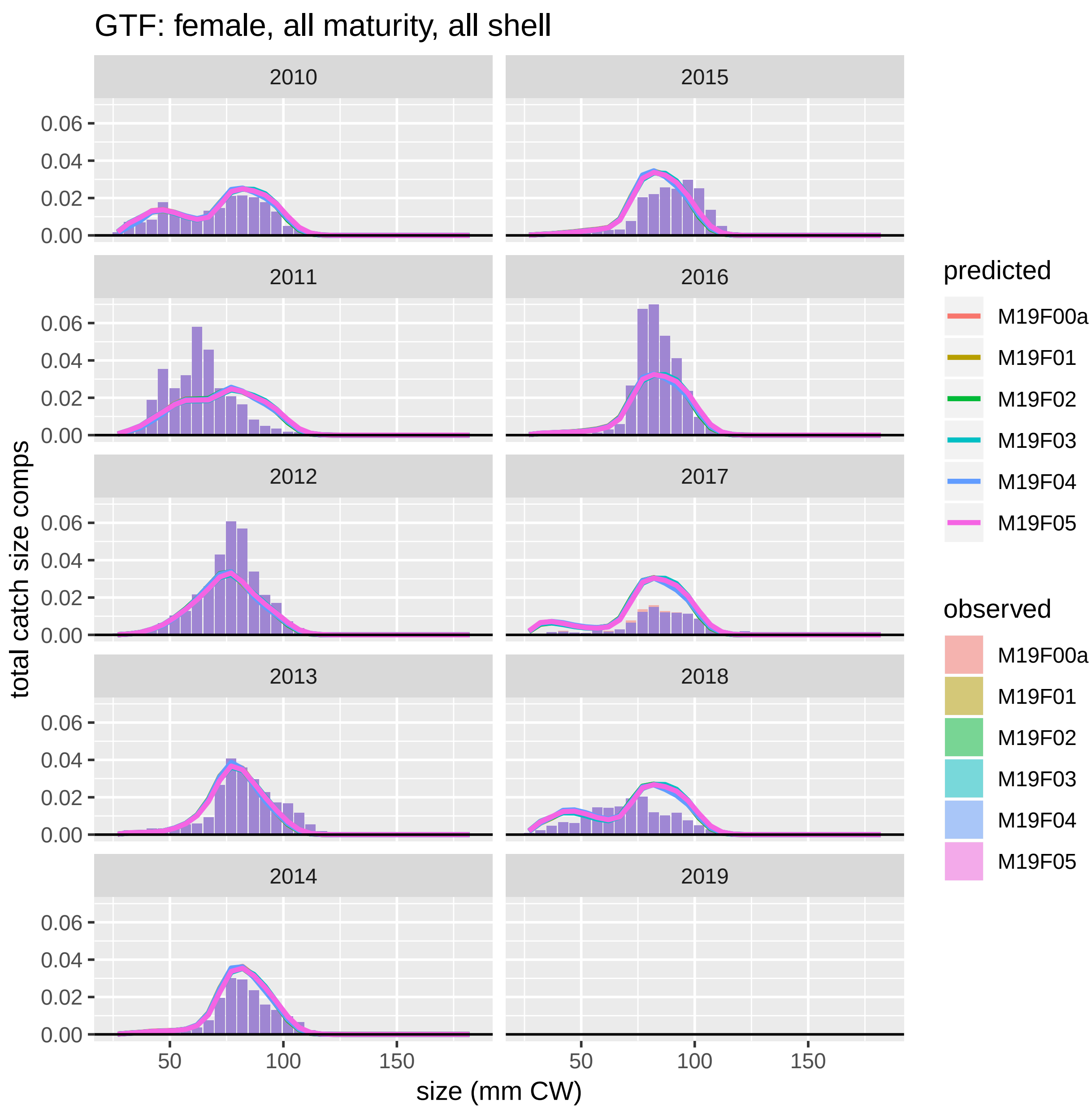


Figure 67: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 5 of 5.

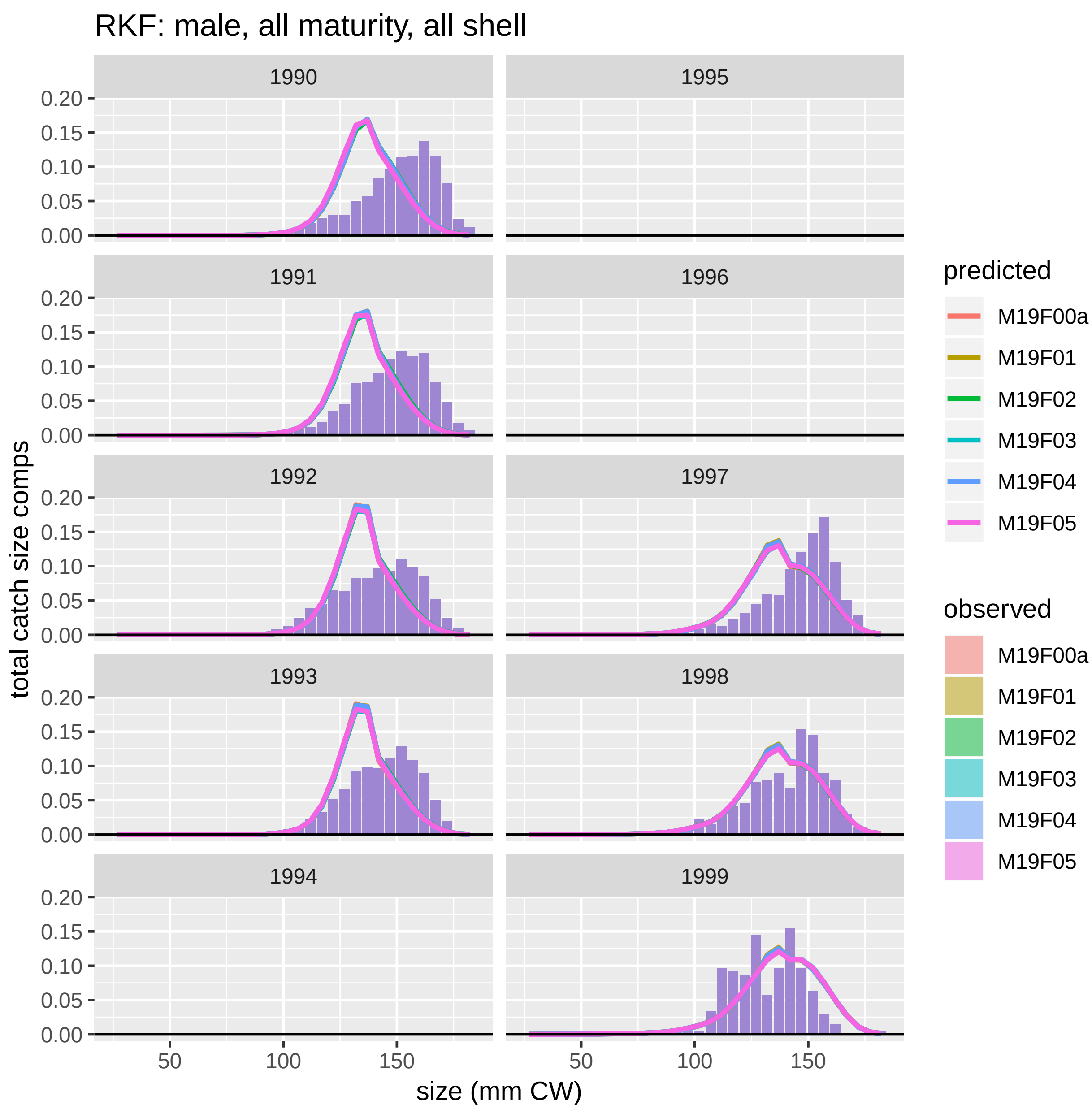


Figure 68: Comparison of observed and predicted male, all maturity, all shell total catch size comps for RKF. Page 1 of 3.

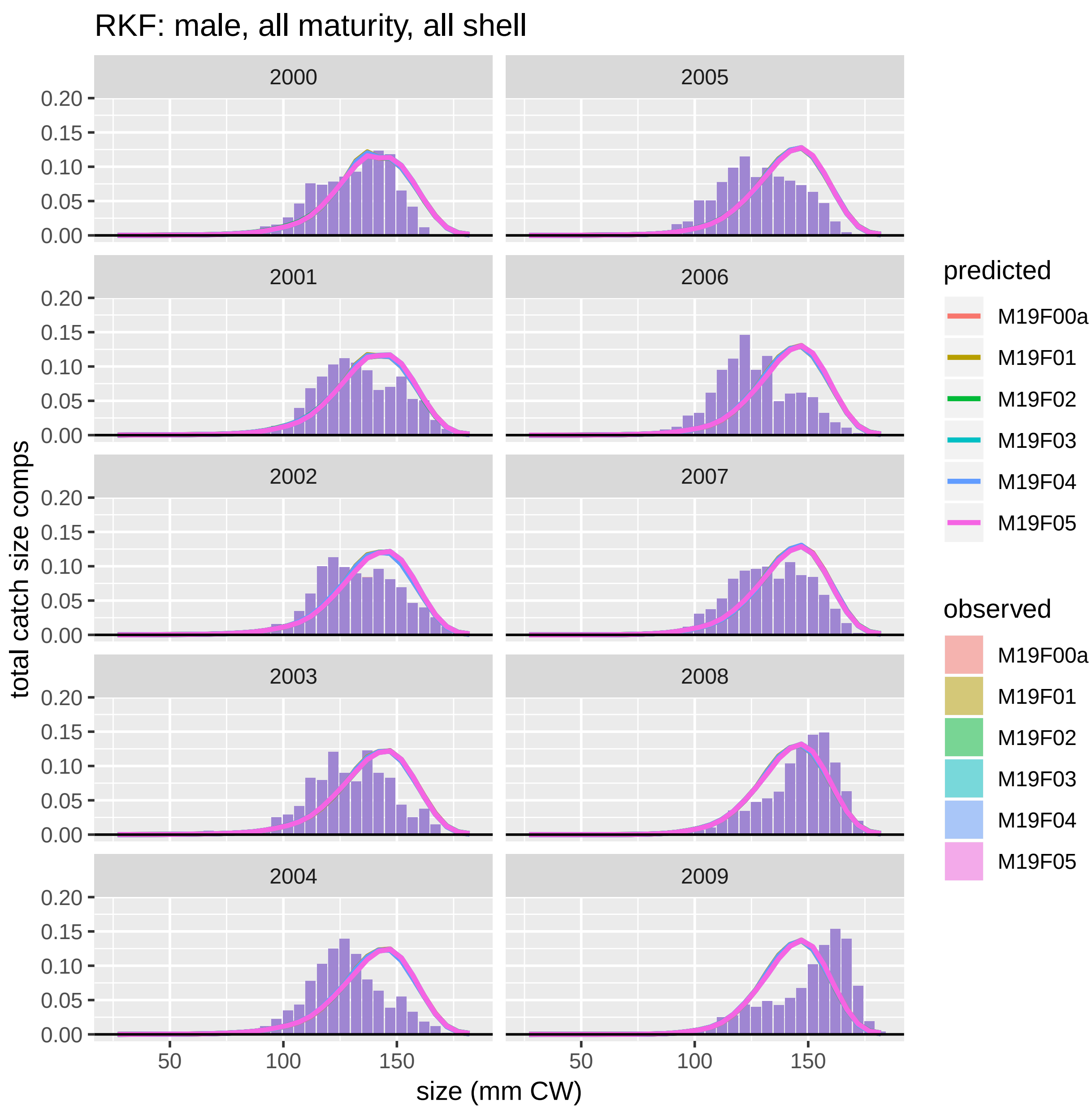


Figure 69: Comparison of observed and predicted male, all maturity, all shell total catch size comps for RKF. Page 2 of 3.

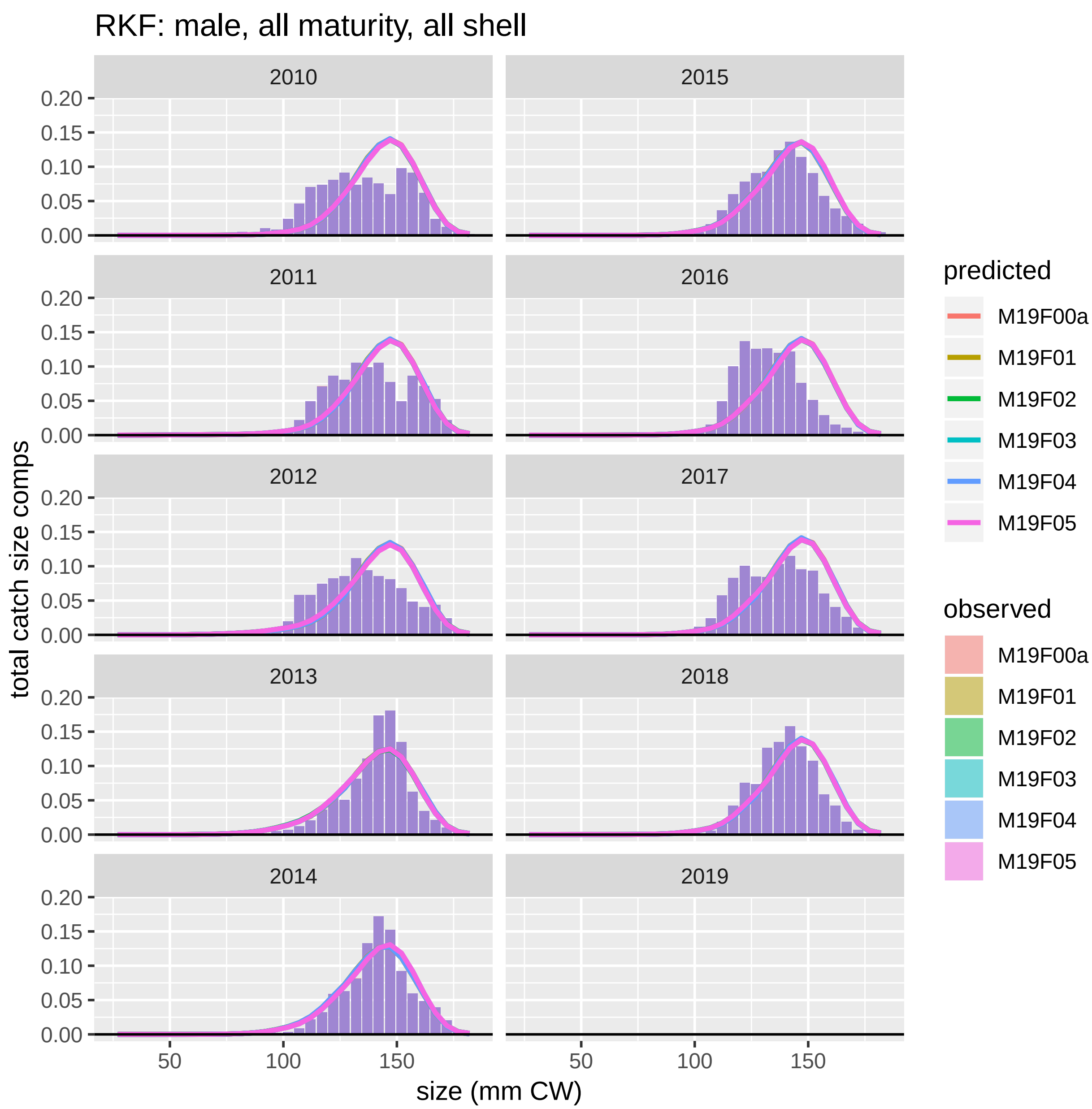


Figure 70: Comparison of observed and predicted male, all maturity, all shell total catch size comps for RKF. Page 3 of 3.

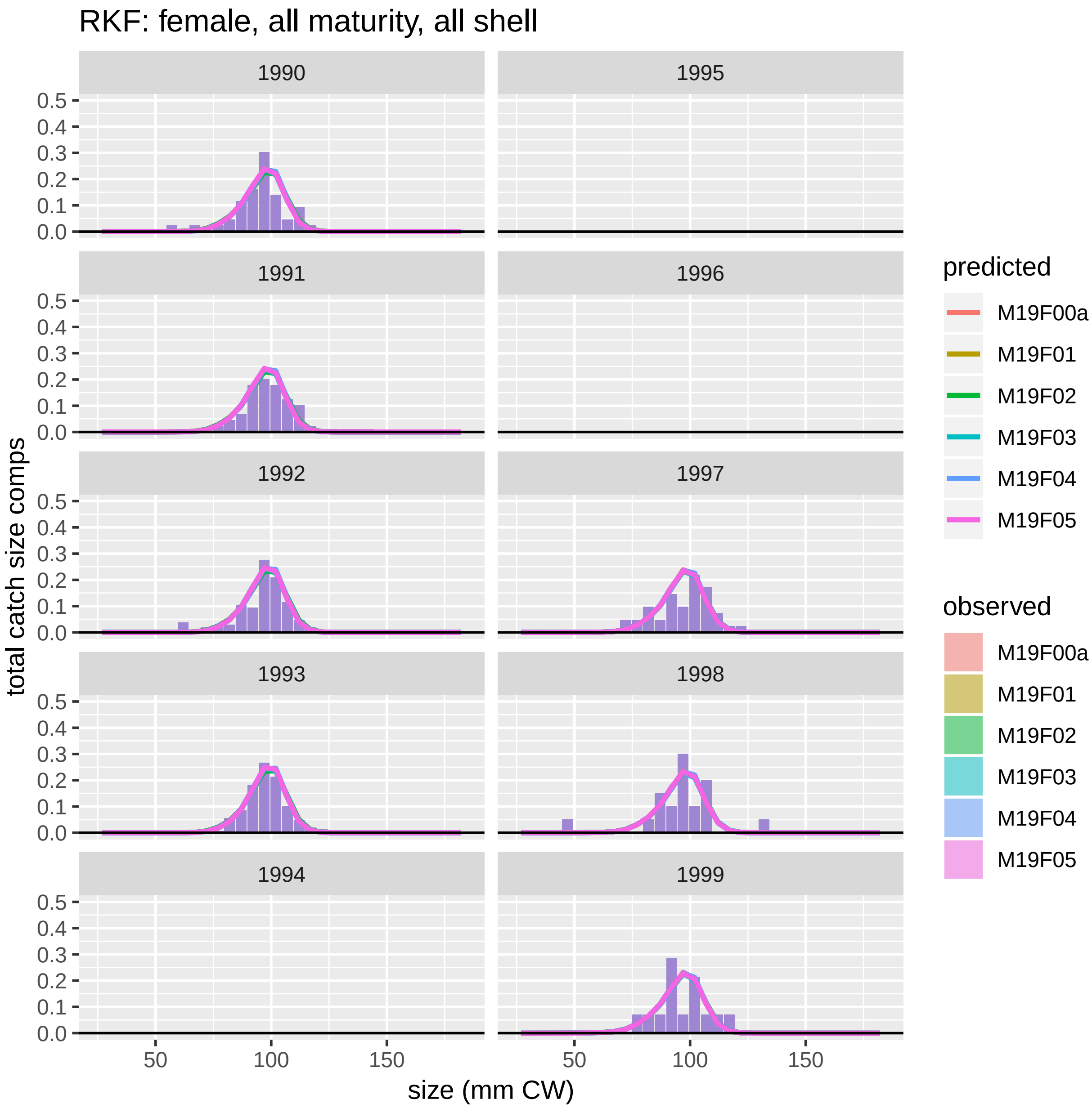


Figure 71: Comparison of observed and predicted female, all maturity, all shell total catch size comps for RKF. Page 1 of 3.

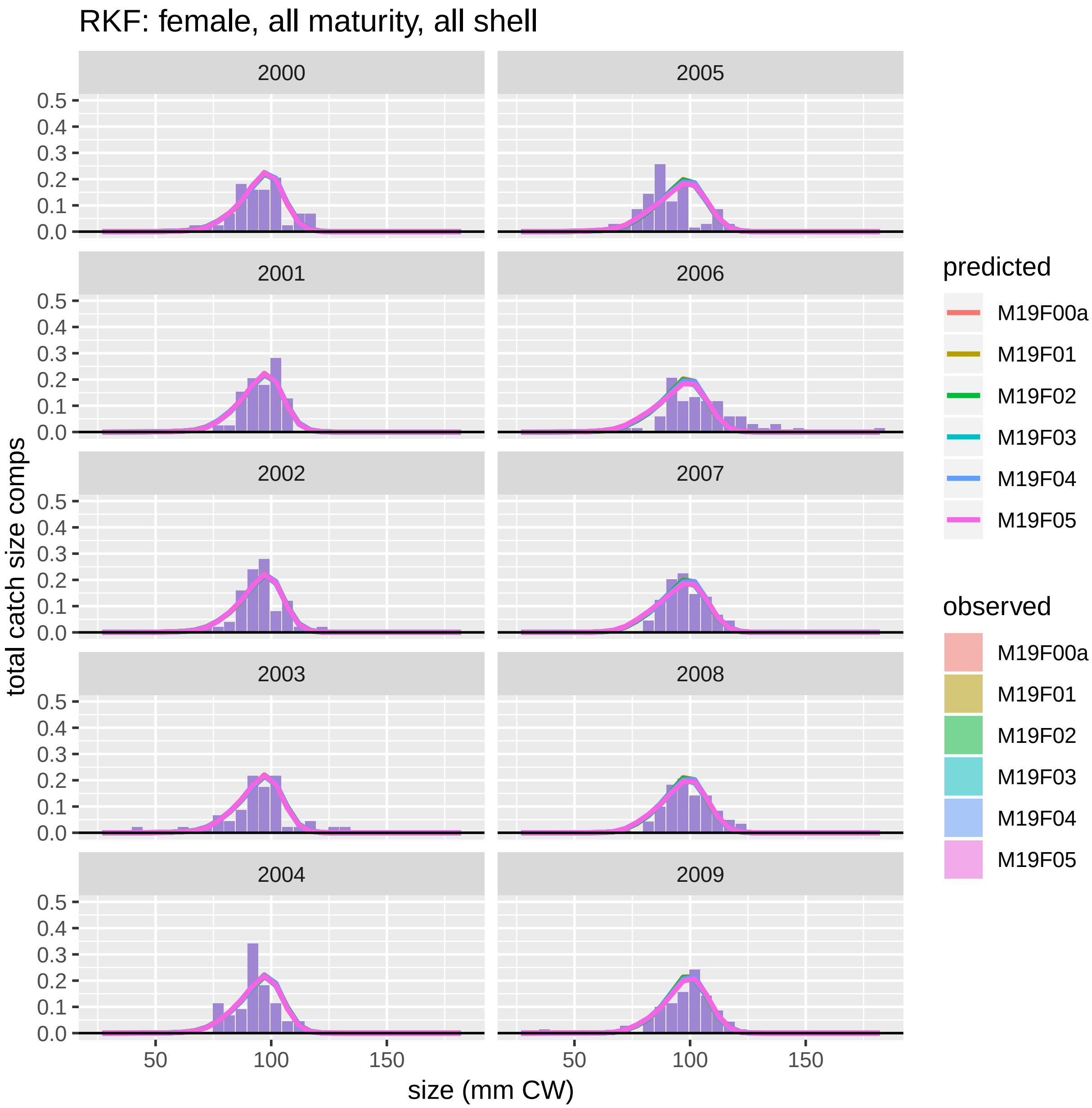


Figure 72: Comparison of observed and predicted female, all maturity, all shell total catch size comps for RKF. Page 2 of 3.

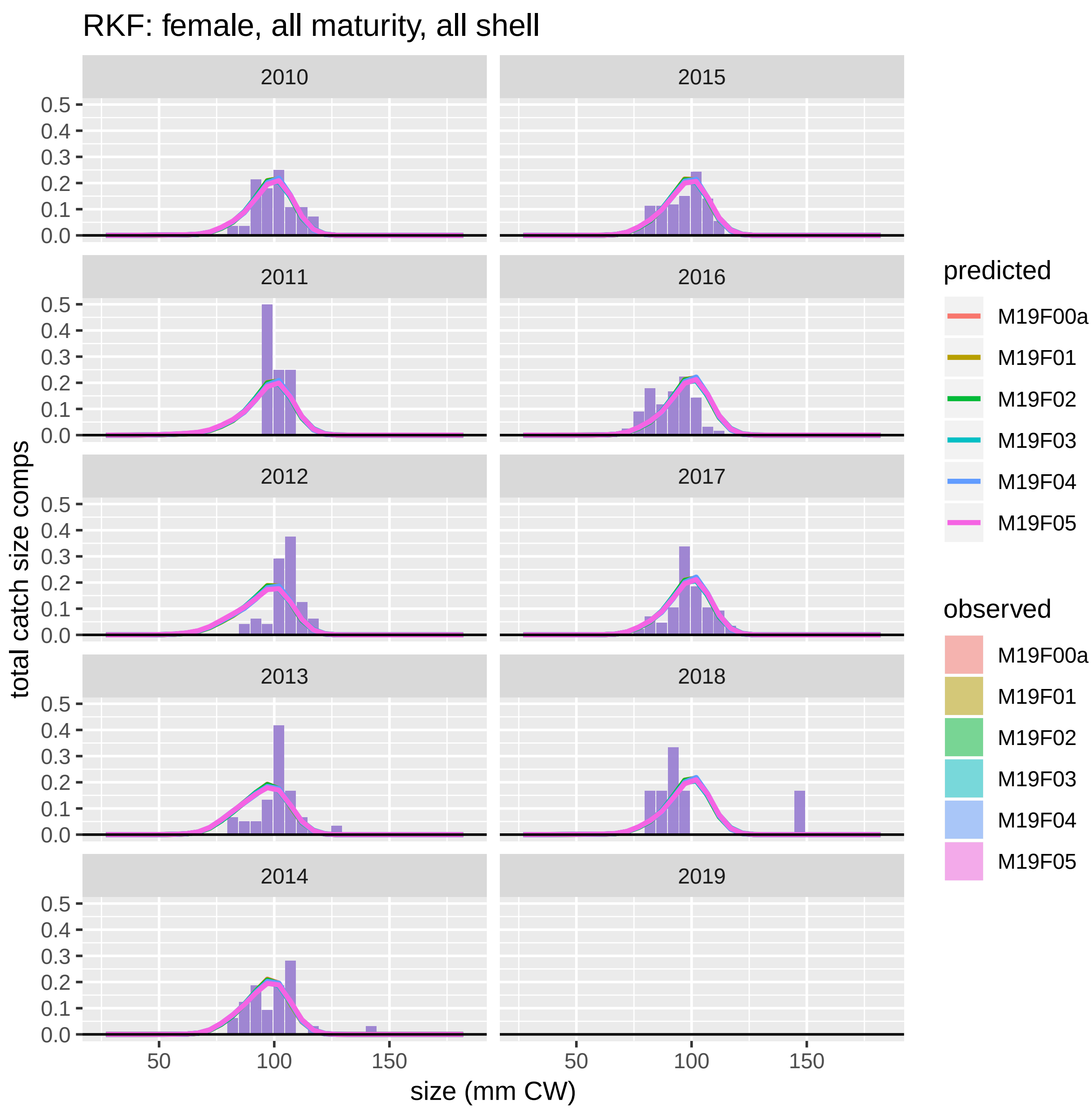


Figure 73: Comparison of observed and predicted female, all maturity, all shell total catch size comps for RKF. Page 3 of 3.

Model Comparisons: Fits to Fisheries Size Composition Data – M19F00a vs M19F01 vs M19F02 vs M19F03 vs M19F04 vs M19F05

William Stockhausen

07 September, 2019

Contents

Introduction

Fits to fishery retained catch and total catch size composition data available to the model(s) are presented in this section. Included are plots of mean fits to size compositions, Pearson's residuals as bubble plots, and effective sample sizes. Not all of the fits presented are necessarily included in the parameter optimization for each model; some fits to datasets for a particular model may be included for comparison purposes with other models which include those data in their optimization. The reader should consult the main assessment document to determine which fits are included in the optimization for any particular model.

Retained catch mean size compositions

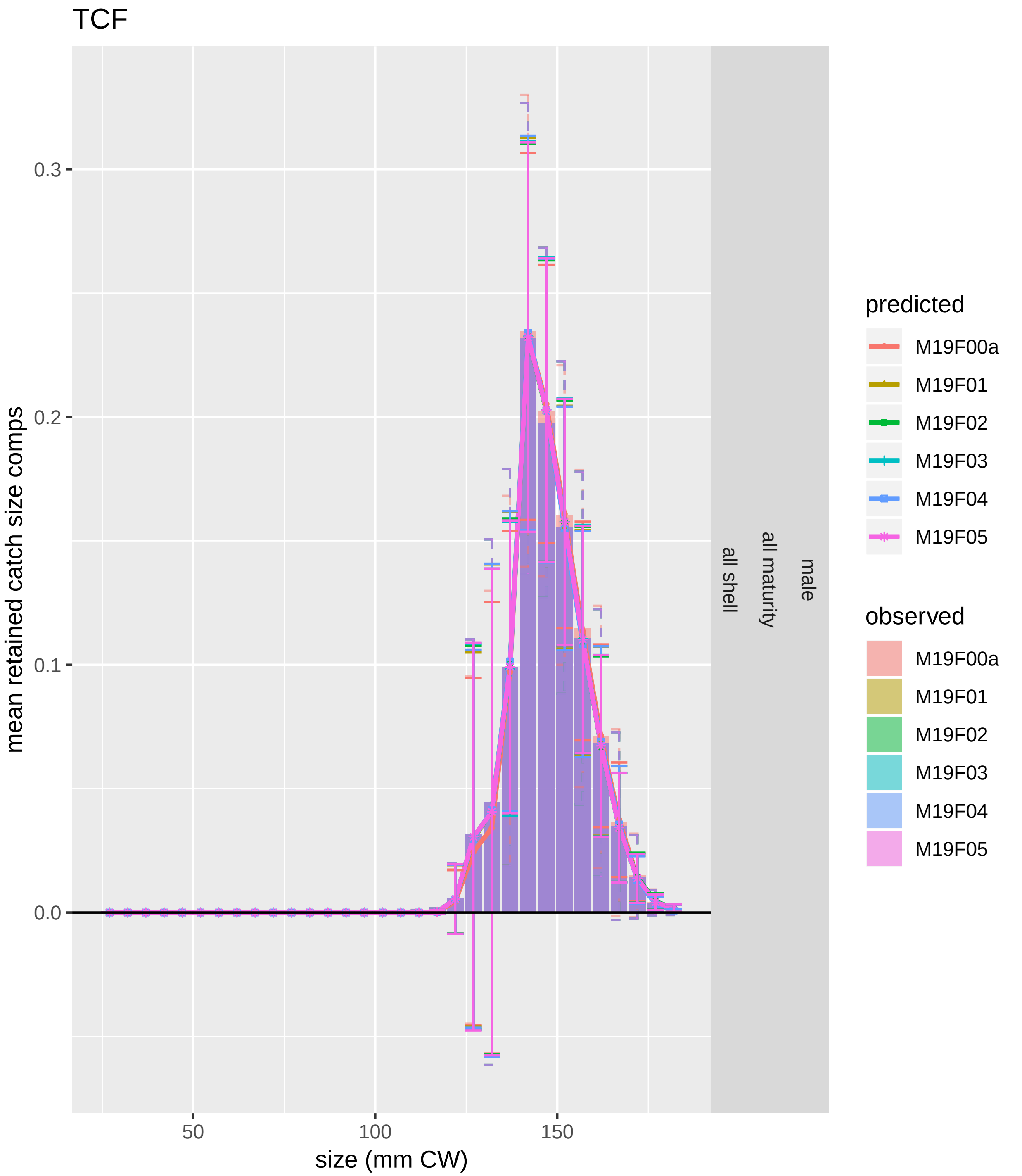


Figure 1: Comparison of observed and predicted mean retained catch size comps for TCF.

Total catch mean size compositions

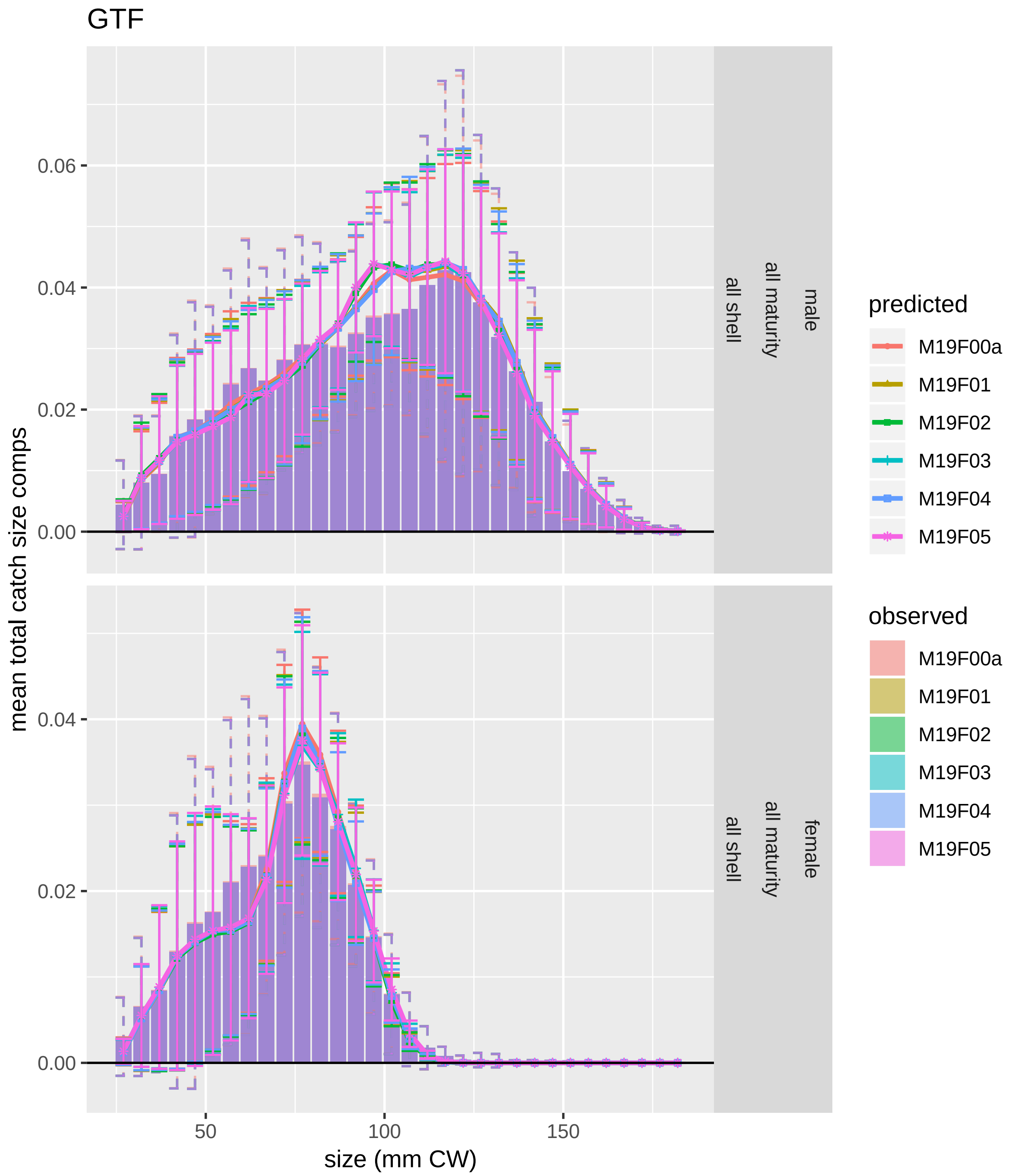


Figure 2: Comparison of observed and predicted mean total catch size comps for GTF.

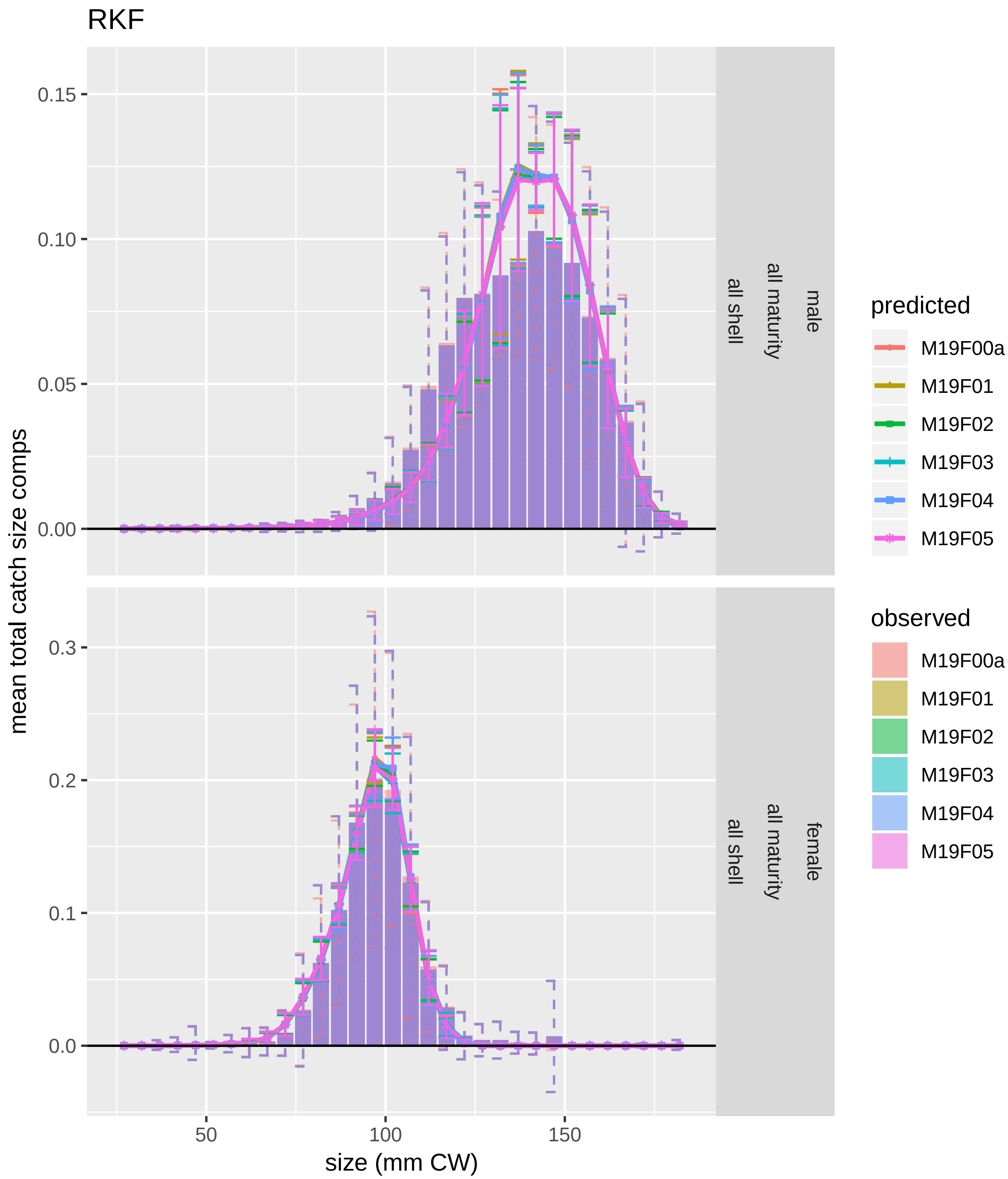


Figure 3: Comparison of observed and predicted mean total catch size comps for RKF.

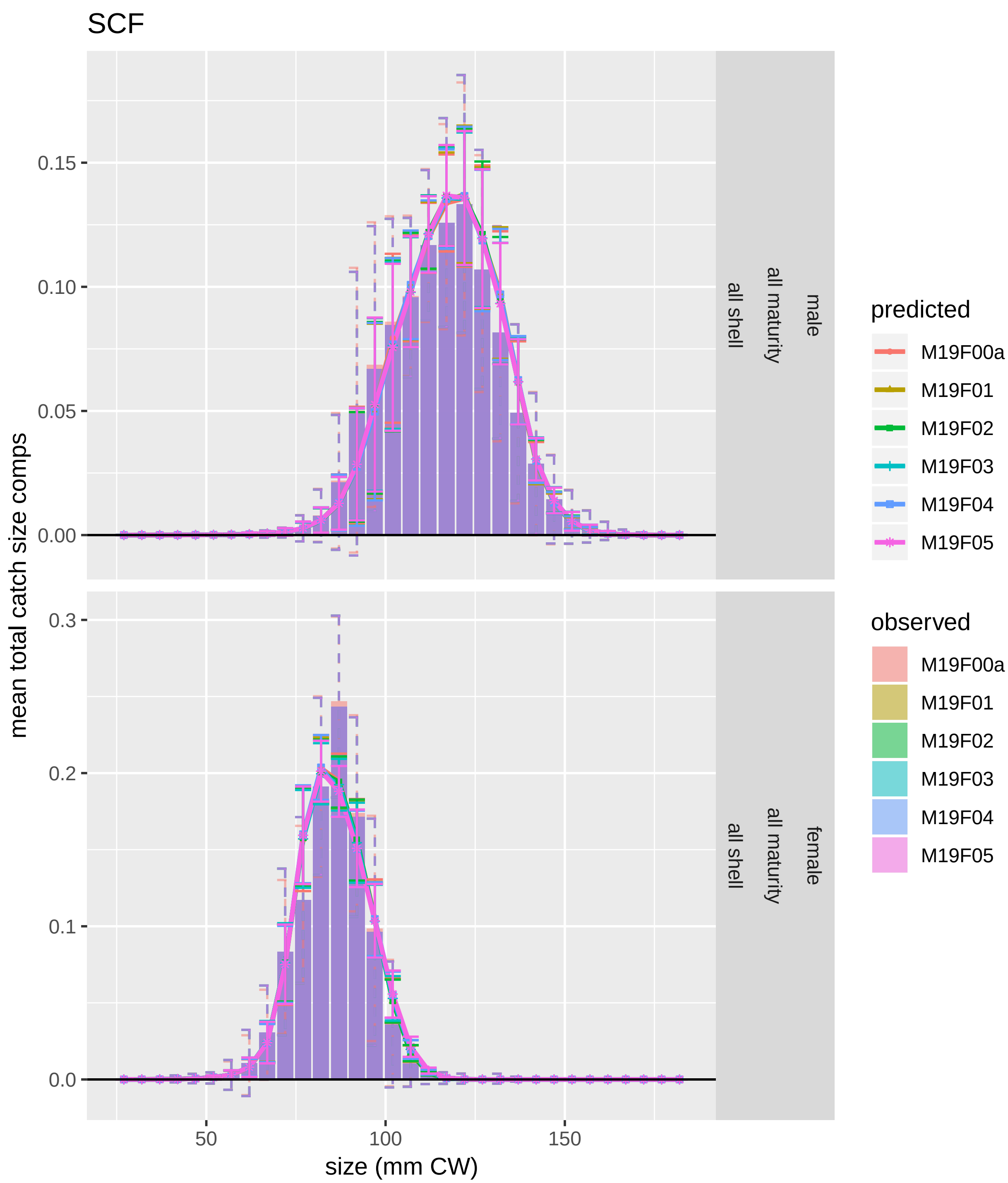


Figure 4: Comparison of observed and predicted mean total catch size comps for SCF.

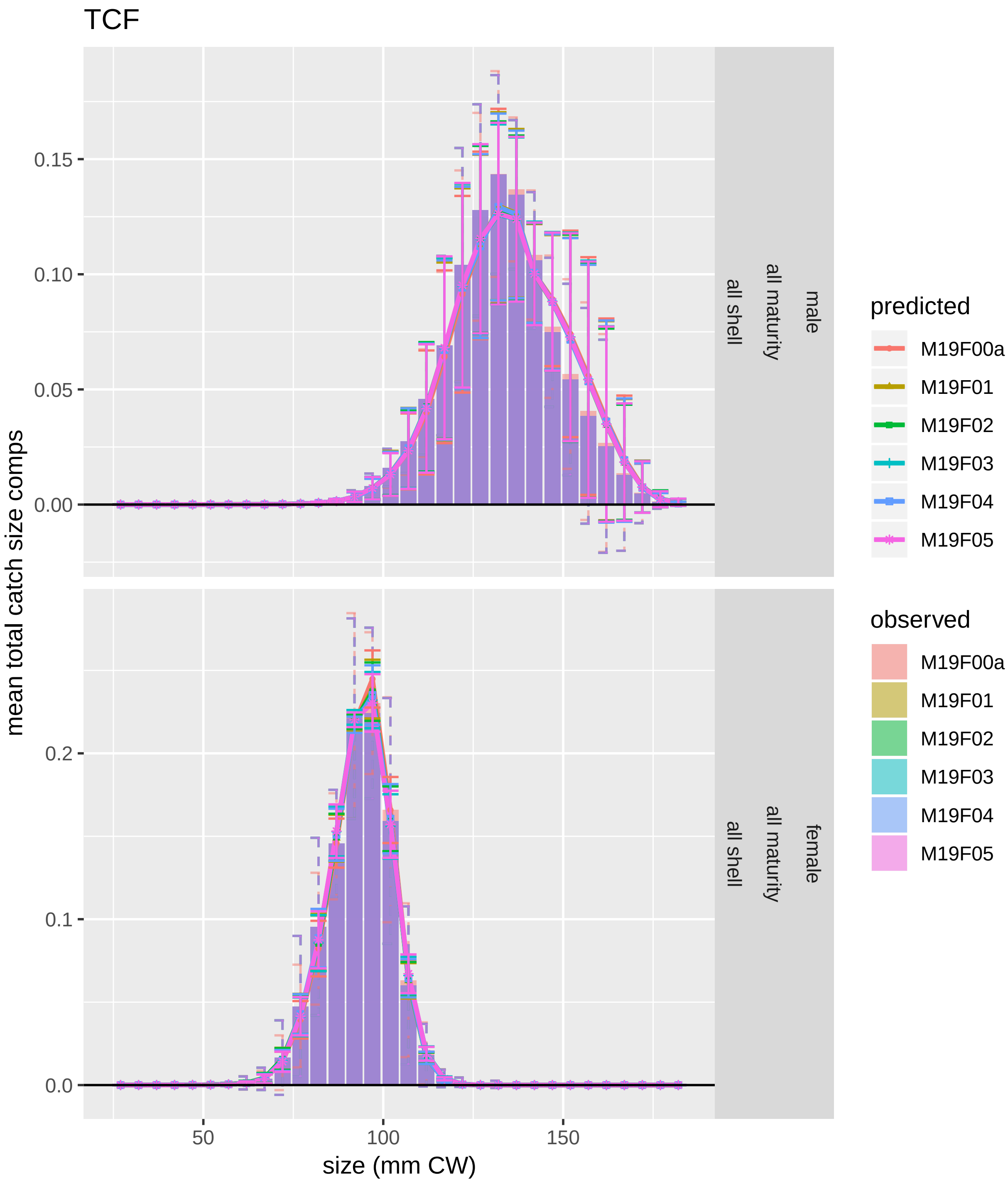


Figure 5: Comparison of observed and predicted mean total catch size comps for TCF.

Fishery retained catch size composition residuals

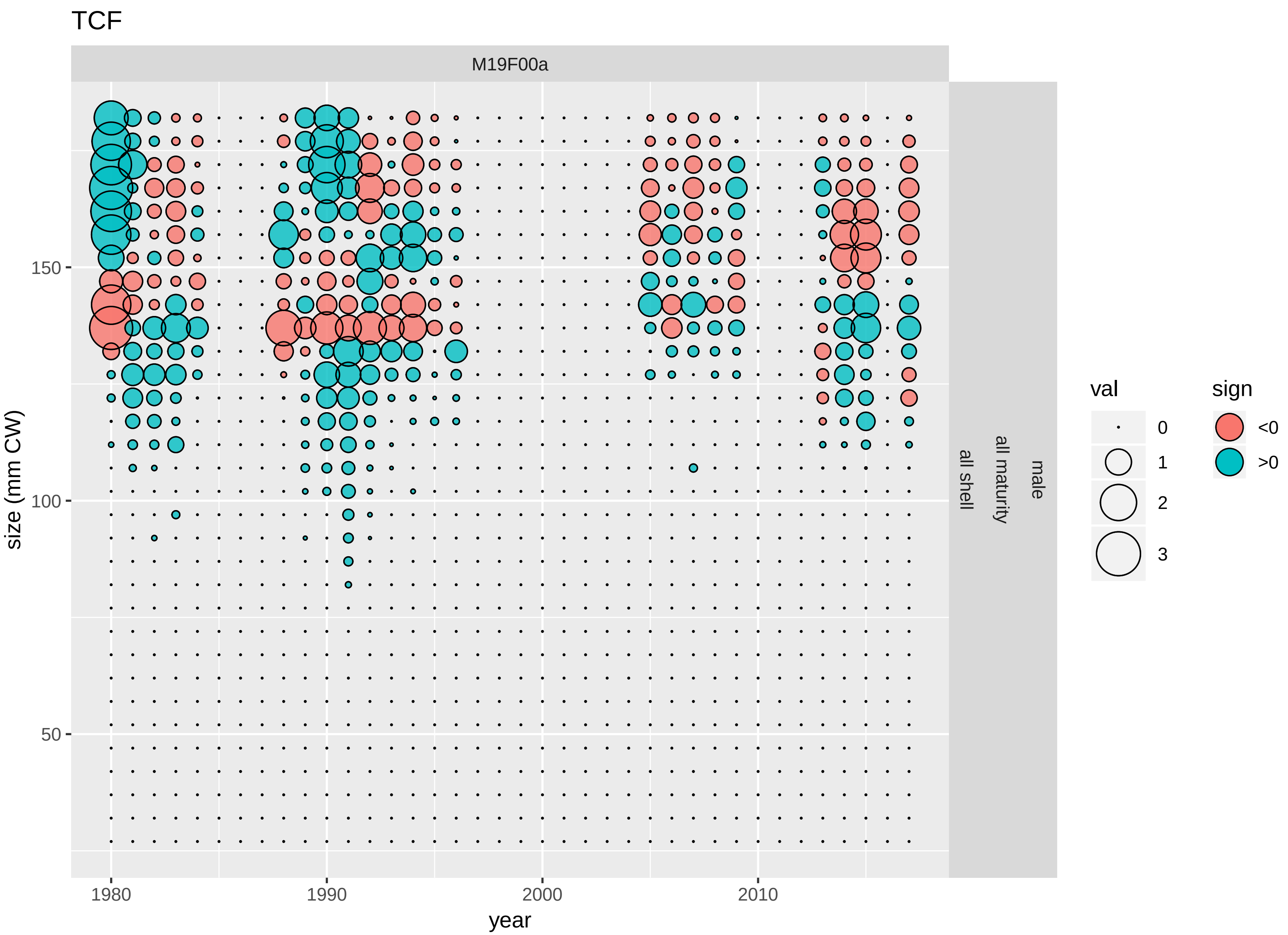


Figure 6: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F00a.

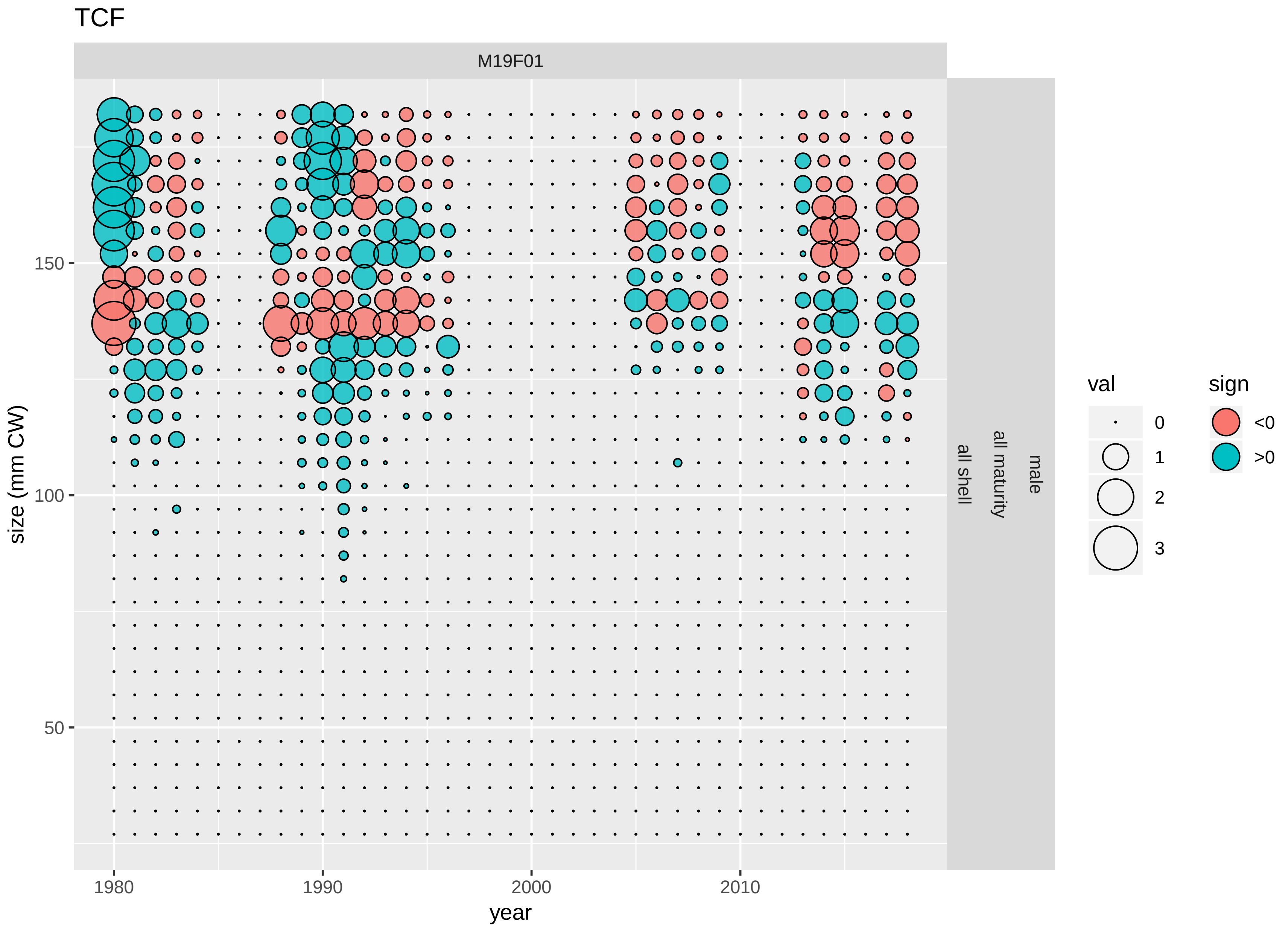


Figure 7: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F01.

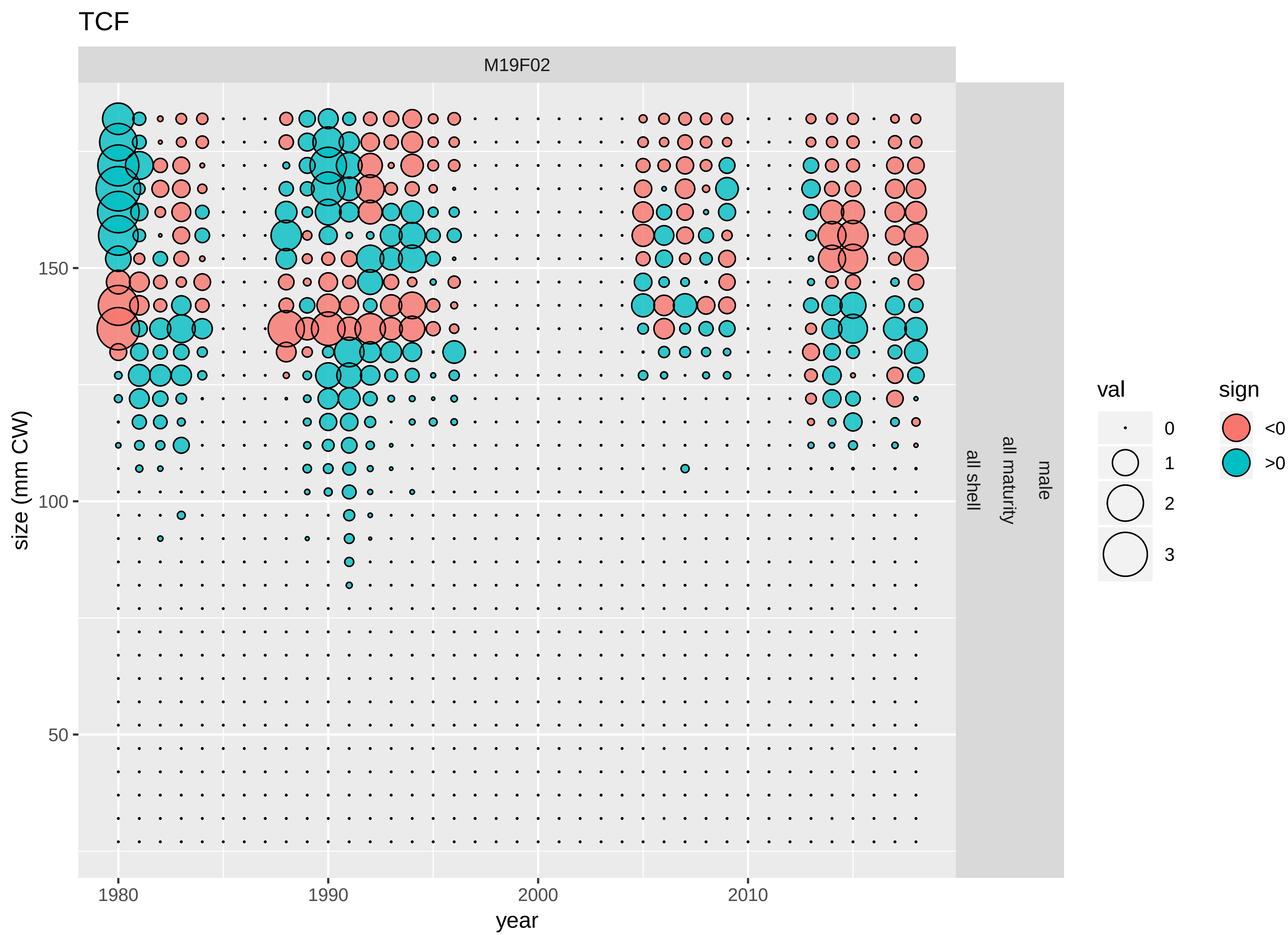


Figure 8: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F02.

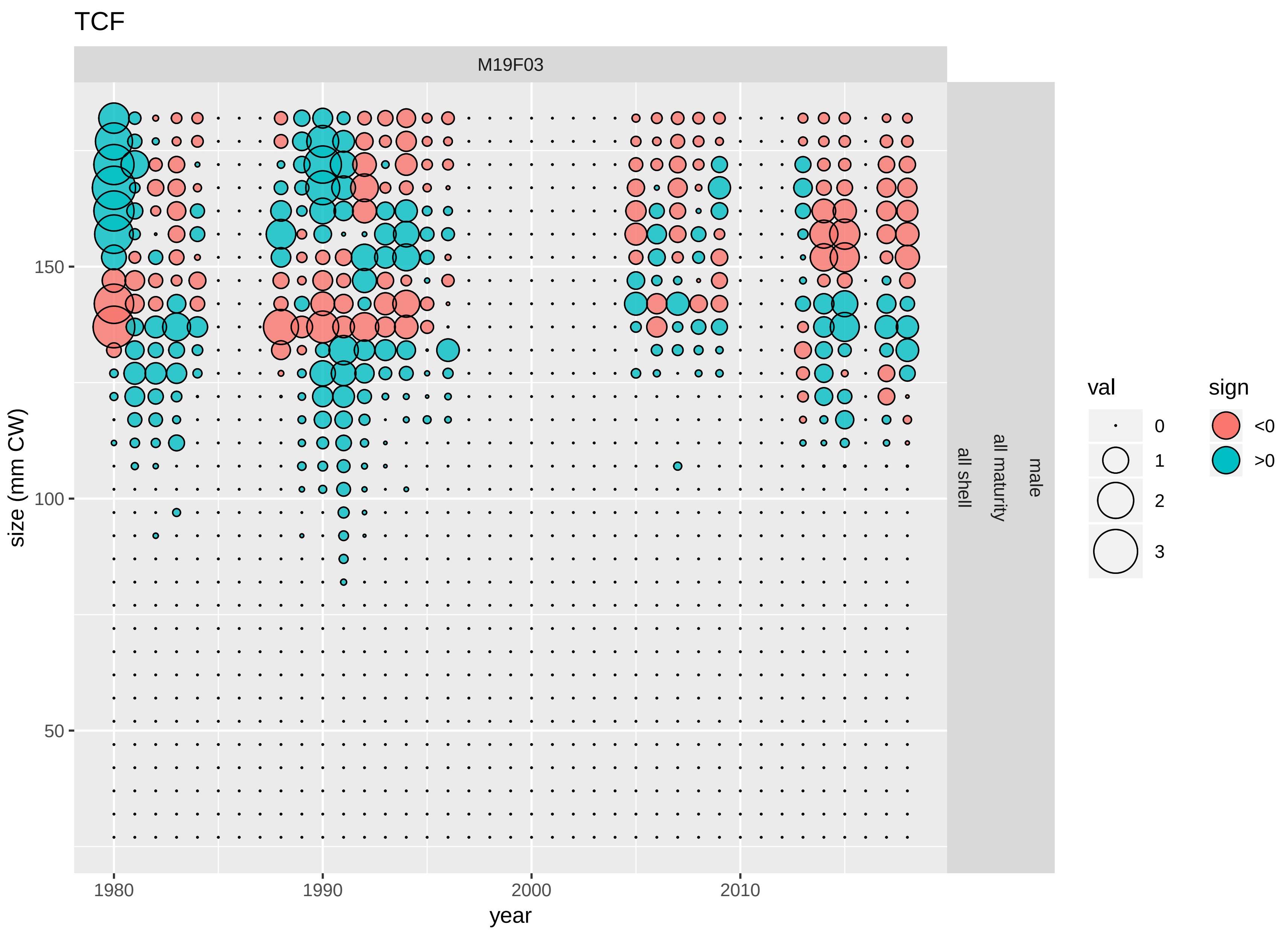


Figure 9: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F03.

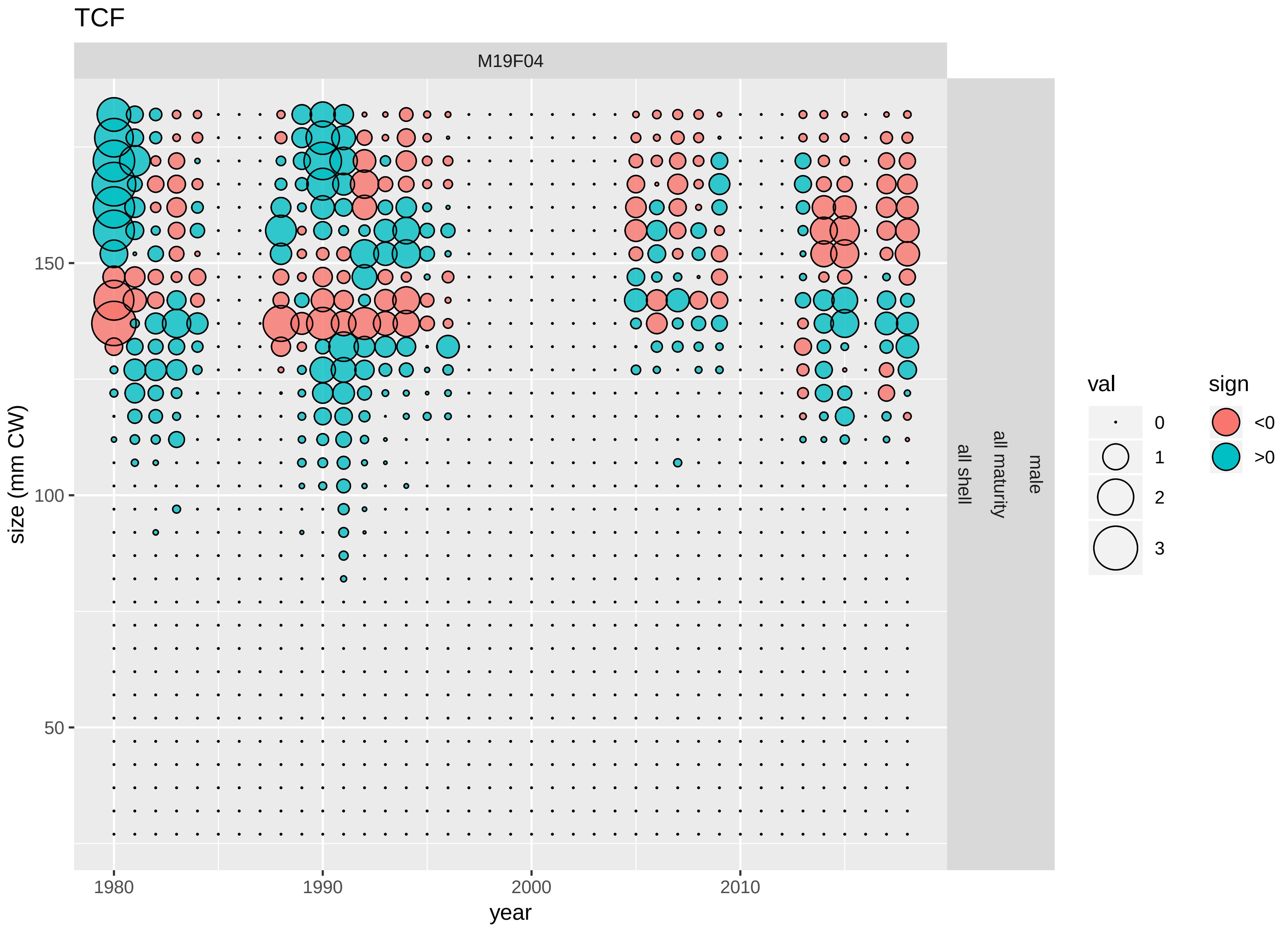


Figure 10: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F04.

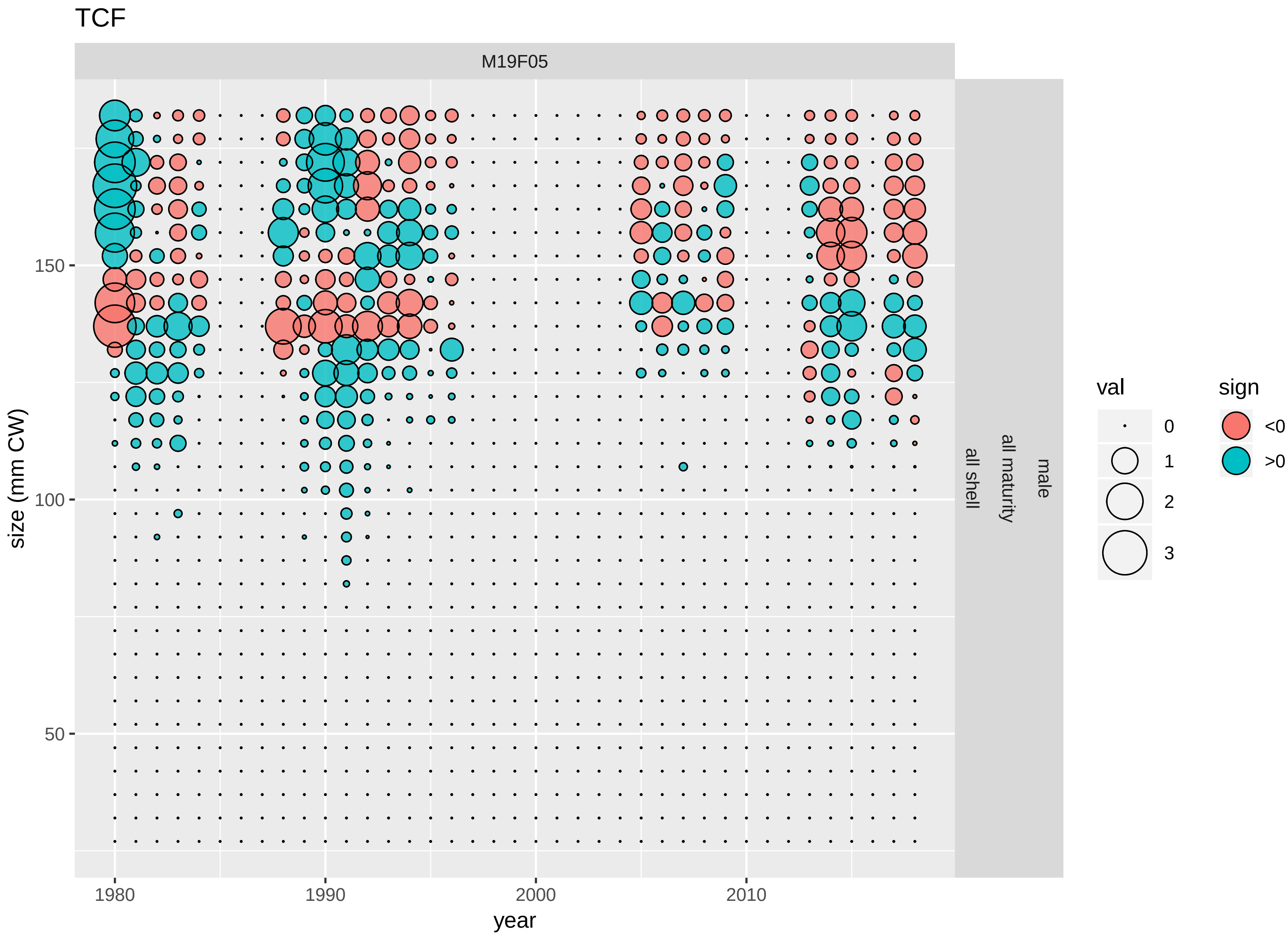


Figure 11: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F05.

Effective Ns for retained catch size compositions

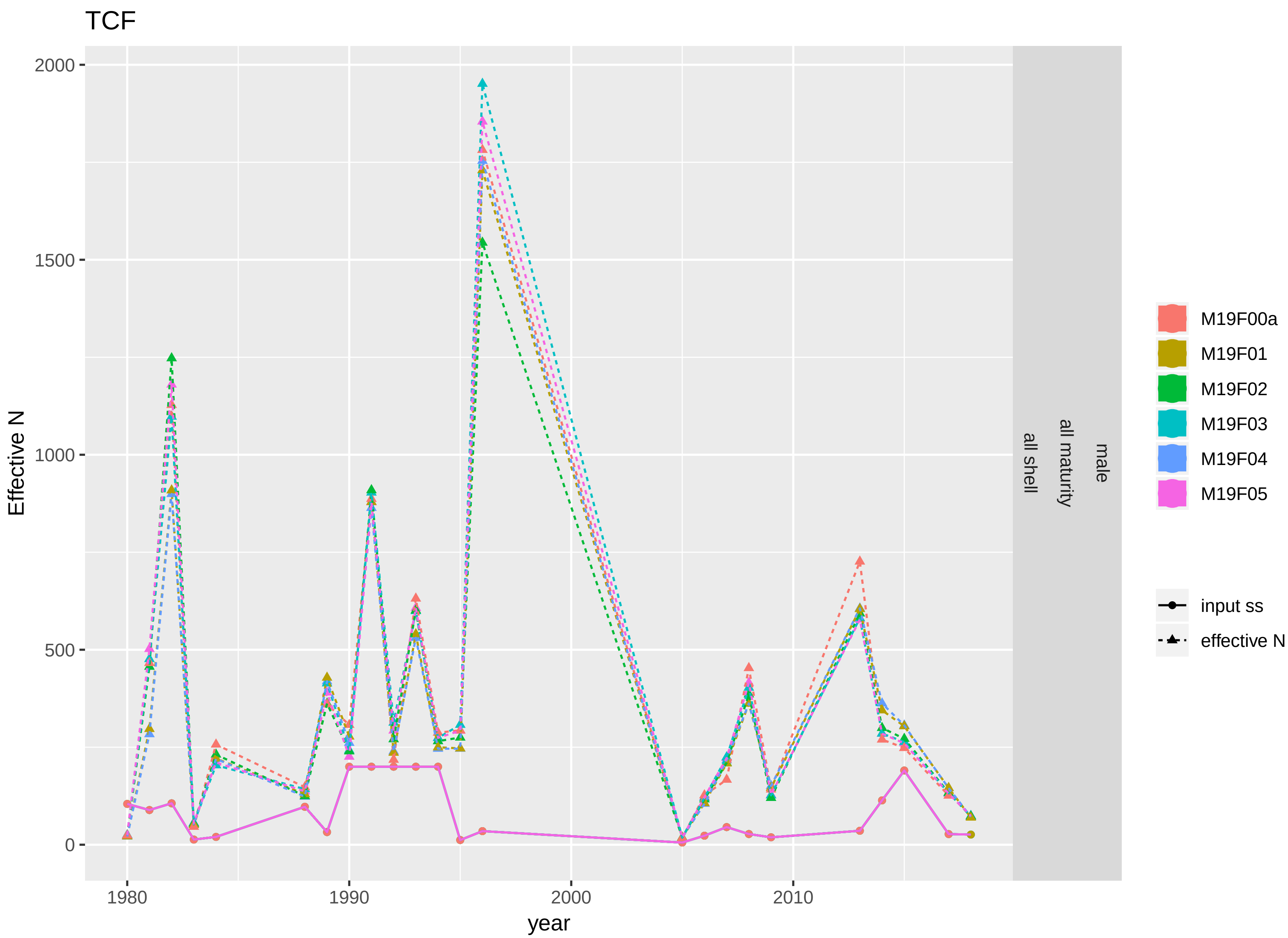


Figure 12: Input and effective sample sizes from retained catch size compositions from the TCF fishery.

Total catch size composition residuals

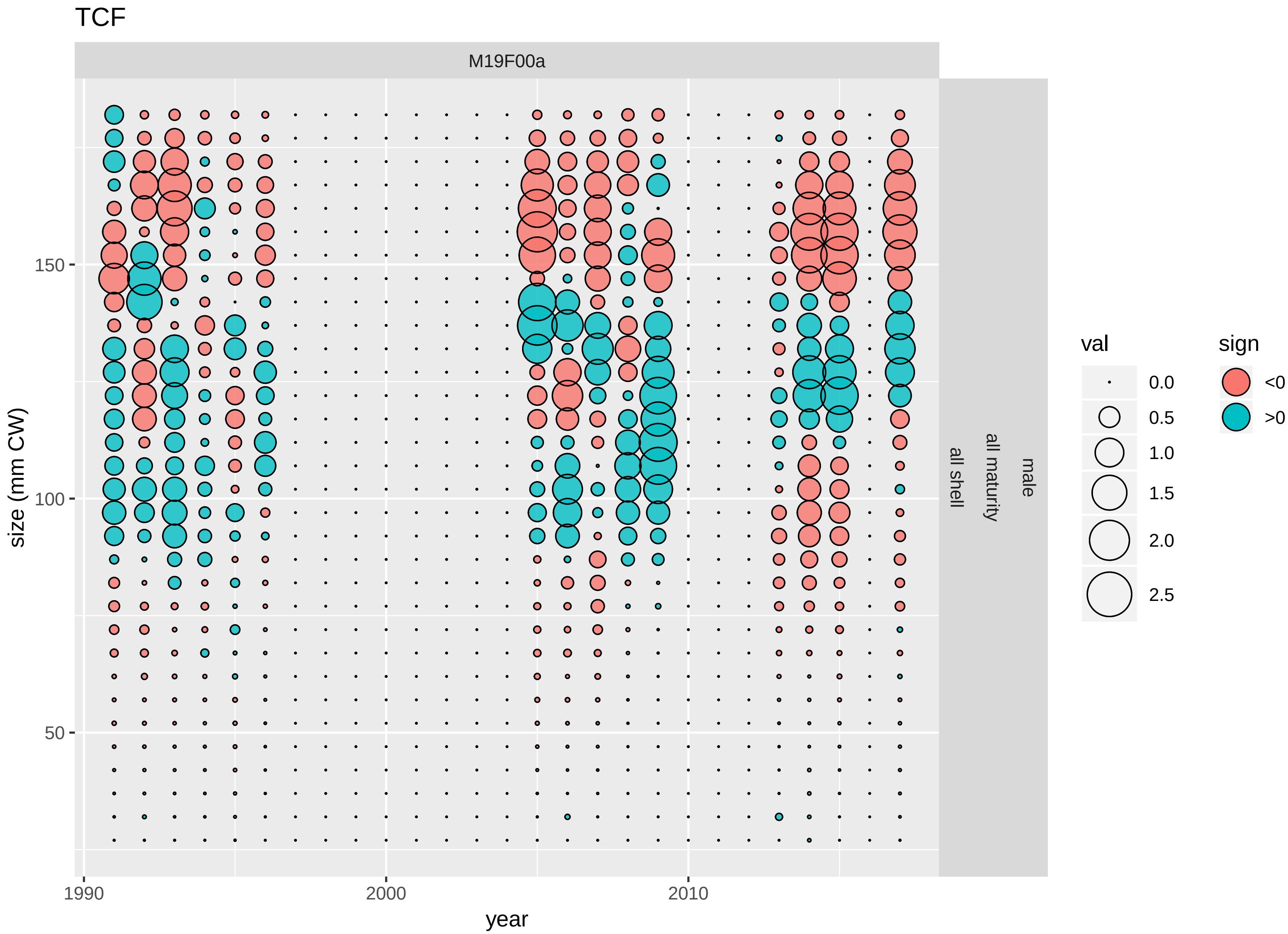


Figure 13: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F00a.

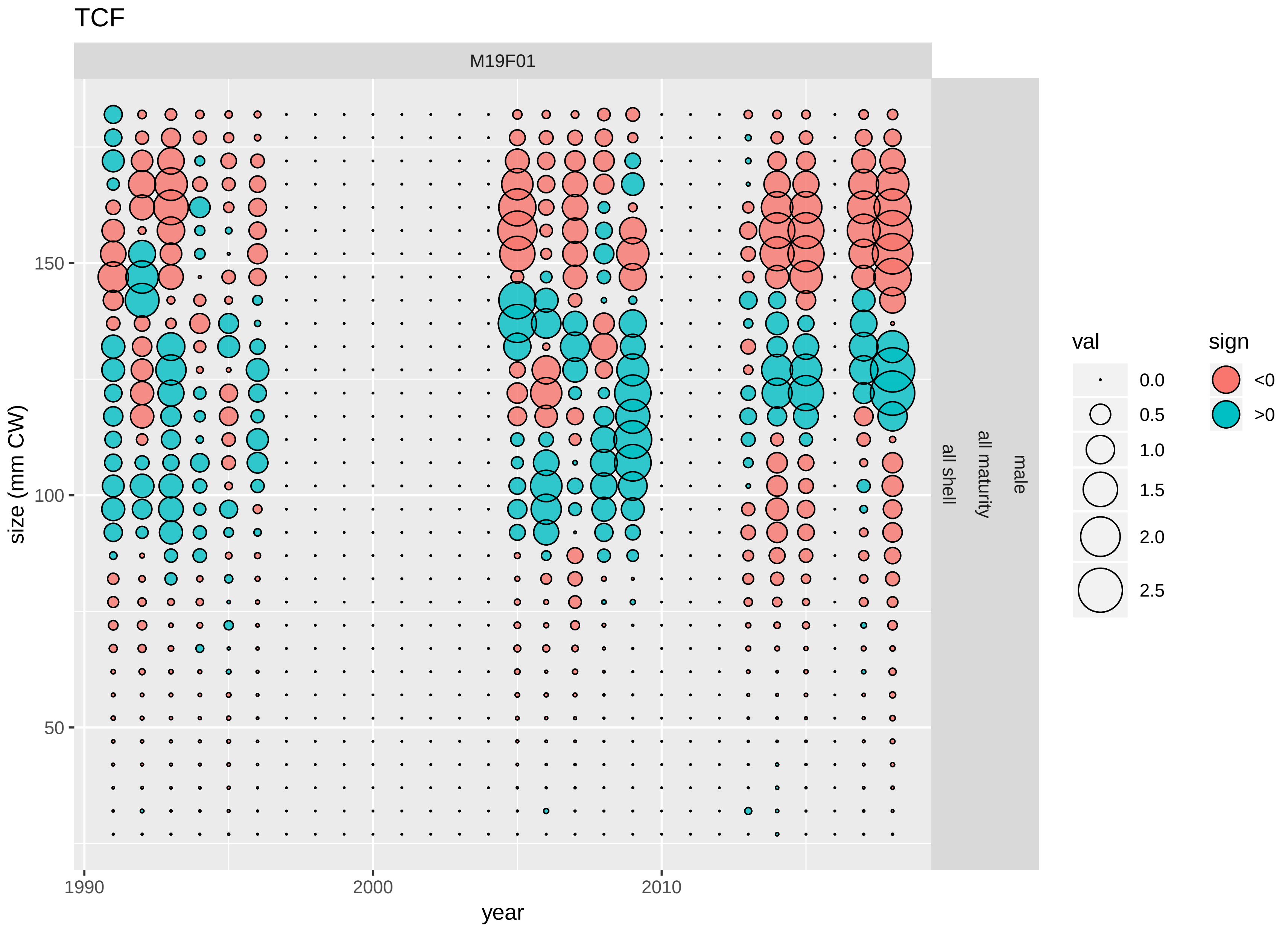


Figure 14: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F01.

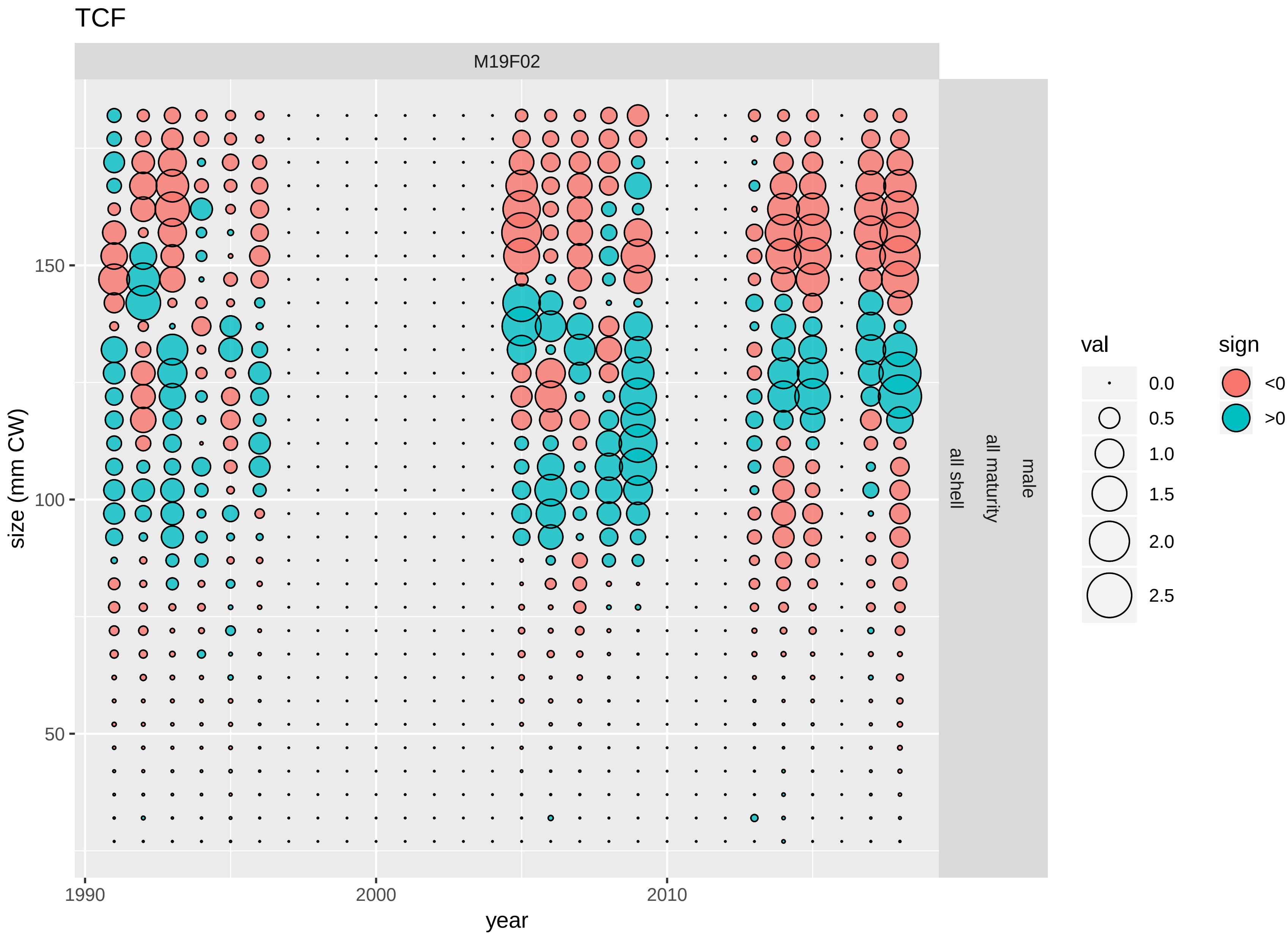


Figure 15: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F02.

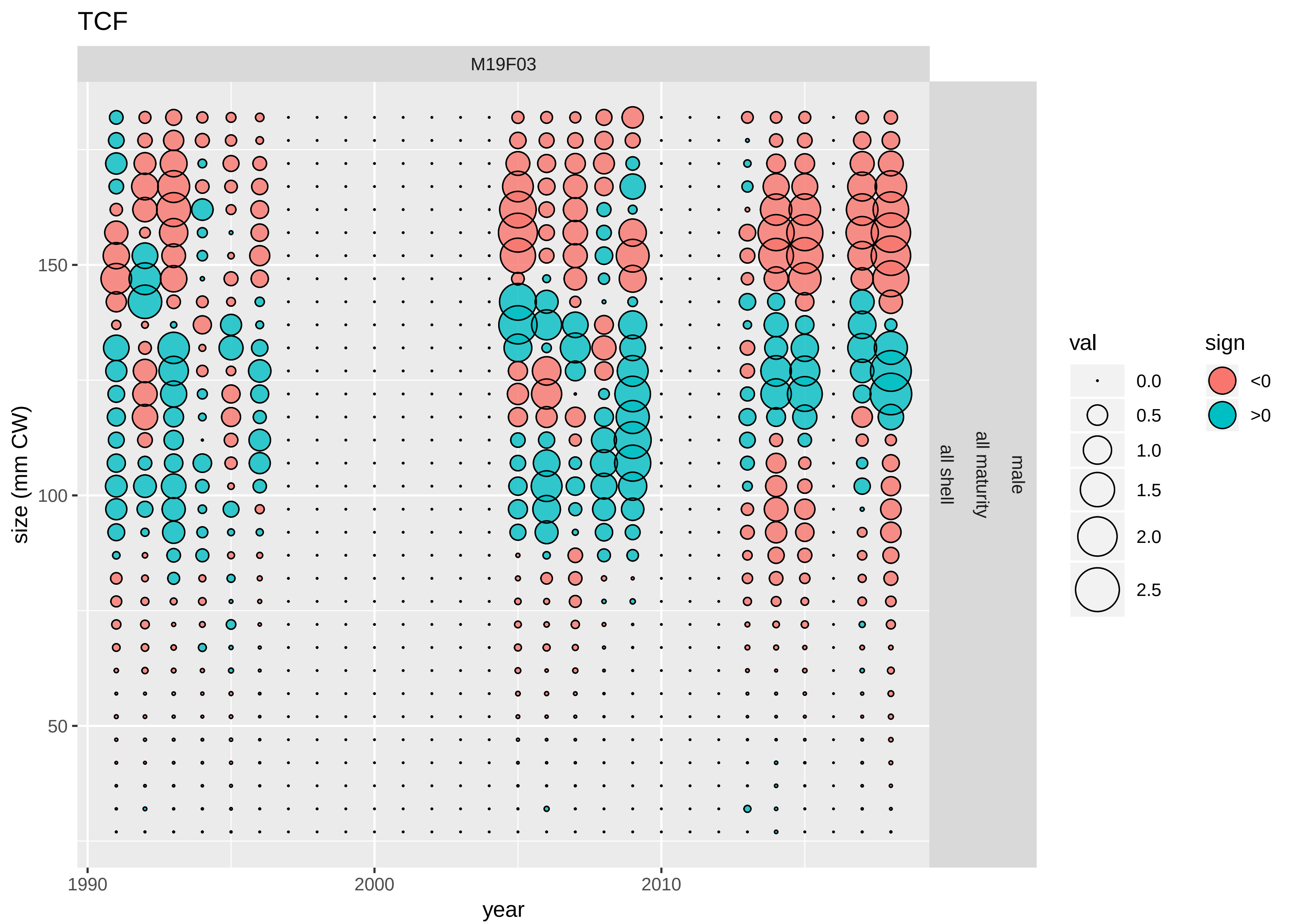


Figure 16: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F03.

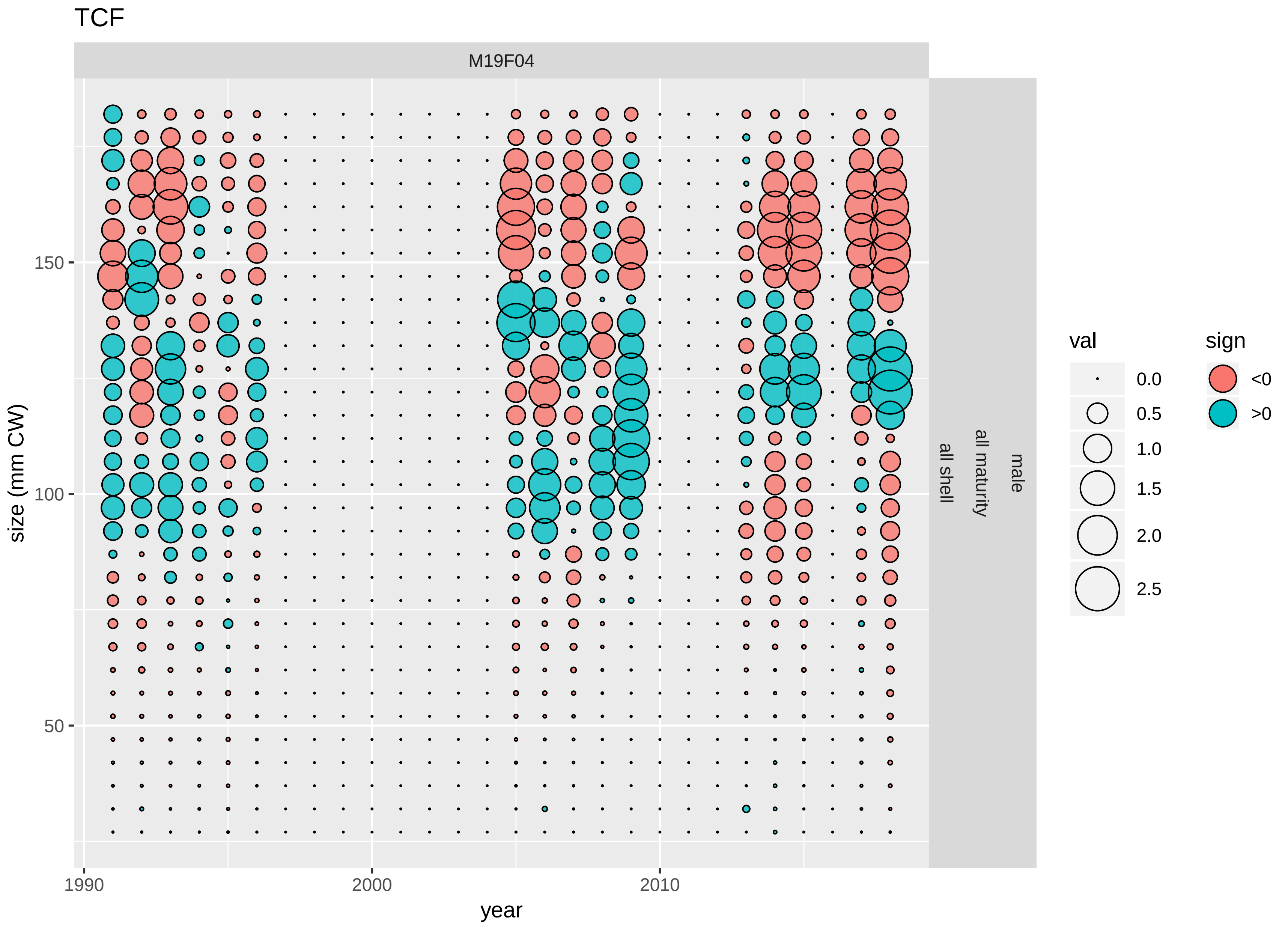


Figure 17: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F04.

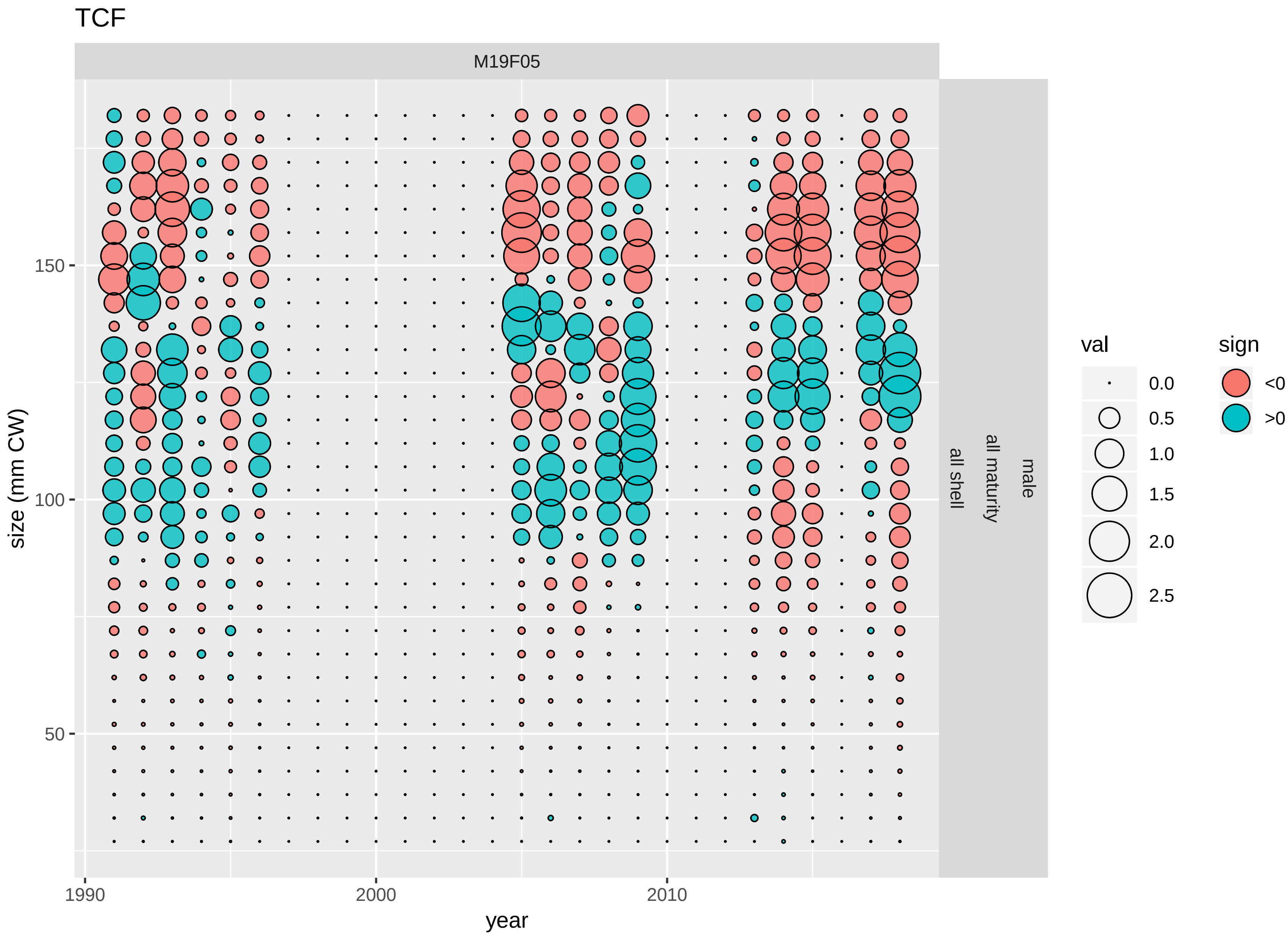


Figure 18: Pearson's residuals for male proportions-at-size from the TCF for scenario M19F05.

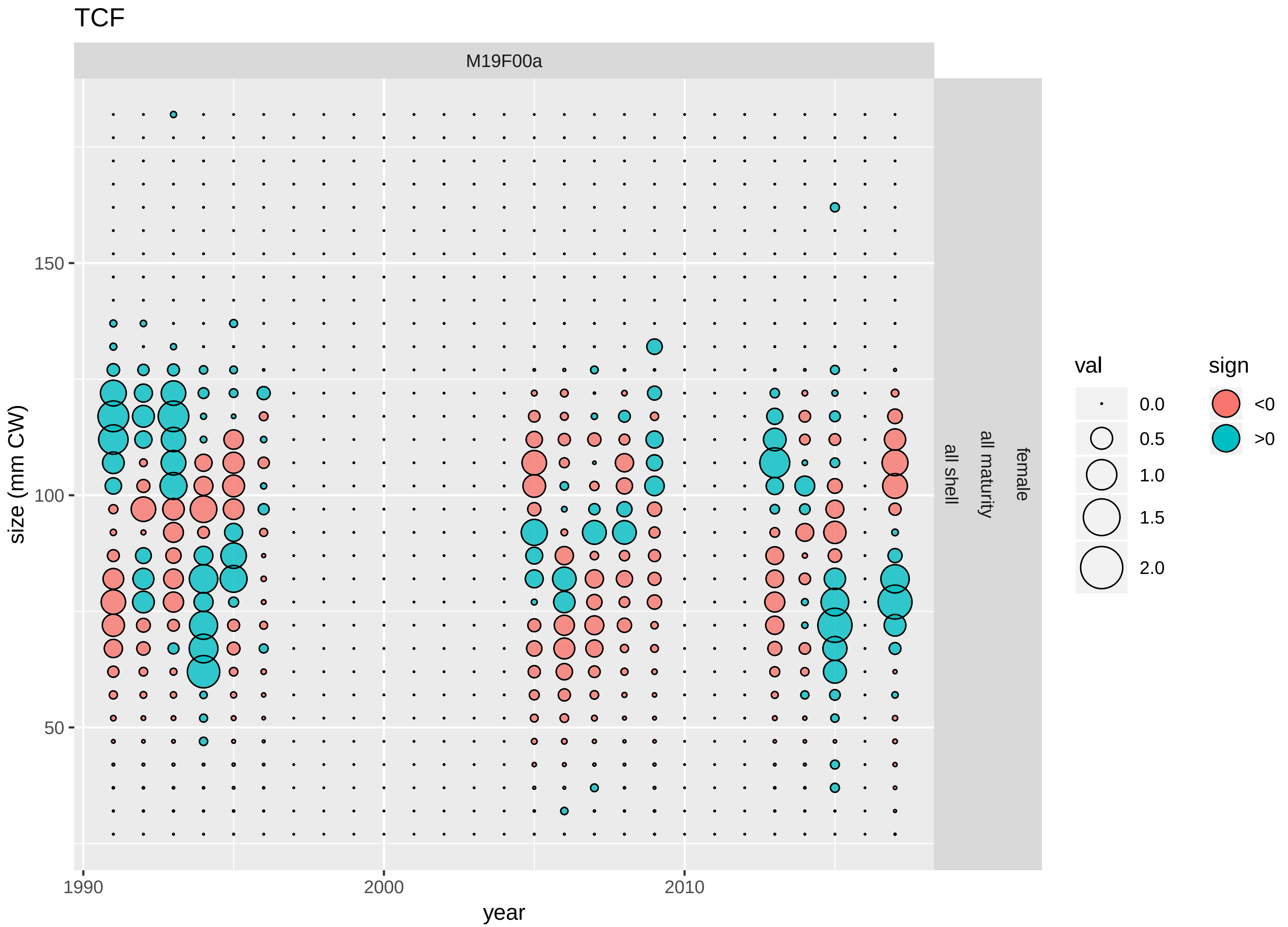


Figure 19: Pearson's residuals for female proportions-at-size from the TCF for scenario M19F00a.

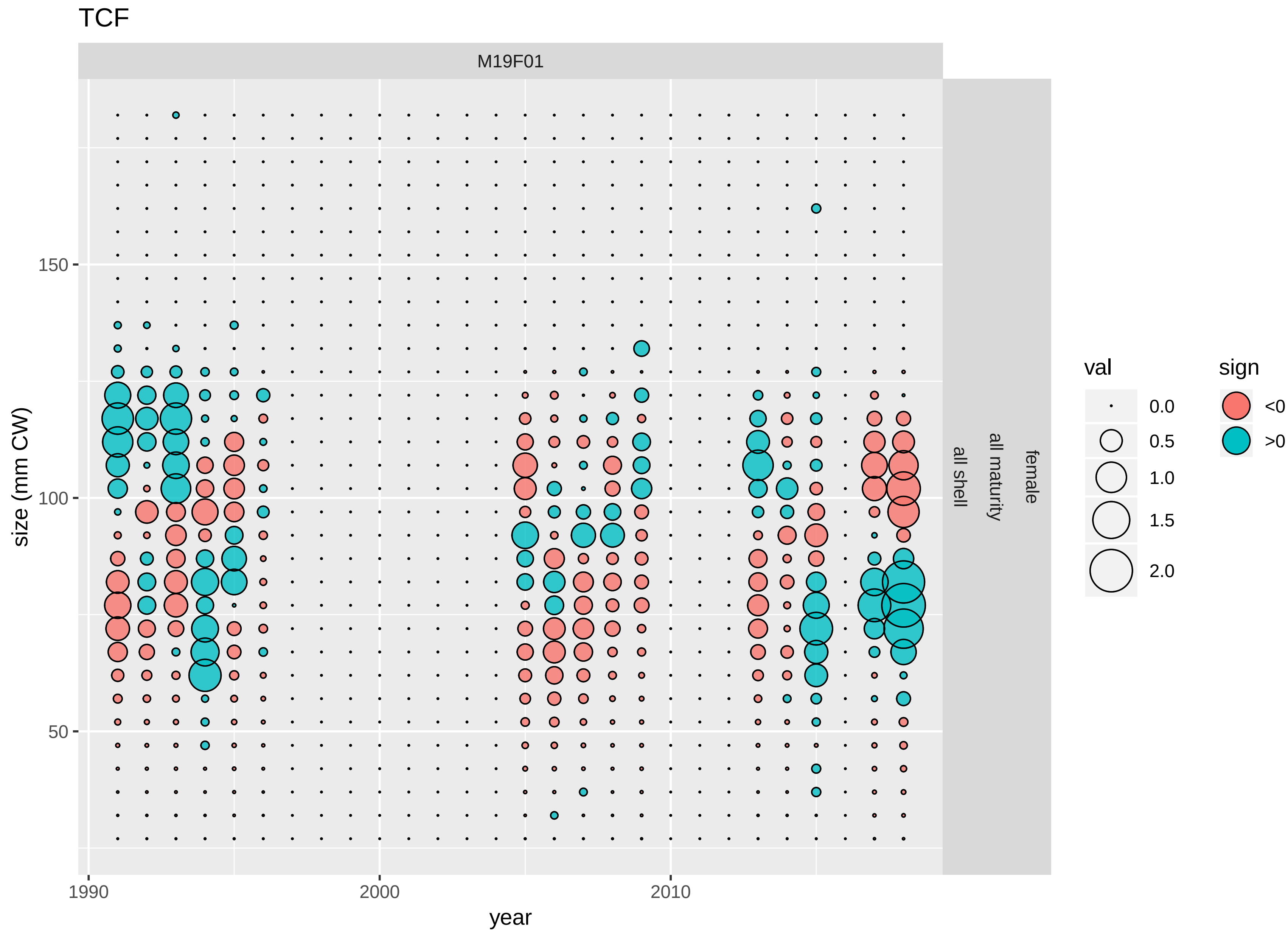


Figure 20: Pearson's residuals for female proportions-at-size from the TCF for scenario M19F01.

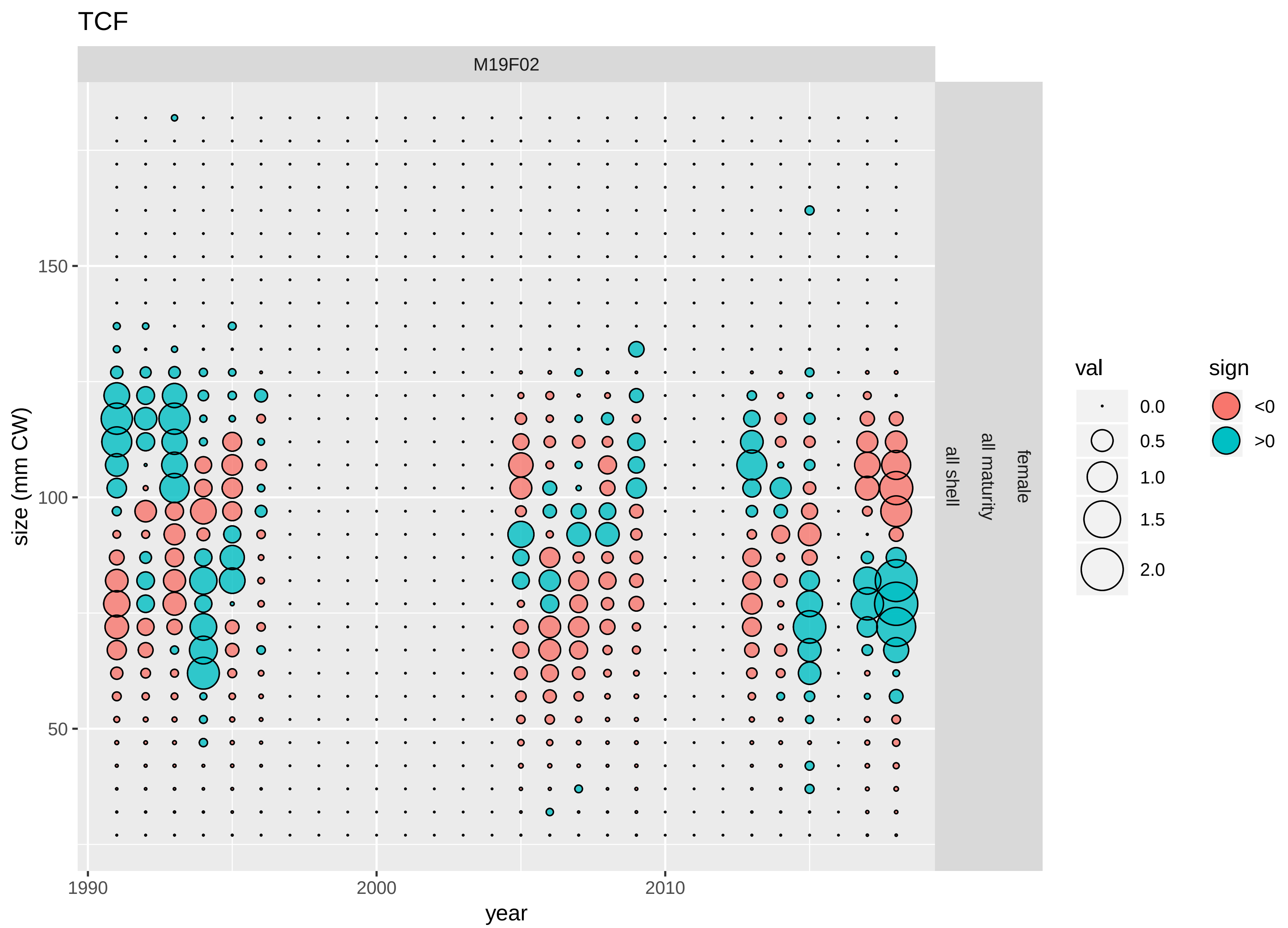


Figure 21: Pearson's residuals for female proportions-at-size from the TCF for scenario M19F02.

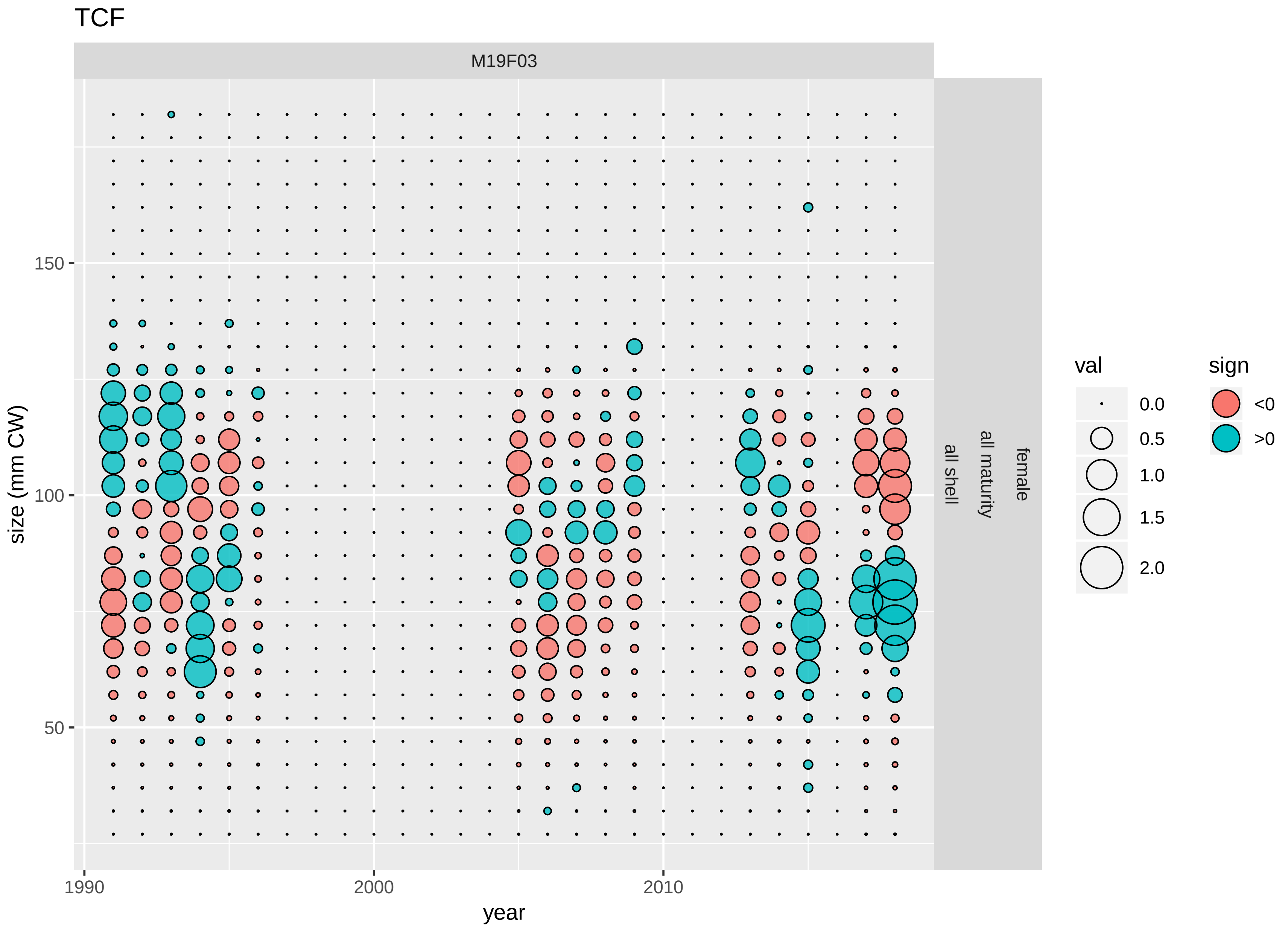


Figure 22: Pearson's residuals for female proportions-at-size from the TCF for scenario M19F03.

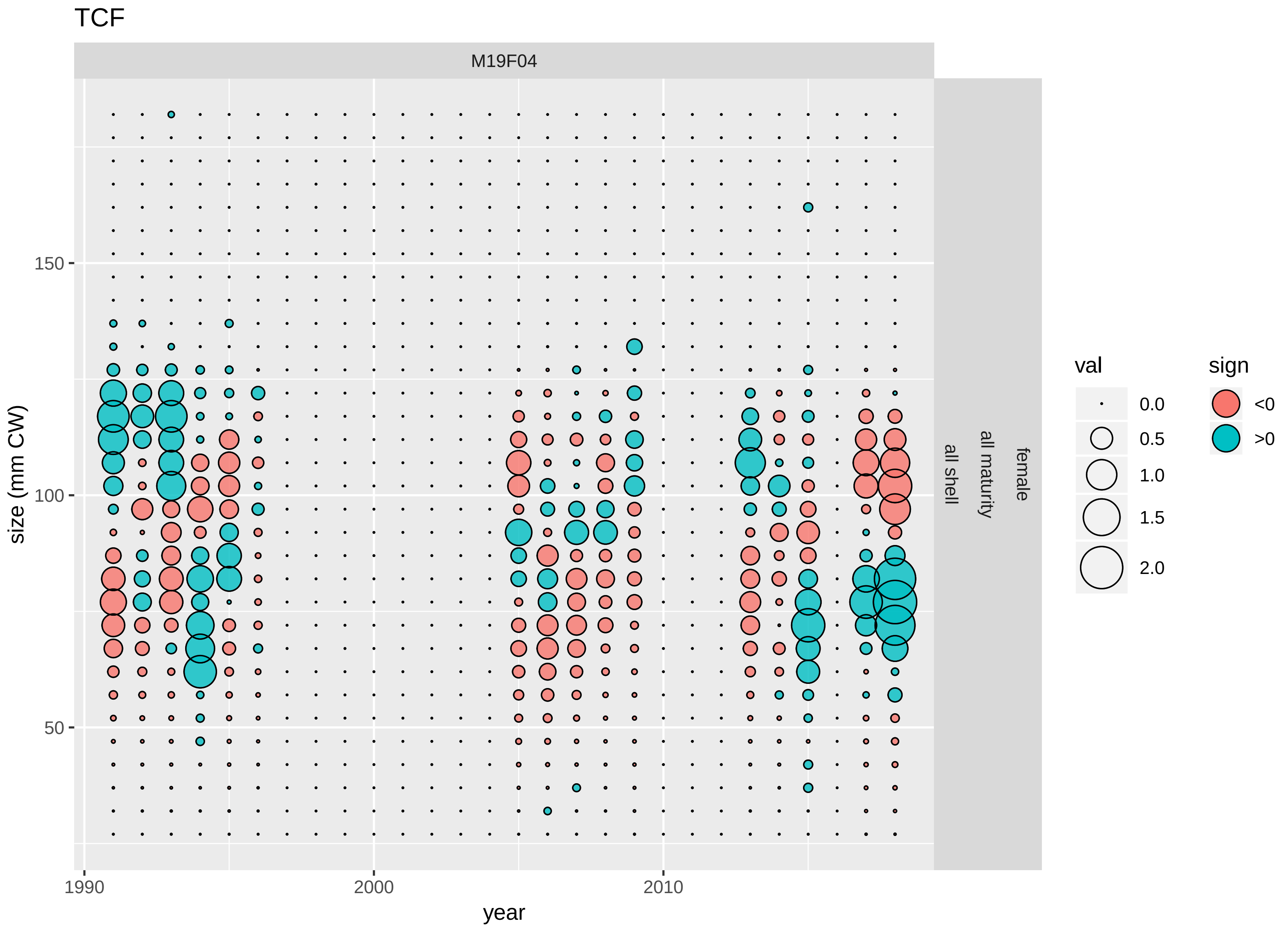


Figure 23: Pearson's residuals for female proportions-at-size from the TCF for scenario M19F04.

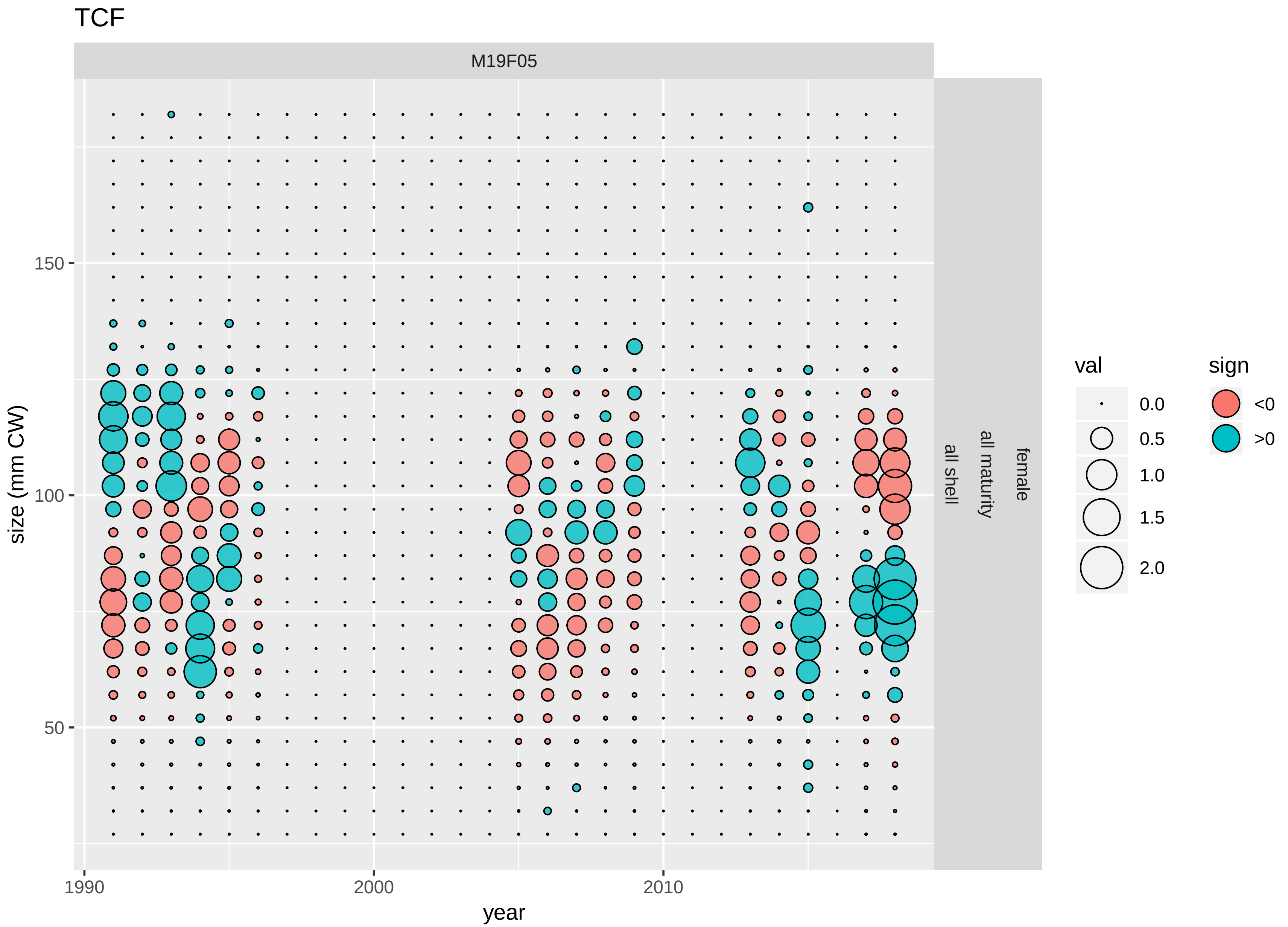


Figure 24: Pearson's residuals for female proportions-at-size from the TCF for scenario M19F05.

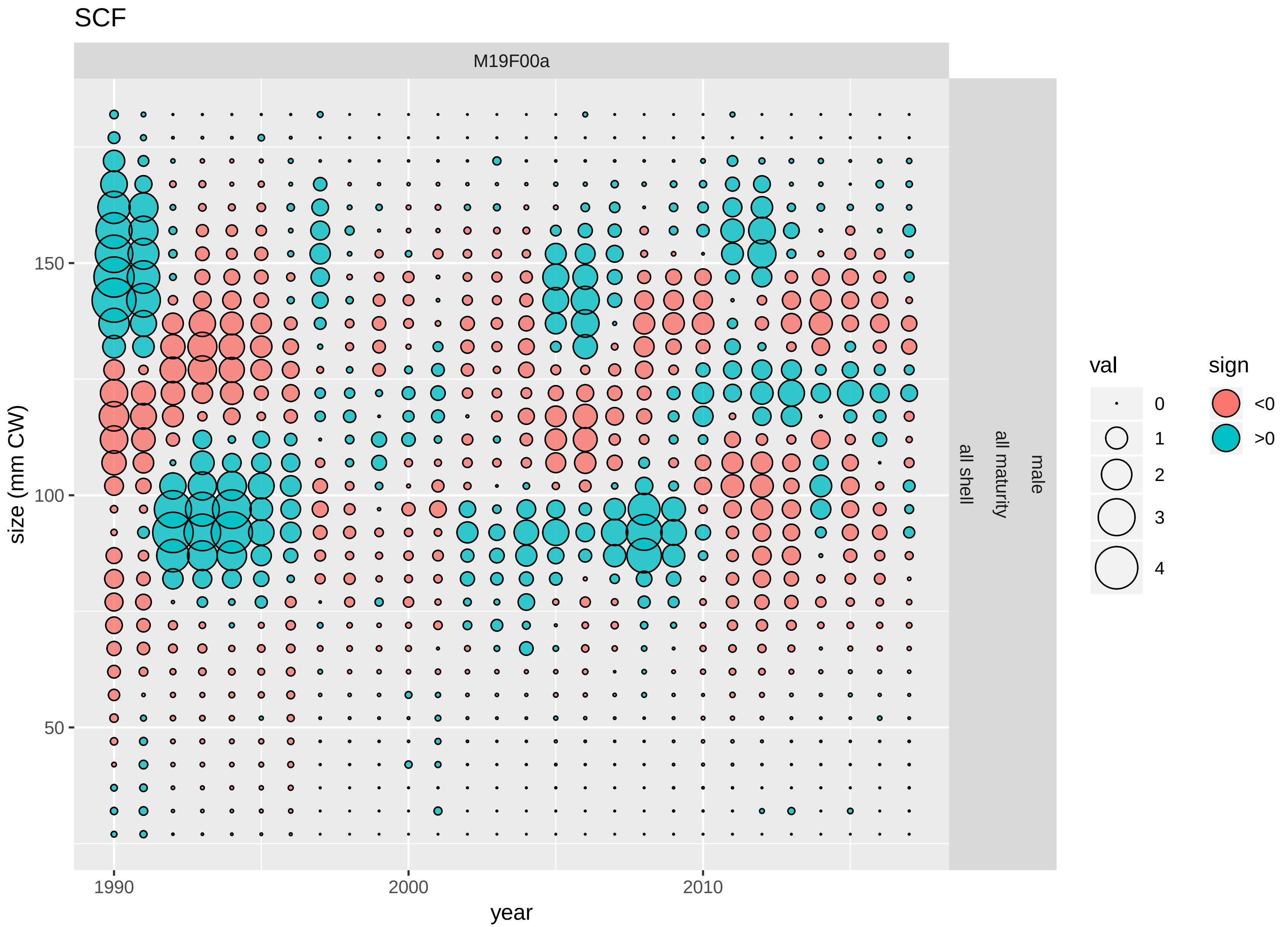


Figure 25: Pearson's residuals for male proportions-at-size from the SCF for scenario M19F00a.

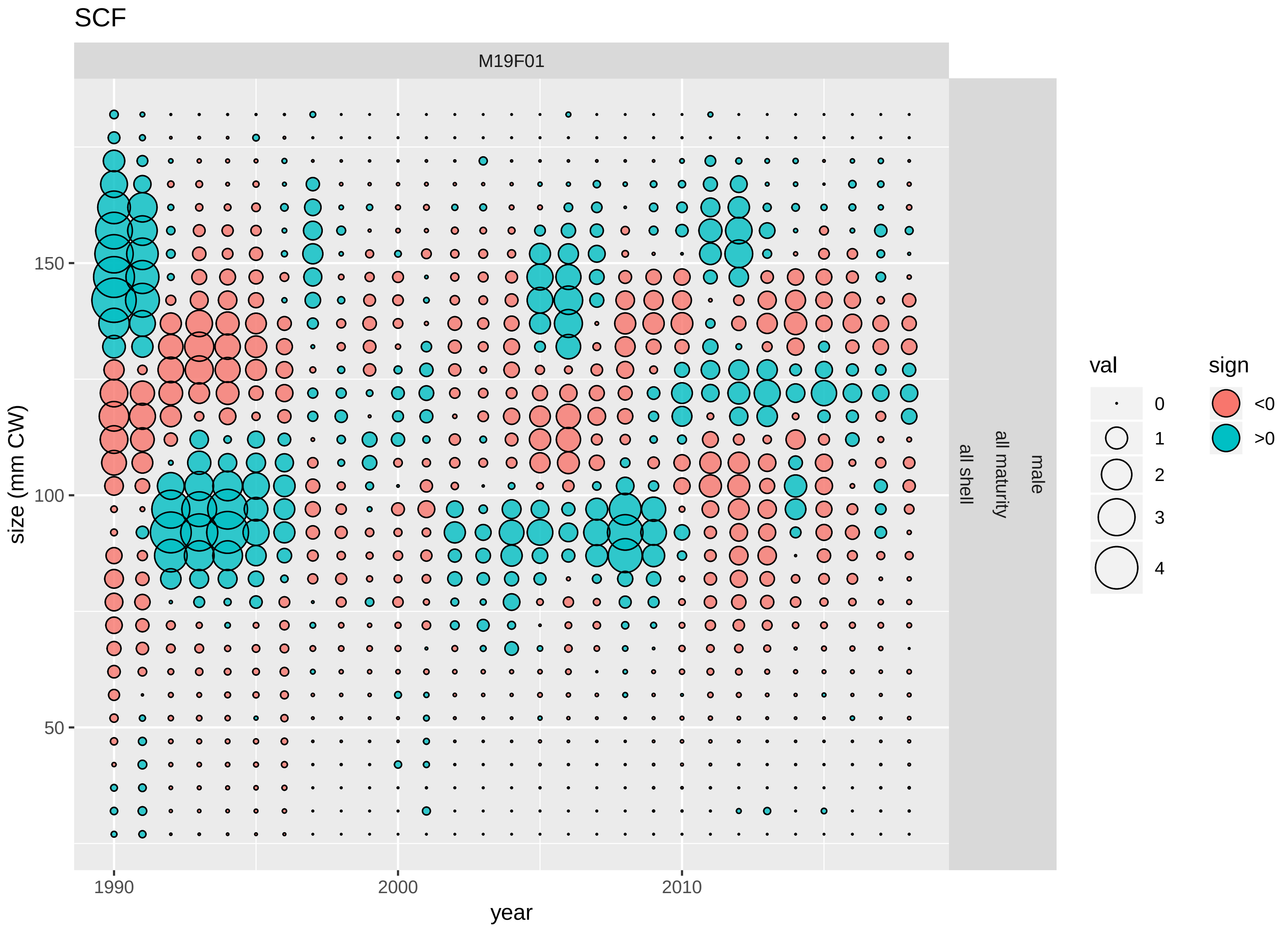


Figure 26: Pearson's residuals for male proportions-at-size from the SCF for scenario M19F01.

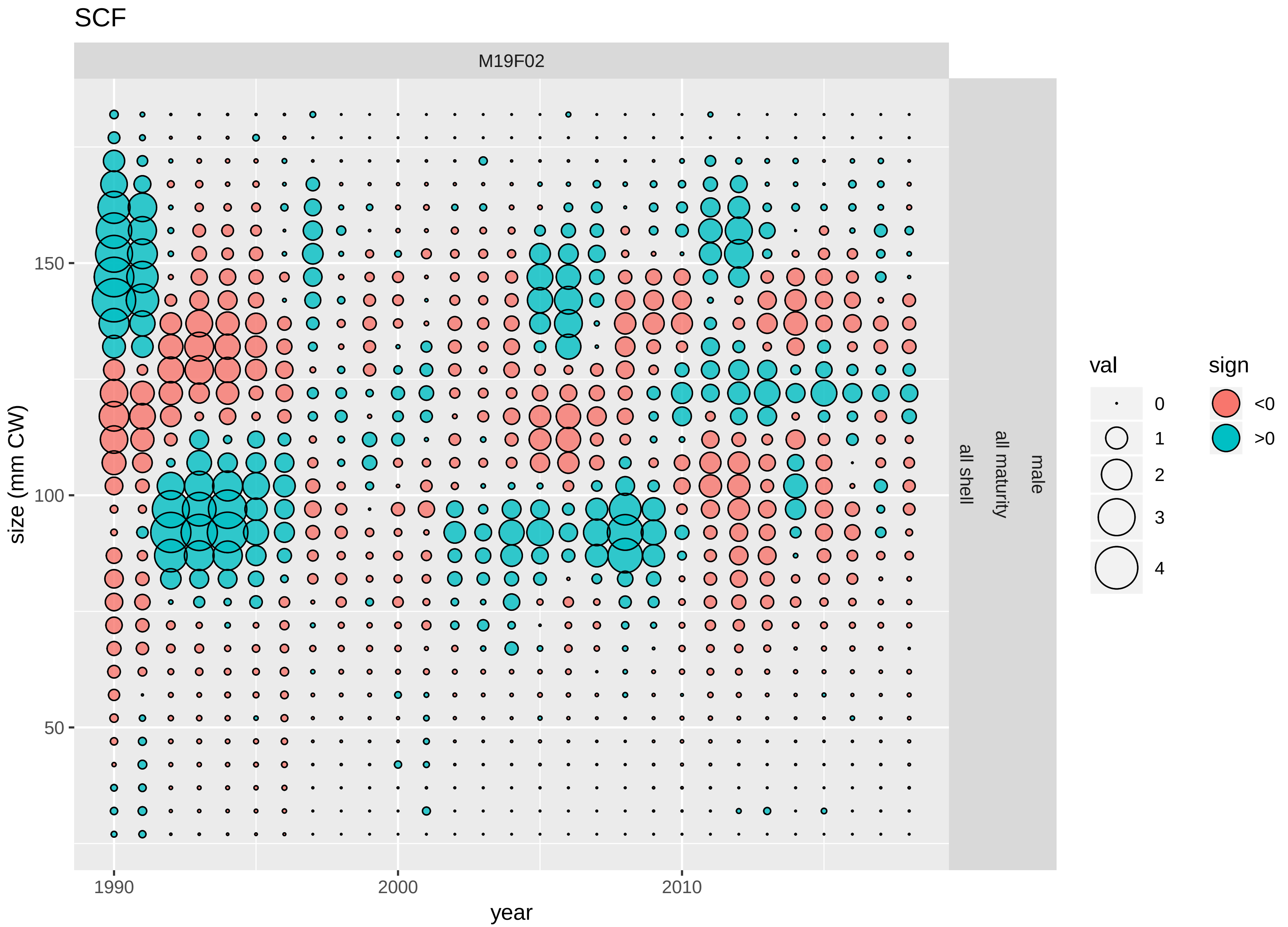


Figure 27: Pearson's residuals for male proportions-at-size from the SCF for scenario M19F02.

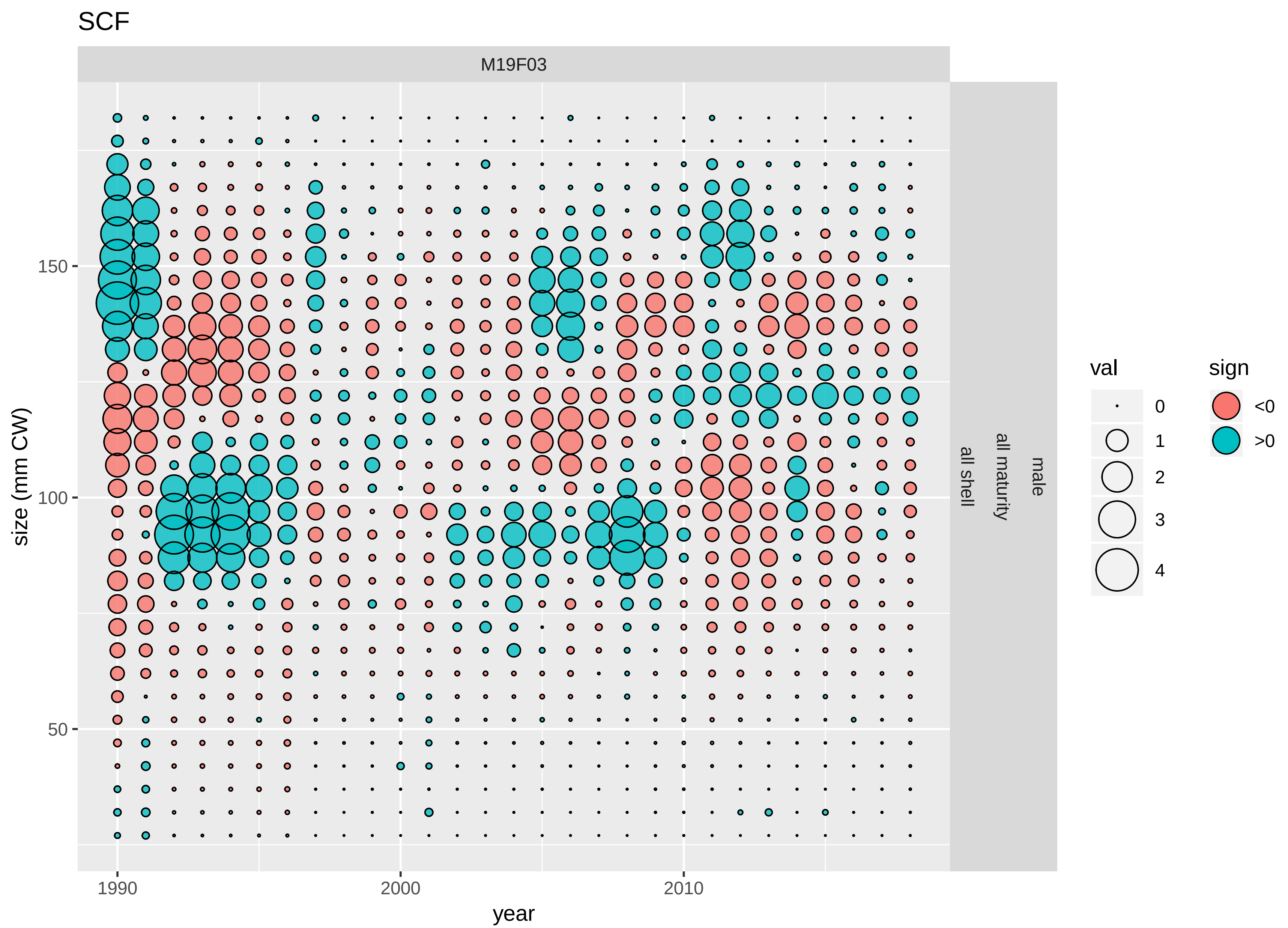


Figure 28: Pearson's residuals for male proportions-at-size from the SCF for scenario M19F03.

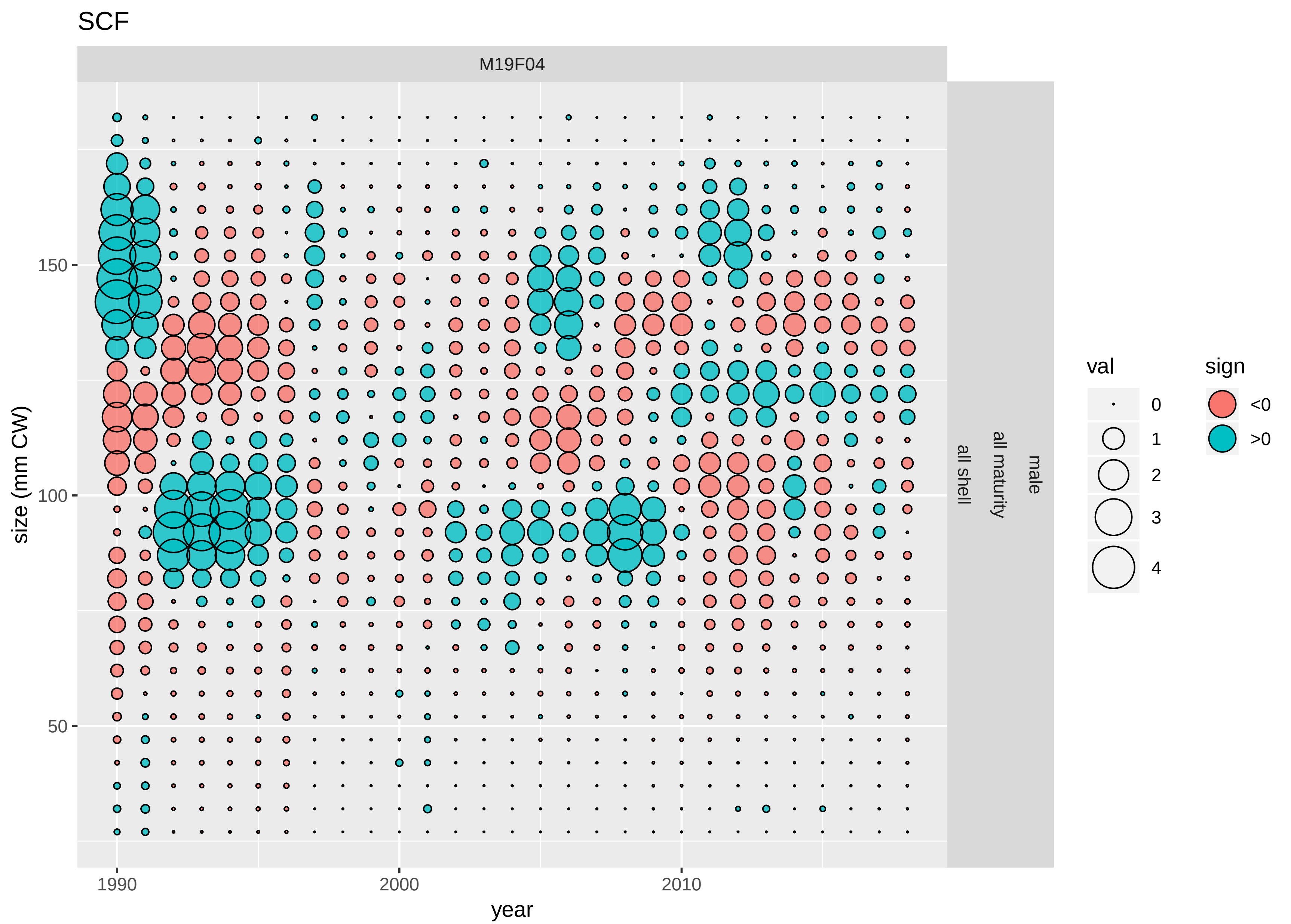


Figure 29: Pearson's residuals for male proportions-at-size from the SCF for scenario M19F04.

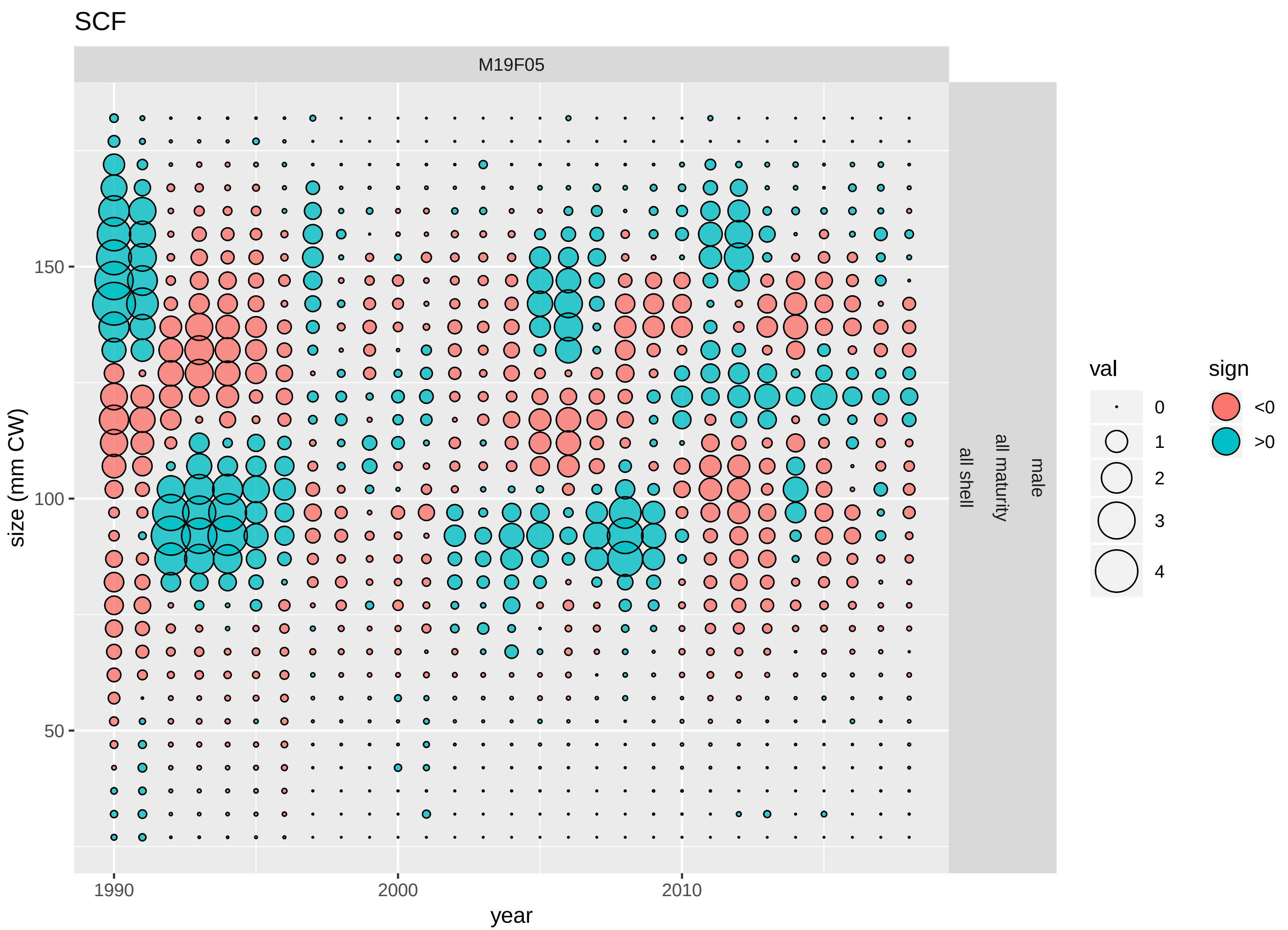


Figure 30: Pearson's residuals for male proportions-at-size from the SCF for scenario M19F05.

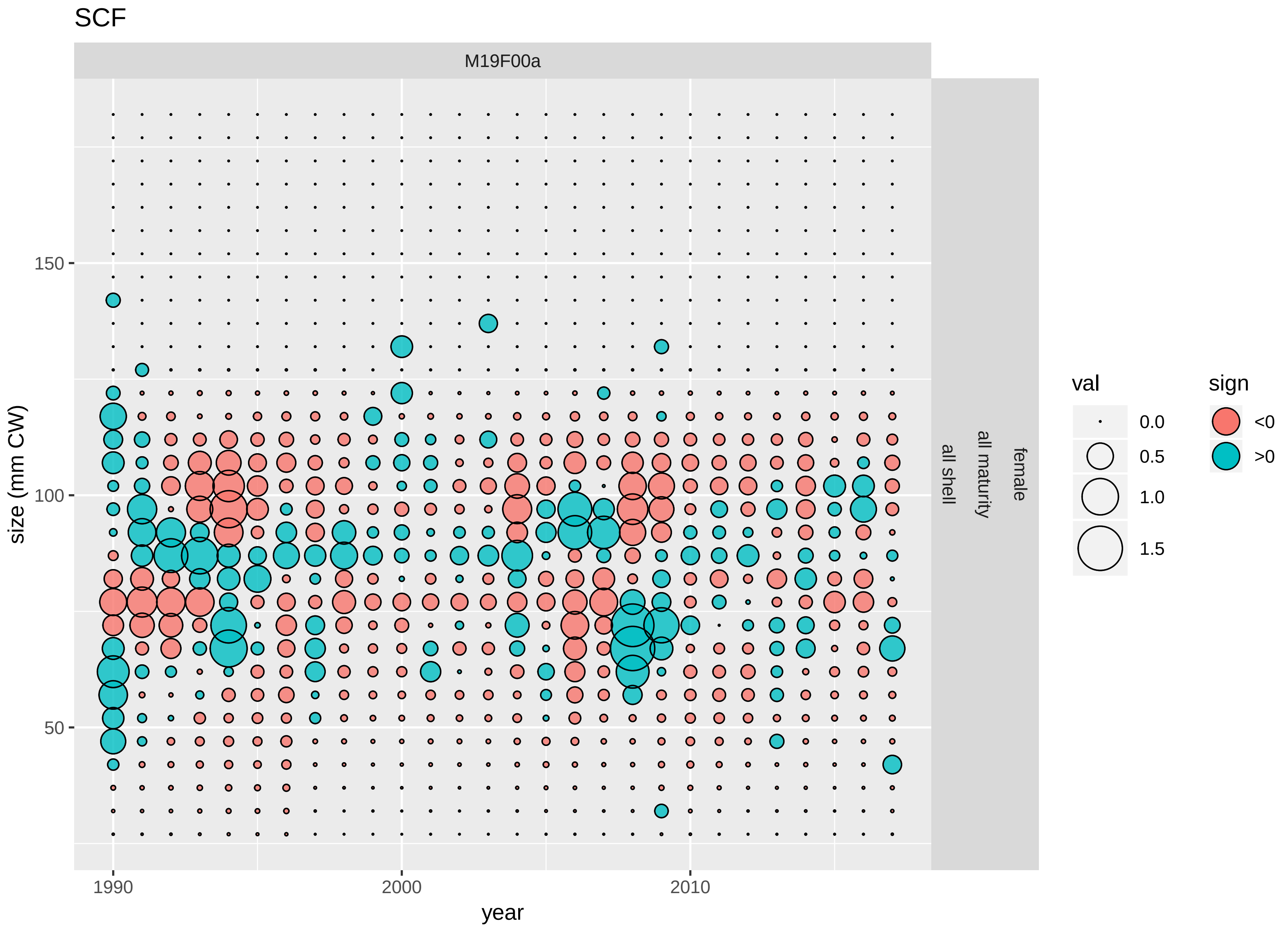


Figure 31: Pearson's residuals for female proportions-at-size from the SCF for scenario M19F00a.

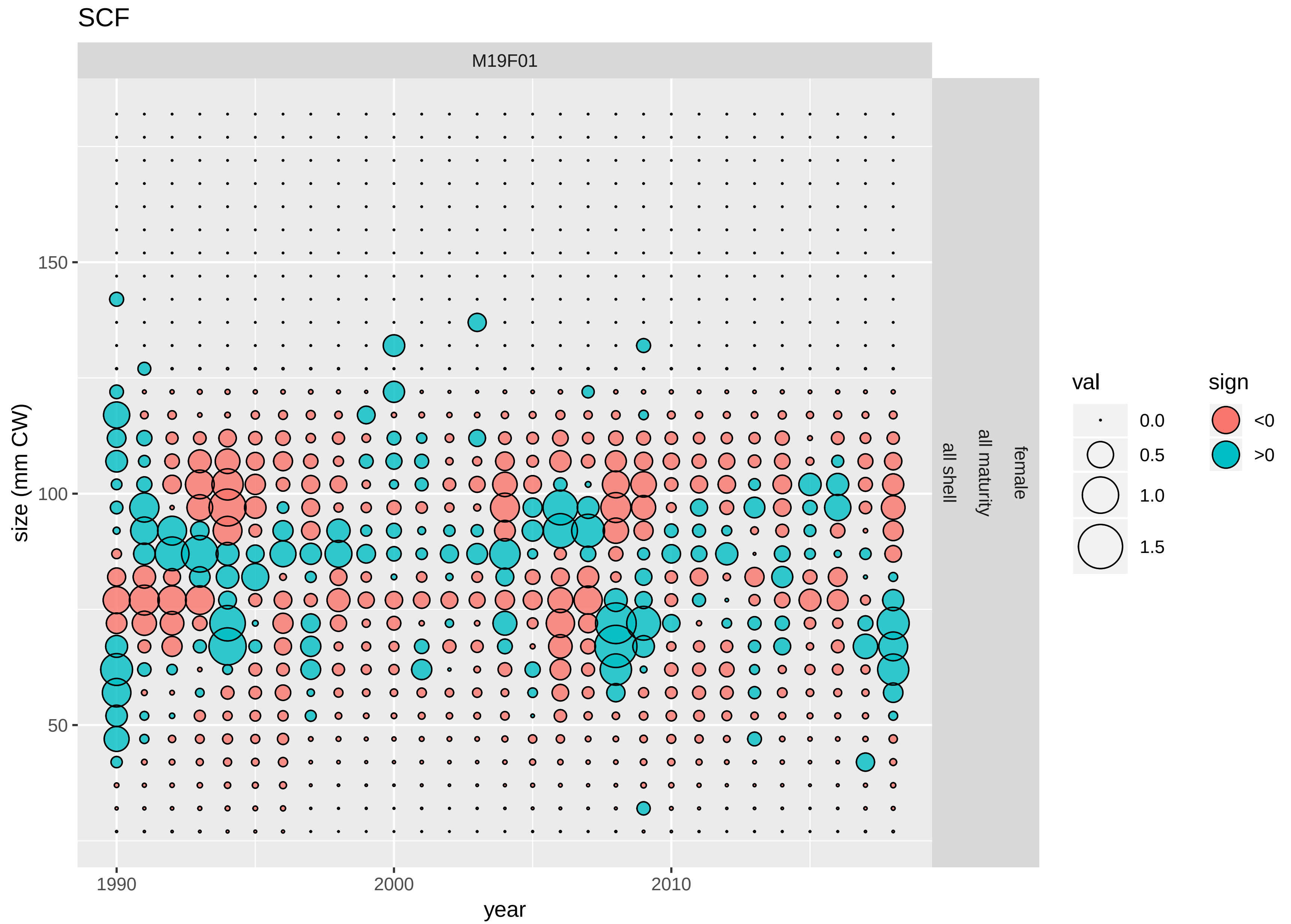


Figure 32: Pearson's residuals for female proportions-at-size from the SCF for scenario M19F01.

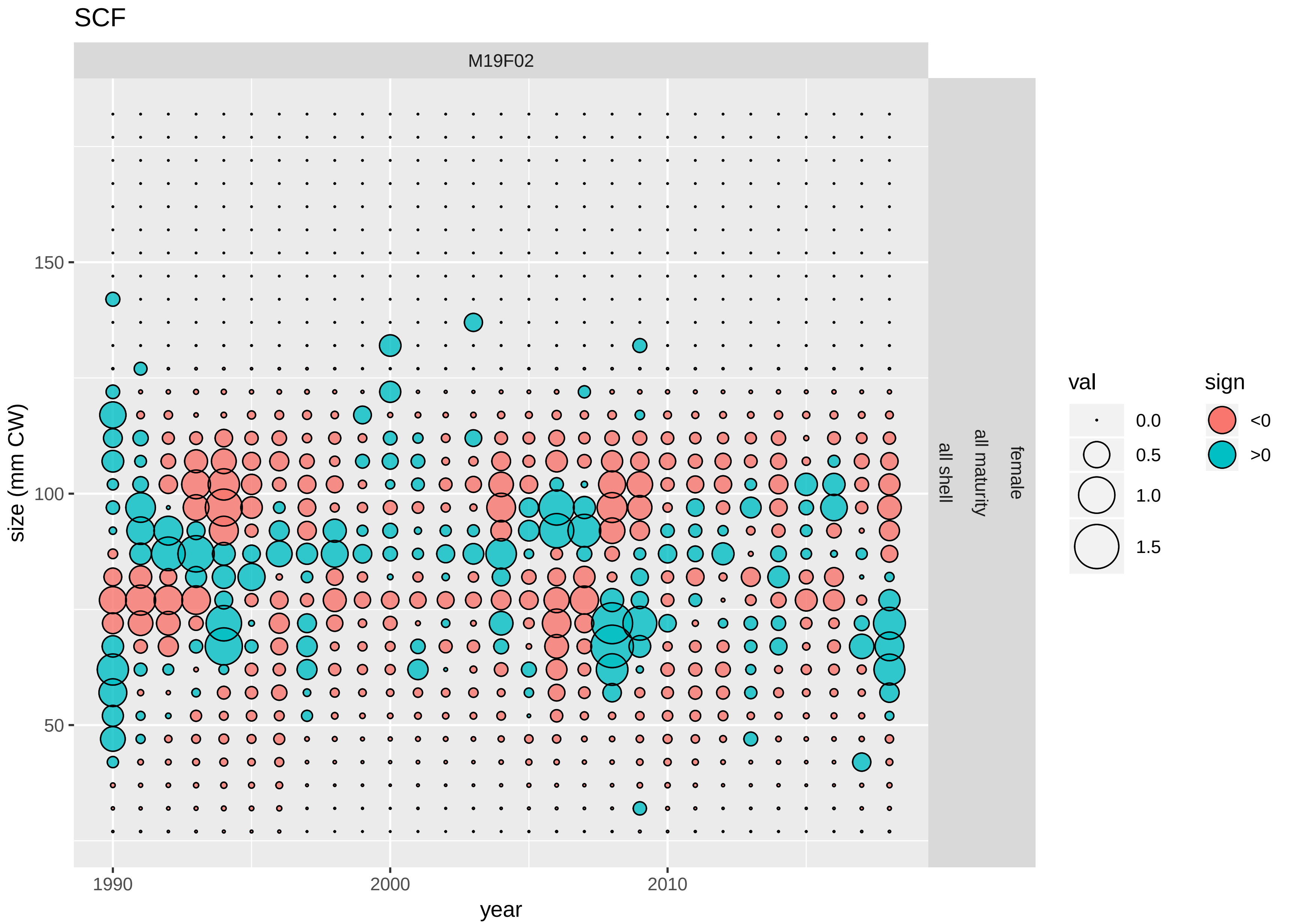


Figure 33: Pearson's residuals for female proportions-at-size from the SCF for scenario M19F02.

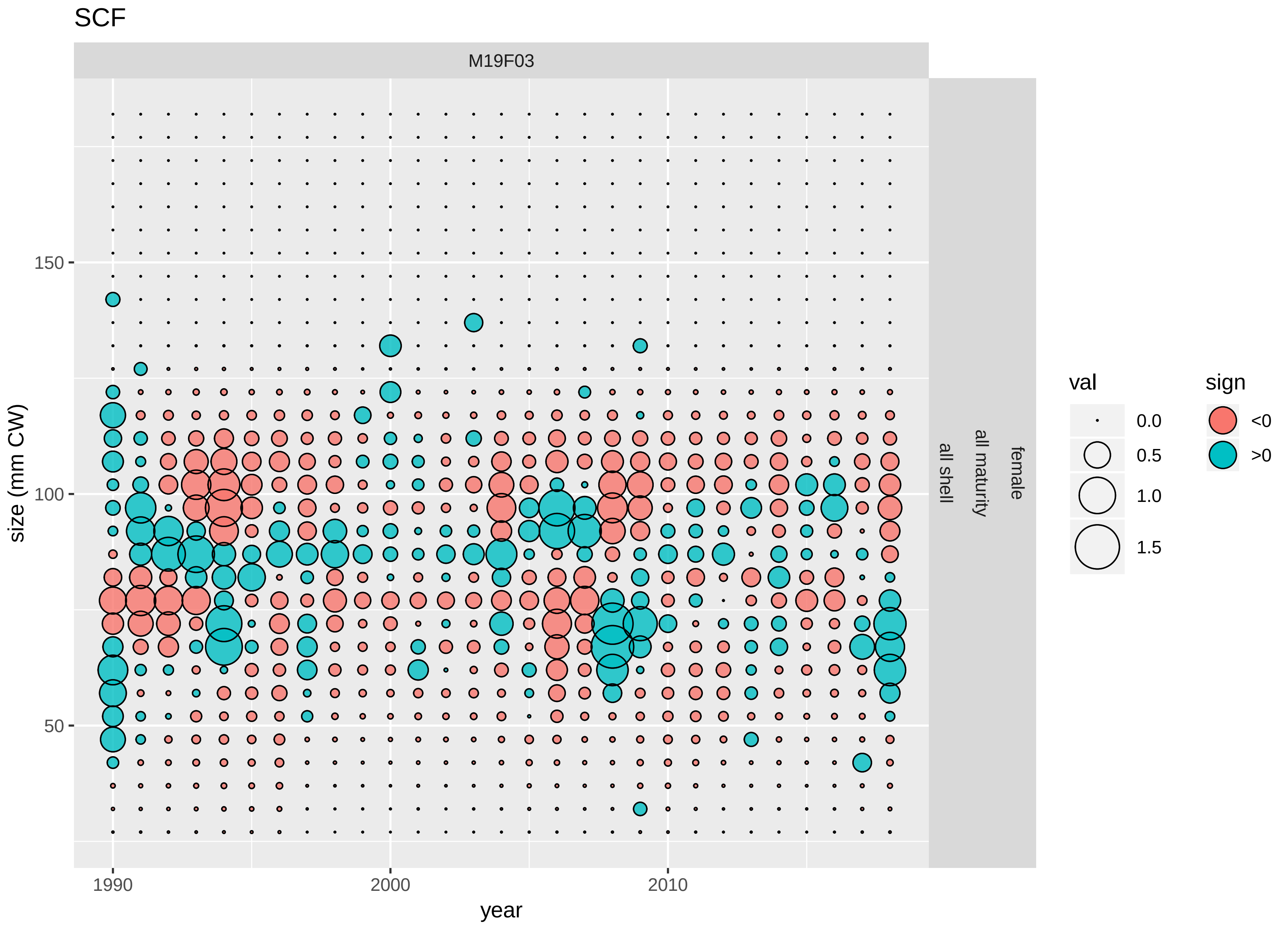


Figure 34: Pearson's residuals for female proportions-at-size from the SCF for scenario M19F03.

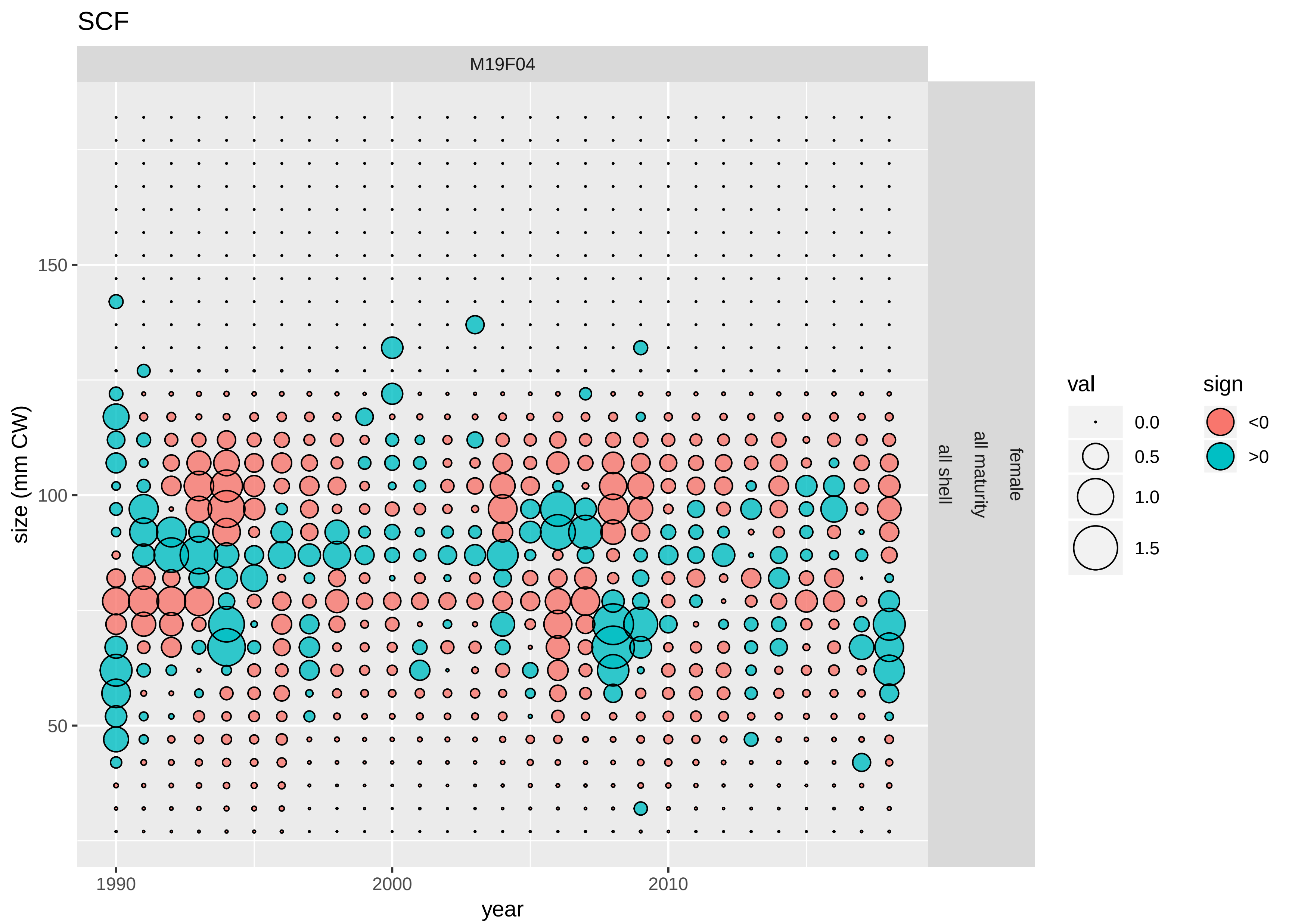


Figure 35: Pearson's residuals for female proportions-at-size from the SCF for scenario M19F04.

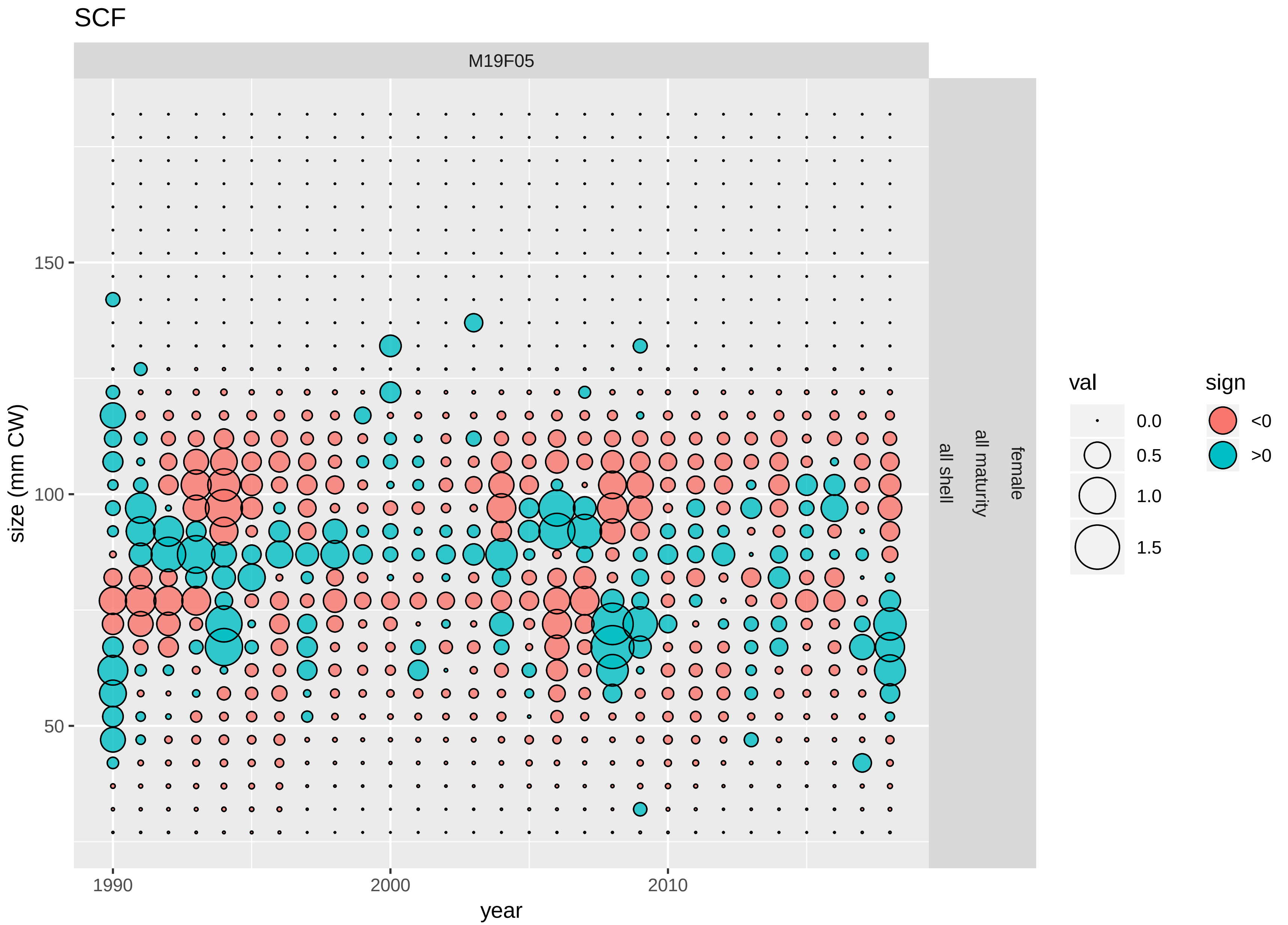


Figure 36: Pearson's residuals for female proportions-at-size from the SCF for scenario M19F05.

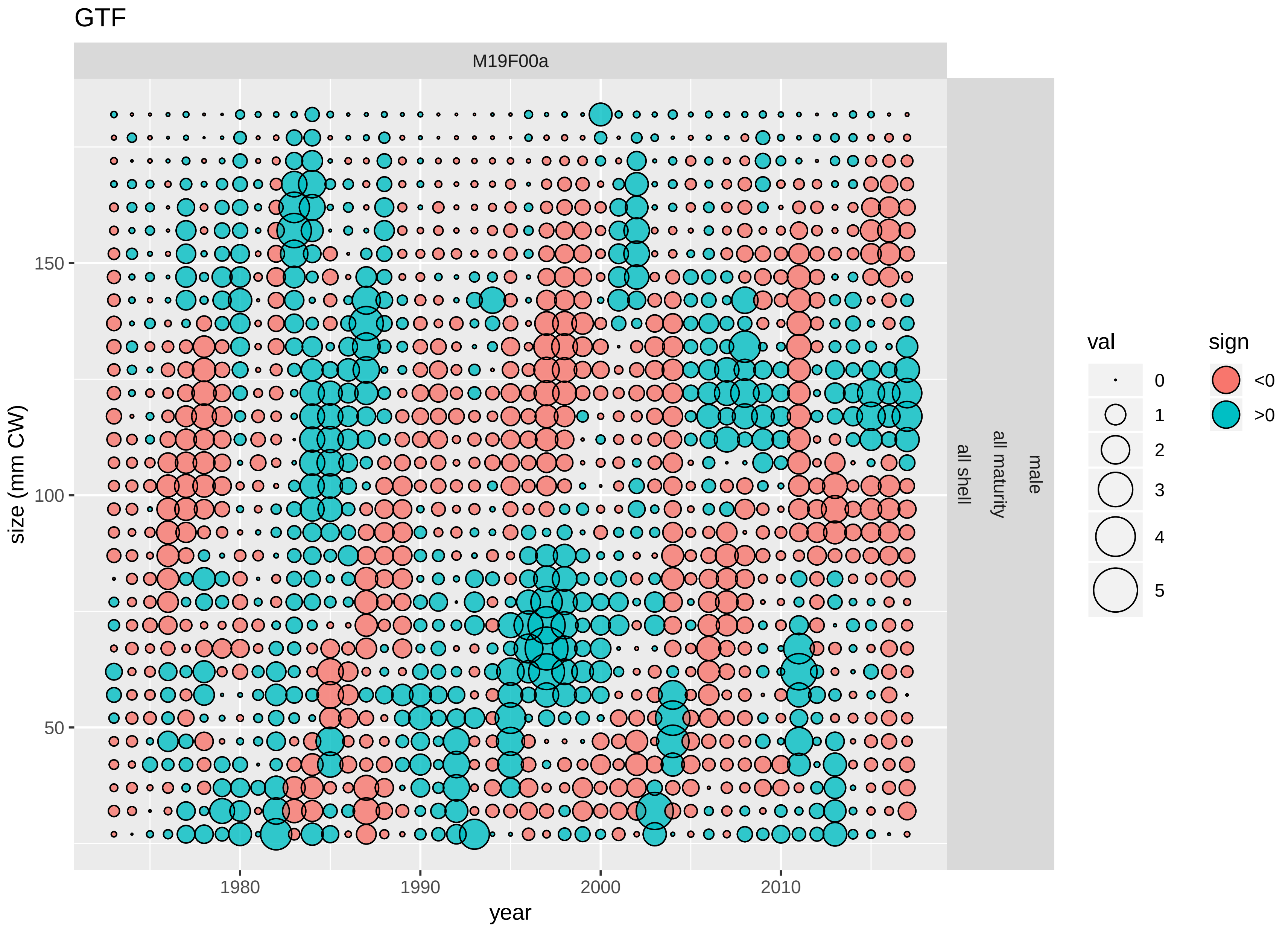


Figure 37: Pearson's residuals for male proportions-at-size from the GTF for scenario M19F00a.

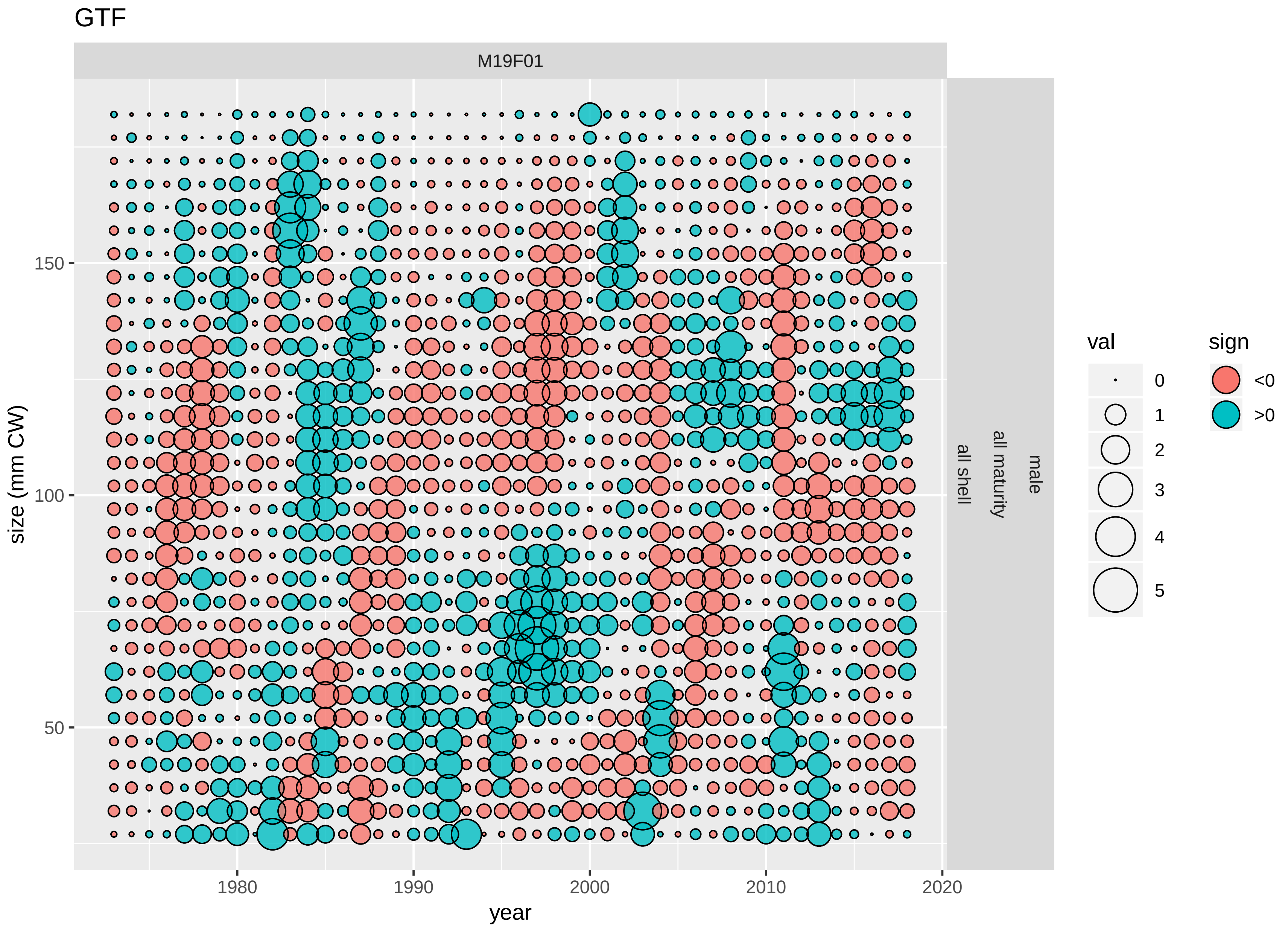


Figure 38: Pearson's residuals for male proportions-at-size from the GTF for scenario M19F01.

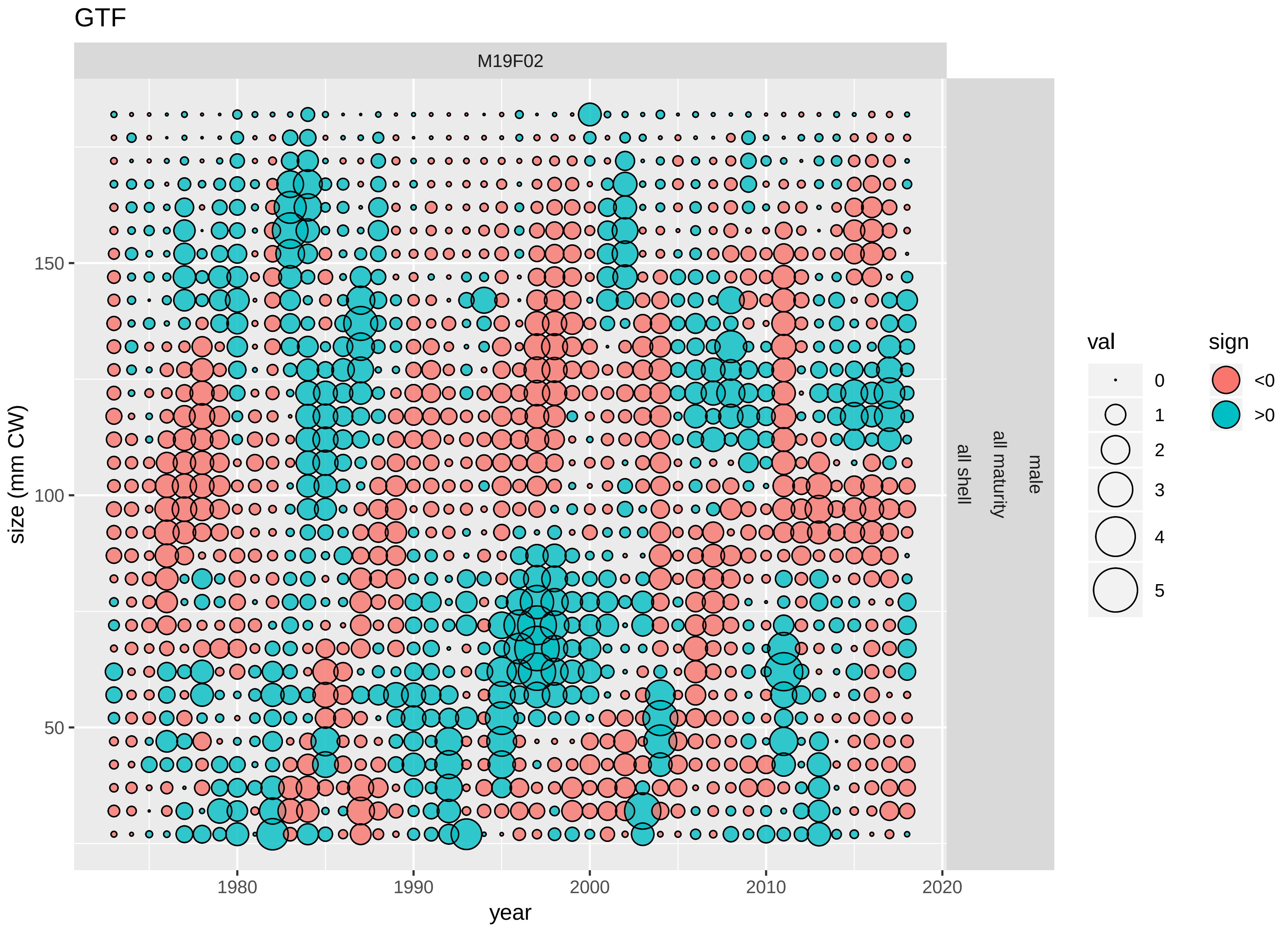


Figure 39: Pearson's residuals for male proportions-at-size from the GTF for scenario M19F02.

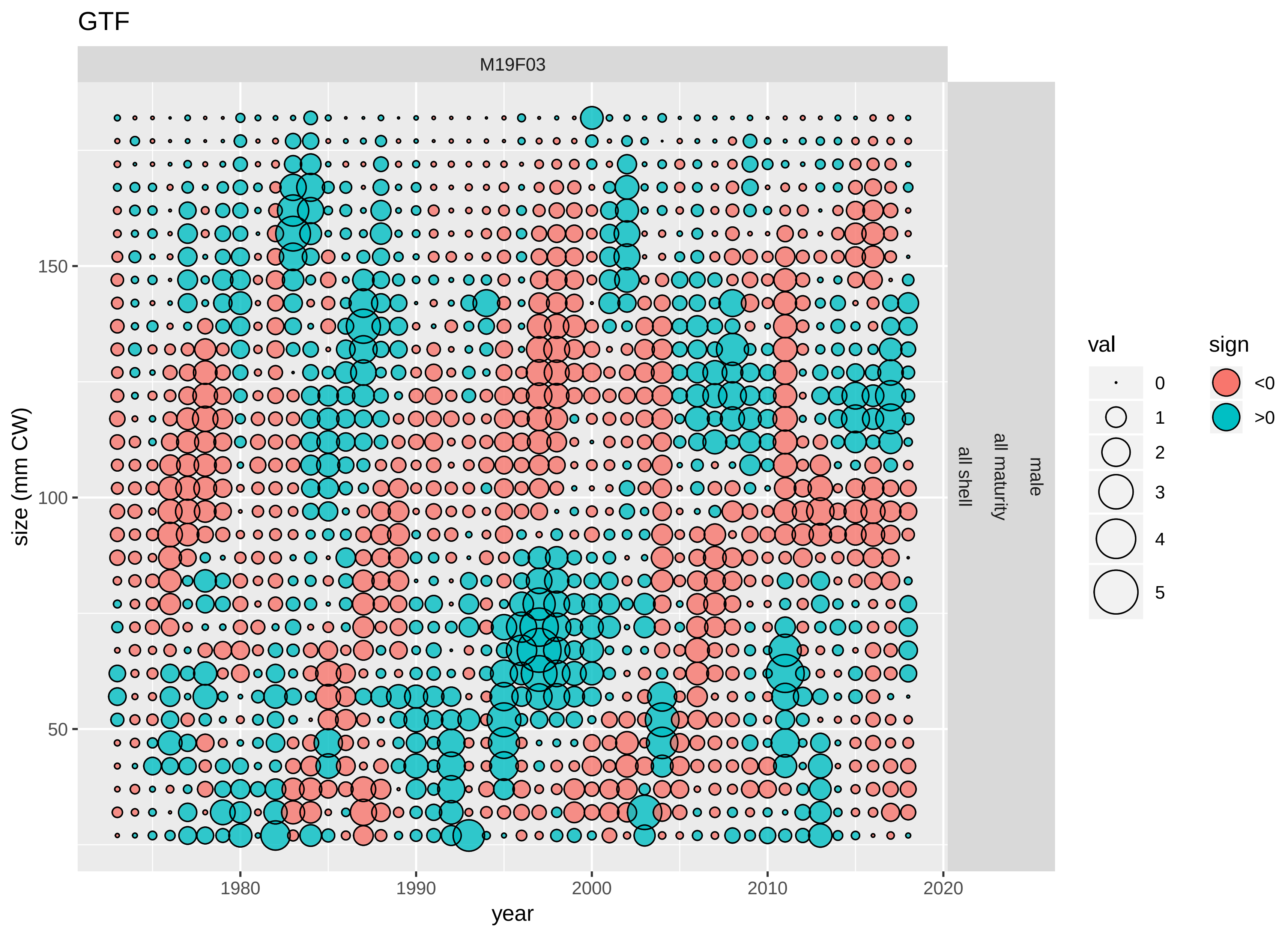


Figure 40: Pearson's residuals for male proportions-at-size from the GTF for scenario M19F03.

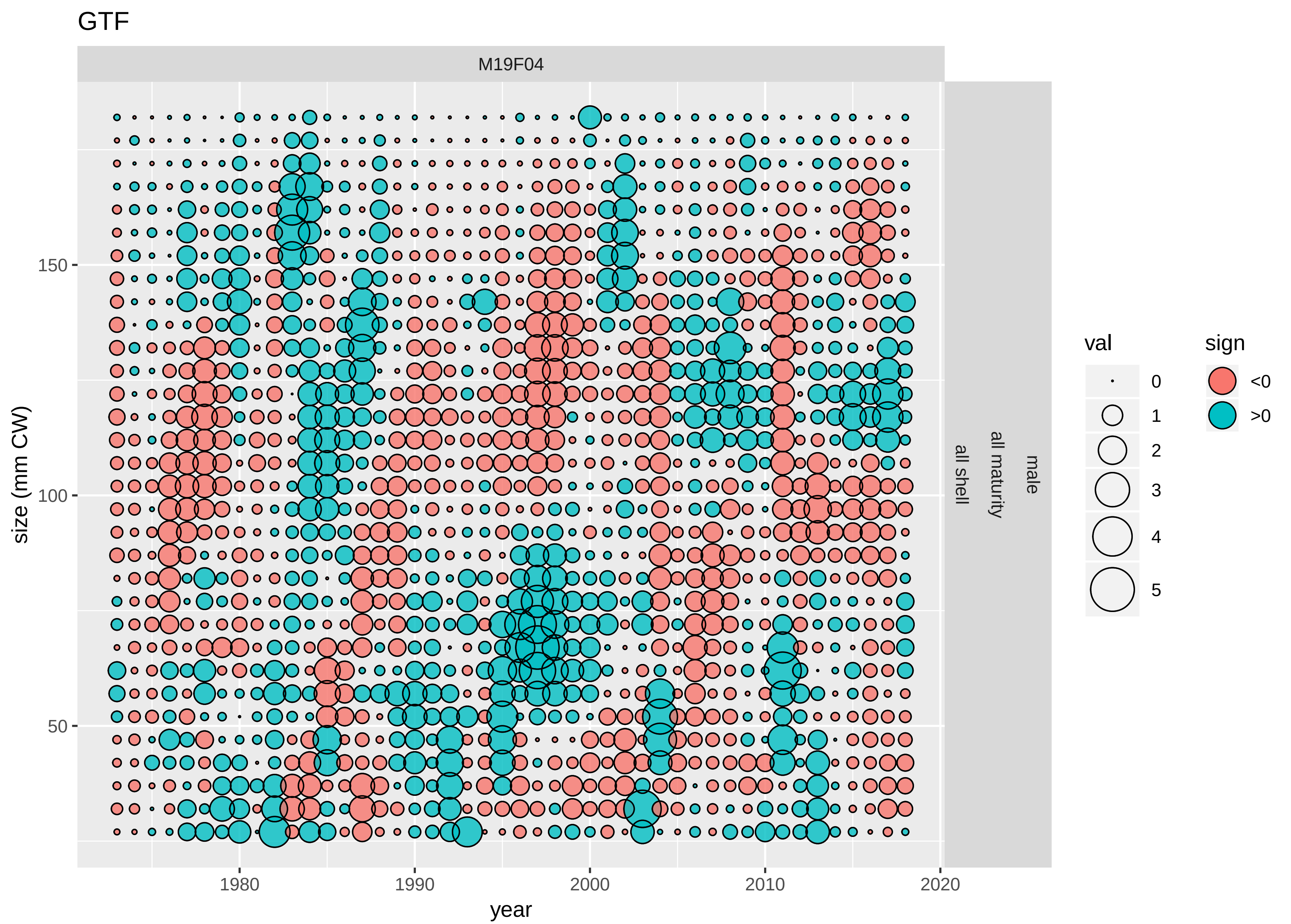


Figure 41: Pearson's residuals for male proportions-at-size from the GTF for scenario M19F04.

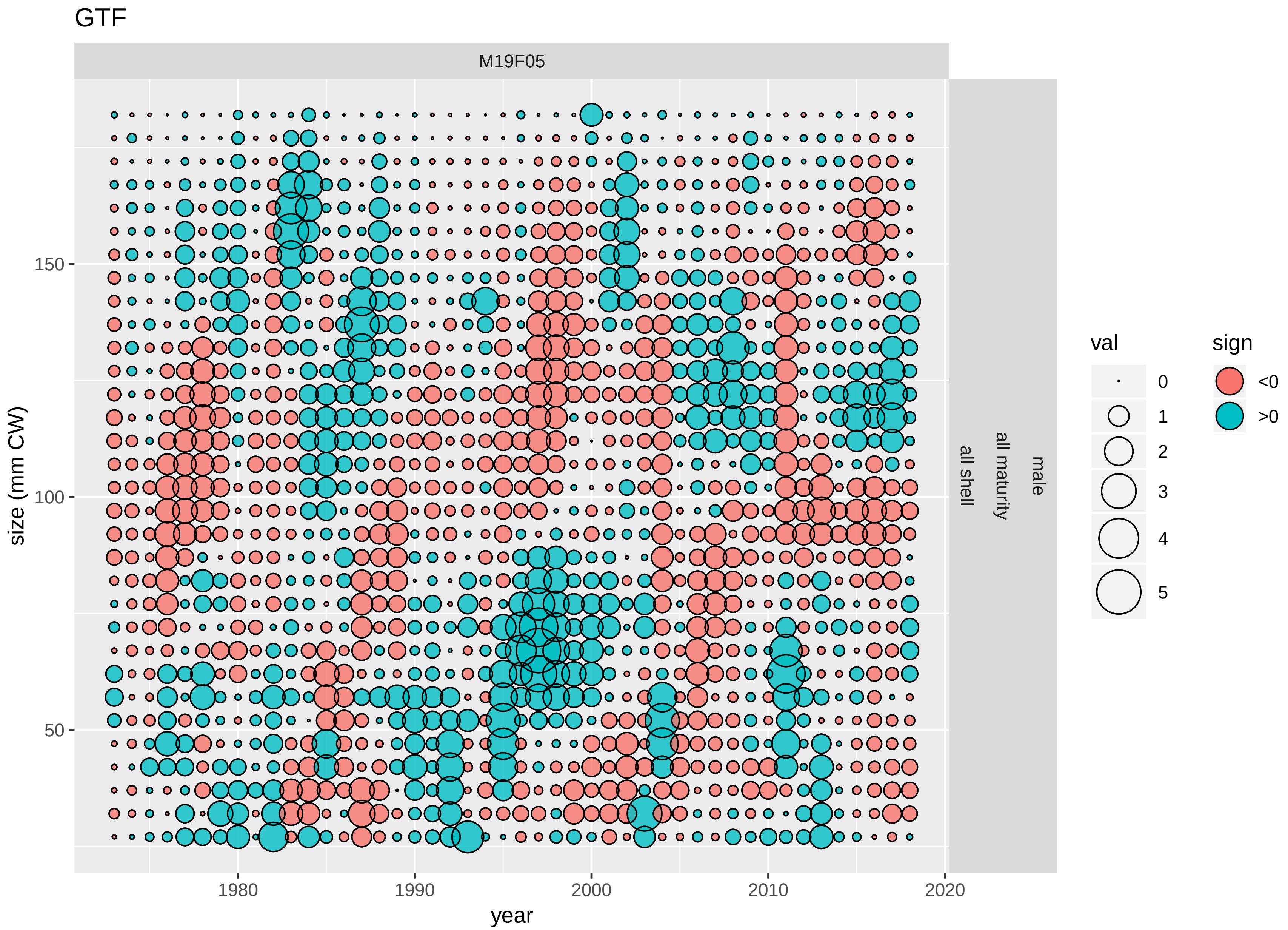


Figure 42: Pearson's residuals for male proportions-at-size from the GTF for scenario M19F05.

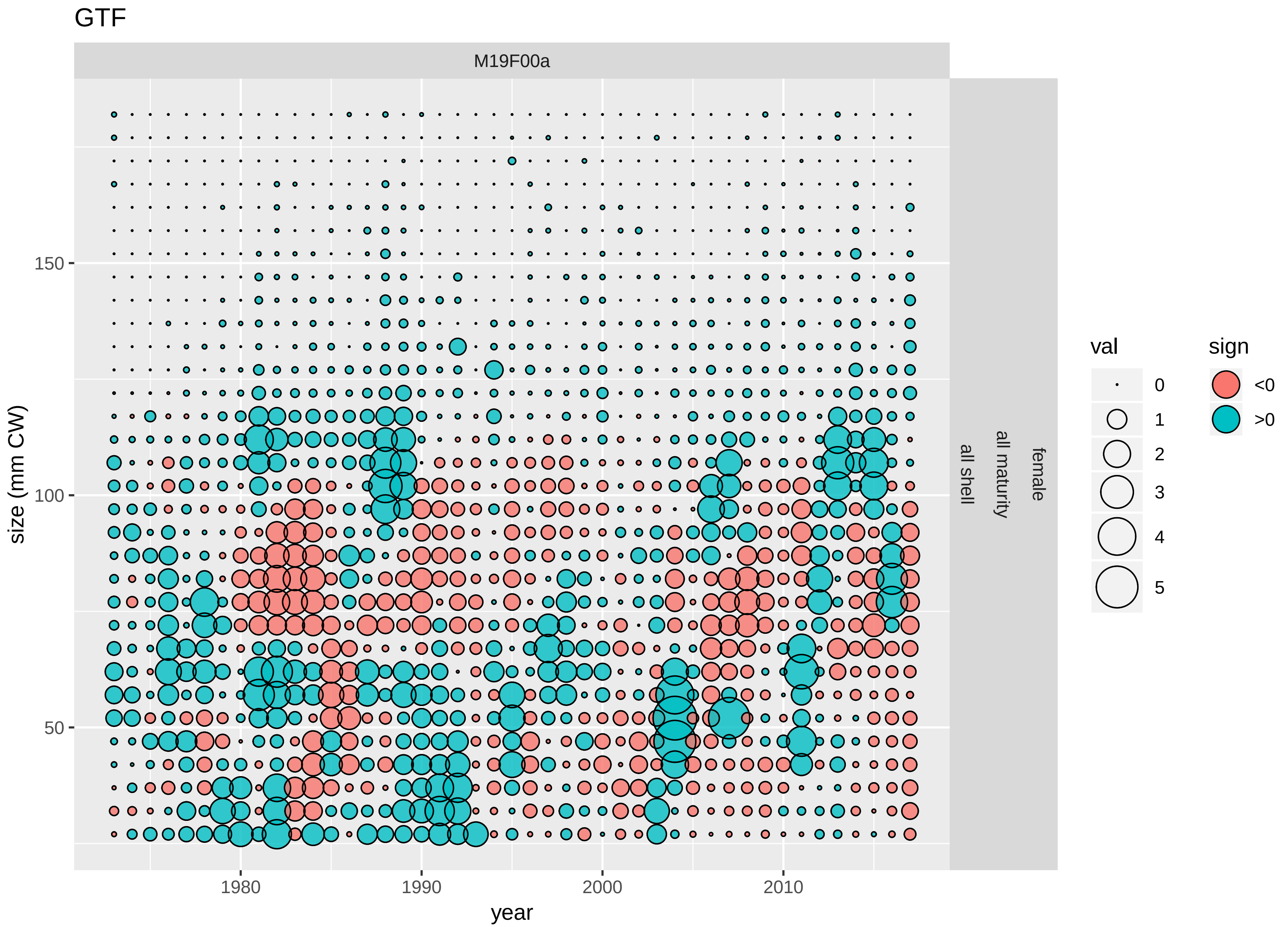


Figure 43: Pearson's residuals for female proportions-at-size from the GTF for scenario M19F00a.

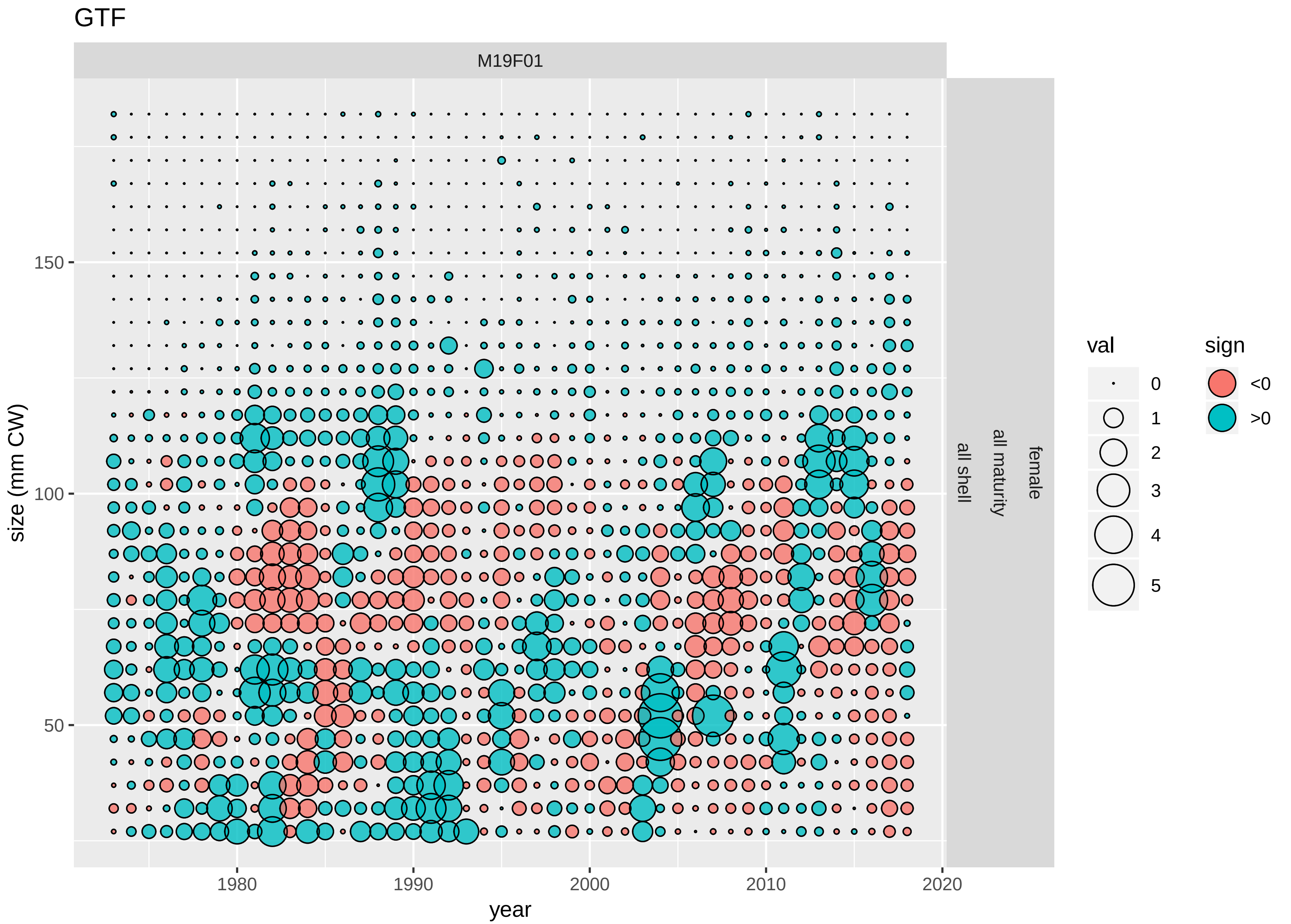


Figure 44: Pearson's residuals for female proportions-at-size from the GTF for scenario M19F01.

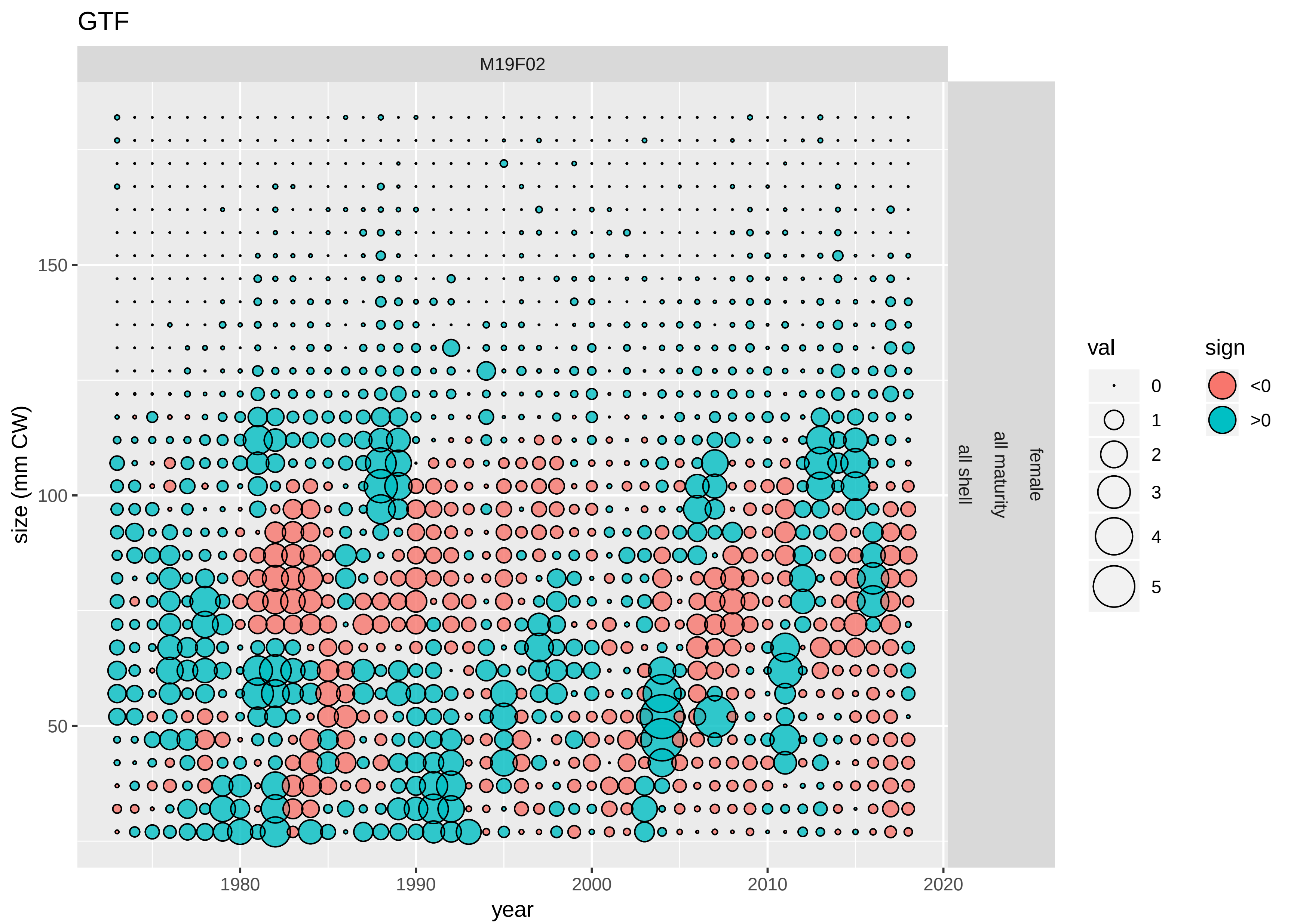


Figure 45: Pearson's residuals for female proportions-at-size from the GTF for scenario M19F02.

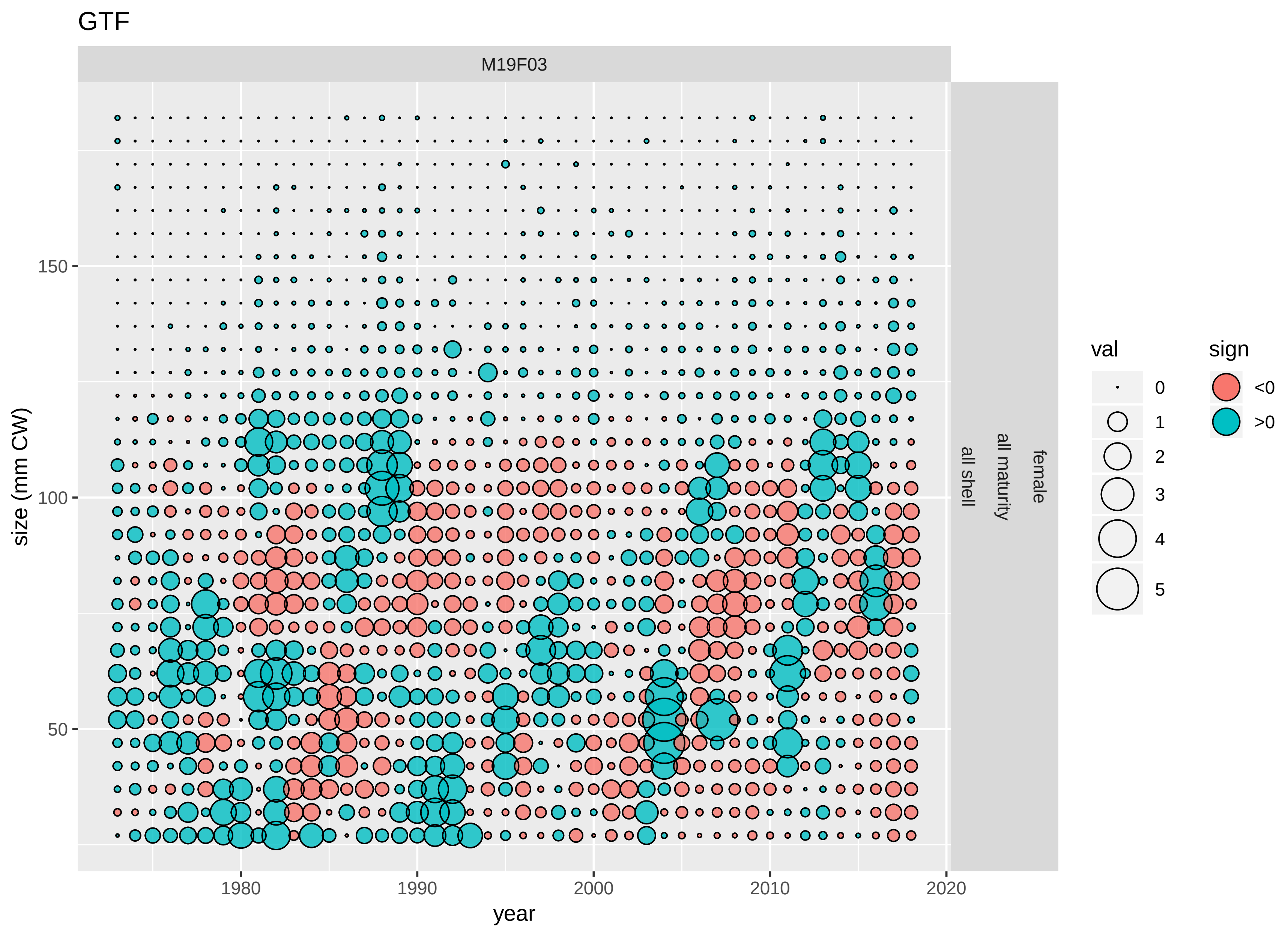


Figure 46: Pearson's residuals for female proportions-at-size from the GTF for scenario M19F03.

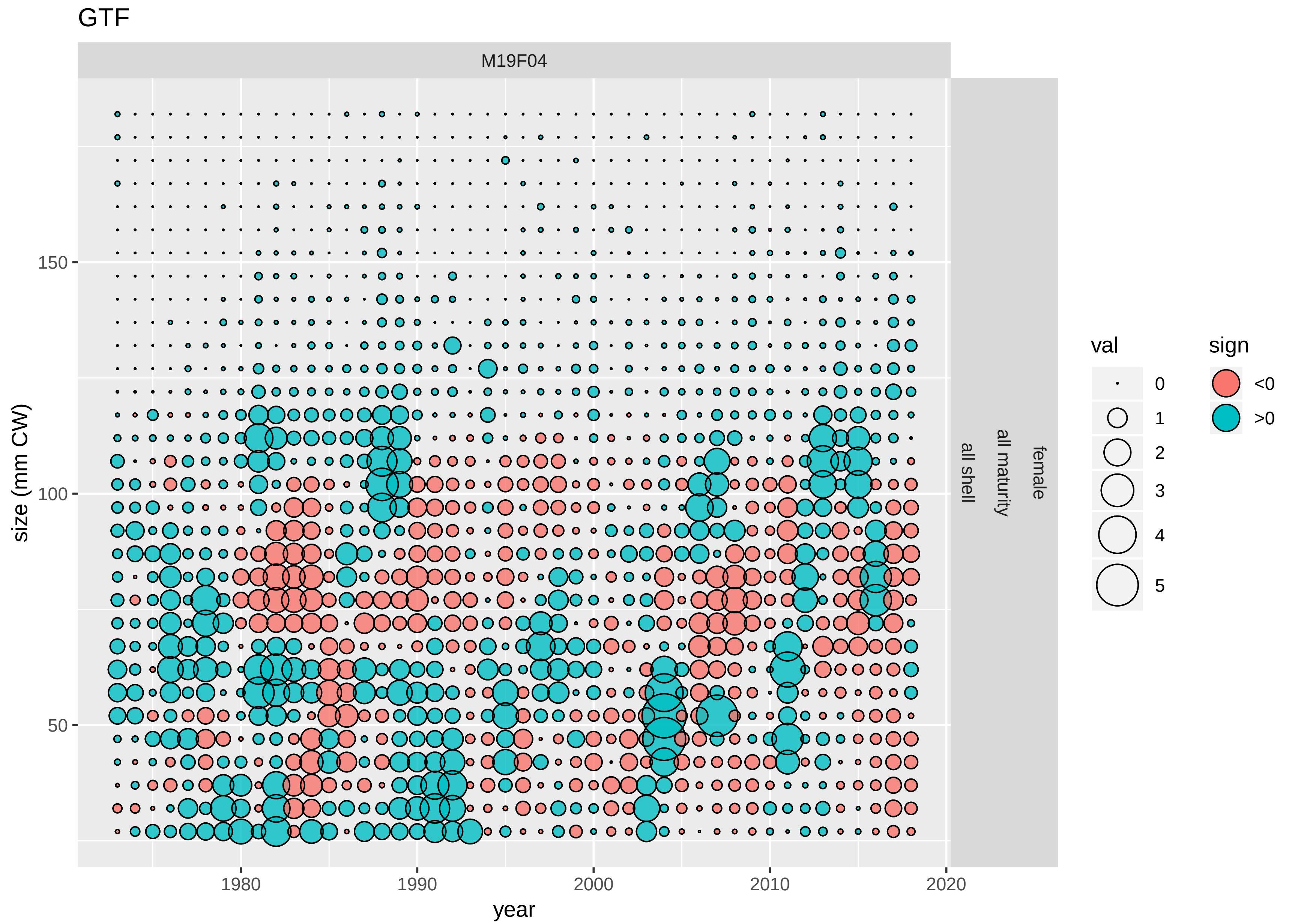


Figure 47: Pearson's residuals for female proportions-at-size from the GTF for scenario M19F04.

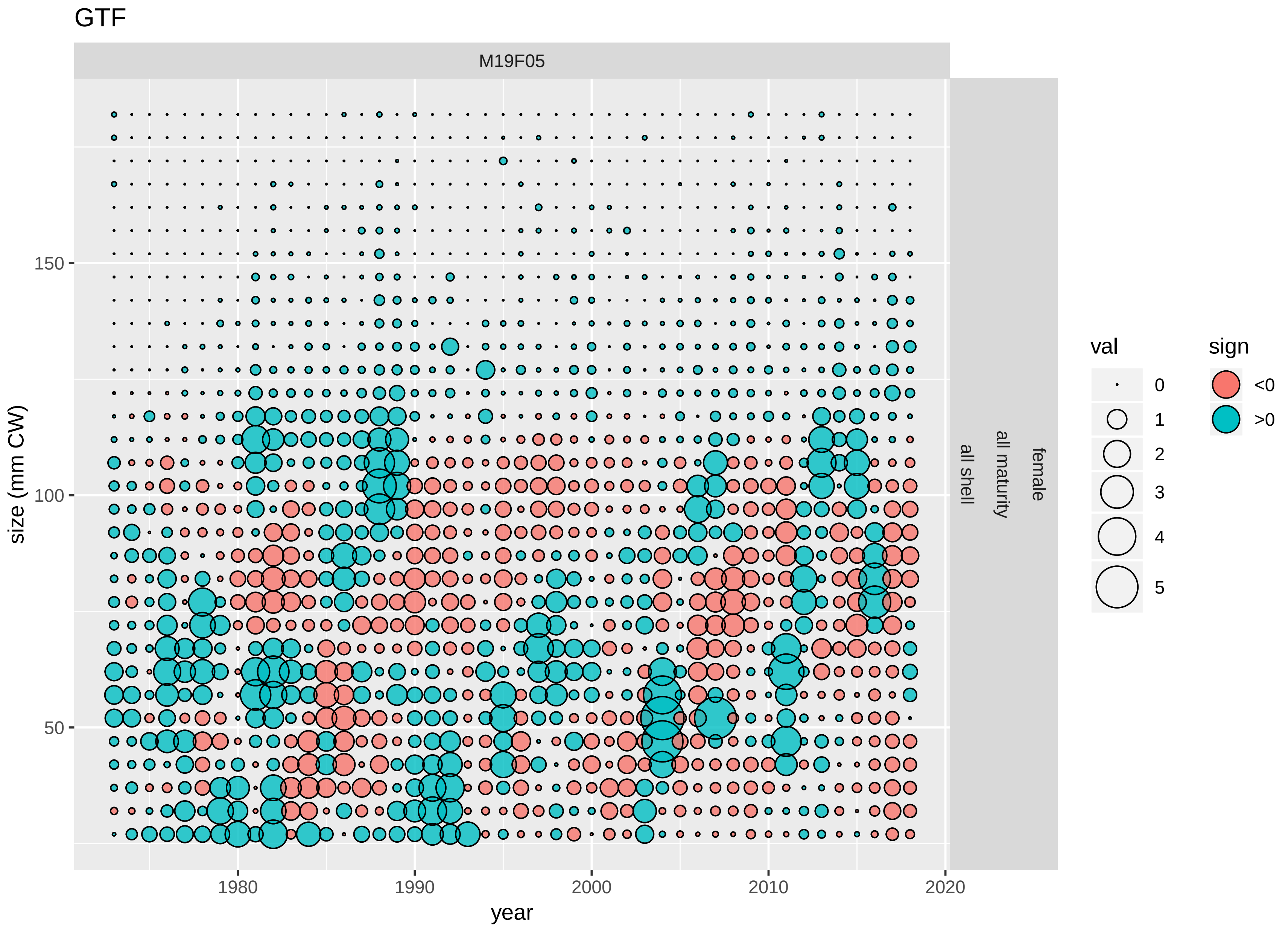


Figure 48: Pearson's residuals for female proportions-at-size from the GTF for scenario M19F05.

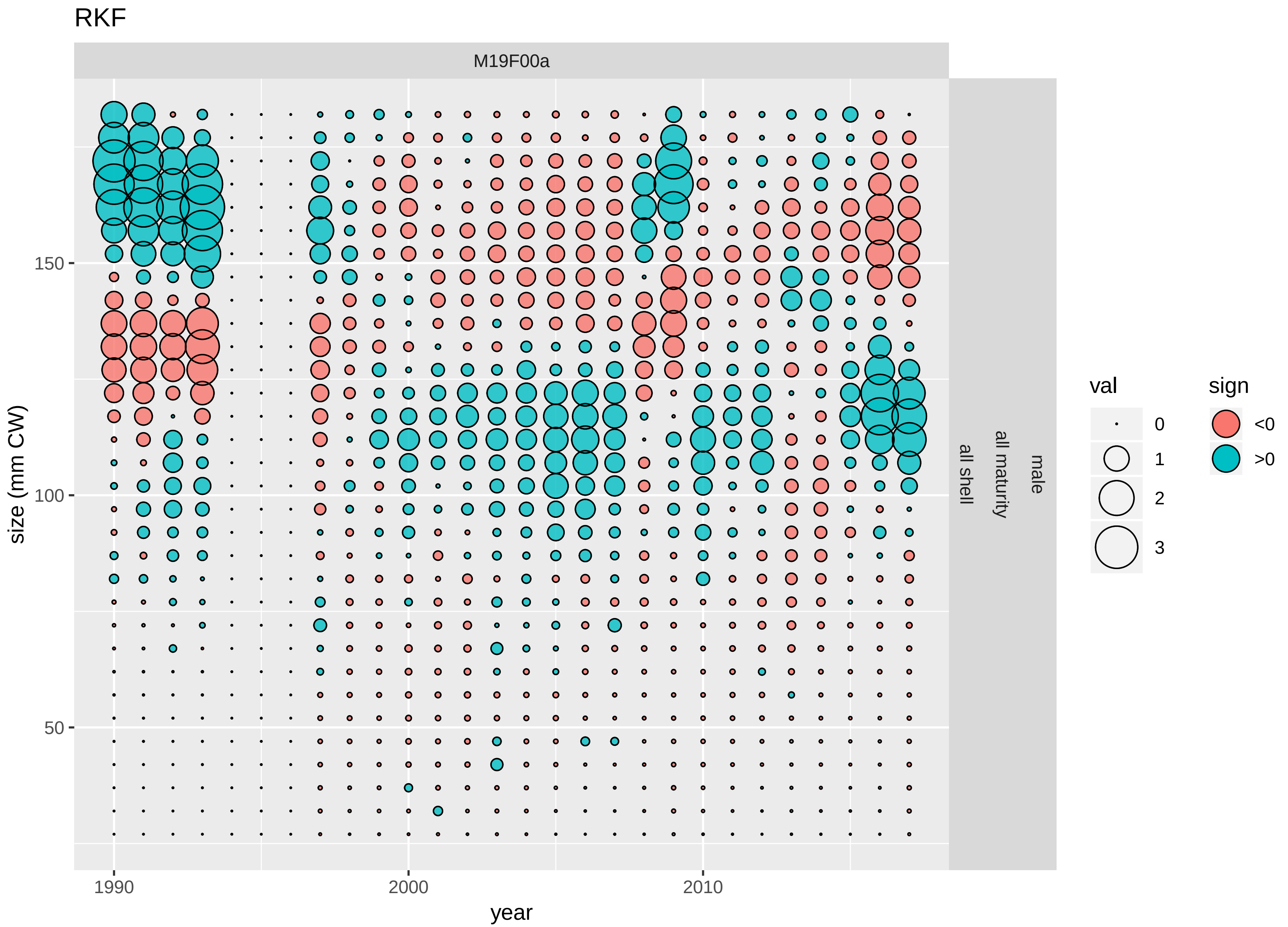


Figure 49: Pearson's residuals for male proportions-at-size from the RKF for scenario M19F00a.

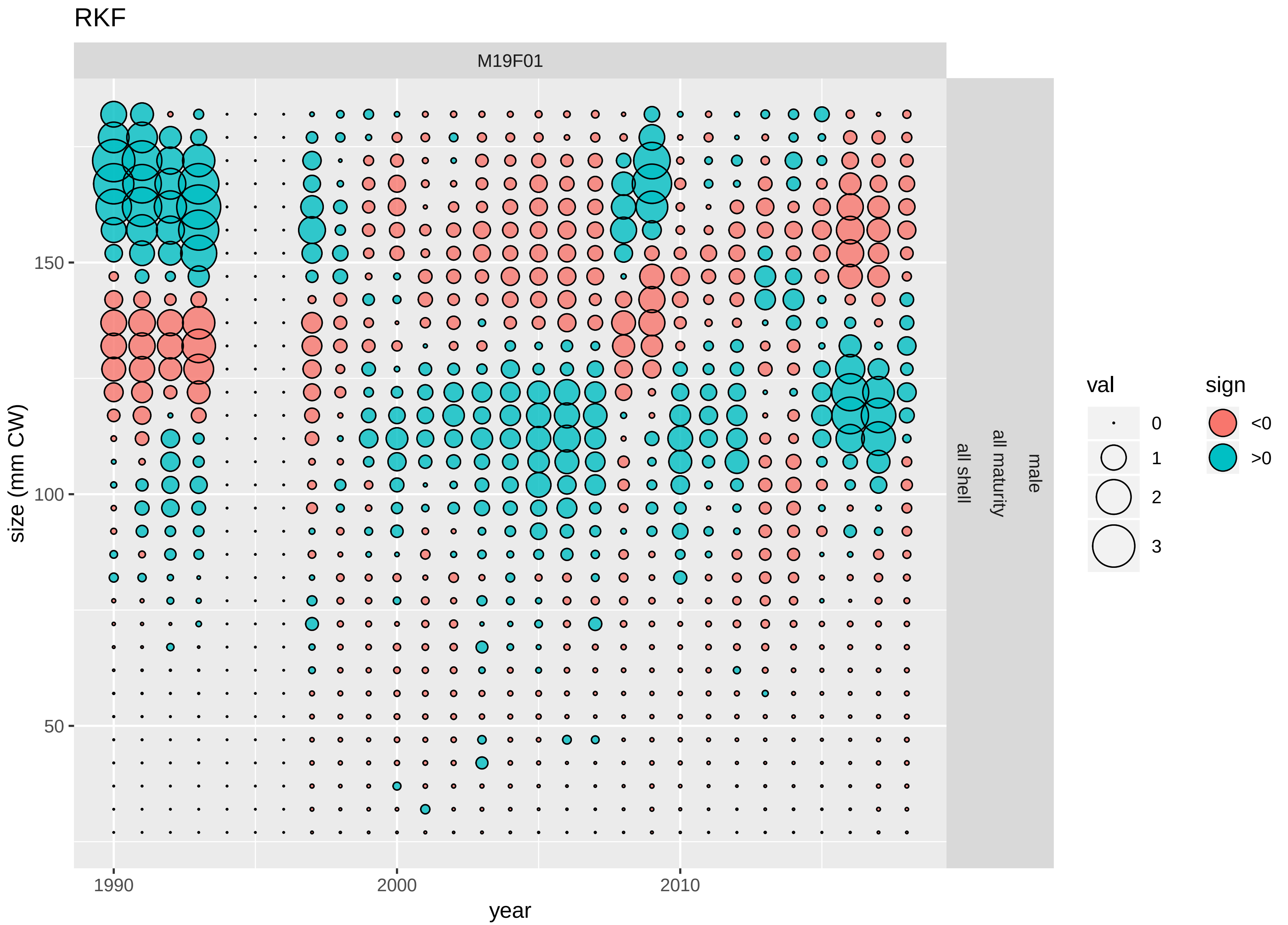


Figure 50: Pearson's residuals for male proportions-at-size from the RKF for scenario M19F01.

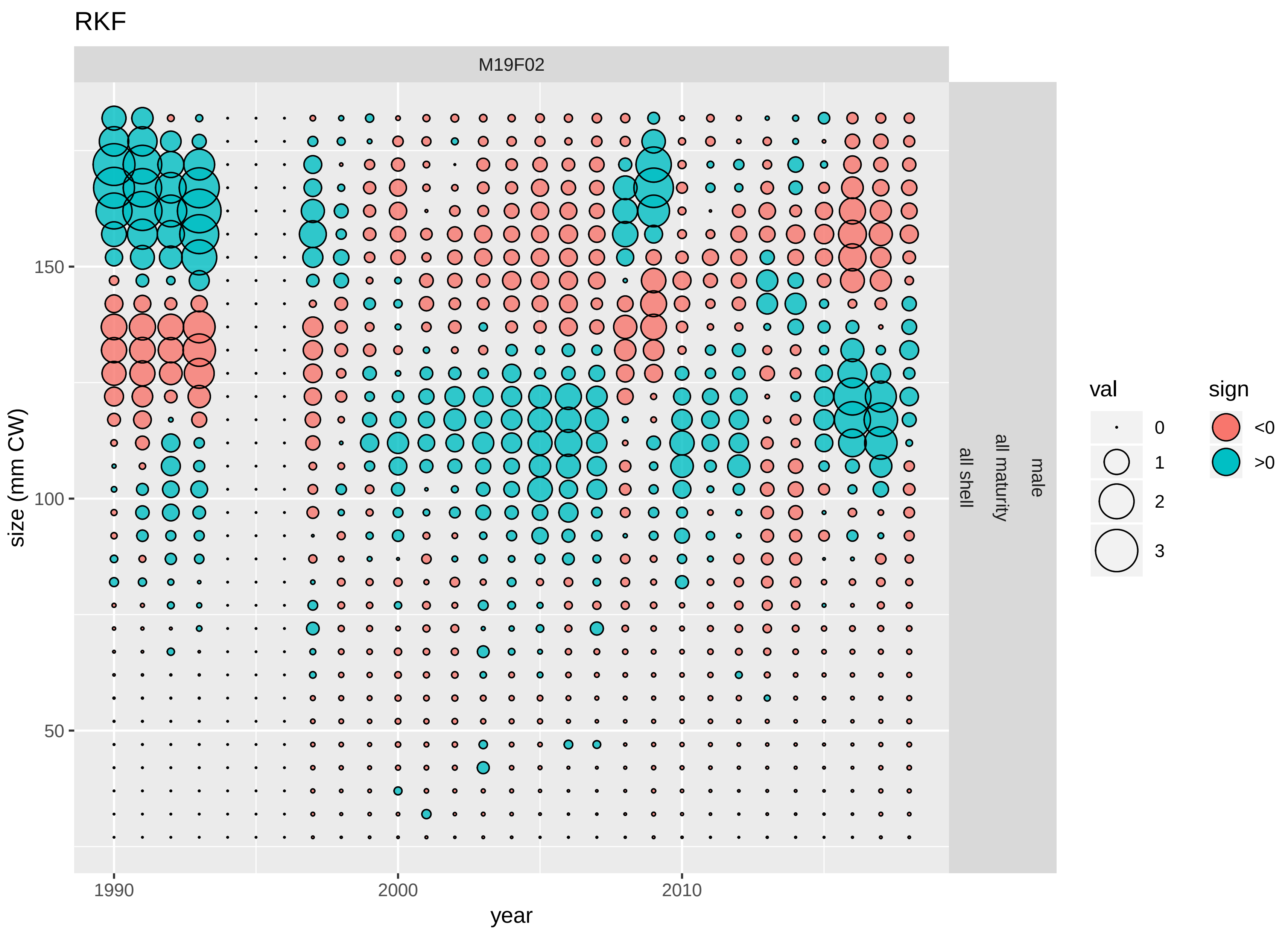


Figure 51: Pearson's residuals for male proportions-at-size from the RKF for scenario M19F02.

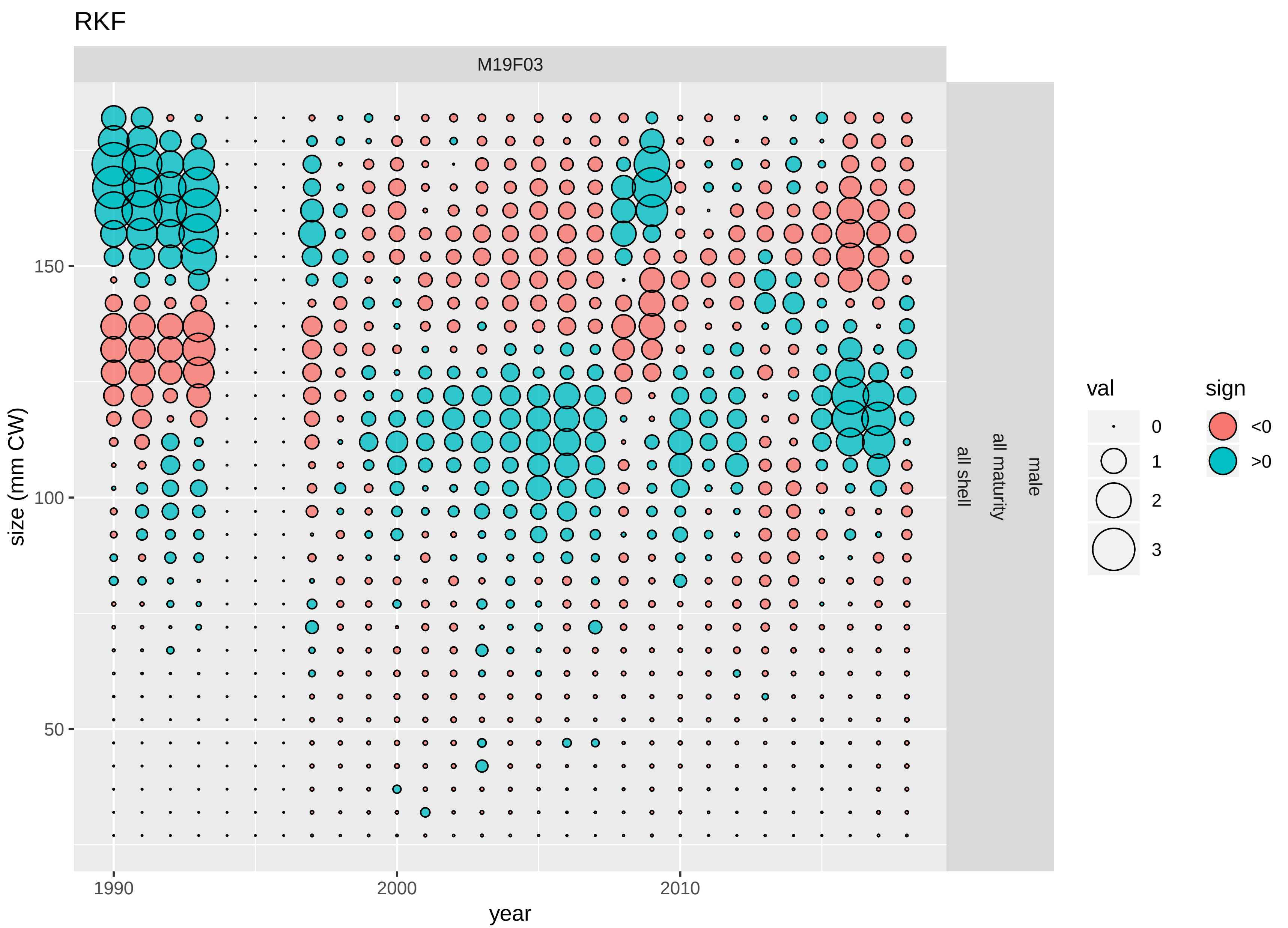


Figure 52: Pearson's residuals for male proportions-at-size from the RKF for scenario M19F03.

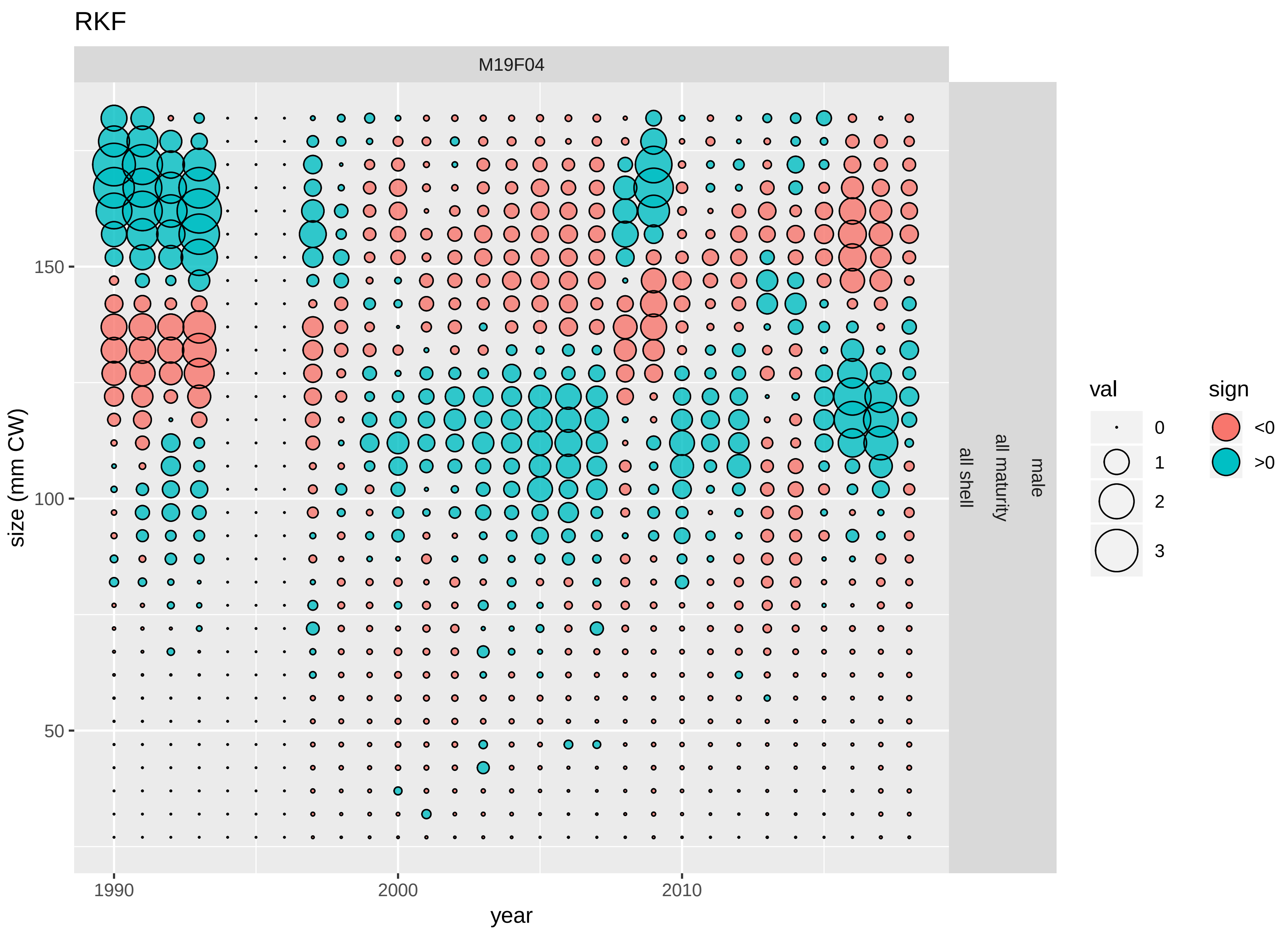


Figure 53: Pearson's residuals for male proportions-at-size from the RKF for scenario M19F04.

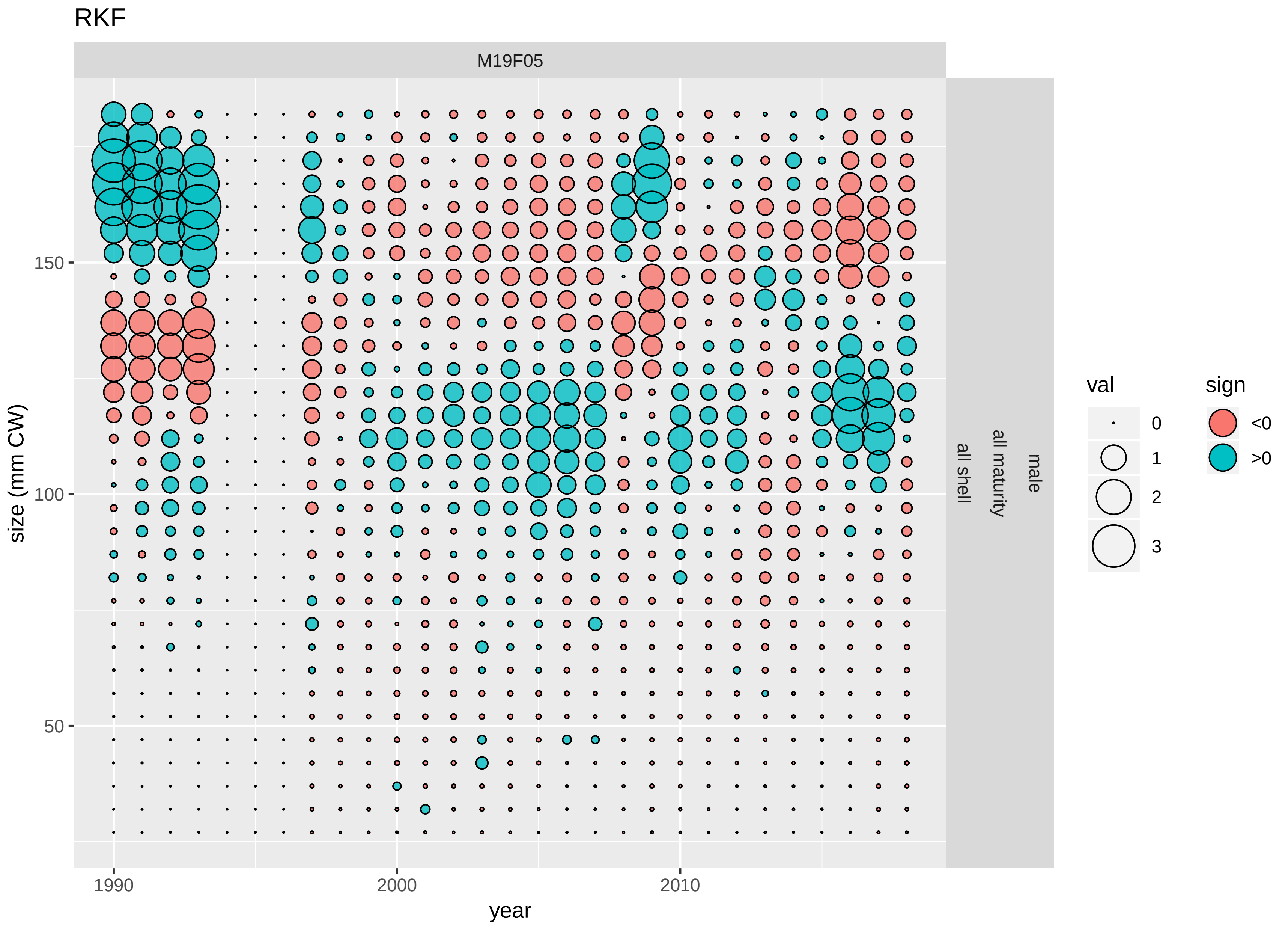


Figure 54: Pearson's residuals for male proportions-at-size from the RKF for scenario M19F05.

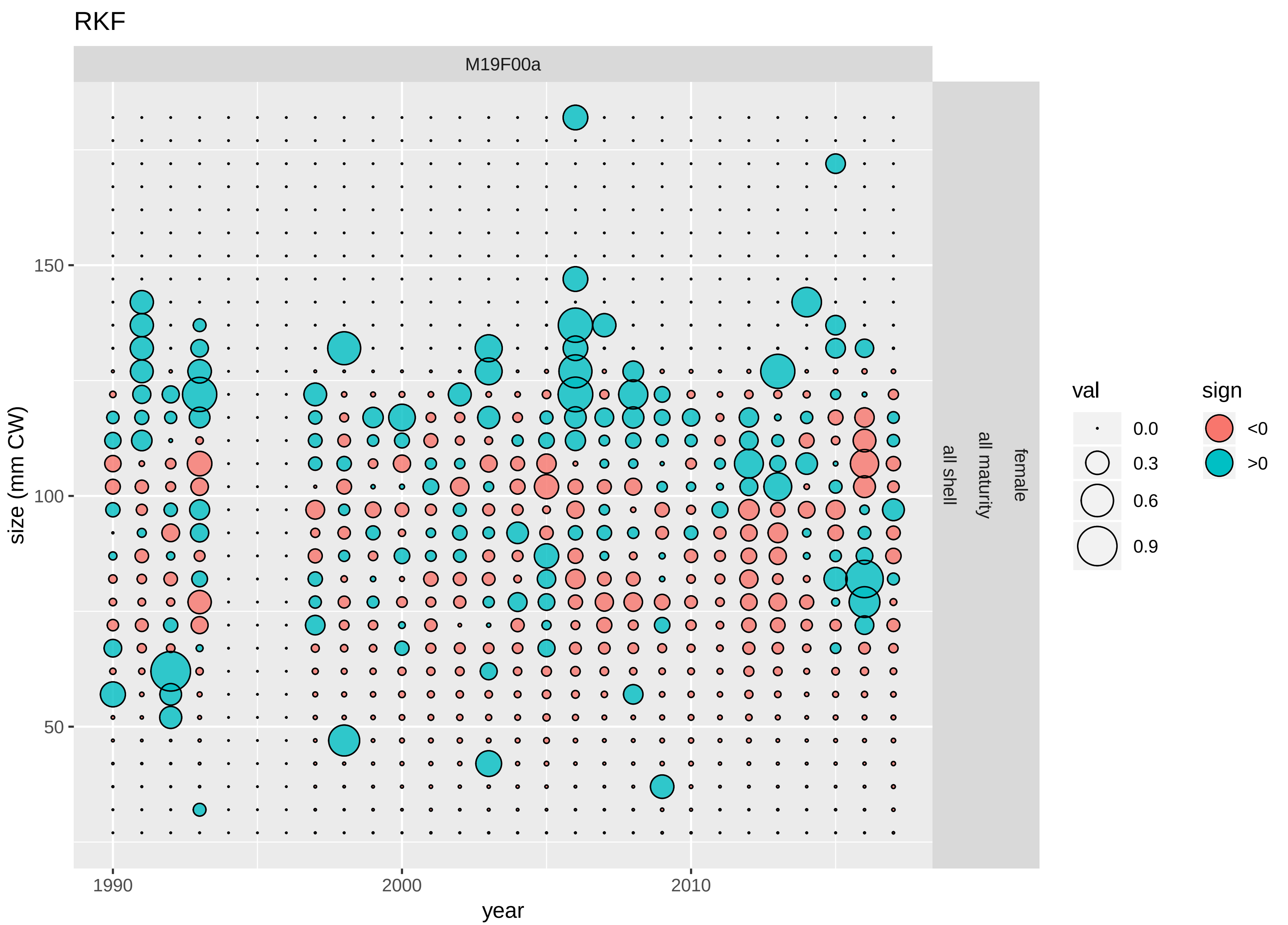


Figure 55: Pearson's residuals for female proportions-at-size from the RKF for scenario M19F00a.

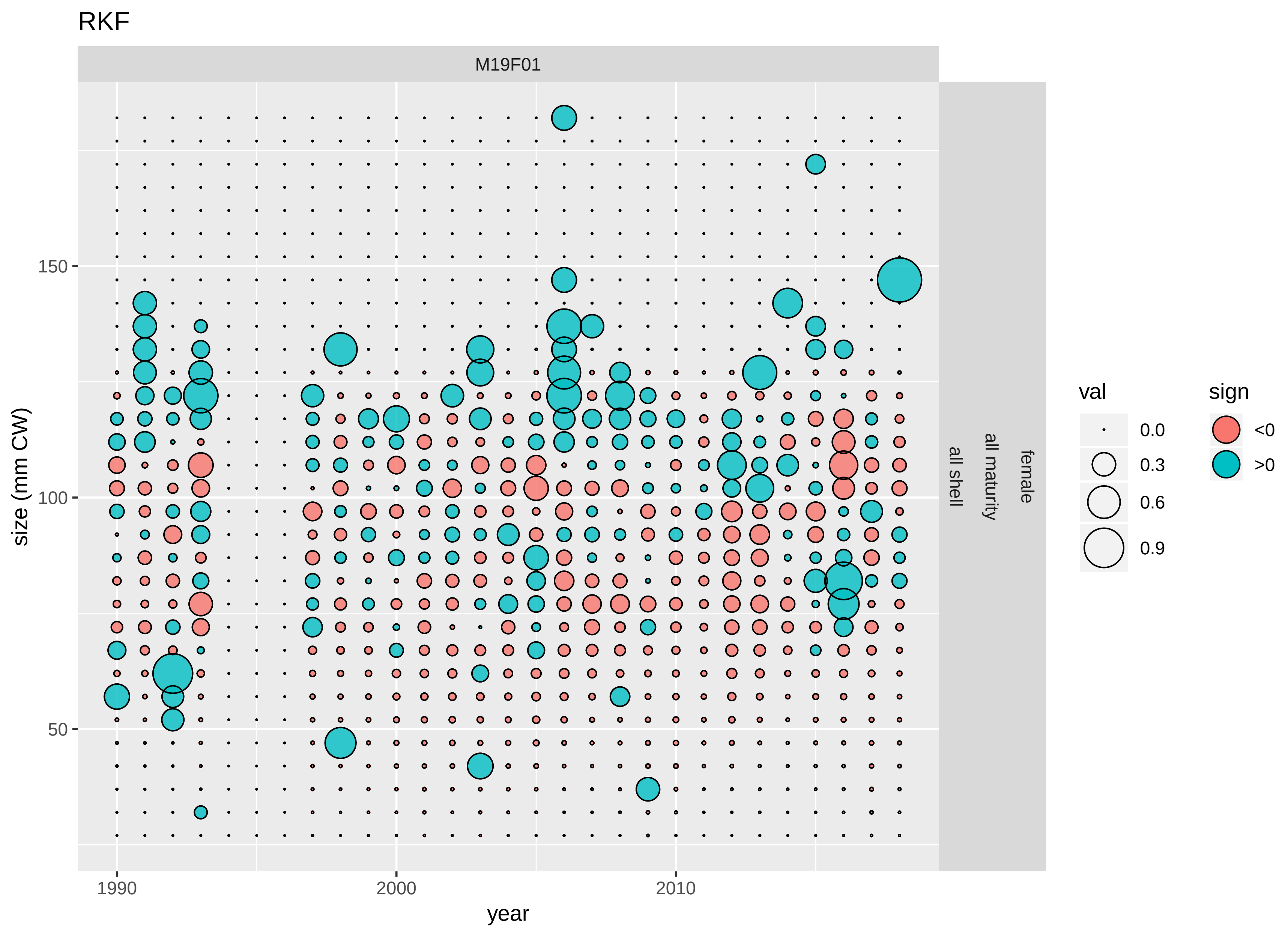


Figure 56: Pearson's residuals for female proportions-at-size from the RKF for scenario M19F01.

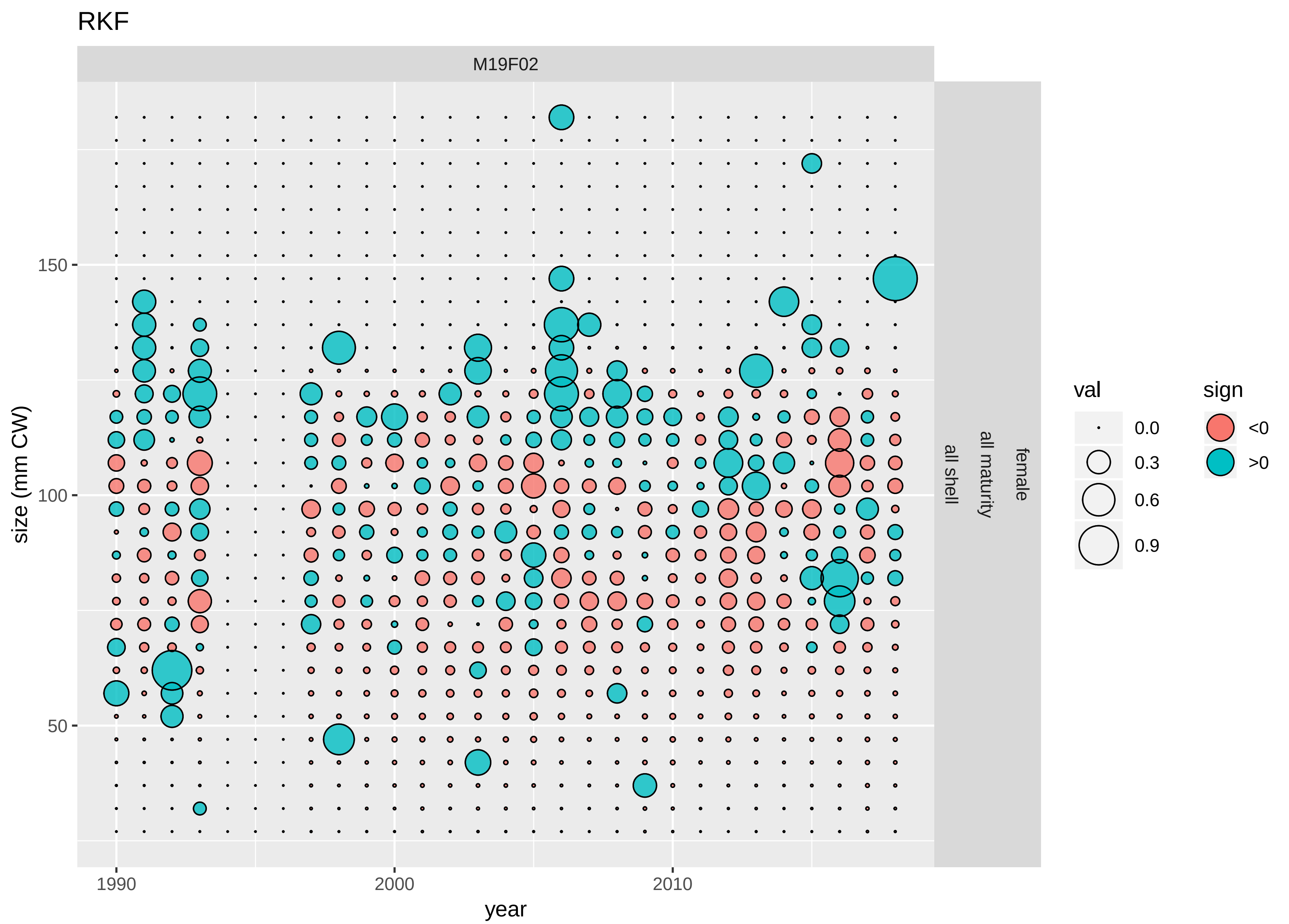


Figure 57: Pearson's residuals for female proportions-at-size from the RKF for scenario M19F02.

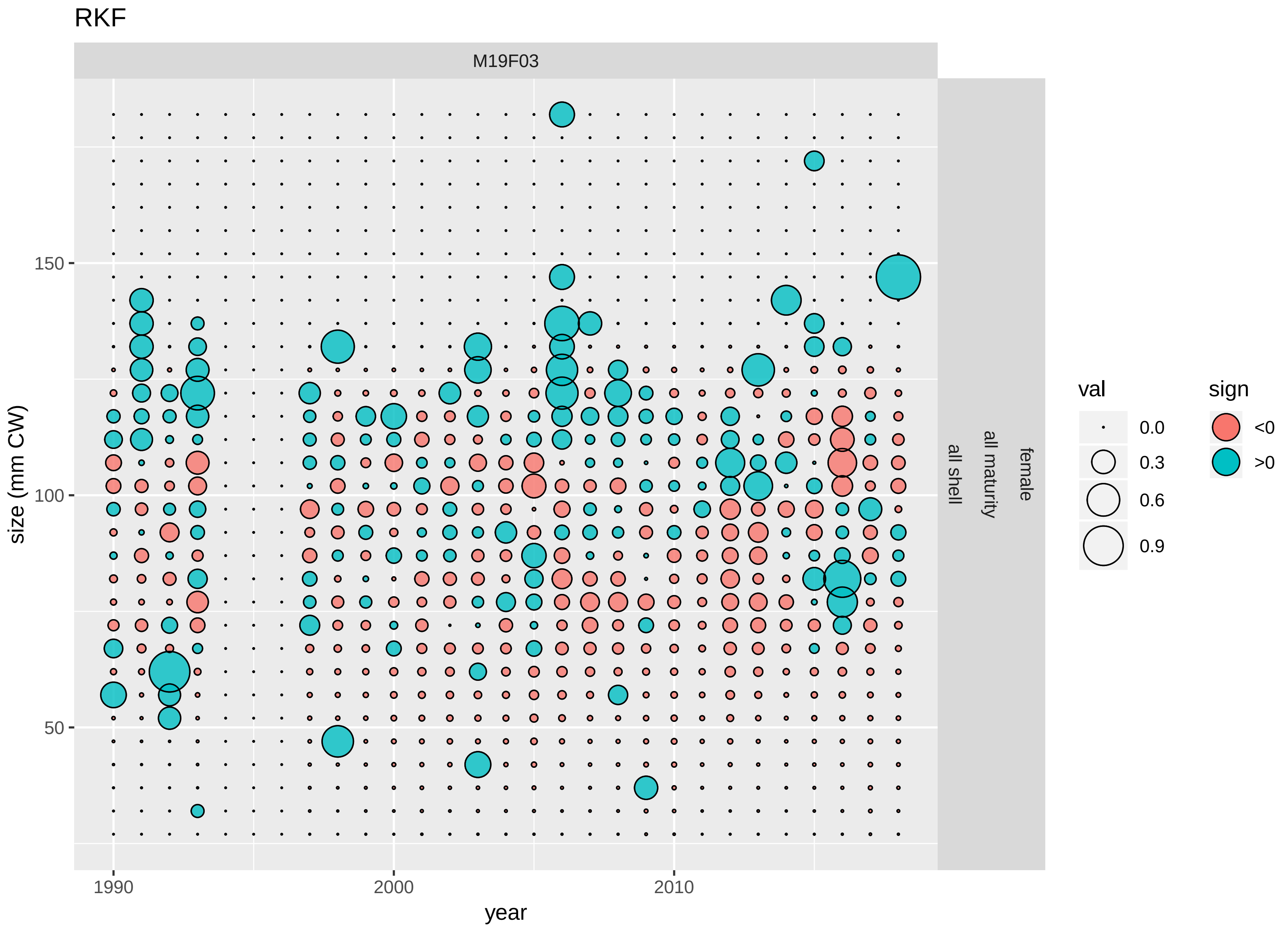


Figure 58: Pearson's residuals for female proportions-at-size from the RKF for scenario M19F03.

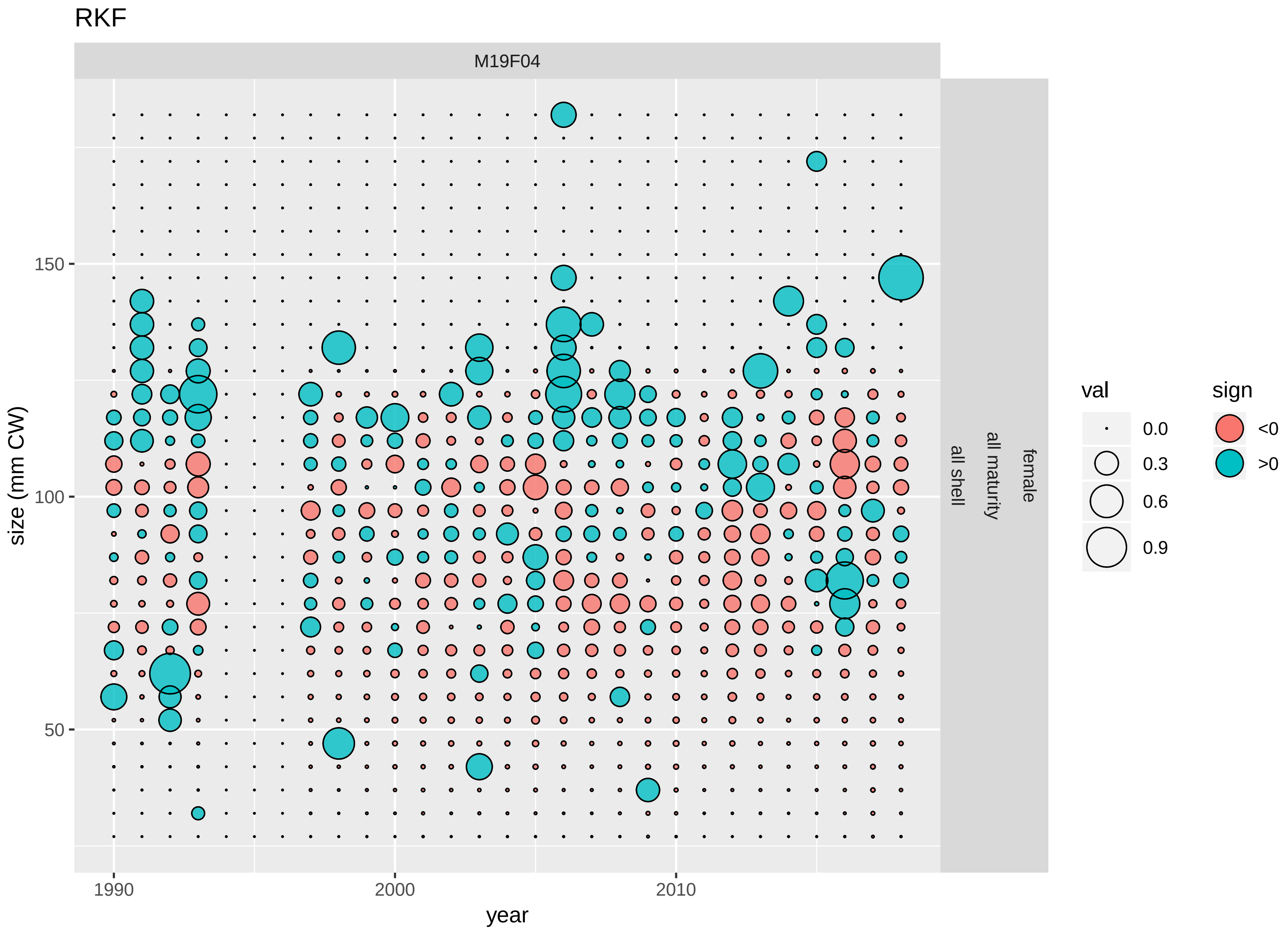


Figure 59: Pearson's residuals for female proportions-at-size from the RKF for scenario M19F04.

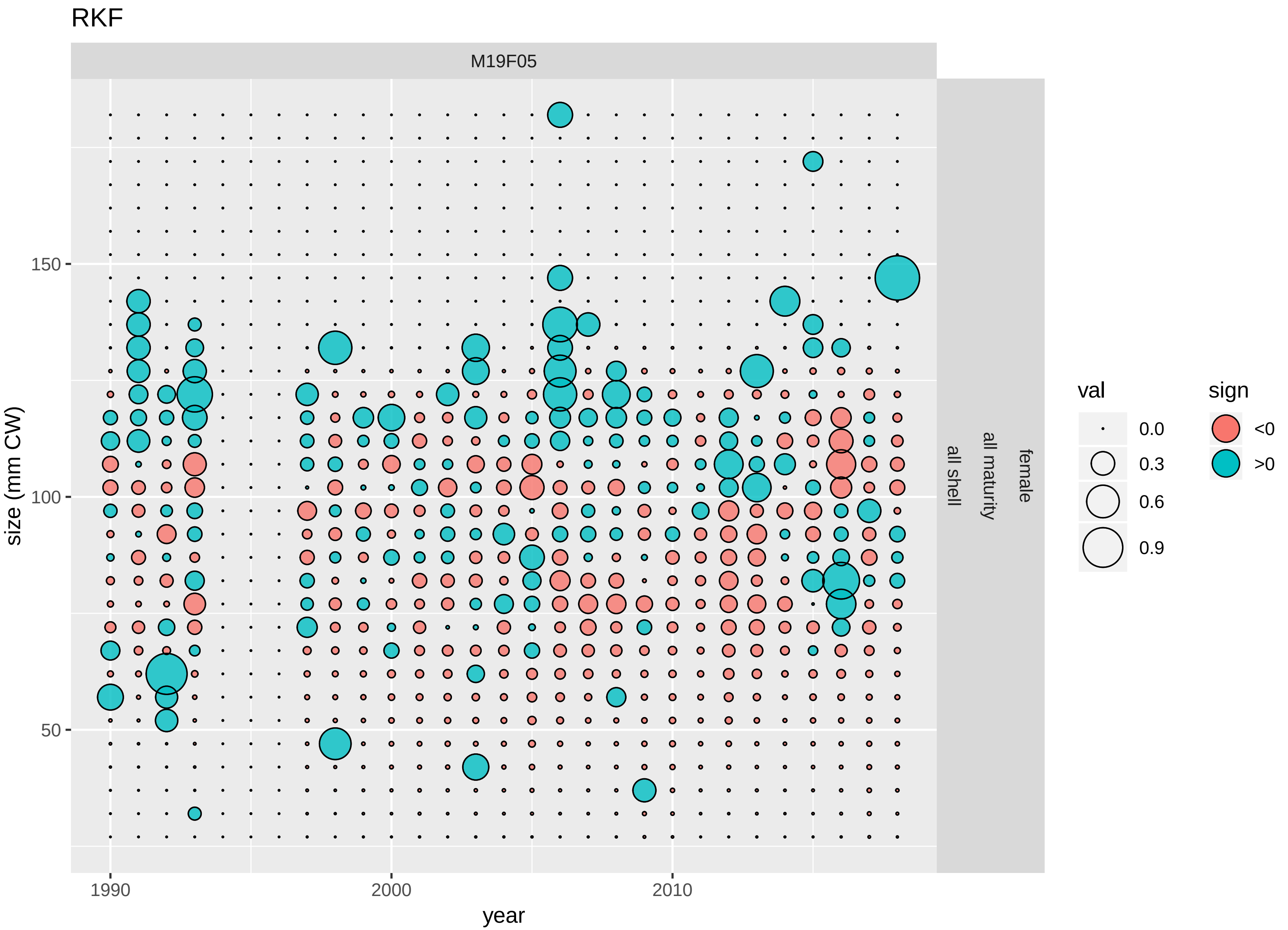


Figure 60: Pearson's residuals for female proportions-at-size from the RKF for scenario M19F05.

Effective Ns for total catch size compositions

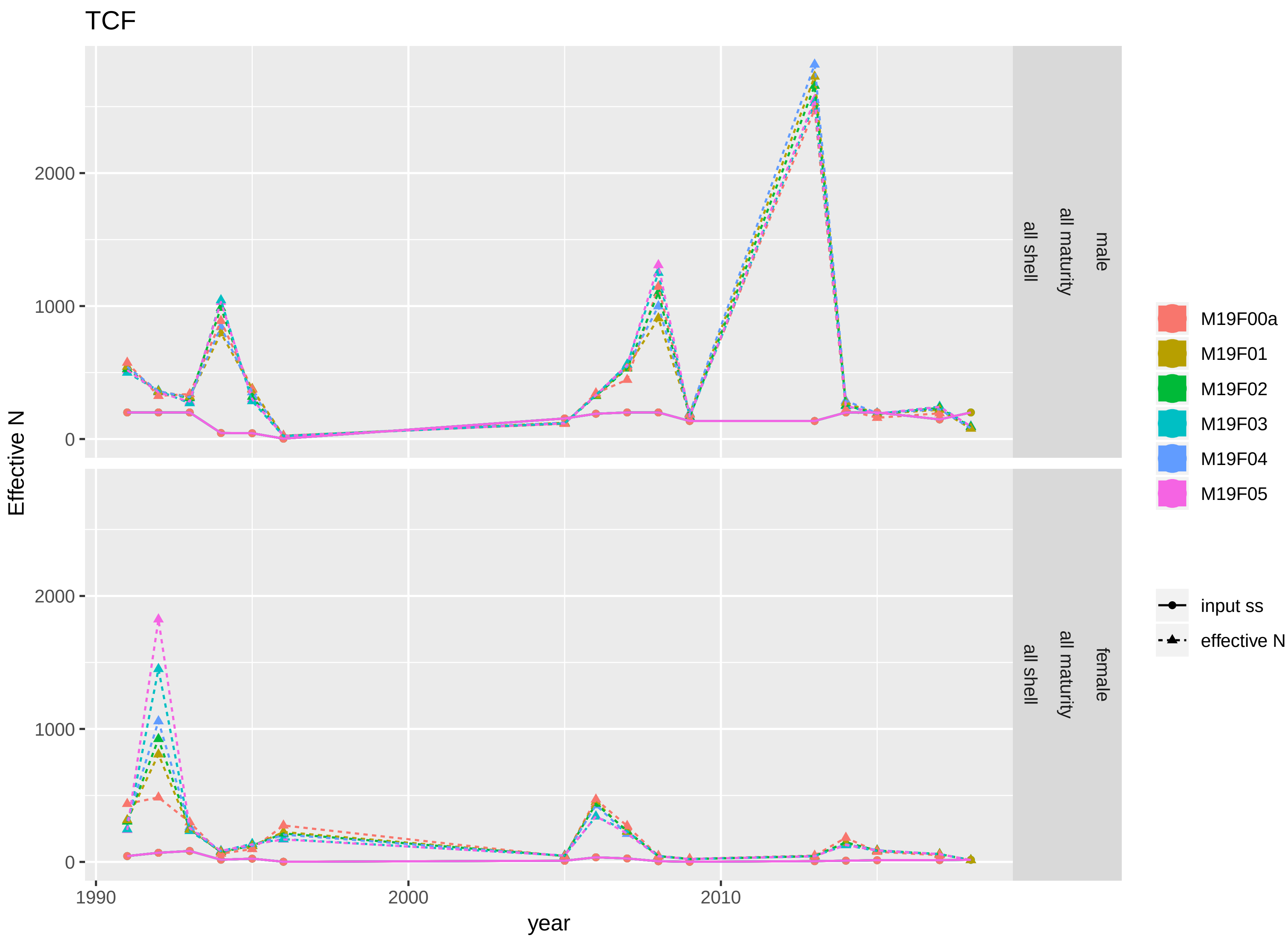


Figure 61: Input and effective sample sizes from total catch size compositions from the TCF fishery.

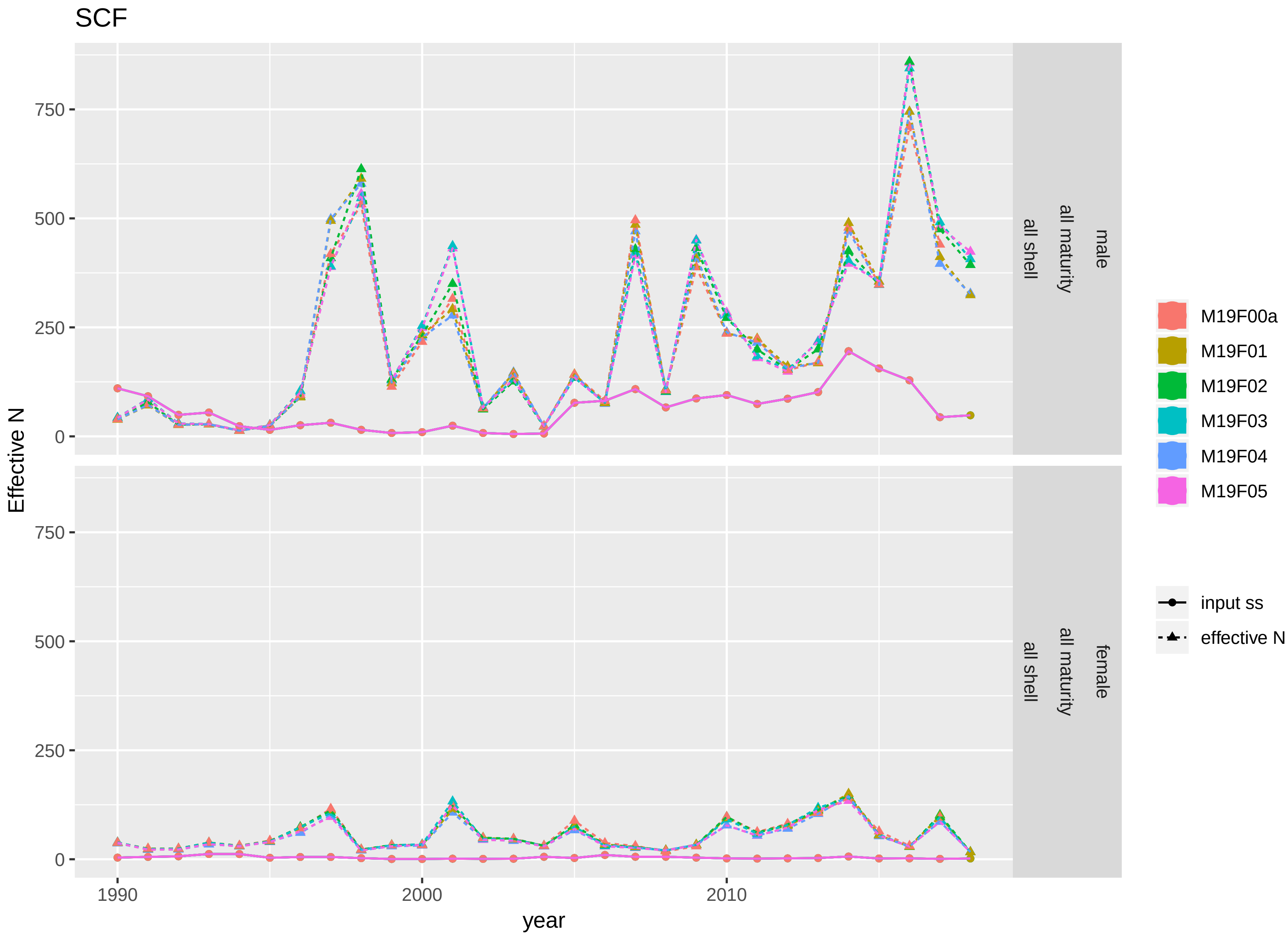


Figure 62: Input and effective sample sizes from total catch size compositions from the SCF fishery.

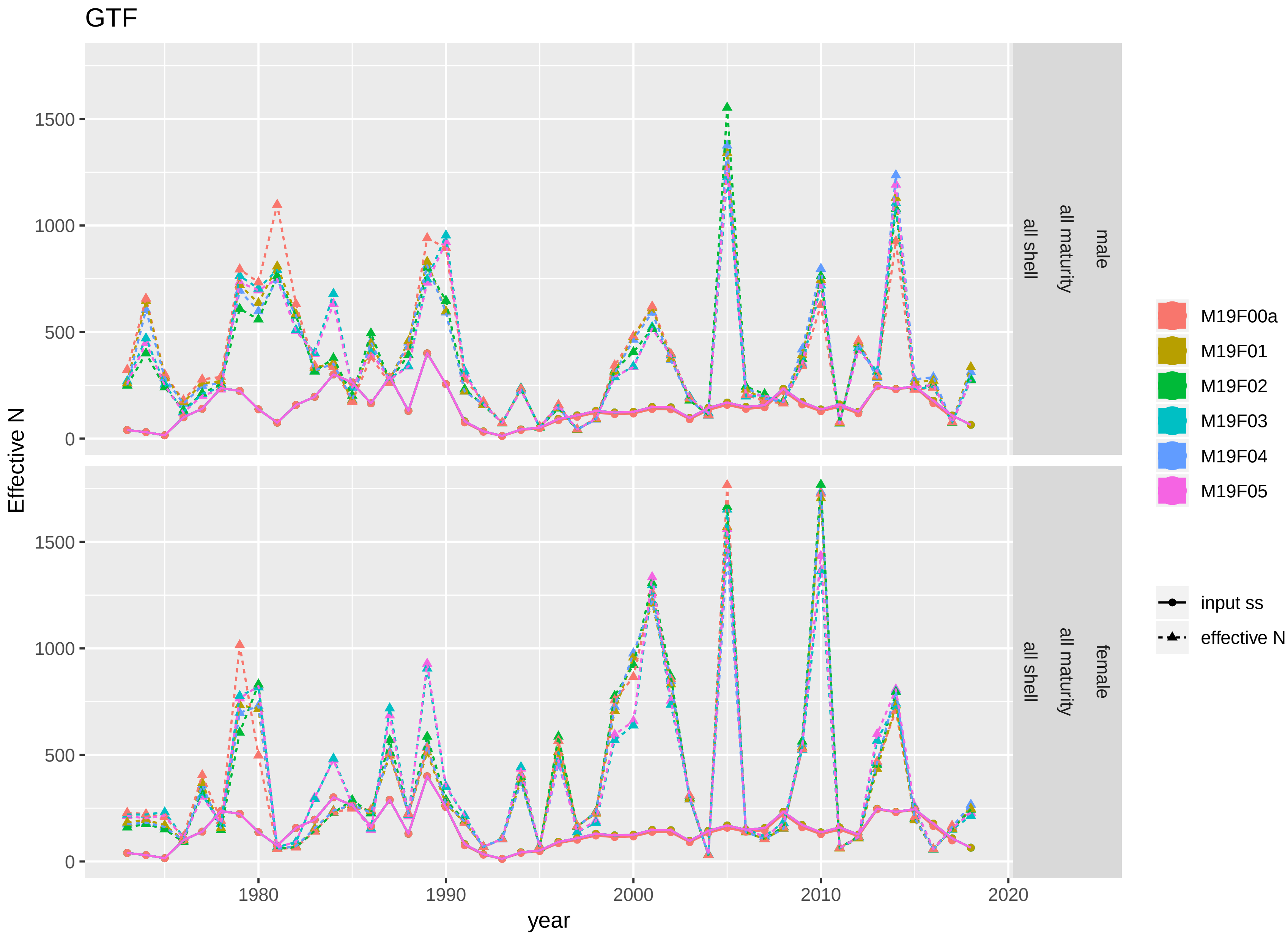


Figure 63: Input and effective sample sizes from total catch size compositions from the GTF fishery.

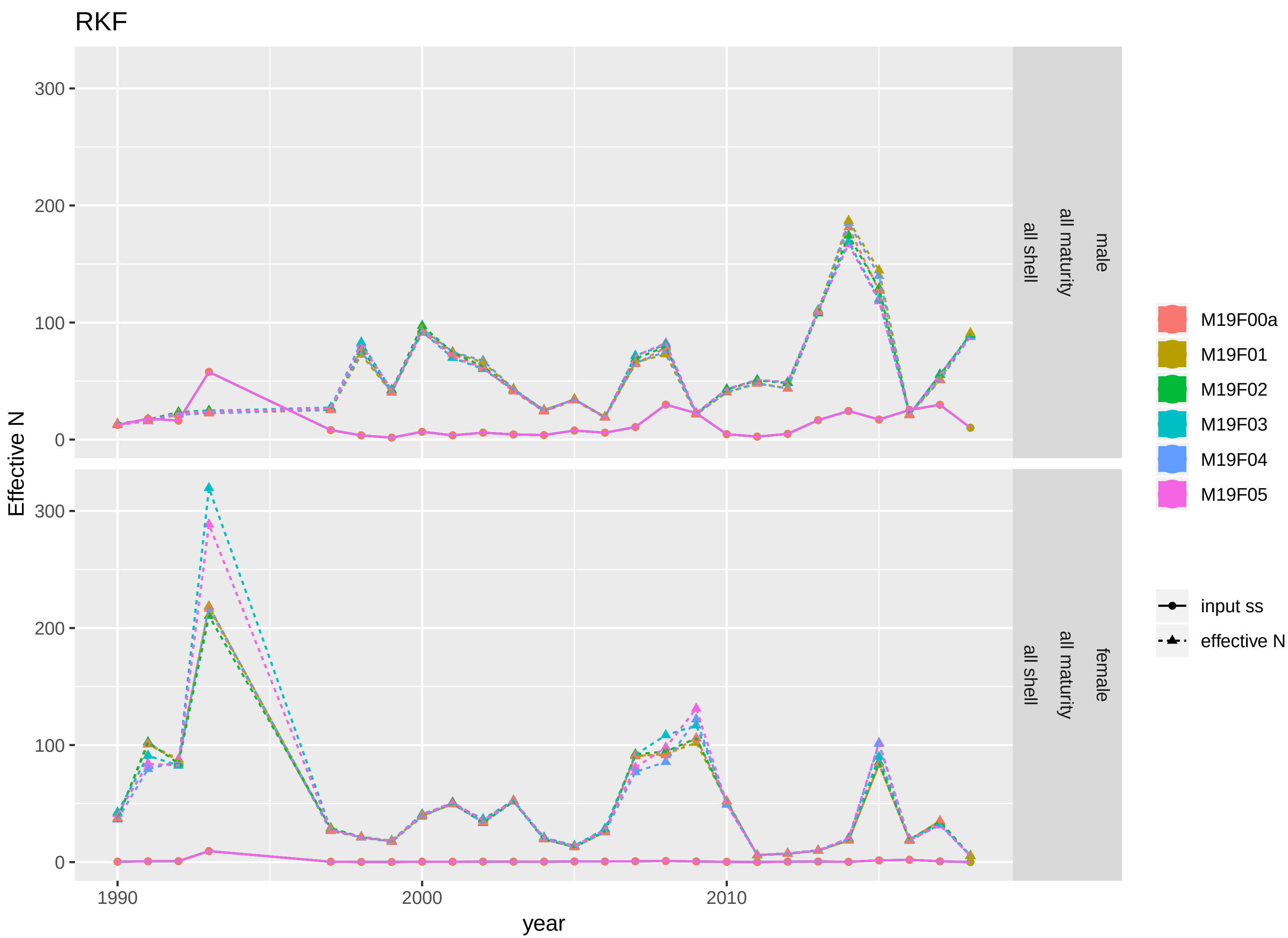


Figure 64: Input and effective sample sizes from total catch size compositions from the RKF fishery.

Model Comparisons: Fits to Surveys Size Composition Data – M19F00a vs M19F01 vs M19F02 vs M19F03 vs M19F04 vs M19F05

William Stockhausen

07 September, 2019

Contents

Introduction

Fits to survey size composition data available to the model(s) are presented in this section. Included are plots of mean fits to size compositions, Pearson's residuals as bubble plots, and effective sample sizes. Not all of the fits presented are necessarily included in the parameter optimization for each model; some fits to datasets for a particular model may be included for comparison purposes with other models which include those data in their optimization. The reader should consult the main assessment document to determine which fits are included in the optimization for any particular model.

Mean survey size compositions

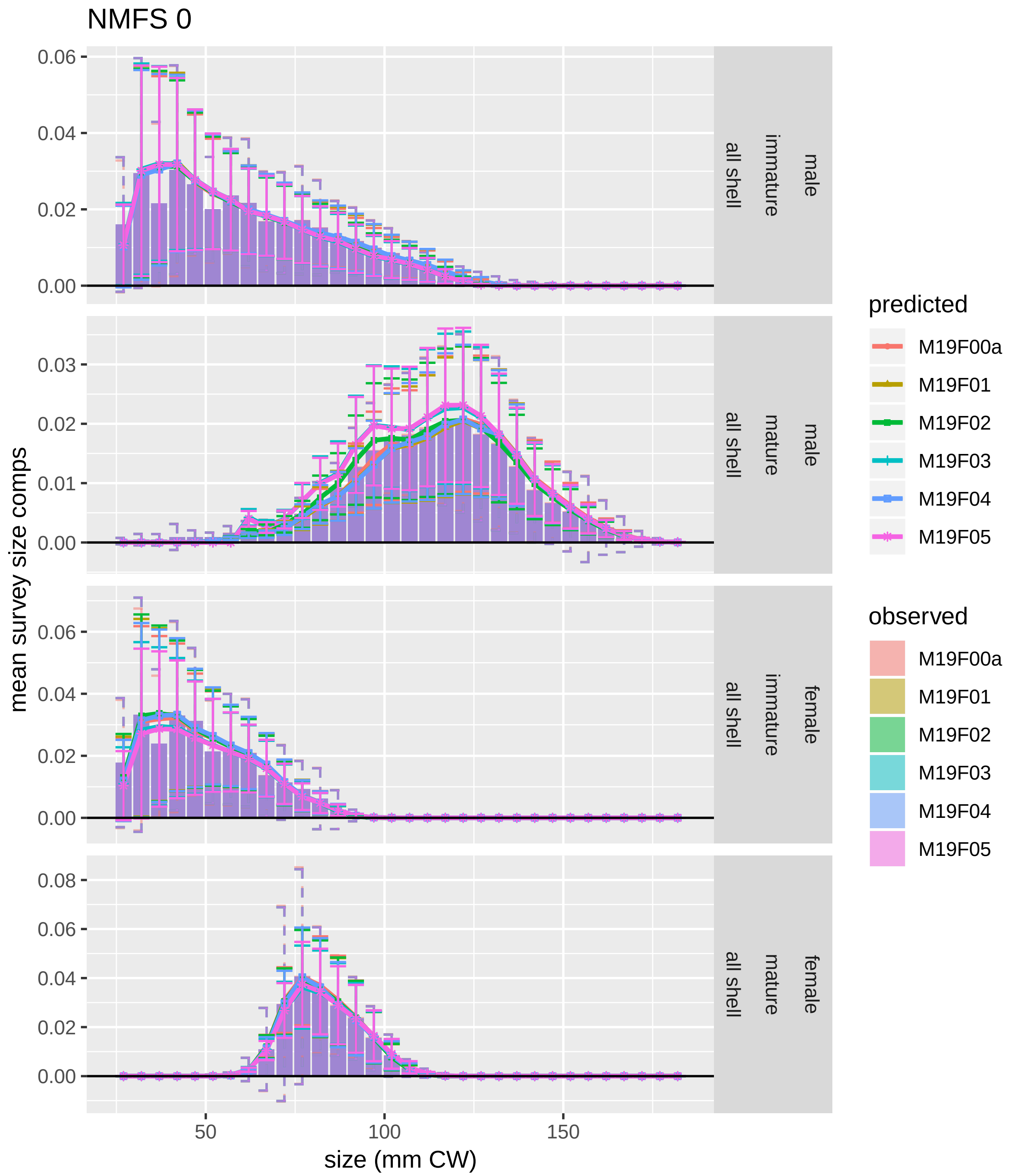


Figure 1: Comparison of observed and predicted mean survey size comps for NMFS 0.

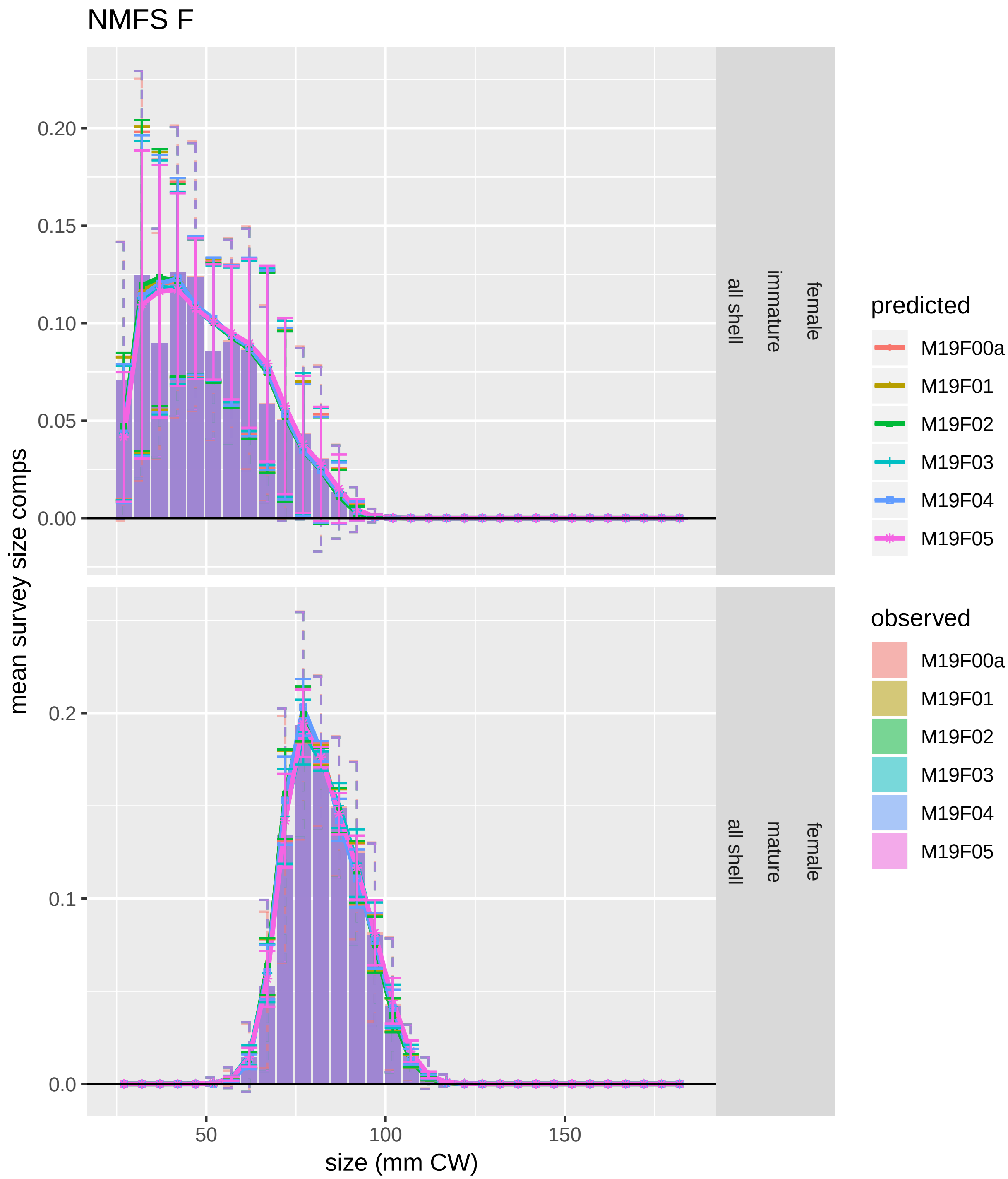


Figure 2: Comparison of observed and predicted mean survey size comps for NMFS F.

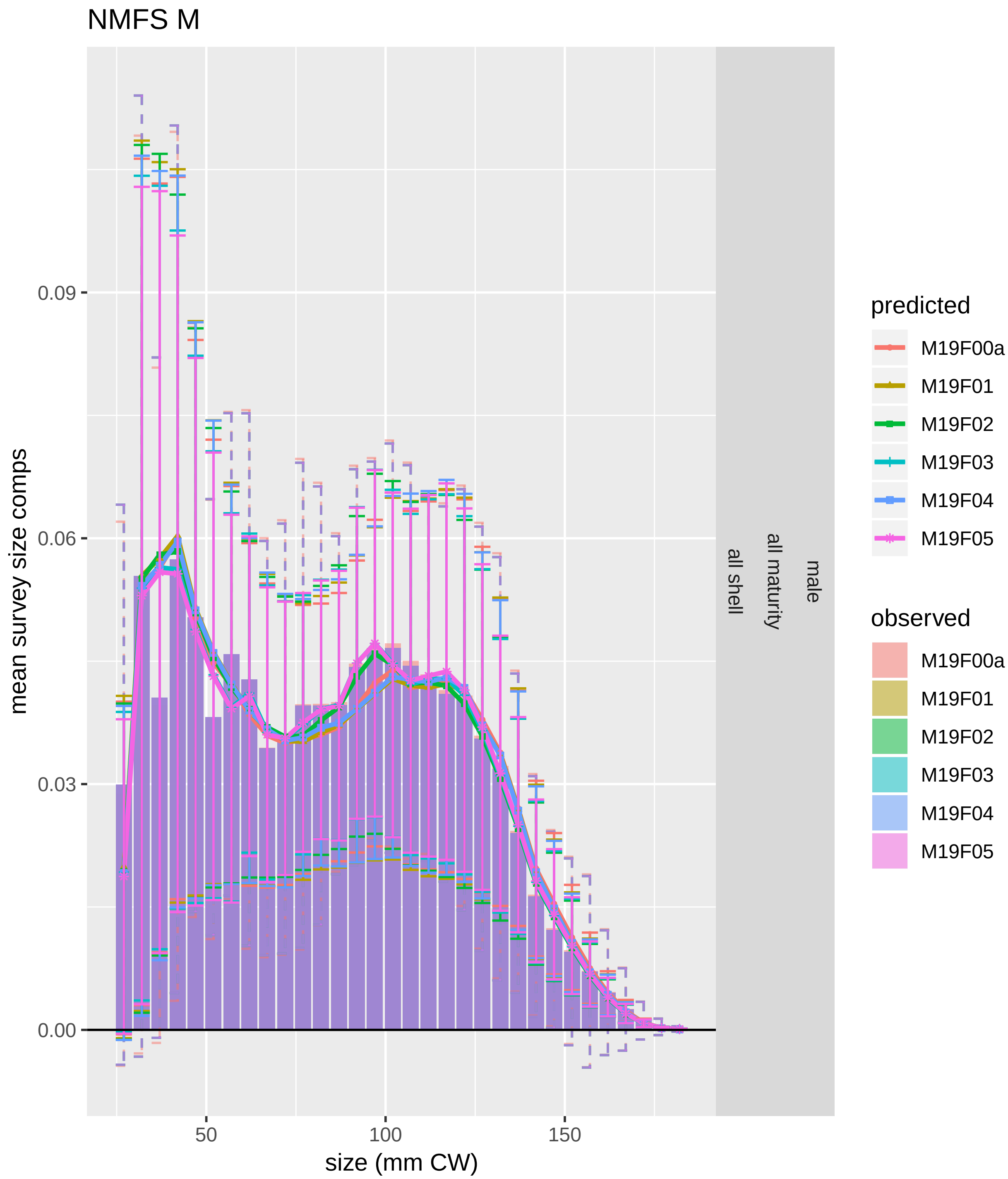


Figure 3: Comparison of observed and predicted mean survey size comps for NMFS M.

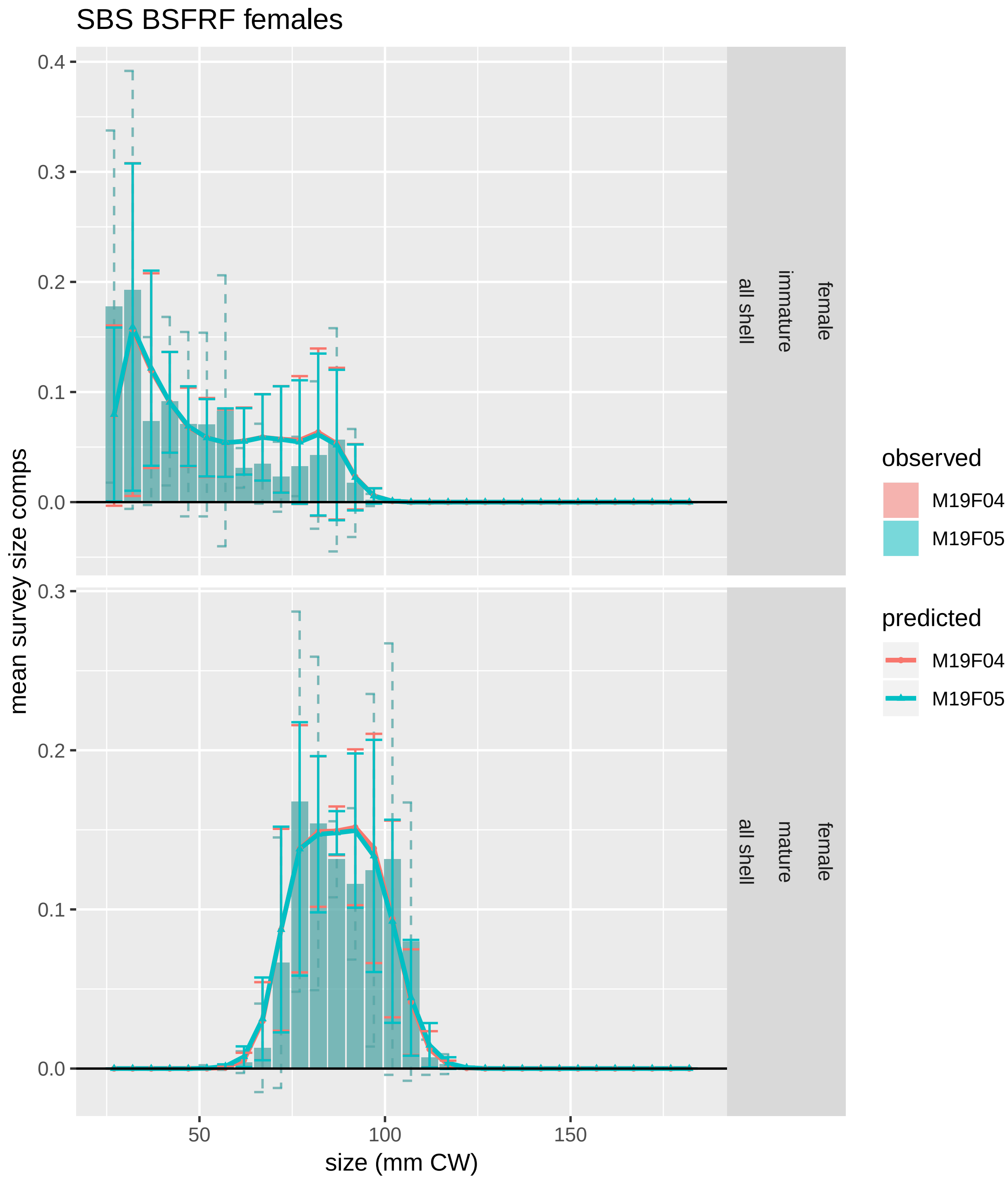


Figure 4: Comparison of observed and predicted mean survey size comps for SBS BSFRF females.

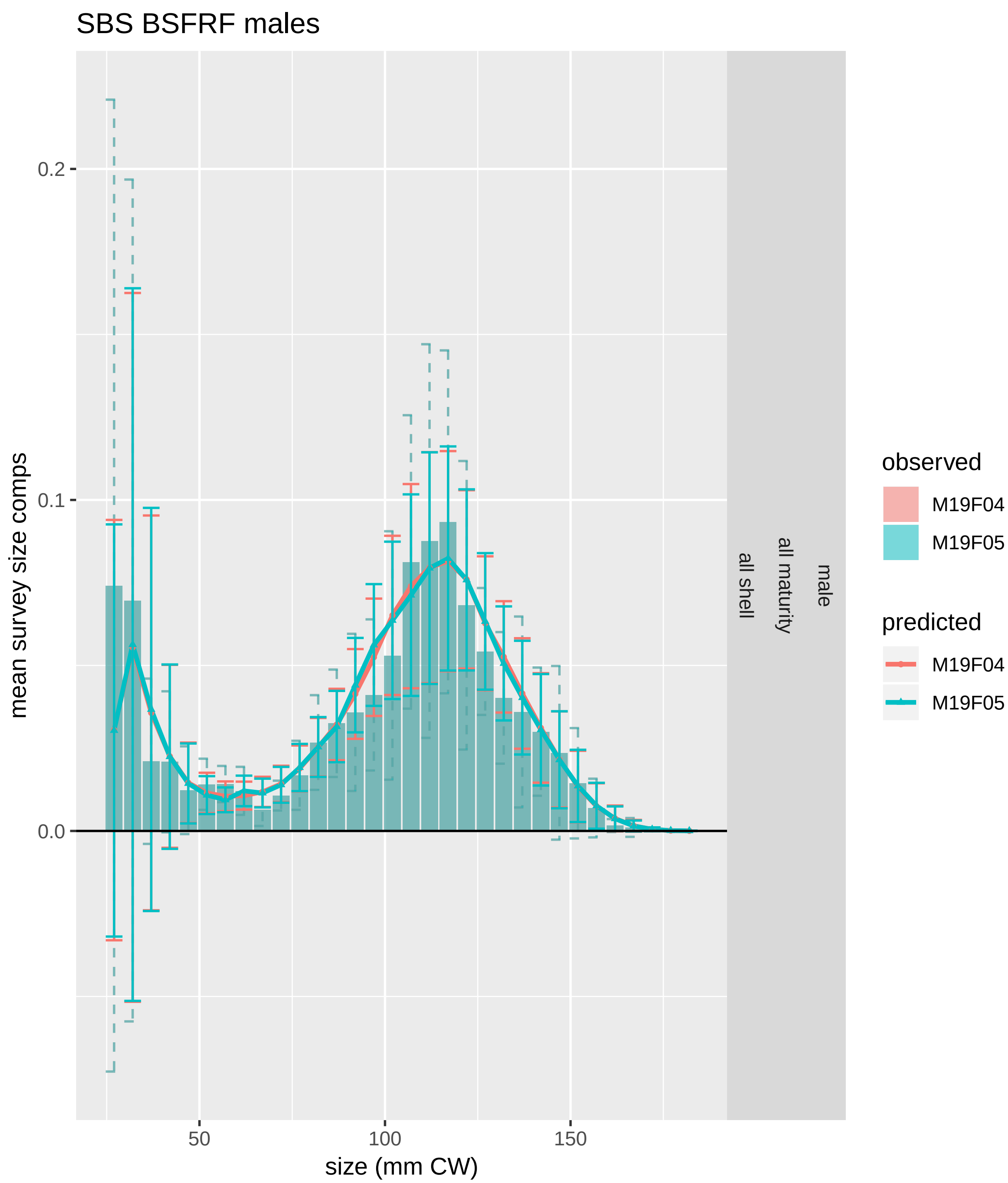


Figure 5: Comparison of observed and predicted mean survey size comps for SBS BSFRF males.

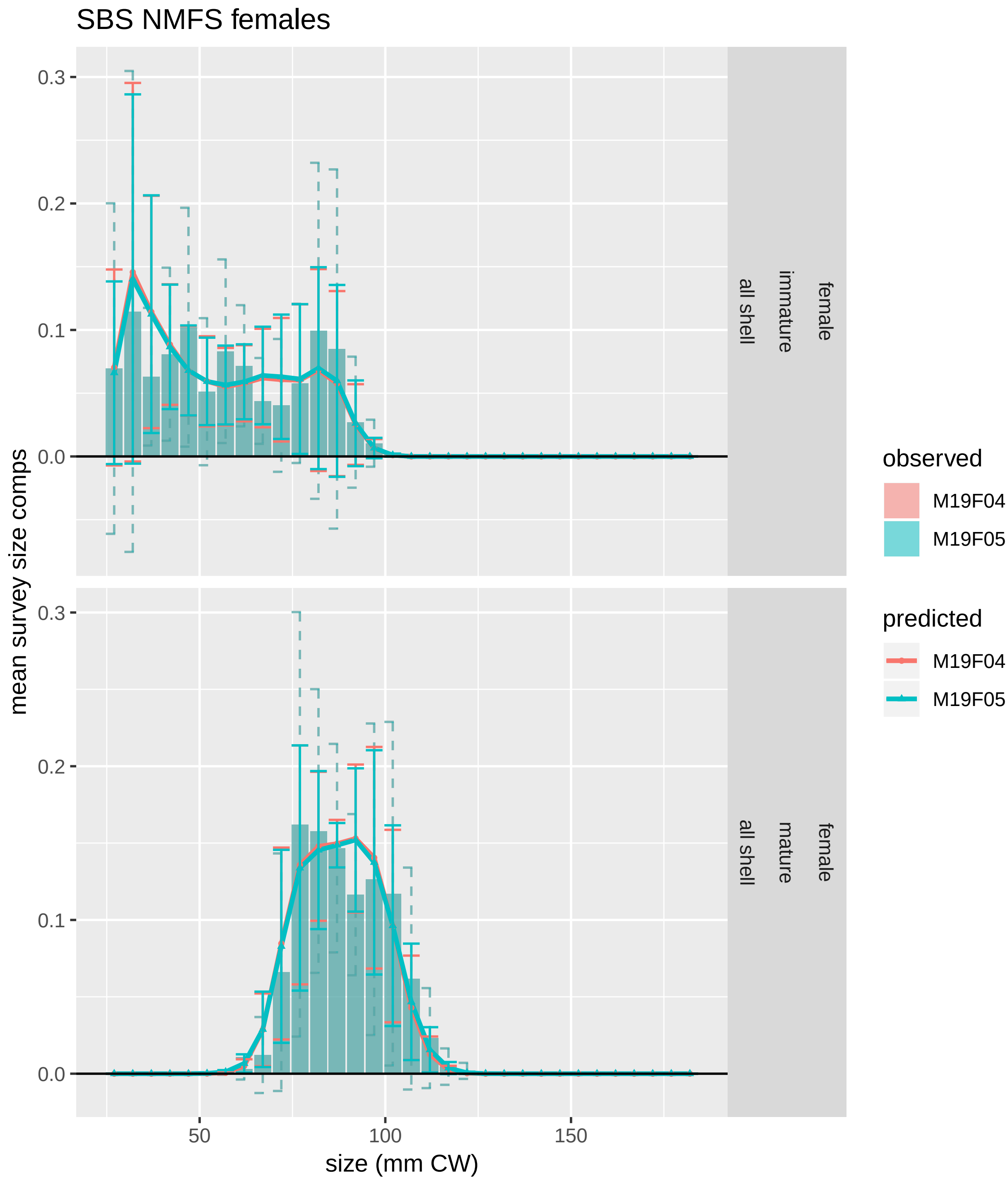


Figure 6: Comparison of observed and predicted mean survey size comps for SBS NMFS females.

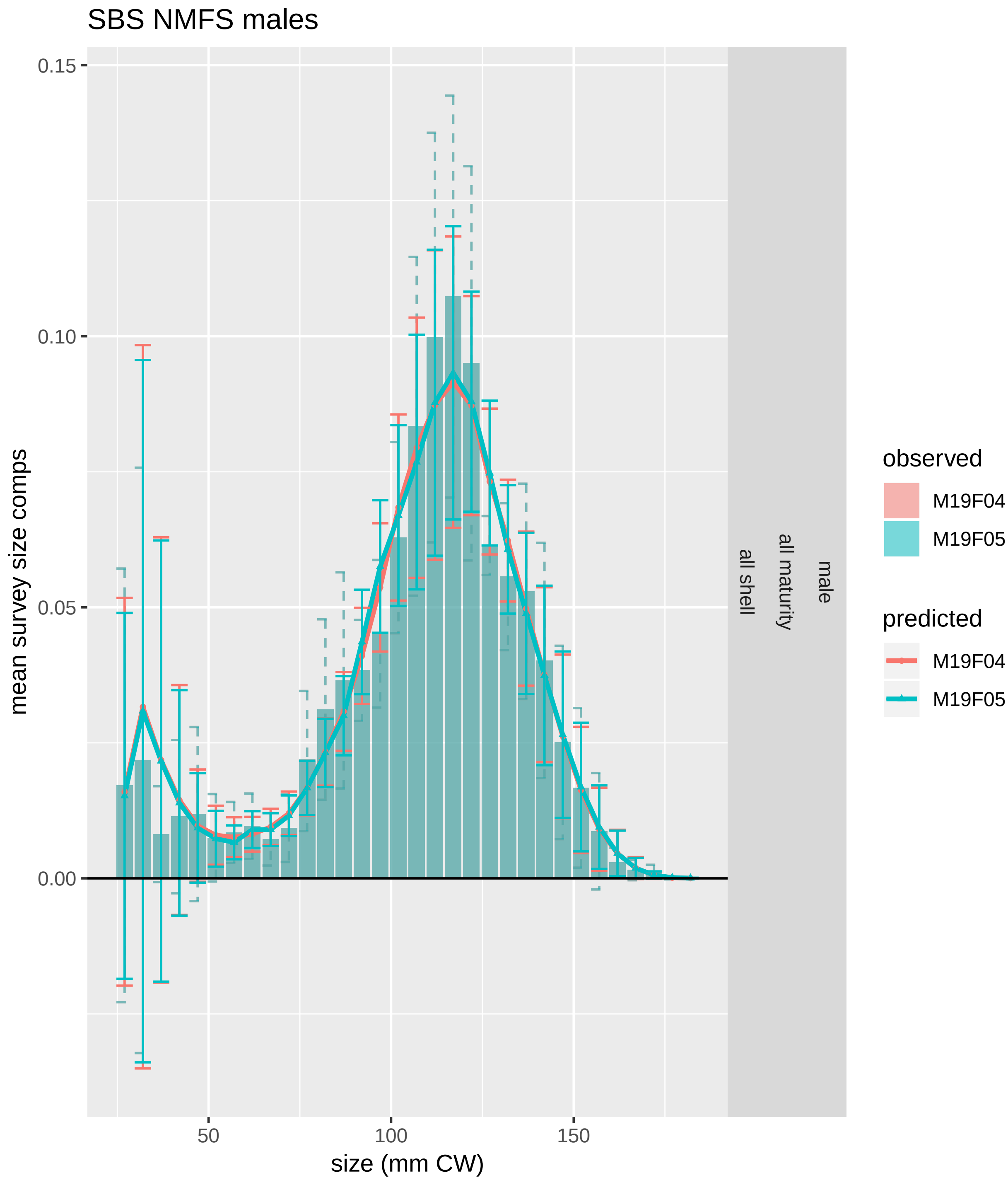


Figure 7: Comparison of observed and predicted mean survey size comps for SBS NMFS males.

Residuals to survey size composition data

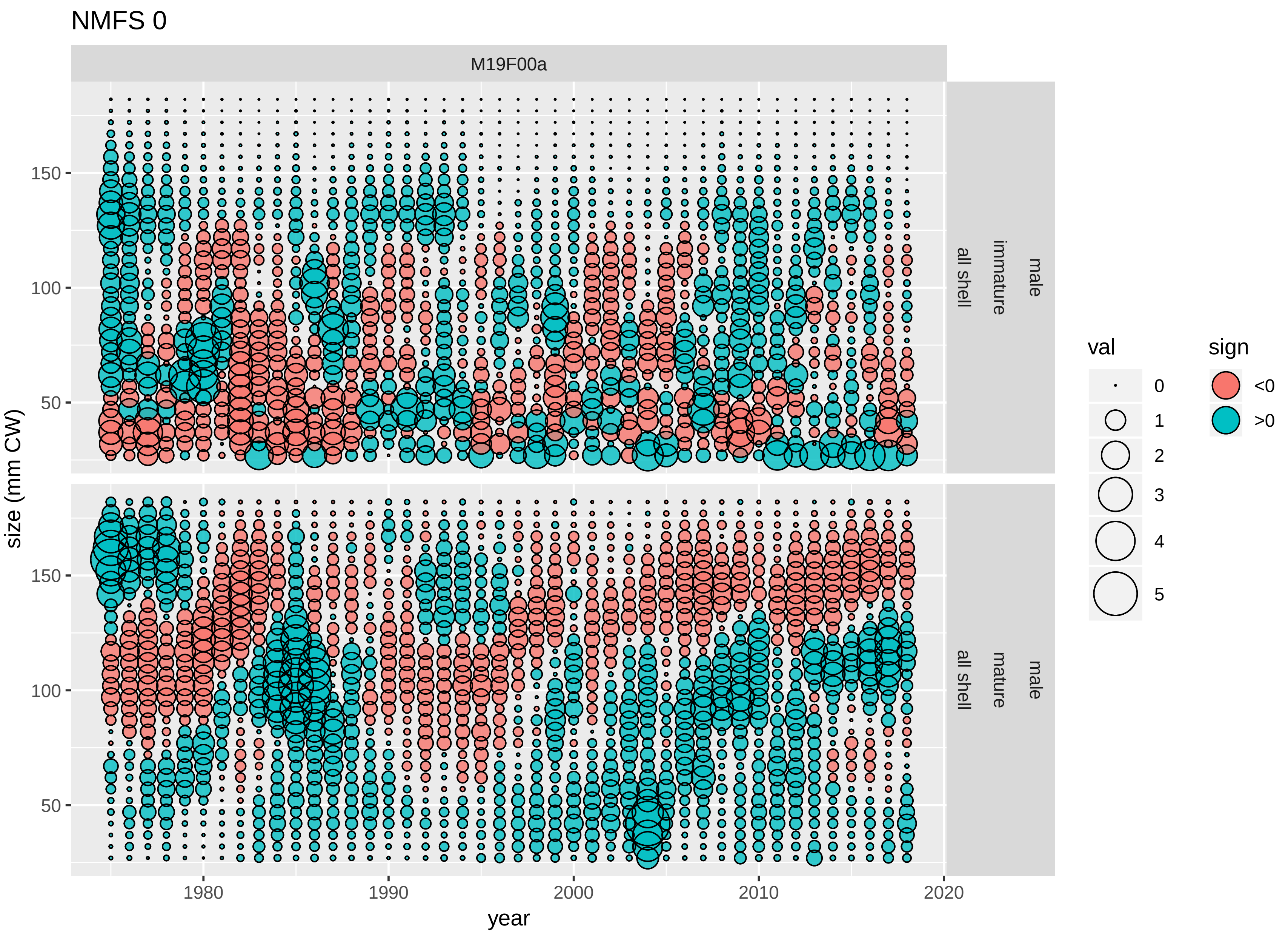


Figure 8: Pearson's residuals for male proportions-at-size from the NMFS 0 for scenario M19F00a.

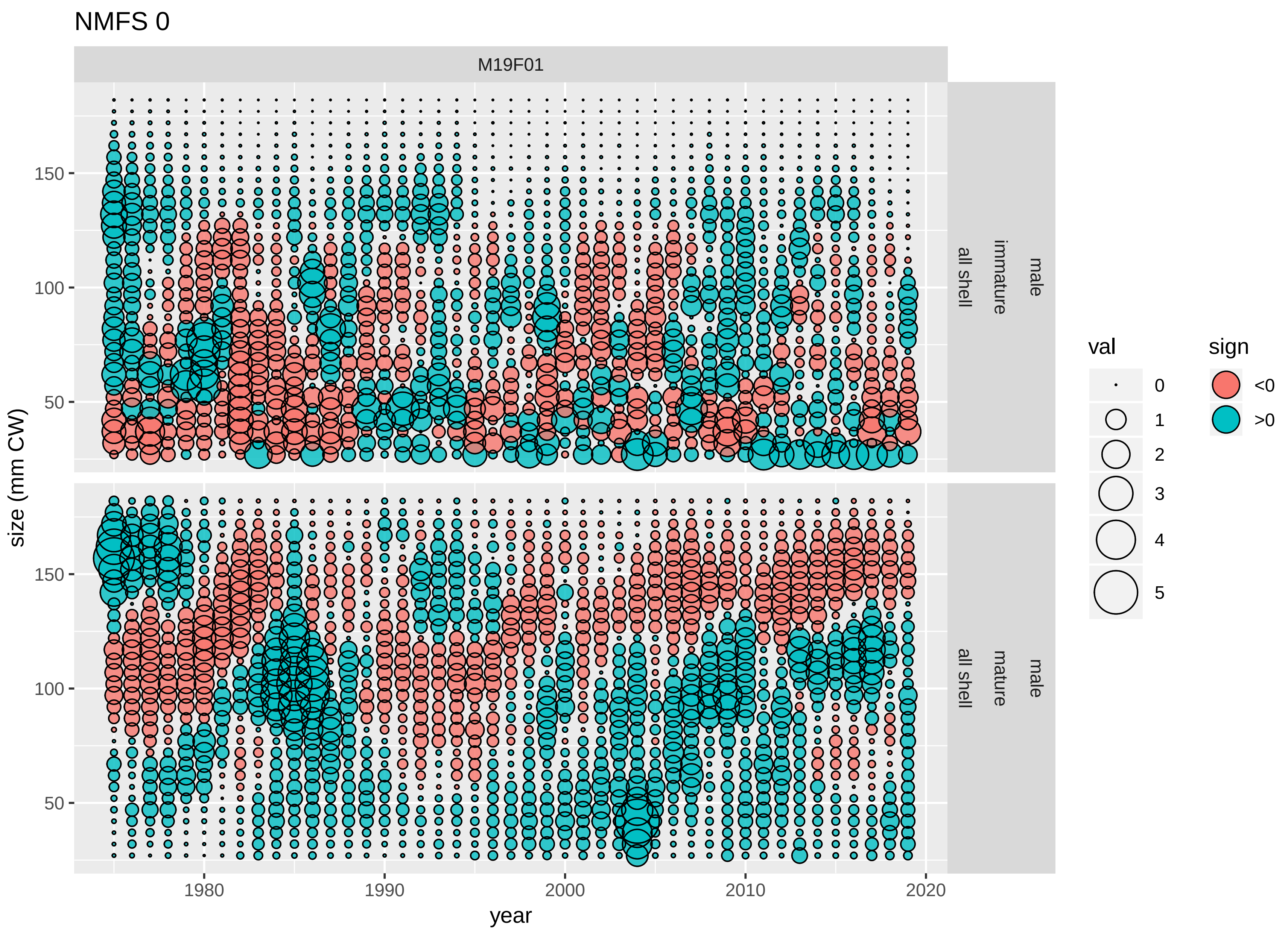


Figure 9: Pearson's residuals for male proportions-at-size from the NMFS 0 for scenario M19F01.

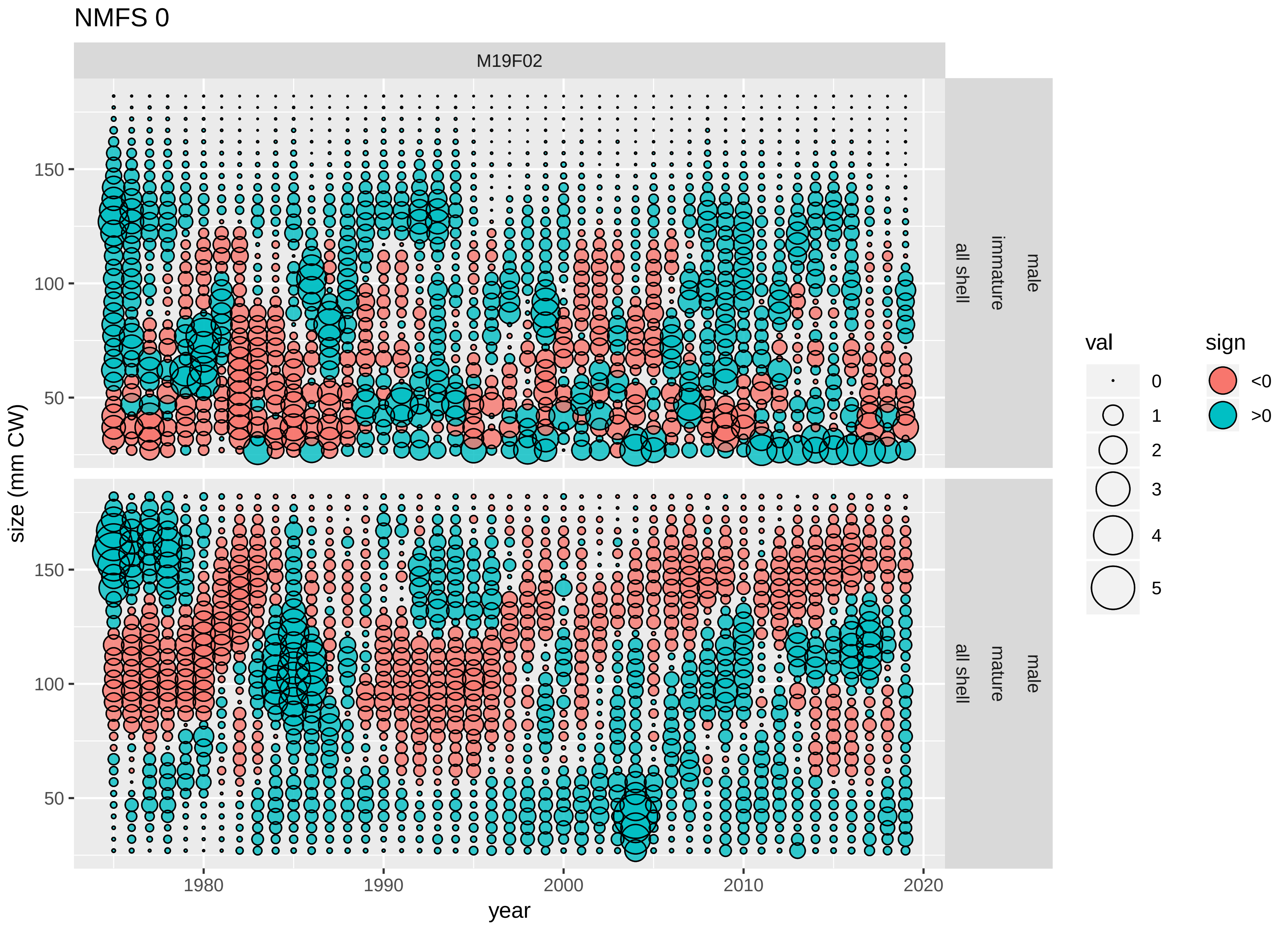


Figure 10: Pearson's residuals for male proportions-at-size from the NMFS 0 for scenario M19F02.

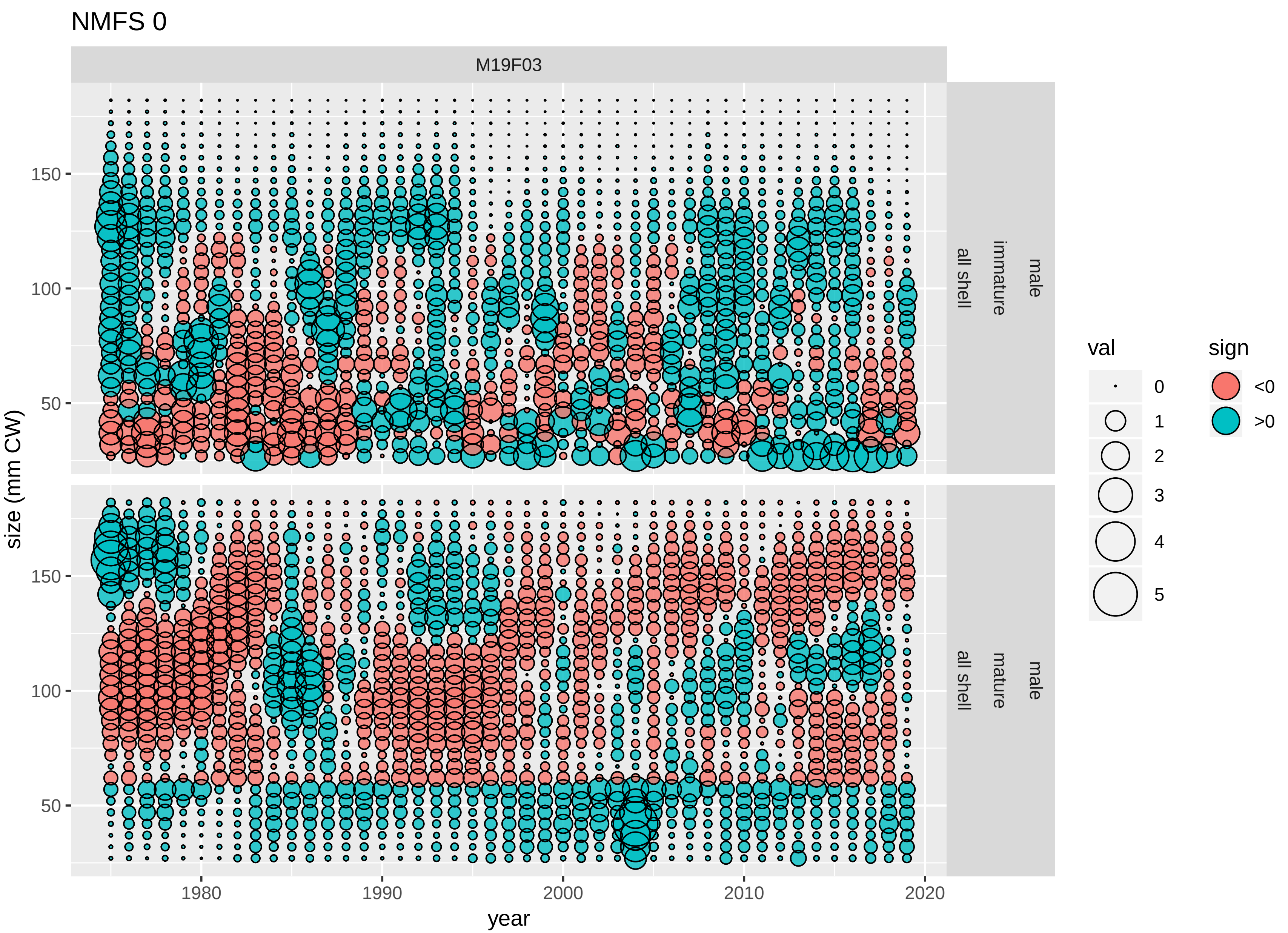


Figure 11: Pearson's residuals for male proportions-at-size from the NMFS 0 for scenario M19F03.

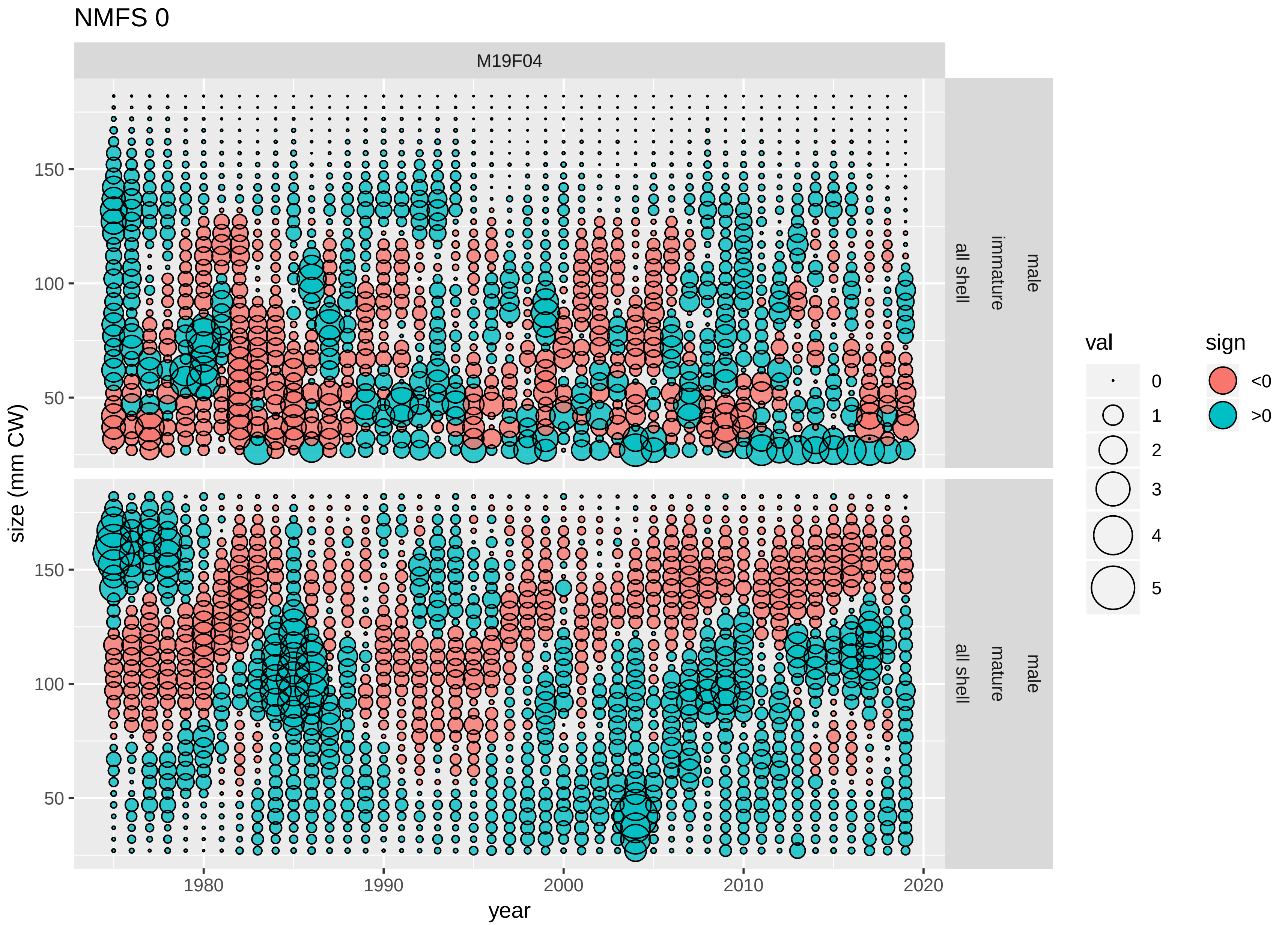


Figure 12: Pearson's residuals for male proportions-at-size from the NMFS 0 for scenario M19F04.

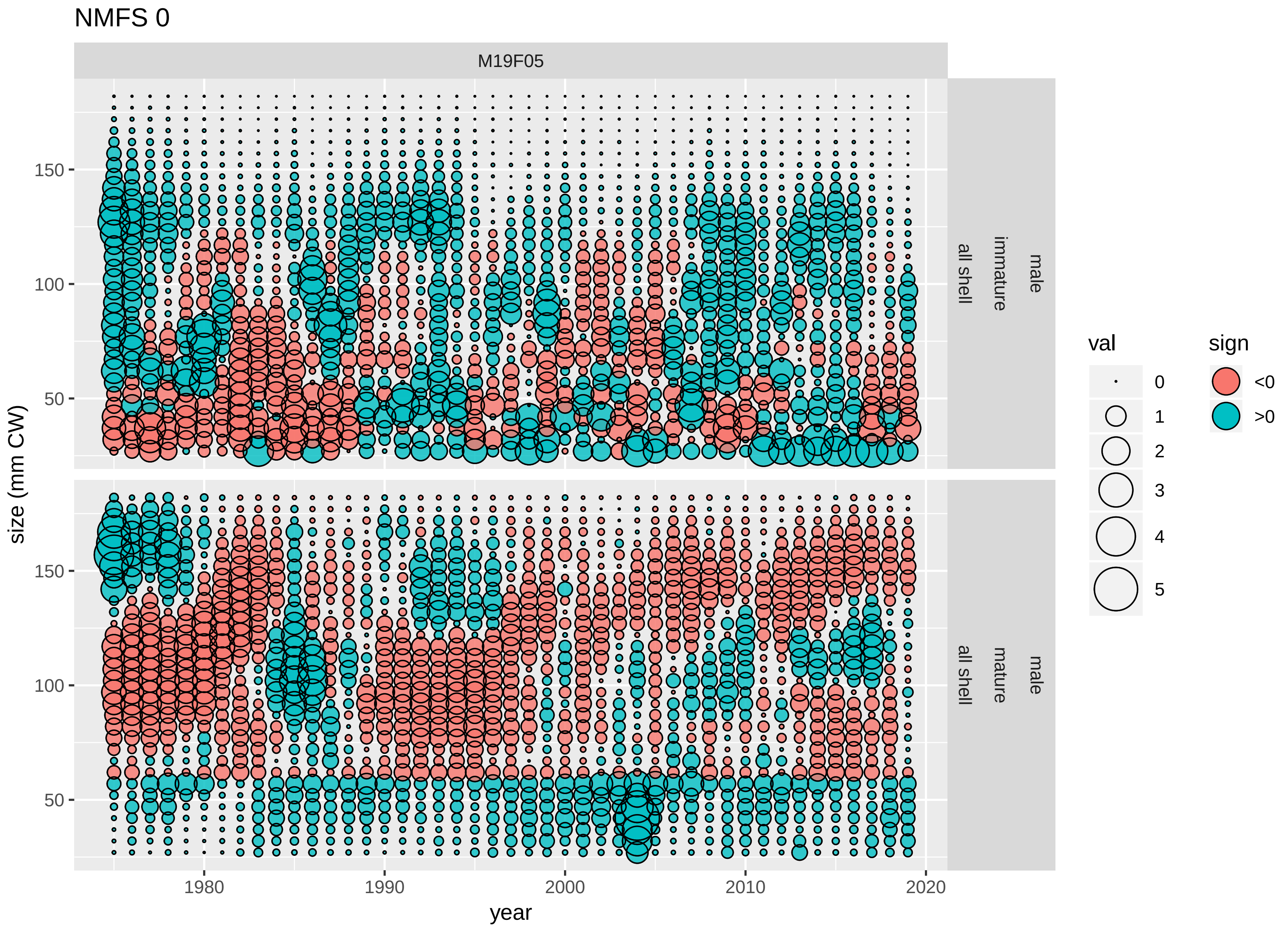


Figure 13: Pearson's residuals for male proportions-at-size from the NMFS 0 for scenario M19F05.

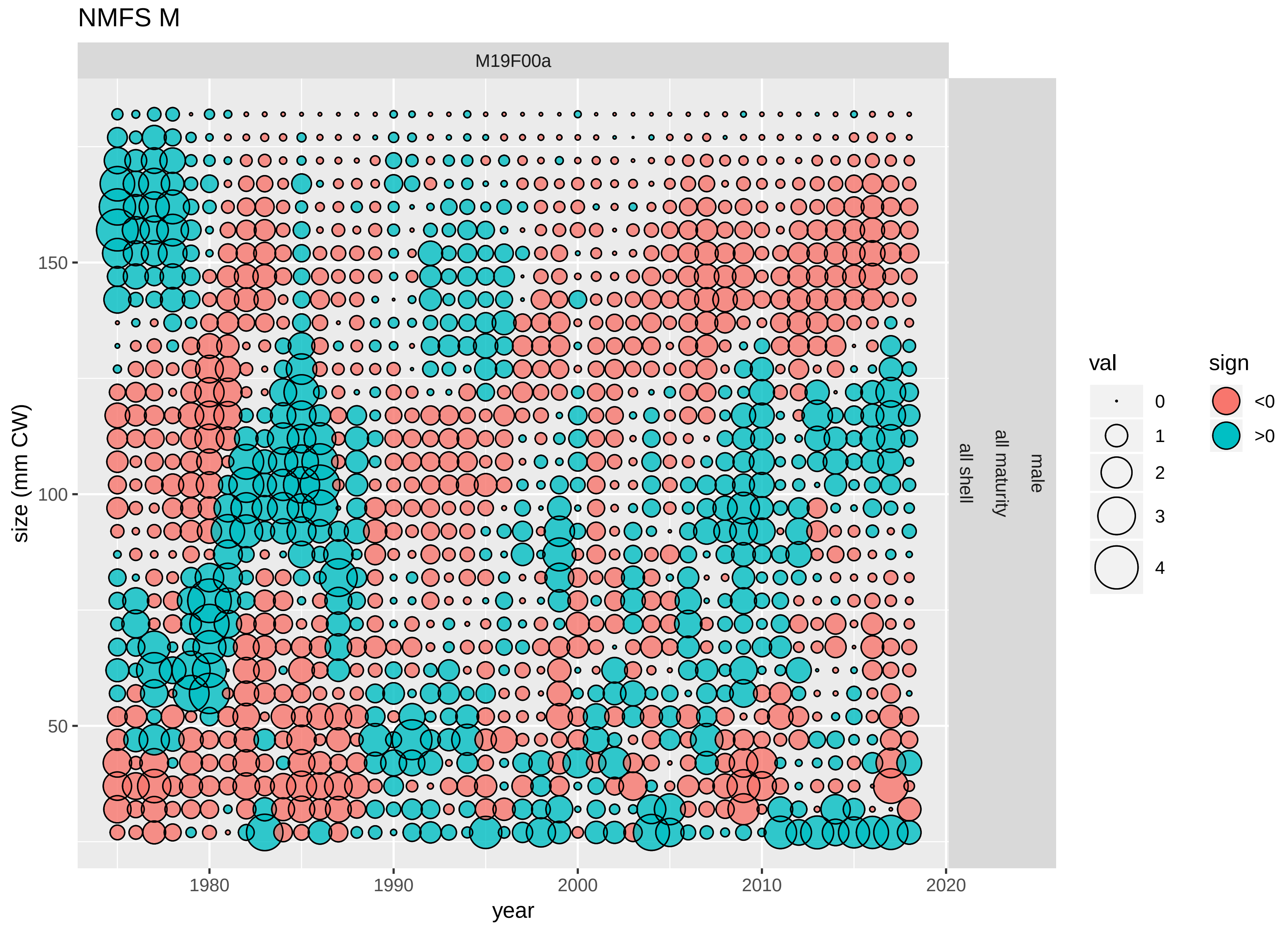


Figure 14: Pearson's residuals for male proportions-at-size from the NMFS M for scenario M19F00a.

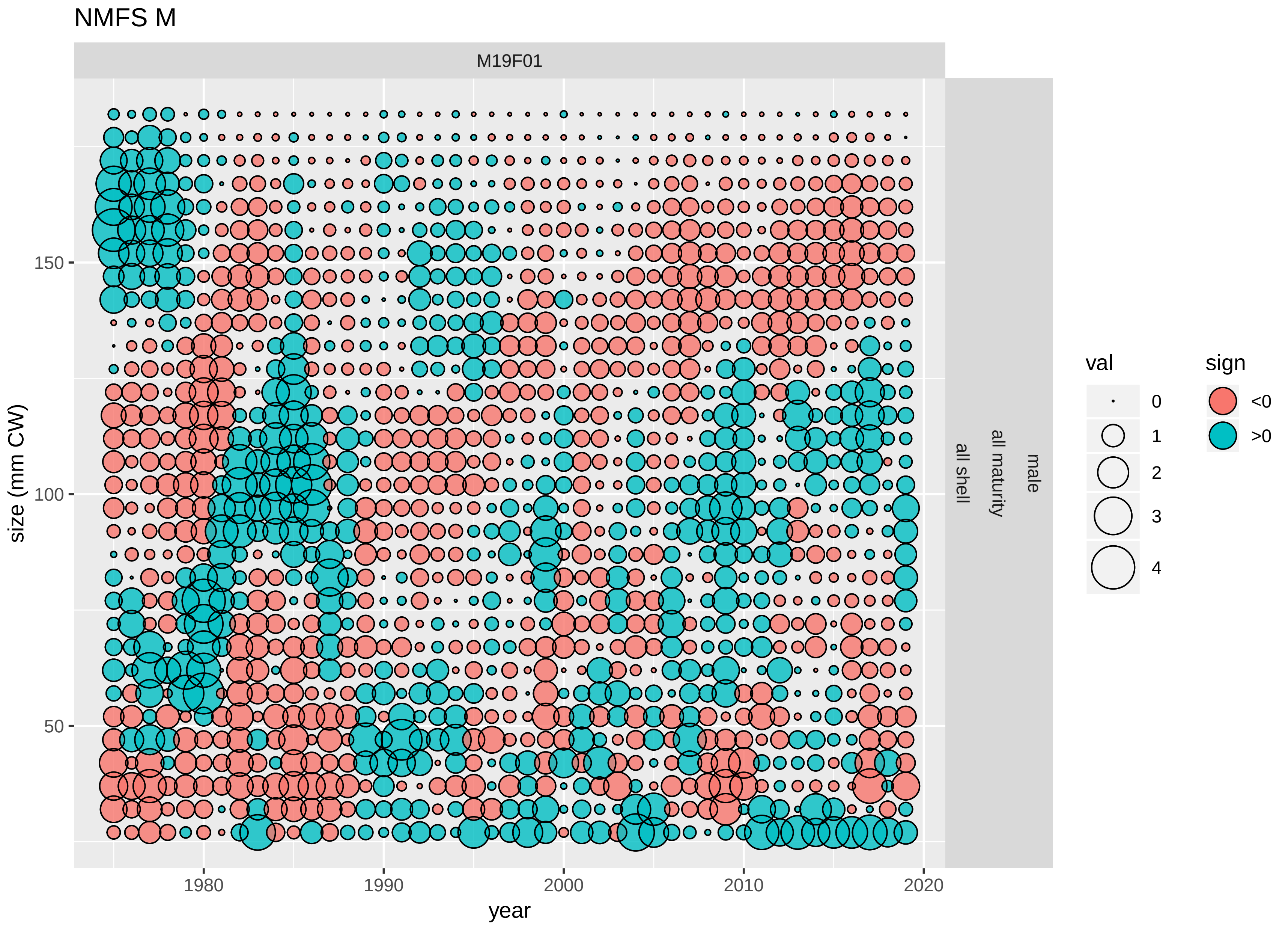


Figure 15: Pearson's residuals for male proportions-at-size from the NMFS M for scenario M19F01.

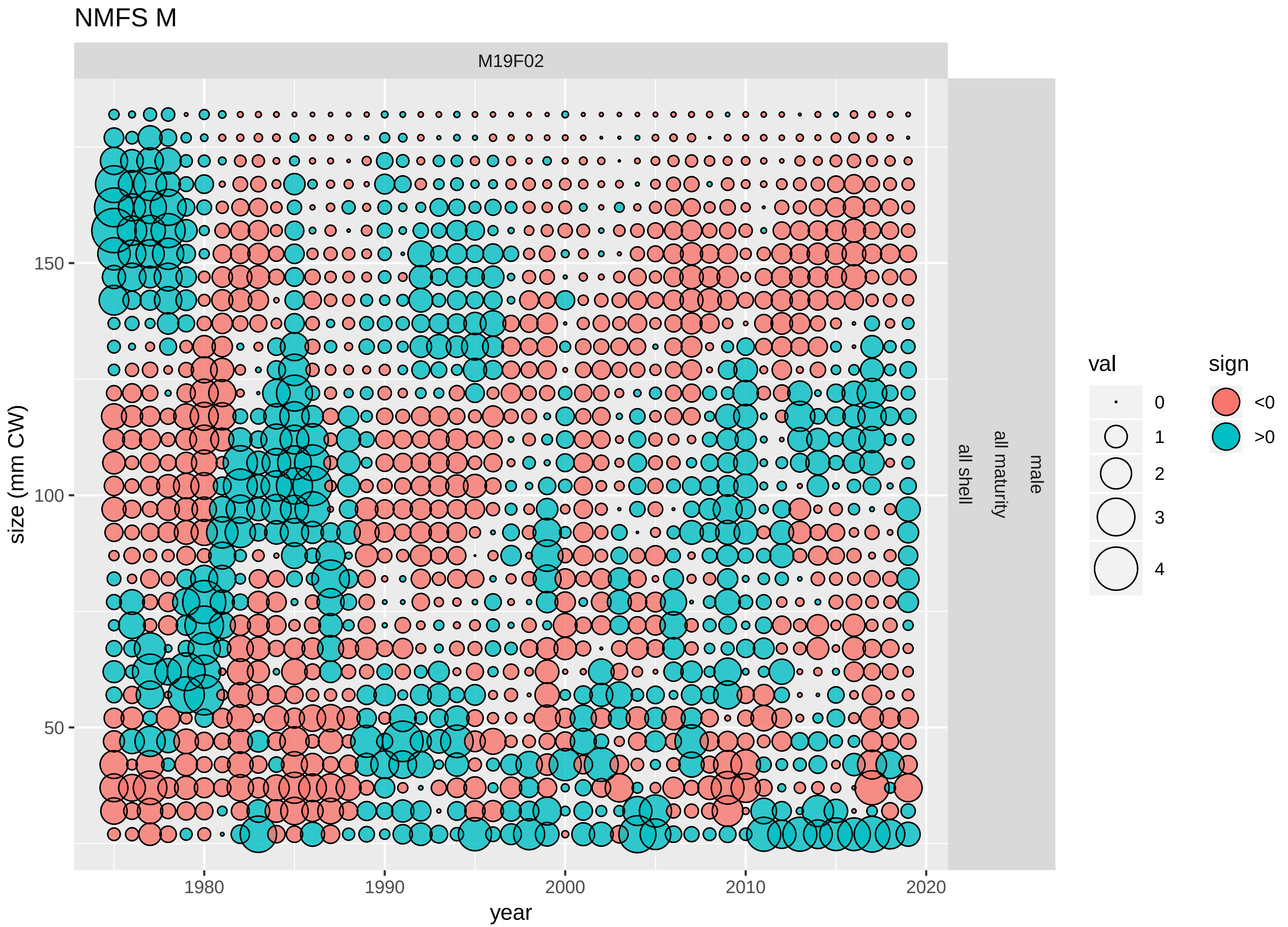


Figure 16: Pearson's residuals for male proportions-at-size from the NMFS M for scenario M19F02.

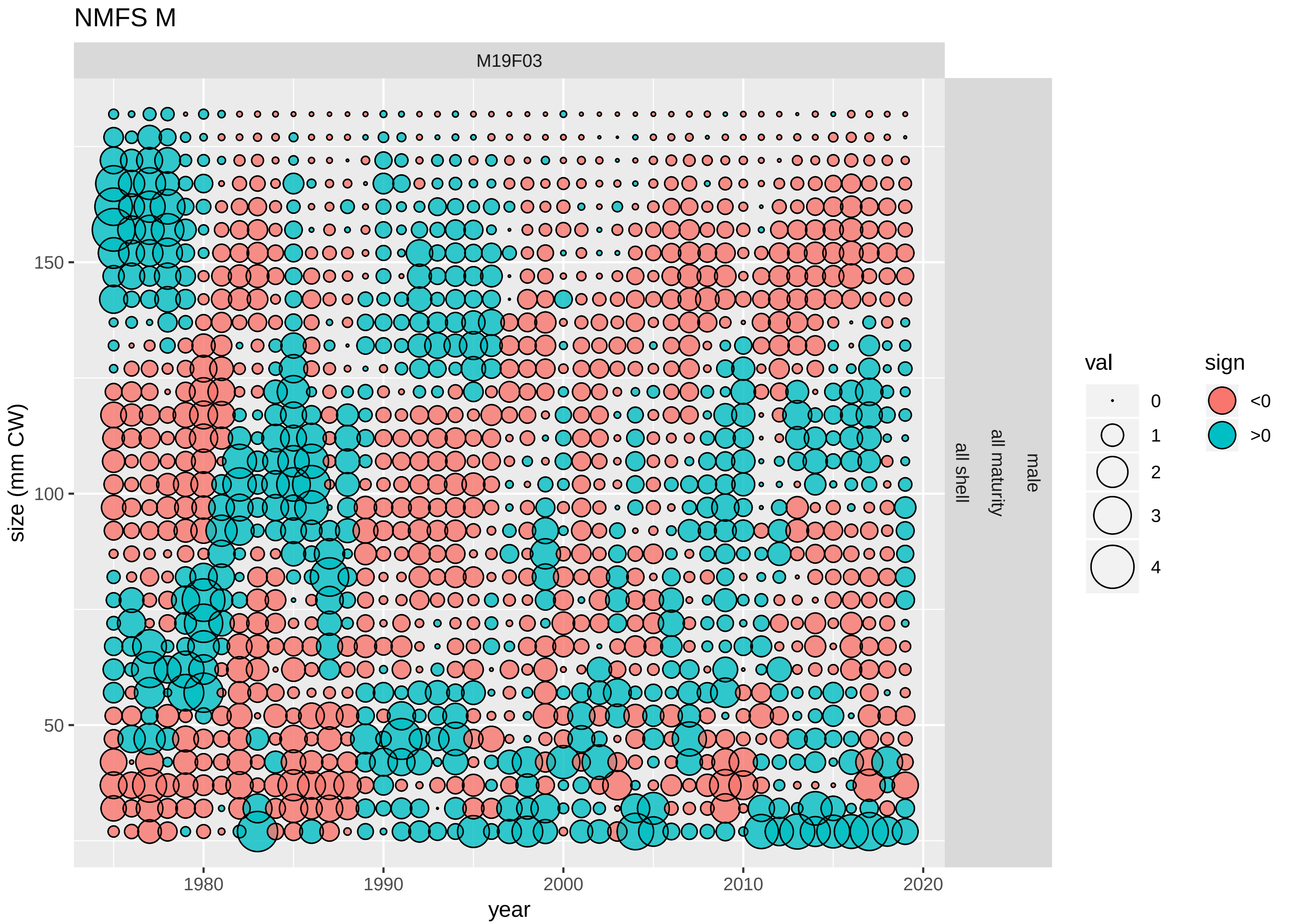


Figure 17: Pearson's residuals for male proportions-at-size from the NMFS M for scenario M19F03.

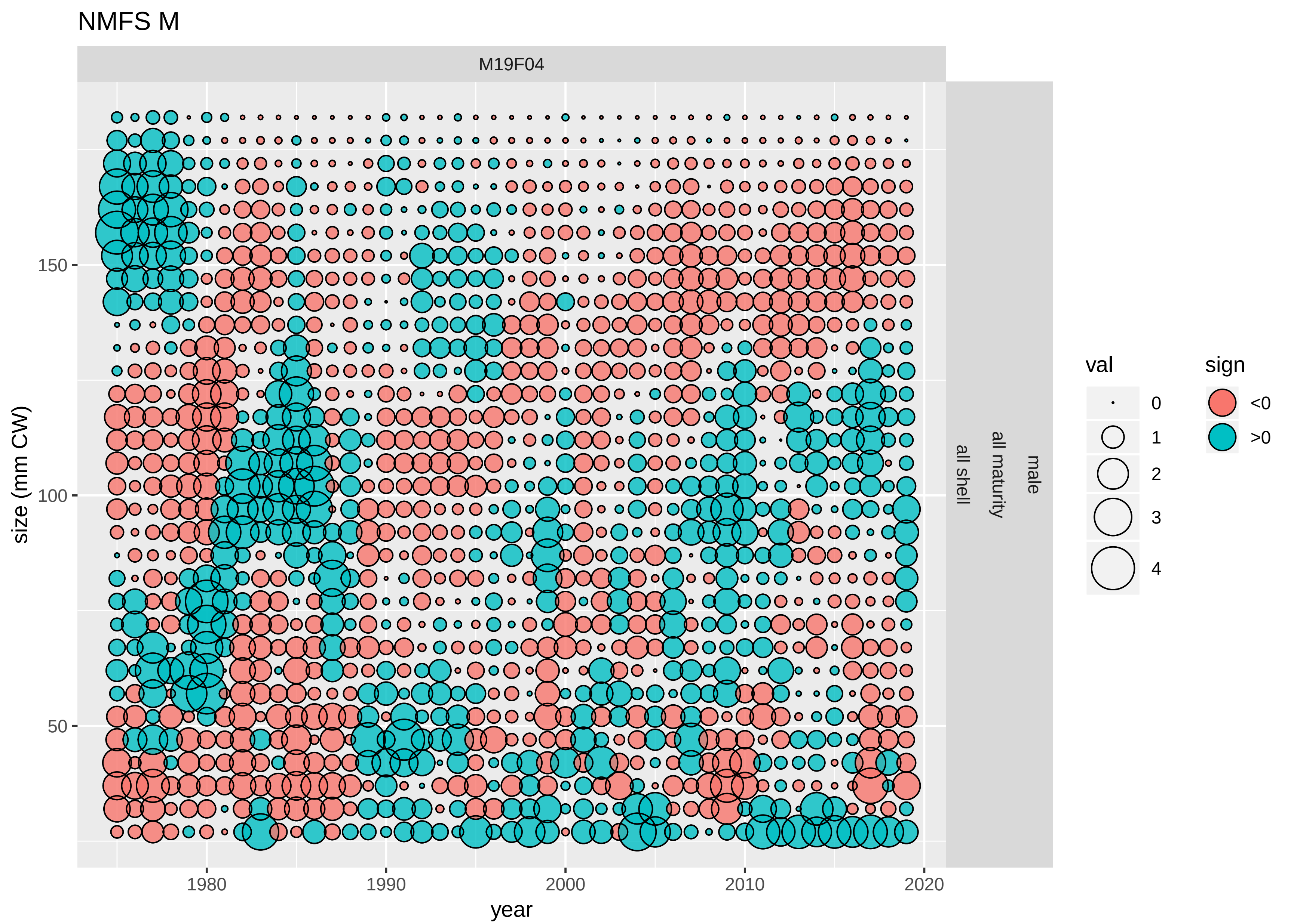


Figure 18: Pearson's residuals for male proportions-at-size from the NMFS M for scenario M19F04.

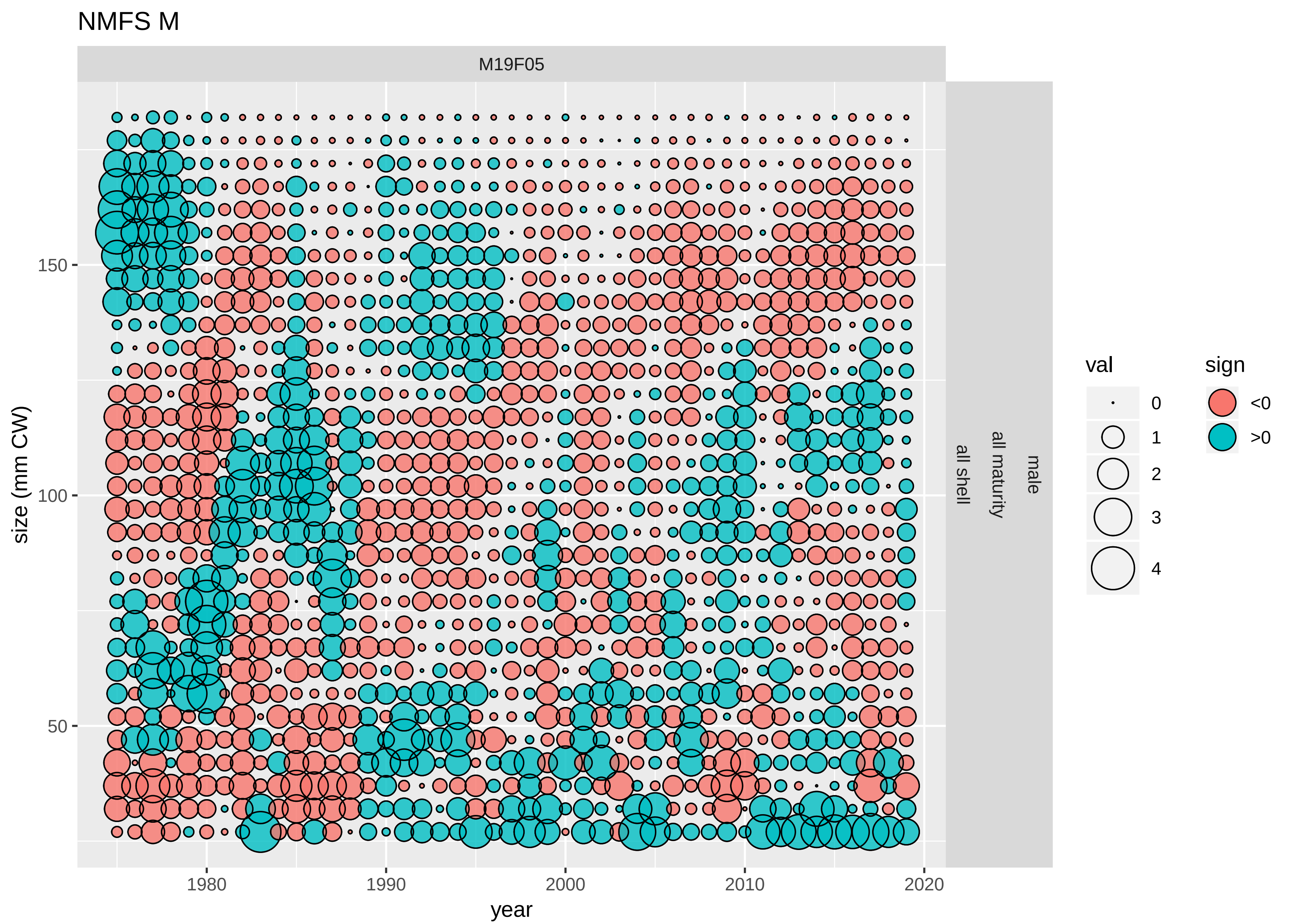


Figure 19: Pearson's residuals for male proportions-at-size from the NMFS M for scenario M19F05.

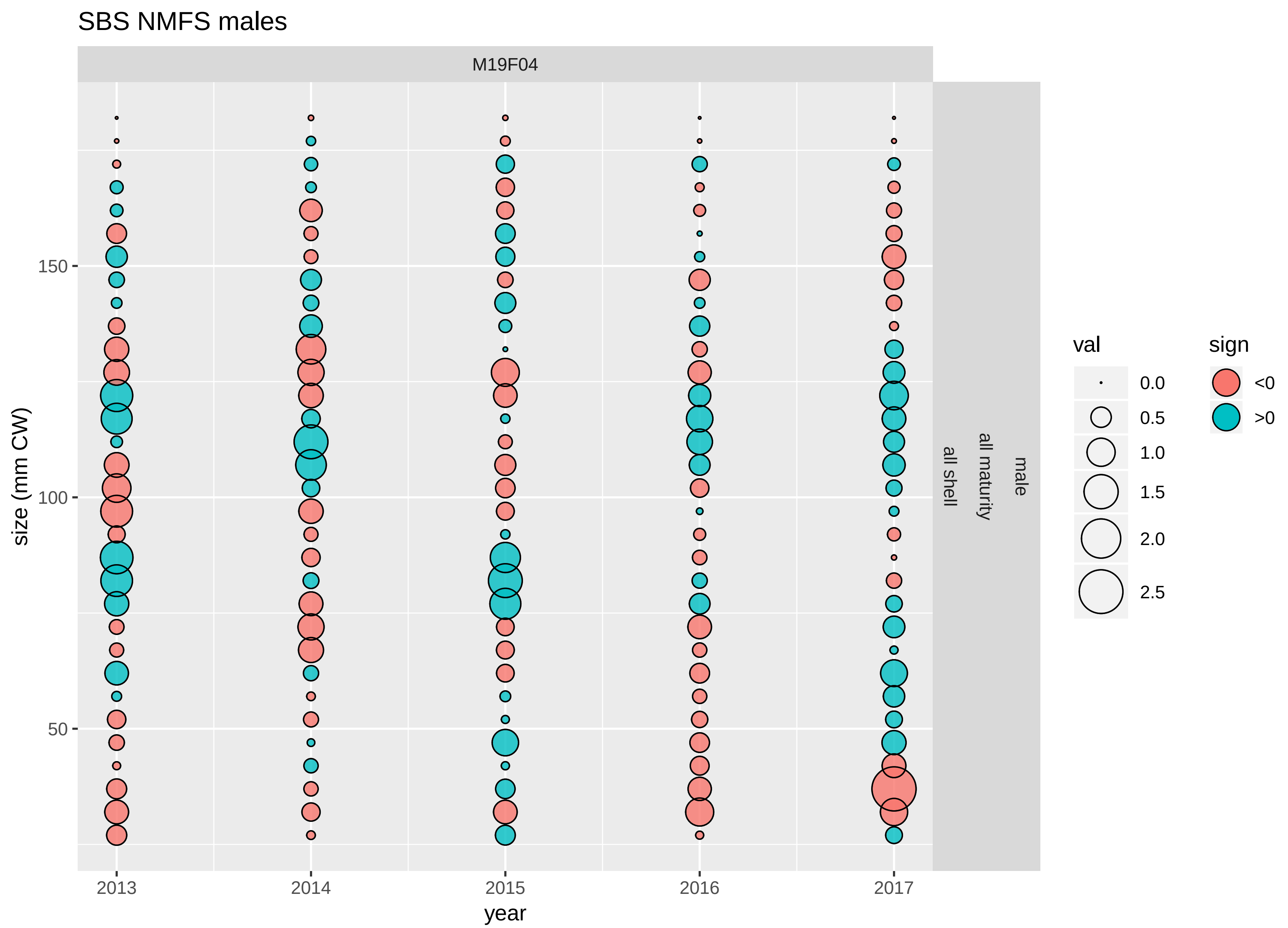


Figure 20: Pearson's residuals for male proportions-at-size from the SBS NMFS males for scenario M19F04.

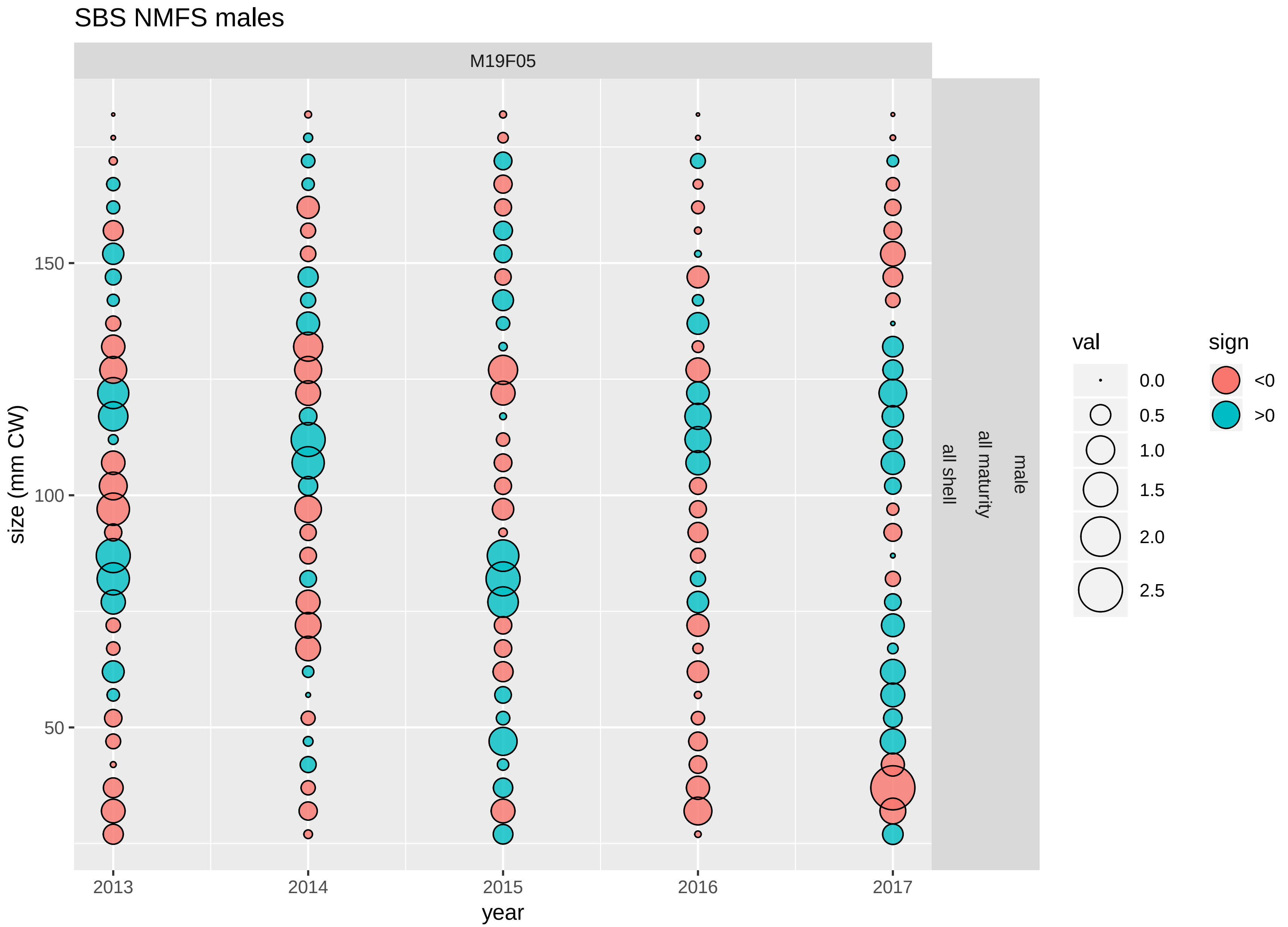


Figure 21: Pearson's residuals for male proportions-at-size from the SBS NMFS males for scenario M19F05.

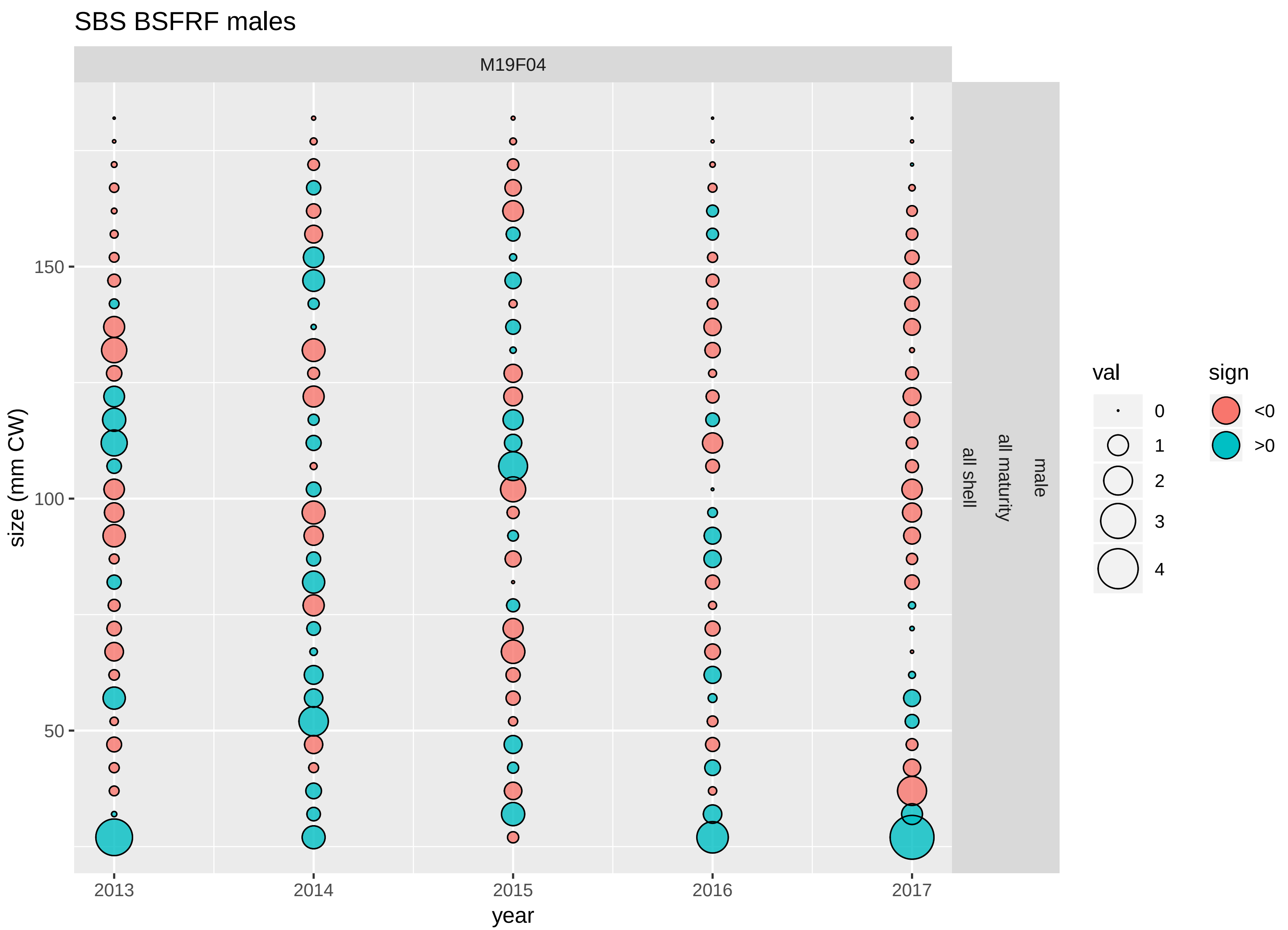


Figure 22: Pearson's residuals for male proportions-at-size from the SBS BSFRF males for scenario M19F04.

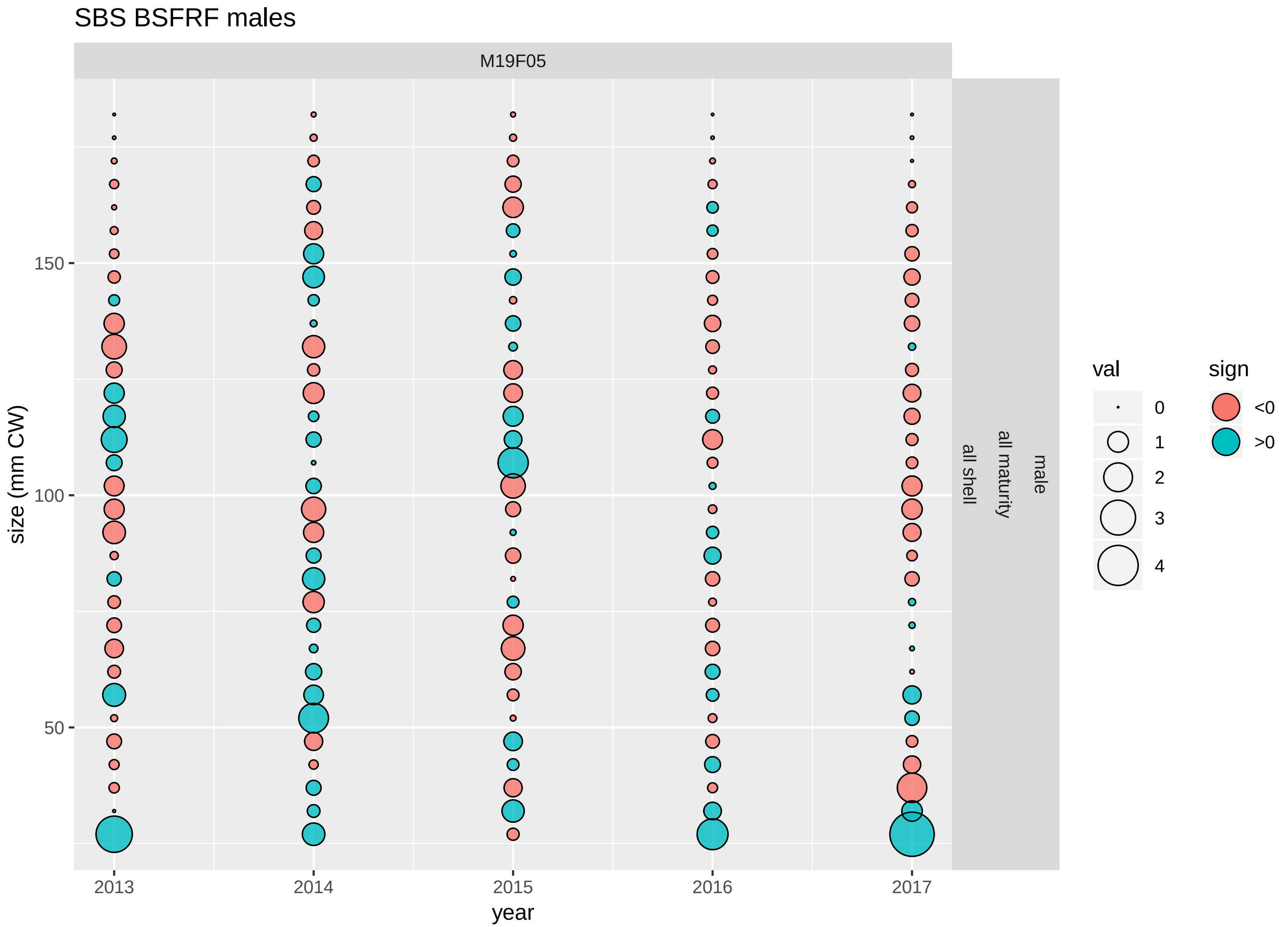


Figure 23: Pearson's residuals for male proportions-at-size from the SBS BSFRF males for scenario M19F05.

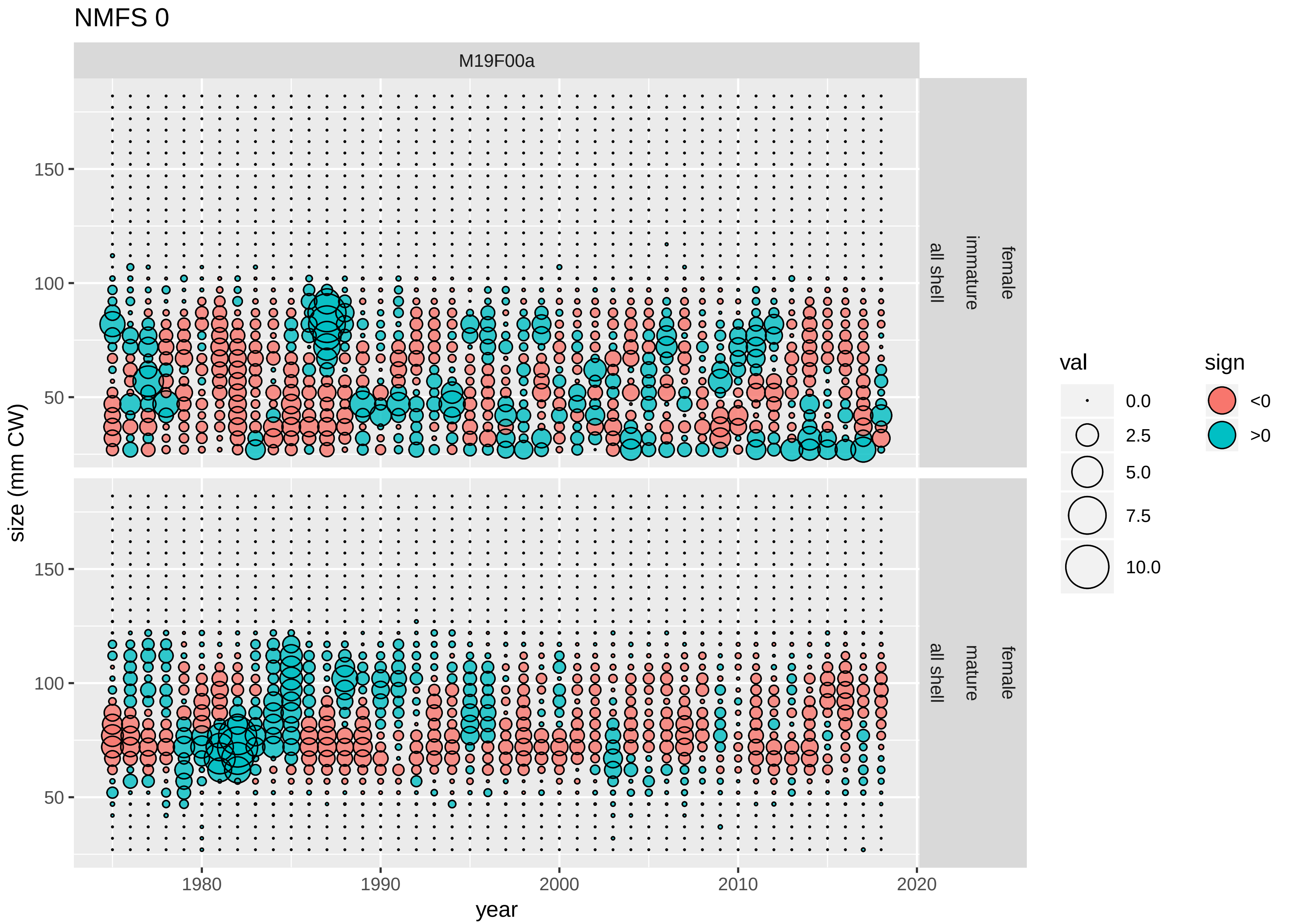


Figure 24: Pearson's residuals for female proportions-at-size from the NMFS 0 for scenario M19F00a.

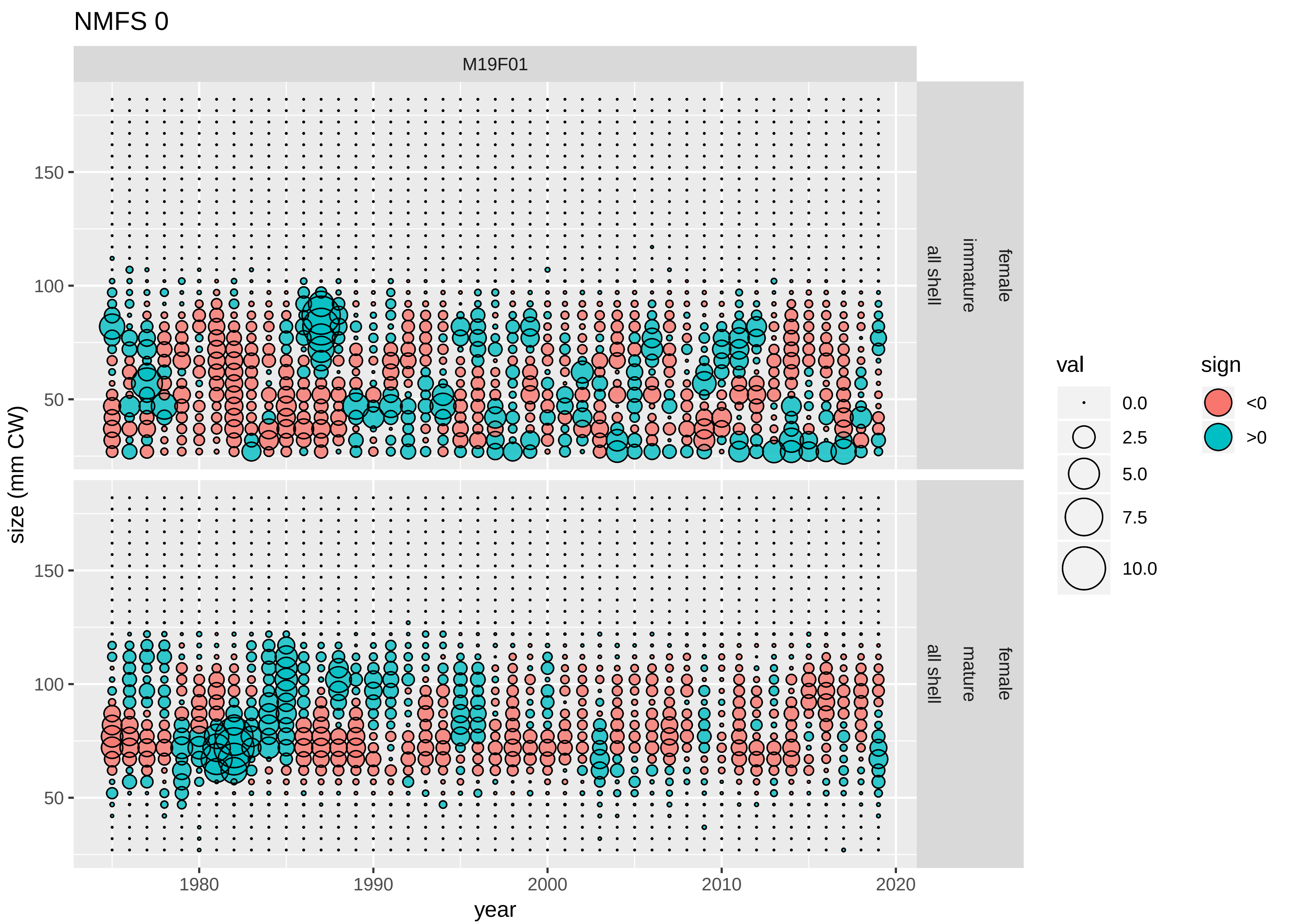


Figure 25: Pearson's residuals for female proportions-at-size from the NMFS 0 for scenario M19F01.

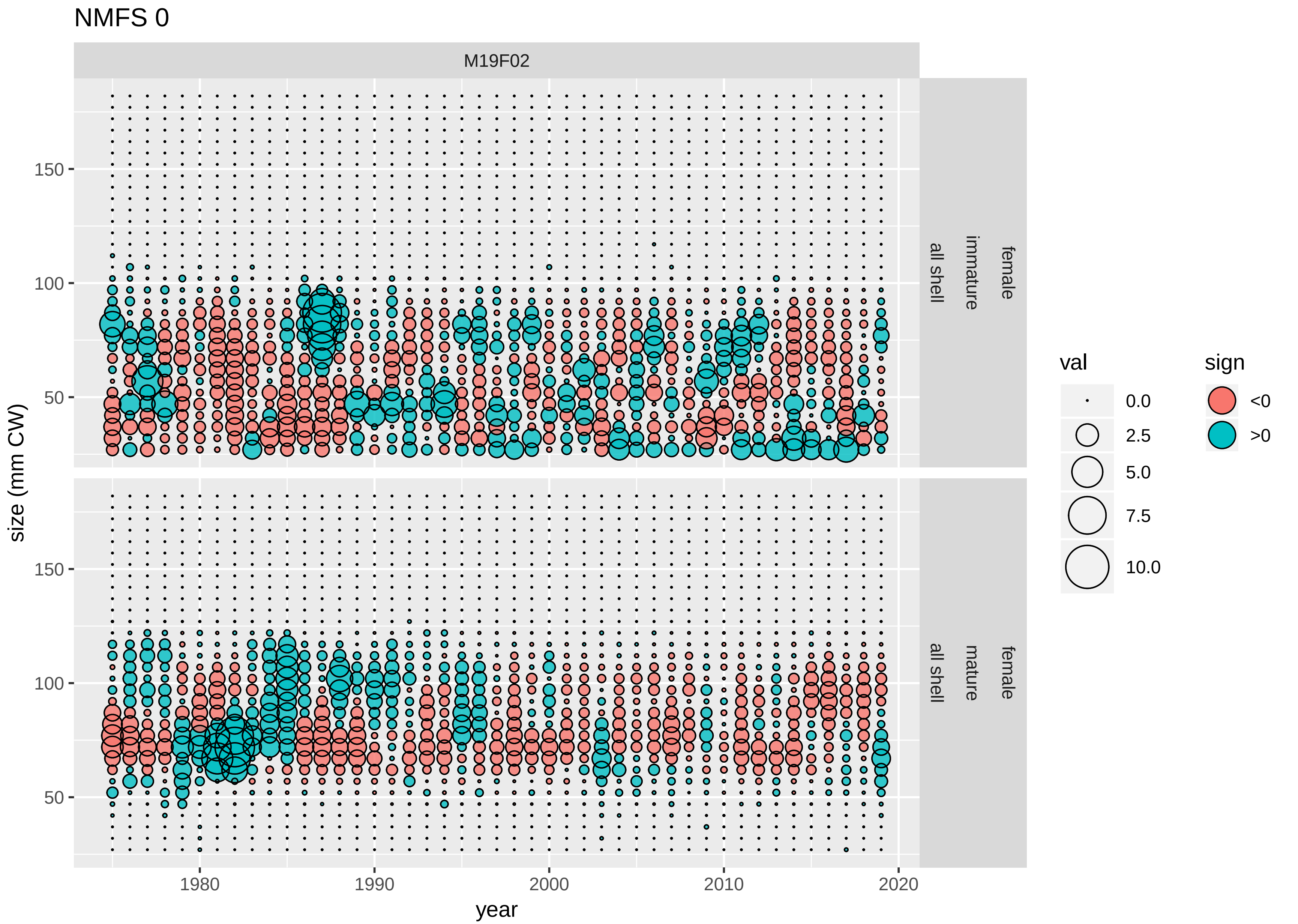


Figure 26: Pearson's residuals for female proportions-at-size from the NMFS 0 for scenario M19F02.

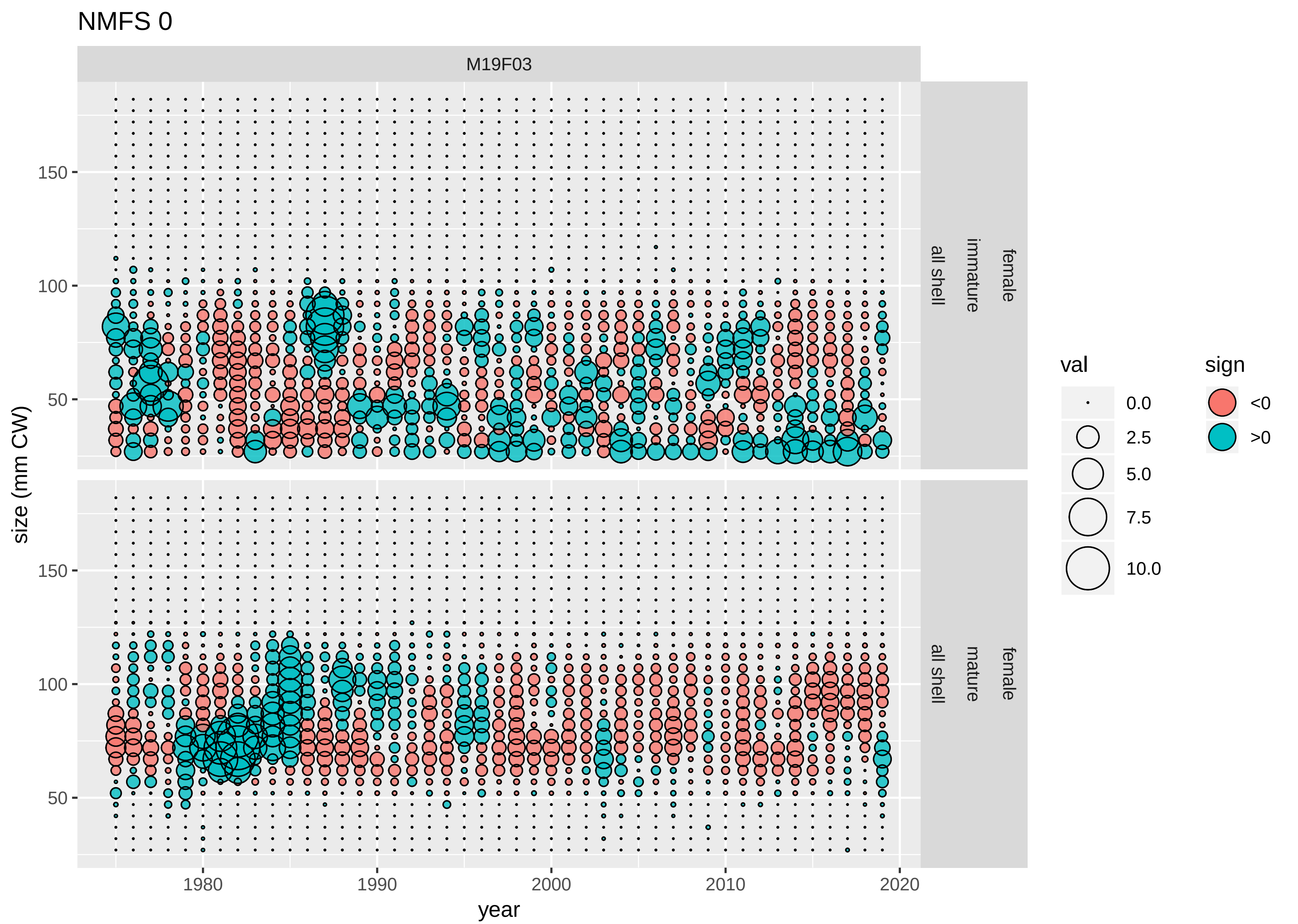


Figure 27: Pearson's residuals for female proportions-at-size from the NMFS 0 for scenario M19F03.

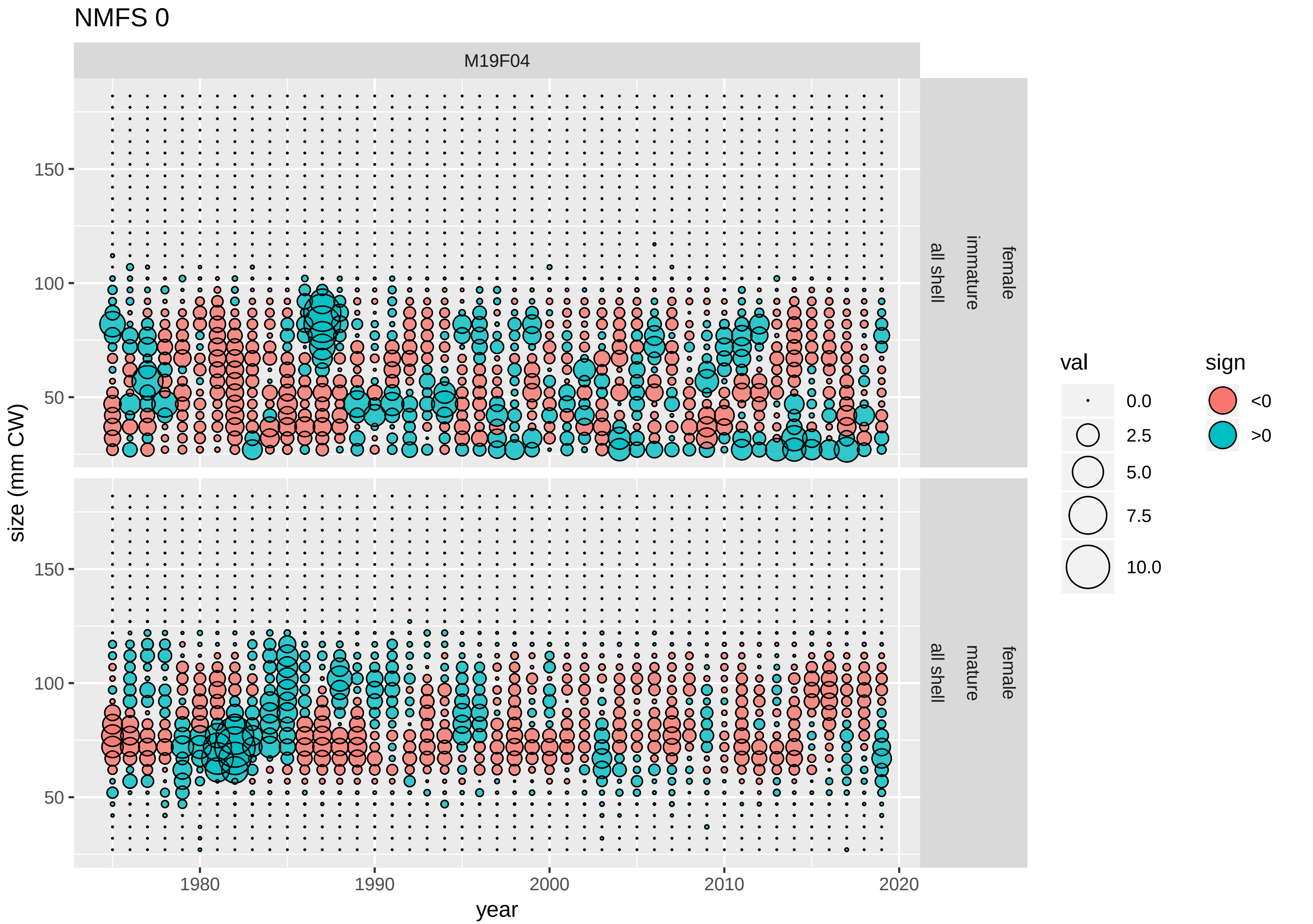


Figure 28: Pearson's residuals for female proportions-at-size from the NMFS 0 for scenario M19F04.

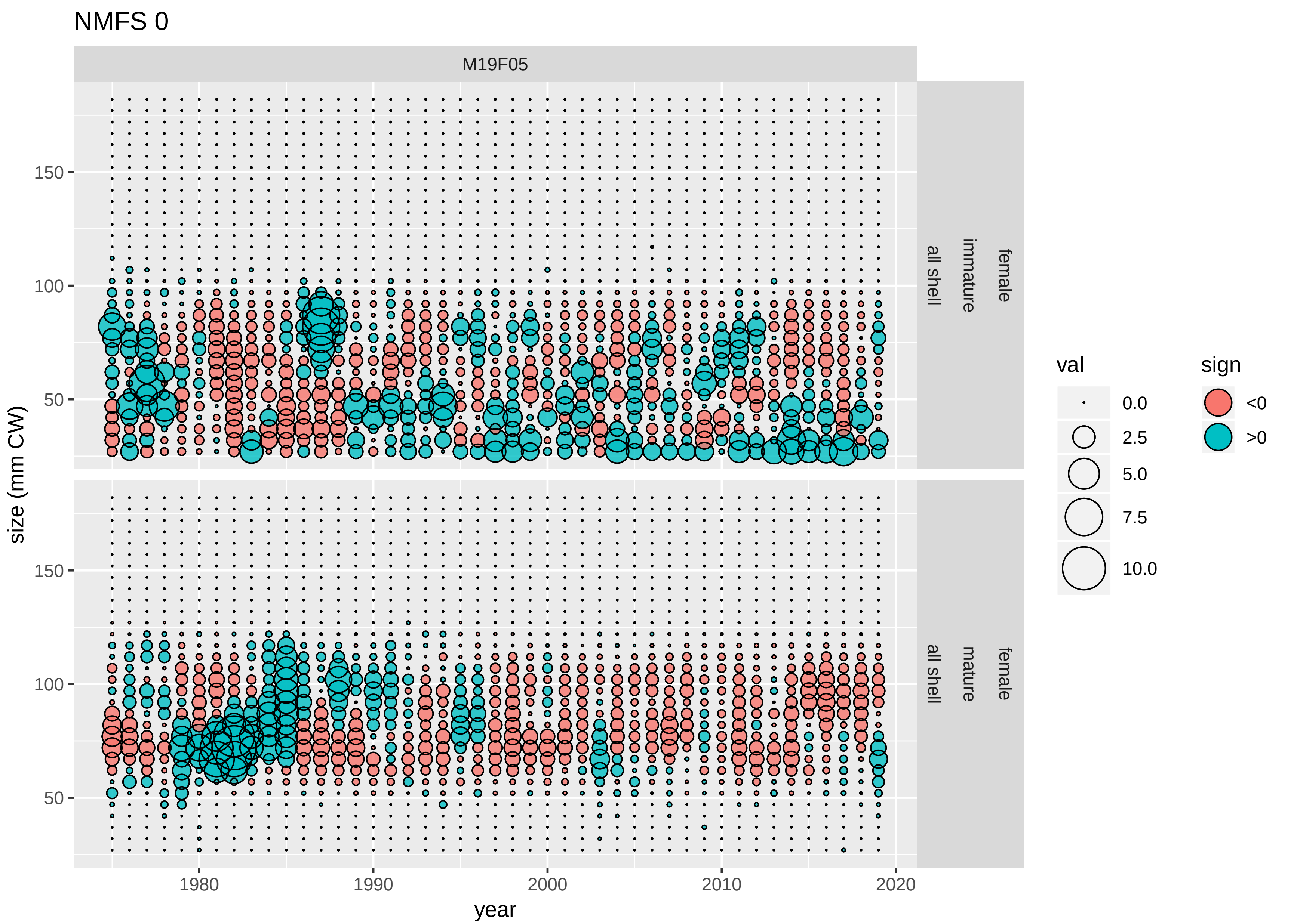


Figure 29: Pearson's residuals for female proportions-at-size from the NMFS 0 for scenario M19F05.

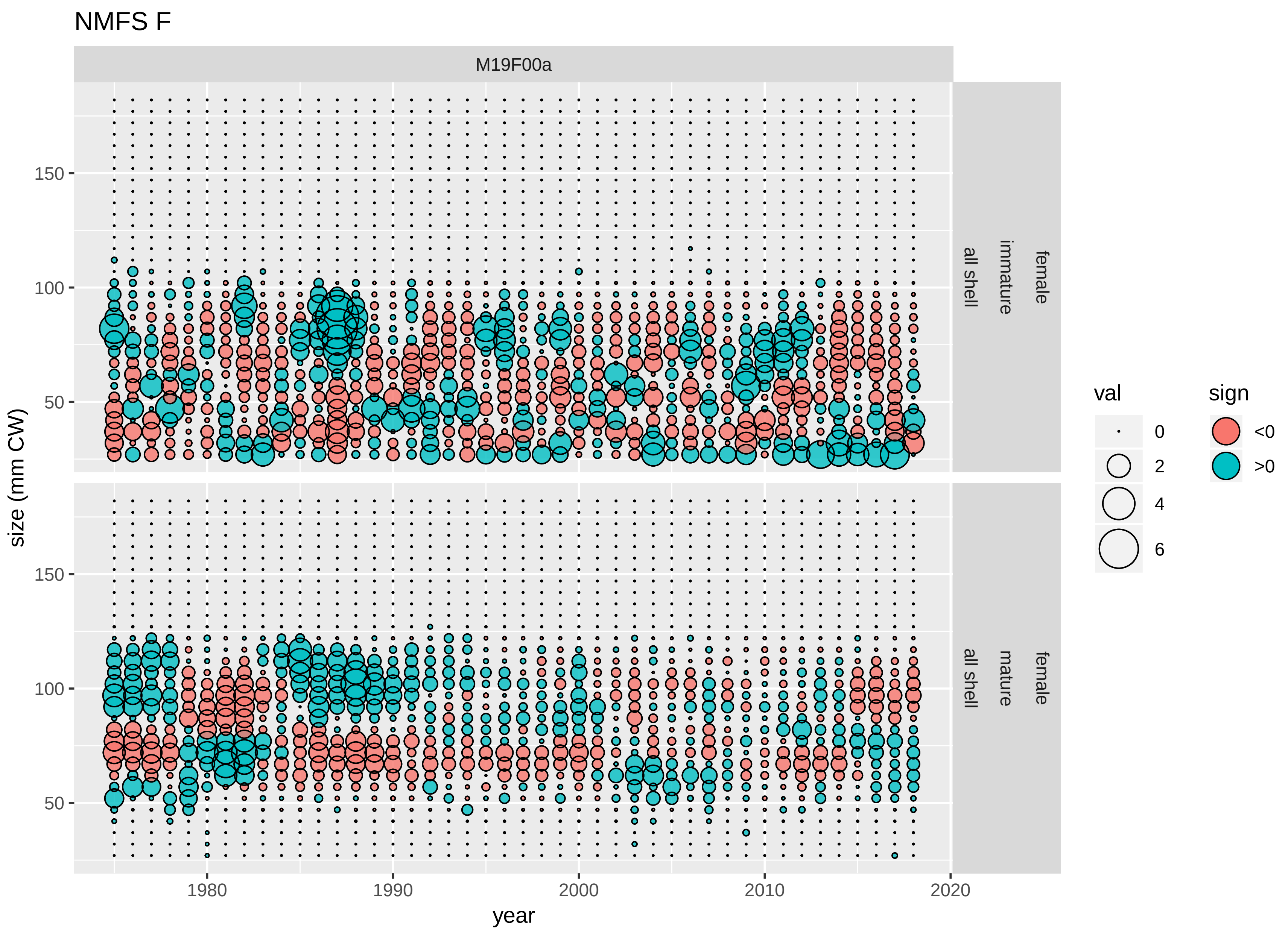


Figure 30: Pearson's residuals for female proportions-at-size from the NMFS F for scenario M19F00a.

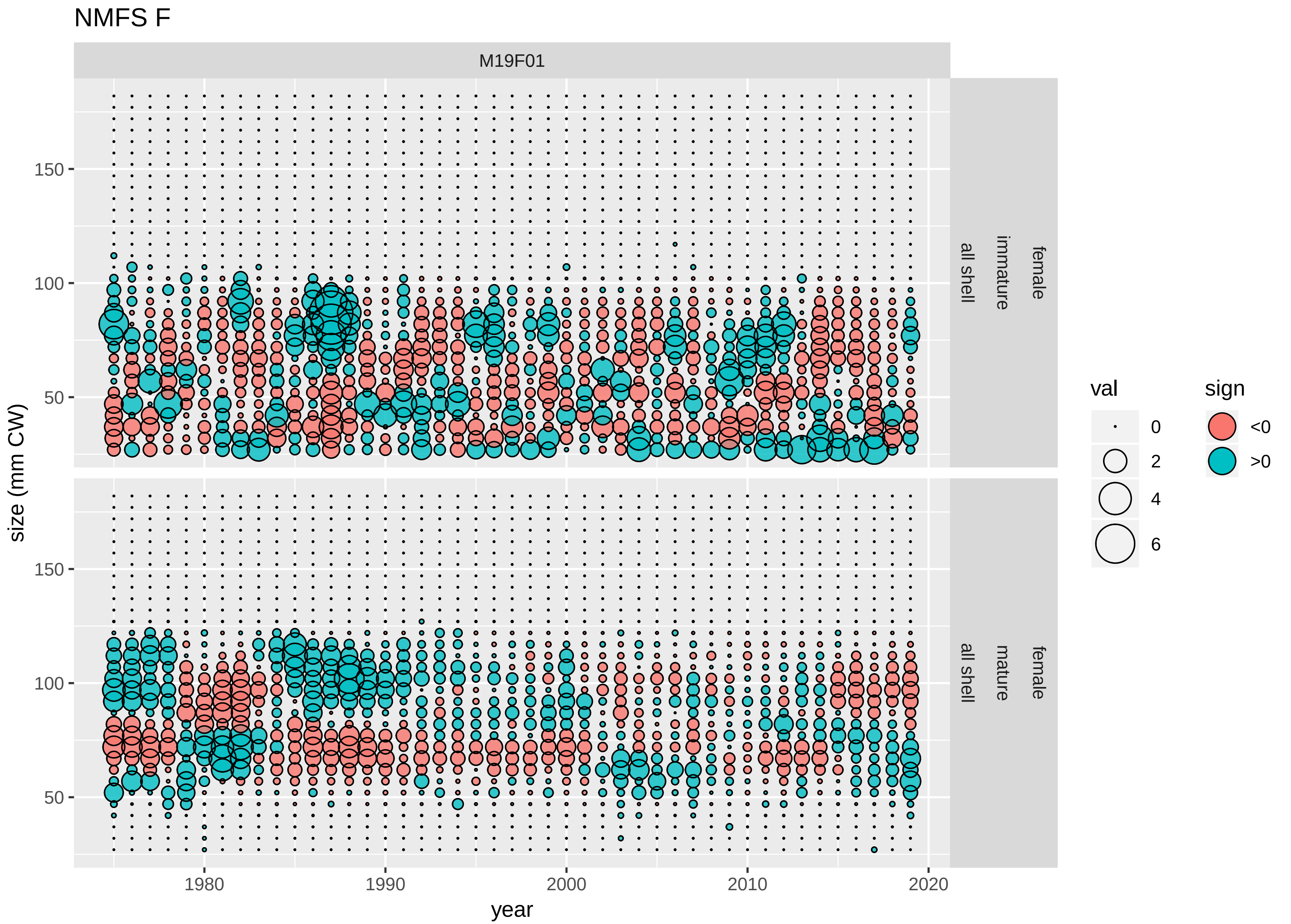


Figure 31: Pearson's residuals for female proportions-at-size from the NMFS F for scenario M19F01.

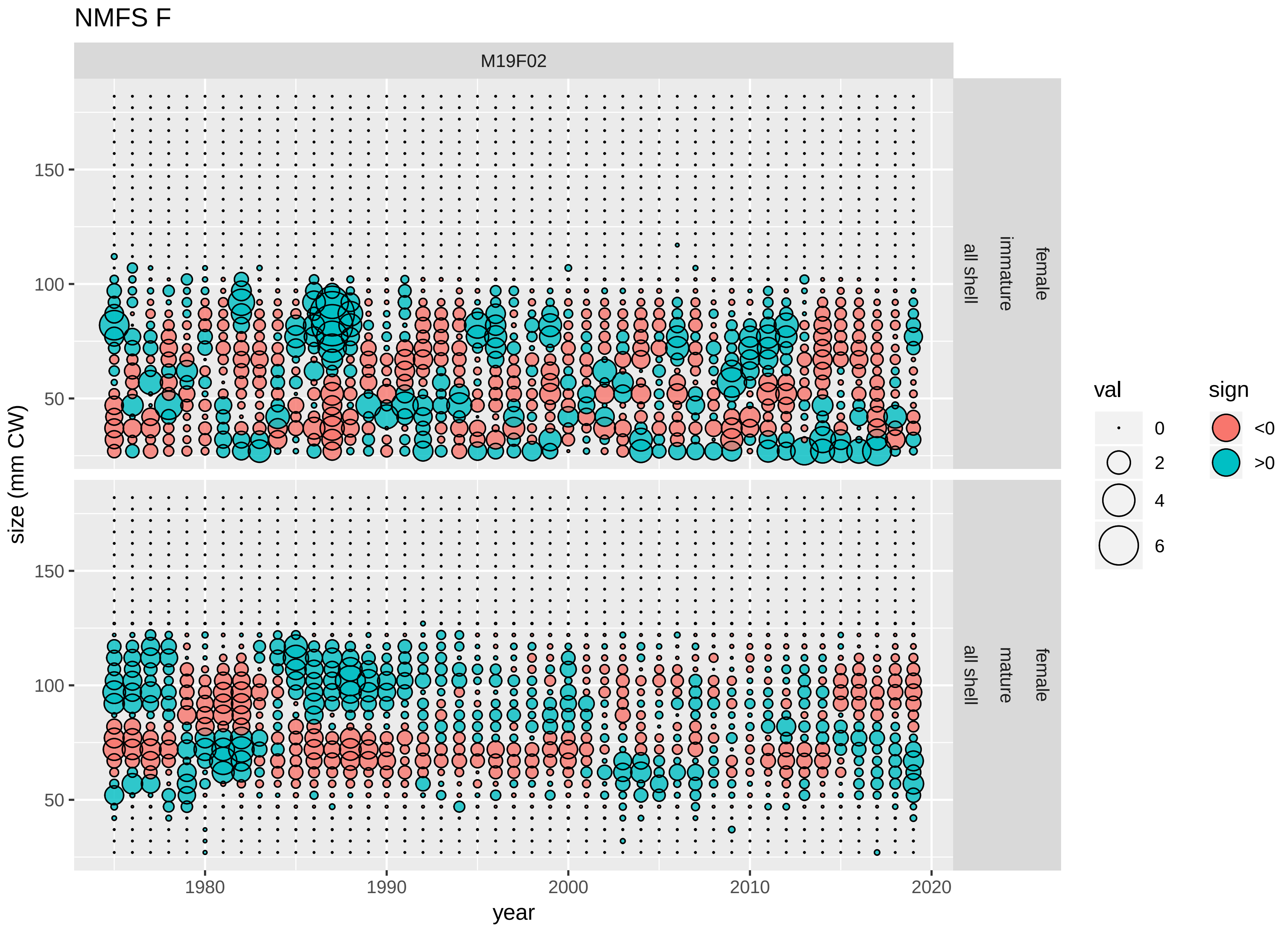


Figure 32: Pearson's residuals for female proportions-at-size from the NMFS F for scenario M19F02.

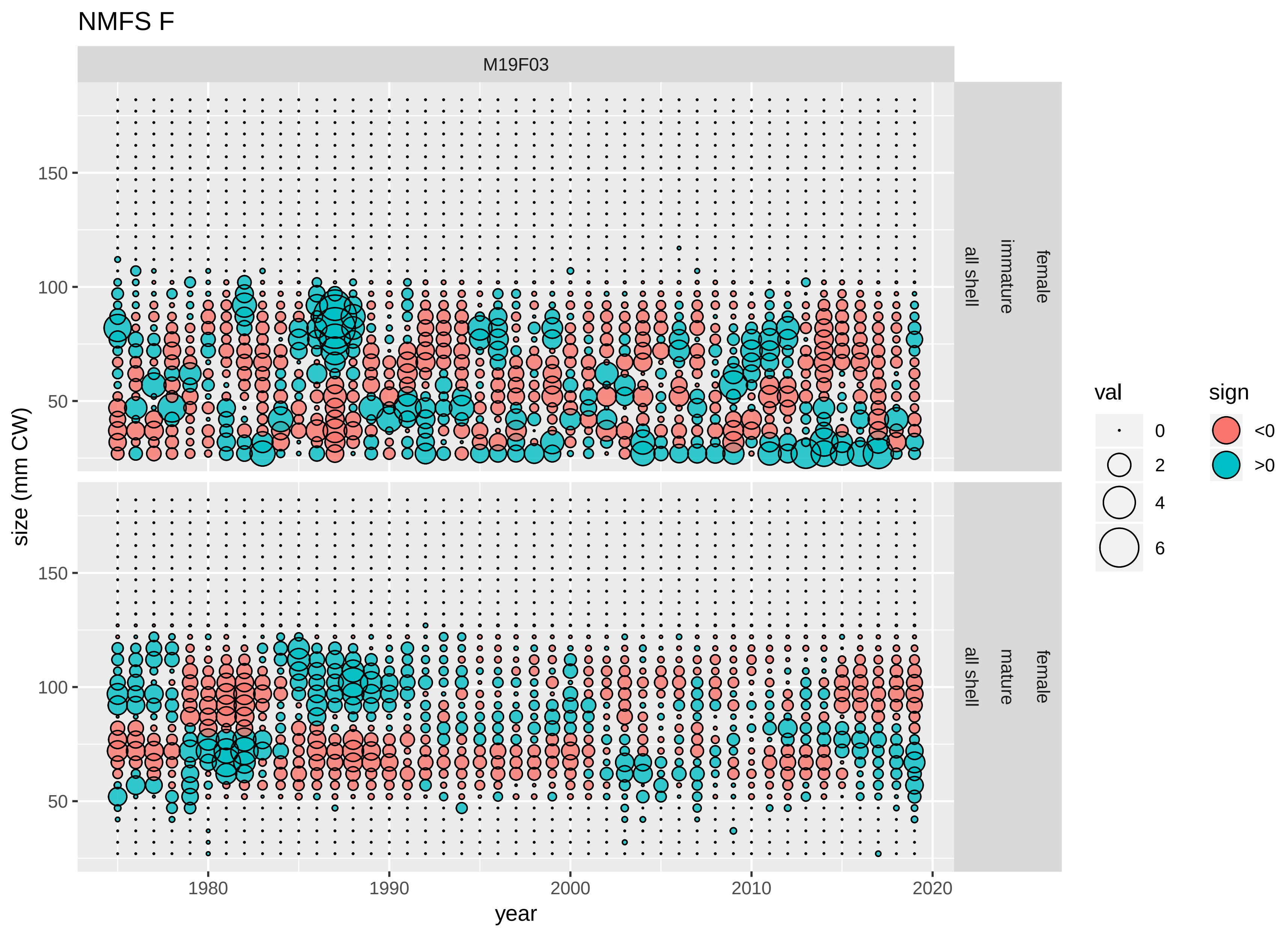


Figure 33: Pearson's residuals for female proportions-at-size from the NMFS F for scenario M19F03.

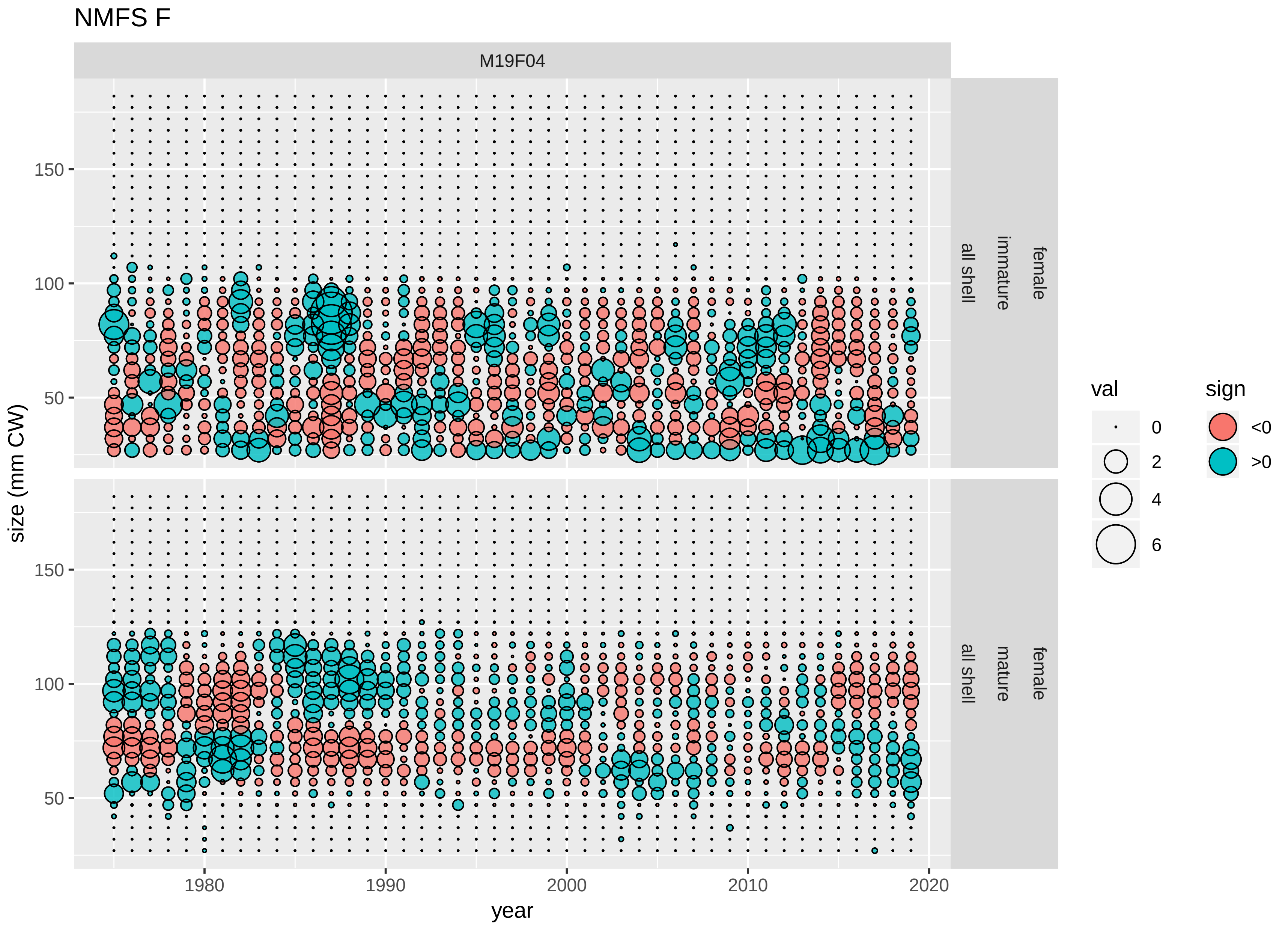


Figure 34: Pearson's residuals for female proportions-at-size from the NMFS F for scenario M19F04.

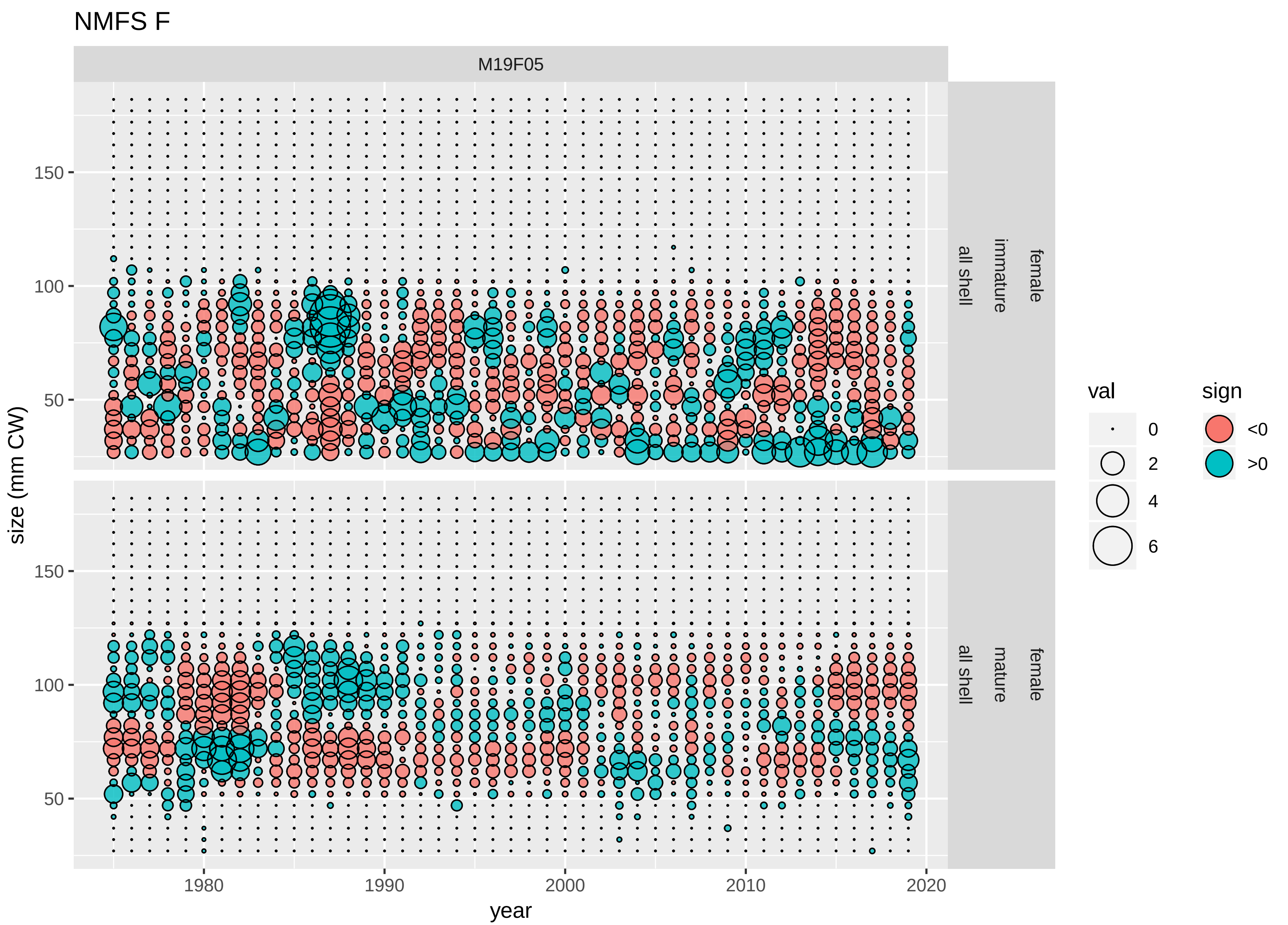


Figure 35: Pearson's residuals for female proportions-at-size from the NMFS F for scenario M19F05.

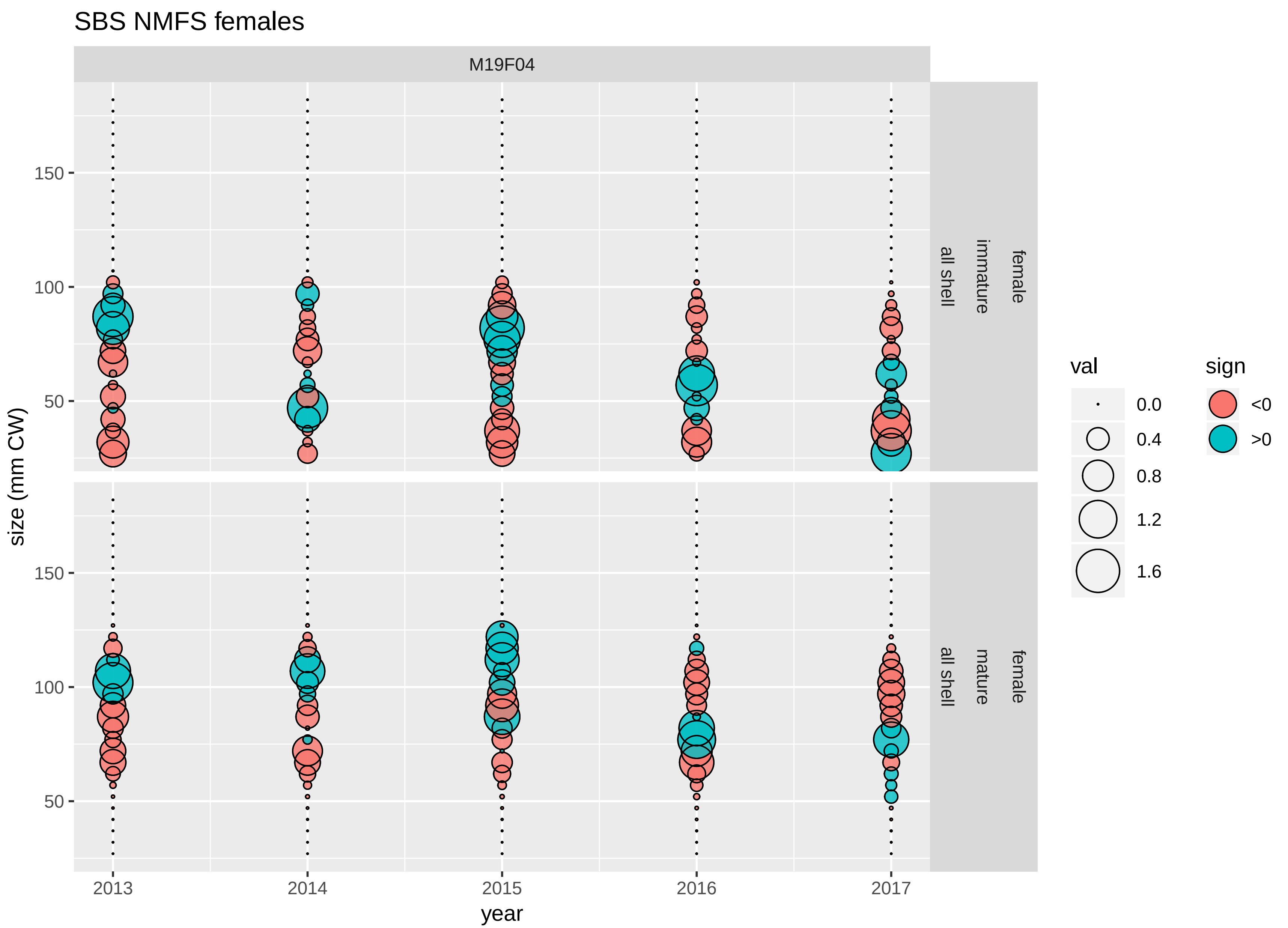


Figure 36: Pearson's residuals for female proportions-at-size from the SBS NMFS females for scenario M19F04.

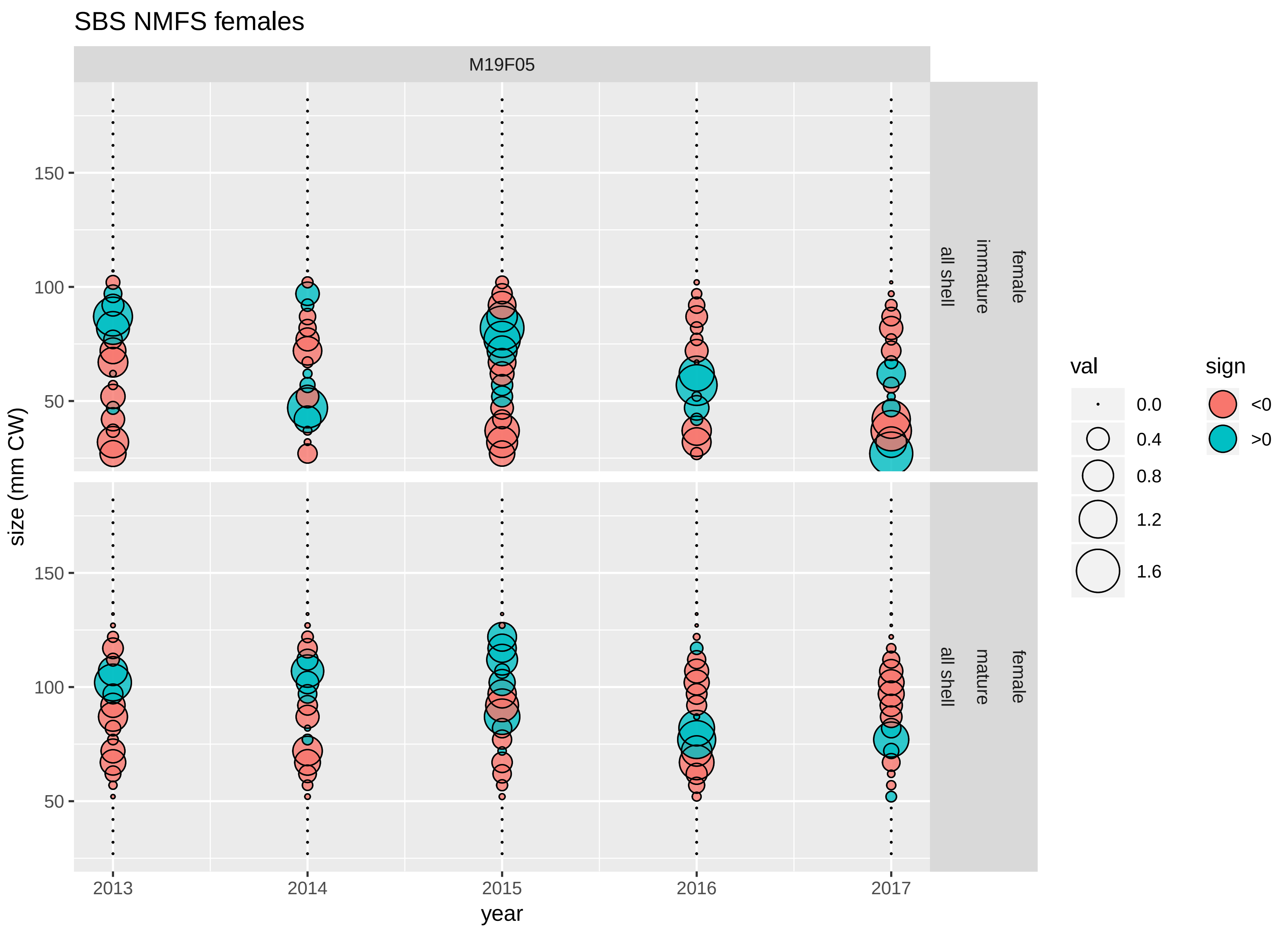


Figure 37: Pearson's residuals for female proportions-at-size from the SBS NMFS females for scenario M19F05.

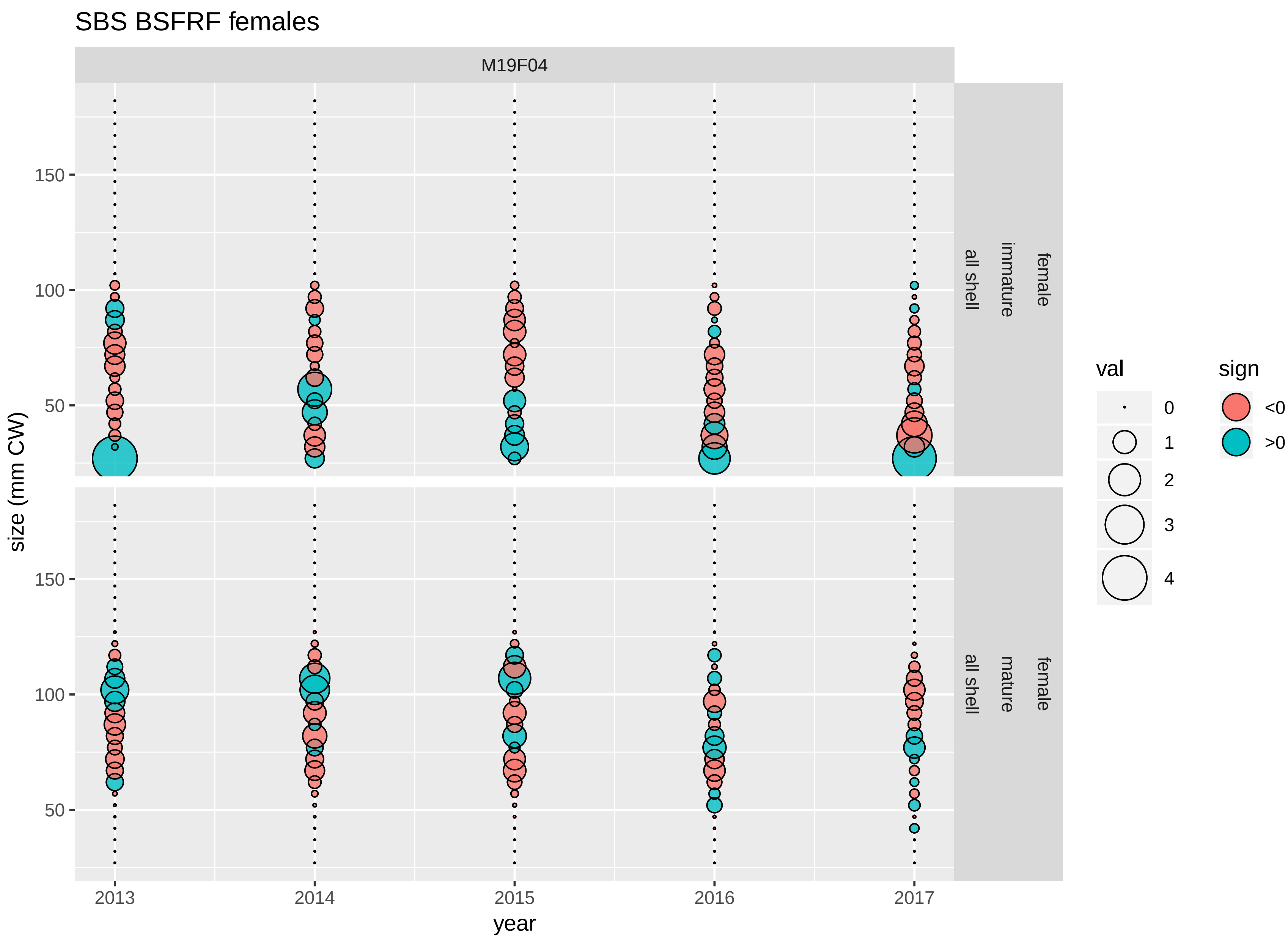


Figure 38: Pearson's residuals for female proportions-at-size from the SBS BSFRF females for scenario M19F04.

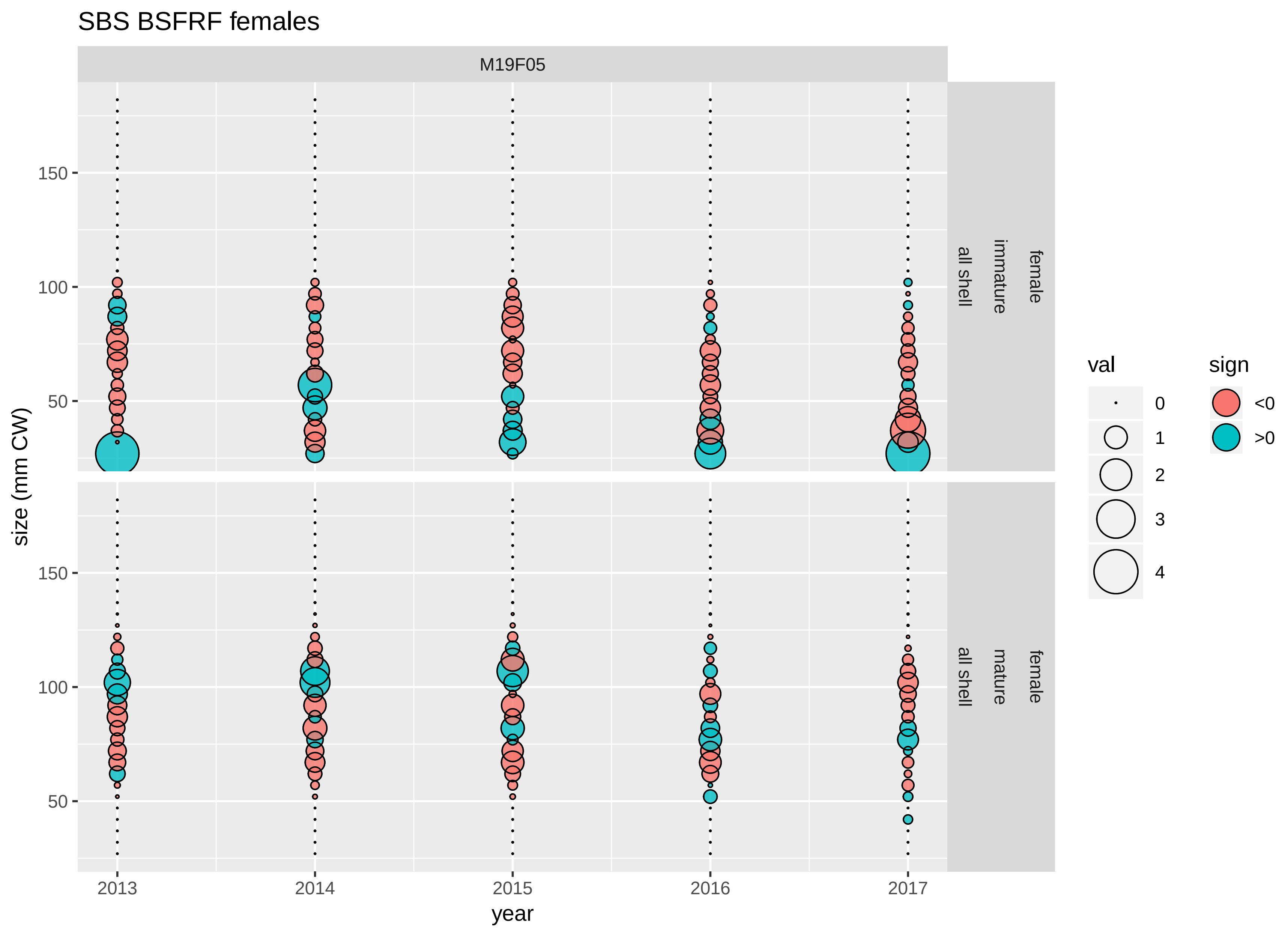


Figure 39: Pearson's residuals for female proportions-at-size from the SBS BSFRF females for scenario M19F05.

Effective sample sizes for survey size compositions

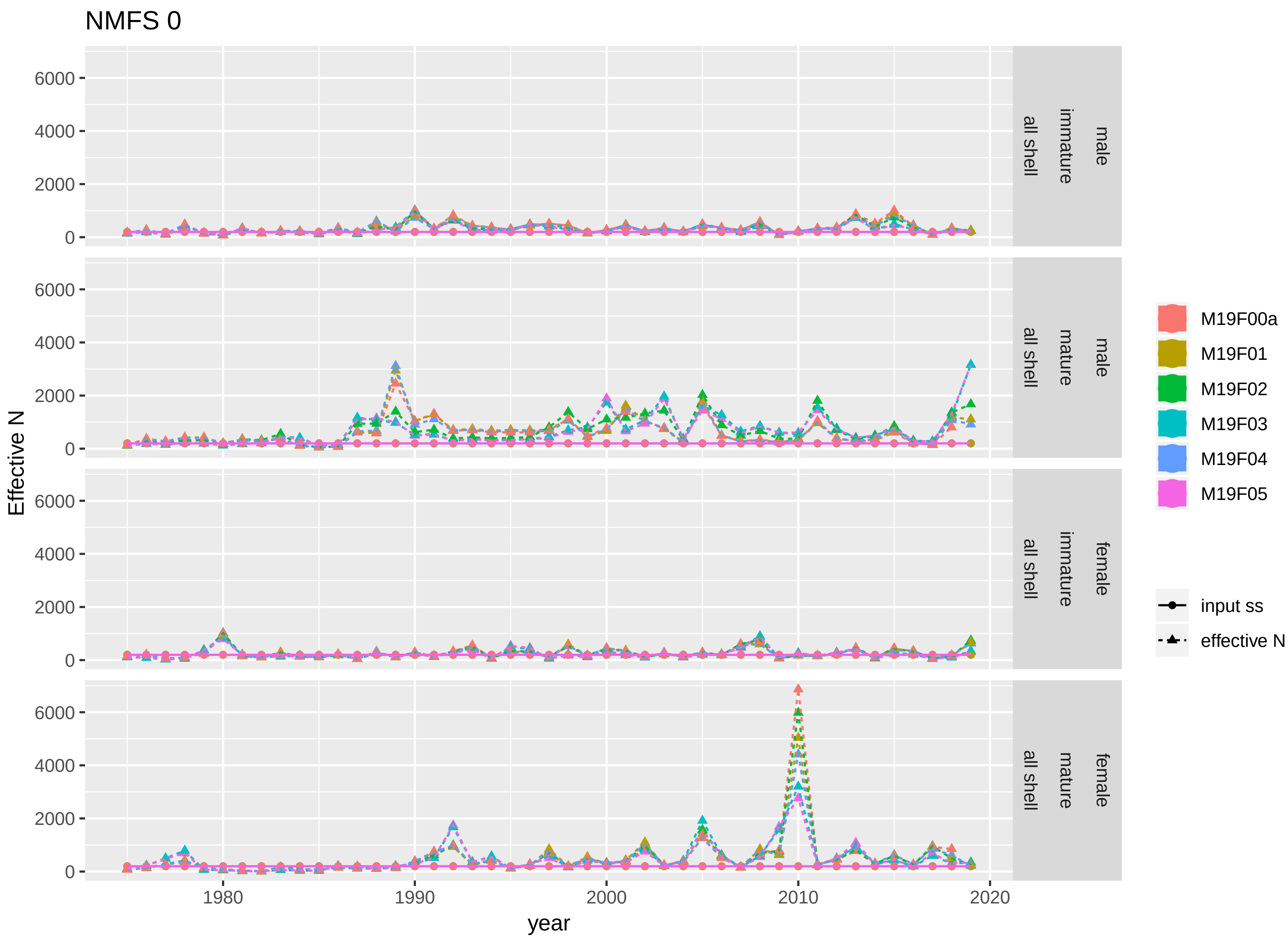


Figure 40: Input and effective sample sizes from retained catch size compositions from the NMFS 0.

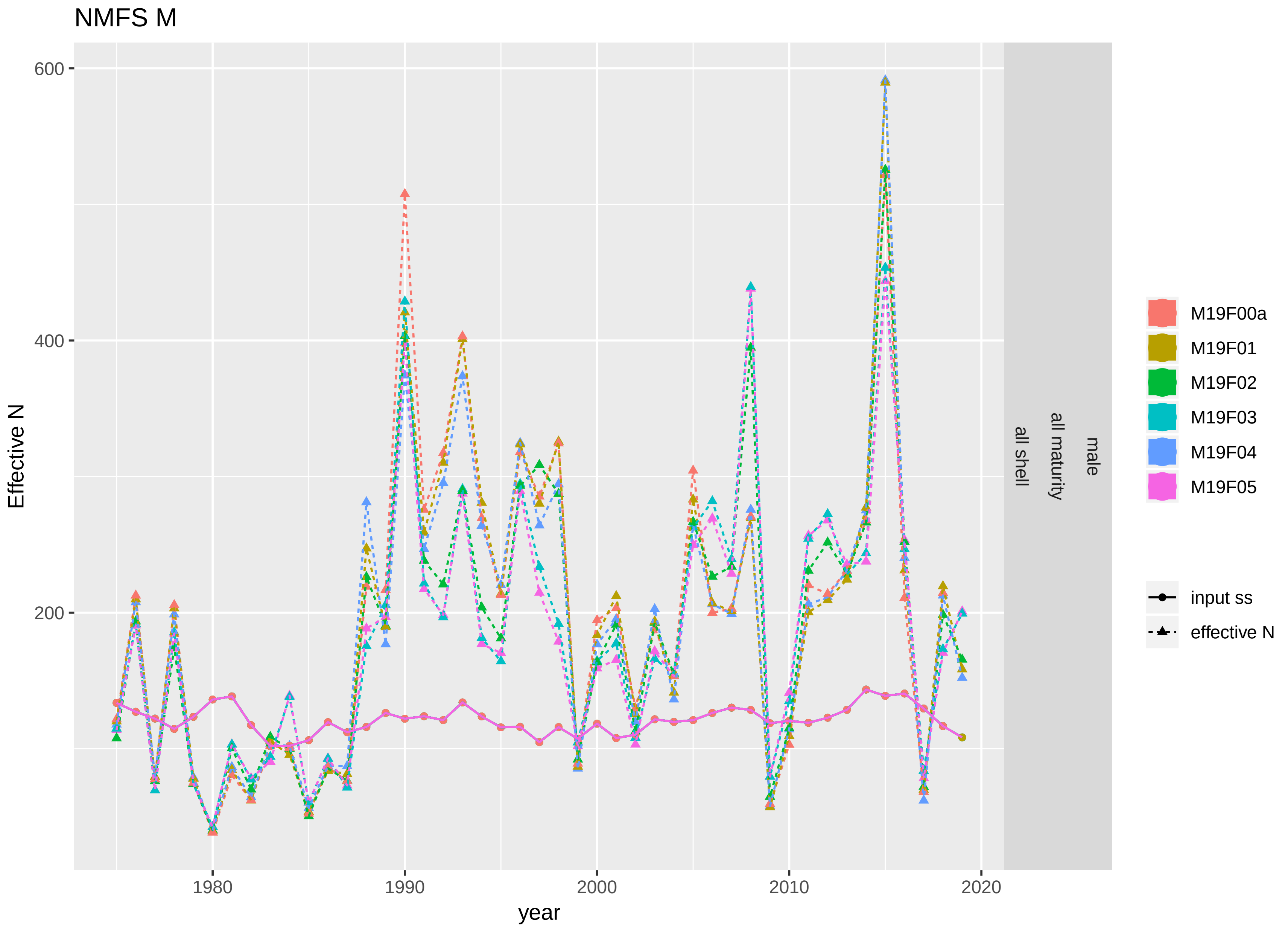


Figure 41: Input and effective sample sizes from retained catch size compositions from the NMFS M.

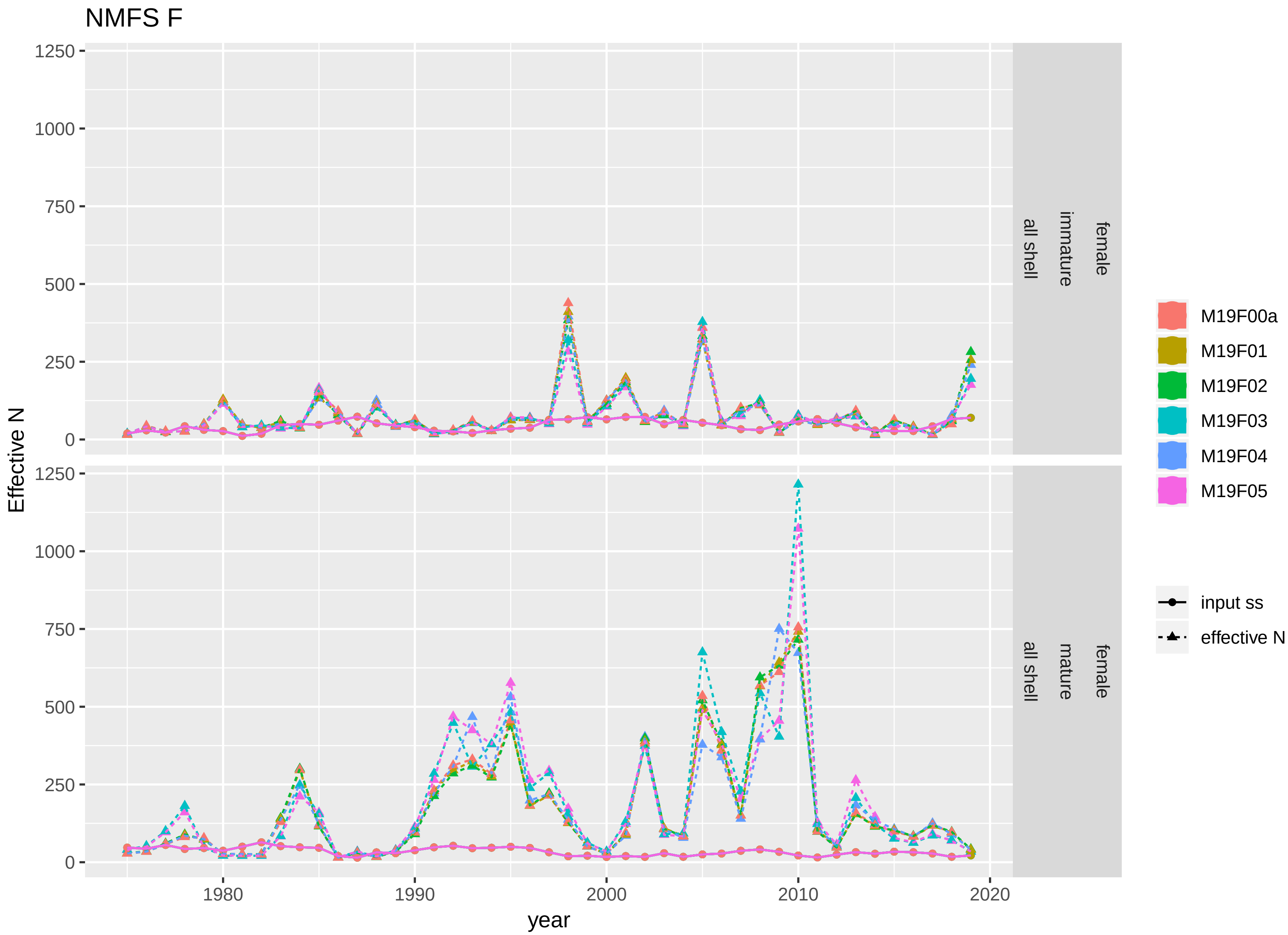


Figure 42: Input and effective sample sizes from retained catch size compositions from the NMFS F.

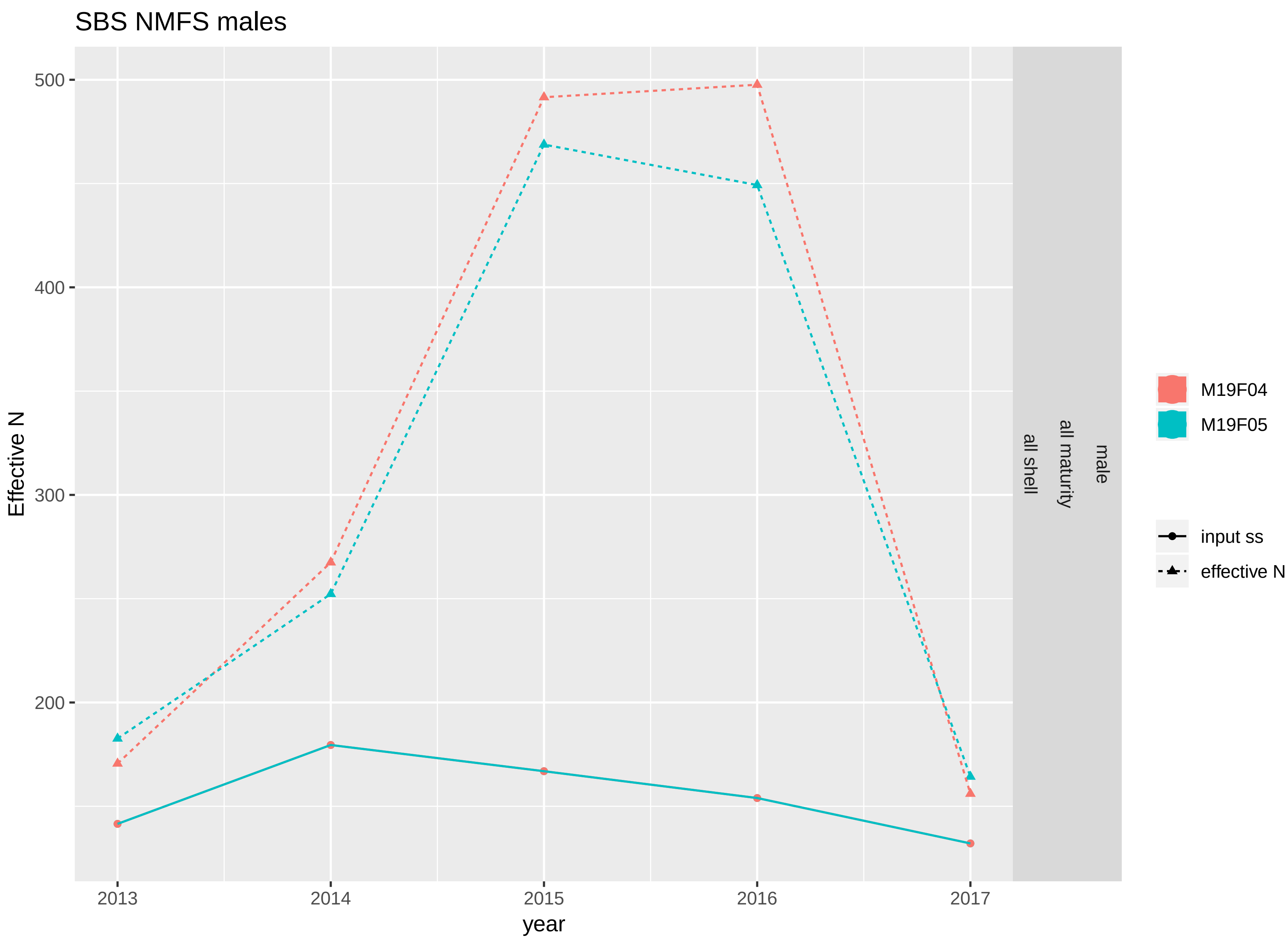


Figure 43: Input and effective sample sizes from retained catch size compositions from the SBS NMFS males.

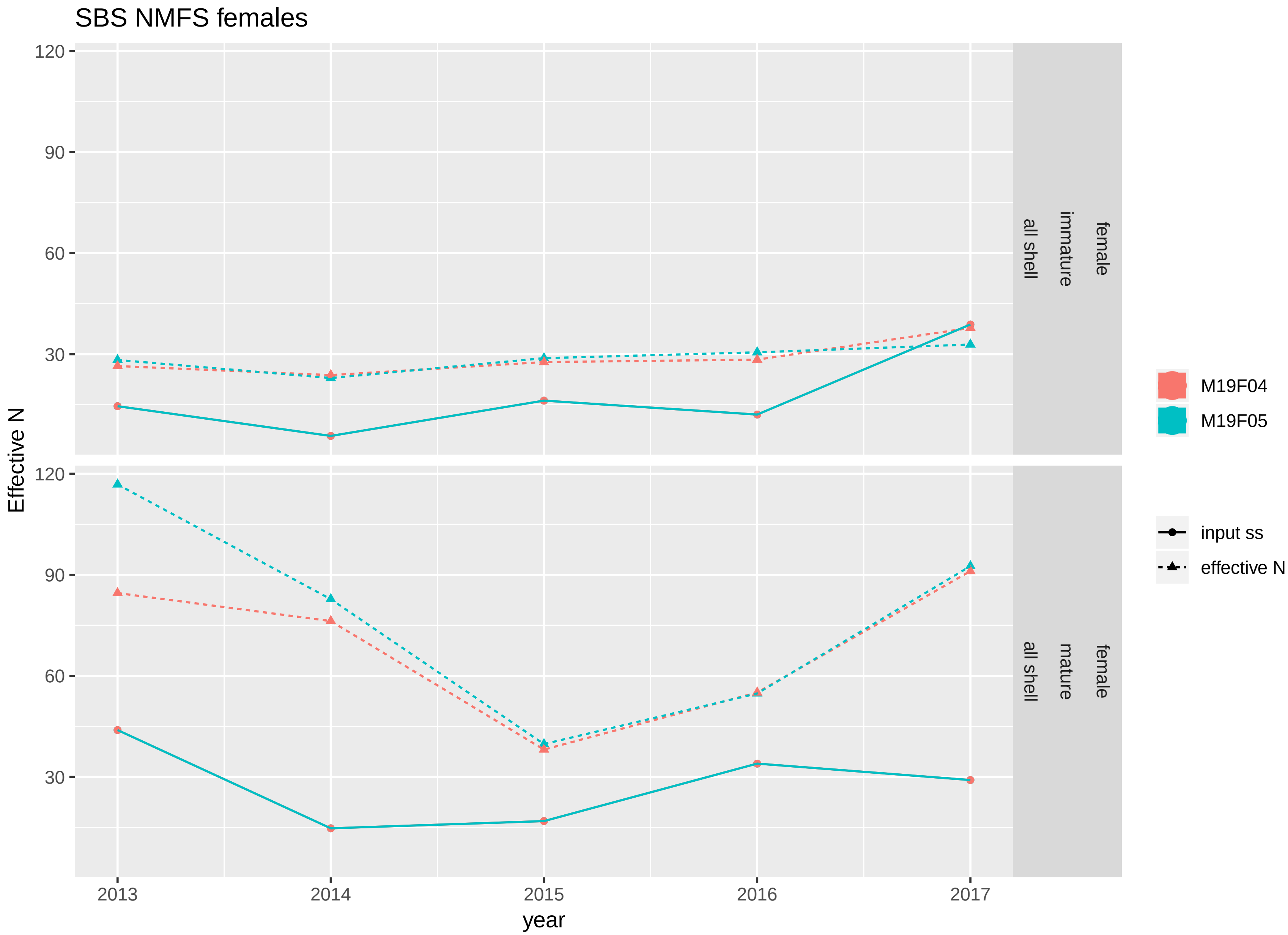


Figure 44: Input and effective sample sizes from retained catch size compositions from the SBS NMFS females.

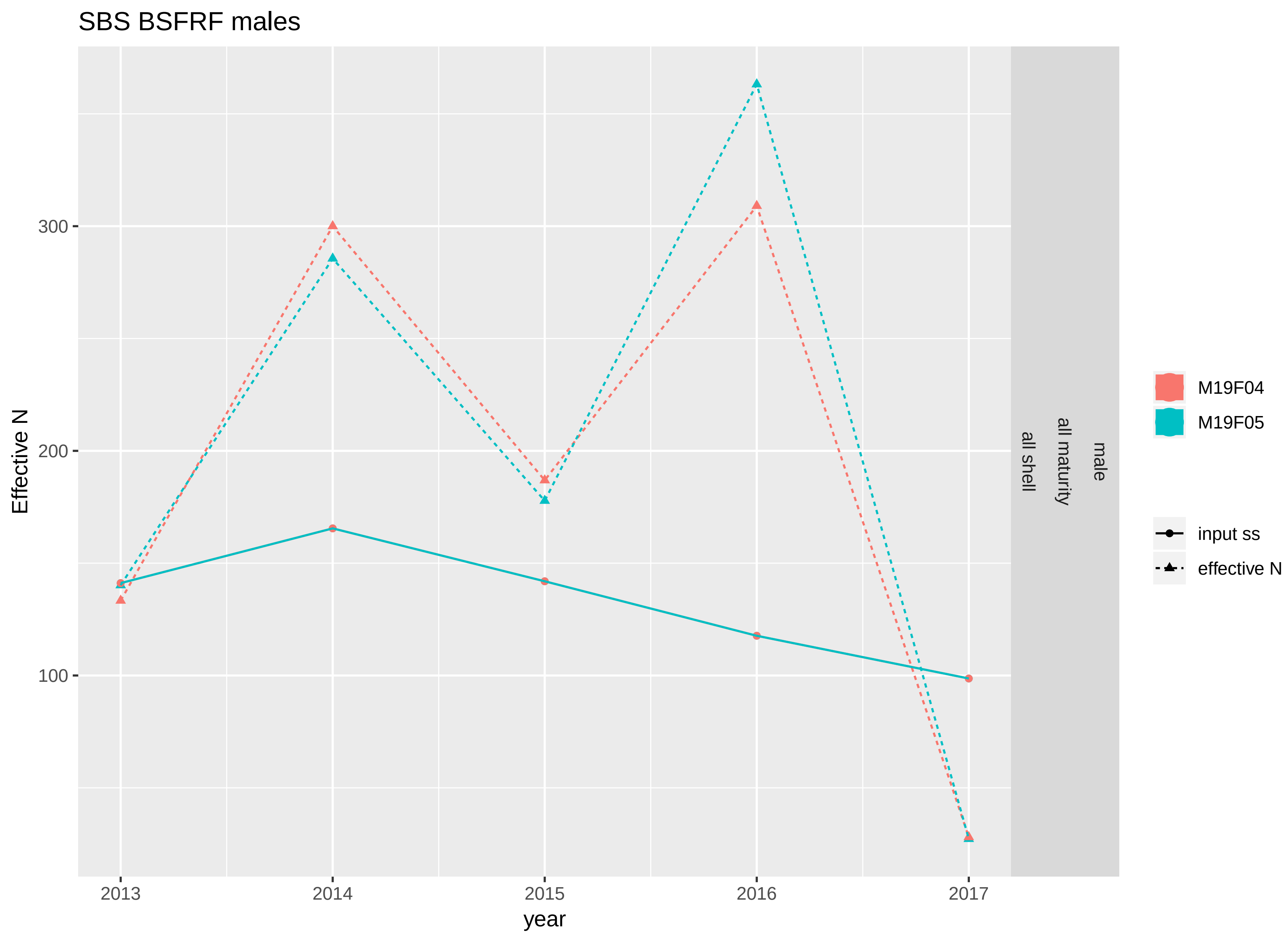


Figure 45: Input and effective sample sizes from retained catch size compositions from the SBS BSFRF males.

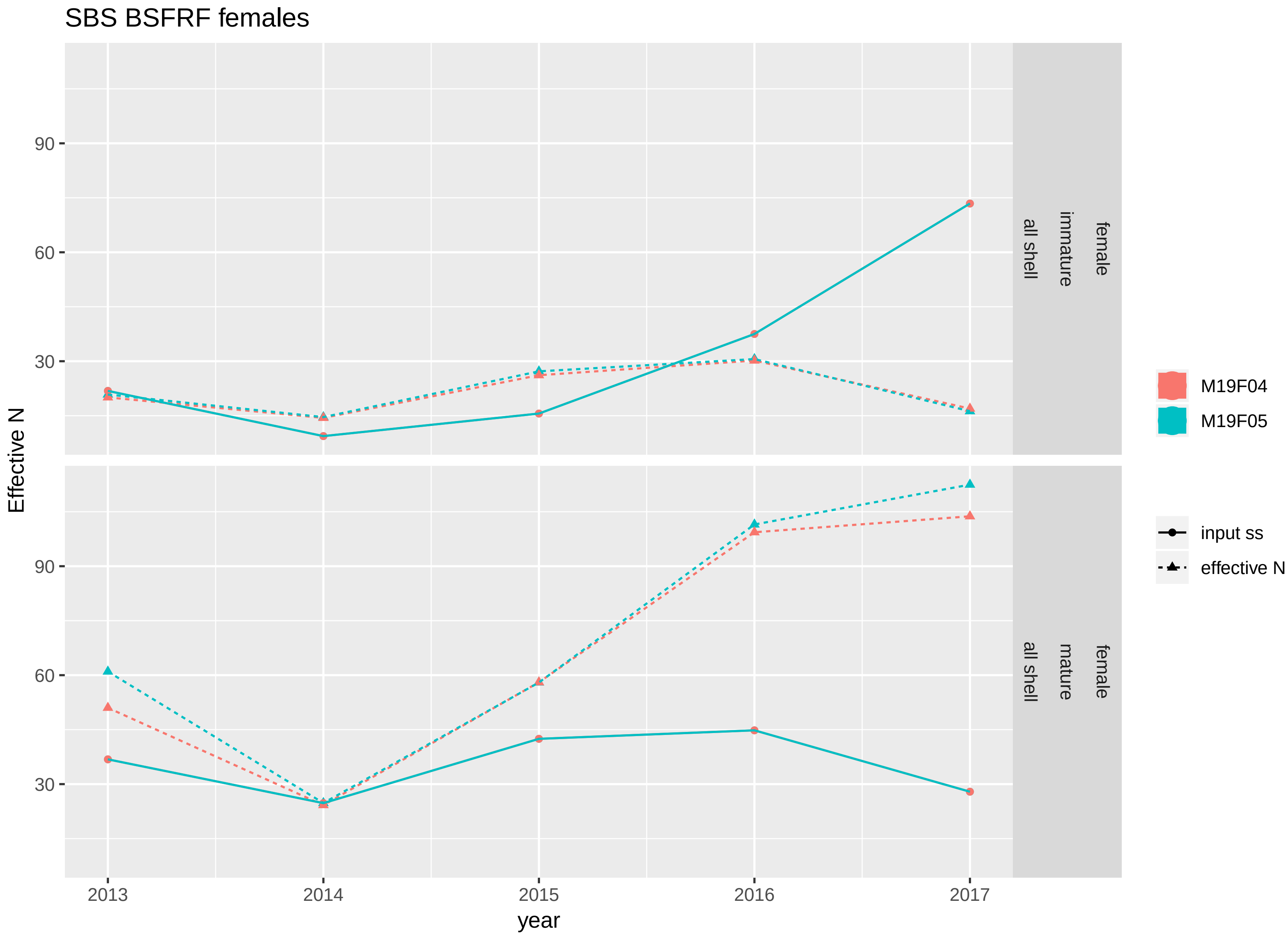


Figure 46: Input and effective sample sizes from retained catch size compositions from the SBS BSFRF females.

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:

$$RA_t = \frac{\sum_{t-1}^{t+1} MMB_t/\sigma_t^2}{\sum_{t-1}^{t+1} 1/\sigma_t^2} \tag{3}$$

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.

$$F_{OFL} = \begin{cases} Bycatchonly & if \frac{MMB}{MMB_{MSY}} \leq 0.25 \\ \frac{\lambda M(\frac{MMB}{MMB_{MSY}} - \alpha)}{1-\alpha} & if 0.25 < \frac{MMB}{MMB_{MSY}} < 1 \\ \lambda M & if MMB > MMB_{MSY} \end{cases} \tag{5}$$

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.

J. References

Some references are not cited, but were retained in this list given relevance to PIRKC.

Bell, M. C. 2006. Review of Alaska crab overfishing definitions: Report to University of Miami Independent System for peer reviews. April 24-28, 2006 Seattle, Washington, 35 p.

Bowers, F., M. Schwenzfeier, K. Herring, M. Salmon, H. Fitch, J. Alas, B. Baechler. 2011. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea, and the Westward Regions Shellfish Observer Program, 2009/2010.

Cahalan, J., J. Mondragon, and J. Gasper. 2010. Catch sampling and estimation in the Federal groundfish fisheries off Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-205, 42 p.

Grant, S.G. and Cheng, @. 2012. Incorporating deep and shallow components of genetic structure into the management of Alaskan red king crab. Evol. Appl. 5(8): 820-837.

Hamel, O. 2015. A method for calculating a meta-analytical prior for the natural mortality rate using multiple life history correlates. ICES Journal of Marine Science. 72: 62-69.

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

Jensen, G.C. 1995. Pacific Coast Crabs and Shrimps. Sea Challengers, Monterey, California, 87p.

Jørstad, K.E., E. Farestveit, H. Rudra, A-L. Agnalt, and S. Olsen. 2002. Studies on red king crab (Paralithodes camtschaticus) introduced to the Barents Sea, p. 425-438. In A. J. Paul, E. G. Dawe, R. Elner, G. S. Jamieson, G. H. Kruse, R. S. Otto, B. Sainte-Marie, T. C. Shirley and D. Woodby (editors), Crabs in cold water regions: biology, management, and economics. Alaska Sea Grant College Program Report No. AK-SG-02-01, University of Alaska, Fairbanks, AK.

Lang, C. A., J. I. Richar, and R. J. Foy. 2019. The 2018 eastern Bering Sea continental shelf and northern Bering Sea trawl surveys: Results for commercial crab species. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-386, 220 p.

Livingston, P. A., A. Ward, G. M. Lang, and M.S. Yang. 1993. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1987 to 1989. United States Department of Commerce, NOAA Technical Memorandum. NMFD-AFSC-11, 192 p.

Livingston, P.A. 1989. Interannual trends in Pacific cod, Gadus macrocephalus, predation on three commercially important crab species in the Eastern Bering Sea. Fishery Bulletin 87:807-827.

Loher, T. and D.A. Armstrong. 2005. Historical changes in the abundance and distribution of ovigerous red king crabs (Paralithodes camtschaticus) in Bristol Bay (Alaska), and potential relationship with bottom temperature. Fisheries Oceanography 14:292-306.

Loher, T., D.A. Armstrong, and B. G. Stevens. 2001. Growth of juvenile red king crab (Paralithodes camtschaticus) in Bristol Bay (Alaska) elucidated from field sampling and analysis of trawl-survey data. Fishery Bulletin 99:572-587.

Long, W.C., Swiney, K.M., Harris, C., Page, H.N., Foy, R.J. 2013. Effects of ocean acidification on juvenile red king crab (Paralithodes camtschaticus) and Tanner crab (Chionoecetes bairdi) growth, condition, calcification, and survival. PLoS ONE 8(4): e60959.

Marukawa, H. 1933. Biological and fishery research on Japanese king crab Paralithodes camtschatica (Tilesius). Fish. Exp. Stn, Tokyo 4:1-152.

Matsuura, S. and Takeshita, K. 1990. Longevity of red king crab, Paralithodes camtschatica, revealed by long-term rearing study, p. 65-90. In B. Melteff (editor) International Symposium on King and Tanner crabs. Alaska Sea Grant College Program Report No. 90-04, University of Alaska Fairbanks, AK.

NMFS. 2000. Endangered Species Act Section 7 Consultation Biological Assessment: Crab fisheries authorized under the Fishery Management Plan for Bering Sea/Aleutian Islands king and Tanner crabs. National Marine Fisheries Service, Alaska Region, 14 p.

NMFS. 2002. Endangered Species Act Section 7 Consultation Biological Assessment: Crab fisheries authorized under the Fishery Management Plan for Bering Sea/Aleutian Islands king and Tanner crabs. National Marine Fisheries Service, Alaska Region, 59 p.

NMFS. 2004. Final Environmental Impact Statement for Bering Sea and Aleutian Islands Crab Fisheries. National Marine Fisheries Service, Alaska Region

NPFMC (North Pacific Fishery Management Council). 1994. Environmental Assessment/Regulatory Impact/Review/Initial Regulatory Flexibility analysis for Amendment 21a to the Fishery Management Plan for Bering Sea and Aleutian Islands Groundfish. Anchorage, Alaska.

NPFMC (North Pacific Fishery Management Council). 1998. Fishery Management Plan for the Bering Sea/Aleutian Islands king and Tanner crabs. Anchorage, Alaska 105 p.

NPFMC (North Pacific Fishery Management Council). 2003. Environmental Assessment for Amendment 17 to the Fishery Management Plan for the king and Tanner crab fisheries in the Bering Sea/Aleutian Islands: A rebuilding plan for the Pribilof Islands blue king crab stock. Anchorage, Alaska 87 p.

NPFMC (North Pacific Fishery Management Council). 2008. Environmental Assessment for Amendment 24 to the Fishery Management Plan for the king and Tanner crab fisheries in the Bering Sea/Aleutian Islands:

to revise overfishing definitions. Anchorage, Alaska 194 p.

Otto R.S., R.A. MacIntosh, and P.A. Cummiskey. 1990. Fecundity and other reproductive parameters of female red king crab (Paralithodes camtschatica) in Bristol Bay and Norton Sound, Alaska, p. 65-90 In B. Melteff (editor) Proceedings of the International Symposium on King and Tanner crabs. Alaska Sea Grant College Program Report No. 90-04, University of Alaska Fairbanks, AK.

Overland, J., Rodionov, S., Minobe, S., and Bond, N. 2008. North Pacific regime shifts: definitions, issues, and recent transitions. Progress in Oceanography, 77: 92-102.

Powell G.C. and R.B. Nickerson. 1965. Reproduction of king crabs, Paralithodes camtschatica (Tilesius). Journal of Fisheries Research Board of Canada 22:101-111.

Powell, G.C. 1967. Growth of king crabs in the vicinity of Kodiak Island, Alaska. Informational Leaflet 92, Alaska Department of Fish and Game, 58 p.

Punt, A.E., Szuwalski, C.S., and Stockhausen, W. 2014. An evaluation of stock-recruitment proxies and environmental change points for implementing the US Sustainable Fisheries Act. Fish. Res., 157: 28-40.

Seeb J.E., Kruse G.H., Seeb L.W., Weck R.G. Proceedings of the International Symposium on King and Tanner Crabs. 1990. Genetic structure of red king crab populations in Alaska facilitates enforcement of fishing regulations; pp. 491–502. Alaska Sea Grant College Program Report, 90-04.

Shirley, S. M. and T. C. Shirley. 1989. Interannual variability in density, timing and survival of Alaskan red king crab Paralithodes camtschatica larvae. Marine Ecology Progress Series 54:51-59.

Shirley, T. C., S. M. Shirley, and S. Korn. 1990. Incubation period, molting and growth of female red king crabs: effects of temperature, p. 51-63. In B. Melteff (editor) Proceedings of the International Symposium on King and Tanner Crabs. Alaska Sea Grant College Program Report No. 90-04, University of Alaska Fairbanks, AK.

Siddeek, M.S.M, L. J. Watson, S. F. Blau, and H. Moore. 2002. Estimating natural mortality of king crabs from tag recapture data, p. 51-75. In A. J. Paul, E. G. Dawe, R. Elner, G. S. Jamieson, G. H. Kruse, R. S. Otto, B. Sainte-Marie, T. C. Shirley and D. Woodby (editors), Crabs in cold water regions: biology, management, and economics. Alaska Sea Grant College Program Report No. AK-SG-02-01, University of Alaska, Fairbanks, AK.

Somerton, D. A. 1980. A computer technique for estimating the size of sexual maturity in crabs. Canadian Journal of Fisheries and Aquatic Science 37: 1488-1494.

Stevens, B.B. 1990. Temperature-dependent growth of juvenile red king crab (Paralithodes camtschatica), and its effects on size-at-age and subsequent recruitment in the eastern Bering Sea. Canadian Journal of Fisheries and Aquatic Sciences 47:1307-1317.

Stevens, B.G. and K. M. Swiney. 2007b. Growth of female red king crabs Paralithodes camtshaticus during pubertal, primiparous, and multiparous molts. Alaska Fisheries Research Bulletin 12:263-270.

Stevens, B.G. and K.M. Swiney. 2007a. Hatch timing, incubation period, and reproductive cycle for primiparous and multiparous red king crab Paralithodes camtschaticus. Journal of Crustacean Biology 27:37-48.

Szuwalski, C.S., R. Foy and B.J. Turnock (2015). 2015 Stock assessment and fishery evaluation report for the Pribilof Island red king crab fishery of the Bering Sea and Aleutian Islands regions. In: Bering Sea and Aleutian Islands Crab Stock Assessment and Fishery Evaluation 2015. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Szuwalski, C.S. (2015) Biases in biomass estimates and selecting bind width in size-structured assessment methods. Fisheries Research.

Szuwalski, C.S. and Punt, A.E. 2013a. Regime shifts and recruitment dynamics of snow crab, Chionoecetes opilio, in the eastern Bering Sea. Fish. Ocean., 22(5): 345-354.

Szuwalski, C. S., and Punt, A. E. 2013b. Fisheries management for regime-based ecosystems: a management strategy evaluation for the snow crab fishery in the eastern Bering Sea. ICES J. Mar. Sci.,70: 955-967.

Then, A. Y., Hoenig, J. M., Hall, N. G., and Hewitt, D. A. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES Journal of Marine Science, 72: 82–92.

Turnock, B.J., C.S. Szuwalski, and R.J. Foy. 2016. 2016 Stock assessment and fishery evaluation report for the Pribilof Island red king crab fishery of the Bering Sea and Aleutian Islands regions. In: Bering Sea and Aleutian Islands Crab Stock Assessment and Fishery Evaluation 2016. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

Weber, D. D. 1967. Growth of the immature king crab Paralithodes camtschatica (Tilesius). Bulletin No. 21, North Pacific Commission, 53 p.

Weber, D.D. 1974. Observations on growth of southeastern Bering Sea king crab, Paralithodes camtschatica, from a tag-recovery study, 1955-65. Data Report 86, National Marine Fisheries Service, 122 p.

Zheng, J. and G. H. Kruse. 2000. Recruitment patterns of Alaskan crabs in relation to decadal shifts in climate and physical oceanography. ICES Journal of Marine Science 57:438-451.

Zheng, J. M.C. Murphy, and G.H. Kruse. 1995. A length-based population model and stock-recruitment relationships for red king crab, Paralithodes camtschaticus, in Bristol Bay, Alaska. Canadian Journal of Fisheries and Aquatic Science 52:1229-1246.

Zheng, J. and Siddeek, M.S.M. 2018. Bristol Bay red king crab stock assessment. In: Bering Sea and Aleutian Islands Crab Stock Assessment and Fishery Evaluation 2018. North Pacific Fishery Management Council, P. O. Box 103136, Anchorage, Ak 99510.

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   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 0.0
```

```
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 0.01162
2001 1 3 1 1 0 0 200 0 0 0 0 0 0 0 0 0 0.003012048 0 0.012048193 0.05
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

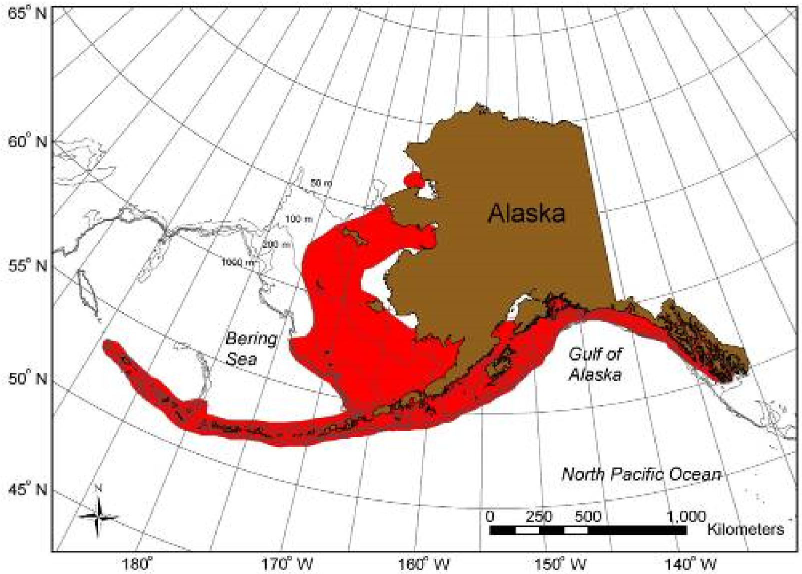


Figure 1: Red king crab distribution in the North Pacific

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## [[1]]
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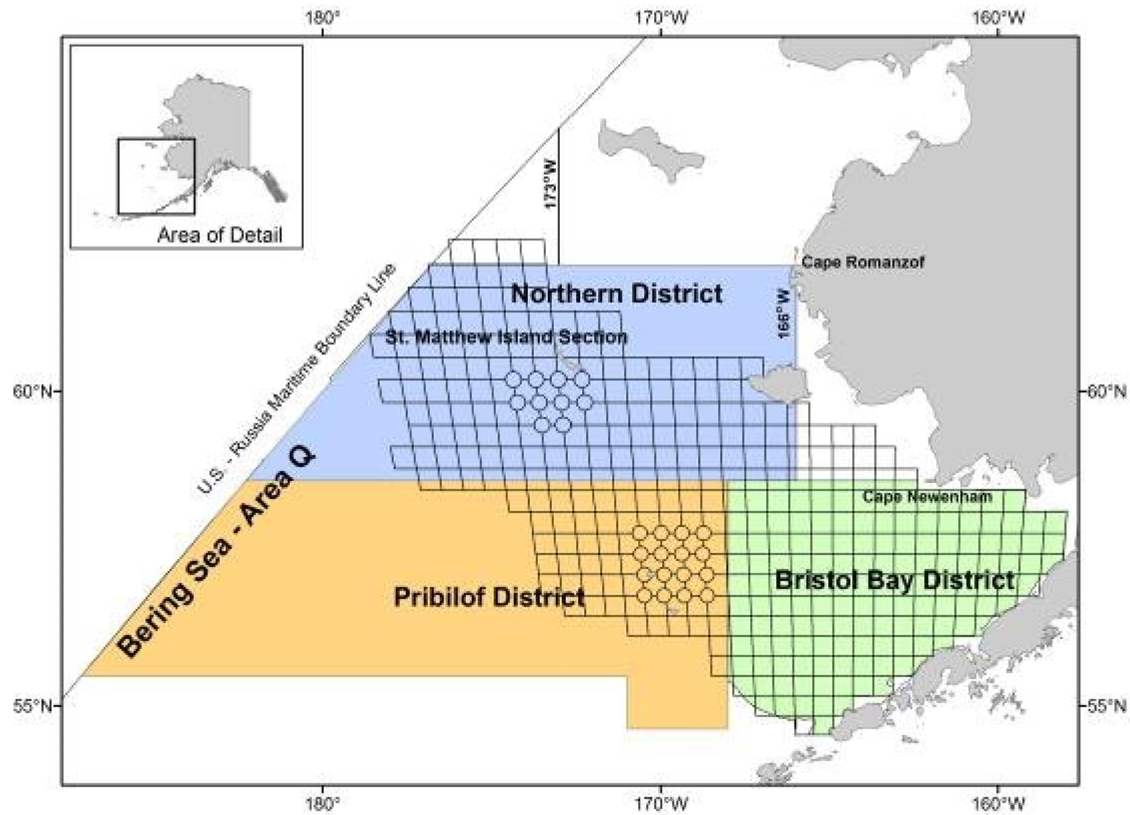

Figure 2: Pribilof Island management area in the Bering Sea

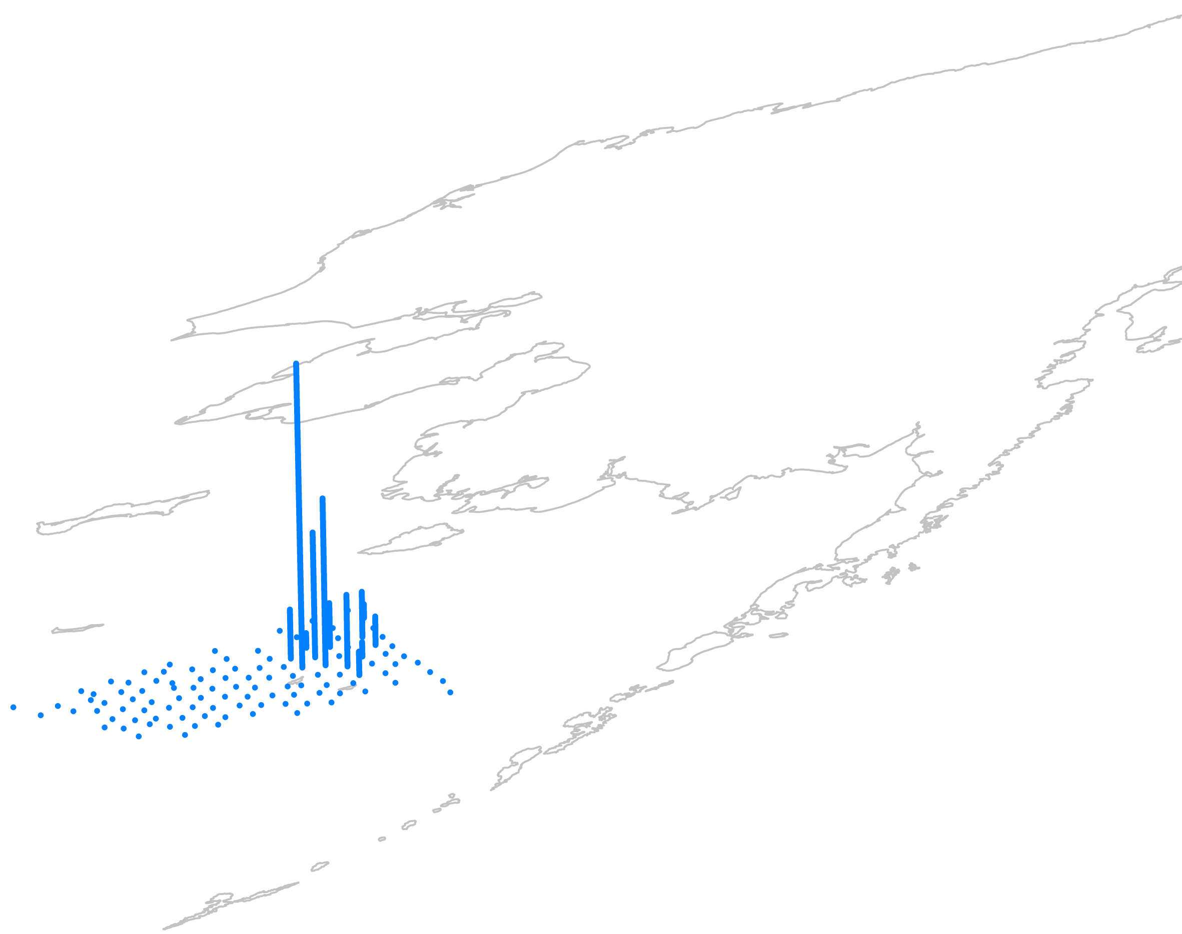

Figure 3: Observed relative male abundance by survey stations in 2019.

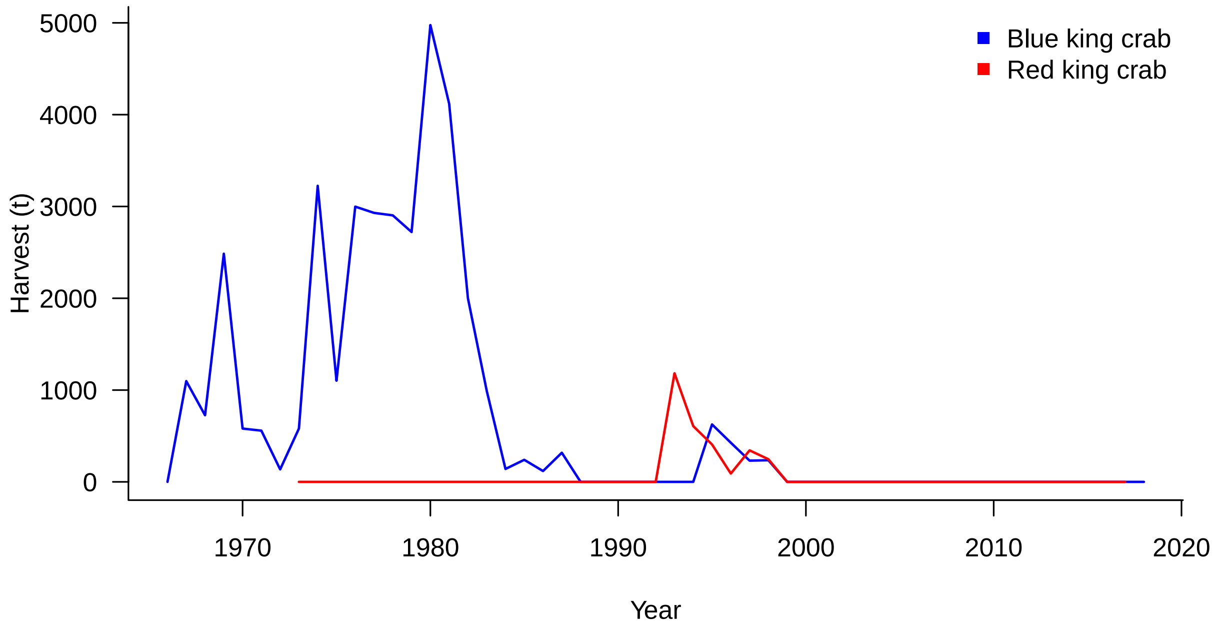

Figure 4: Historical directed harvests of blue king crab and red king crab around the Pribilof Islands.

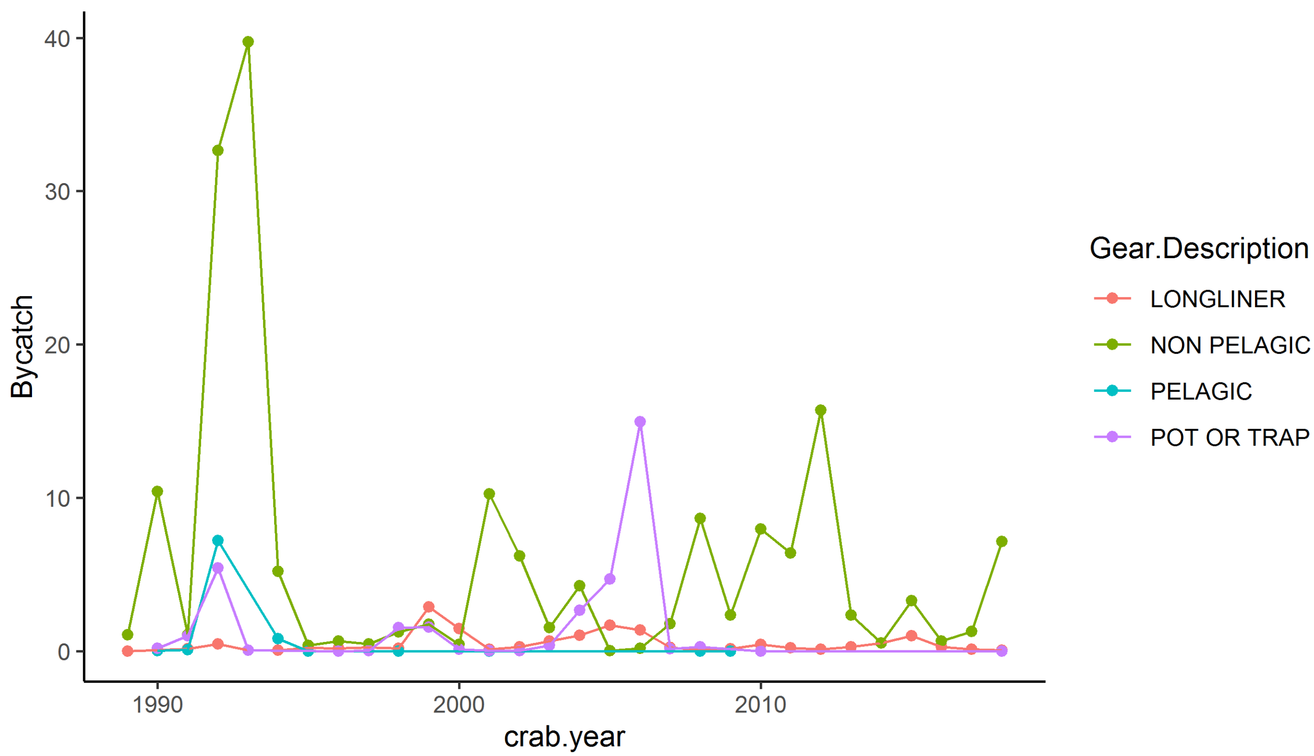

Figure 5: Bycatch by fleet by year in metric tonnes of PIRKC.

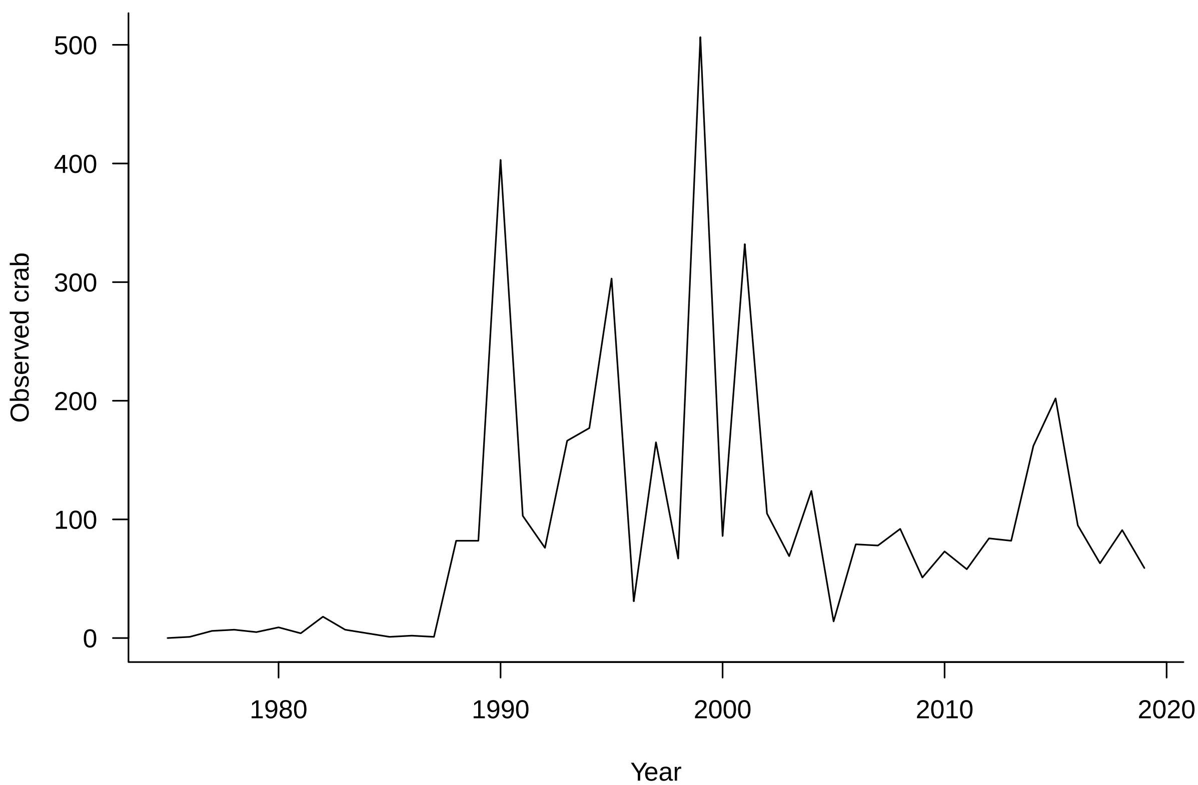

Figure 6: Total number of observed crab by year.

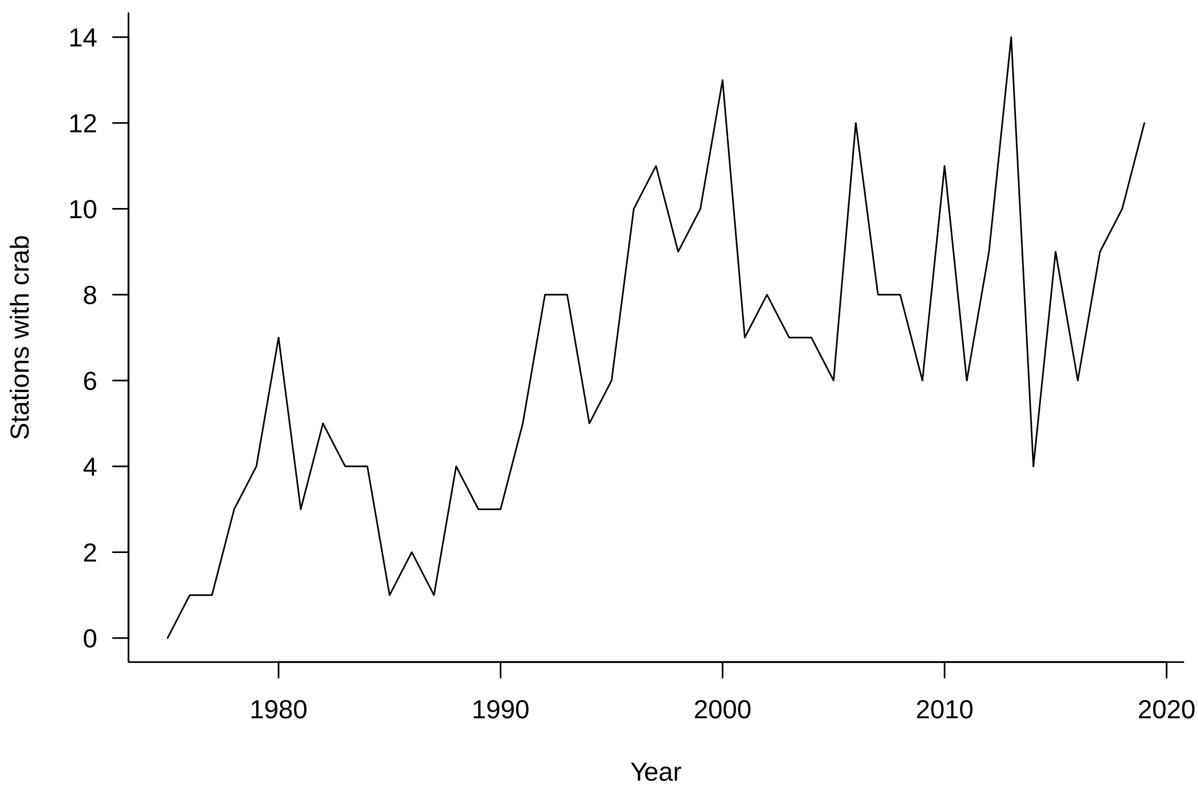

Figure 7: The number of stations at which crab were observed.

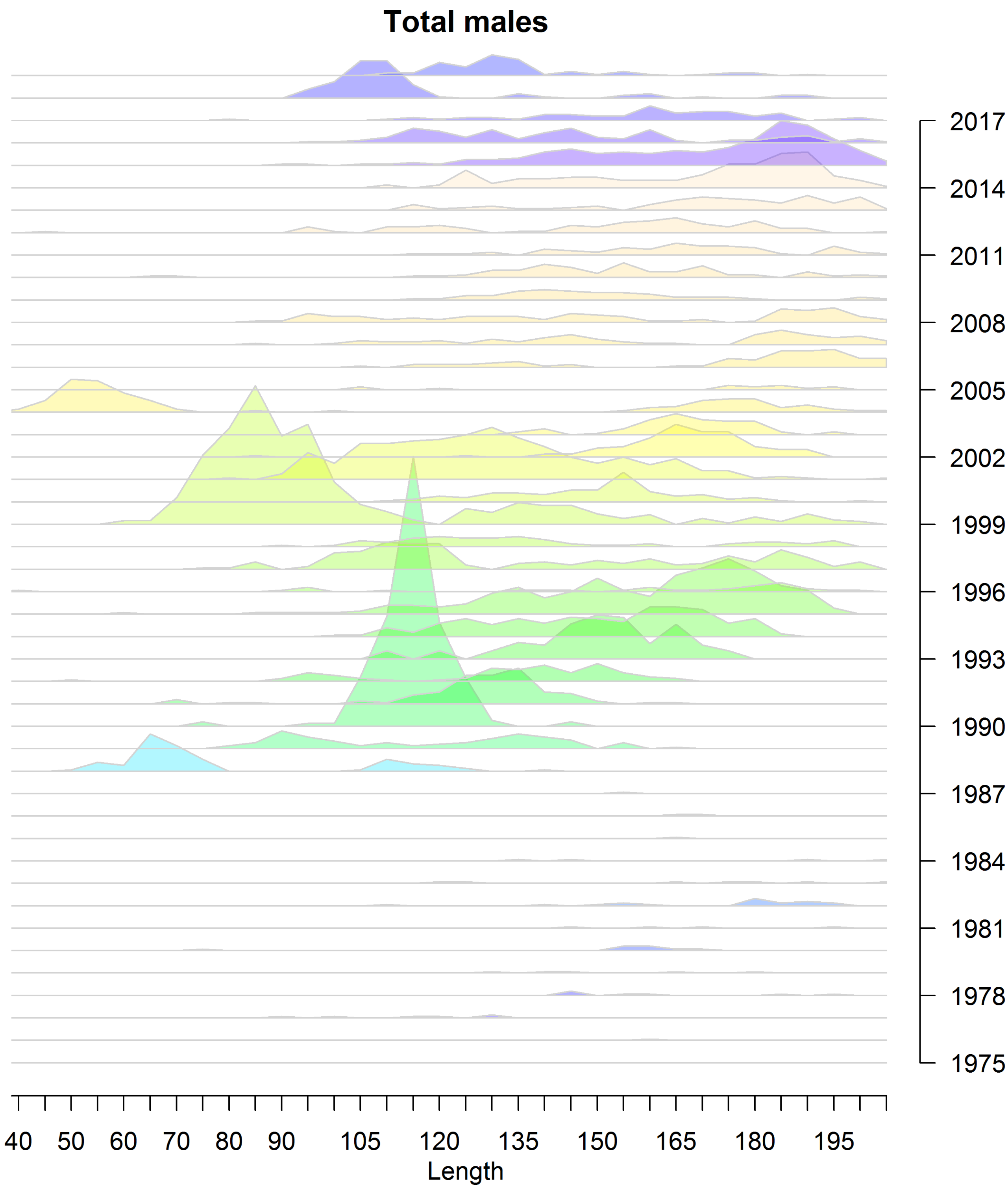

Figure 8: Observed male numbers at length by year.

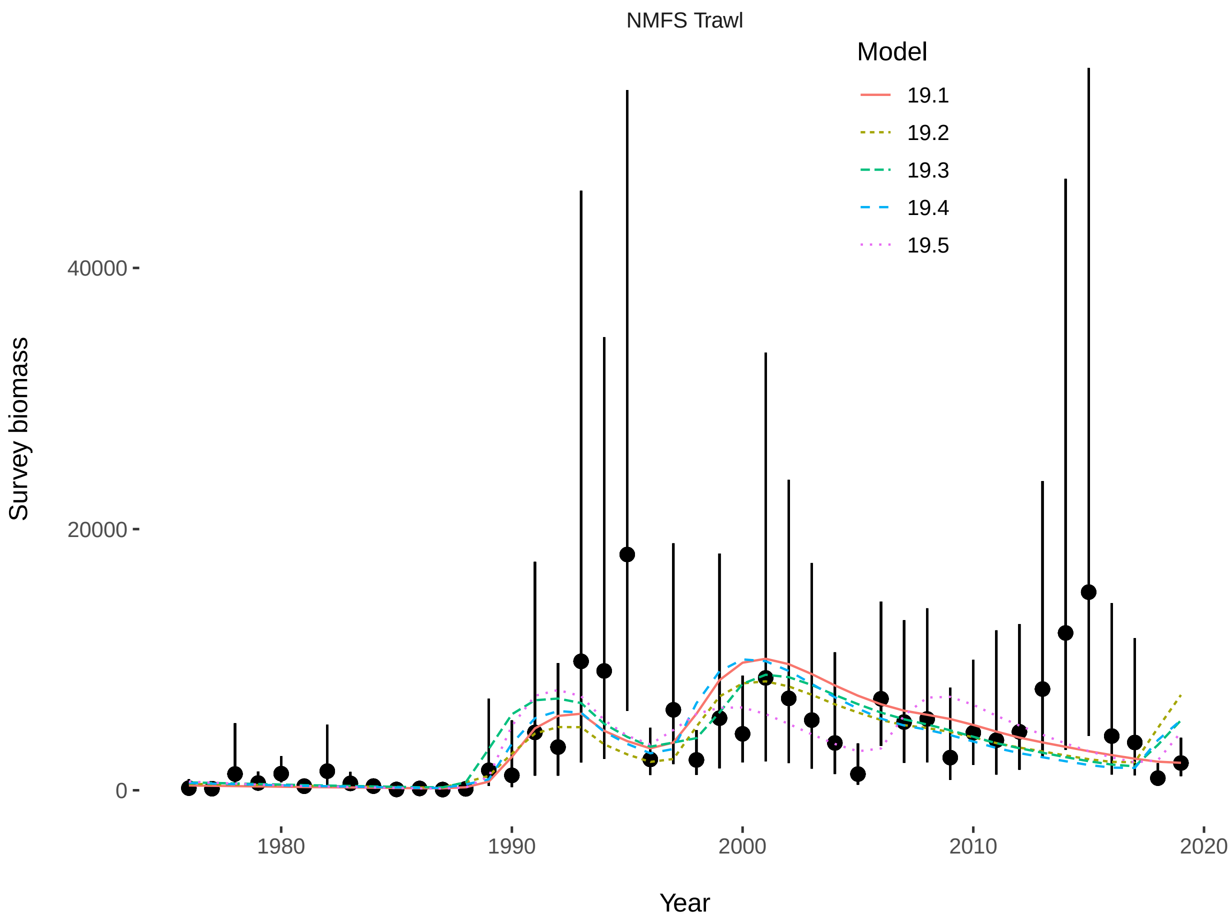

Figure 9: Fits of integrated assesssment scenarios to mature male biomass from the NMFS summer trawl survey.

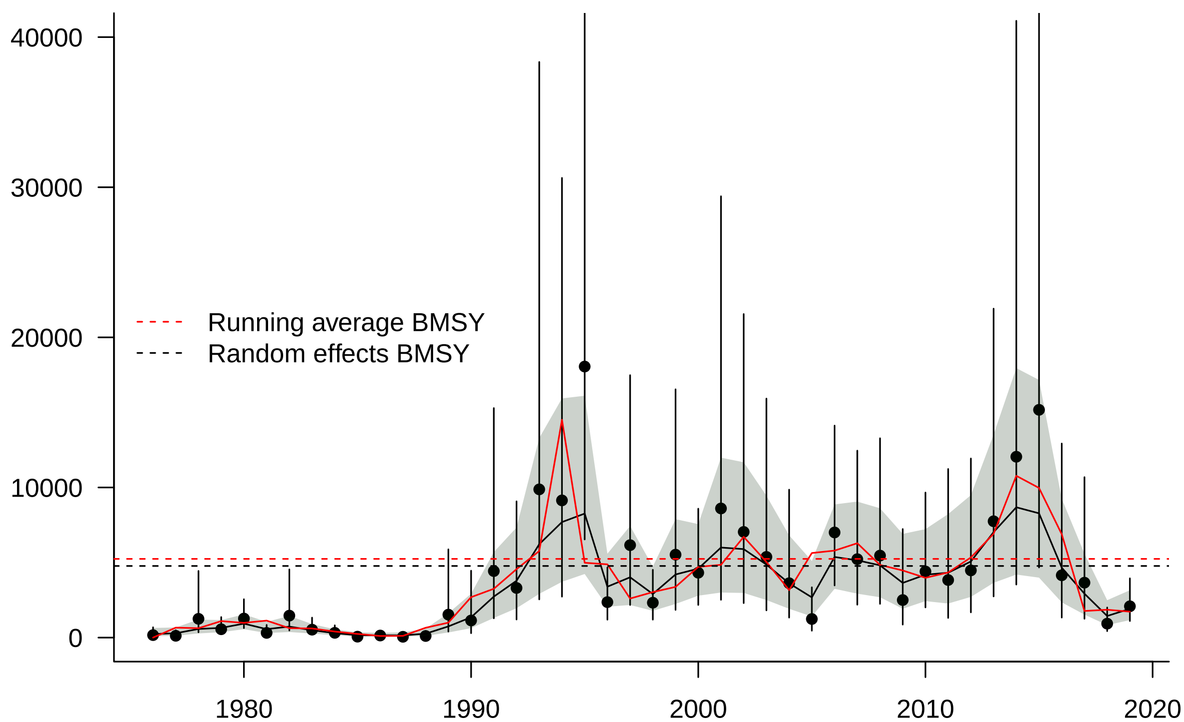

Figure 10: Comparison of estimated MMB among running average and random effects models.

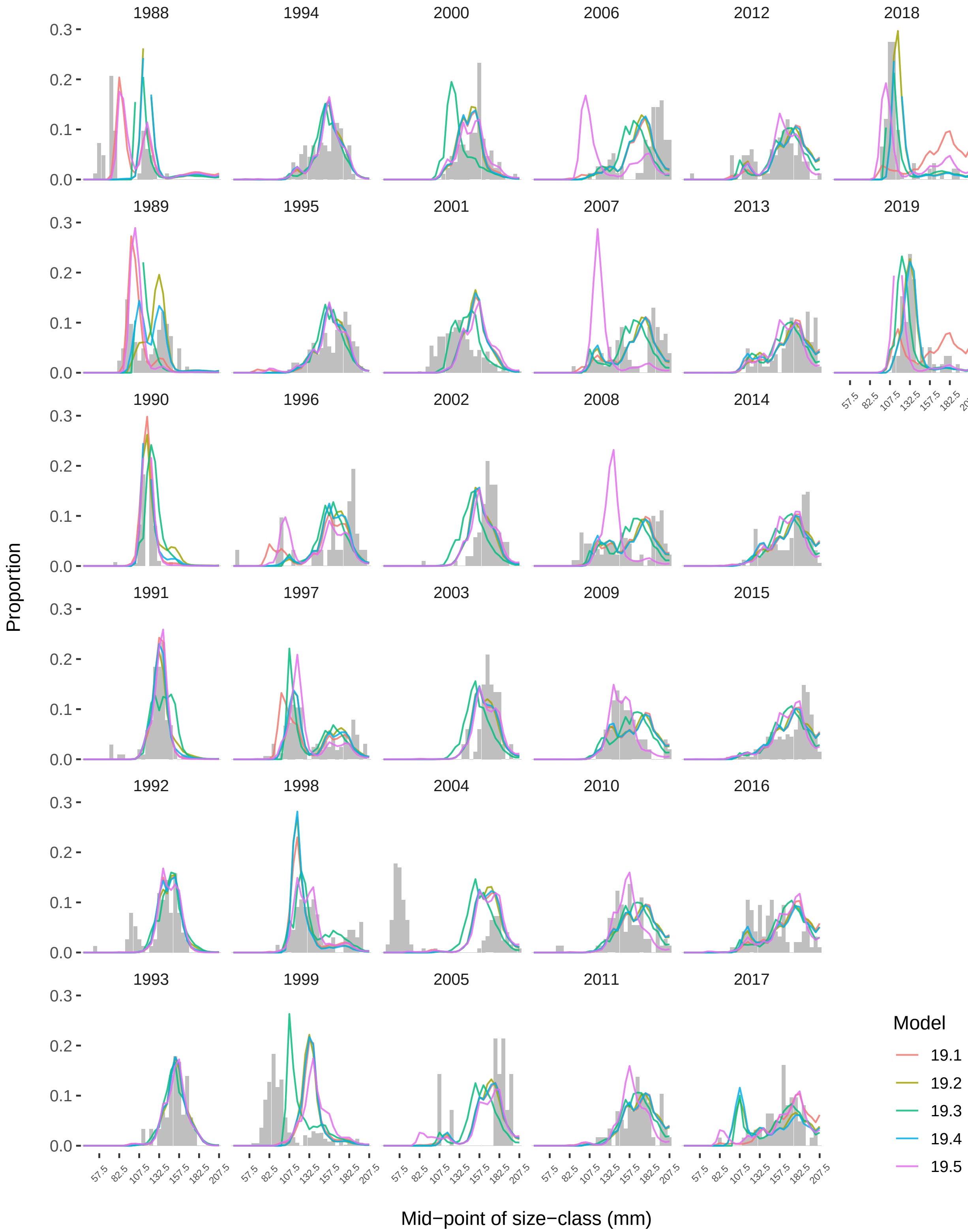

Figure 11: Model fits to survey size composition data.

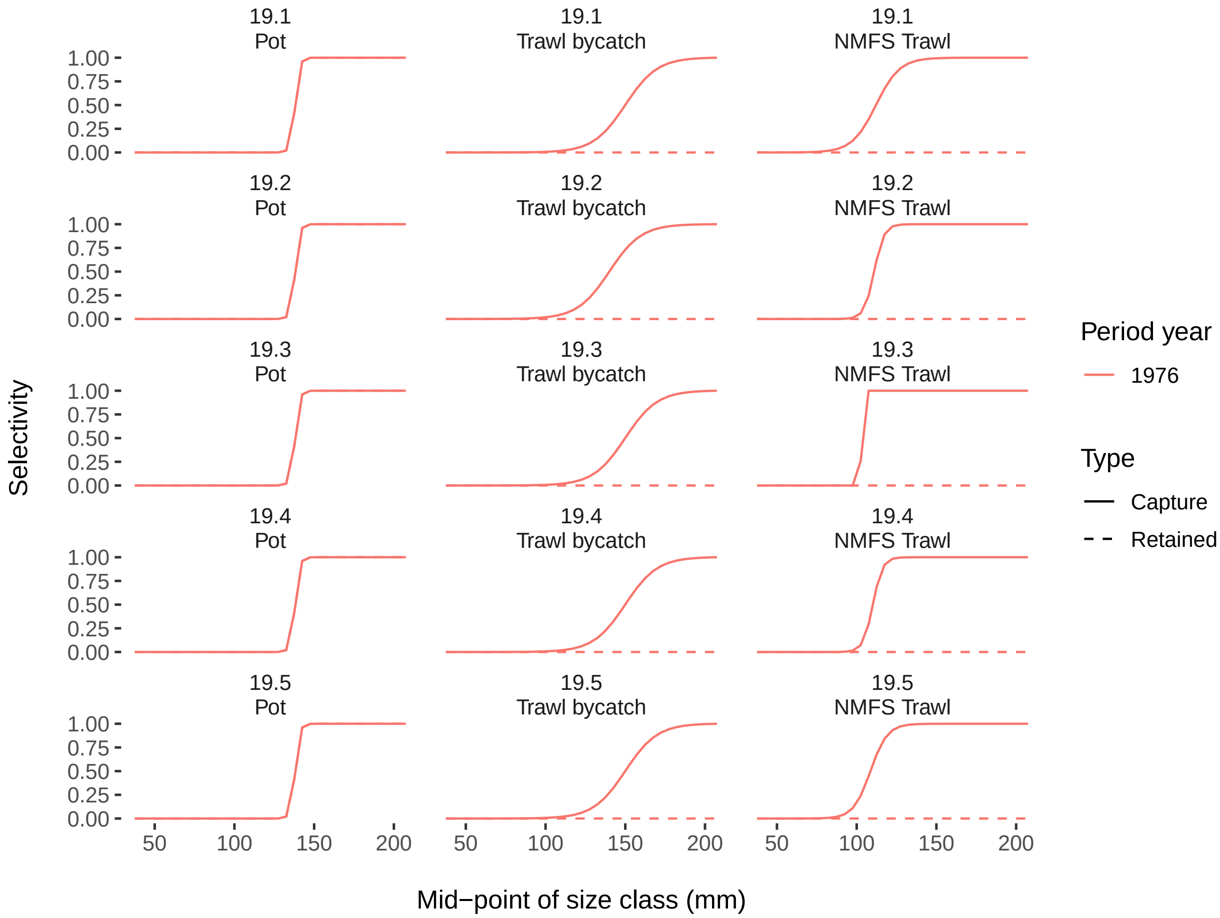

Figure 12: Estimated survey selectivity, assumed fishery selectivity, assumed trawl selectivity.

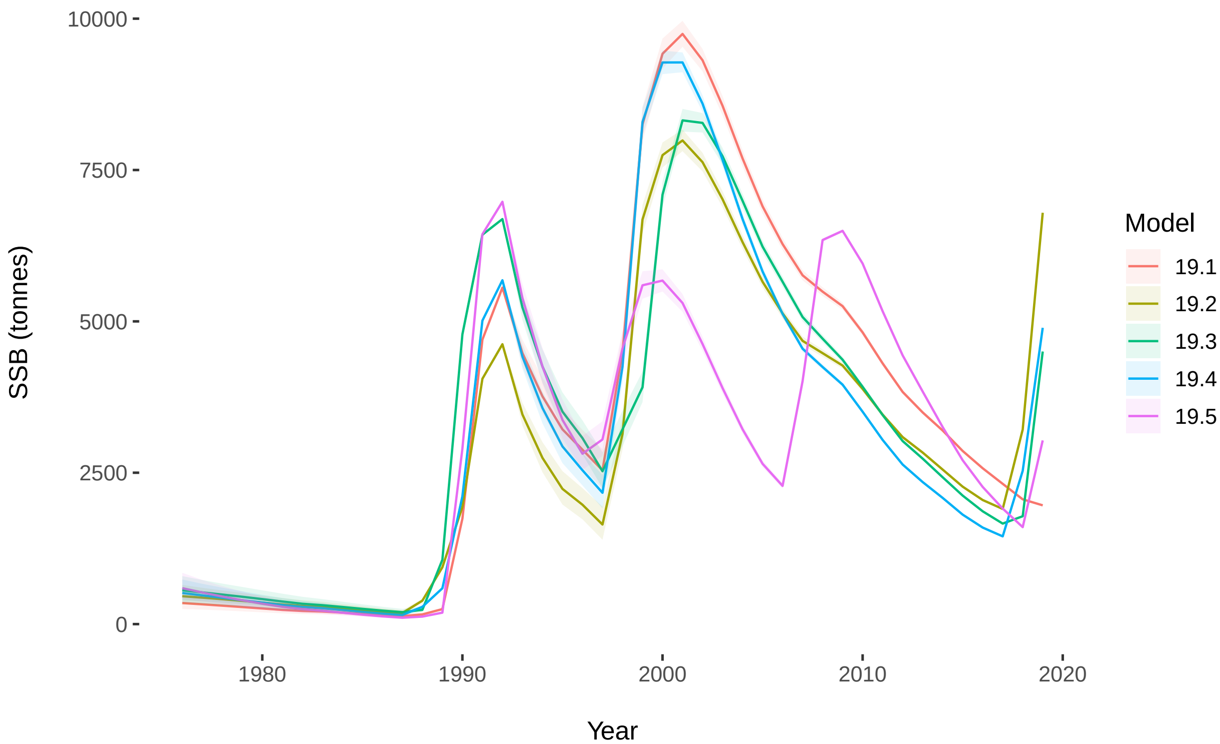

Figure 13: Model predicted mature male biomass at mating time

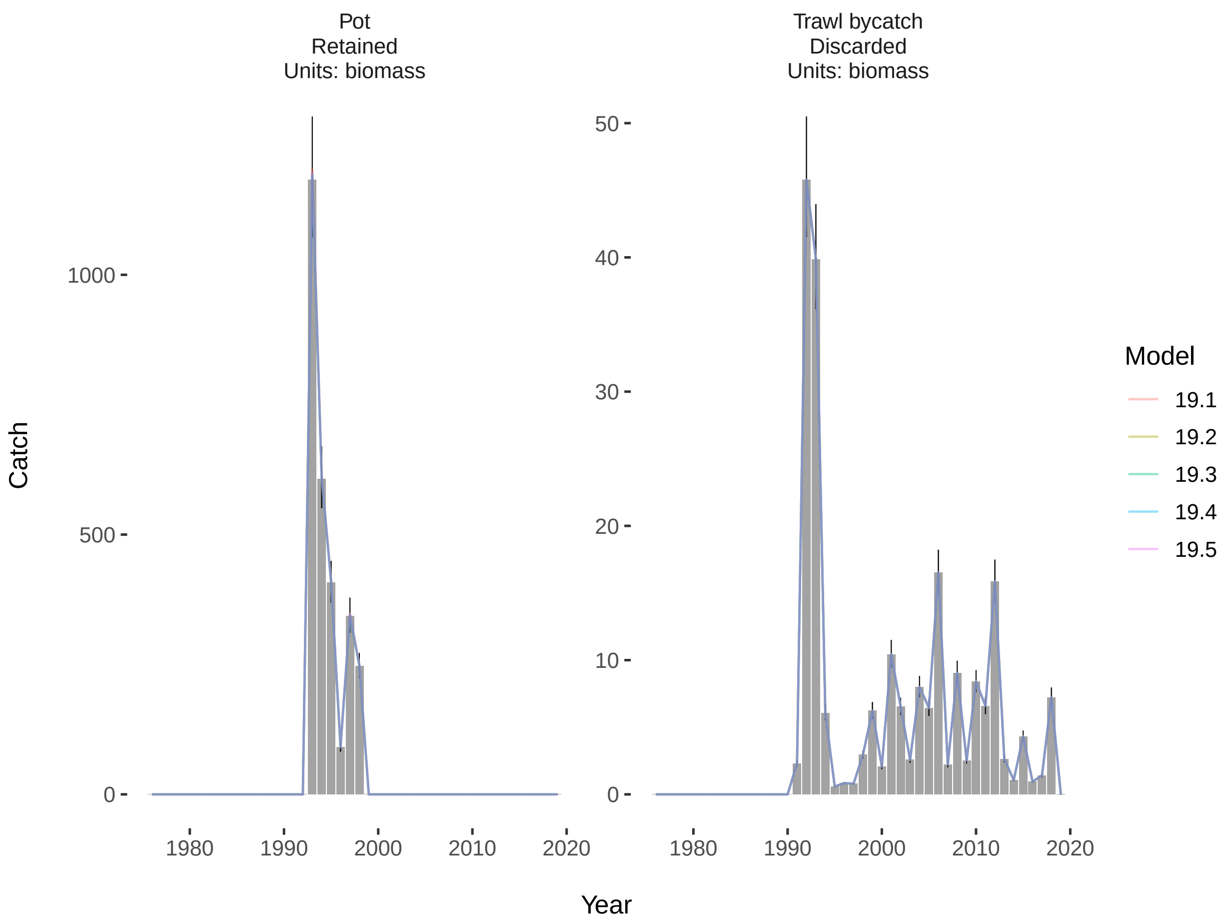

Figure 14: Model fits to catch data.

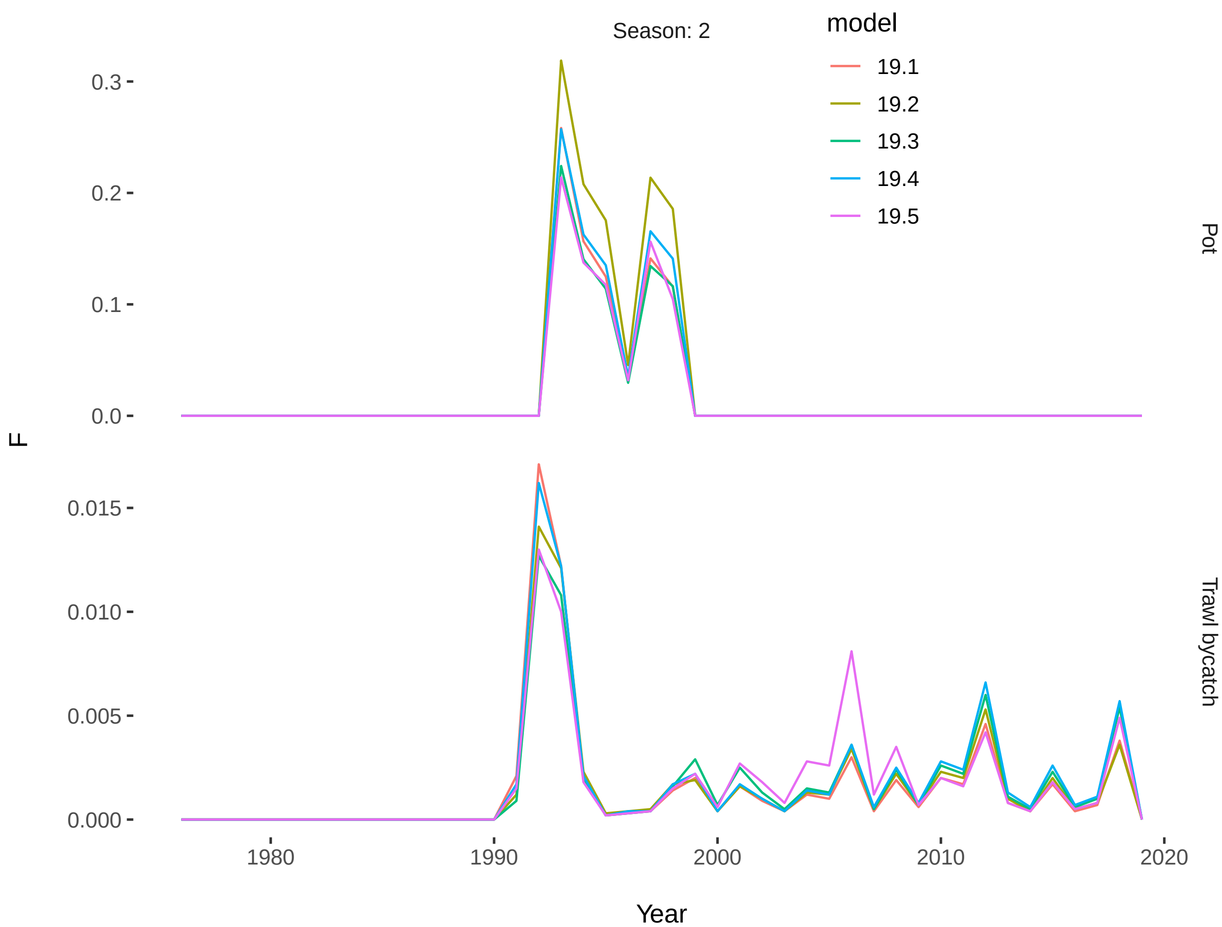

Figure 15: Model predicted fishing mortalities

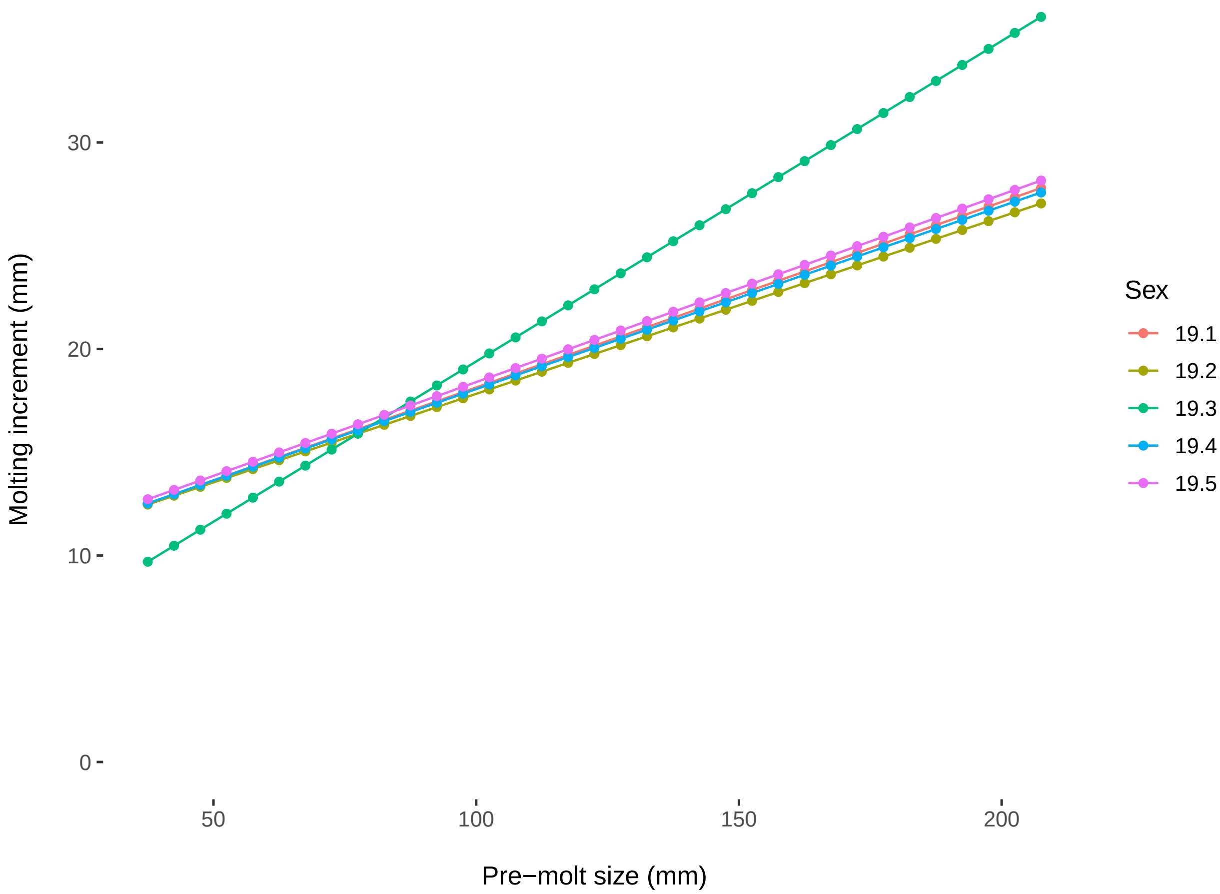

Figure 16: Predicted molt increments

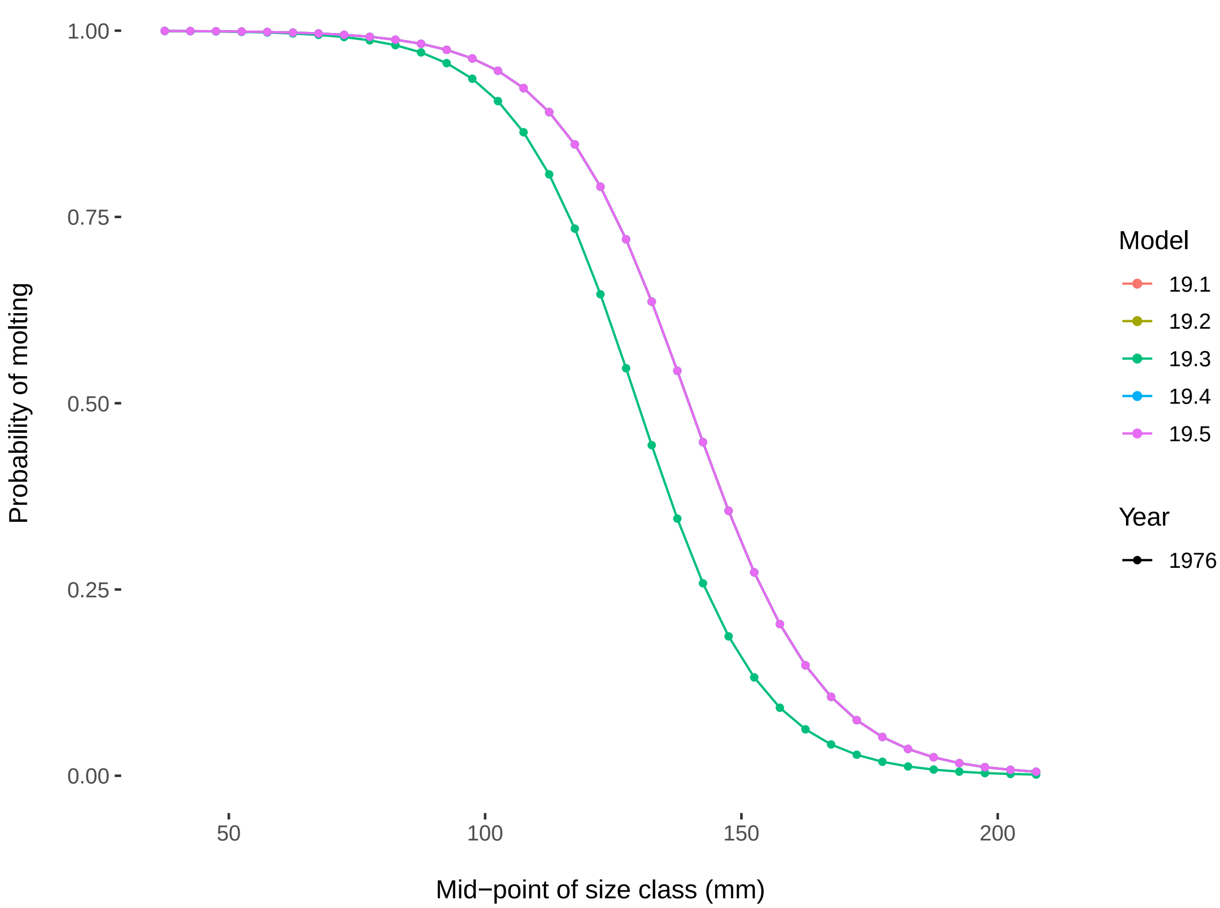

Figure 17: Speified probability of molting by size (mm)

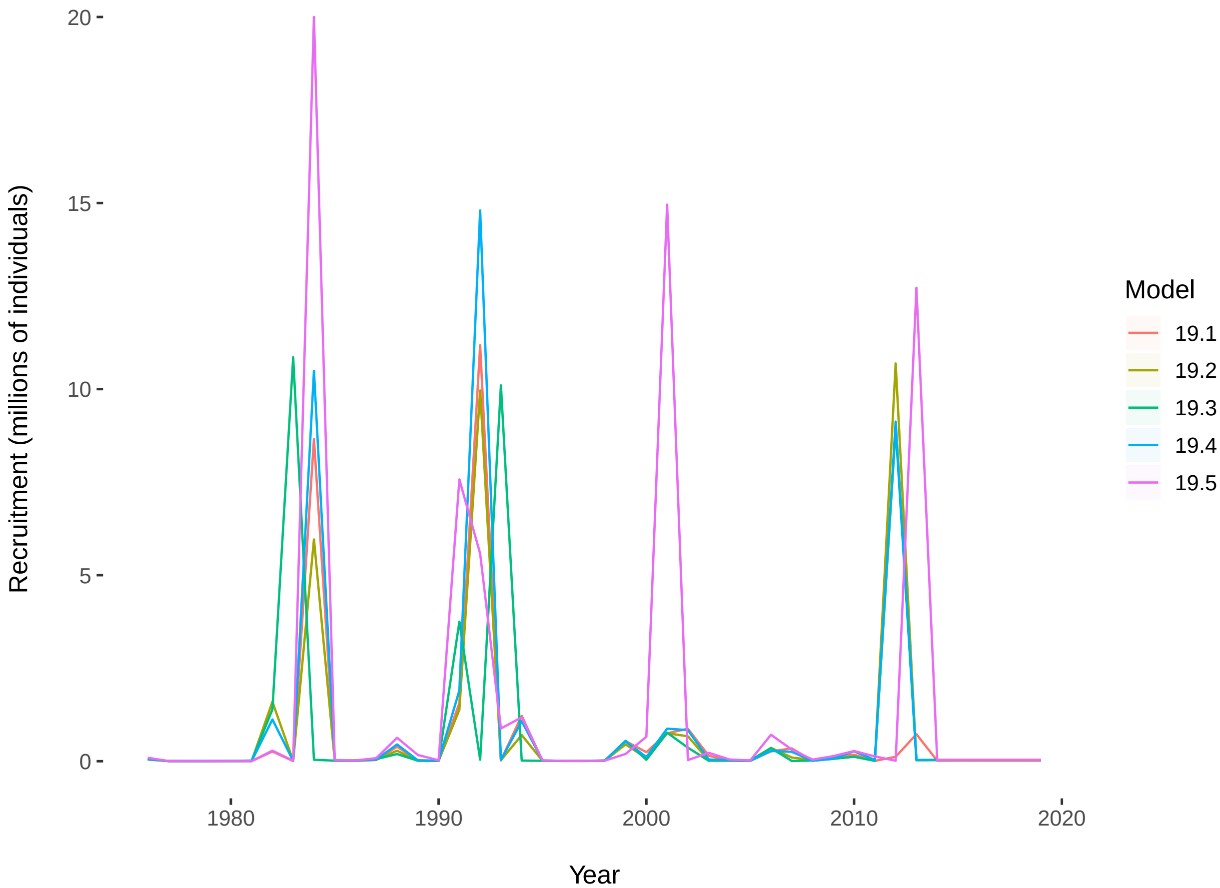

Figure 18: Estimated recruitment.

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

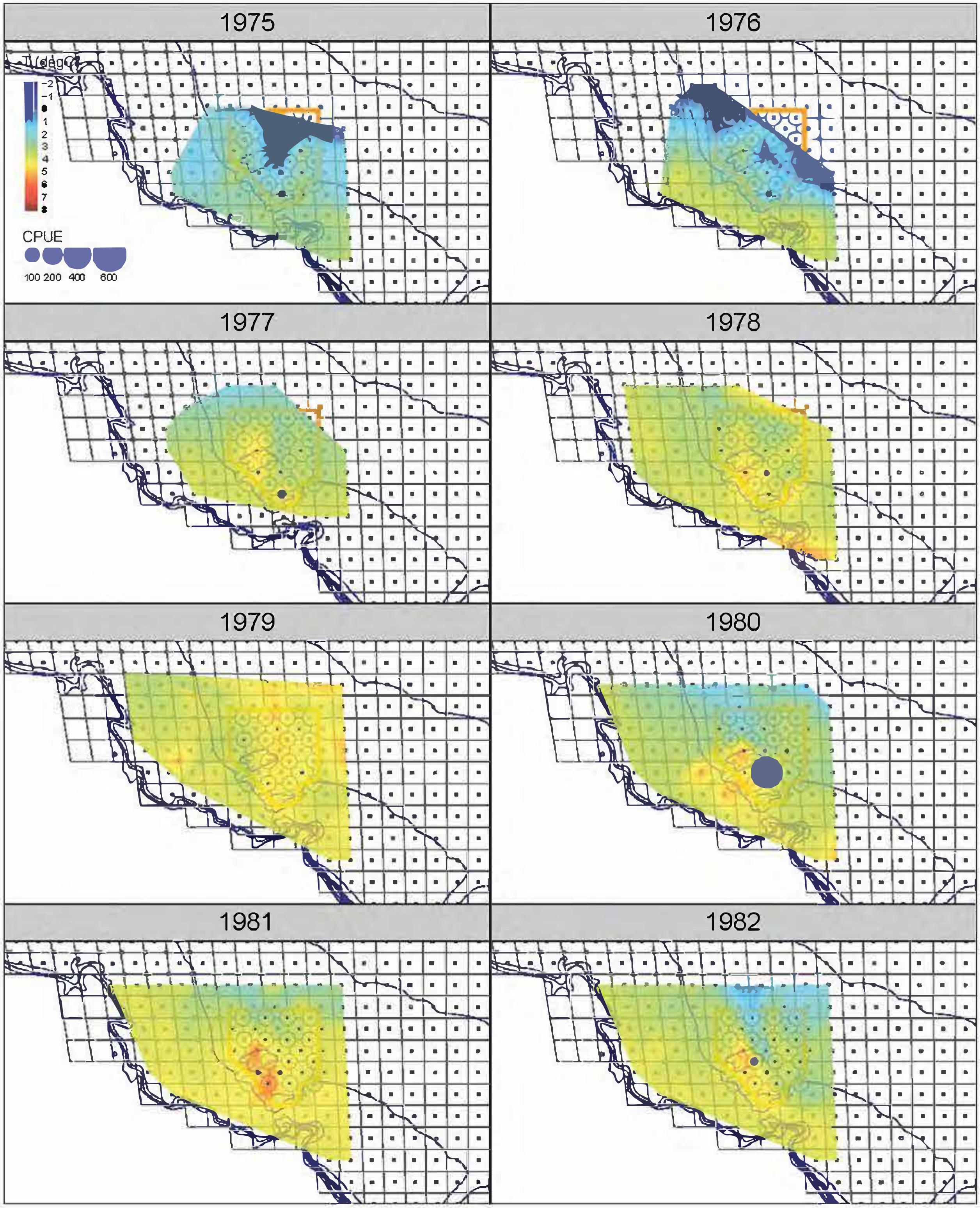

Figure 11: Survey CPUE (biomass) for females PIBKC. Page 1 of 6

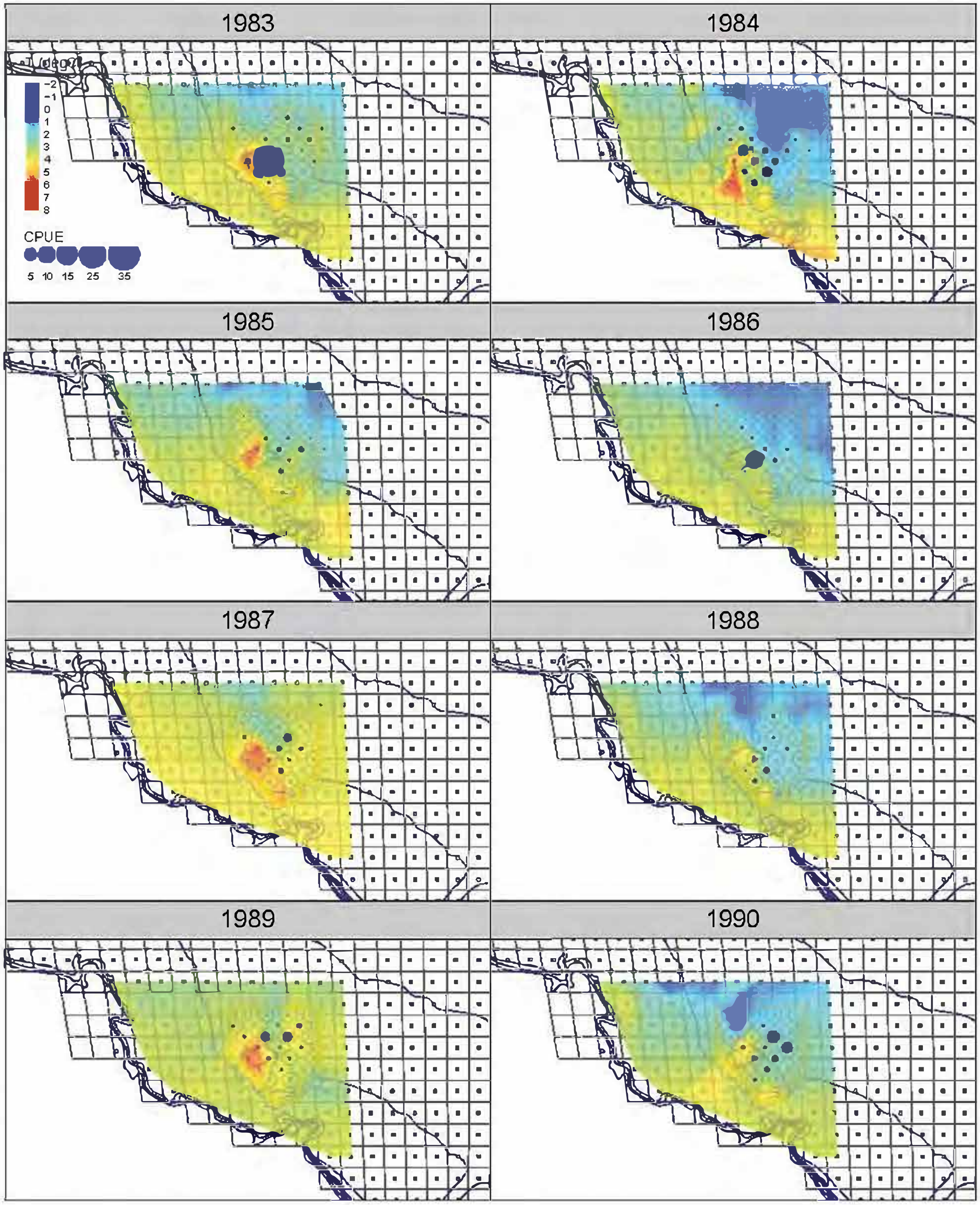

Figure 12: Survey CPUE (biomass) for females PIBKC. Page 2 of 6

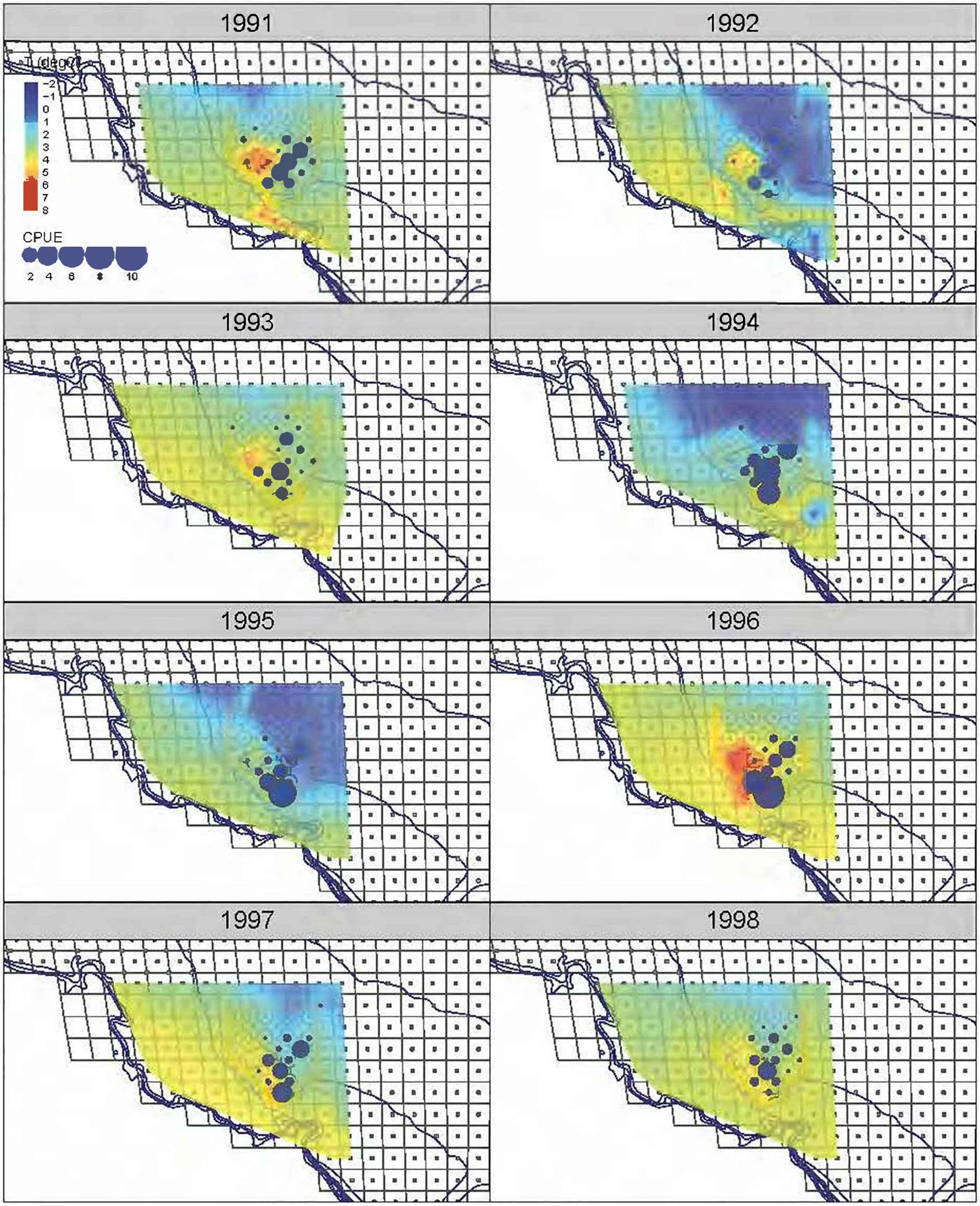

Figure 13: Survey CPUE (biomass) for females PIBKC. Page 3 of 6

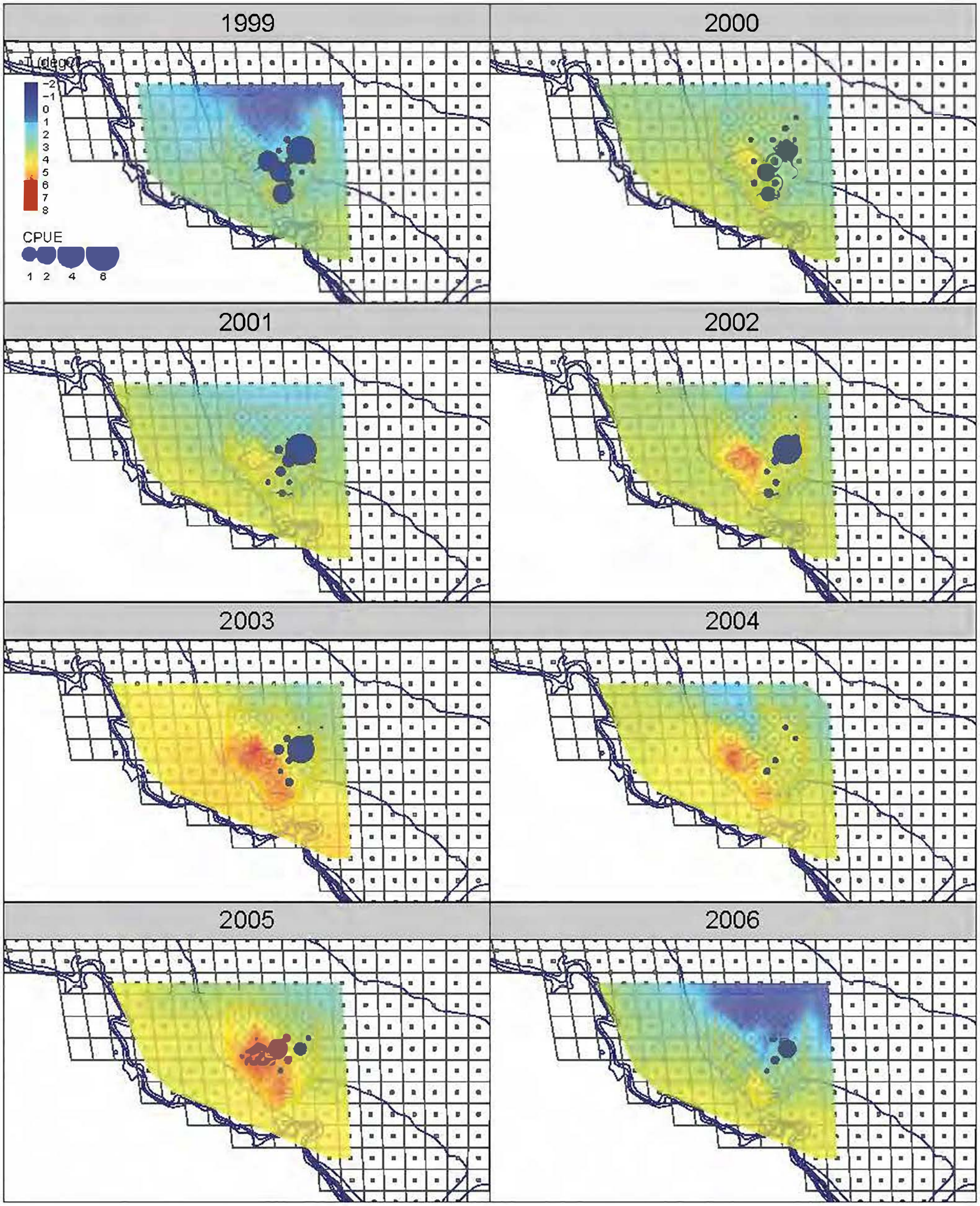

Figure 14: Survey CPUE (biomass) for females PIBKC. Page 4 of 6

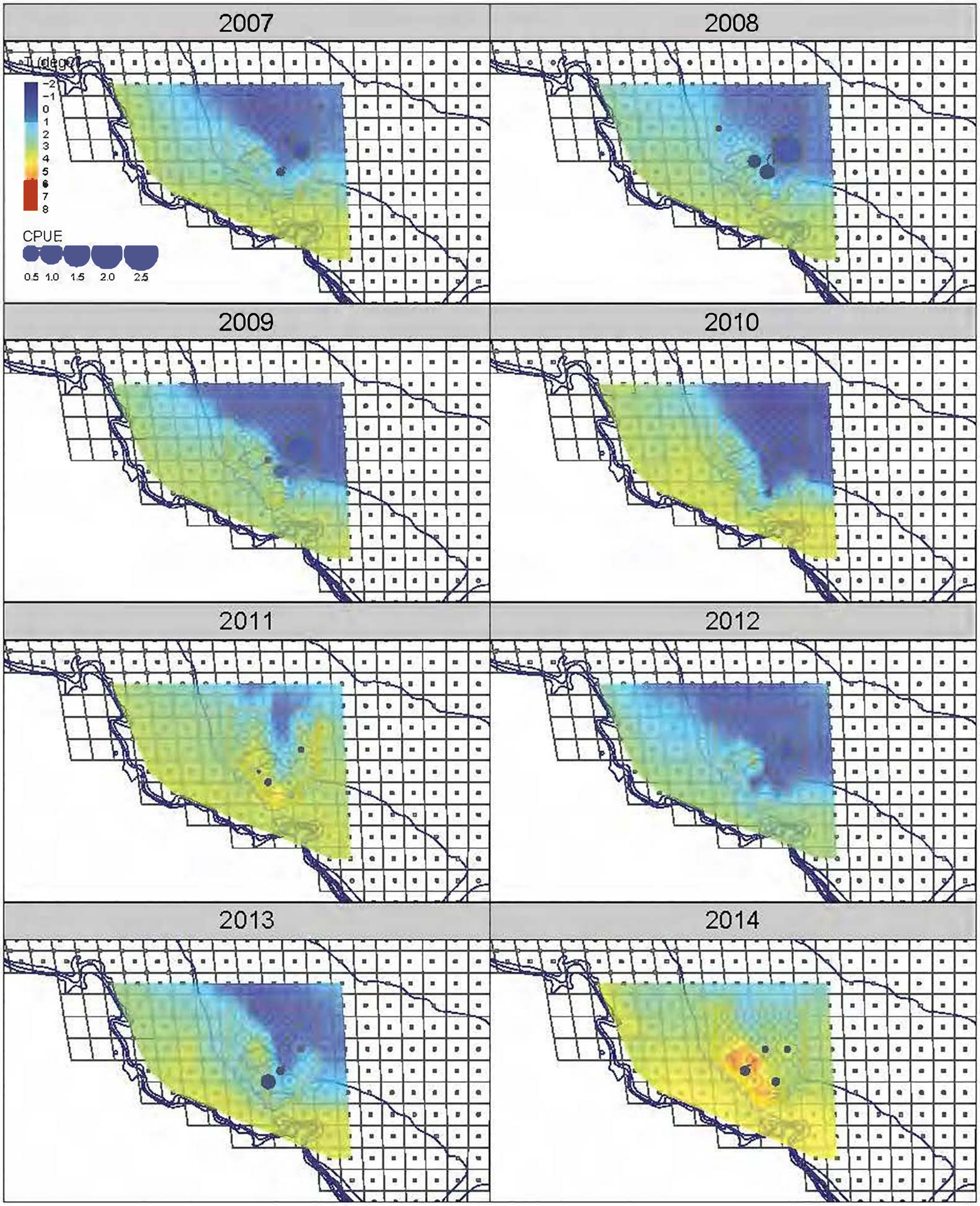

Figure 15: Survey CPUE (biomass) for females PIBKC. Page 5 of 6

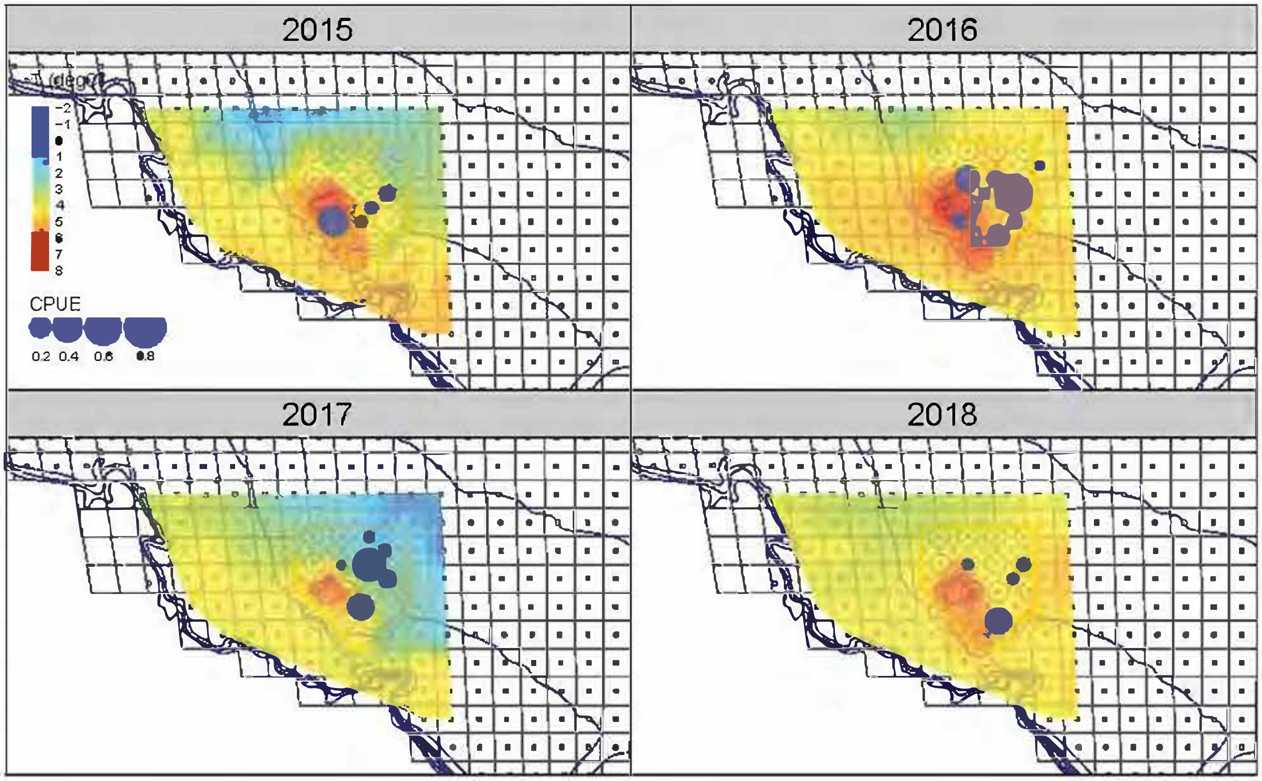

Figure 16: Survey CPUE (biomass) for females PIBKC. Page 6 of 6

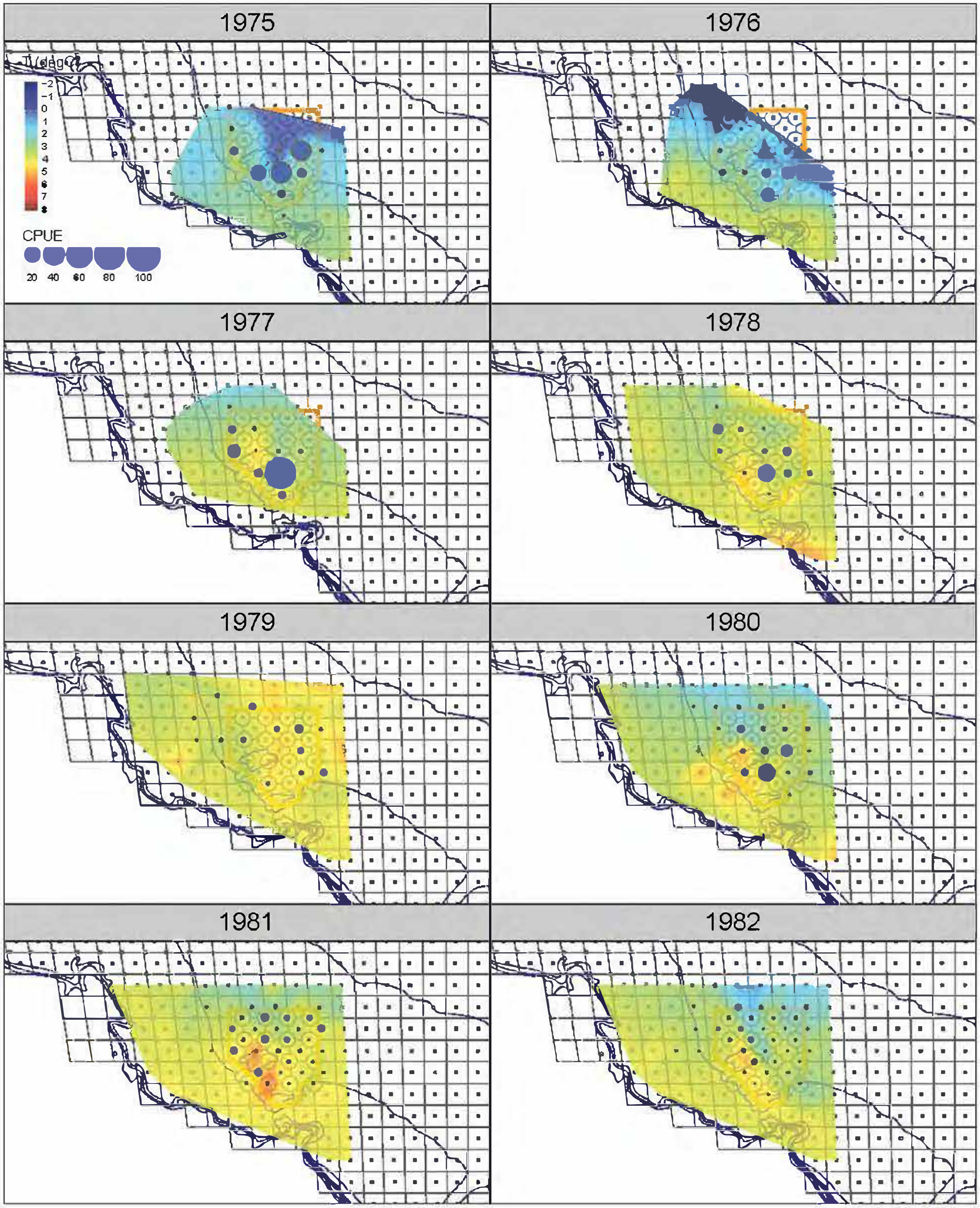

Figure 17: Survey CPUE (biomass) for males PIBKC. Page 1 of 6

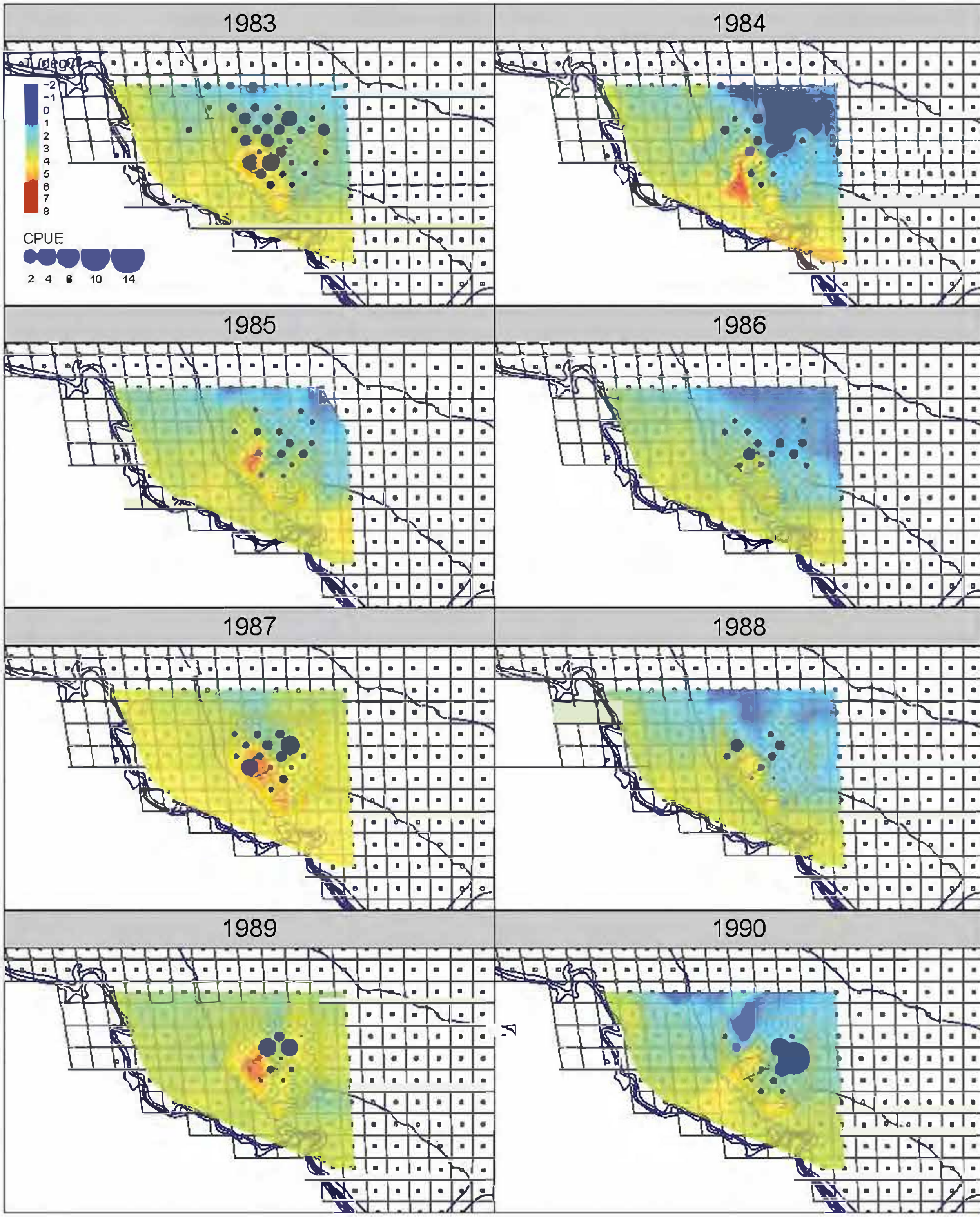

Figure 18: Survey CPUE (biomass) for males PIBKC. Page 2 of 6

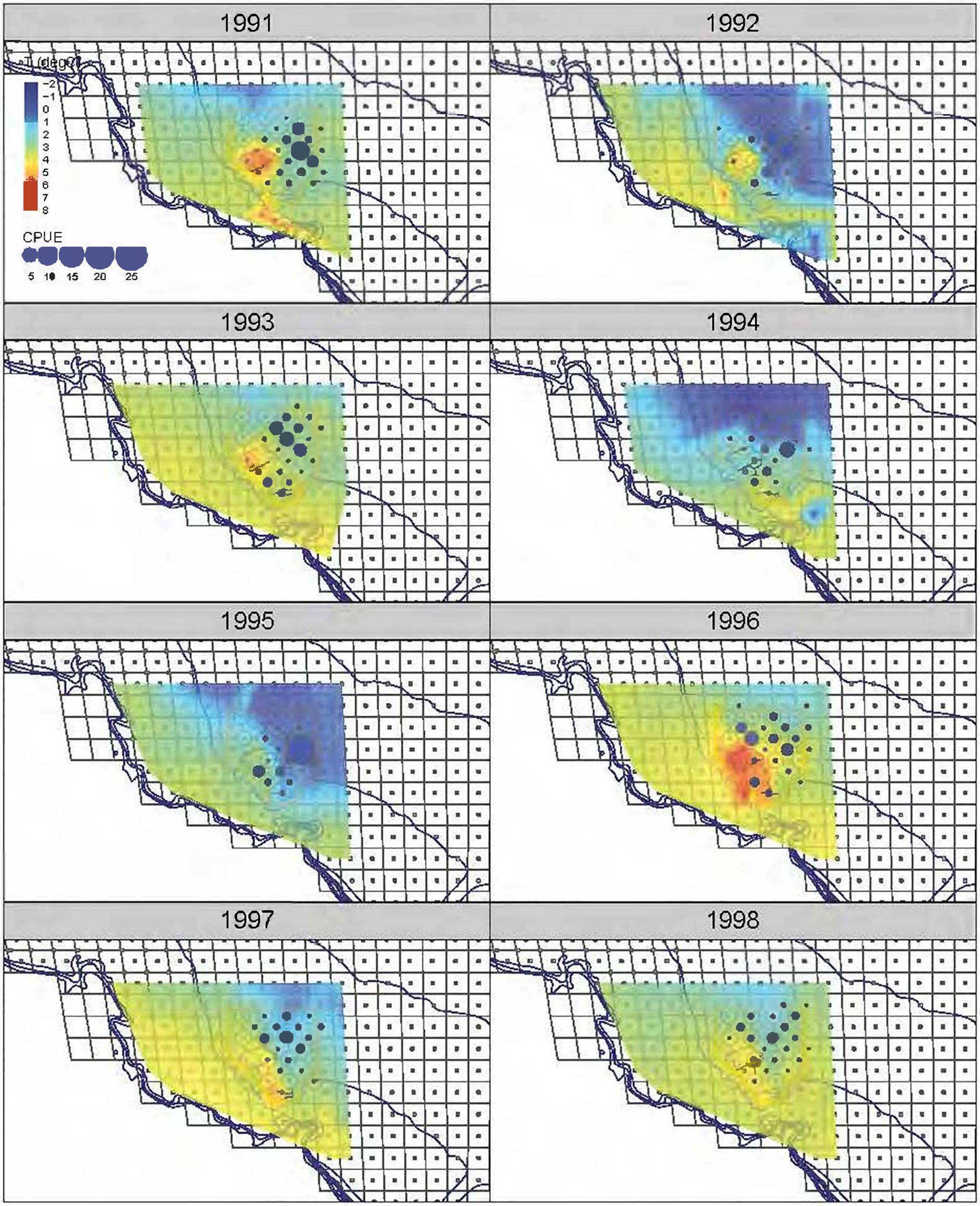

Figure 19: Survey CPUE (biomass) for males PIBKC. Page 3 of 6

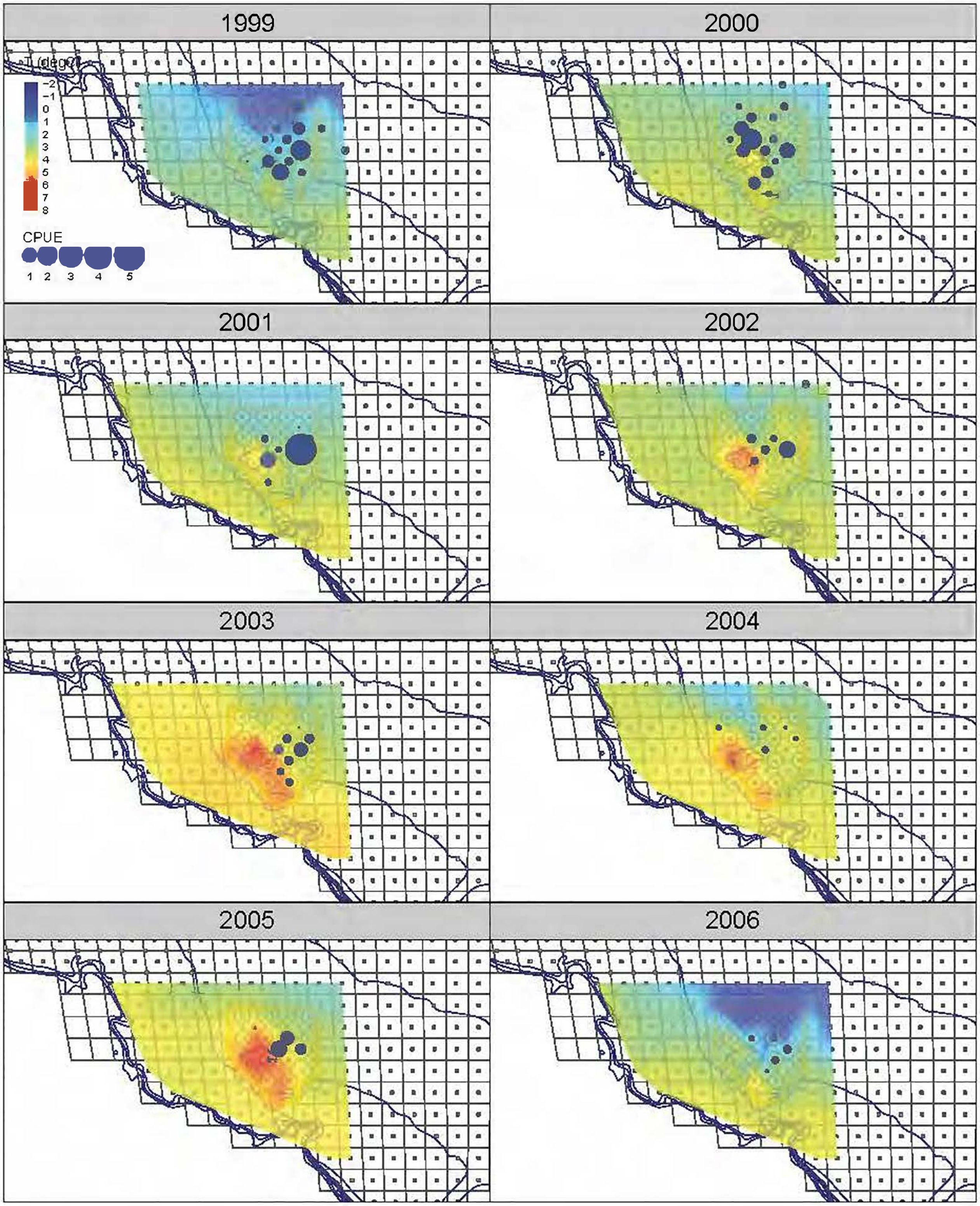

Figure 20: Survey CPUE (biomass) for males PIBKC. Page 4 of 6

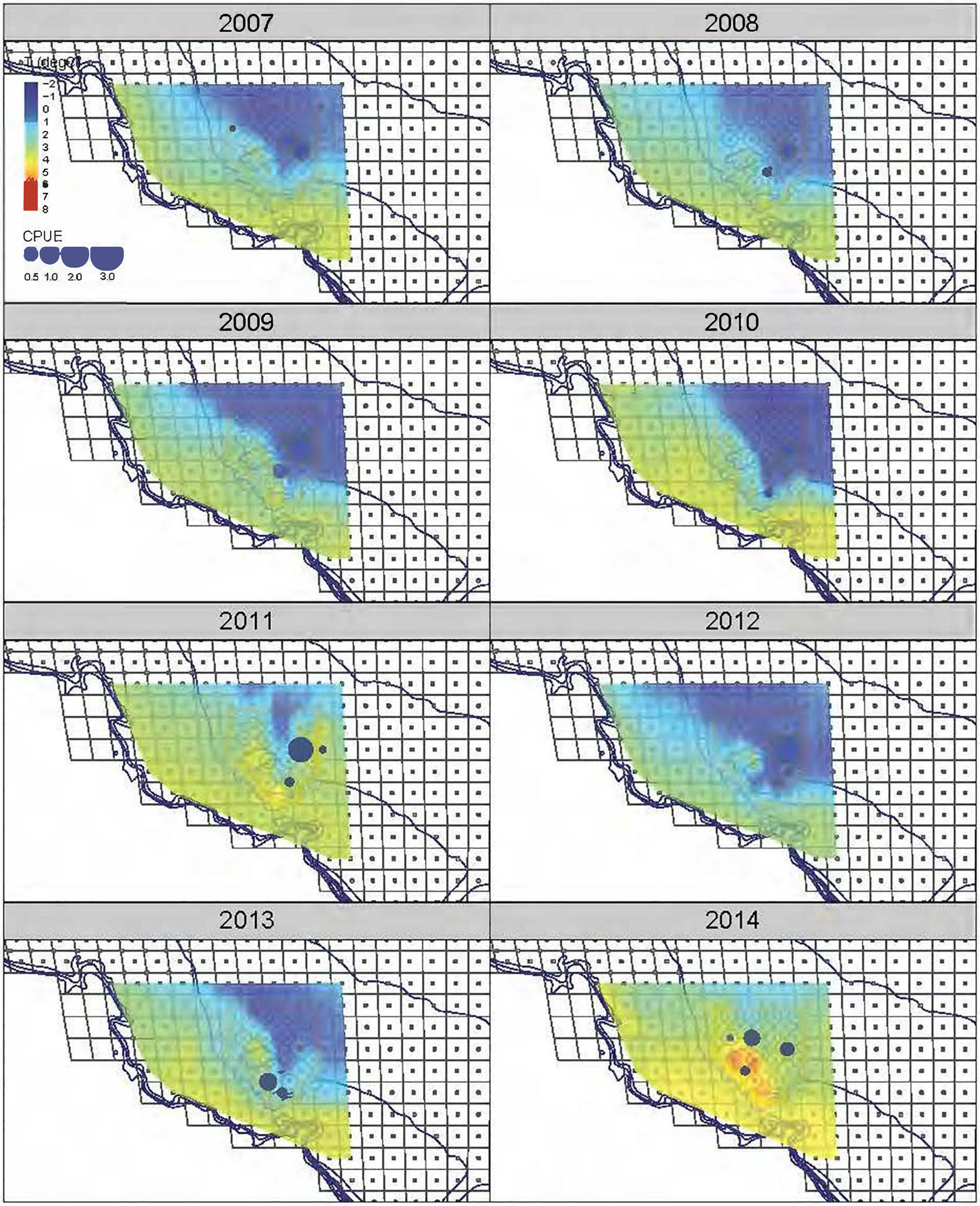

Figure 21: Survey CPUE (biomass) for males PIBKC. Page 5 of 6

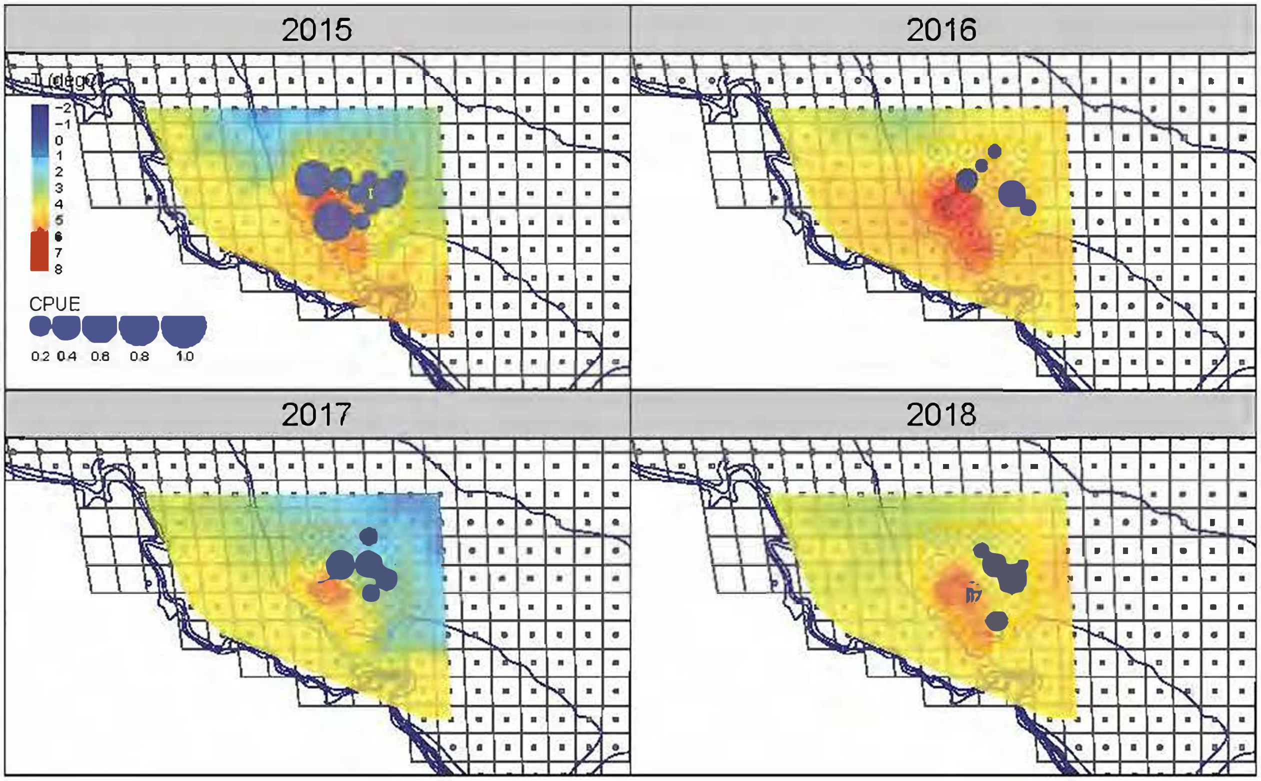

Figure 22: Survey CPUE (biomass) for males PIBKC. Page 6 of 6

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.

Literature Cited

ADF&G. 2006. 2006-2008 commercial king and tanner crab fishing regulations. Alaska Department of Fish and Game, Juneau, AK. 160 pp.

ADF&G. 2008. Annual Management Report for the Commercial and Subsistence Shellfish Fisheries of the Aleutian Islands, Bering Sea and the Westward Region's Shellfish Observer Program, 2006/07. Alaska Department of Fish and Game, Division of Sport Fish and Commercial Fisheries, Fishery Management Report 08-02, Kodiak.

Armstrong, D.A., J.L. Armstrong, G. Jensen, R. Palacios, and G. Williams. 1987. Distribution, abundance, and biology of blue king and Korean hair crabs around the Pribilof Islands. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 67:1-278.

Armstrong, D.A., J.L. Armstrong, R. Palacios, G. Jensen, and G. Williams. 1985. Early life history of juvenile blue king crab, *Paralithodes platypus*, around the Pribilof Islands. Pp. 211-229 in: Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks.

Bowers, F., M. Schwenzfeier, K. Herring, M. Salmon, H. Fitch, J. Alas, B. Baechler. 2011. Annual management report for the commercial and subsistence shellfish fisheries of the Aluetian Islands, Bering Sea, and the Westward Region's Shellfish Observer Program, 2009/2010.

Blau, F. S. 1997. Alaska king crabs: wildlife notebook series. Alaska Department of Fish and Game. http://www.adfg.state.ak.us/pubs/notebook/shellfsh/kingcrab.php, last accessed April 8, 2008.

CPT, 2017. C7 Crab PT Report: Crab Plan Team Meeting; May 2-5, 2017; Juneau, AK. North Pacific Fishery Management Council, 605 W 4th Avenue, Suite 306, Anchorage, AK 99501. 19 pp. http://npfmc.legistar.com/gateway.aspx?M=F&ID=569a4c57-d994-4b26-b389-c80743ed0c08.pdf

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

Foy, R.J. 2013. 2013 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 Aveneue, Suite 306, Anchorage, AK 99501-2252.

Jensen, G.C., and D. A. Armstrong. 1989. Biennial reproductive cycle of blue king crab, Paralithodes platypus, at the Pribilof Islands, Alaska and comparison to a congener, P. catschatica. Can. J. Fish. Aquat. Sci., 46:932-940.

Jensen, G.C., D.A. Armstrong and G. Williams. 1985. Reproductive biology of the blue king crab, Paralithodes platypus, in the Pribilof Islands. Pp. 109-122 in: Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks.

NMFS. 2005. APPENDIX F.3. ESSENTIAL FISH HABITAT ASSESSMENT REPORT for the Bering Sea and Aleutian Islands King and Tanner Crabs. NOAA Fisheries, Juneau, AK. 35pp. NPFMC. 1994. Environmental Assessment/Regulatory Impact Review/Initial Regulatory Flexibility analysis for Amendment 21a to the Fishery Management Plan for Bering Sea and Aleutian Island Groundfish. NMFS Alaska Region, PO Box 21668, Juneau, AK 99802-1668.

NPFMC. 2003. Environmental assessment for amendment 17 to the fishery management plan for the king and tanner crab fisheries in the Bering Sea/Aleutian Islands a rebuilding plan for the Pribilof Islands blue king crab stock. North Pacific Fishery Management Council Anchorage, 101 pp.

NPFMC. 2008. Environmental Assessment for Amendment 24 to the Fishery Management Plan for the king and Tanner crab fisheries in the Bering Sea/Aleutian Islands: to revise overfishing definitions. Anchorage, Alaska 194 p.

NPFMC. 2008. Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands Regions 2008 Crab SAFE. North Pacific Fishery Management Council Anchorage, 259 pp.

NPFMC. 2014a. Final Environmental Assessment for proposed amendment 43 to the Fishery Management Plan for Bering Sea/Aleutian Island King and Tanner Crabs and proposed amendment 103 to the Fishery Management Plan for Groundfish of the Bering Sea and Aleutian Island. North Pacific Fishery Management Council, 605 West 4th Ave, Anchorage, AK 99501. 190 pp.

NPFMC. 2014b. Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands. 2014 Final Crab SAFE. North Pacific Fishery Management Council, 605 W. 4th Aveneue, Suite 306, Anchorage, AK 99501-2252.

Otto, R.S and P.A. Cummiskey. 1990. Growth of adult male blue king crab (Paralithodes platypus). pp 245-258 in: Proceeding of the the International Symposium on King and Tanner Crabs:, Alaska Sea Grant Report No 90-04, University of Alaska, Fairbanks, AK.

Paul, A. J. and J. M. Paul. 1980. The effect of early starvation on later feeding success of king crab zoeae. J. Exp. Mar. Bio. Ecol., 44: 247-251.

Selin, N.I., and Fedotov, P.A. 1996. Vertical distribution and some biological characteristics of the blue king crab Paralithodes platypus in the northwestern Bering Sea. Mar. Biol. 22: 386-390.

Siddeek, M.S.M., L.J. Watson, S.F. Blau, and H. Moore. 2002. Estimating natural mortality of king crabs from tag recapture data. pp 51-75 in: Crabs in cold water regions: biology, management, and economics. Alaska Sea Grant Report No 02-01, University of Alaska, Fairbanks, AK.

Somerton, D.A. 1985. The disjunct distribution of blue king crab, *Paralithodes platypus*, in Alaska: some hypotheses. Pp. 13-21 in: Proceedings of the International King Crab Symposium, Alaska Sea Grant Report No 85-12, University of Alaska, Fairbanks.

Somerton, D.A., and R. A. MacIntosh. 1983. The size at sexual maturity of blue king crab, *Paralithodes platypus*, in Alaska. Fishery Bulletin, 81(3):621-628.

Somerton, D.A., and R. A. MacIntosh. 1985. Reproductive biology of the female blue king crab *Paralithodes platypus* near the Pribilof Islands, Alaska. J. Crustacean Biology, 5(3): 365-376.

Stevens, B.S. 2006a. Embryo development and morphometry in the blue king crab *Paralithodes platypus* studied by using image and cluster analysis. J. Shellfish Res., 25(2):569-576.

Stevens, B.S. 2006b. Timing and duration of larval hatching for blue king crab *Paralithodes platypus* Brandt, 1850 held in the laboratory. J. Crustacean Biology, 26(4):495-502.

Stevens, B.S., S.L. Persselin and J.A. Matweyou. 2008. Survival of blue king crab *Paralithodes platypus* Brandt, 1850, larvae in cultivation: effects of diet, temperature and rearing density. Aquaculture Res., 39:390-397.

Stockhausen, W.T. 2014. 2014 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.

Stockhausen, W.T. 2015. 2015 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.

Stockhausen, W.T. 2016. 2016 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.

Stockhausen, W.T. 2017. 2017 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 991-1102.

Zheng, J., M.C. Murphy and G.H. Kruse. 1997. Application of a catch-survey analysis to blue king crab stocks near Pribilof and St. Matthew Islands. Alaska Fish. Res. Bull. 4(1):62-74.

Zheng et al. 2016. 2016 Stock Assessment and Fishery Evaluation Report for the Bristol Bay Red 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 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.

	Males								Females					
Year	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

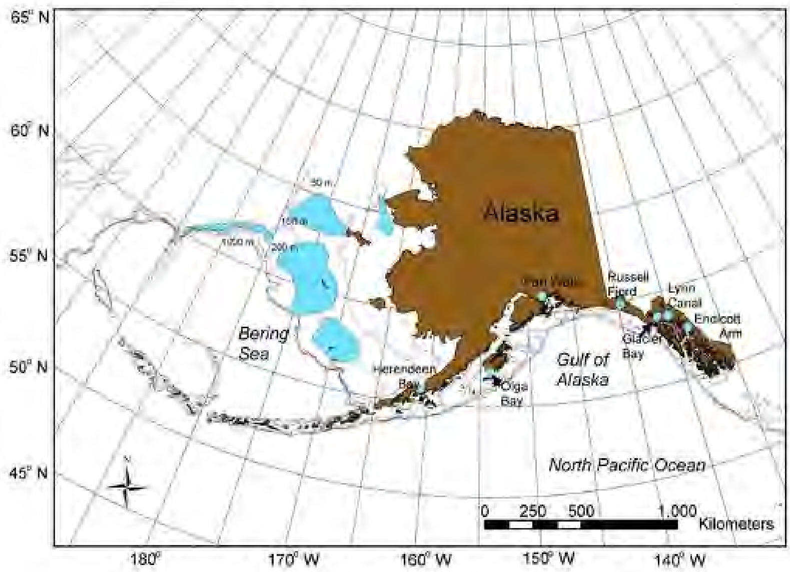

Figure 1: Distribution of blue king crab, *Paralithodes platypus*, in Alaskan waters.

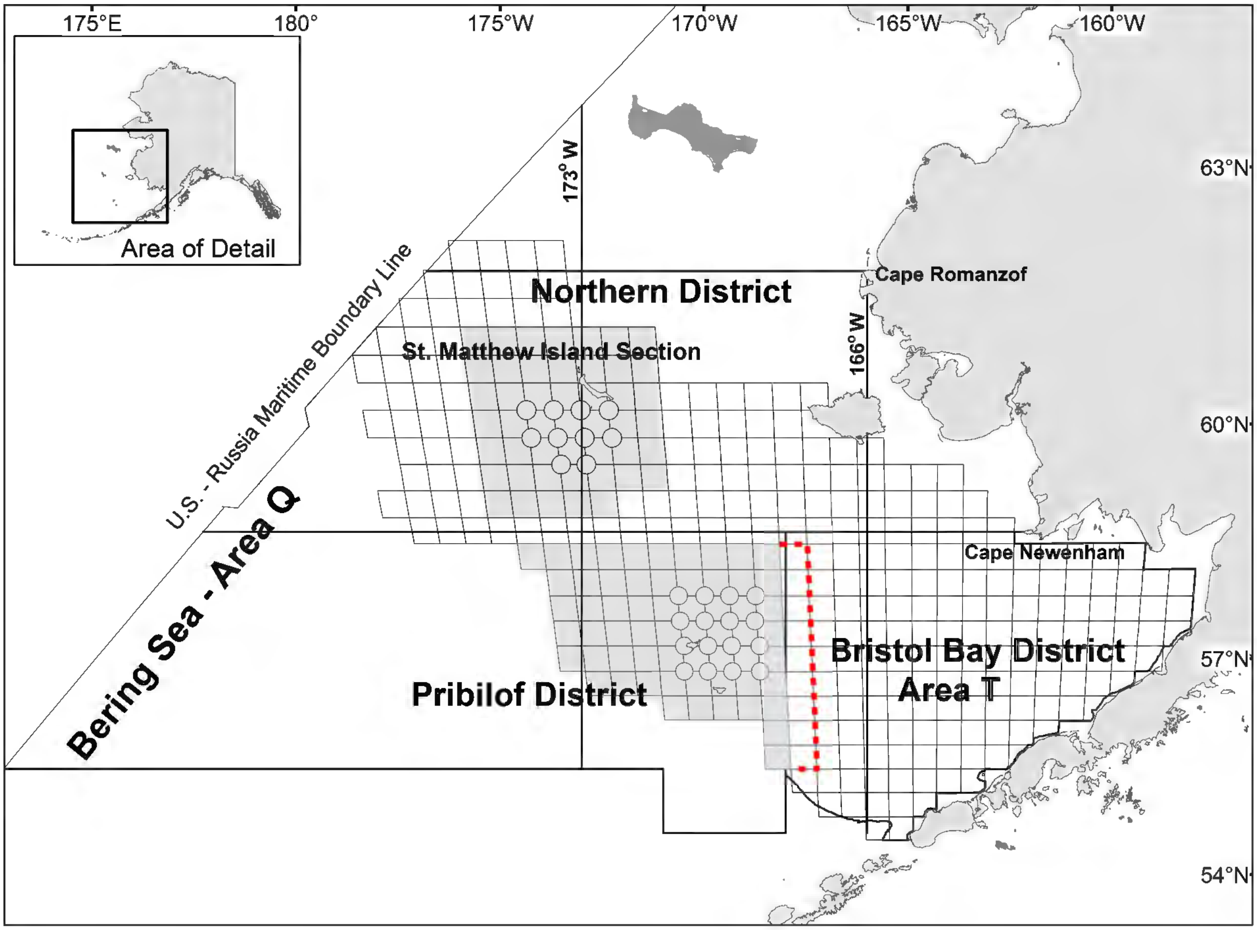

Figure 2: Map of the ADFG King Crab Registration Area Q (Bering Sea), showing (among others) the Pribilof District, which constitutes the stock boundary for PIBKC. The figure also indicates the additional 20nm strip (red dotted line) added in 2013 for calculating biomass and catch data in the Pribilof District.

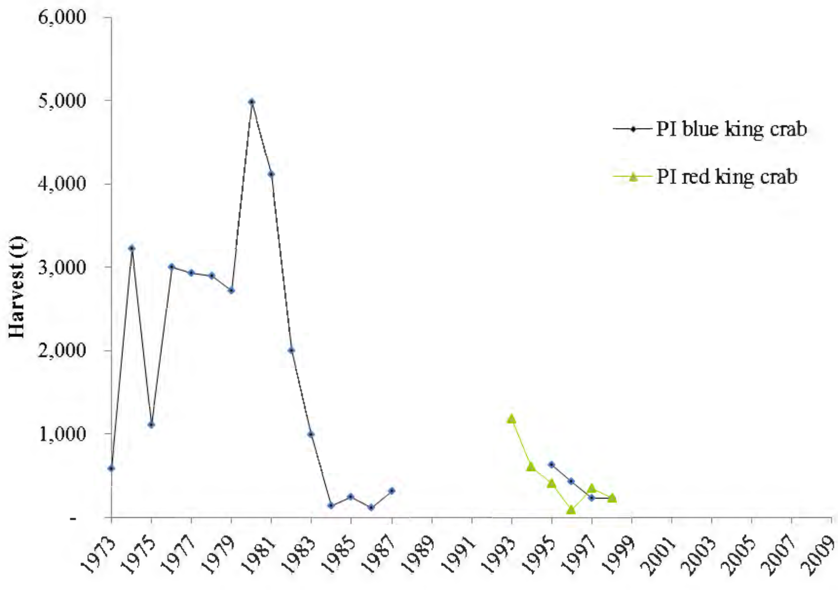

Figure 3: Historical harvests and Guideline Harvest Levels (GHLs) for Pribilof Islands red and blue king crab (from Bowers et al., 2011).

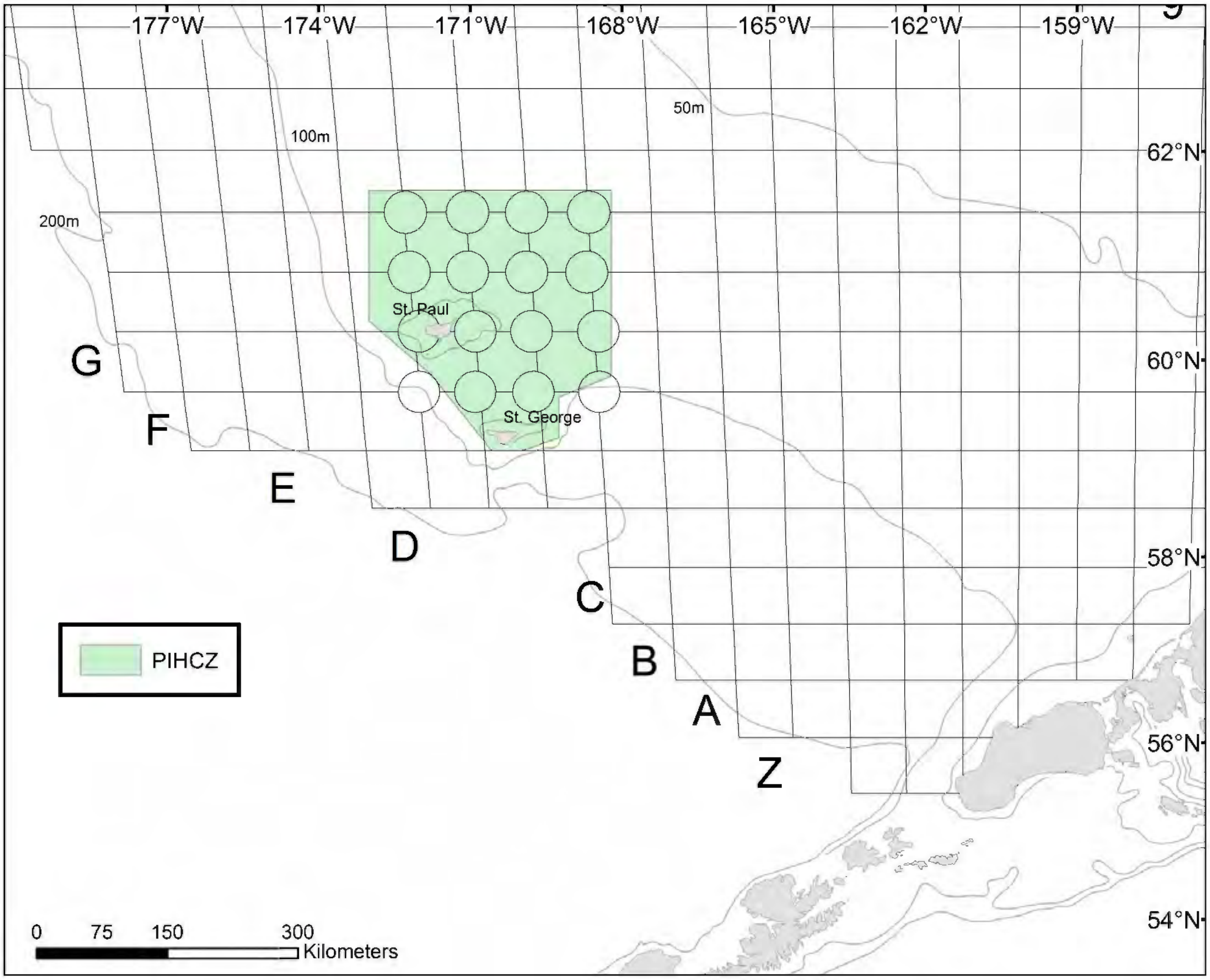

Figure 4: The shaded area shows the Pribilof Islands Habitat Conservation Zone (PIHCZ). Trawl fishing is prohibited year-round in this zone (as of 1995), as is pot fishing for Pacific cod (as of 2015). Also shown is a portion of the NMFS annual EBS bottom trawl survey grid.

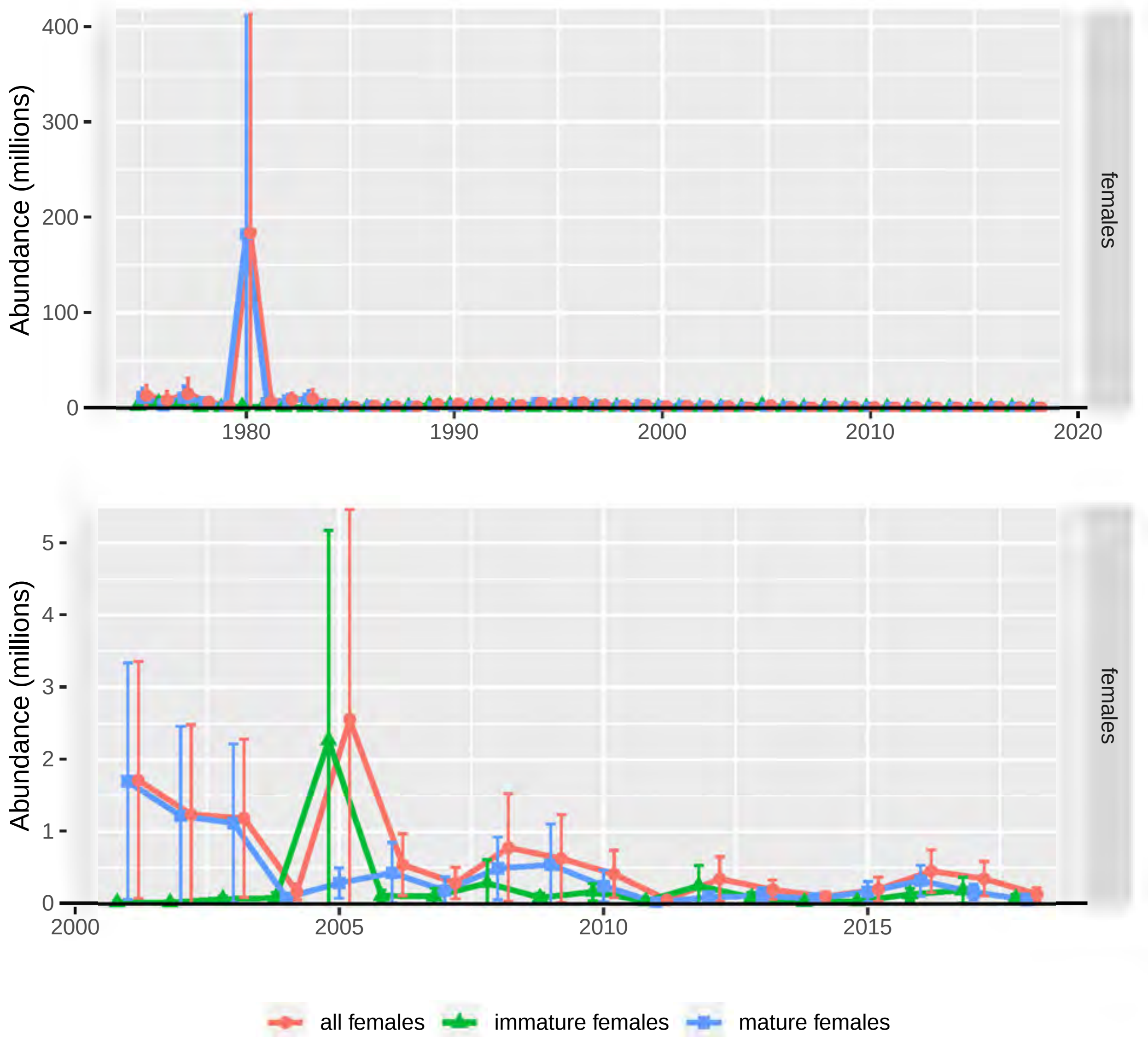

Figure 5: Time series of survey abundance for females (immature, mature, and total).

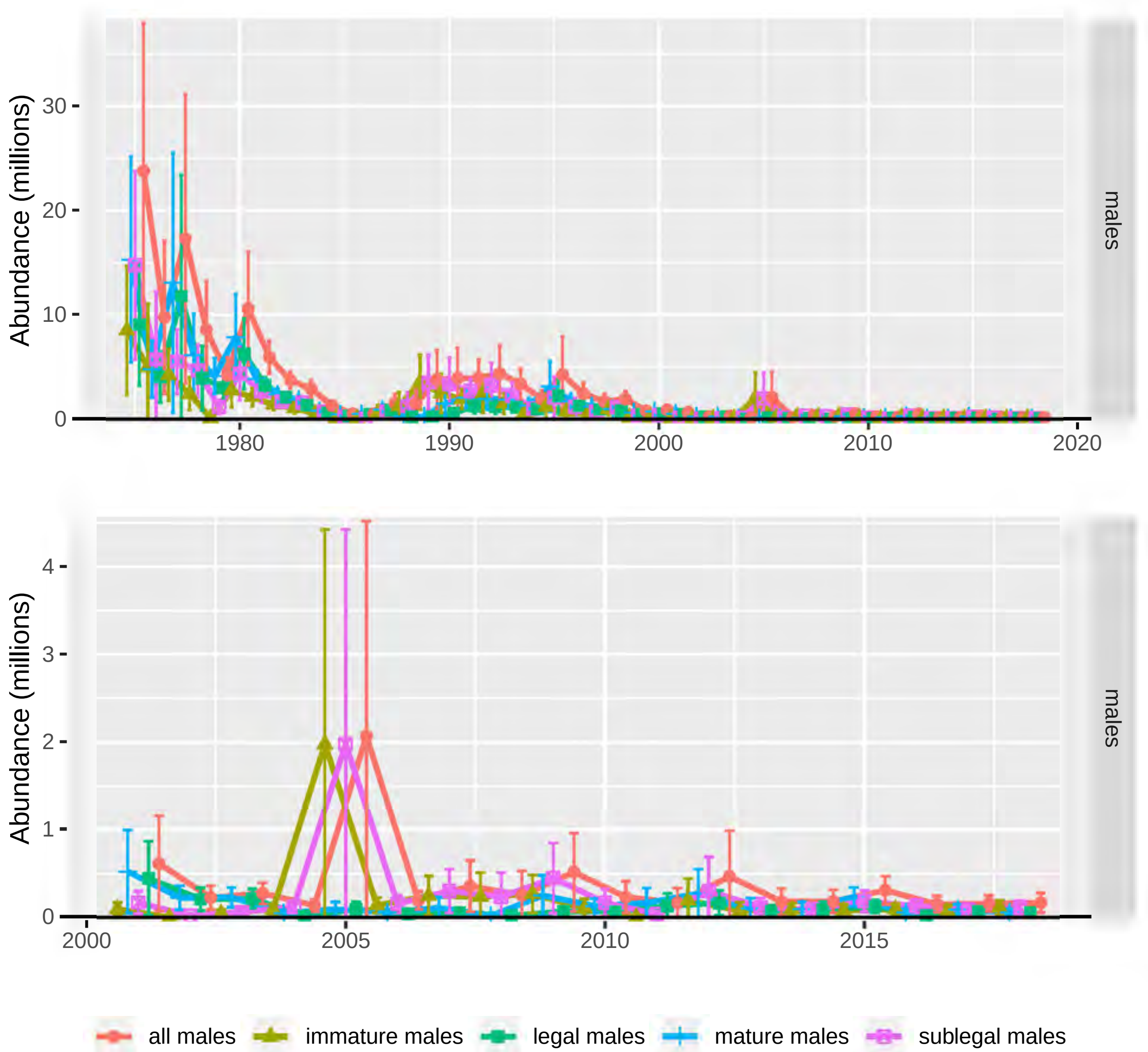

Figure 6: Time series of survey abundance for males in several categories (immature, mature, sublegal, legal and total).

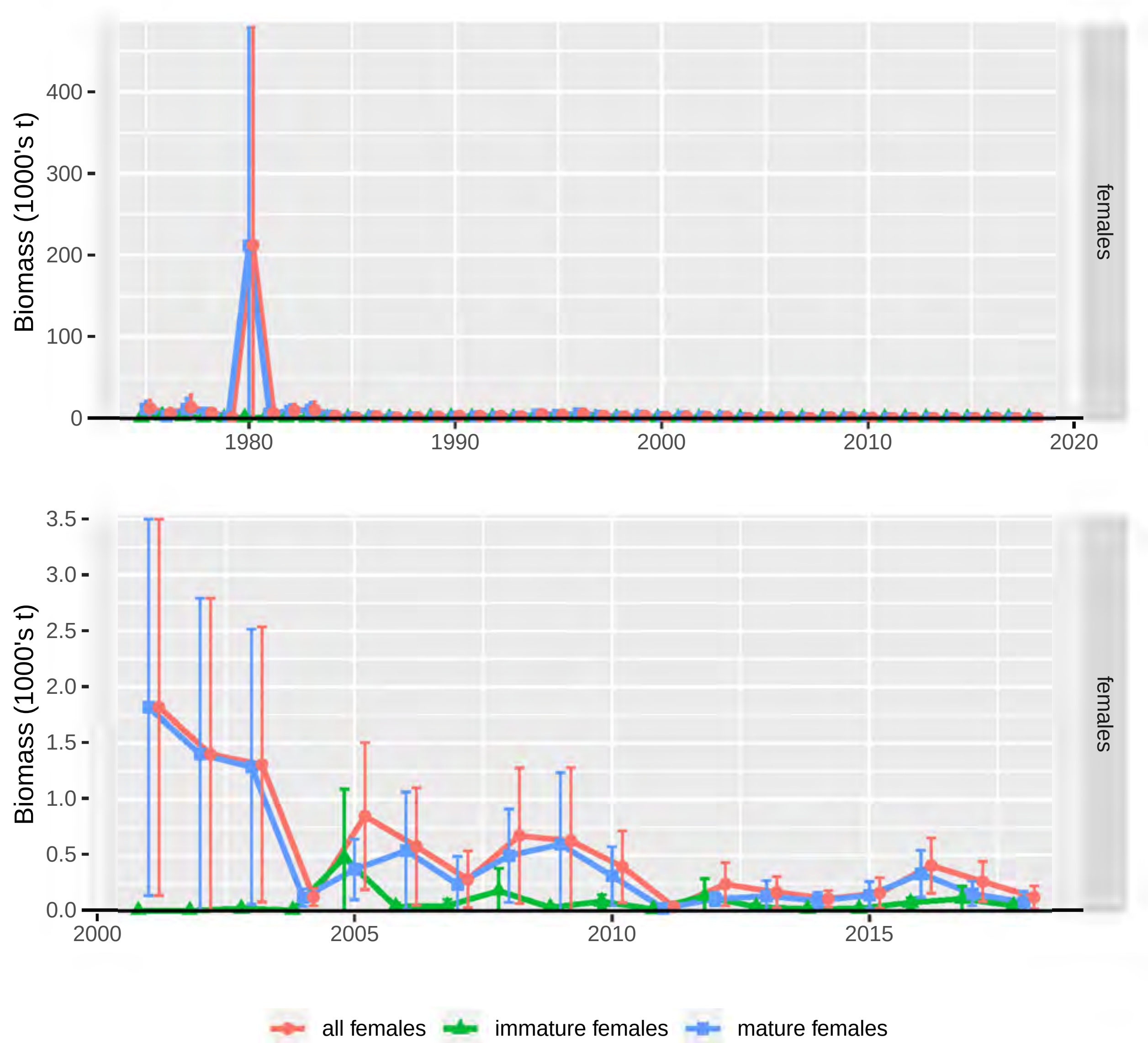

Figure 7: Time series of survey abundance for females (immature, mature, and total).

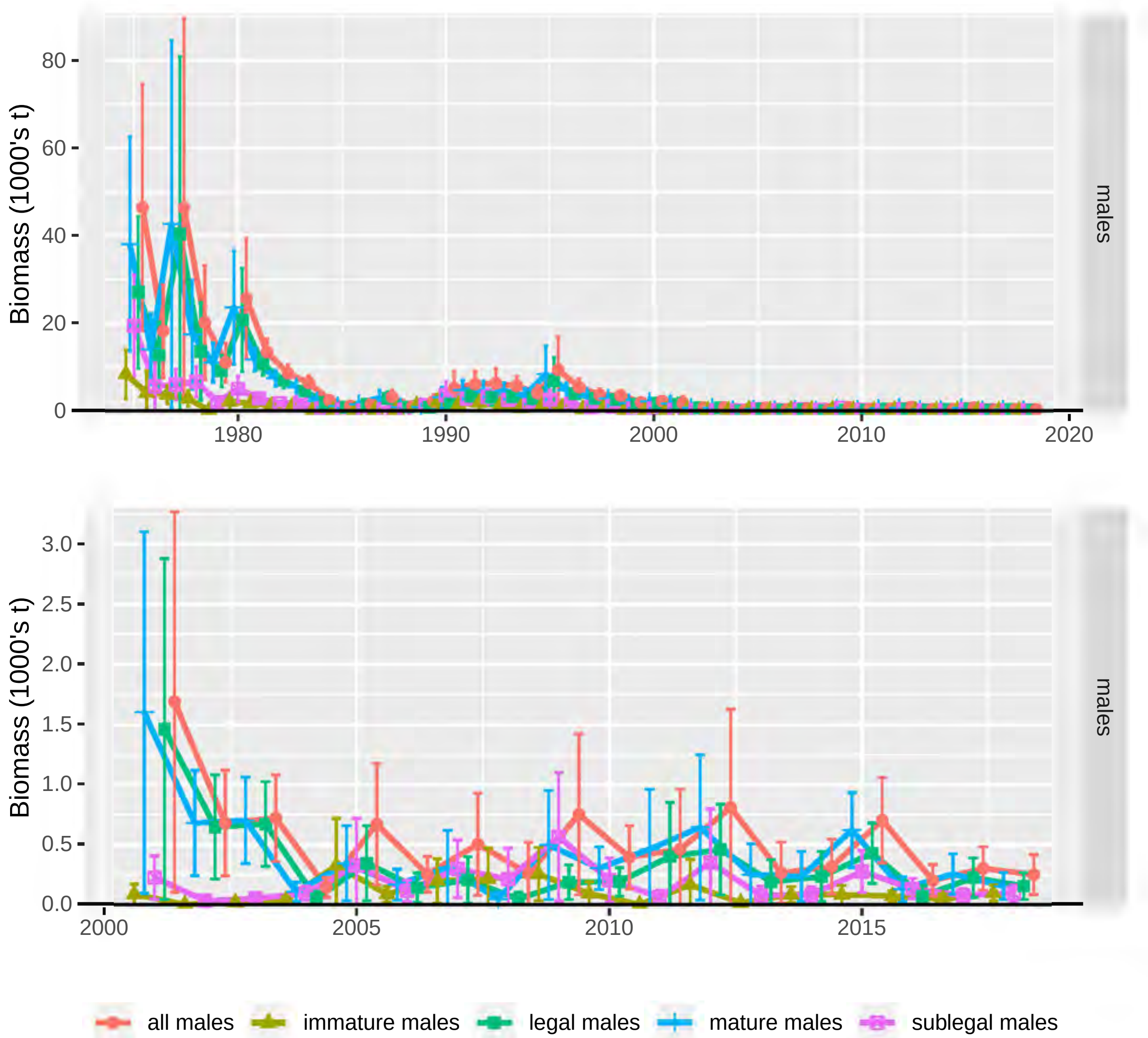

Figure 8: Time series of survey biomass for males in several categories (immature, mature, sublegal, legal and total).

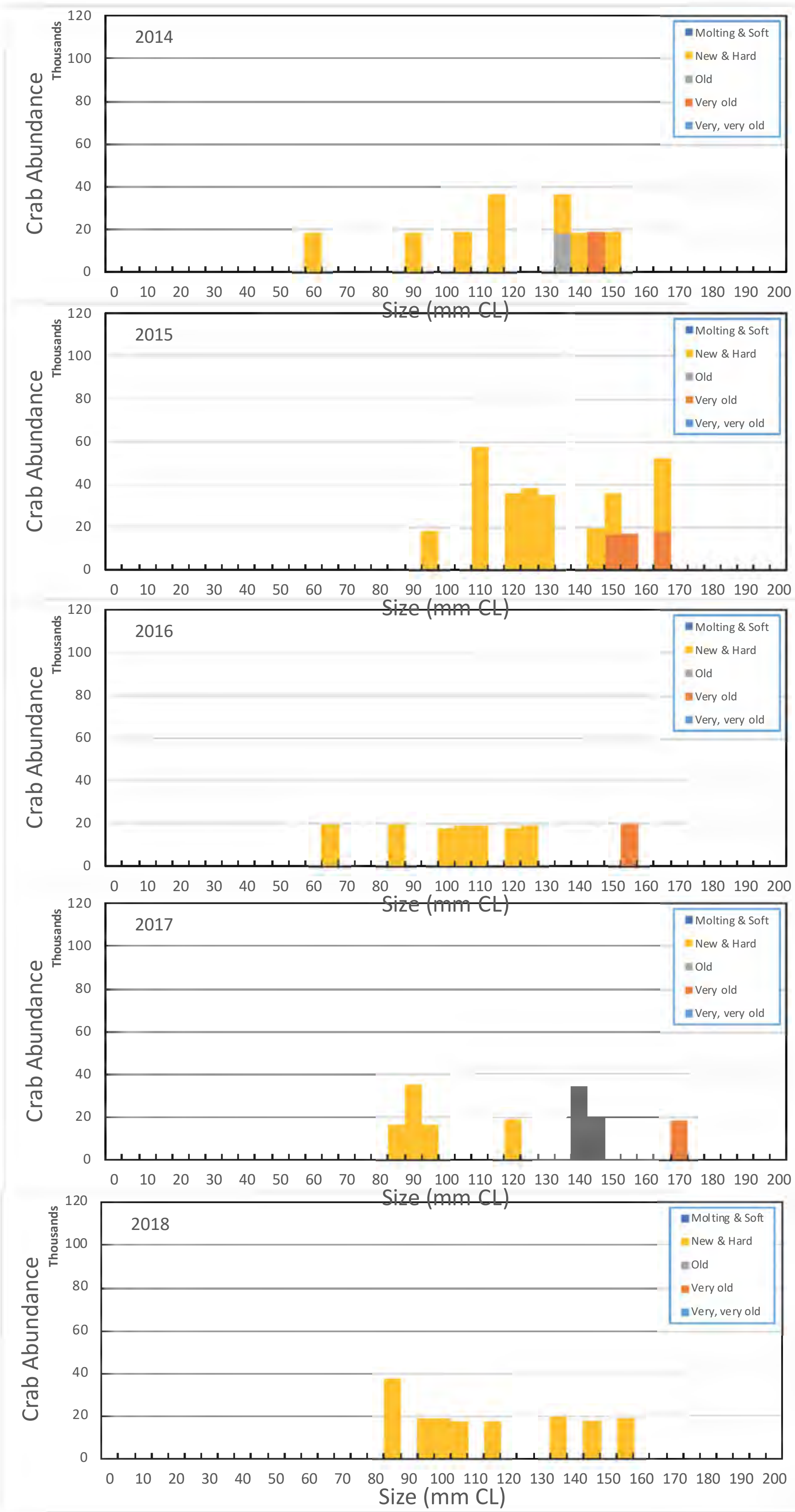

Figure 9: Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from recent NMFS EBS bottom trawl surveys.

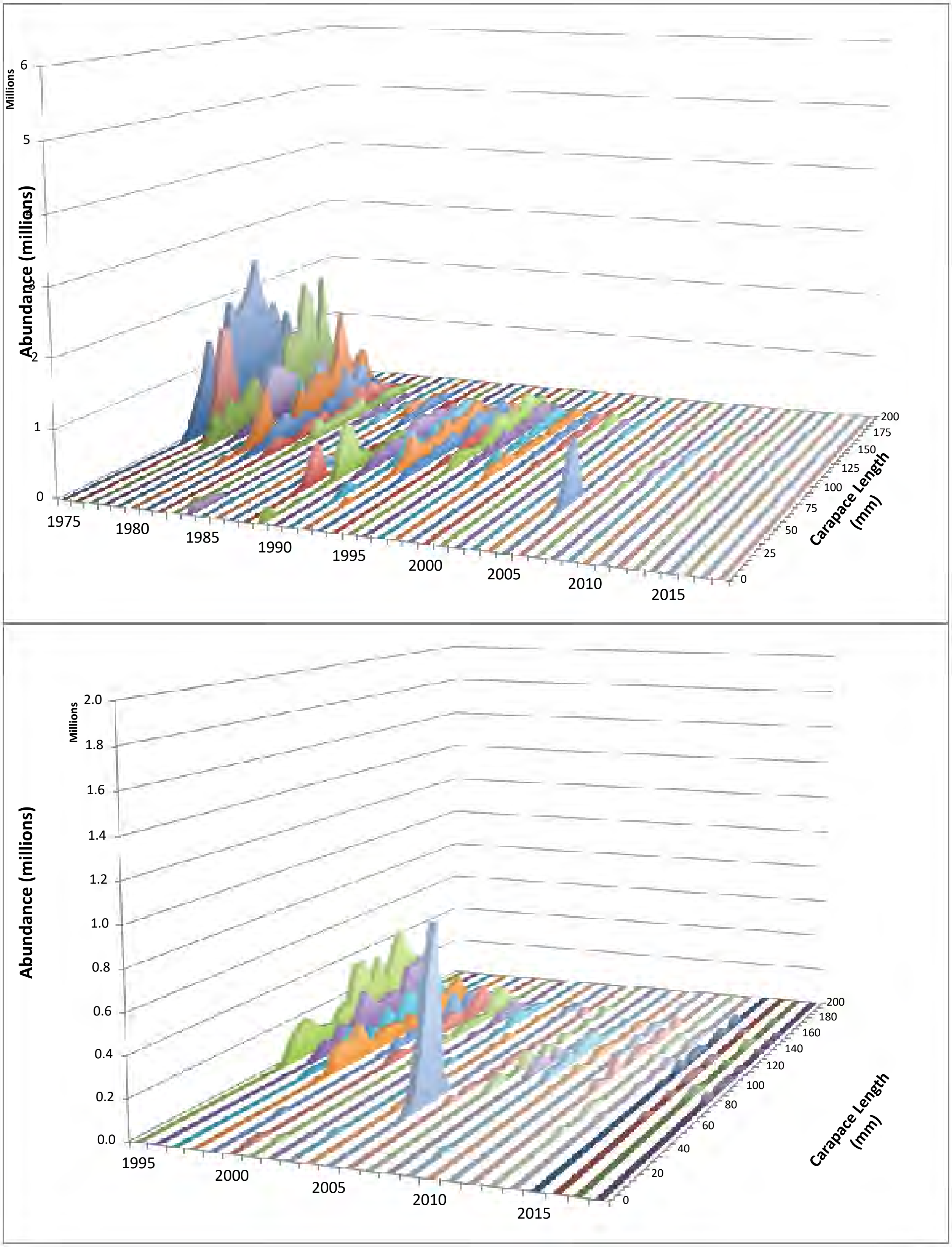

Figure 10: Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islands blue king crab by 5 mm length bins. The top row shows the entire time series, the bottom shows the size compositions since 1995.

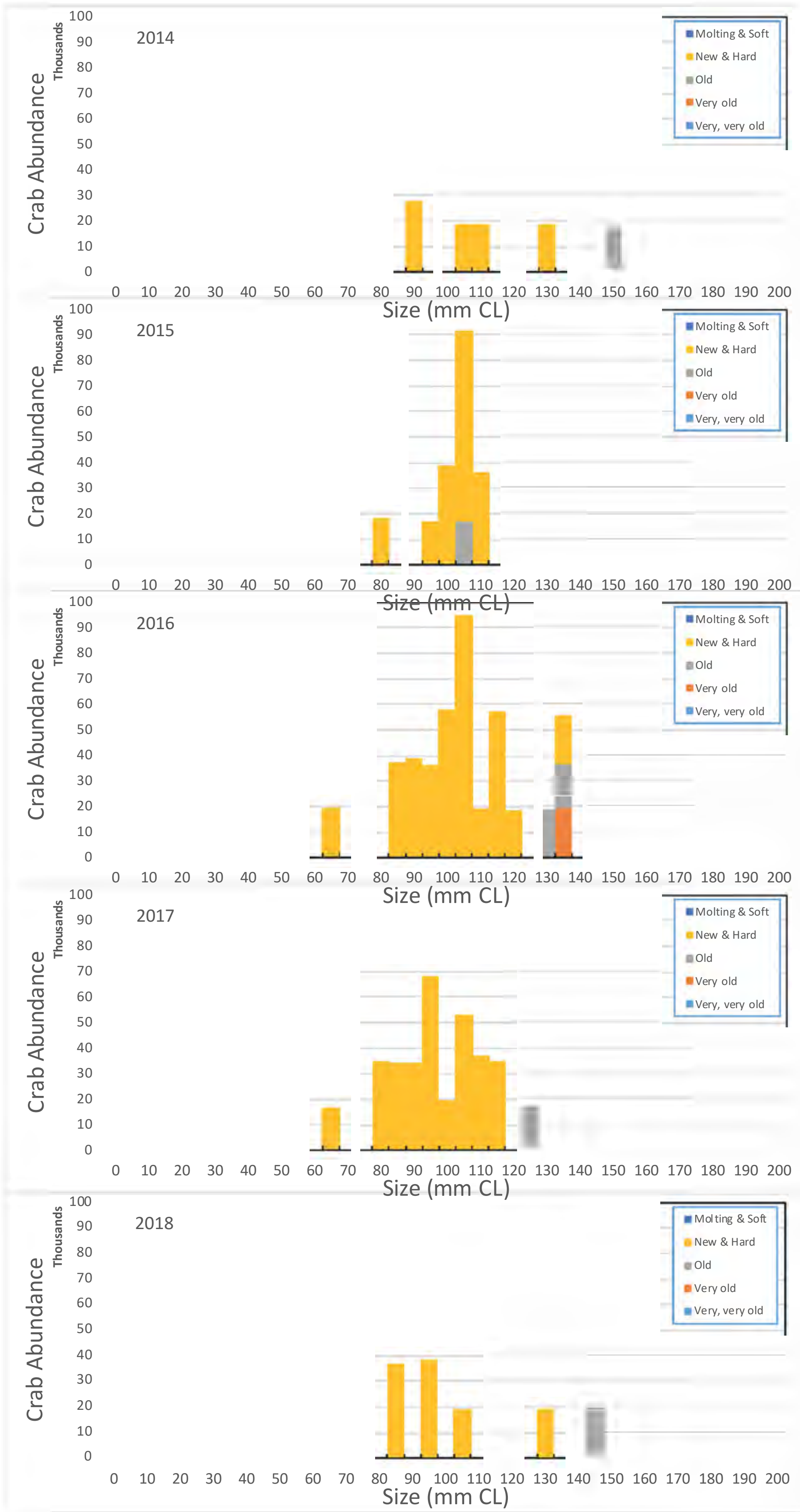

Figure 11: Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from recent NMFS EBS bottom trawl surveys.

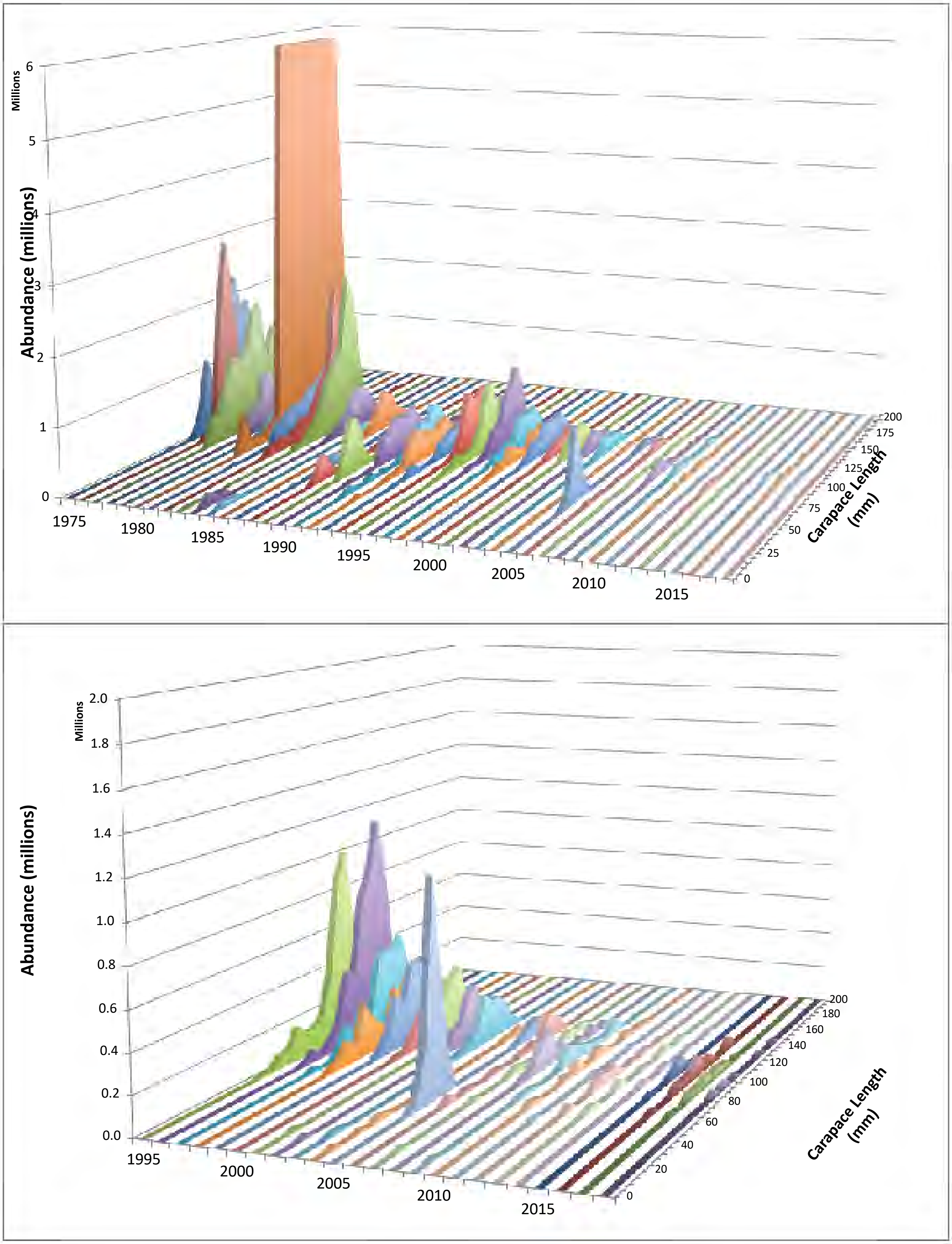

Figure 12: Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islands blue king crab by 5 mm length bins. The top row shows the entire time series, the bottom shows the size compositions since 1995.

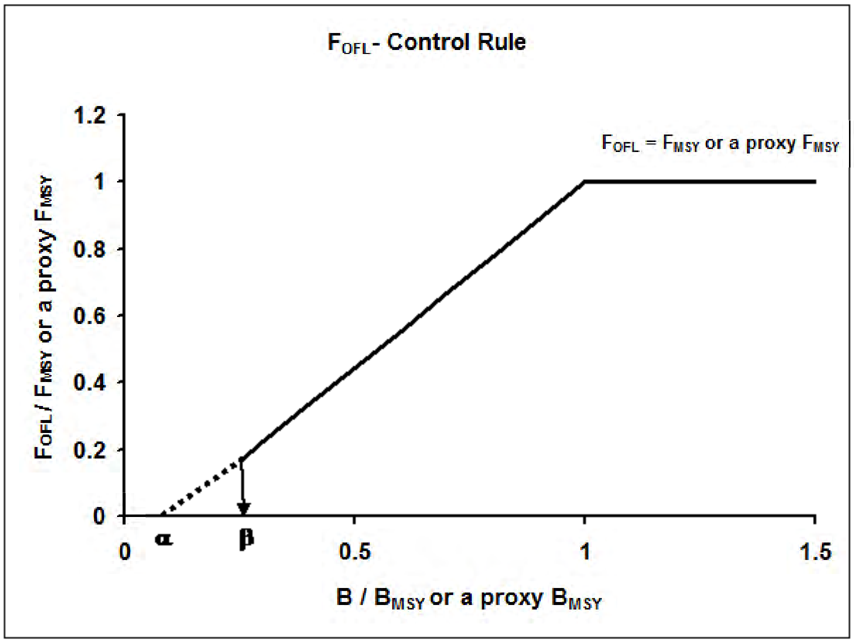

Figure 13: F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β (= 0.25).

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

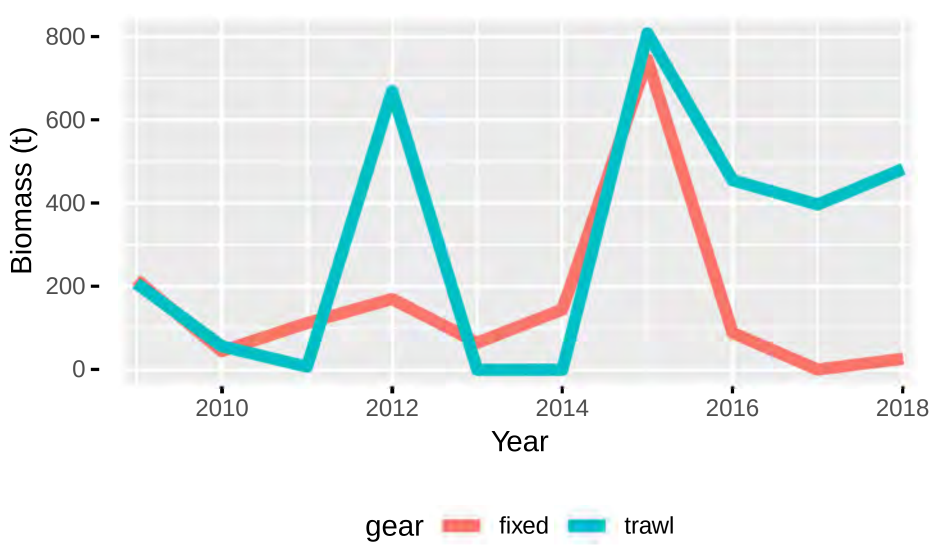

Figure 1: Bycatch of PIBKC in the groundfish fisheries by gear type.

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

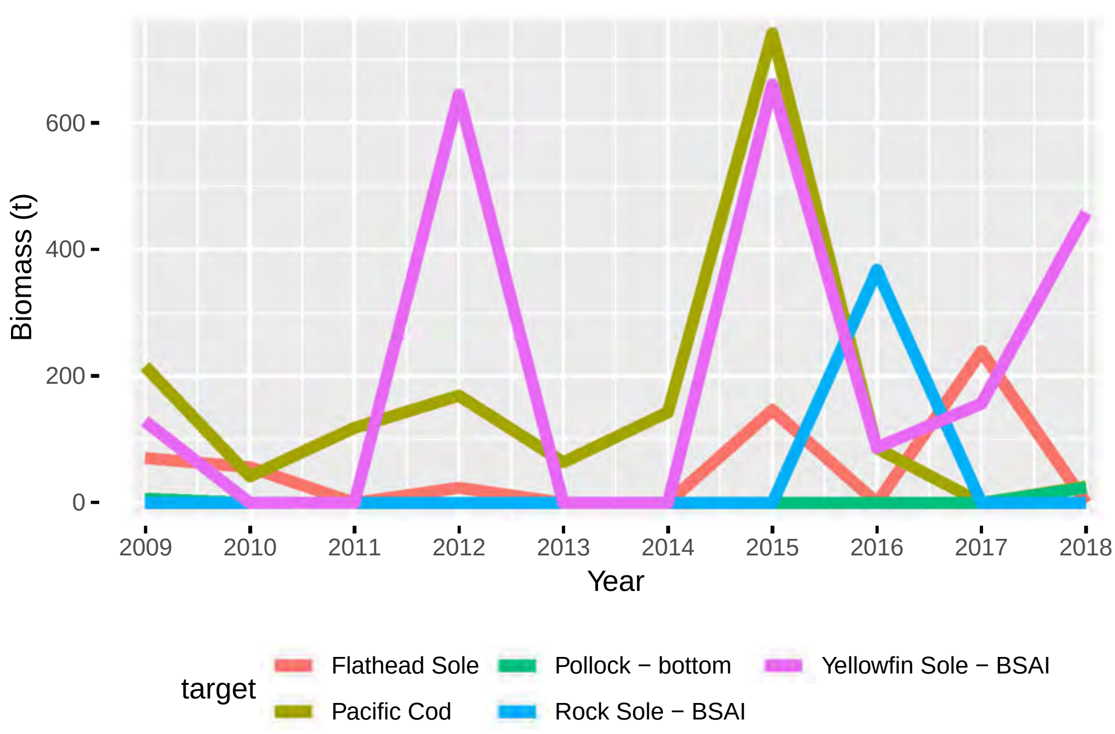

Figure 2: Bycatch of PIBKC in the groundfish fisheries, by target type.

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.

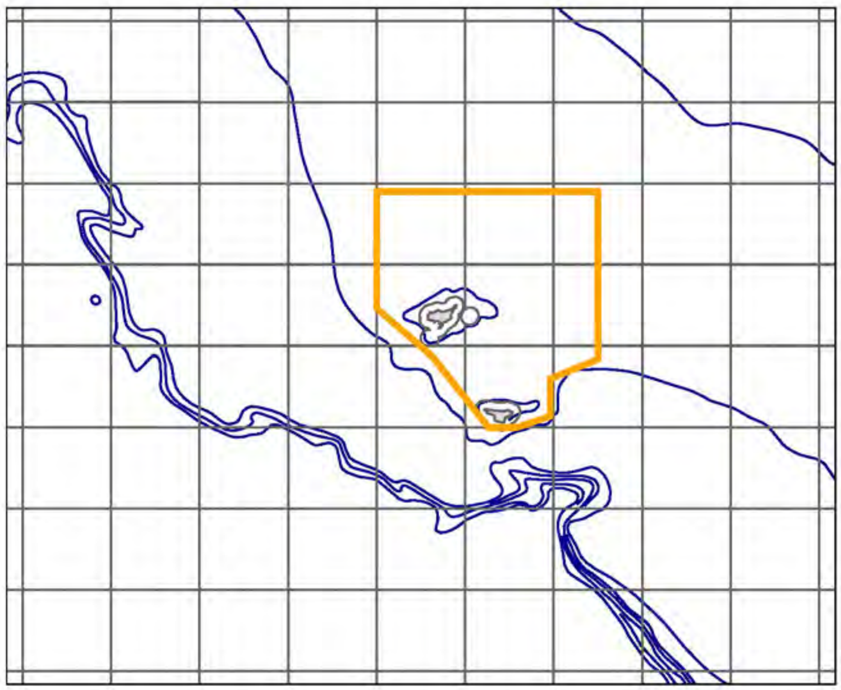

Figure 3: Basemap for subsequent maps, with EBS bathymetry (blue lines), ADFG stat areas (black rectangles), and the Pribilof Islands Habitat Conservation Area (orange outline).

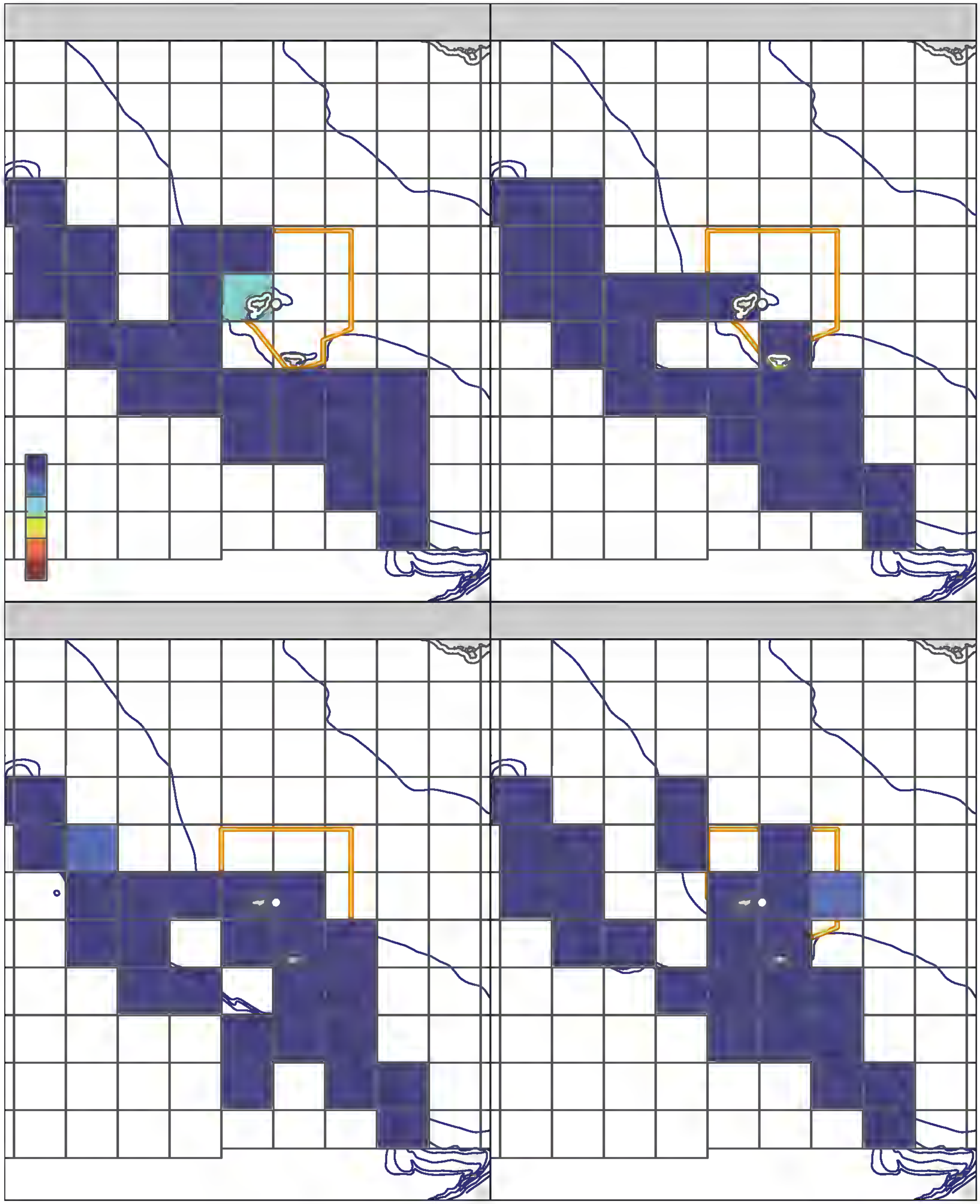

Figure 4: (1 of 3). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries.

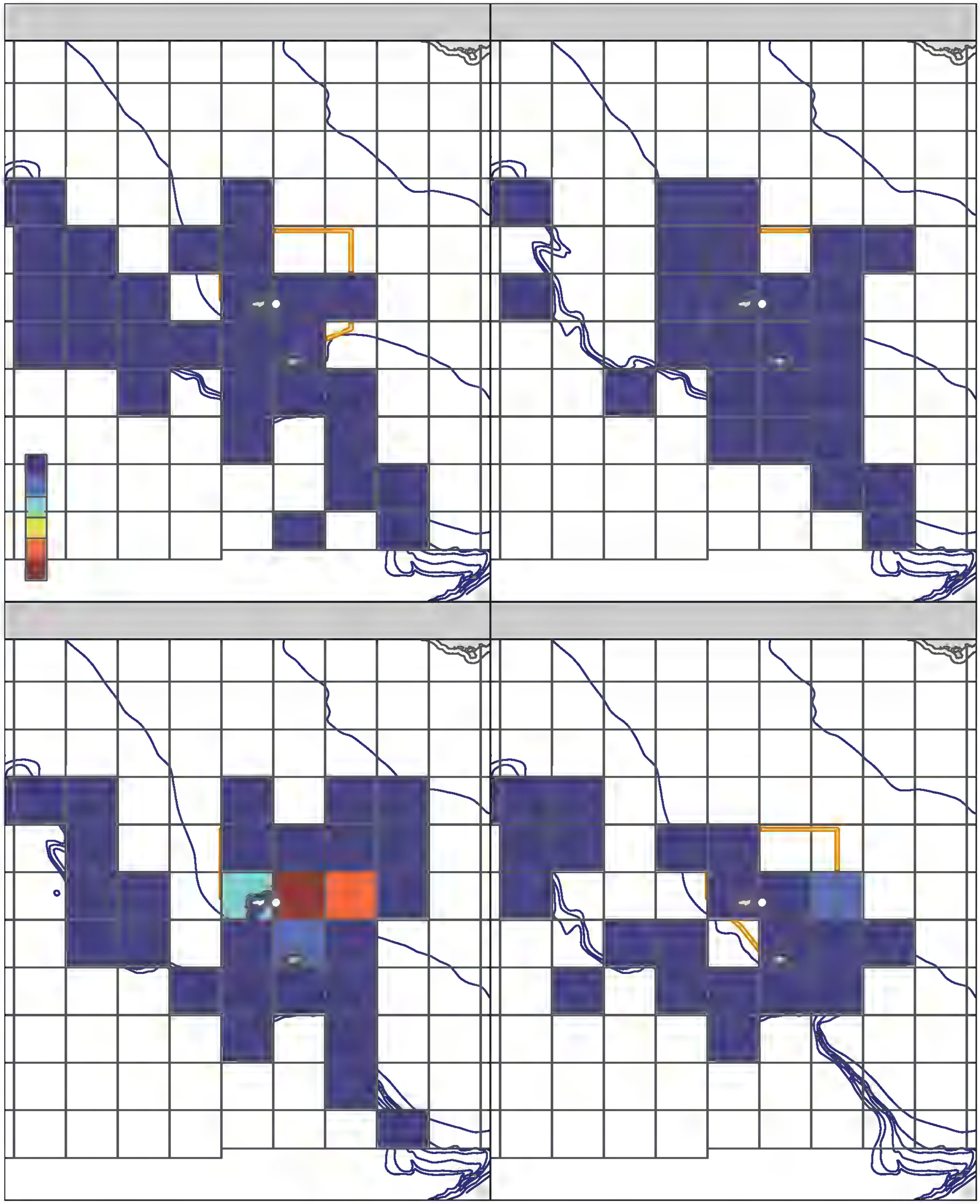

Figure 5: (2 of 3). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries.

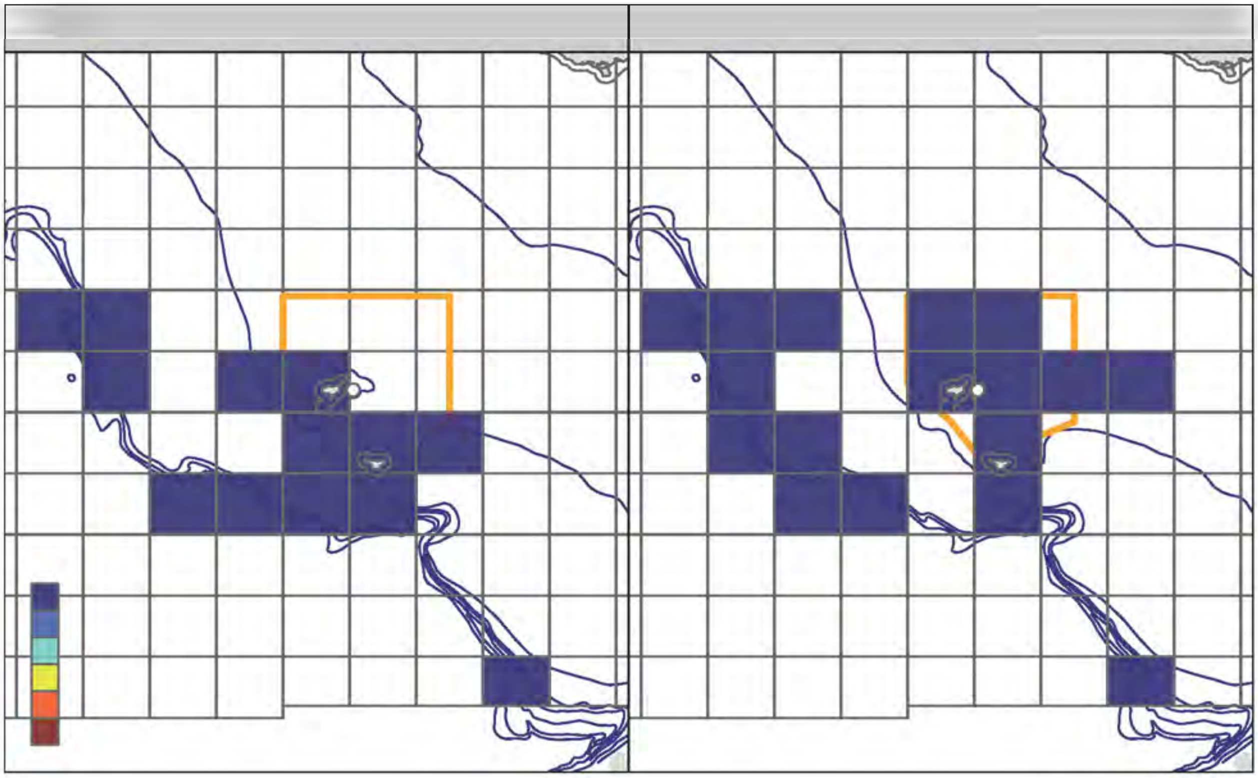

Figure 6: (3 of 3). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries.

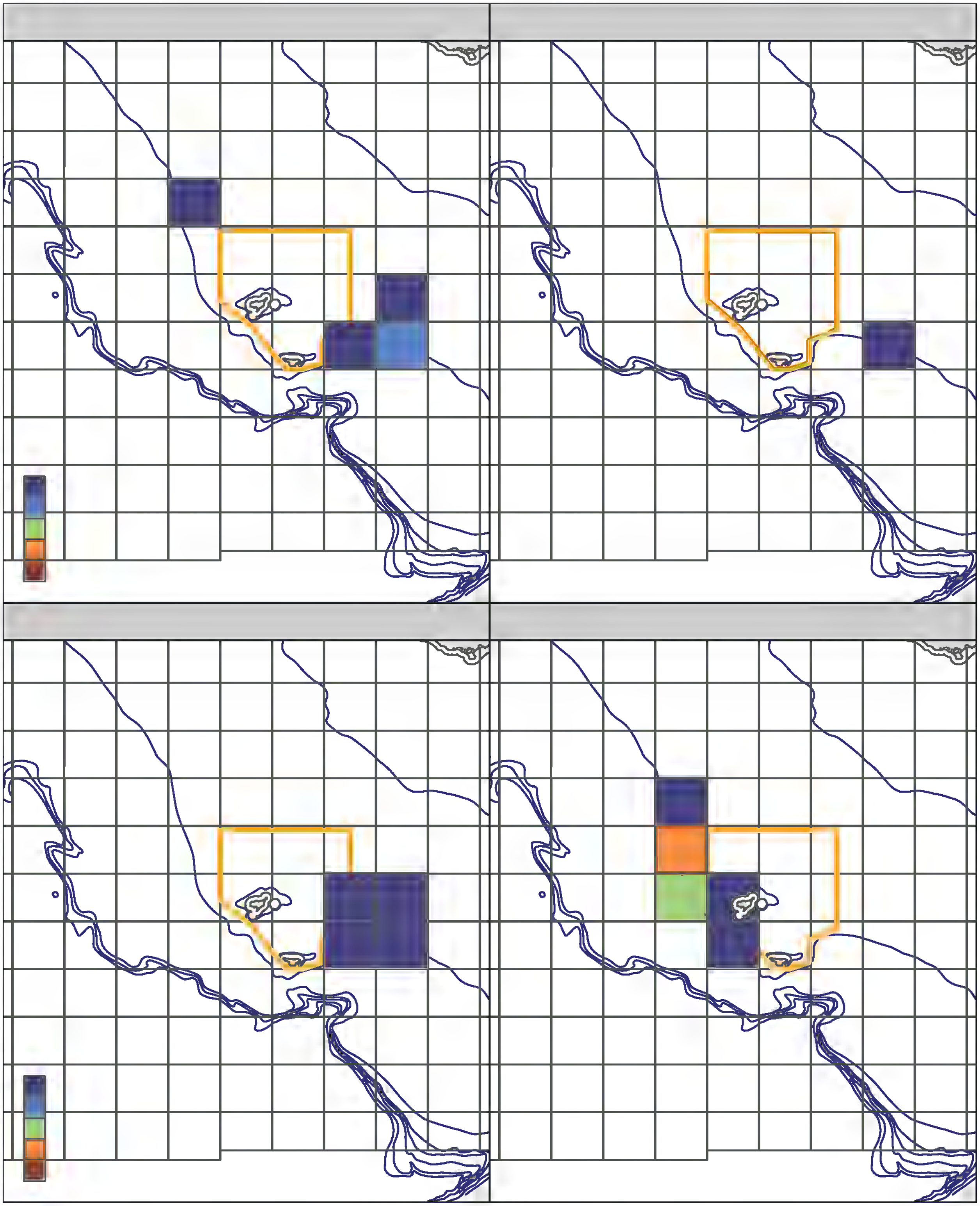

Figure 7: (1 of 3). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries.

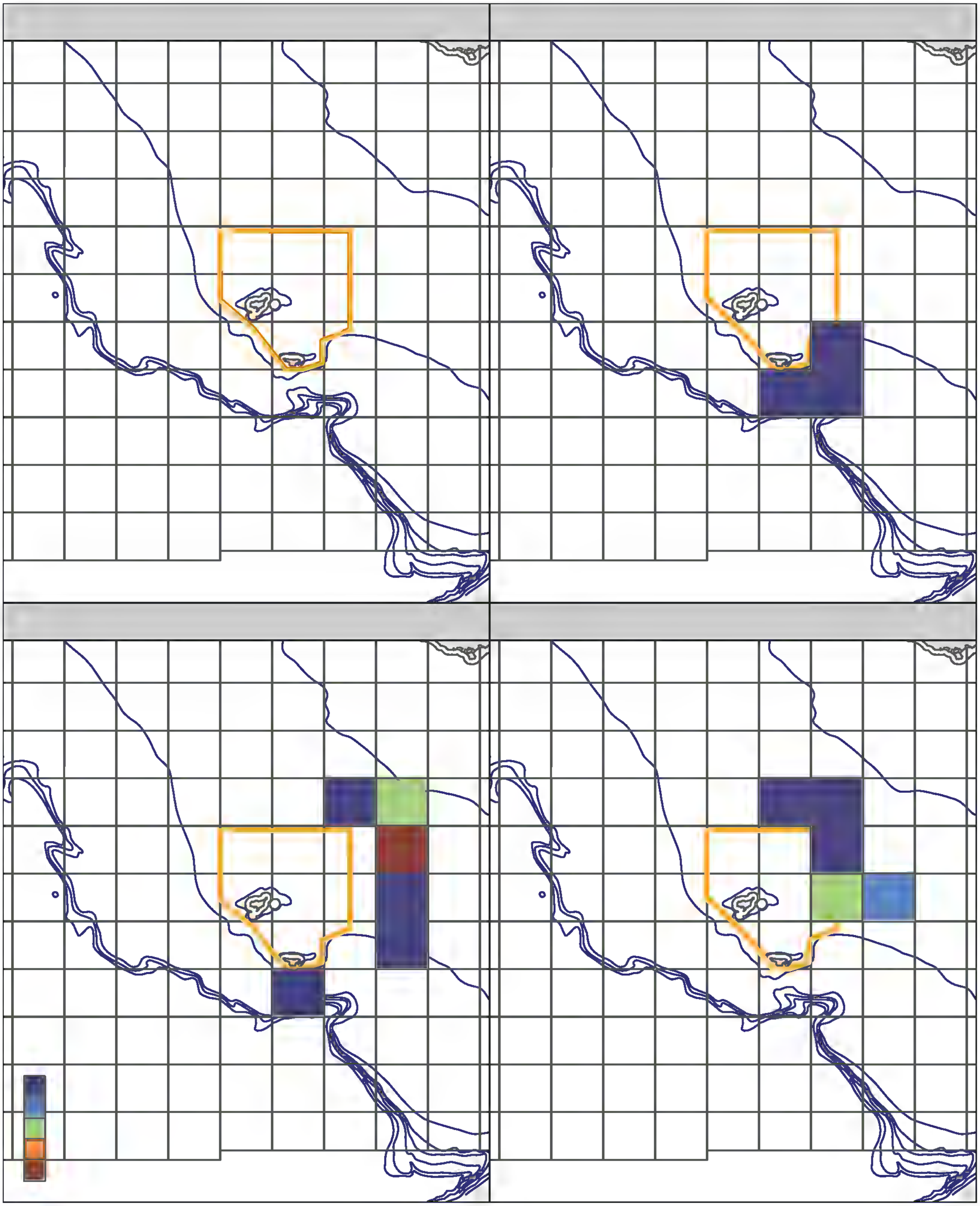

Figure 8: (2 of 3). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries.

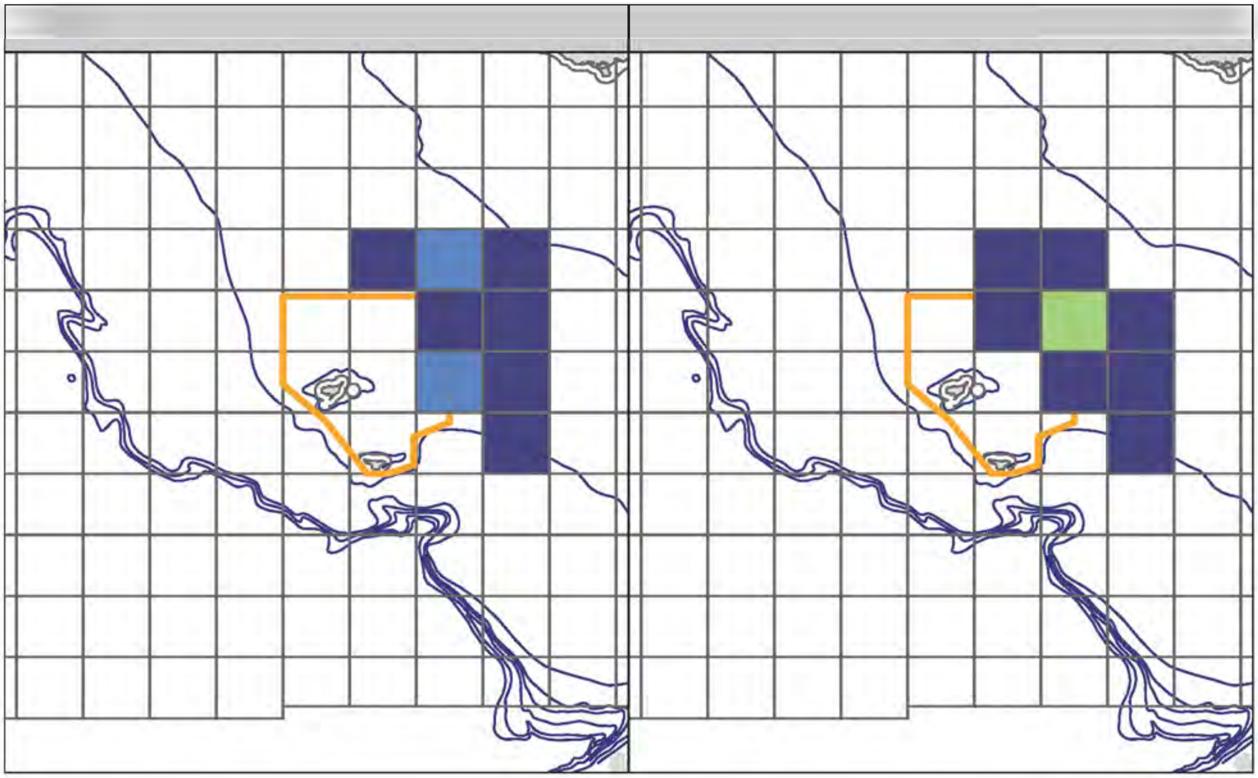

Figure 9: (3 of 3). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries.

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.

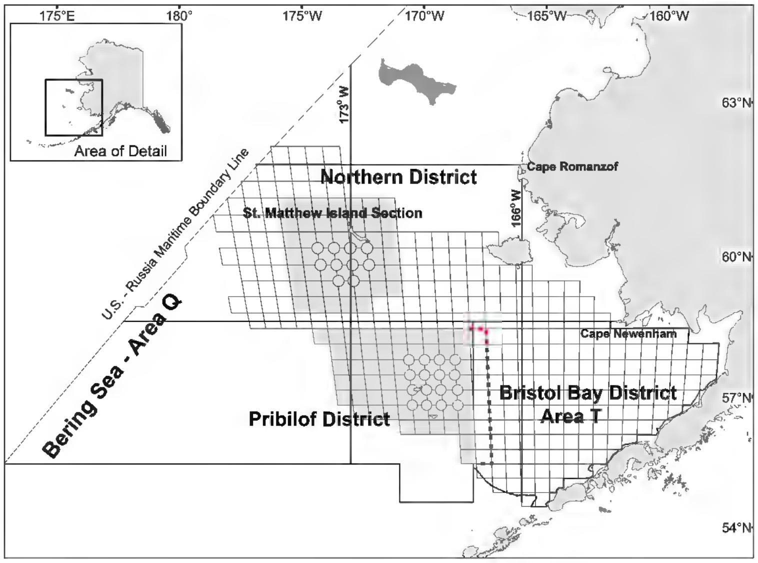

Figure 1: Map of the Pribilof District, which defines the stock area for the Pribilof Islands blue king crab stock. The grid indicates the locations of NMFS EBS survey stations.

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.

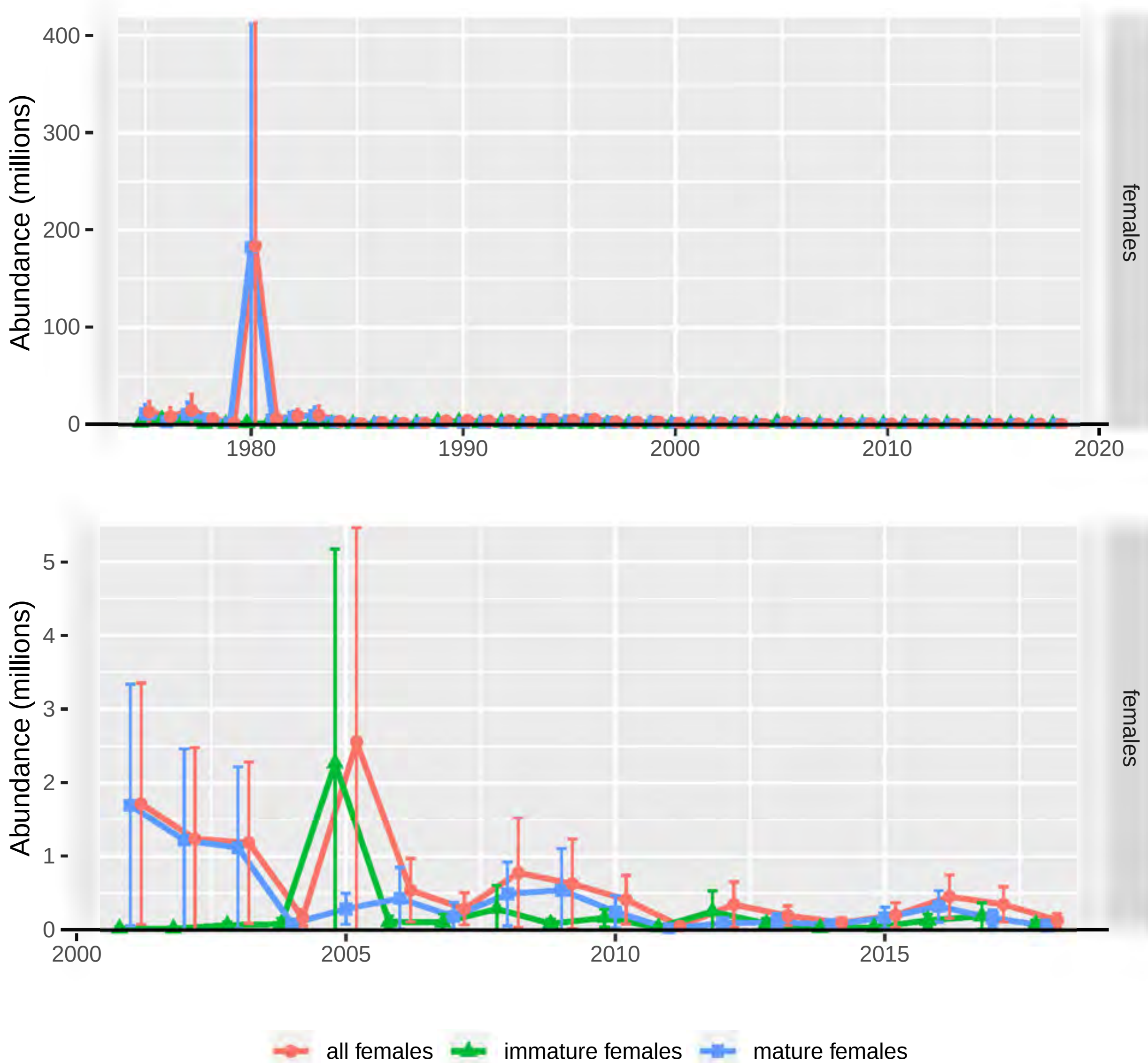

Figure 2: NMFS survey abundance time series for female PIBKC. Upper plot is entire time series, lower plot since 2001.

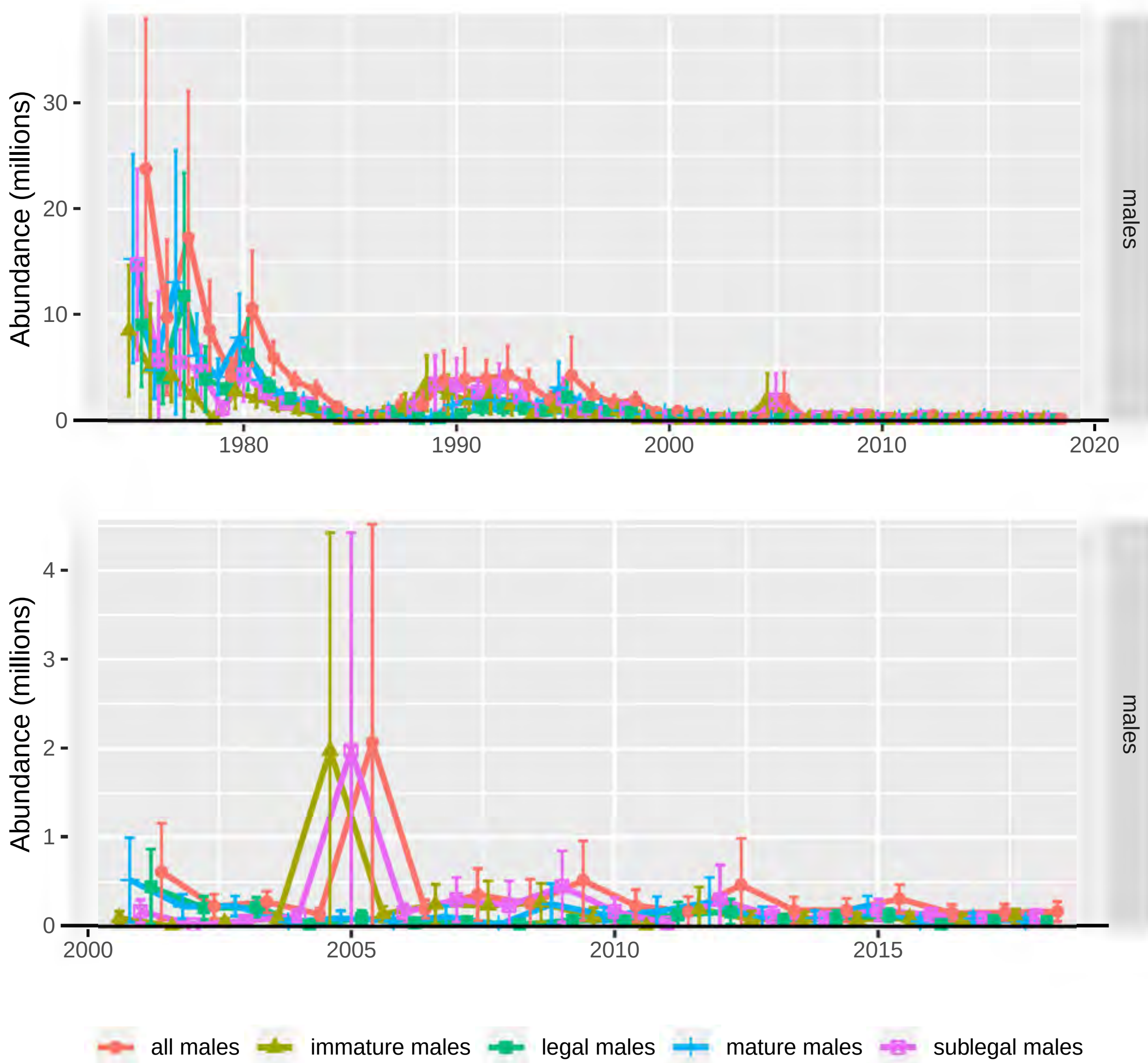

Figure 3: NMFS survey abundance time series for male PIBKC. Upper plot is entire time series, lower plot since 2001.

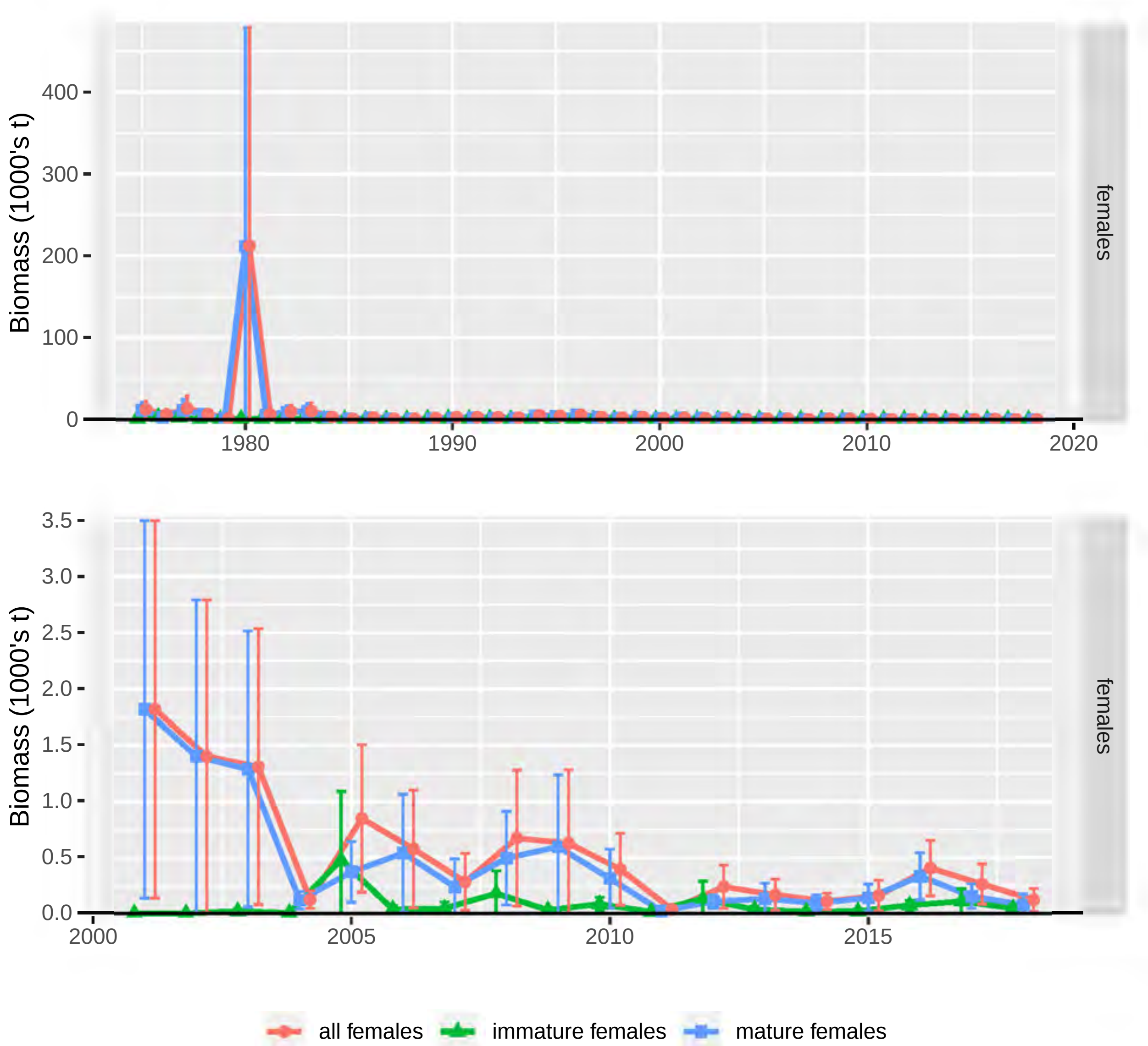

Figure 4: NMFS survey biomass time series for female PIBKC. Upper plot is entire time series, lower plot since 2001.

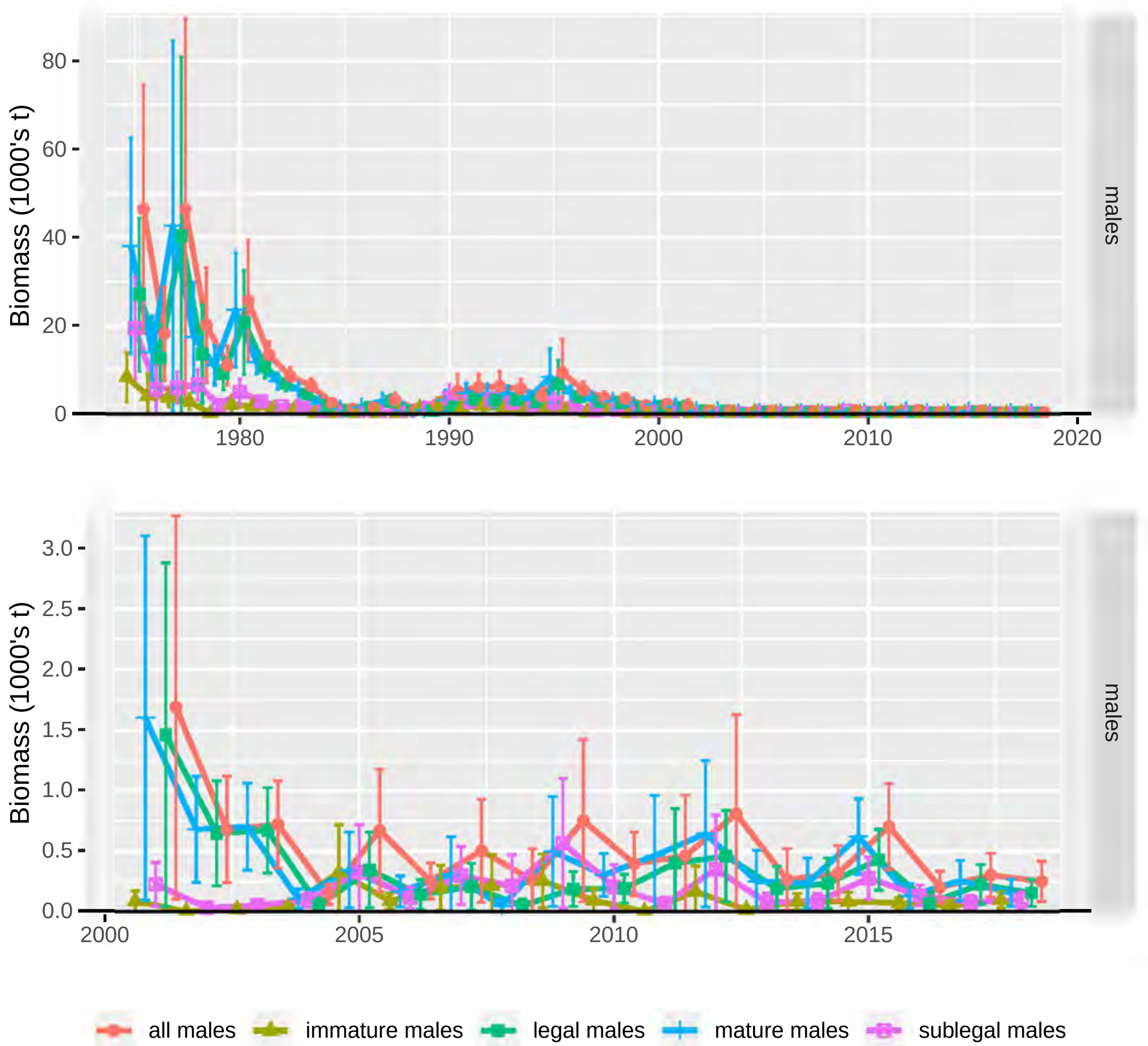

Figure 5: NMFS survey biomass time series for male PIBKC. Upper plot is entire time series, lower plot since 2001.

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	
	number	non-0	no.	non-0	no.	non-0	no.
year	of hauls	hauls	crab	hauls	crab	hauls	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	
year	number of hauls	non-0 hauls	no. crab	non-0 hauls	no. crab	non-0 hauls	no. crab	non-0 hauls	no. crab	non-0 hauls	no. 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	
	abundance	cv	abundance	cv	abundance	cv
year	millions		millions		millions	
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.

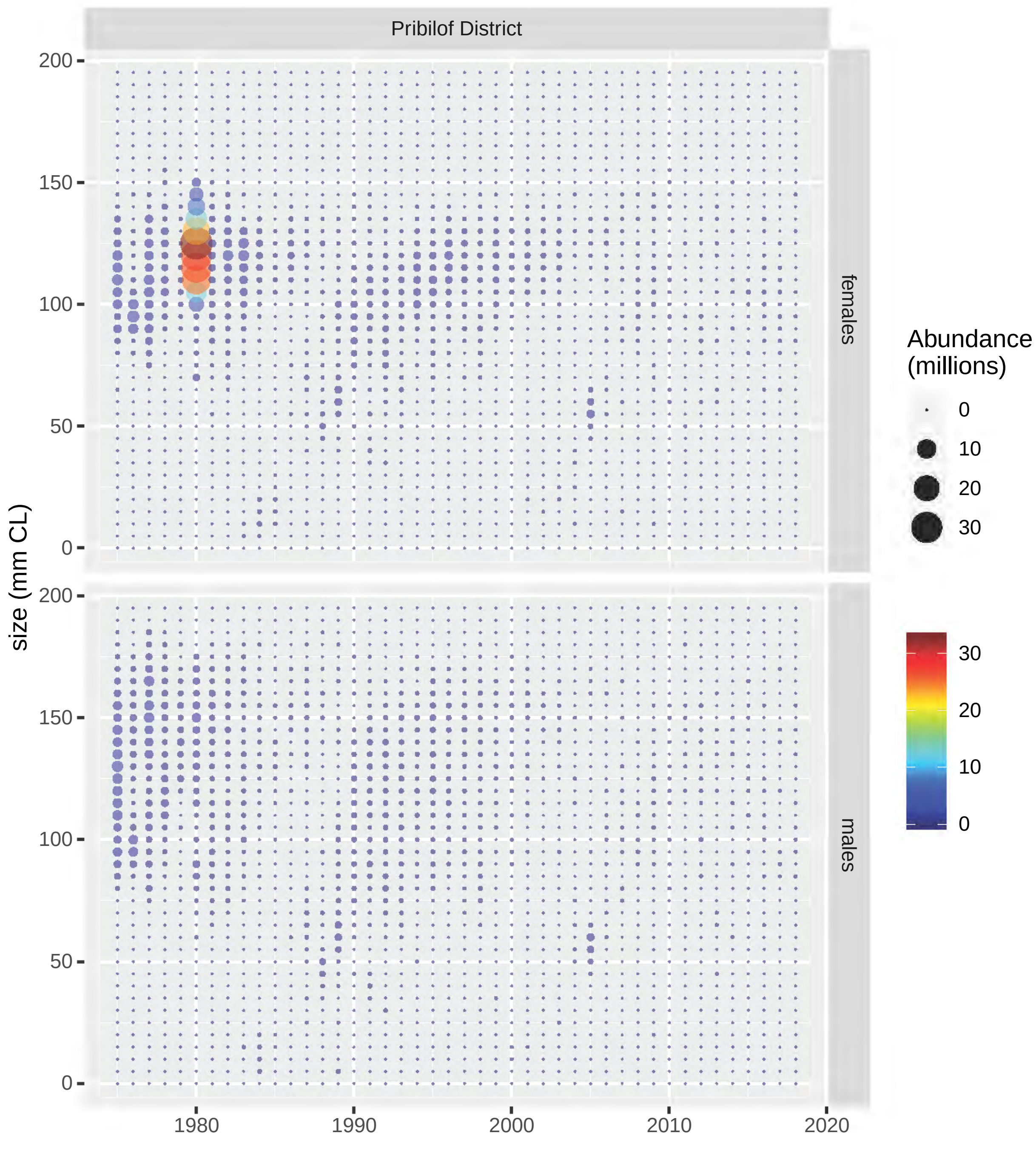

Figure 6: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, over the entire survey period.

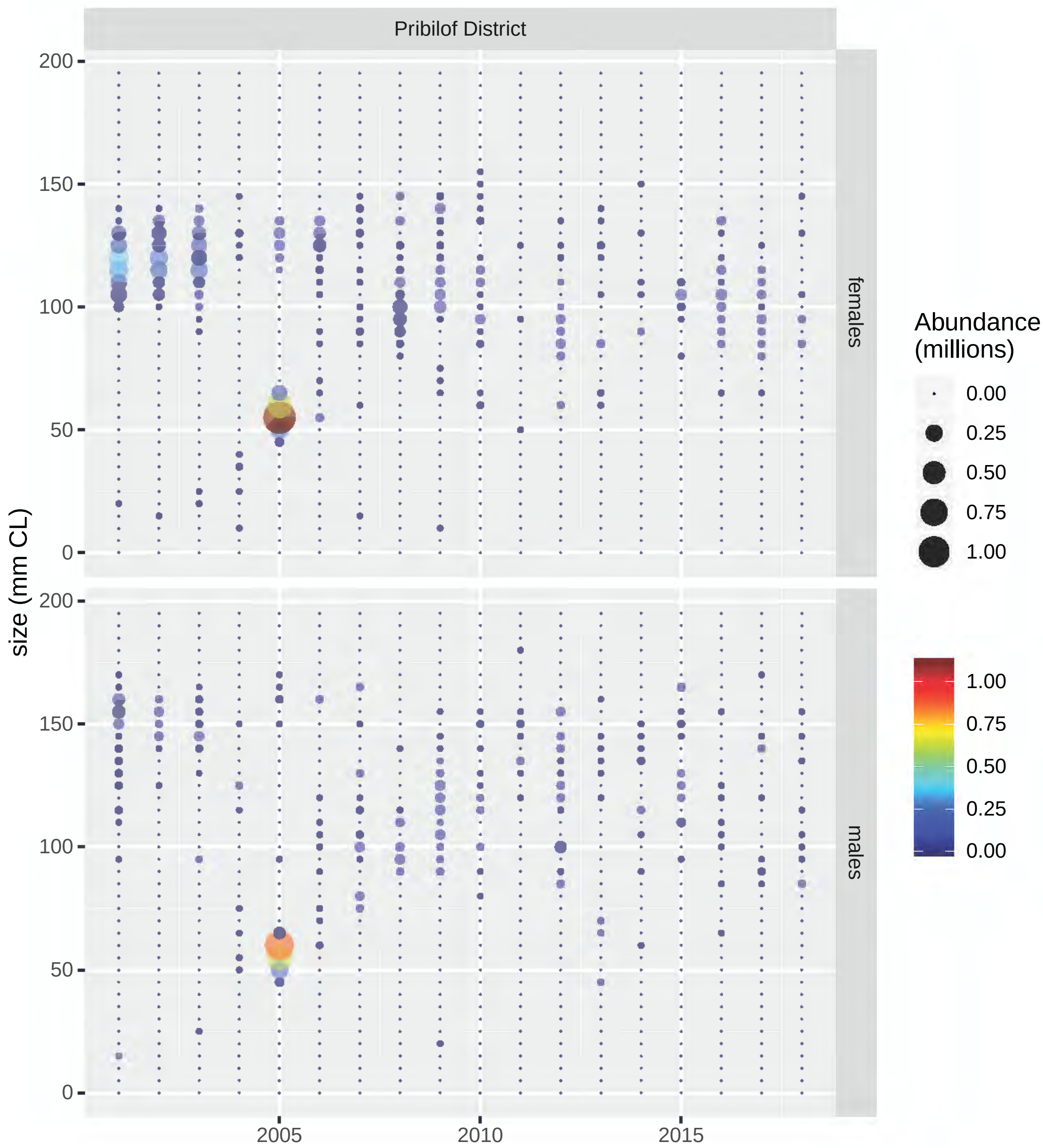

Figure 7: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, since 2001.

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.

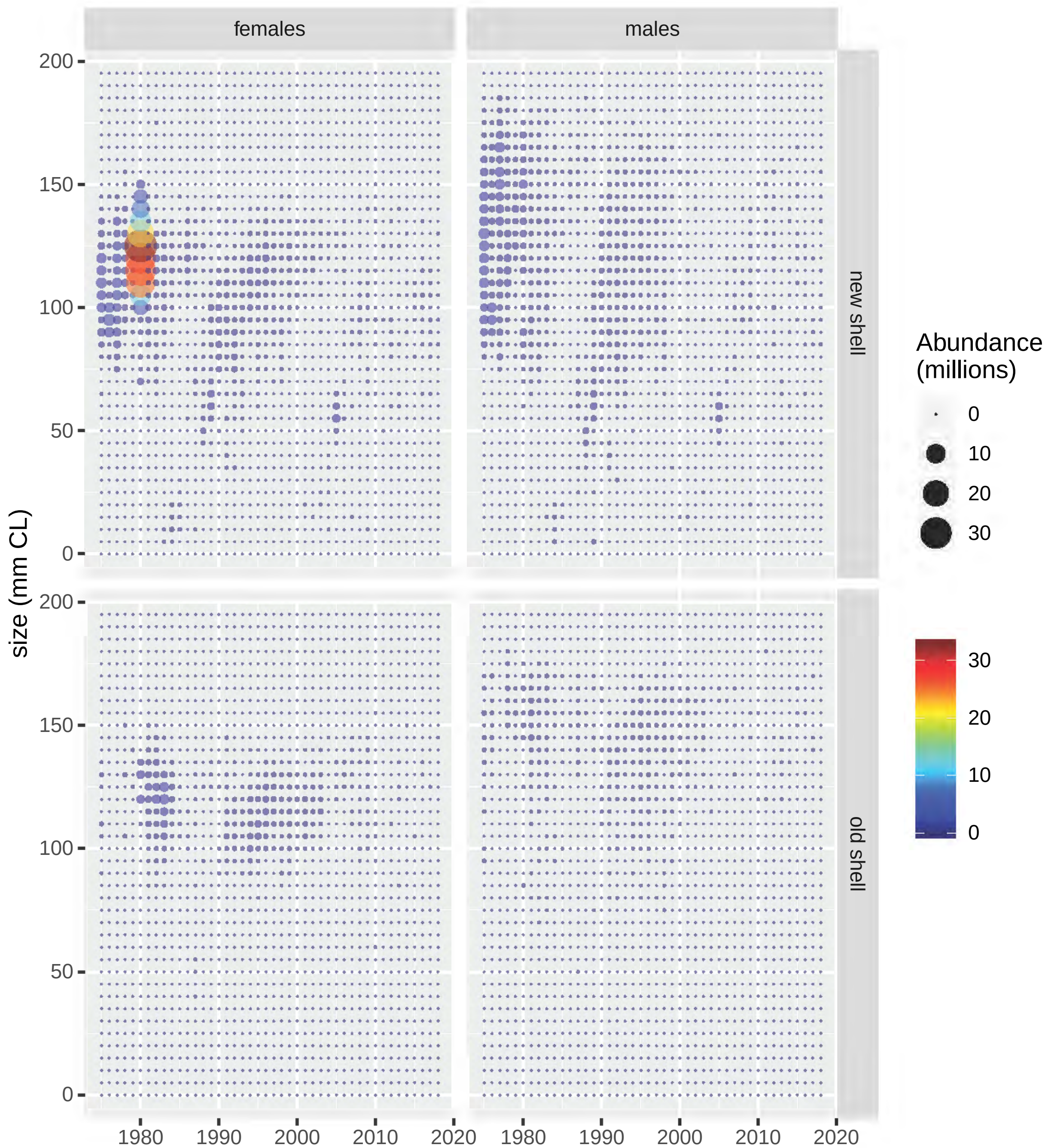

Figure 8: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex and shell condition, for entire survey period.

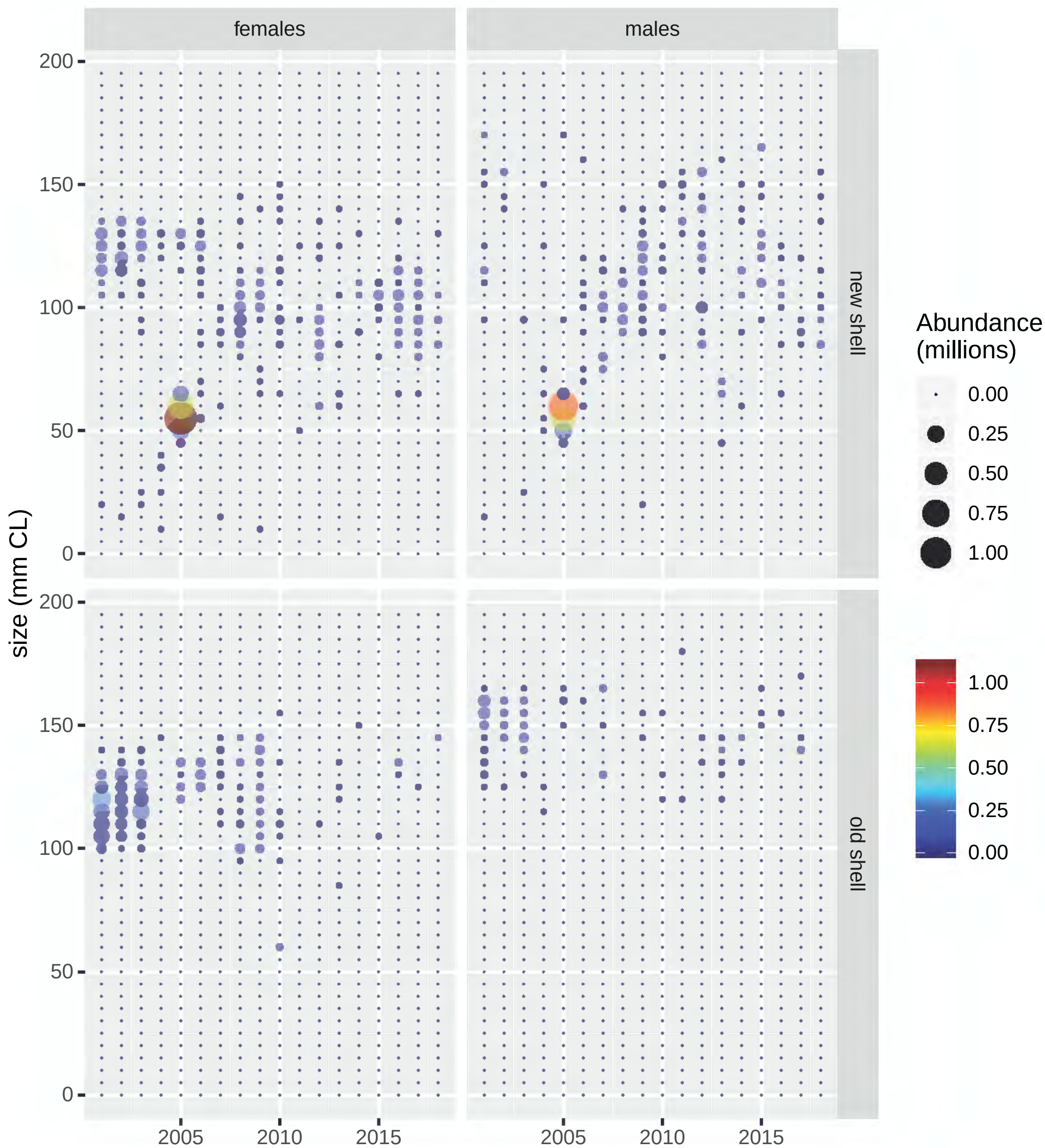

Figure 9: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex and shell condition, since 2000.

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:

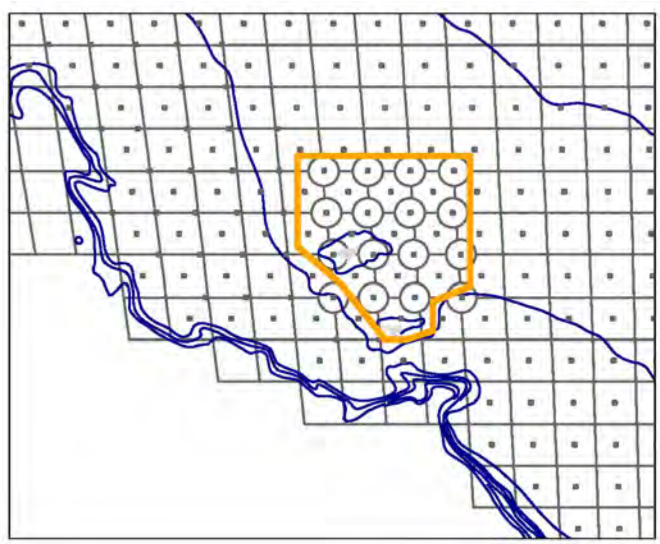

Figure 10: Basemap for future maps, with EBS bathymetry (blue lines), NMFS EBS trawl survey station grid (black) lines, and the Pribilof Islands Habitat Conservation Area (orange outline).

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

William Stockhausen

05 April, 2019

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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):

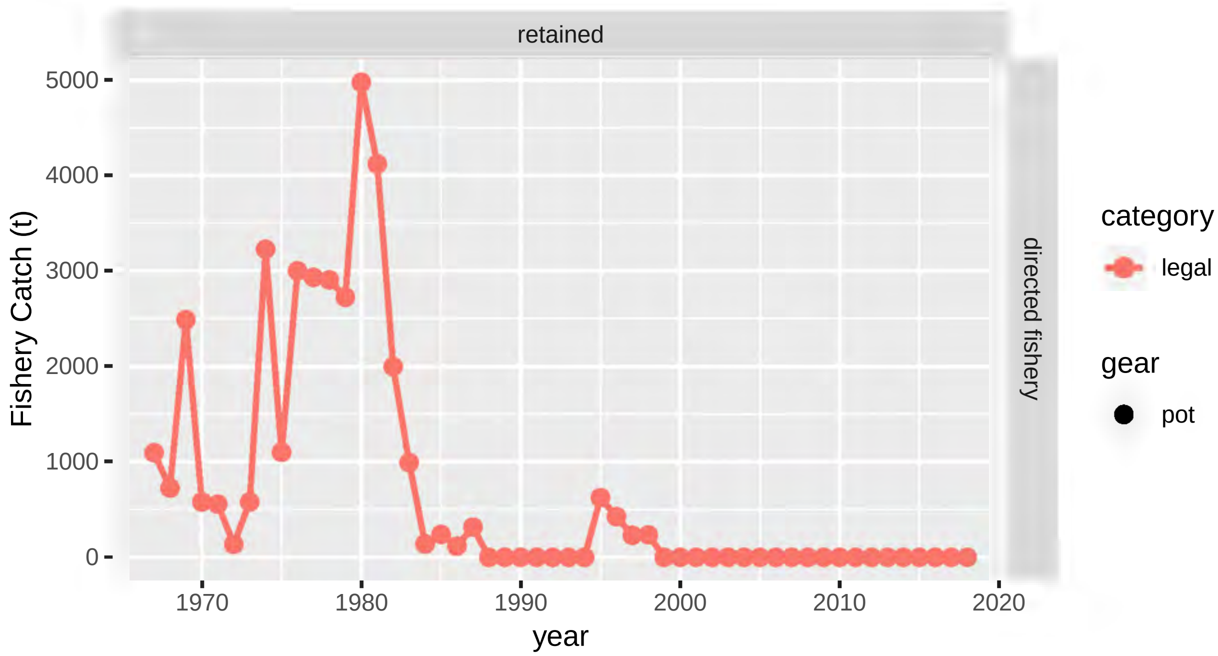

Figure 1: Time series of retained PIBKC catch in the directed fishery.

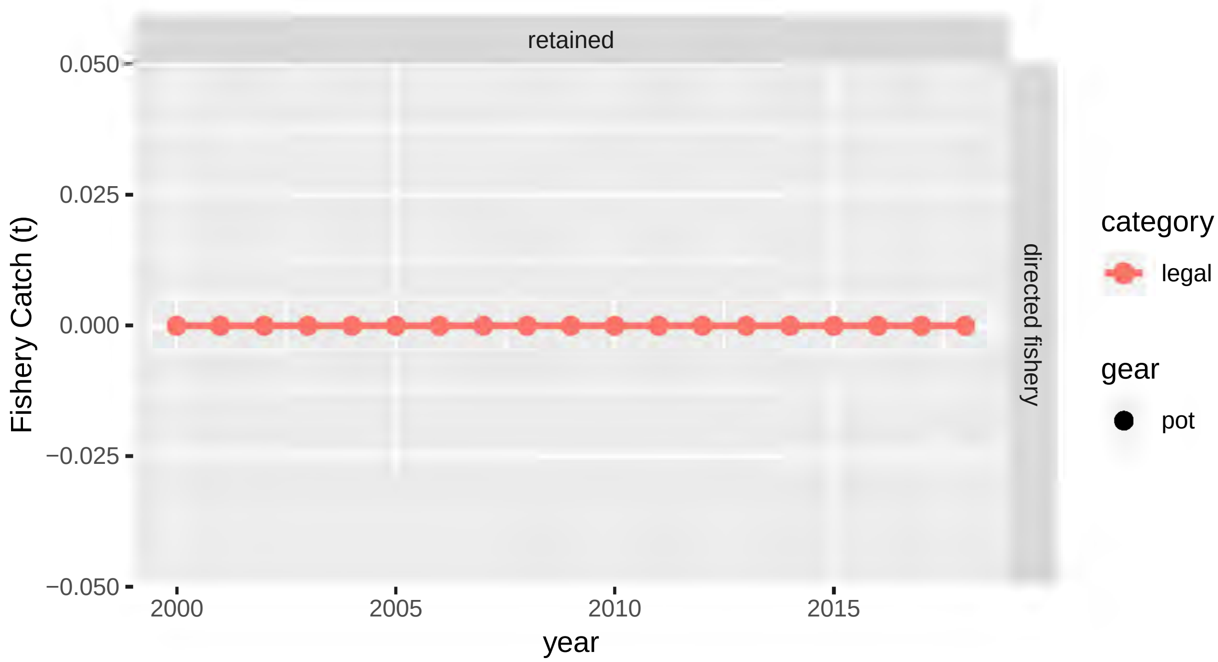

Figure 2: Time series of retained PIBKC catch in the directed fishery (recent time period).

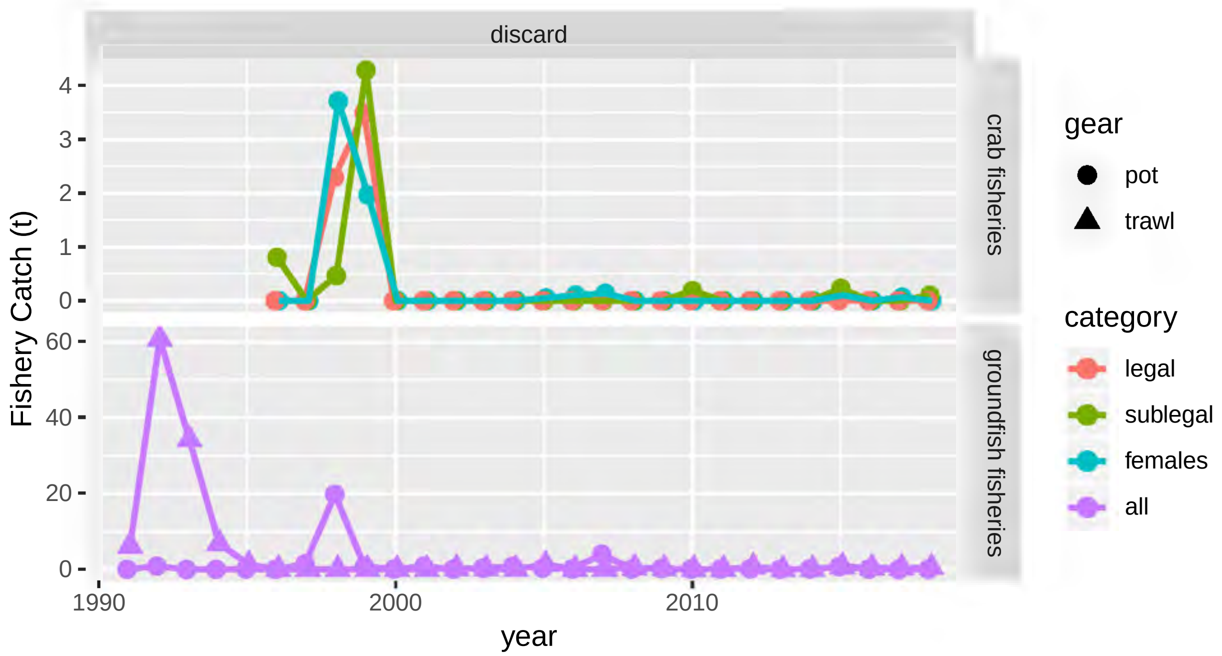

Figure 3: Time series of PIBKC bycatch in the crab and groundfish fisheries.

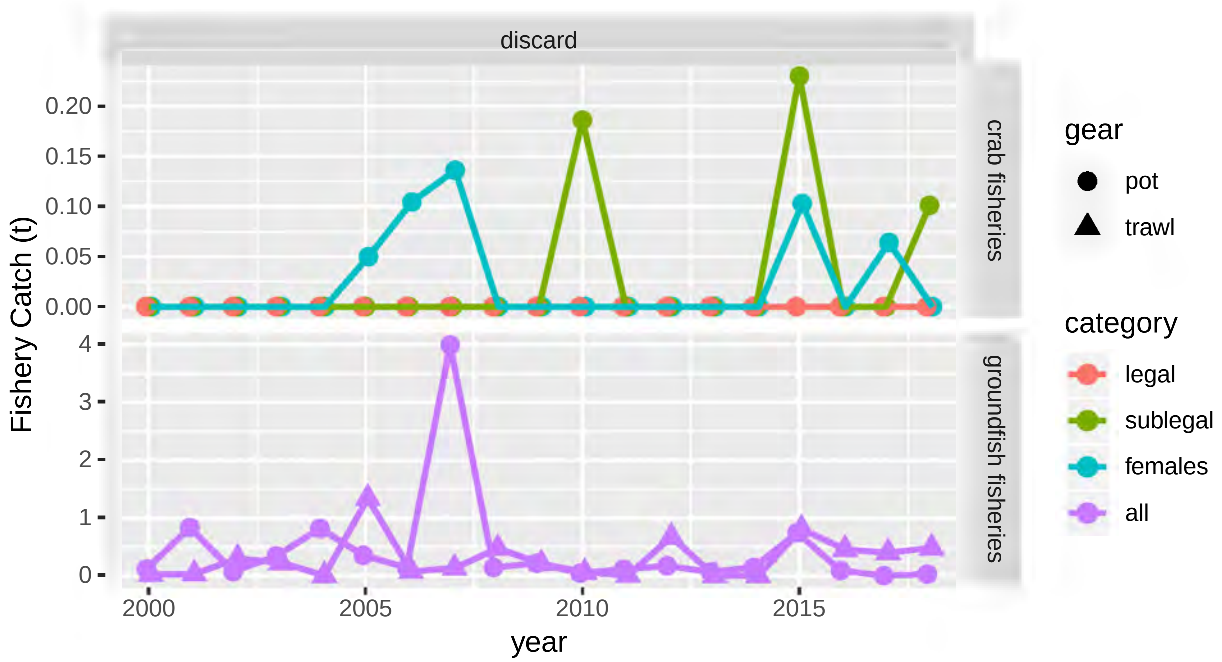

Figure 4: Time series of PIBKC bycatch in the crab and groundfish fisheries (recent time period).

The following figures illustrate the time series of PIBKC survey biomass in the NMFS EBS bottom trawl survey:

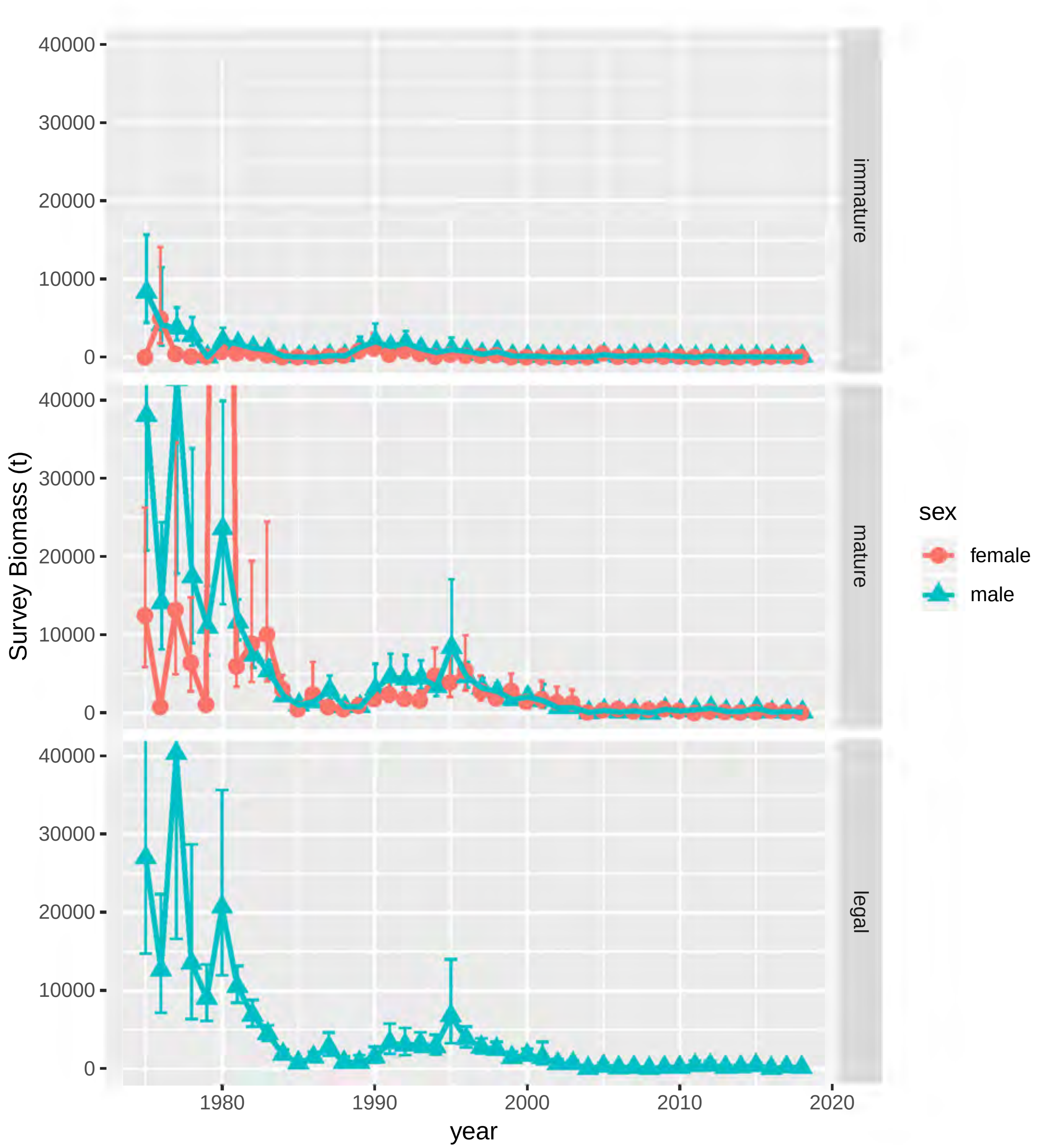

Figure 5: Time series of NMFS EBS bottom trawl survey biomass for PIBKC. Confidence intervals shown are 80% CI's, assuming lognormal error distributions.

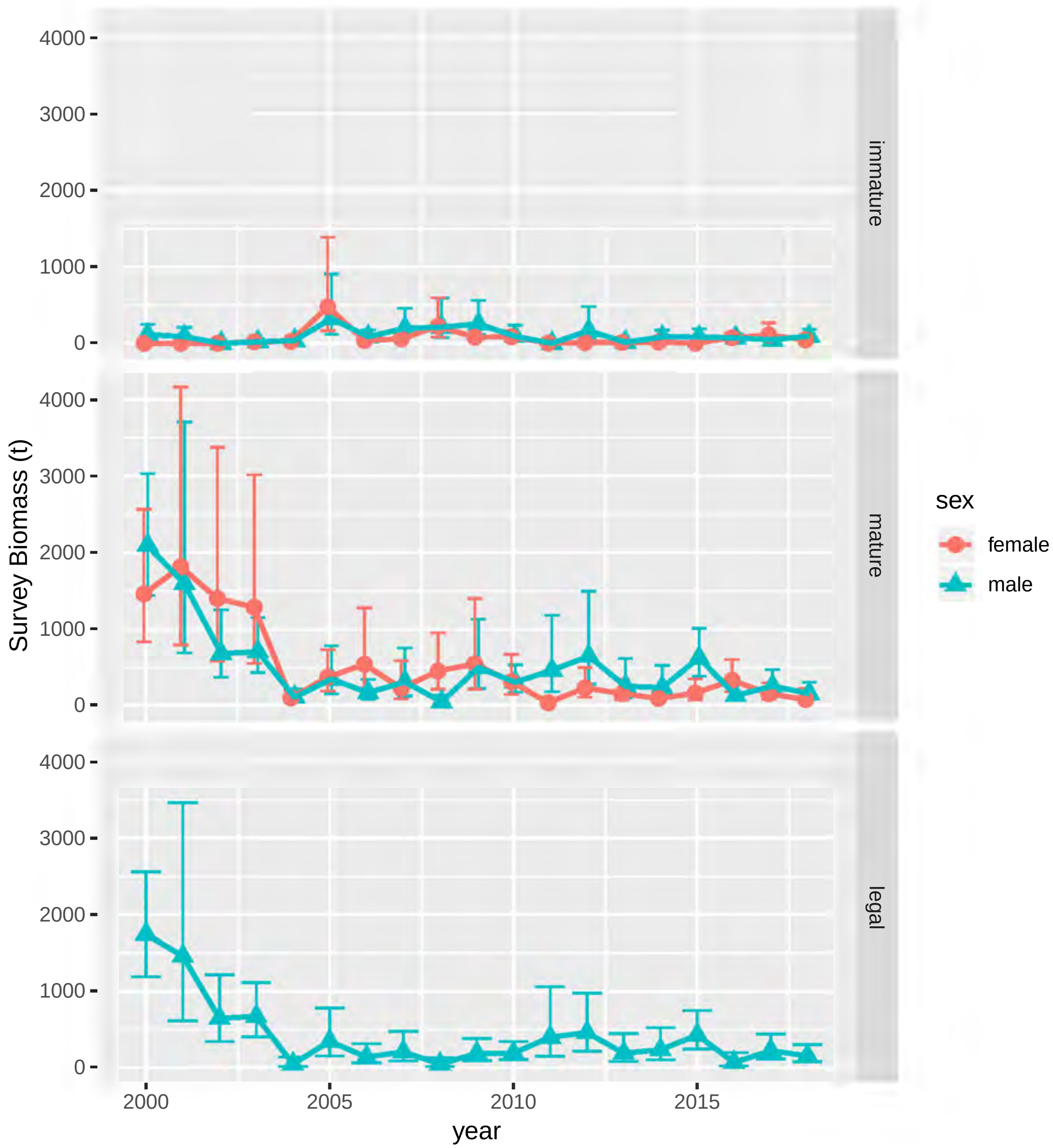

Figure 6: Time series of NMFS EBS bottom trawl survey biomass for PIBKC (recent time period). Confidence intervals shown are 80% CI's, assuming lognormal error distributions.

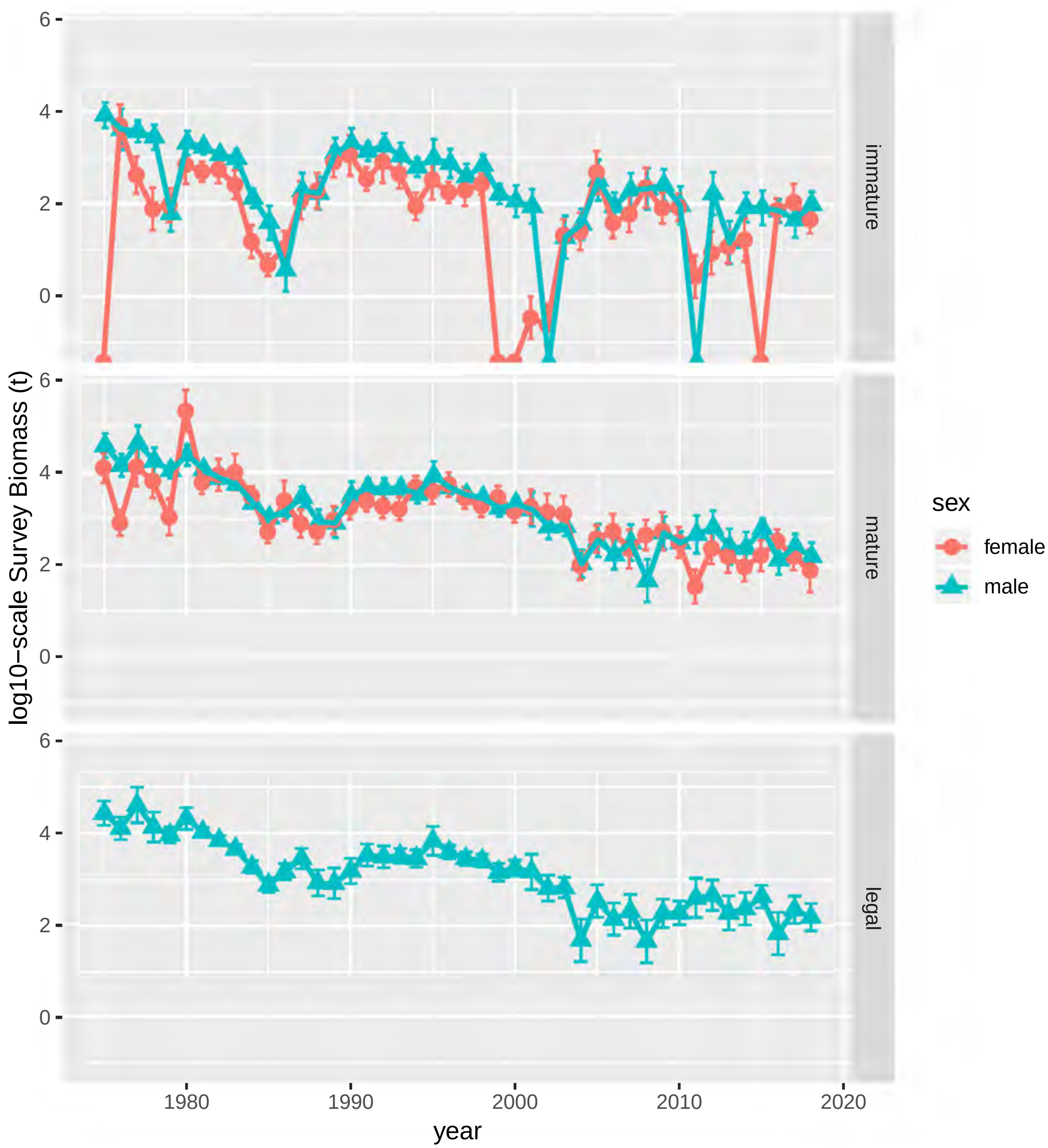

Figure 7: Log10-scale time series for the NMFS EBS bottom trawl survey biomass for PIBKC. Confidence intervals shown are 80% CI's, assuming lognormal error distributions.

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

$$ln(MMB_{s_y}) = < ln(MMB_s) >_y + \eta_y, \text{ where } \eta_y \sim N(0, \sigma^2_{s_y})$$

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:

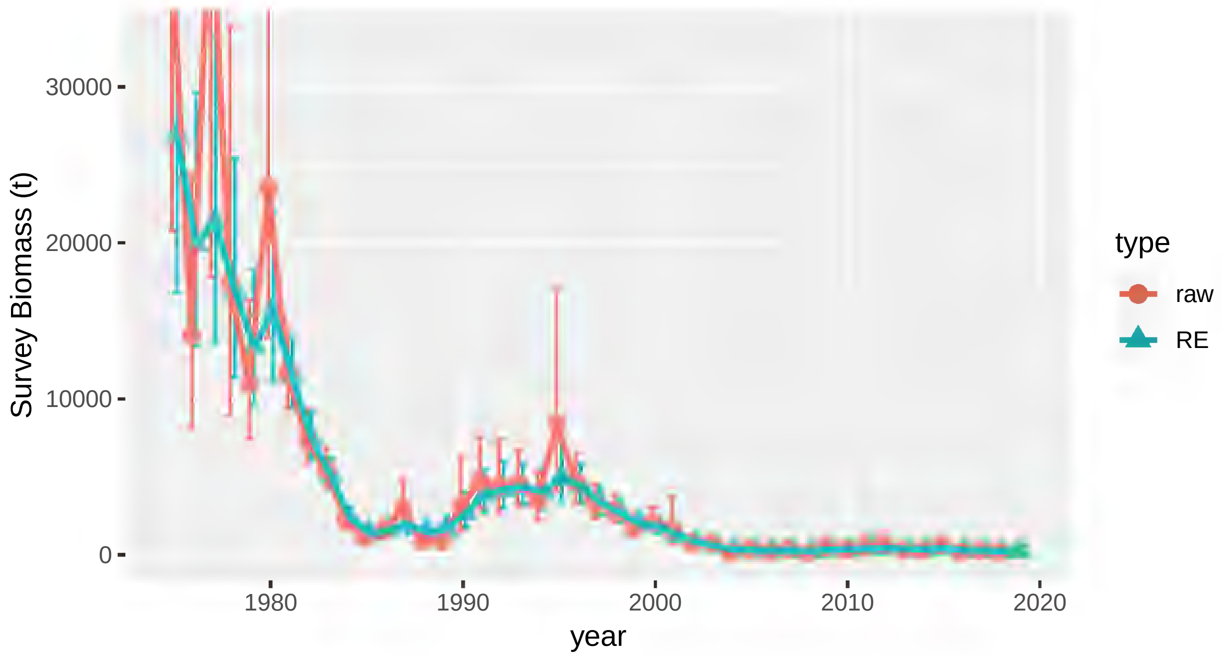

Figure 8: Arithmetic-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions. The final smoothed value is a 1-step prediction.

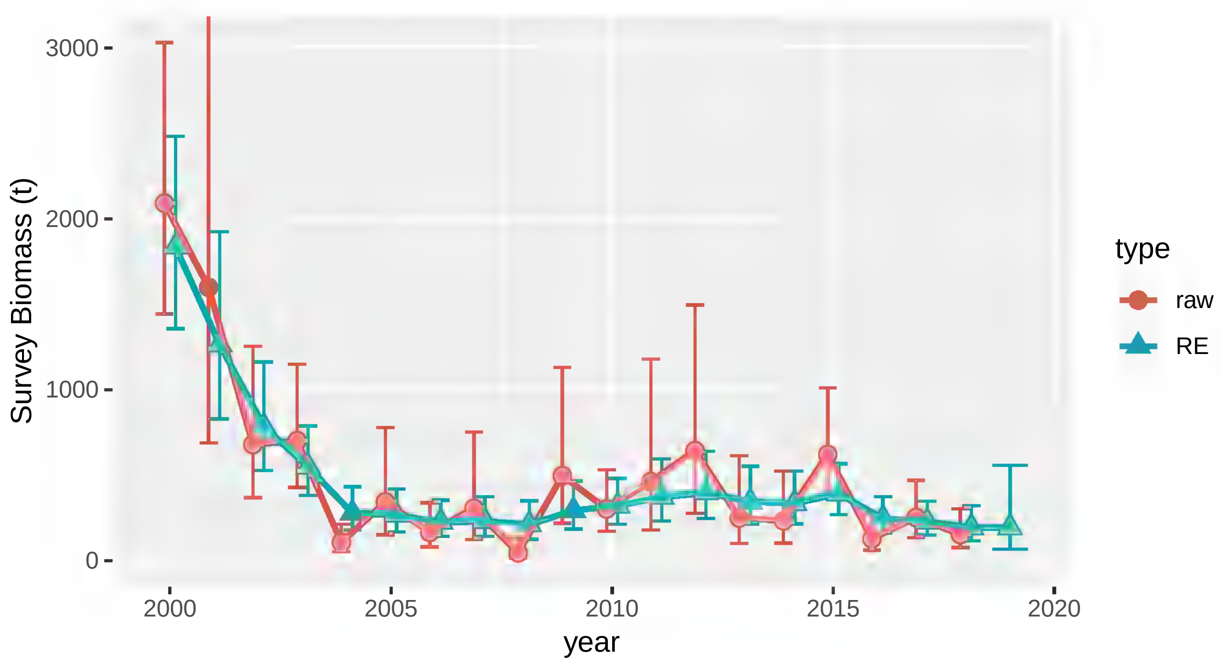

Figure 9: Arithmetic-scale raw and smoothed survey MMB time series, since 2000. Confidence intervals shown are 80% CIs, assuming lognormal error distributions. The final smoothed value is a 1-step prediction.

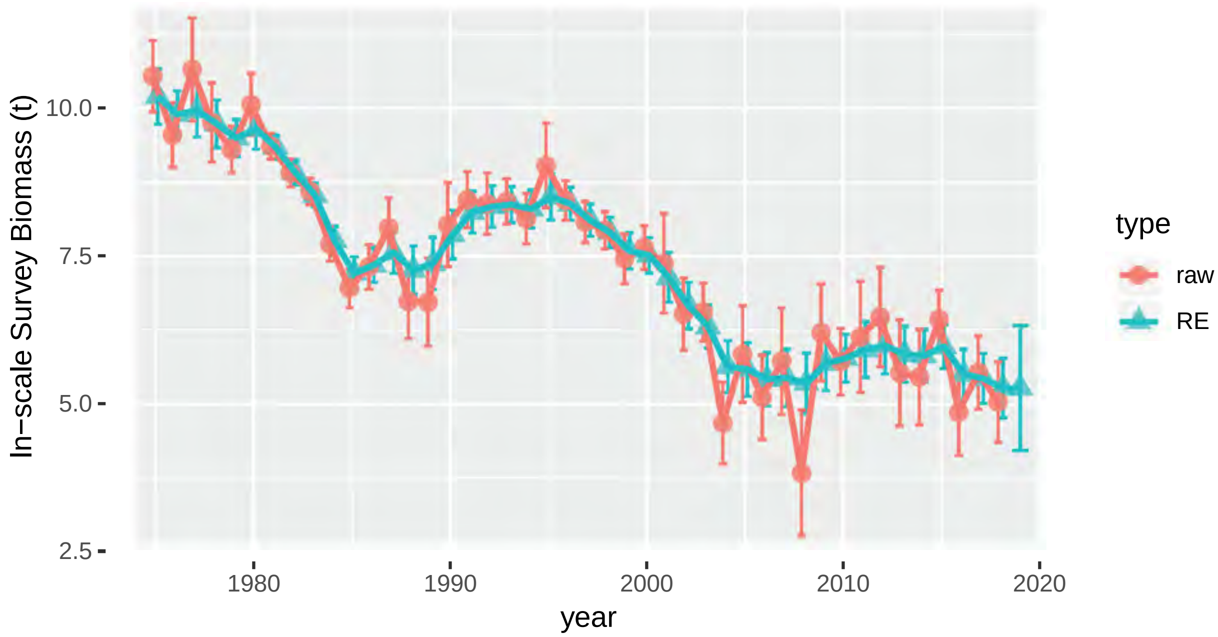

Figure 10: Log-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions. The final smoothed value is a 1-step prediction.

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).

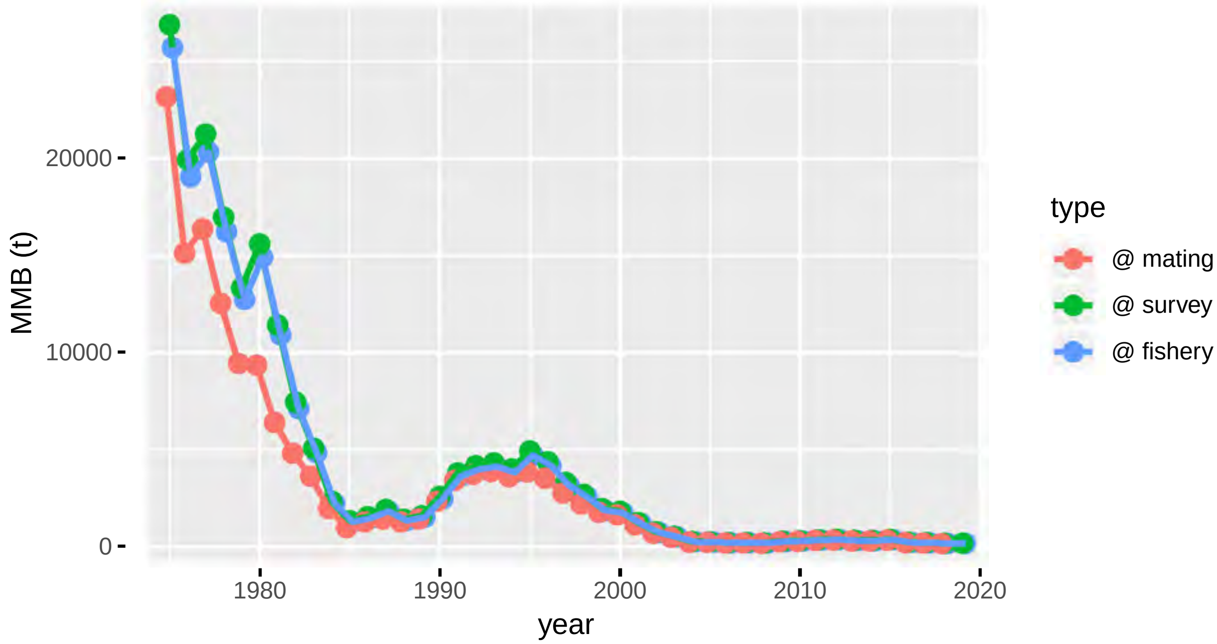

Figure 11: Estimated time series for MMB using the RE method at the time of the survey (the random effects time series), at the time of the fishery, and at the time of mating. The value for MMB at the time of the survey in the assessment year is a 1-step ahead prediction because the survey has not yet 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

References

CPT. 2015. Introduction. In: Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands Regions 2015 Final Crab SAFE. North Pacific Fishery Management Council, 605 W. 4th Avenue, #306, Anchorage, AK 99501. 35 pp.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

SSC. 2015. SCIENTIFIC AND STATISTICAL COMMITTEE to the NORTH PACIFIC FISHERY MANAGEMENT COUNCIL. October 5th – 7th, 2015. 33 pp. http://npfmc.legistar.com/gateway.aspx?M=F&ID=acaba646-c746-4ad5-acb4-f6d70d72b06f.pdf

Stockhausen, W. 2015. 2015 stock assessment for the Pribilof Islands blue king crab fisheries of the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the KING AND TANNER CRAB FISHERIES of the Bering Sea and Aleutian Islands Regions 2015 Final Crab SAFE. North Pacific Fishery Management Council, 605 W. 4th Avenue, #306, Anchorage, AK 99501. p. 511-561.

Saint Matthew Island Blue King Crab Stock Assesssment 2019

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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). The ADFG pot survey did not occur in 2019, but in 2018 the relative biomass in this index was the lowest in the time series (12% of the mean from the 11 surveys conducted since 1995). The assessment model estimates tempers this increase and suggests that the stock (in survey biomass units) is presently at about 27% of the long term model-predicted survey biomass average, similar to the last two 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 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 fishery closures in the last three years (and hence overfishing has not occurred) (Tables 1, 3, and 4). Computations which indicate the relative impact of fishing (i.e., the

[1] 1983/84 refers to a fishing year that extends from 1 July 1983 to 30 June 1984.

"dynamic B_0") suggests, that the current spawning stock biomass has been reduced to 52% 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. Alternative reference point time frame included for comparison for projection year (alt).

Year	MSST	Biomass (MMB_{mating})	TAC	Retained catch	Total male catch	OFL	ABC
2014/15	1.86	2.48	0.30	0.14	0.15	0.43	0.34
2015/16	1.84	2.11	0.19	0.05	0.053	0.28	0.22
2016/17	1.97	2.23	0.00	0.00	0.001	0.14	0.11
2017/18	1.85	1.29	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		1.08				0.04	0.03
2019/20alt		1.04				0.08	0.07

Table 2: Status and catch specifications (million pounds) for the reference model.Alternative reference point time frame included for comparison for projection year (alt).

Year	MSST	Biomass (MMB_{mating})	TAC	Retained catch	Total male catch	OFL	ABC
2014/15	4.1	5.47	0.655	0.309	0.332	0.94	0.75
2015/16	4.1	4.65	0.419	0.110	0.117	0.62	0.49
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	0.00	0.00	0.002	0.08	0.07
2019/20		2.38				0.096	0.08
2019/20alt		2.299				0.18	0.15

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 as the default reference period. Both the full time frame and the current regime are presented here for consideration for 2019/20.

Table 3: Basis for the OFL (1000 t) from the reference model.

Year	Tier	B_{MSY}	Biomass (MMB_{mating})	B/B_{MSY}	F_{OFL}	γ	Basis for B_{MSY}	Natural mortality
2014/15	4b	3.28	2.71	0.82	0.14	1	1978-2014	0.18
2015/16	4b	3.71	2.45	0.66	0.11	1	1978-2015	0.18
2016/17	4b	3.67	2.23	0.61	0.09	1	1978-2016	0.18
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	1.08	0.31	0.042	1	1978-2018	0.18
2019/20	4b	2.05	1.04	0.51	0.082	1	1996-2018	0.18

A. Summary of Major Changes

Changes in Management of the Fishery

There are no new changes in management of the fishery.

Changes to the Input Data

Data used in this assessment have been updated to include the most recently available fishery and survey numbers. This assessment includes of one new survey data point - the 2019 NMFS trawl-survey estimate of abudance. The triennial ADF&G pot survey was not conducted in 2019. The NMFS trawl-surveys have associated size compositon data. The assessment also uses updated 2010-2018 groundfish 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 Alasks 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, per.com. 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 seasons (using the appropriate catch equation rather than assuming an applied pulse removal). Season length in Gmacs is controlled by changing the proportion of natural mortality that is applied each season. 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 2018. There is only one new data set to be included this year so this becomes the updated reference model. Two alternative models are presented to assess sensitivity to the model, while another is provided for alternative reference point calculations (Table 3) using a recent regime time frame. The **fit survey** configuration simply adds emphasis on the design-based survey data (by assuming a lower input variance). The **add CV pot** configuration estimates an additional CV on the pot survey data, which in turn allows the model to fit the trawl-survey estimates better.

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*

   Progress was limited in implementing this feature. We will conduct a retrospective analysis within the next year.

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.

Comment: *Breakpoint analysis for reference point time frames that does not rely on stock-recruit relationship*

We applied the STARS method to the recruitment time series, Appendix C.

Comment: *Regarding rebuilding projection specifications and options, the SSC and CPT requests are:*

1. *bring forth reference points for status determination for both regim time frames*

   See reference point table (Table 3). Completed

2. *bring forth projections 1 and 5 from the May CPT, both with mean recruitment 1) current time frame (1978-2018) and 2) breakpt time period (1996-2018)*

   Completed. Refer to Appendix C.

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.

[2]NOAA grant Bering Sea Crab Research II, NA16FN2621, 1997.

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.

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 numbers. This assessment uses one new survey data point, which is the 2019 NMFS trawl-survey estimate of abudance, and its associated size compositon data. The assessment also uses updated 1993-2018 groundfish and fixed gear bycatch estimates based on AKRO data. The fishery was closed in 2018/19 so no directed fishery catch data were 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 (1992/93-2018/19; Table 6).

Figure 4 maps stations from which SMBKC trawl-survey and pot-survey data were obtained. Further information concerning the NMFS trawl survey as it relates to commercial crab species is available in Daly et al. (2014); see Gish et al. (2012) for a description of ADF&G SMBKC pot-survey methods. It should be noted that the two surveys cover different geographic regions and that each has in some years encountered proportionally large numbers of male blue king crab in areas 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.

[3] D. Pengilly, ADF&G, pers. comm.

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 (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

Four models are presented with the reference model being the same configuration as approved last year (Ianelli et al. 2018), two sensitivities are considered, one which weights the survey data more heavily and one that adds an additional CV on the ADF&G pot survey data. In addition to these sensitivities, we evaluated the impacts of adding new data to the reference model. In summary, the following lists the models presented and the naming convention used:

1. **18.0 - 2018 Model**: the 2018 recommended model without any new data
2. **19.0 - 2019 Reference Model**: new data for 2019: NMFS trawl-survey and bycatch updates for groundfish
3. **19.0a - 2019 Model - alt reference pts**: model 19.0 with alternative time frames for reference points and projections
4. **19.1 - fit survey**: an exploratory scenario that's the same as the reference model except the NMFS trawl survey is up-weighted by $\lambda^{\mathrm{NMFS}} = 1.5$ and the ADF&G pot survey is up-weighted by $\lambda^{\mathrm{ADFG}} = 2$.

5. **19.2 - add CV pot**: includes an estimated additional CV on the ADF&G pot survey

Note that SSC convention would label these (item 2 above) as model 16.0 (the model first developed in that year). Since only a few models are presented here, for simplicity we labeled model 16.0 as "reference" and for the others, we used the simple naming convention presented above.

Results

a. Sensitivity to new data

Results for scenarios are provided with comparisons to the 2018 model and sensitivity to new 2019 data are shown in Figures 6 and 7 with recruitment and spawning biomass shown in Figures 8 and 9, respectively. The fits to survey CPUEs and spawning biomass show that the addition of new data results in a slight increase compared to the 2018 assessment. However, neither last years or this years reference model 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. The SDNR for the trawl survey is 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 this year.
The SDNRs for the pot surveys show 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 shows the same pattern among each of the scenarios as the SDNR. The MAR values for the trawl survey and pot survey size compositions were relatively good, ranging from 0.60 to 0.65 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 through 17.

There are some differences in parameter estimates among models as reflected in the log-likelihood components and the management quantities. The parameter estimates in the "fit survey" and "add CV pot" scenarios differ the most, as expected, particularly the estimate of the ADF&G pot survey catchability (q) (see Table 15). Also, the residuals for recruitment in the first size group are large for these model runs, presumably because higher estimates of recruits in some years are required by the model to match the observed biomass trends.

Selectivity estimates show some variability between models (Figure 10). Estimated recruitment is variable over time for all models and in recent years is well below average (Figure 11). Estimated mature male biomass on 15 February also fluctuates considerably (Figure 12). Estimated natural mortality each year (M_t) is presented in Figure 13.

Estimates of fishing morality, from the reference model, 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 model fits to total male ($\geq$ 90 mm CL) trawl survey biomass tend to miss the recent peak around 2010, and fits recent survey data points on the lower end of their error bars (Figures 14). These fits are most likely being pulled down by the recent decline in the ADF&G pot survey data points, since the **add CV pot** model captures the upward error bars for these data points when it is allowed to fit the ADF&G pot survey data very poorly. All of the models fit the pot survey CPUE poorly (Figure 15), with the **add CV pot** model having the worst fit due to the addition of variability (Figure 16). For the trawl survey the standardized residuals have similar patterns with the exception of recent years for the **add CV pot** model (19.2), generally poor fit to the last 15 years of data (Figure 17). The standardized residuals for the ADF&G pot survey have similar patterns but are much larger for the "add CV pot" model than the others, for obvious reasons (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 all scenarios. Representative residual plots of the composition data fits are generally poor (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).

Unsurprisingly, the **fit surveys** model fits the the NMFS survey biomass and ADF&G pot survey CPUE data better but still has a similar residual pattern (Figures 14 and 15). It is worth noting that that this scenario (included for exploratory purposes) resulted in worse SDNR and MAR values for the two abundance indices.

e. Retrospective and historical analyses

This is only the third year a formal assessment model developed for this stock. As such, retrospective patterns and historical analyses relative to fisheries impacts are limited.

f. Uncertainty and sensitivity analyses.

Estimated standard deviations of parameters and selected management measures for the models are summarized in Tables 12, 13, and 14 (compiled in Table 15). Probabilities for mature male biomass and OFL in 2019 are presented in Section F.

g. Comparison of alternative model scenarios.

The estimates of mature male biomass (Figure 12), for the **fit survey** sensitivity differs from the other models due to a low value for pot survey catchability being estimated (which tends to scale the population estimate). Difference in the mature male biomass since 2010 in the **add CV pot** model are due to the model following the trajectory of the trawl survey and downweighting the declines in the pot survey. The **fit Survey** scenario upweights both the trawl and pot surveys abundance indices and represents a model run that places greater emphasis on the abundance indices. The **add CV pot** scenario places more emphasis on the trawl survey, essentially ignoring the pot survey results in more recent years (since 2010).

In summary, the use of the reference model for management purposes is preferred since it provides the best fit to all of the data and is consistent with previous model specifications. Research on alternative model specifications (e.g., natural mortality variability) was limited this year since the authors were focused on the time frame to estimate reference points and rebuilding projections (Appendix C). Consequently, the reference model appears reasonable and appropriate for ABC and OFL determinations for this stock in 2019. Additionally, the **fit surveys** and the **add CV pot** models provide conflicting conditions of this stock depending on which survey results are more believable. These conflicting results, in addition to the stock being in a overfished state, should highlight the caution needed providing management advice.

F. Calculation of the OFL and ABC

The overfishing level (OFL) is the fishery-related mortality biomass associated with fishing mortality F_{OFL}. The SMBKC stock is currently managed as Tier 4, and only a Tier 4 analysis is presented here. Thus, given stock estimates or suitable proxy values of B_{MSY} and F_{MSY}, along with two additional parameters α and β, F_{OFL} is determined by the control rule

$$F_{OFL} = \begin{cases} F_{MSY}, & \text{when } B/B_{MSY} > 1 \\ F_{MSY}\frac{(B/B_{MSY}-\alpha)}{(1-\alpha)}, & \text{when } \beta < B/B_{MSY} \leq 1 \end{cases} \tag{1}$$
$$F_{OFL} < F_{MSY} \text{ with directed fishery } F = 0 \text{ when } B/B_{MSY} \leq \beta$$

where B is quantified as mature-male biomass (MMB) at mating with time of mating assigned a nominal date of 15 February. Note that as B itself is a function of the fishing mortality F_{OFL} (therefore numerical approximation of F_{OFL} is required). As implemented for this assessment, all calculations proceed according to the model equations given in Appendix A. F_{OFL} is taken to be full-selection fishing mortality in the directed pot fishery and groundfish trawl and fixed-gear fishing mortalities set at their model geometric mean values over years for which there are data-based estimates of bycatch-mortality biomass.

The currently recommended Tier 4 convention is to use the full assessment period, currently 1978- 2018, 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 ABC is 80% of the OFL.

Table 4: Comparisons of management measures for the model scenarios. Biomass and OFL are in tons.

Component	model 19.0 (ref)	model 19.1 (fit survey)	model 19.2 (add CV pot)	model 19.0a (alt regime)
MMB_{2019}	1151.299	2537.418	3430.487	1151.299
B_{MSY}	3484.398	7645.093	3709.633	2052.737
MMB/B_{MSY}	0.310	0.285	0.834	0.508
F_{OFL}	0.042	0.000	0.147	0.082
OFL_{2019}	43.736	0.911	427.429	82.314
ABC_{2019}	34.989	0.729	341.943	65.852

G. Rebuilding Analysis

This stock was declared overfished in fall of 2018 and a rebuilding plan is being constructed concurrent to the 2019 stock assessment (Appendix C). Model scenarios presented here all suggest the stock is still overfished.

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. Temporal changes in spatial distributions near the island.
4. 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 2018 noted ocean conditions warmer than normal with an absence of a "cold pool" in the region. This could have detrimental effects on the SMBKC stocks 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 52% of what it would have been in the absence of fishing (Figure 27). 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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K. References

Alaska Department of Fish and Game (ADF&G). 2013. Crab observer training and deployment manual. Alaska Department of Fish and Game Shellfish Observer Program, Dutch Harbor. Unpublished.

Collie, J.S., A.K. Delong, and G.H. Kruse. 2005. Three-stage catch-survey analysis applied to blue king crabs. Pages 683-714 [In] Fisheries assessment and management in data-limited situations. University of Alaska Fairbanks, Alaska Sea Grant Report 05-02, Fairbanks.

Daly, B., R. Foy, and C. Armistead. 2014. The 2013 eastern Bering Sea continental shelf bottom trawl survey: results for commercial crab species. NOAA Technical Memorandum 295, NMFS-AFSC.

Donaldson, W.E., and S.C. Byersdorfer. 2005. Biological field techniques for lithodid crabs. University of Alaska Fairbanks, Alaska Sea Grant Report 05-03, Fairbanks.

Fitch, H., M. Deiman, J. Shaishnikoff, and K. Herring. 2012. Annual management report for the commercial and subsistence shellfish fisheries of the Bering Sea, 2010/11. Pages 75-1776 [In] Fitch, H., M. Schwenzfeier, B. Baechler, T. Hartill, M. Salmon, and M. Deiman, E.

Evans, E. Henry, L. Wald, J. Shaishnikoff, K. Herring, and J. Wilson. 2012. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the Westward Region's Shellfish Observer Program, 2010/11. Alaska Department of Fish and Game, Fishery Management Report No. 12-22, Anchorage.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124-1138.

Gaeuman, W.B. 2013. Summary of the 2012/13 mandatory crab observer program database for the Bering Sea/Aleutian Islands commercial crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 13-54, Anchorage.

Gish, R.K., V.A. Vanek, and D. Pengilly. 2012. Results of the 2010 triennial St. Matthew Island blue king crab pot survey and 2010/11 tagging study. Alaska Department of Fish and Game, Fishery Management Report No. 12-24, Anchorage.

Ianelli, J., D. Webber, and J. Zheng, 2017. Stock assessment of Saint Matthews Island blue king crab. North Pacific Fishery Management Council. Anchorage AK.

Ianelli, J., and J. Zheng, 2018. Stock assessment of Saint Matthews Island blue king crab. North Pacific Fishery Management Council. Anchorage AK.

Jensen, G.C., and D.A. Armstrong. 1989. Biennial reproductive cycle of blue king crab, *Paralithodes platypus*, at the Pribilof Islands, Alaska and comparison to a congener, *P. camtschatica*. Can. J. Fish. Aquat. Sci. 46: 932-940.

Moore, H., L.C. Byrne, and D. Connolly. 2000. Alaska Department of Fish and Game summary of the 1998 mandatory shellfish observer program database. Alaska Dept. Fish and Game, Commercial Fisheries Division, Reg. Inf. Rep. 4J00-21, Kodiak.

North Pacific Fishery Management Council (NPFMC). 1998. Fishery Management Plan for Bering Sea/Aleutian Islands king and Tanner crabs. North Pacific Fishery Management Council, Anchorage.

North Pacific Fishery Management Council (NPFMC). 1999. Environmental assessment/regulatory impact review/initial regulatory flexibility analysis for Amendment 11 to the Fishery Management Plan for Bering Sea/Aleutian Islands king and Tanner crabs. North Pacific Fishery Management Council, Anchorage.

North Pacific Fishery Management Council (NPFMC). 2000. Environmental assessment/regulatory impact review/initial regulatory flexibility analysis for proposed Amendment 15 to the Fishery Management Plan for king and Tanner crab fisheries in the Bering Sea/Aleutian Islands and regulatory amendment to the Fishery Management Plan for the groundfish fishery of the Bering Sea and Aleutian Islands area: A rebuilding plan for the St. Matthew blue king crab stock. North Pacific Fishery Management Council, Anchorage. Draft report.

North Pacific Fishery Management Council (NPFMC). 2007. Public Review Draft: Environmental assessment for proposed Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands king and Tanner crabs to revise overfishing definitions. 14 November 2007. North Pacific Fishery Management Council, Anchorage.

Otto, R.S. 1990. An overview of eastern Bering Sea king and Tanner crab fisheries. Pages 9-26 [In] Proceedings of the international symposium on king and Tanner crabs. University of Alaska Fairbanks, Alaska Sea Grant Program Report 90-4, Fairbanks.

Otto, R.S., and P.A. Cummiskey. 1990. Growth of adult male blue king crab (*Paralithodes platypus*). Pages 245-258 [In] Proceedings of the international symposium on king and Tanner crabs. University of Alaska Fairbanks, Alaska Sea Grant Report 90-4, Fairbanks.

Paul, J.M., A. J. Paul, R.S. Otto, and R.A. MacIntosh. 1991. Spermatophore presence in relation to carapace length for eastern Bering Sea blue king crab (*Paralithodes platypus*, Brandt, 1850) and red king crab (*P. camtschaticus*, Tilesius, 1815). J. Shellfish Res. 10: 157-163.

Pengilly, D. and D. Schmidt. 1995. Harvest Strategy for Kodiak and Bristol Bay red king crab and St. Matthew Island and Pribilof blue king crab. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Special Publication Number 7, Juneau.

Somerton, D.A., and R.A. MacIntosh. 1983. The size at sexual maturity of blue king crab, Paralithodes platypus, in Alaska. Fishery Bulletin 81: 621-828.

Thorson, J.T., and L.A.K. Barnett. 2017. Comparing estimates of abundance trends and distribution shifts using single- and multispecies models of fishes and biogenic habitat. ICES Journal of Marine Science 75:1311-1321.

Thorson, J.T., J.N. Ianelli, E. Larsen, L. Ries, M.D. Scheuerell, C. Szuwalski, and E. Zipkin. 2016. Joint dynamic species distribution models: a tool for community ordination and spatiotemporal monitoring. Glob. Ecol. Biogeogr. 25(9): 1144–1158. geb.12464.

Thorson, J.T., Scheuerell, M.D., Shelton, A.O., See, K.E., Skaug, H.J., and Kristensen, K. 2015. Spatial factor analysis: a new tool for estimating joint species distributions and correlations in species range. Methods Ecol. Evol. 6(6): 627–637. doi:10.1111/2041-210X.12359.

Webber, D., J. Zheng, and J. Ianelli, 2016. Stock assessment of Saint Matthews Island Blue King Crab. North Pacific Fishery Managment Council. Anchorage AK.

Zheng, J. 2005. A review of natural mortality estimation for crab stocks: data-limited for every stock? Pages 595-612 [In] Fisheries Assessment and Management in Data-Limited Situations. University of Alaska Fairbanks, Alaska Sea Grant Program Report 05-02, Fairbanks.

Zheng, J., and G.H. Kruse. 2002. Assessment and management of crab stocks under uncertainty of massive die-offs and rapid changes in survey catchability. Pages 367-384 [In] A.J. Paul,E.G. Dawe, R. Elner, G.S. Jamieson, G.H. Kruse, R.S. Otto, B. Sainte-Marie, T.C. Shirley, and D. Woodby (eds.). Crabs in Cold Water Regions: Biology, Management, and Economics. University of Alaska Fairbanks, Alaska Sea Grant Report 02-01, Fairbanks.

Zheng, J., M.C. Murphy, and G.H. Kruse. 1997. Application of catch-survey analysis to blue king crab stocks near Pribilof and St. Matthew Islands. Alaska Fish. Res. Bull. 4:62-74.

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	1.633
2017	0.052	6.032
2018	0.001	1.281

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				

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

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 (19.0) model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.582	0.137
$\log(\bar{R})$	13.912	0.045
$\log(n^0_1)$	14.963	0.175
$\log(n^0_2)$	14.532	0.210
$\log(n^0_3)$	14.349	0.206
q_{pot}	3.733	0.248
$\log(\bar{F}^{\text{df}})$	-2.159	0.052
$\log(\bar{F}^{\text{tb}})$	-9.457	0.074
$\log(\bar{F}^{\text{fb}})$	-8.154	0.074
log Stage-1 directed pot selectivity 1978-2008	-0.804	0.179
log Stage-2 directed pot selectivity 1978-2008	-0.436	0.128
log Stage-1 directed pot selectivity 2009-2017	-0.470	0.161
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.309	0.065
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.713	0.125
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.042	0.005
OFL	43.736	9.254

Table 13: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the 'fit surveys' (19.1) model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.746	0.088
$\log(\bar{R})$	14.233	0.048
$\log(n^0_1)$	15.288	0.179
$\log(n^0_2)$	15.065	0.201
$\log(n^0_3)$	14.844	0.204
q_{pot}	1.399	0.058
$\log(\bar{F}^{\text{df}})$	-2.921	0.039
$\log(\bar{F}^{\text{tb}})$	-10.000	0.000
$\log(\bar{F}^{\text{fb}})$	-8.993	0.066
log Stage-1 directed pot selectivity 1978-2008	-0.485	0.172
log Stage-2 directed pot selectivity 1978-2008	-0.091	0.123
log Stage-1 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.068	0.067
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.000	0.000
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.000	0.000
OFL	0.911	0.175

Table 14: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the 'add CV pot' (19.2) model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.860	0.206
$\log(\bar{R})$	14.216	0.053
$\log(n^0_1)$	14.962	0.174
$\log(n^0_2)$	14.482	0.211
$\log(n^0_3)$	14.313	0.205
q_{pot}	2.135	0.445
$\log(\bar{F}^{\mathrm{df}})$	-2.359	0.055
$\log(\bar{F}^{\mathrm{tb}})$	-9.656	0.079
$\log(\bar{F}^{\mathrm{fb}})$	-8.355	0.079
log Stage-1 directed pot selectivity 1978-2008	-0.784	0.179
log Stage-2 directed pot selectivity 1978-2008	-0.423	0.130
log Stage-1 directed pot selectivity 2009-2017	-0.902	0.178
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.369	0.063
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-1.064	0.122
log Stage-2 ADF&G pot selectivity	-0.134	0.074
log add CV_{pot}	-0.351	0.144
F_{OFL}	0.147	0.018
OFL	427.429	99.801

Table 15: Comparisons of parameter estimates for the model scenarios.

Parameter	Ref	FitSurvey	addCVpot
$\log(\bar{F}^{\mathrm{df}})$	-2.159	-2.921	-2.359
$\log(\bar{F}^{\mathrm{fb}})$	-8.154	-8.993	-8.355
$\log(\bar{F}^{\mathrm{tb}})$	-9.457	-10.000	-9.656
$\log(\bar{R})$	13.912	14.233	14.216
$\log(n^0_1)$	14.963	15.288	14.962
$\log(n^0_2)$	14.532	15.065	14.482
$\log(n^0_3)$	14.349	14.844	14.313
F_{OFL}	0.050	0.000	0.147
q_{pot}	3.733	1.399	2.135
log Stage-1 ADF&G pot selectivity	-0.713	-0.000	-1.064
log Stage-1 directed pot selectivity 1978-2008	-0.804	-0.485	-0.784
log Stage-1 directed pot selectivity 2009-2017	-0.470	-0.000	-0.902
log Stage-1 NMFS trawl selectivity	-0.309	-0.068	-0.369
log Stage-2 ADF&G pot selectivity	-0.000	-0.000	-0.134
log Stage-2 directed pot selectivity 1978-2008	-0.436	-0.091	-0.423
log Stage-2 directed pot selectivity 2009-2017	-0.000	-0.000	-0.000
log Stage-2 NMFS trawl selectivity	-0.000	-0.000	-0.000
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.582	1.746	1.860
OFL	57.464	0.911	427.429

Table 16: Comparisons of data weights, SDNR and MAR (standard deviation of normalized residuals and median absolute residual) values for the model scenarios.

Component	model 19.0 (ref)	model 19.1 (fit survey)	model 19.2 (add CV pot)
NMFS trawl survey weight	1.00	1.50	1.00
ADF&G pot survey weight	1.00	2.00	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	1.00
SDNR NMFS trawl survey	1.66	2.24	1.42
SDNR ADF&G pot survey	4.36	6.64	8.32
SDNR directed pot LF	0.70	1.03	0.64
SDNR NMFS trawl survey LF	1.30	1.80	1.03
SDNR ADF&G pot survey LF	0.95	2.83	0.67
MAR NMFS trawl survey	1.35	1.52	1.18
MAR ADF&G pot survey	2.76	3.42	4.07
MAR directed pot LF	0.52	0.64	0.36
MAR NMFS trawl survey LF	0.60	0.84	0.51
MAR ADF&G pot survey LF	0.65	1.99	0.56

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 assumed variances are modified (e.g., **Fit surveys** model).

Component	19.0 (ref)	19.1 (fit survey)	19.2 (add CV pot)
Pot Retained Catch	-68.46	-66.12	-69.56
Pot Discarded Catch	5.15	30.71	3.20
Trawl bycatch Discarded Catch	-7.71	5.29	-7.71
Fixed bycatch Discarded Catch	-7.67	-7.68	-7.70
NMFS Trawl Survey	10.56	66.22	-7.87
ADF&G Pot Survey CPUE	85.62	219.49	6.30
Directed Pot LF	-103.93	-93.25	-105.46
NMFS Trawl LF	-252.96	-189.41	-276.80
ADF&G Pot LF	-91.09	-39.04	-97.37
Recruitment deviations	58.10	69.65	52.25
F penalty	9.66	9.66	9.66
M penalty	6.46	6.46	6.46
Prior	13.71	13.71	16.20
Total	-342.55	25.71	-478.40
Total estimated parameters	144.00	144.00	145.00

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 2017**.

Year	n_1	n_2	n_3	MMB	CV MMB
1978	3149901	2026113	1691808	4627	0.177
1979	4406952	2386335	2320120	6531	0.123
1980	3777269	3285078	3513392	10382	0.083
1981	1439121	3229331	4921922	10816	0.063
1982	1622786	1836080	4944197	7698	0.072
1983	821366	1450607	3510769	4623	0.099
1984	671941	865303	2019469	3097	0.124
1985	943457	630172	1441282	2736	0.143
1986	1387169	717248	1221156	2678	0.139
1987	1347381	1004912	1314785	3161	0.127
1988	1251503	1076403	1524571	3450	0.123
1989	2889898	1044524	1679883	3943	0.118
1990	1869765	1956051	1979670	5042	0.093
1991	1933011	1669653	2453269	5049	0.094
1992	2082017	1589639	2406643	5216	0.086
1993	2341075	1662864	2511682	5447	0.078
1994	1585169	1823739	2578928	5186	0.073
1995	1852864	1441917	2463118	5033	0.074
1996	1740308	1479903	2356653	4813	0.076
1997	902302	1427751	2278132	4172	0.096
1998	639111	928069	1850726	2741	0.112
1999	372911	318597	713616	1693	0.105
2000	414886	317064	791944	1838	0.087
2001	376659	340465	860780	1993	0.079
2002	131970	326484	926346	2099	0.074
2003	297533	182946	950670	1982	0.075
2004	213183	229387	914205	1968	0.074
2005	475801	196960	899501	1903	0.075
2006	721959	335307	895860	2051	0.077
2007	456687	520406	985267	2397	0.077
2008	852808	425832	1113937	2560	0.062
2009	597966	624587	1225354	2600	0.058
2010	574487	535464	1292414	2136	0.060
2011	436291	474745	1108376	1500	0.073
2012	214022	361716	768850	913	0.115
2013	241596	206596	463647	1049	0.103
2014	151449	205539	514426	983	0.111
2015	167400	149336	481170	936	0.112
2016	268617	142863	469732	991	0.109
2017	163496	199675	489663	1086	0.108
2018	122409	158548	524010	1053	0.105

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 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).

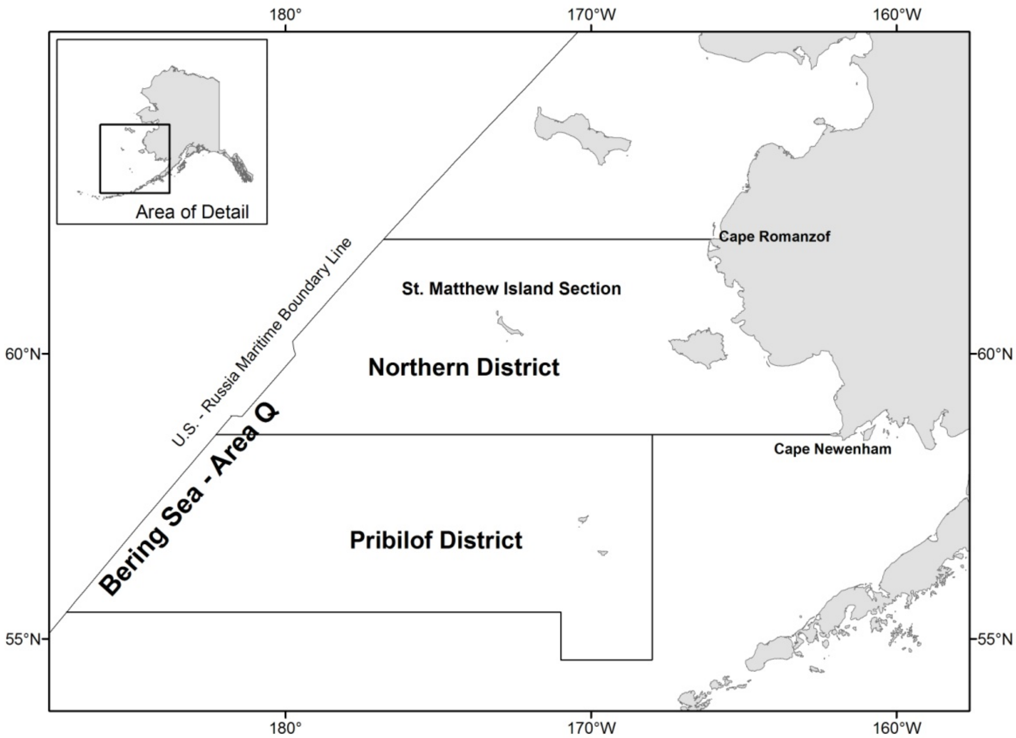


Figure 2: Blue king crab Registration Area Q (Bering Sea)

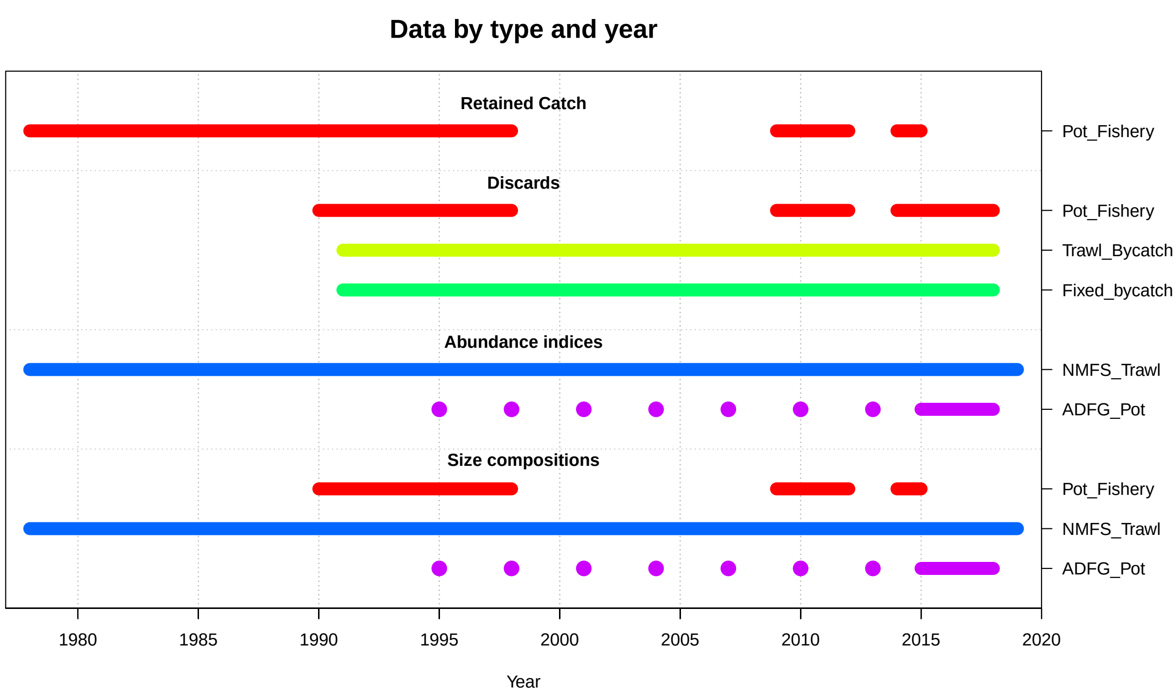


Figure 3: Data extent for the SMBKC assessment.

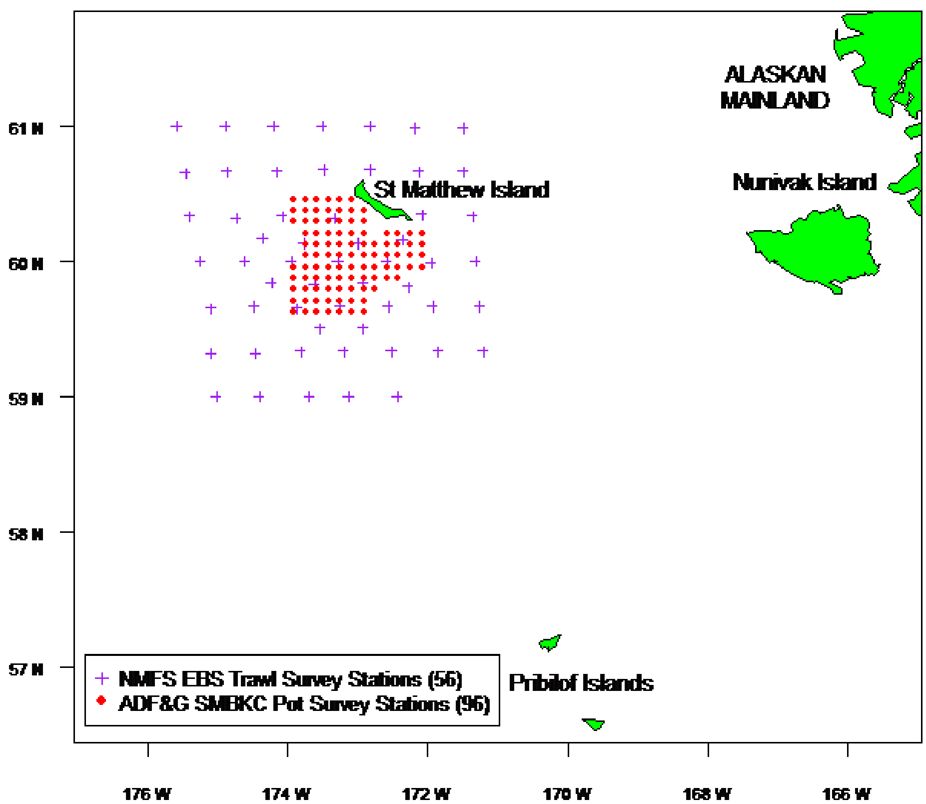


Figure 4: Trawl and pot-survey stations used in the SMBKC stock assessment.

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.

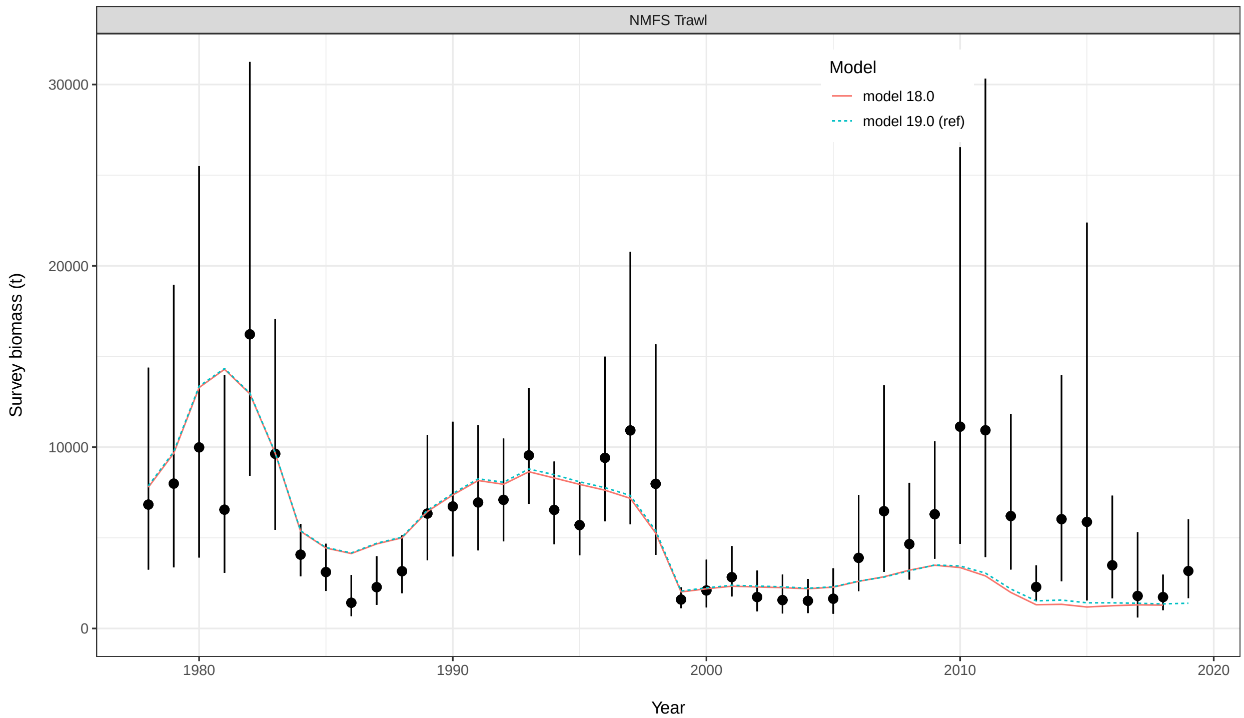


Figure 6: Fits to NMFS area-swept trawl estimates of total (/*ge* 90mm) male survey biomass with the addition of new data (the Reference Model is with new data, 2018 Model is last year's accepted model). Error bars are plus and minus 2 standard deviations.

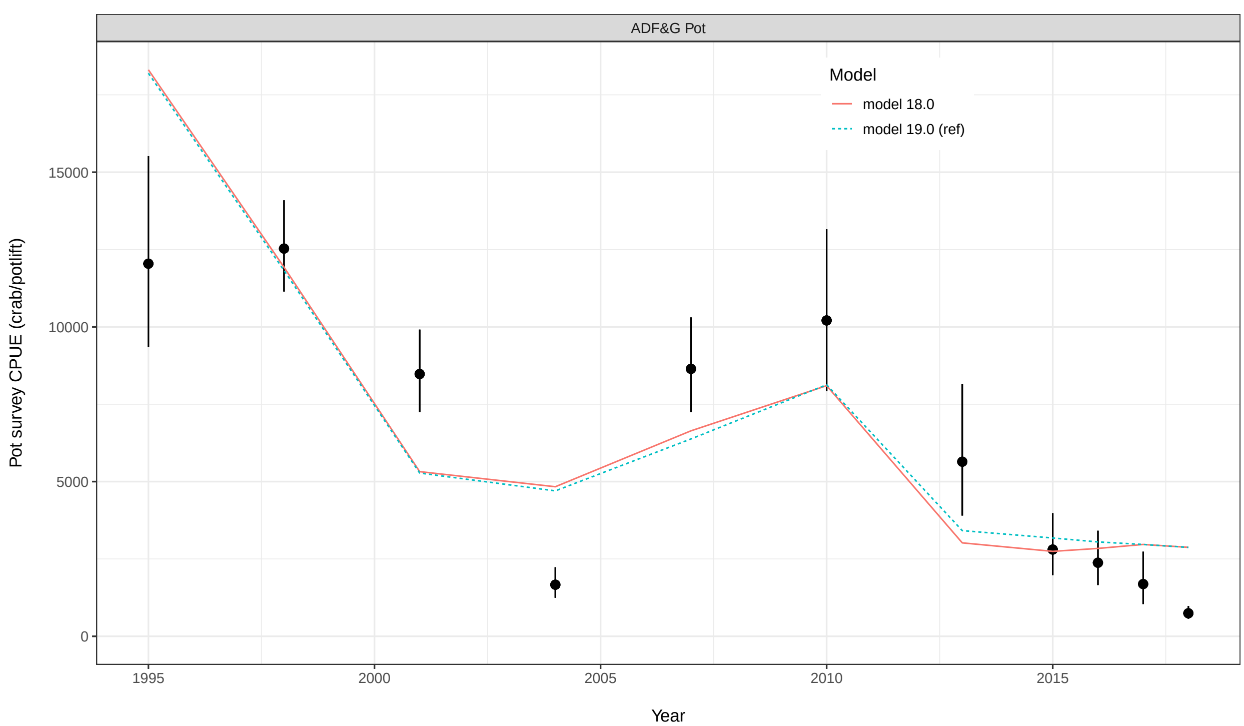


Figure 7: Comparisons of fits to CPUE from the ADF&G pot surveys with the addition of new data (note that there is no new pot data for 2019). Error bars are plus and minus 2 standard deviations.

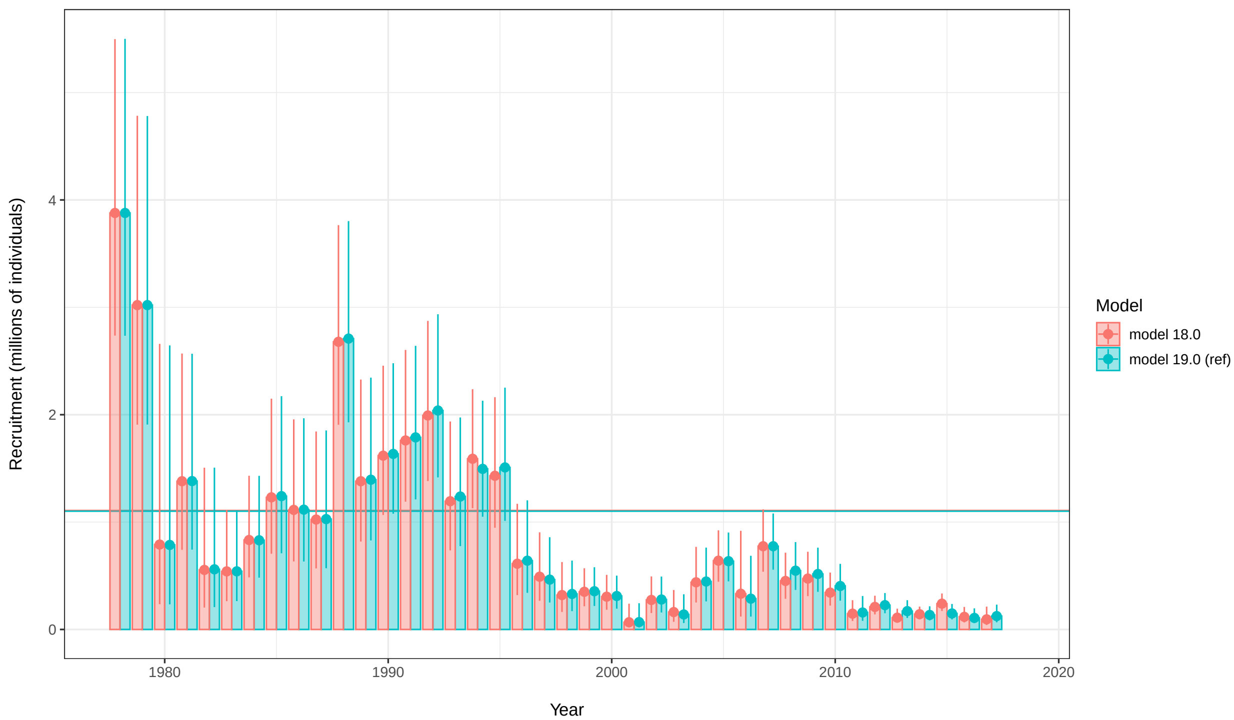


Figure 8: Sensitivity of new data in 2019 on estimated recruitment ; 1978-2017.

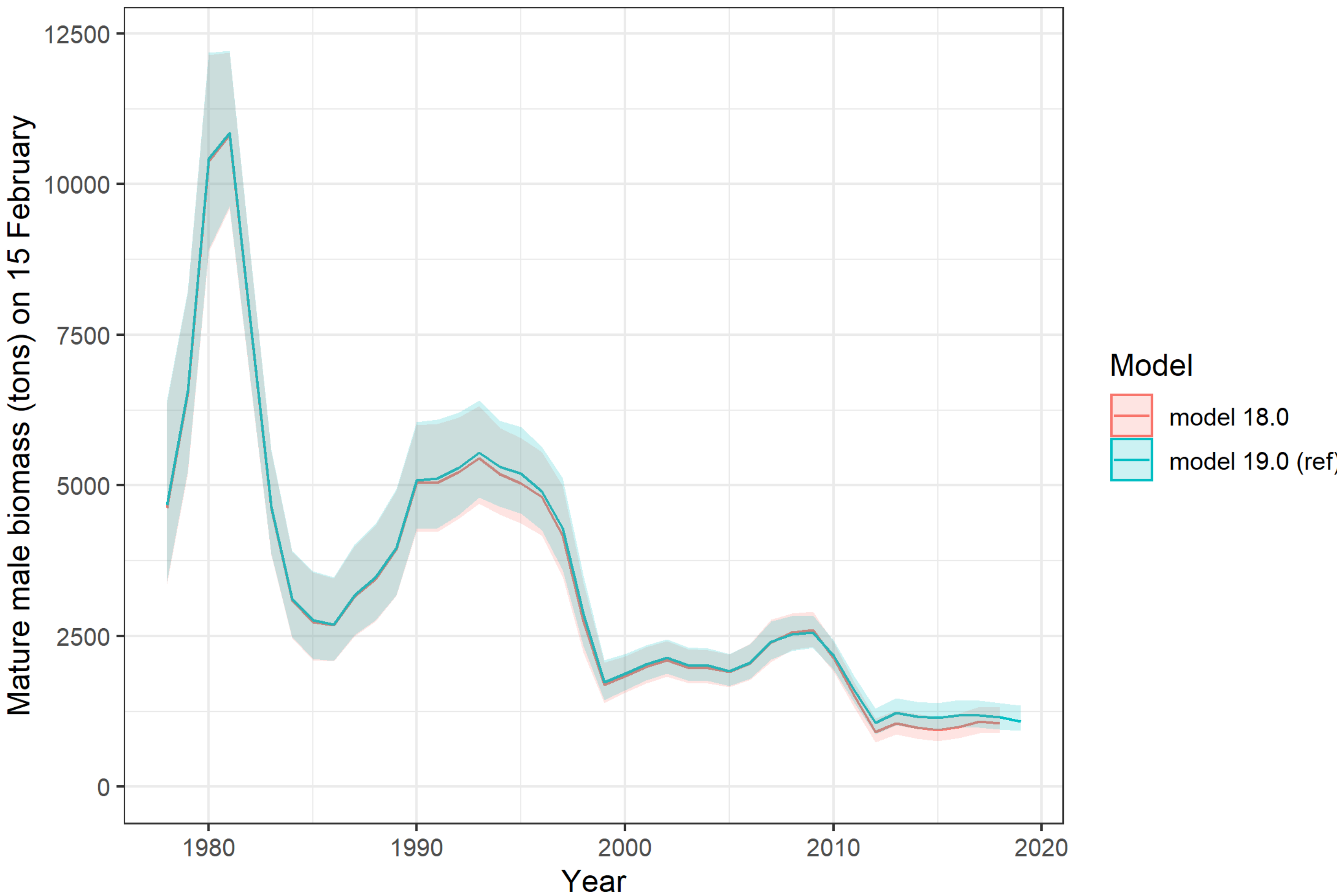


Figure 9: Sensitivity of new data in 2019 on estimated mature male biomass (MMB); 1978-2019.

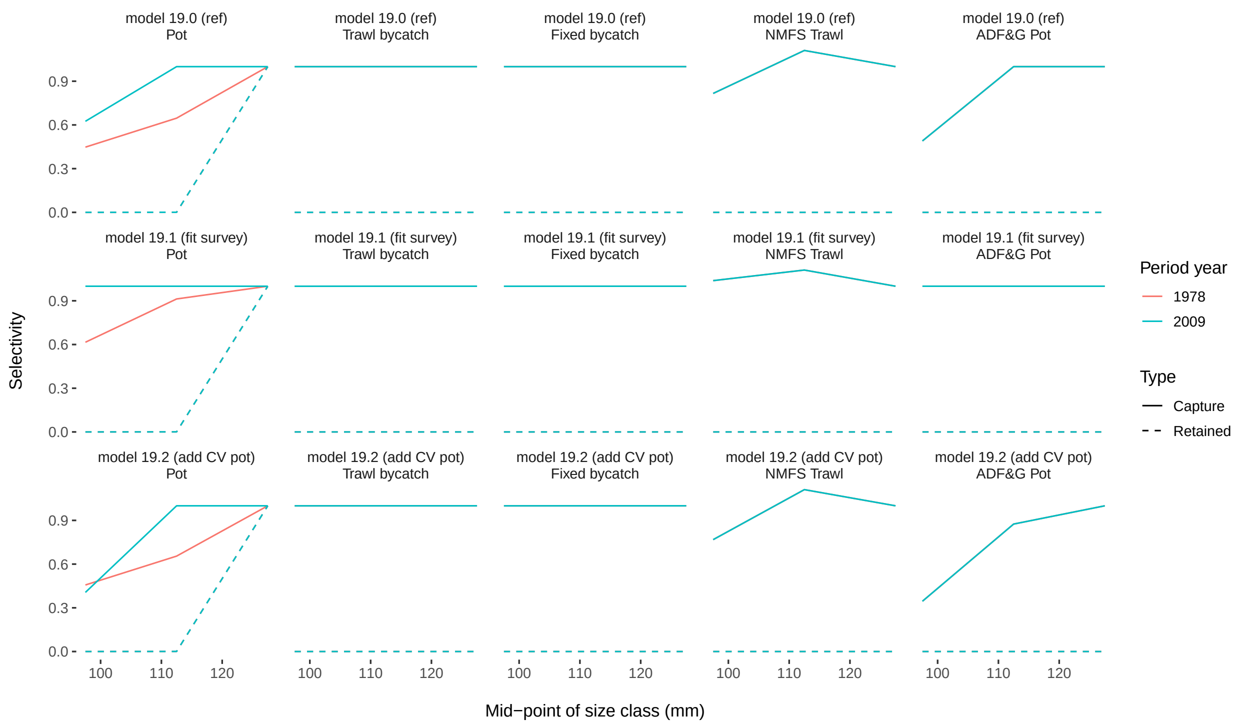


Figure 10: Comparisons of the estimated stage-1 and stage-2 selectivities for the different model scenarios (the stage-3 selectivities are all fixed at 1). Estimated selectivities are shown for the directed pot fishery, the trawl bycatch fishery, the fixed bycatch fishery, the NMFS trawl survey, and the ADF&G pot survey. Two selectivity periods are estimated in the directed pot fishery, from 1978-2008 and 2009-2018.

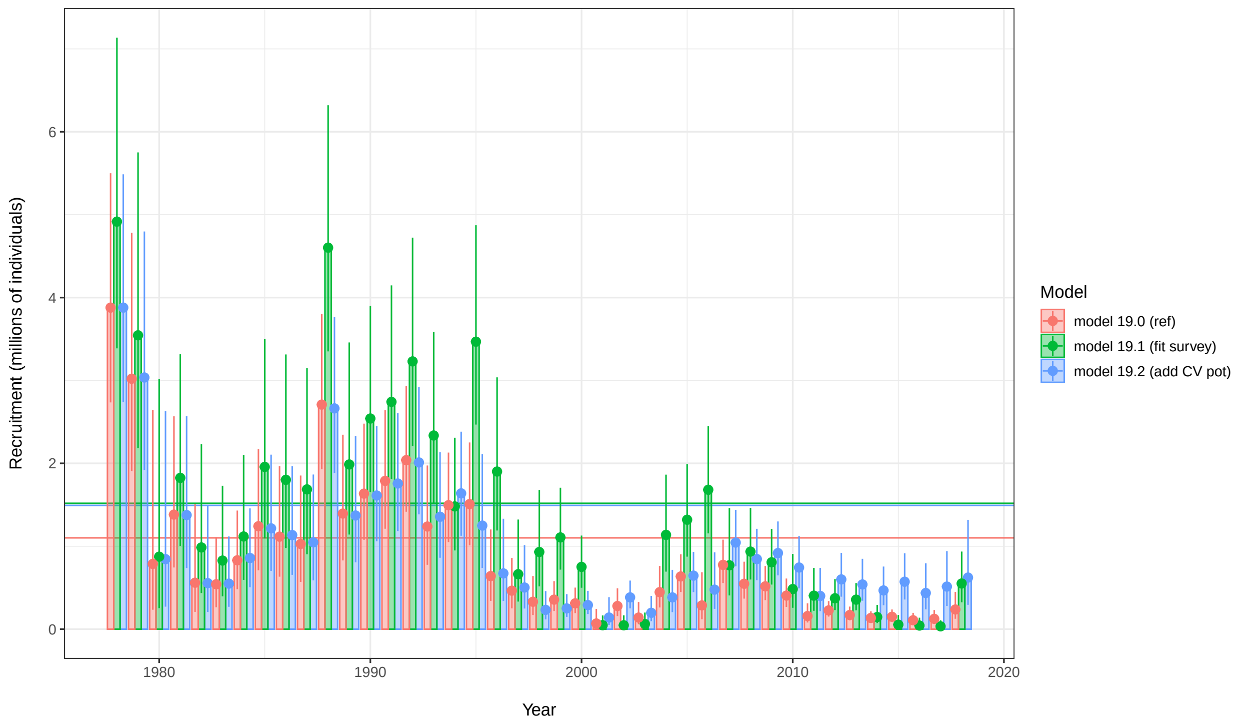


Figure 11: Estimated recruitment 1979-2018 comparing model alternatives. The solid horizontal lines in the background represent the estimate of the average recruitment parameter ($\bar{R}$) in each model scenario.

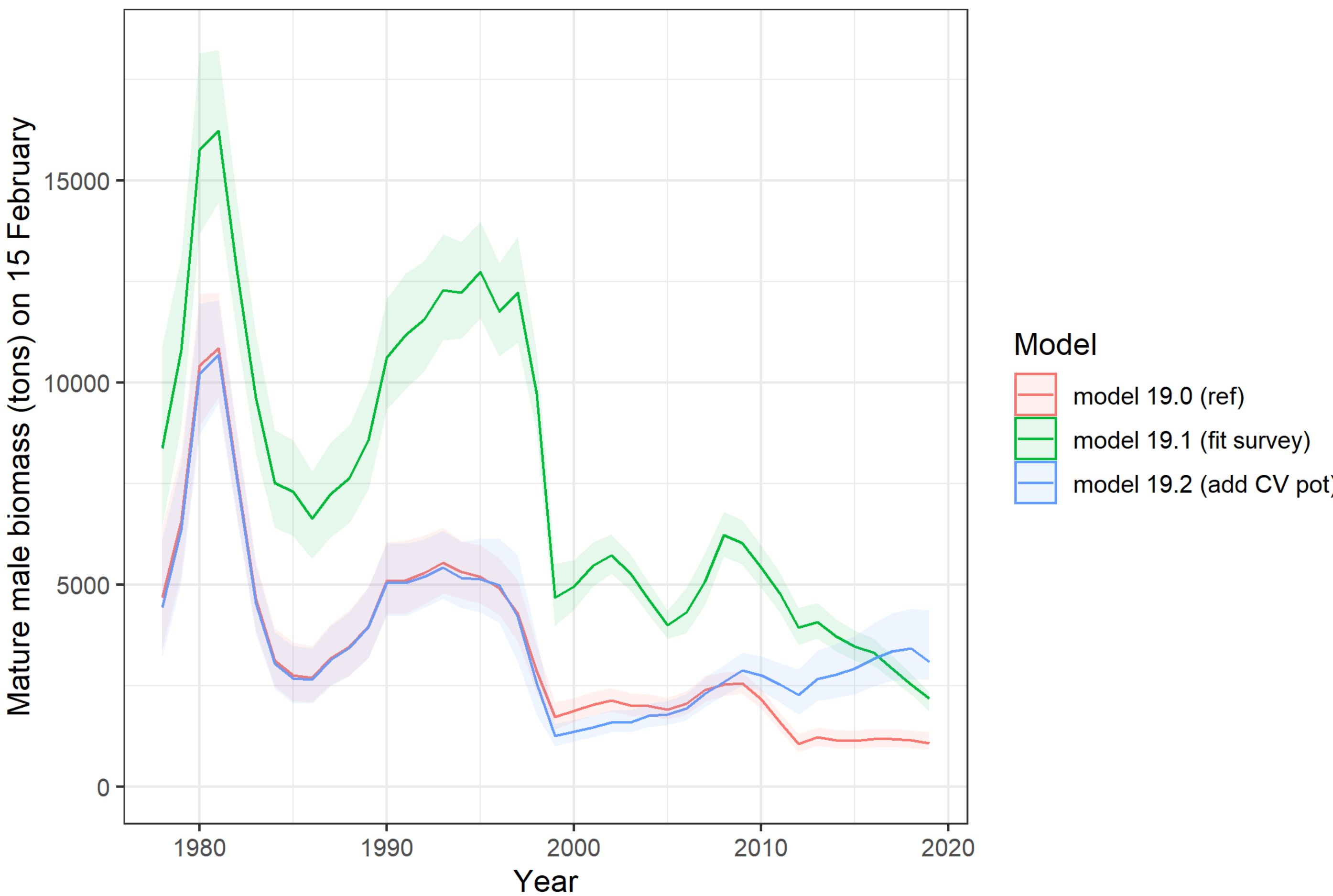


Figure 12: Comparisons of estimated mature male biomass (MMB) time series on 15 February during 1978-2019 for each of the model scenarios.

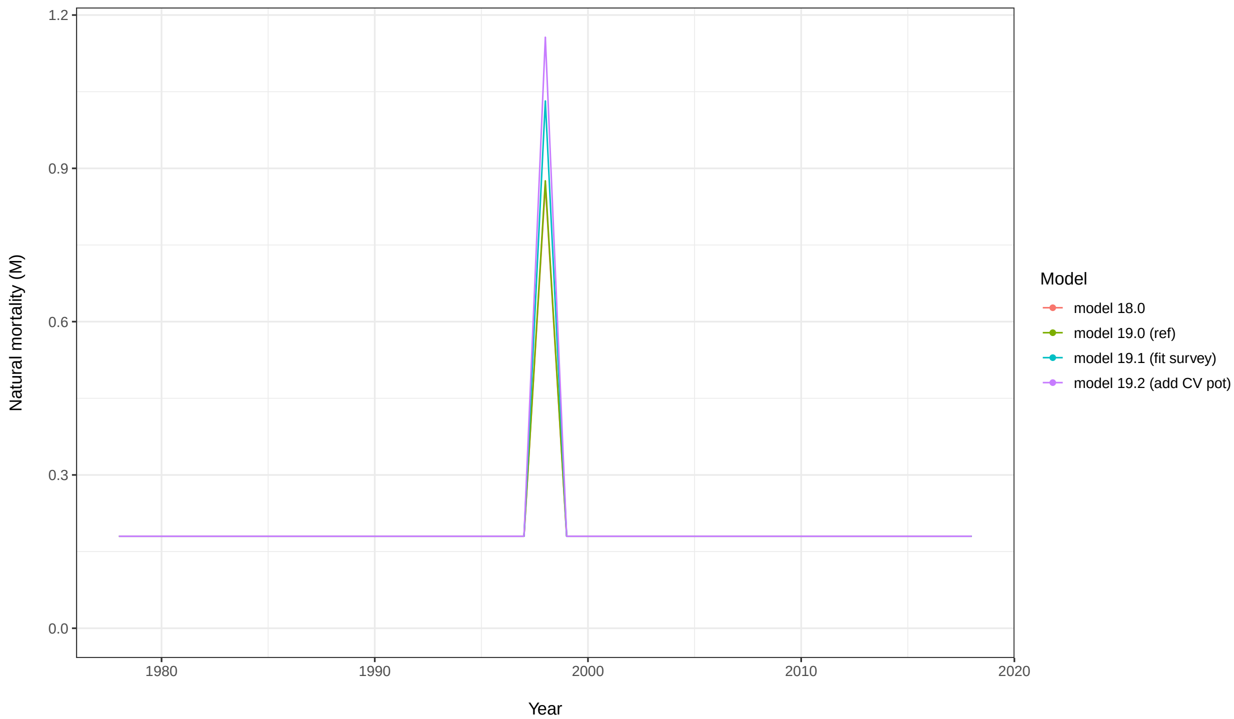


Figure 13: Time-varying natural mortality (M_t). Estimated pulse period occurs in 1998/99 (i.e. M_{1998}).

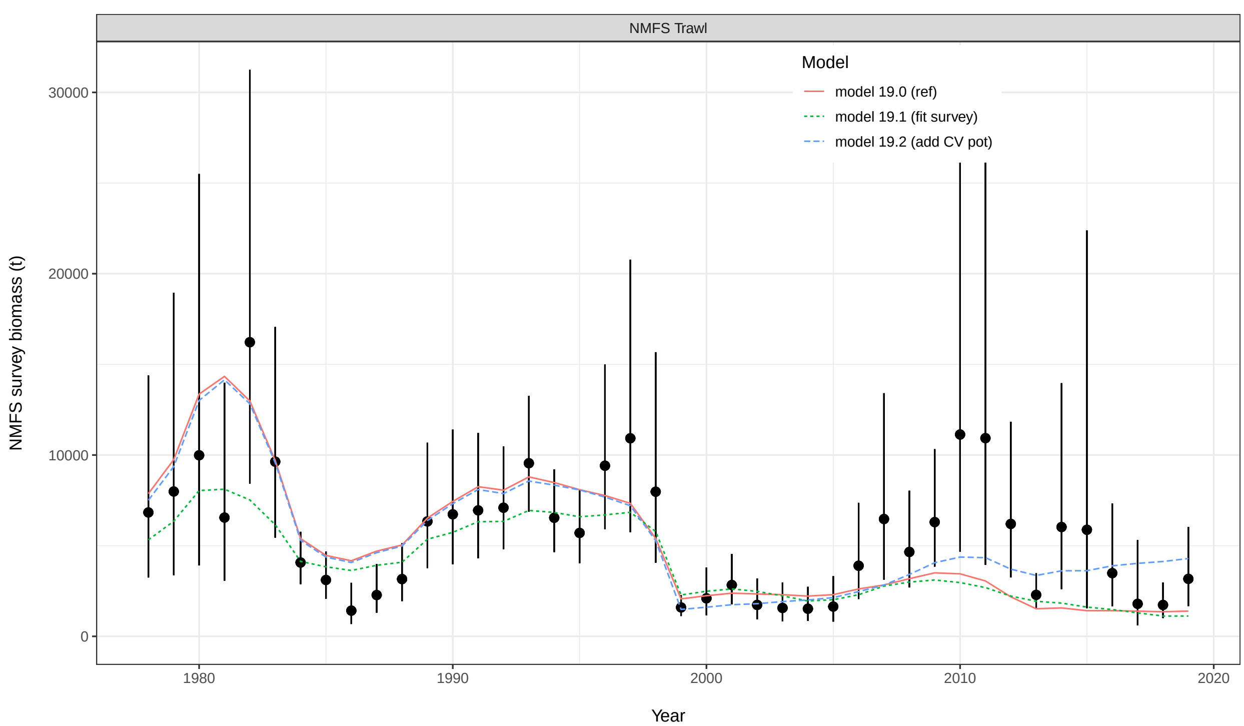


Figure 14: Comparisons of area-swept estimates of total (90+ mm CL) male survey biomass (tons) and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

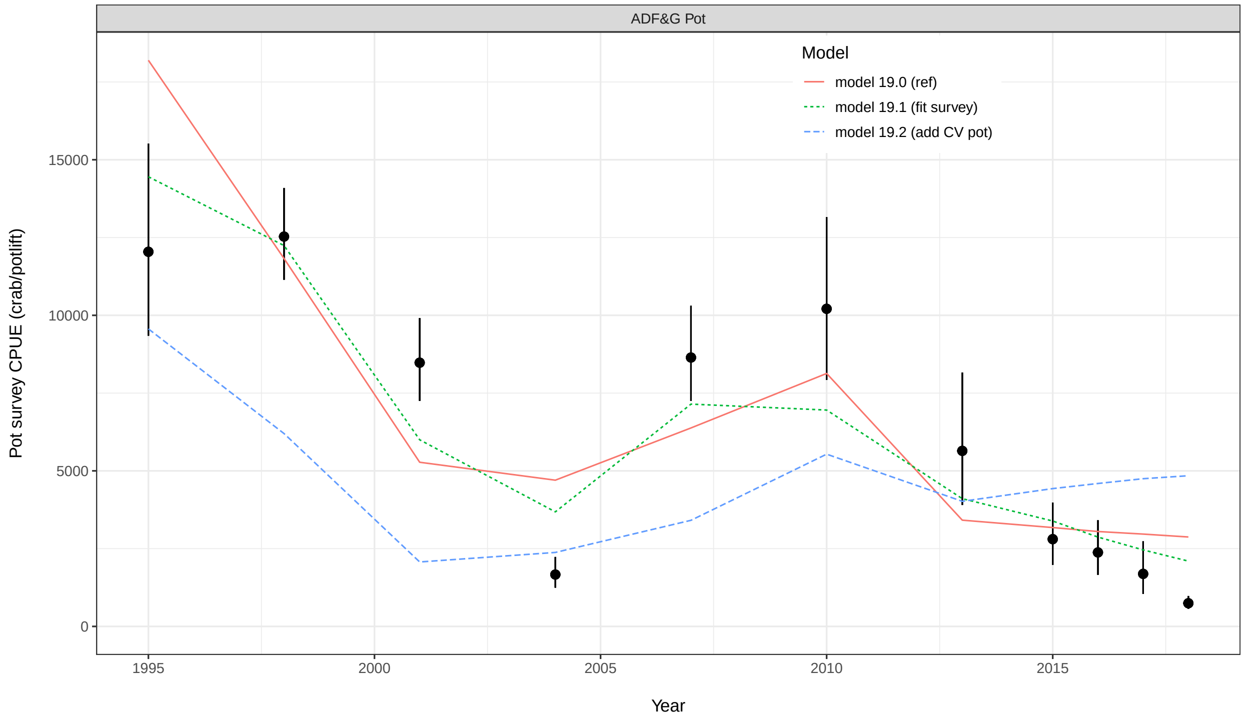


Figure 15: Comparisons of total (90+ mm CL) male pot survey CPUEs and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

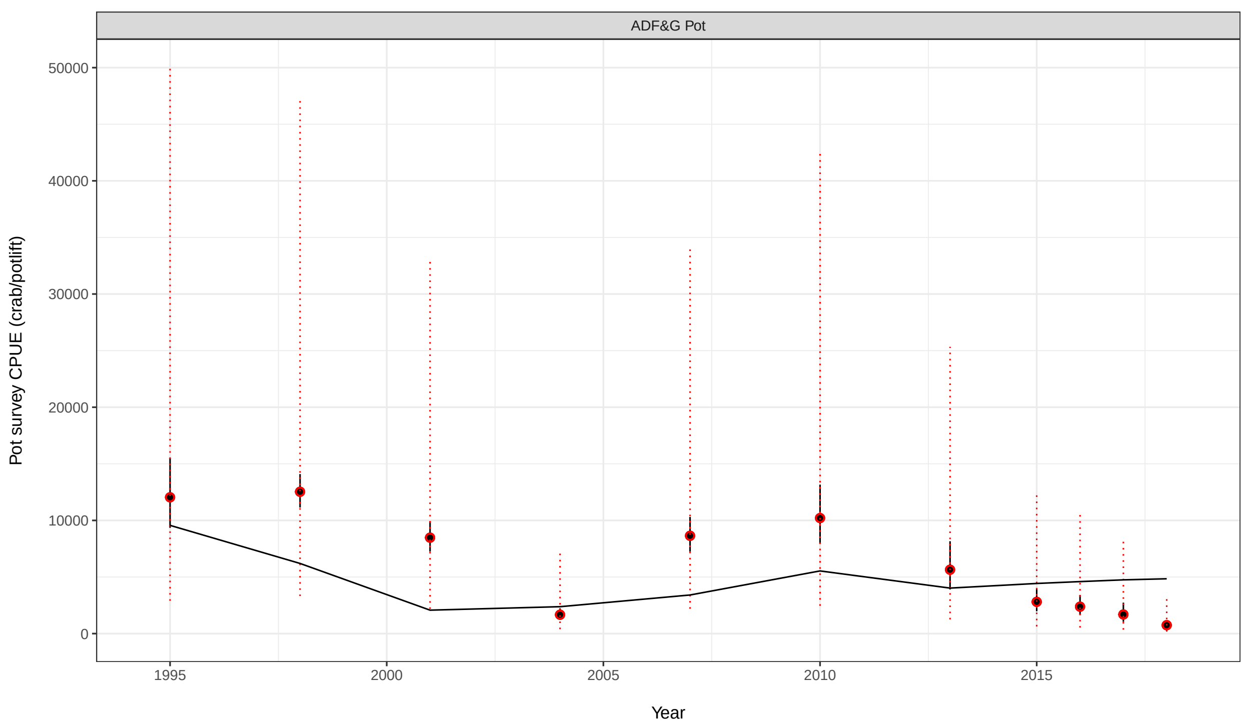


Figure 16: Comparisons of total (90+ mm CL) male pot survey CPUEs and model predictions for the ‘add CV pot’ scenario. The black error bars are plus and minus 2 standard deviations, while the red ones incorporate the additional variability .

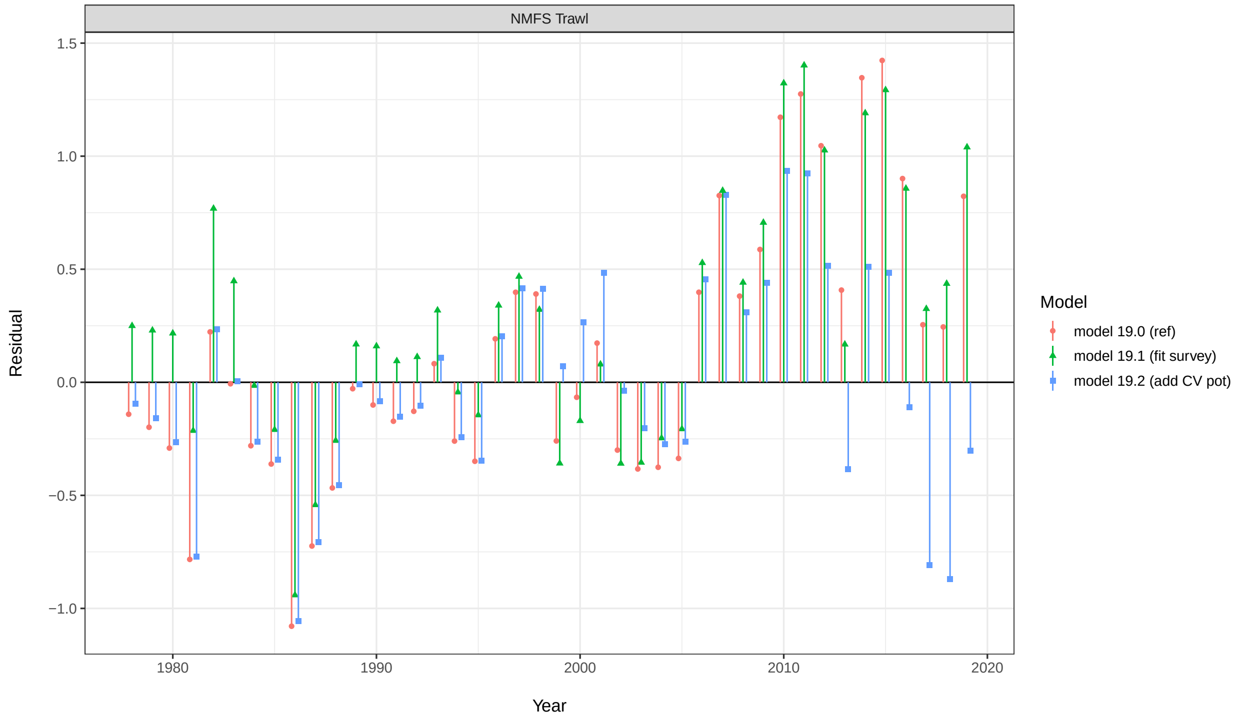


Figure 17: Standardized residuals for area-swept estimates of total male survey biomass for the model scenarios.

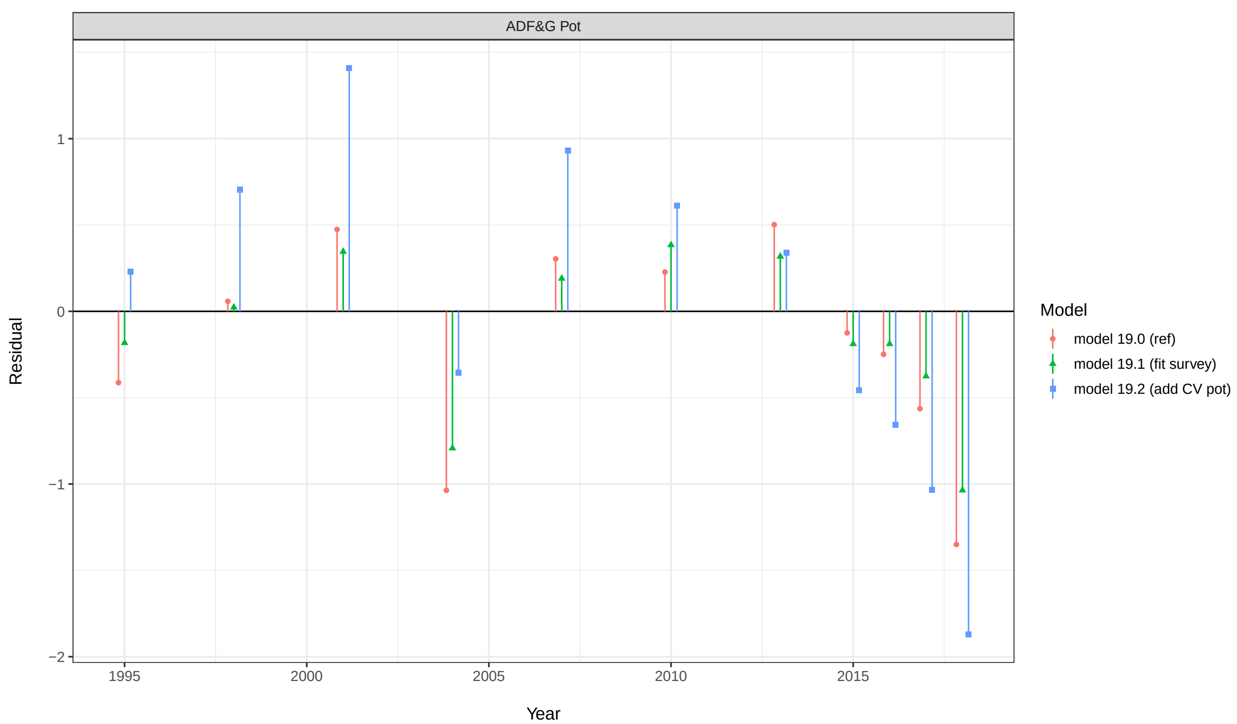


Figure 18: Standardized residuals for total male pot survey CPUEs for each of the Gmacs model scenarios.

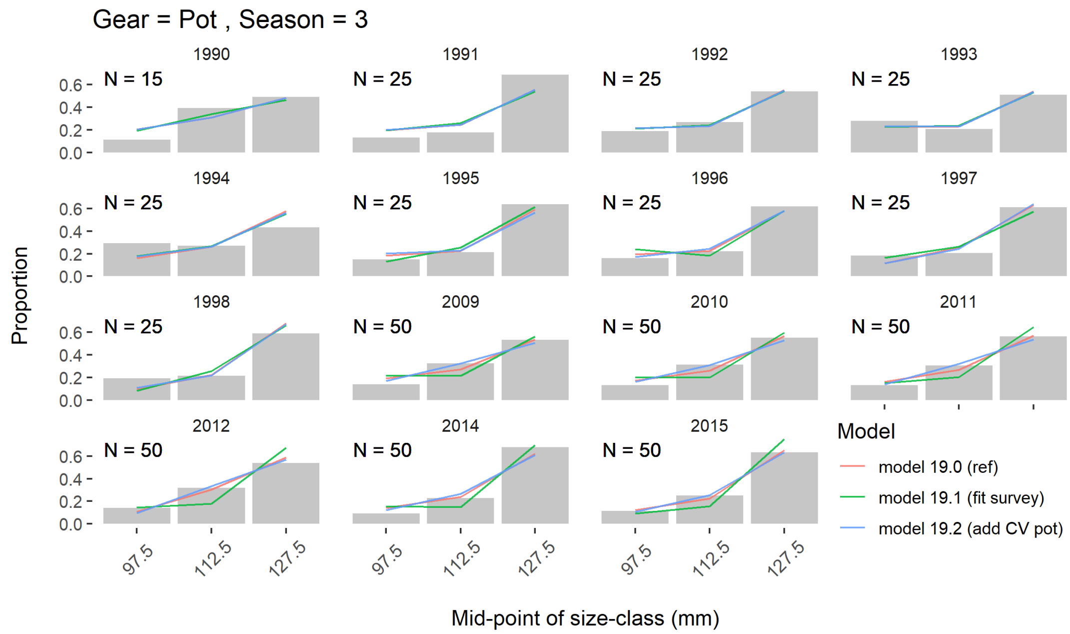


Figure 19: Observed and model estimated size-frequencies of SMBKC by year retained in the directed pot fishery for the model scenarios.

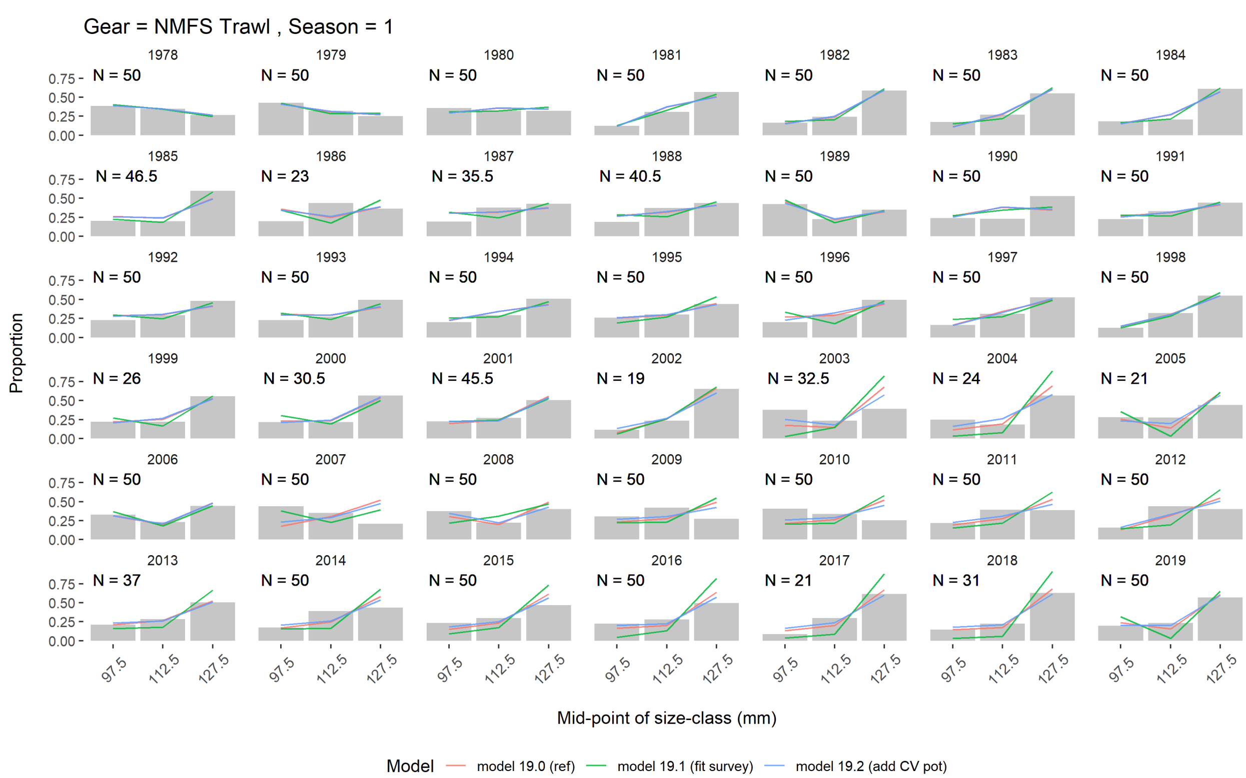


Figure 20: Observed and model estimated size-frequencies of discarded male SMBKC by year in the NMFS trawl survey for the model scenarios.

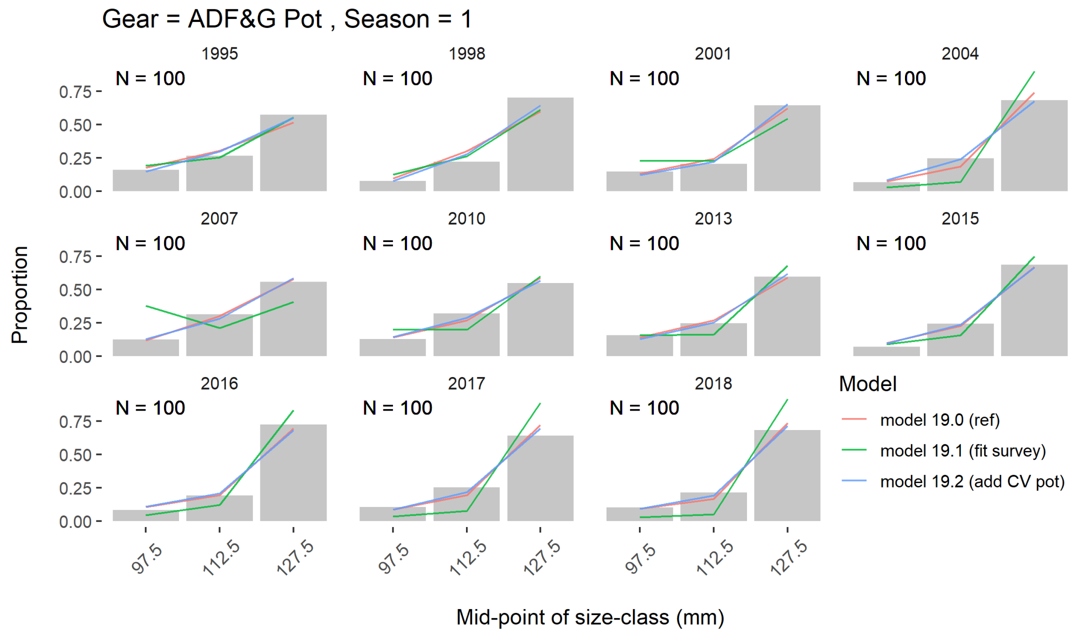


Figure 21: Observed and model estimated size-frequencies of discarded SMBKC by year in the ADFG pot survey for the model scenarios.

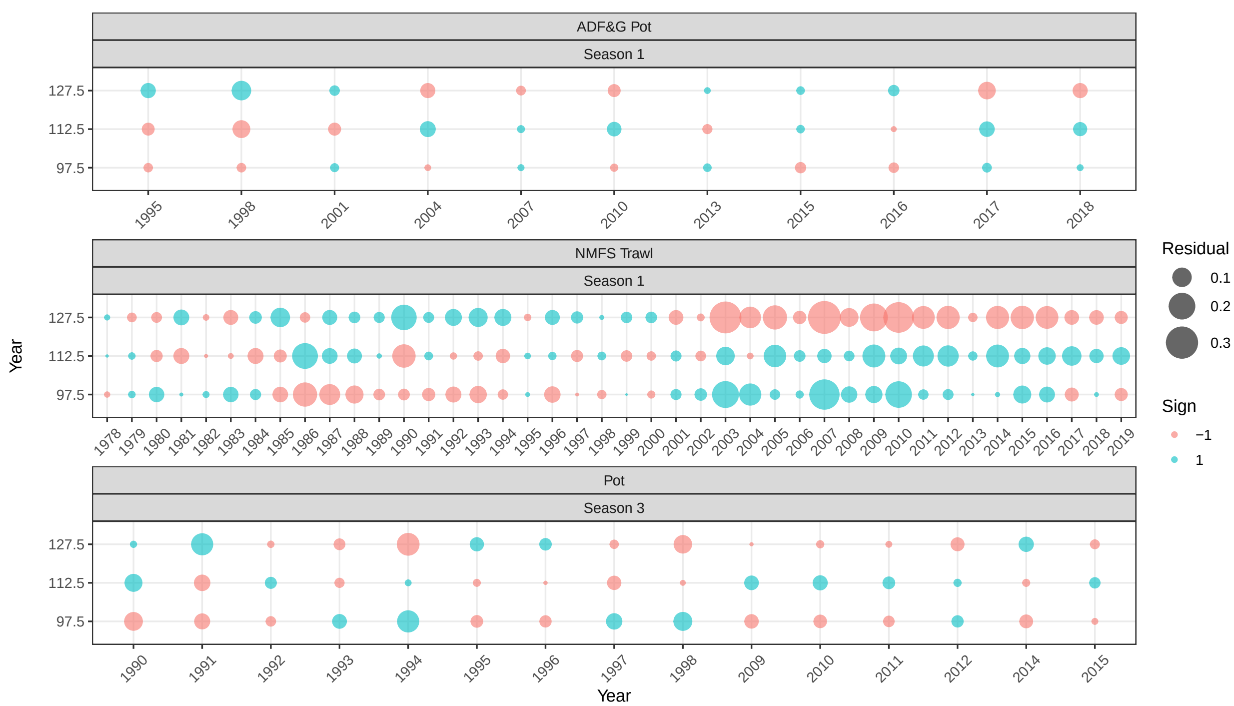


Figure 22: Bubble plots of residuals by stage and year for the all the size composition data sets (ADF&G pot survey, NMFS trawl survey, and the directed pot fishery) for SMBKC in the **reference** model (19.0).

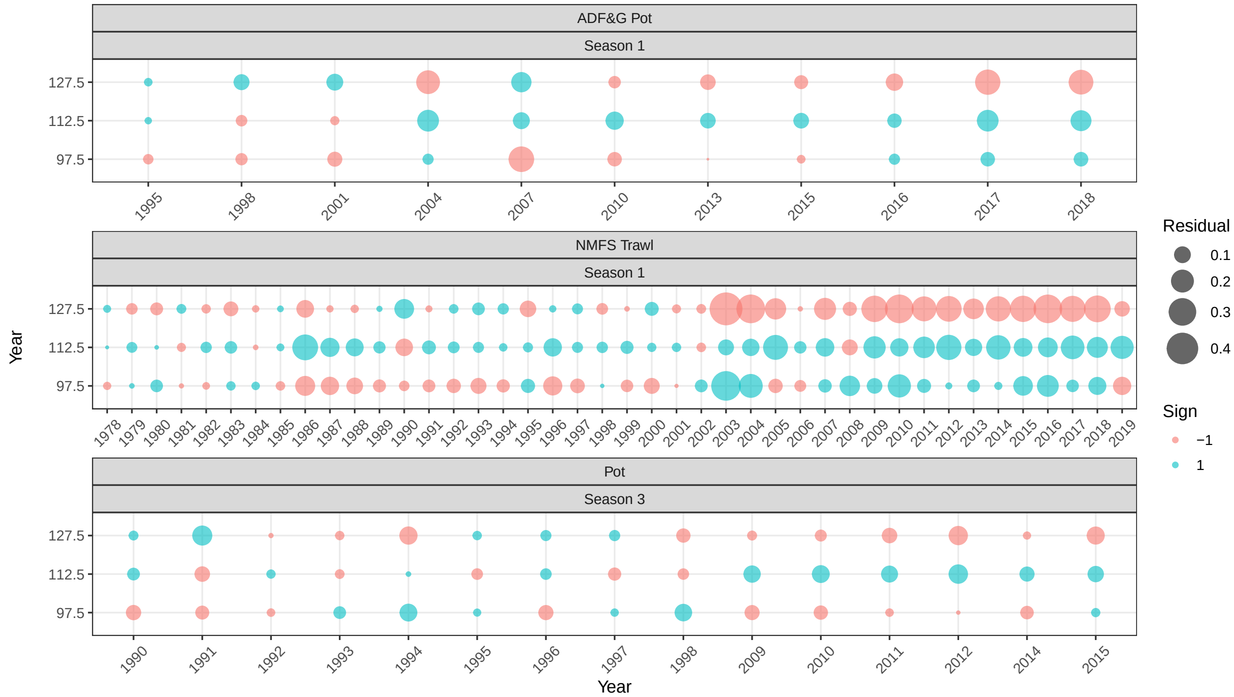


Figure 23: Bubble plots of residuals by stage and year for the all the size composition data sets (ADF&G pot survey, NMFS trawl survey, and the directed pot fishery) for SMBKC in the **fit surveys** model (19.1).

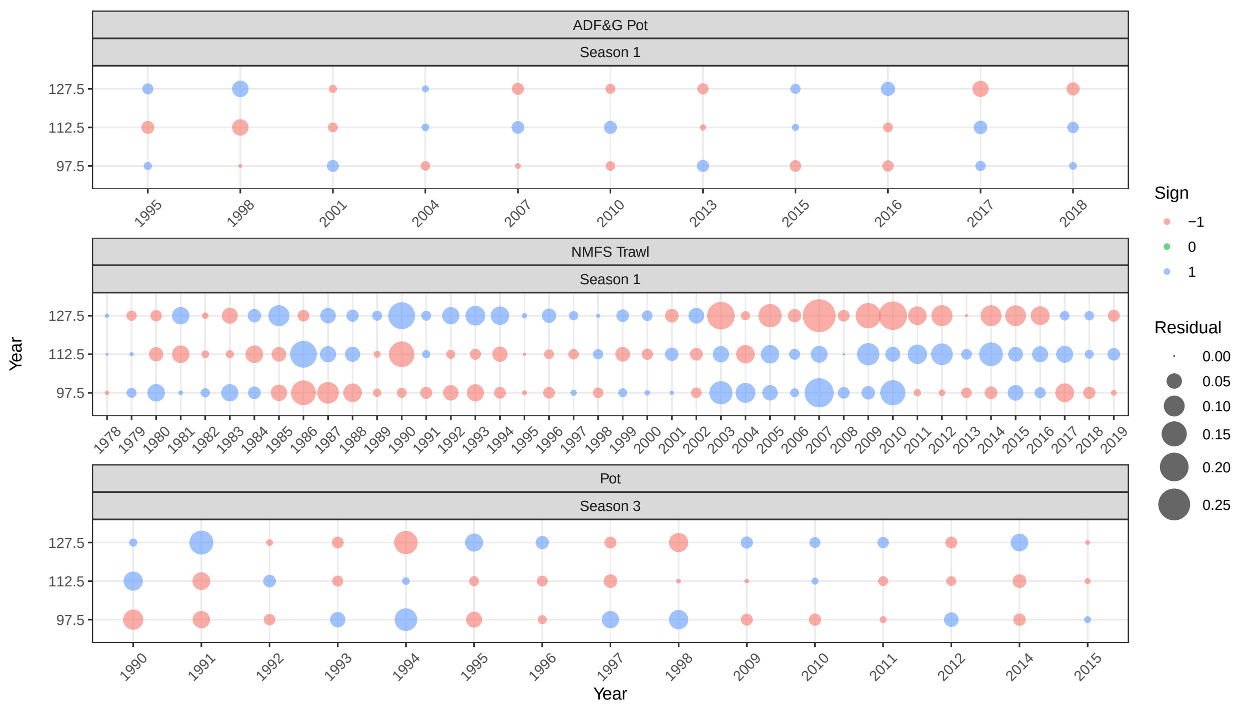


Figure 24: Bubble plots of residuals by stage and year for the all the size composition data sets (ADF&G pot survey, NMFS trawl survey, and the directed pot fishery) for SMBKC in the **add CV pot** model (19.2).

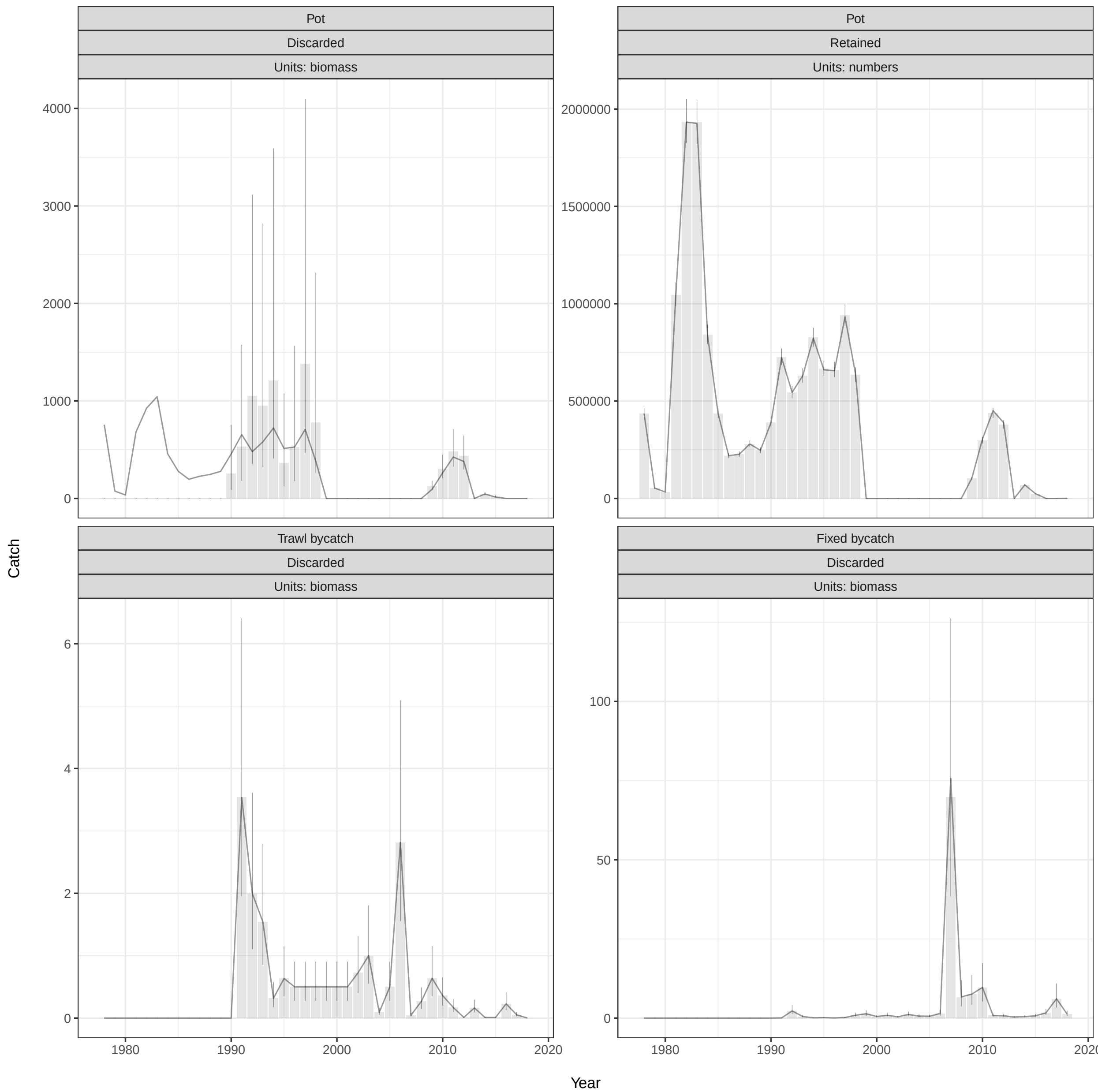


Figure 25: Comparison of observed and model predicted retained catch and bycatches in each of the Gmacs models. Note that difference in units between each of the panels, some panels are expressed in numbers of crab, some as biomass (tons).

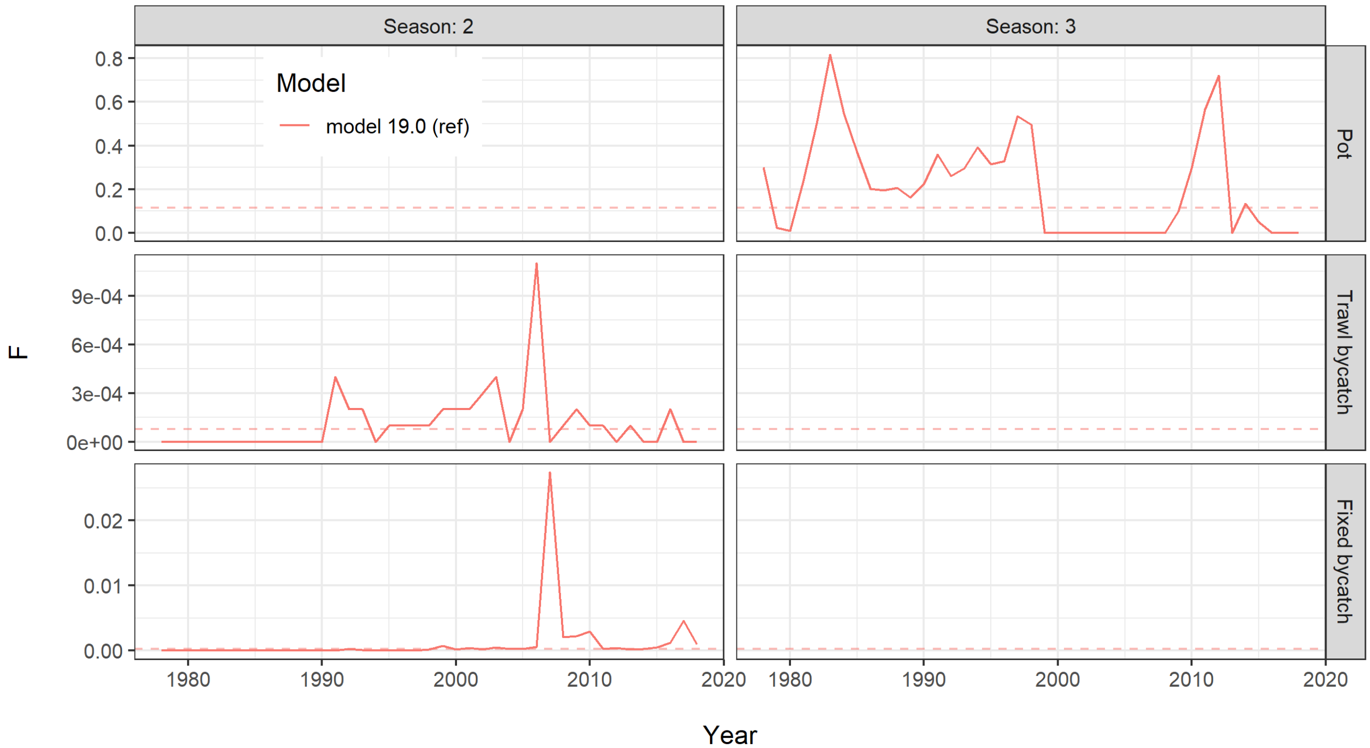


Figure 26: Fishing mortality estimates from the reference model (19.0) for directed and bycatch fleets

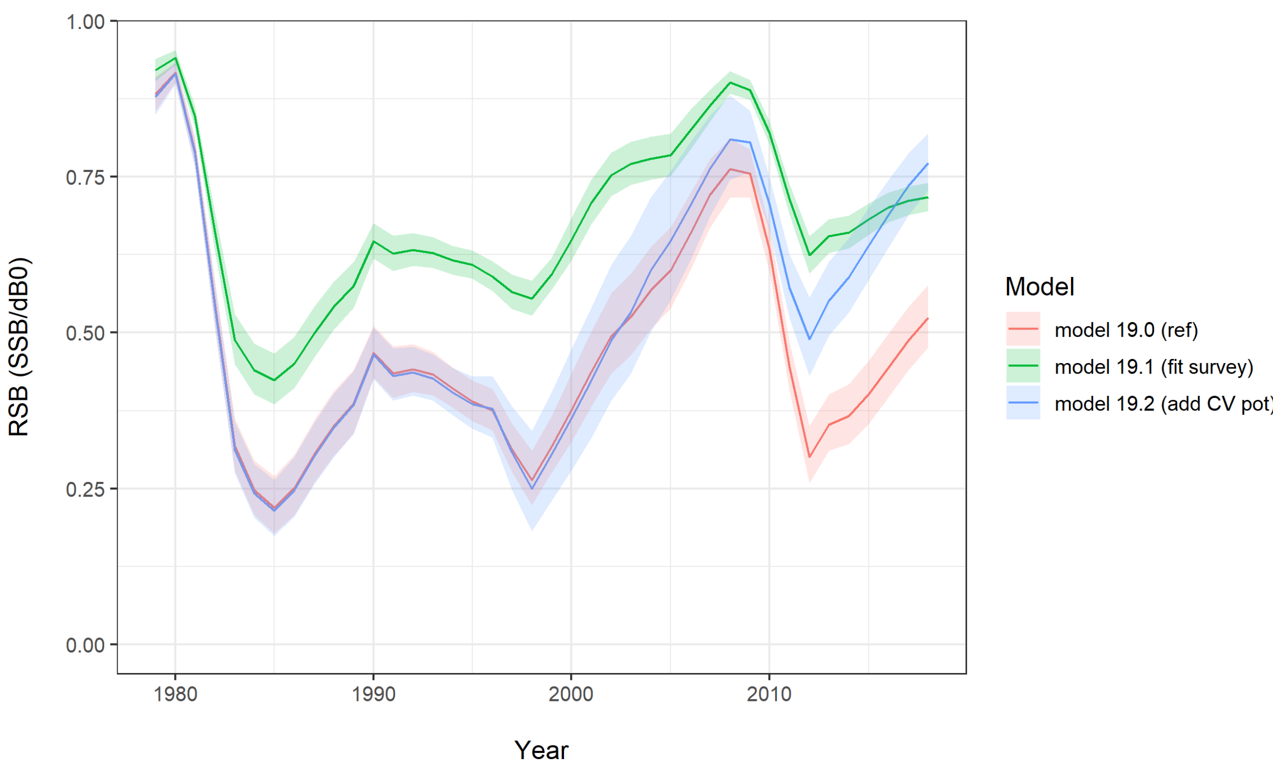


Figure 27: Comparison of mature male biomass relative to the dynamic B zero value, (15 February, 1978-2018) for each of the model scenarios.

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

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^M_{1998}	-3	0.0	3	Normal(0, σ^2_M)	4
Recruitment deviations δ^R_y	-7	0.0	7	Normal(0, σ^2_R)	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 2019

```
#=========================================================================================================
# Gmacs Main  Data  File  Version 1.1:  SM18 with all new data
# 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
2018  # 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
# 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 # (updated)
#0  0.0025  0  0.6245  0.373
# Fishing fleet names (delimited with : no spaces in names)
Pot_Fishery:Trawl_Bycatch:Fixed_bycatch
# Survey names (delimited with : no spaces in names)
NMFS_Trawl:ADFG_Pot
# 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 28  28 #(updated - all should increase 1 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   0.052   0.31    2   1   1   0   0.8
2018    2   2   1   0.001   0.31    2   1   1   0   0.8 # (updated - data is 0 but small value for placeholder)
#   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   1.633   0.31    2   1   1   0   0.5
2017    2   3   1   6.032   0.31    2   1   1   0   0.5
2018    2   3   1   1.281   0.31    2   1   1   0   0.5 # (updated - bycatch_groundfish.R)
##  RELATIVE  ABUNDANCE DATA
##  Units of abundance: 1 = biomass, 2 = numbers
##  for SMBKC Units are in  crabs for Abundance.
##  Number  of  relative  abundance indicies
2
##  Number  of  rows  in  each  index
42  11
# Survey data (abundance indices, units are mt for trawl survey and crab/potlift for pot survey)
# Year, Seas, Fleet,  Sex,  Abundance,  CV    units
1978  1 4 1 6832.819  0.394 1
1979  1 4 1 7989.881  0.463 1
1980  1 4 1 9986.830  0.507 1
1981  1 4 1 6551.132  0.402 1
1982  1 4 1 16221.933 0.344 1
1983  1 4 1 9634.250  0.298 1
```

```
1984  1 4 1 4071.218  0.179 1
1985  1 4 1 3110.541  0.210 1
1986  1 4 1 1416.849  0.388 1
1987  1 4 1 2278.917  0.291 1
1988  1 4 1 3158.169  0.252 1
1989  1 4 1 6338.622  0.271 1
1990  1 4 1 6730.130  0.274 1
1991  1 4 1 6948.184  0.248 1
1992  1 4 1 7093.272  0.201 1
1993  1 4 1 9548.459  0.169 1
1994  1 4 1 6539.133  0.176 1
1995  1 4 1 5703.591  0.178 1
1996  1 4 1 9410.403  0.241 1
1997  1 4 1 10924.107 0.337 1
1998  1 4 1 7976.839  0.355 1
1999  1 4 1 1594.546  0.182 1
2000  1 4 1 2096.795  0.310 1
2001  1 4 1 2831.440  0.245 1
2002  1 4 1 1732.599  0.320 1
2003  1 4 1 1566.675  0.336 1
2004  1 4 1 1523.869  0.305 1
2005  1 4 1 1642.017  0.371 1
2006  1 4 1 3893.875  0.334 1
2007  1 4 1 6470.773  0.385 1
2008  1 4 1 4654.473  0.284 1
2009  1 4 1 6301.470  0.256 1
2010  1 4 1 11130.898 0.466 1
2011  1 4 1 10931.232 0.558 1
2012  1 4 1 6200.219  0.339 1
2013  1 4 1 2287.557  0.217 1
2014  1 4 1 6029.220  0.449 1
2015  1 4 1 5877.433  0.770 1
2016  1 4 1 3485.909  0.393 1
2017  1 4 1 1793.760  0.599 1
2018  1 4 1 1730.742  0.281 1
2019  1 4 1 3170.467  0.337 1 # (updated - EBSsurvey_analysis.R)
1995  1 5 1 12042.000 0.130 2
1998  1 5 1 12531.000 0.060 2
2001  1 5 1 8477.000  0.080 2
2004  1 5 1 1667.000  0.150 2
2007  1 5 1 8643.000  0.090 2
2010  1 5 1 10209.000 0.130 2
2013  1 5 1 5643.000  0.190 2
2015  1 5 1 2805.000  0.180 2
2016  1 5 1 2378.000  0.186 2
2017  1 5 1 1689.000  0.250 2
2018  1 5 1  745.000  0.140 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
  ##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
##  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 2019

```
## ==================================================================================== ##
## 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

#  Use custom natural mortality  (0=no,  1=yes,  by  sex  and  year)
0

# 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 # (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 (males then females)
3
# 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
```

```
## 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)
## 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   2018
   1     2     2   0    0.4   0.001 1.0    0      0      1    3     2009   2018
   1     3     3   0    1.0   0.001 2.0    0      0      1    -2     2009   2018
# Gear-2
   2     7     1   0    40     10.0  200    0      10     200   -3     1978   2018
   2     8     2   0    60     10.0  200    0      10     200   -3     1978   2018
# Gear-3
   3     9     1   0    40     10.0  200    0      10     200   -3     1978   2018
   3    10     2   0    60     10.0  200    0      10     200   -3     1978   2018
# Gear-4
   4     11    1   0    0.7    0.001 1.0    0      0      1   4     1978   2019
   4     12    2   0    0.7    0.001 1.0    0      0      1   4     1978   2019
   4     13    3   0    0.9    0.001 1.0    0      0      1   -5     1978   2019
# Gear-5
   5     14    1   0    0.4    0.001 1.0    0      0      1   4     1978   2019
   5     15    2   0    0.7    0.001 1.0    0      0      1   4     1978   2019
   5     16    3   0    1.0    0.001 2.0    0      0      1   -2     1978   2019
## Retained
# Gear-1
  -1     17    1   0    120       50 200    0      1    900    -7     1978   2018
  -1     18    2   0    123      110 200    0      1    900    -7     1978   2018
# Gear-2
  -2     19    1   0   595    1    999    0      1    999   -3     1978   2018
# Gear-3
  -3     20    1   0   595    1    999    0      1    999   -3     1978   2018
# Gear-4
  -4     21    1   0   595    1    999    0      1    999   -3     1978   2019
# Gear-5
  -5     22    1   0   595    1    999    0      1    999   -3     1978   2019

# 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
   0.2              0.0     3.0     50.0        1    -1 # Pot
   0.0001           0.0     4.0     50.0        1    -1 # Trawl
   0.0001           0.0     4.0     50.0        1    -1 # Fixed
   0.00             0.0     2.00     20.00       -1    -1 # NMFS
   0.00             0.0     2.00     20.00       -1    -1 # ADF&G
## ================================================================================= ##

## ================================================================================= ##
## OPTIONS FOR SIZE COMPOSTION DATA (COLUMN FOR EACH MATRIX)
## ================================================================================= ##
## LIKELIHOOD OPTIONS
##   -1) Multinomial with estimated/fixed sample size
##   -2) Robust approximation to multinomial
##   -3) logistic normal (NIY)
##   -4) multivariate-t (NIY)
##   -5) Dirichlet
## AUTOTAIL COMPRESSION
##   pmin is the cumulative proportion used in tail compression.
## ================================================================================= ##
#  1   1   1  # Type of likelihood
  2   2   2  # Type of likelihood
#  5   5   5   # Type of likelihood
  0   0   0   # Auto tail compression (pmin)
  1   1   1   # Initial value for effective sample size multiplier
 -4  -4  -4   # Phz for estimating effective sample size (if appl.)
  1   2   3   # Composition aggregator
  1   1   1   # LAMBDA
  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
```

```
2018       # last rec_dev
   3       # Estimated rec_dev phase
  -3       # Estimated rec_ini phase
   0       # VERBOSE FLAG (0 = off, 1 = on, 2 = objective func)
   2       # Initial conditions (0 = Unfished, 1 = Steady-state fished, 2 = Free parameters)
   1       # Lambda (proportion of mature male biomass for SPR reference points)
   0       # Stock-Recruit-Relationship (0 = None, 1 = Beverton-Holt)
  10 # 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. Rebuilding analysis for St. Matthew blue king crab

Introduction

In 2018 the MMB for SMBKC fell below 50% of the B_{MSY} proxy or the MSST, using average mature male biomass from 1978-2017. The stock was determined to be overfished (but overfishing is not occurring since the fishery has been closes the last two years) and a rebuilding plan is to be implemented within 2 years. This document summarizes the projections performed on the 2019 assessment model and their associated rebuilding probabilities for the stock using the projections module developed for GMACS (A.Punt pers Comm). All projections presented here are performed on the base or reference model with 2019 data, results include projections that look at a alternative regime time frame for reference point calculations.

Regime shifts

Model output in 2018 (using the reference model) of both biomass and recruitment suggest a shift from higher levels in the first have of the time series to lower levels in the recent regime. These trends warranted an examination of the modeled data to determine if a regime shift has occurred.

Recruitment breakpoint analysis

Upon examination it was clear that recruitment for SMBKC has been consistently lower in recent years. Thus, the crab Plan Team requested that the authors conduct a recruitment breakpoint analysis similar to that conducted for Bristol Bay red king crab in 2017 (Zheng et al. 2017) and eastern Bering Sea Tanner crab in 2013 (Stockhausen 2013). The goal of this analysis was to objectively identify a change in stock productivity based on the recruitment time series. This could then be used to develop alternative rebuilding scenarios and also provide alternative BMSY proxies. Results from assessment model 3 from 2018, which is the base or reference model (Ianelli and Zheng 2018), were used for this analysis. These results were presented at the May 2019 crab Plan Team meeting, the details of this analysis can be found in Appendix D.

Both Ricker and Beverton-Holt (B-H) models resulted in the same breakpoint brood year of 1989, which corresponded to recruitment year of 1996. The model without a breakpoint (i.e., a single period) was about 26 times less probable than the 1989 breakpoint model for the Ricker stock-recruitment relationship and 4 times less probable than the Beverton-Holt, which suggested a possible change in stock productivity from the early high period to the recent low period.

STARS method

The "Sequential t-Test Analysis of Regime Shifts (STARS)" method was suggested as a alternative analysis that could be used to determine of the St.Matthew blue king crab stock has undergone a regime shift (Rodionov and Overland 2005). The advantage of this method is that it can be performed on any time series and does not rely on a stock recruitment relationship. This method identifies discontinuity in a time-series and allows for early detection of a regime shift and subsequent monitoring of changes in its magnitude over time (Rodionov 2004).

Detection of discontinuity is accomplished by sequentially testing whether a new mean recruitment value within a time-series represents a statistically significant deviation from the mean value of the current 'regime.' As data are added to the time-series, the hypothesis of a new 'regime' (i.e. time block) is either confirmed or rejected based on the Student's t-test (Rodionov and Overland 2005). The STARS method is well documented in the literature and has been applied previously to physical and biological indices (Mueter et al. 2007; Reid et al. 2016; Marty 2008; Conversi et al. 2010; Menberg et al. 2014; Blamey et al. 2012; Lindegren et al. 2010; Howard et al. 2007). An R script (STARS.R; Seddon et al. 2011; http://esapubs.org/archive/ecol/E095/262/suppl-1.php) that is equivalent to the v3-2 excel add-in tool (http://www. beringclimate.noaa.gov/regimes), and references the methods from Rodionov 2004 and 2006, was used to run the STARS method on the recruitment time series from the accepted 2018 model output.

Several parameters within the STARS method need specification prior to application to determine the breaks in the recruitment time series. Two parameters, the p-value (the probability level for significance between 'regime' means) and the cutoff length (the approximate minimum number of years within a regime) control the magnitude and scale of the regimes to be detected, or how strong a change in the recruitment needs to be detected. If regimes are longer than the cutoff length, they will be detected. There is a reduced probability of detection for regimes shorter than the cutoff length, but the regimes may still be detected if the shift is of sufficient magnitude (Rodionov 2004). In addition, Huber's weight parameter determines the weight assigned to outliers and thus the magnitude of the average values of each regime (Huber 1964). Finally, the user determines whether to account for autocorrelation and specifies the associated subsample size needed. For this study, a p-value of 0.05 was chosen, which is well within the range of other studies that have applied the STARS method. A range of cutoff values from 5 to 20 were specified within the STARS method to explore the sensitivity, but all values produced the same significant break year of 1996. The default value of one for Huber's weight parameter, and autocorrelation were included (Newman et al. 2003). Two frameworks are available within the STARS method to estimate autocorrelation (Rodionov 2004): the MPK (Marriott-Pope and Kendall) and the IPN4 (Inverse Proportionality with 4 corrections). The two frameworks break the time series into subsamples, estimate bias-corrected first-order autocorrelation for each subsample and then use the median value of all estimates. The two frameworks produce very similar results and only in certain instances (small subsample size) does the IPN4 method significantly outperform the MPK method (Rodionov 2004). Therefore, the IPN4 method was used in this analysis with the suggested subsample size of m=(l+1)/3, where l is the cutoff length.

This parameterization resulted in two potential time blocks: 1978-1995 and 1996–2017, corresponding to a break in 1996 which is the same year as the recruitment breakpoint analysis that was performed in May 2019.

Rebuilding projections

The rebuilding projections were performed using the projection module coded into GMACS in early 2019 (A. Punt per Comm). A preliminary analysis of the rebuilding projections performed at the January crab plan team meeting by A.Punt concluded that bycatch mortality in this fishery was minor and that the rebuilding timeline was mostly dependent on assumptions of recruitment for the stock.

Initial rebuilding projections presented at the May CPT meeting (June SSC meeting) included recruitment options of: Ricker, or Beverton-Holt stock recruit relationship and "random" recruitment. Stock-recruitment models (Ricker, Beverton-Holt) typically fit poorly for crab stocks, and this holds true for SMBKC. Projections using these stock recruitment relationships were still provided for initial review since they scale recruitment to the current status of the stock. The "random"" recruitment option resamples historical recruitment estimates randomly, from a designated period for each projection iteration, such as the entire time series 1978 to 2018 as one example. This option assumes that recruitment is unrelated to stock size, but also relies on choosing the random draws from a biologically and environmentally representative time frame of past recruitment.

Projections were performed to look at a range of combinations of recruitment, bycatch mortality, and implementation of the state harvest policy to determine the probability of recovery for each scenario. Rebuilding time under any of the projection combinations is insensitive to the average values for recent (2013 - 2017 or 2014 - 2018) bycatch. As a sensitivity analysis the projections presented here were also performed using the maximum observed bycatch value, corresponding to year 2007. The implementation of the state harvest policy in the projections (version "d") affected rebuilding times in some projections, but with a much smaller affect of increasing T_{min} than projections at F = M (0.18), therefore the projections presented here use the state of Alaska harvest policy as the upper bound for fishing mortality.

The projections considered in May produced a range of T_{min} values, however, the decision tackled at this meeting was which option is the most biologically and environmentally plausible. The recruitment breakpoint analysis and the STARS method suggested that recent recruitment (1996-2017) differed from the early part of the time series.

Both the CPT and SSC recommendations from the May meeting were to proceed with "random" recruitment projections that drew from two recruitment time periods:

1) the entire time series, 1978 to 2018
2) the current regime, 1996 to 2018

These projections use the state harvest policy as the upper fishing mortality and included average recent bycatch mortality (2014 - 2018). Additionally, sensitivity on T_{min} values to higher bycatch mortality are included to help inform the rebuilding time frame (using maximum observed bycatch in 2007, which is 10 times here than recent bycatch levels).

The important decision points that are needed to move forward with the rebuilding plan are to adapt a consensus on:

- the current state of the stock (reference point time frame),
- the corresponding expectations on future recruitment, and
- the expectations for future bycatch mortality.

Recommendations from the Sept. 2019 CPT meeting were to consider projections that were presented in May in addition to those initially presented in this document. Therefore, this document was updated to also include additional projections: projection 4 - random recruitment from recent years (1996-2018) with the current reference point time frame (1978-2018) and projection 2 - ricker stock-recruit relationship using entire time series (Tables 1 and 2).

Table 1: Projections performed with associated recruitment assumptions.

Projection	recruitment	B_{MSY} proxy	recruitment years
1	random recruitment	1978-2018	1978-2018
2	ricker	1978-2018	
4	random recruitment	1978-2018	1996-2018
5	random recruitment	1996-2018	1996-2018

Table 2: Versions for each of the projections.

Version	Bycatch mortality	SOA harvest policy
d	present (2014-2018)	yes
aa	max value (2007)	yes

Results

Bycatch mortality

Rebuilding time under any of the projection combinations is insensitive to the average values for recent (2014 - 2018) bycatch. A sensitivity analysis to larger bycatch levels was performed using the maximum observed bycatch value, corresponding to year 2007 in the model input (Figures 1 and 2).

Random recruitment entire time series (1978 - 2018)

Projections using "random" recruitment (projection 1) resampled from the entire time series (1978-2018) implied environmental conditions as being equal to this period. Under this hypothesis the probability of recovery produces, under average recent bycatch levels, a T_{min} = 6.05 years under no directed fishery mortality (F = 0), and a T_{min} = 9.0 years when the state harvest policy is implemented (Figure 3). The recruitment breakpoint analysis performed on this stock (Appendix D) suggested that recruitment conditions equal to the full period are unlikely and overly optimistic.

Random recruitment from current regime (1996 - 2018)

The recruitment breakpoint analysis suggested that a shift occurred in 1996. Both the "random" recruitment time period and the time period to calculate the B_{MSY} proxy should reflect this (Table 3). Projection 5 matches these two time frames, and under average recent bycatch levels, has a T_{min} = 9.0 years for the probability of recovery to this new/current B_{MSY} proxy under no directed fishery mortality (F = 0), and a T_{min} a little over 9.0 years under the state harvest policy implementation (Figure 4). The consistencies in these T_{min} values is due to the state harvest policy thresholds being based on past periods rather than having adopted to changes in B_{MSY} proxy years.

Projection 4 uses recruitment from the recent regime but keeps the reference point time frame for the entire time series of data (1978-2018). Although this is a mis-match of the reference point and recruitment time frame it encompasses expectations for the recruitment of the stock with respect to the environment and the current stock status (Figure 5).

Ricker stock-recruit relationship (1978 - 2018)

While the stock-recruit relationship for St. Matt's blue king crab is weak, it still provides an estimate of recruitment potential that responds to the status of the mature male biomass, therefore it is also presented here for comparison (Figure 6). The benefit of this projection is that it incorporates the stock status into the recruitment considerations without changing the time frame to draw either recruitment or the B_{MSY} proxy.

Discussion

The projections initially considered here produced T_{min} values that fell between 6 and a little over 11 years (Tables 4 and 5), however, the question remains which option is the most biologically and environmentally plausible. The recruitment breakpoint analysis (Appendix D) suggested that recent recruitment (1996-2018) differed from the early part of the time series. Recruitment success for SMBKC, as with many crab species, is driven by environmental conditions. In the Bering Sea recent environmental conditions appear to be unfavorable for recruitment success for this stock, which may be due to the longer larval duration of blue king crab.

Projections that include average recent bycatch levels have a T_{min} value less than 10 years under no directed fishing (F = 0). These values increased with maximum bycatch levels, however these projections assume that these high bycatch levels would persist annually throughout the 50 year projection. Even with increased bycatch to higher levels in some years the rebuilding time frame would not be expected to increase dramatically (Table 5).

Assuming that recent trends in recruitment and biomass represent a current environmental "regime", the most biologically and environmental plausible projection would be projection 5, which suggests the stock would rebuild in less than 10 years to a more representative B_{MSY} that is based on current recruitment conditions. However, if adjusting the reference point time frame is not considered valid the projections suggest a rebuilding time frame < 10 years to the current B_{MSY} proxy levels, with large assumptions on upcoming recruitment variability. When the reference point time frame or B_{MSY} proxy years are kept to the entire time series the probability of recovery of the stock ranges from >100 years (assuming recent recruitment) to less than 10 years if recruitment is allowed to be randomly draw from the entire time series. Overall, the CPT and the author feel that these two outlooks are more pessimistic and more optimistic, respectively, than the reality for this stock. Projection 2, which uses a stock-recruit relationship, provides some intermediate reference for T_{min}.

According to the federal rebuilding framework if T_{min} exceeds 10 years, then the method for determining a T_{max} would be defined by one of three options. These are: T_{min} plus one generation time, time to rebuild to B_{msy} if fished at 75% of MFMT, or T_{min} multiplied by two. The rough generation time calculated for this stock, assuming a recruitment age of 7 years, is approximately 14 years. The CPT entertained estimates of T_{max} that reflected these, while also stressing the important of recruitment assumptions for this stock.

Tables

Table 3: B_{MSY} proxy options for 2018 model 3, all Tier 4b.

Year	Basis for B_{MSY}	B_{MSY} proxy	MSST	Biomass(MMB_{mating})	B/B_{MSY}	F_{OFL}	M
2019/20	1978-2018	3.48	1.74	1.08	0.31	0.042	0.18
2019/20	1996-2018	2.05	1.025	1.04	0.51	0.082	0.18

Table 4: T_{min} for each projection version d with no directed fishing (F=0) and average recent bycatch.

Projection	recruitment	B_{MSY} proxy	recruitment yrs	T_{min}
1	random recruitment	1978-2018	1978-2018	6.05 years
2	ricker	1978-2018	1978-2018	14.5 years
4	random recruitment	1978-2018	1996-2018	>100 years
5	random recruitment	1996-2018	1996-2018	9.0 years

Table 5: T_{min} for each projection version aa with maximum observed bycatch.

Projection	recruitment	B_{MSY} proxy	recruitment yrs	F level	T_{min}
1	random recruitment	1978-2018	1978-2018	F = 0	6.5 years
1	random recruitment	1978-2018	1978-2018	F = SHR	11.0 years
5	random recruitment	1996-2018	1996-2018	F = 0	11.25 years
5	random recruitment	1996-2018	1996-2018	F = SHR	13.0 years

Figures

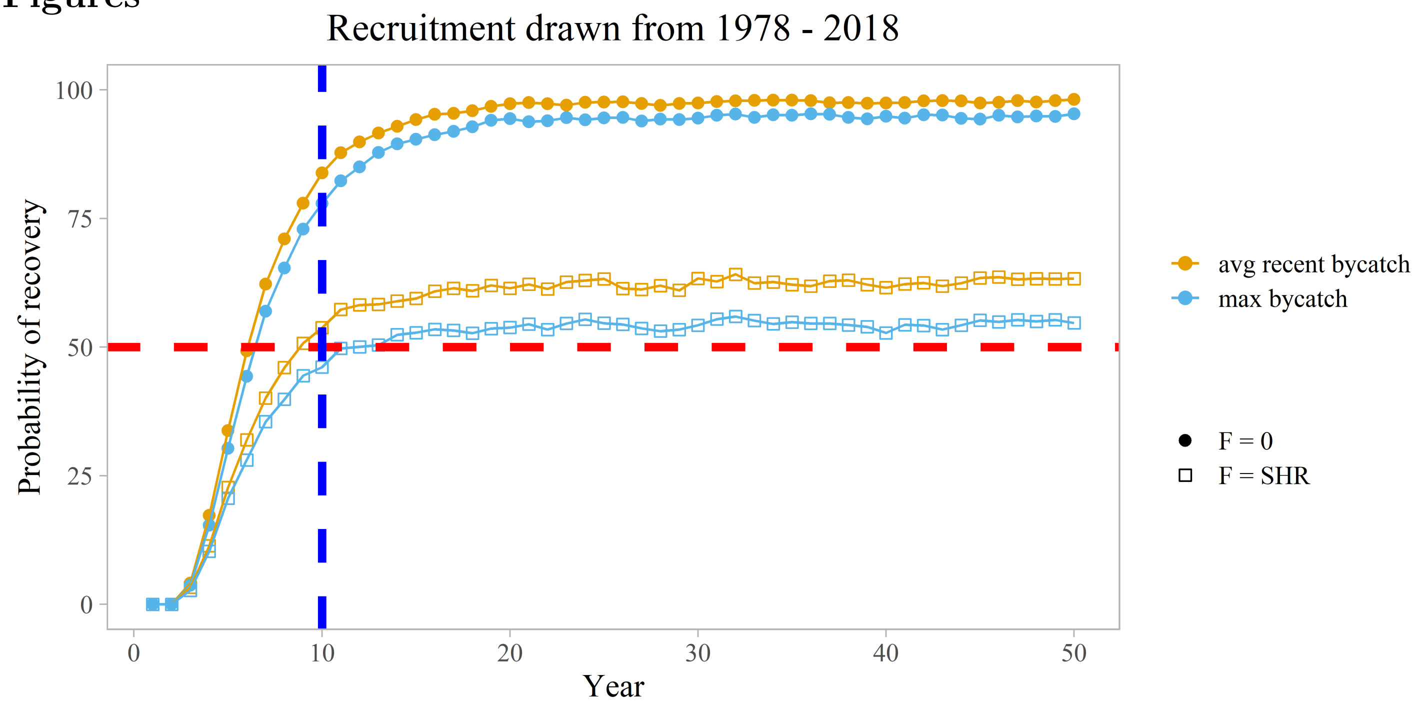


Figure 1: Comparisons of probability of recovery with random recruitment from 1978 to 2018 under different bycatch levels, show as with a min F = 0 and a max F equivalent to the state harvest rate (SHR).

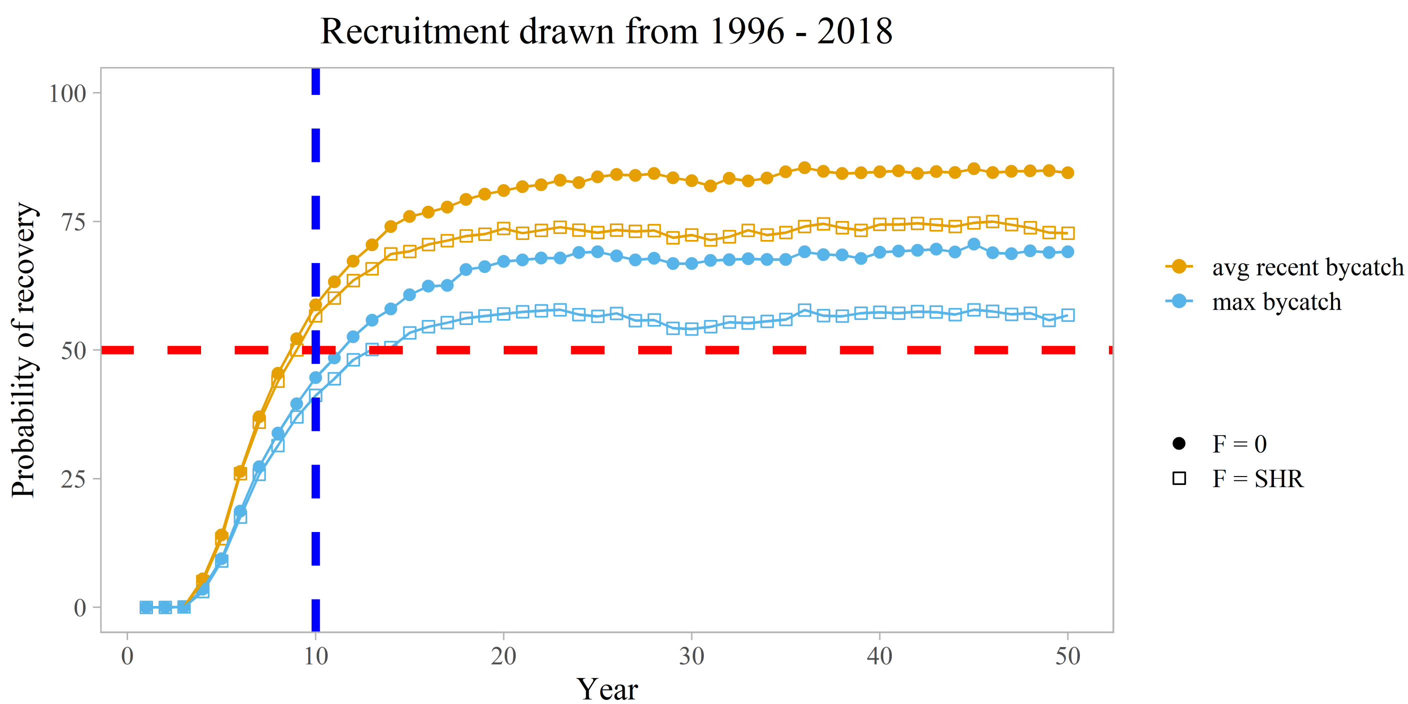


Figure 2: Comparisons of probability of recovery with random recruitment from 1996 to 2018 under different bycatch levels, show as with a min F = 0 and a max F equivalent to the state harvest rate (SHR).

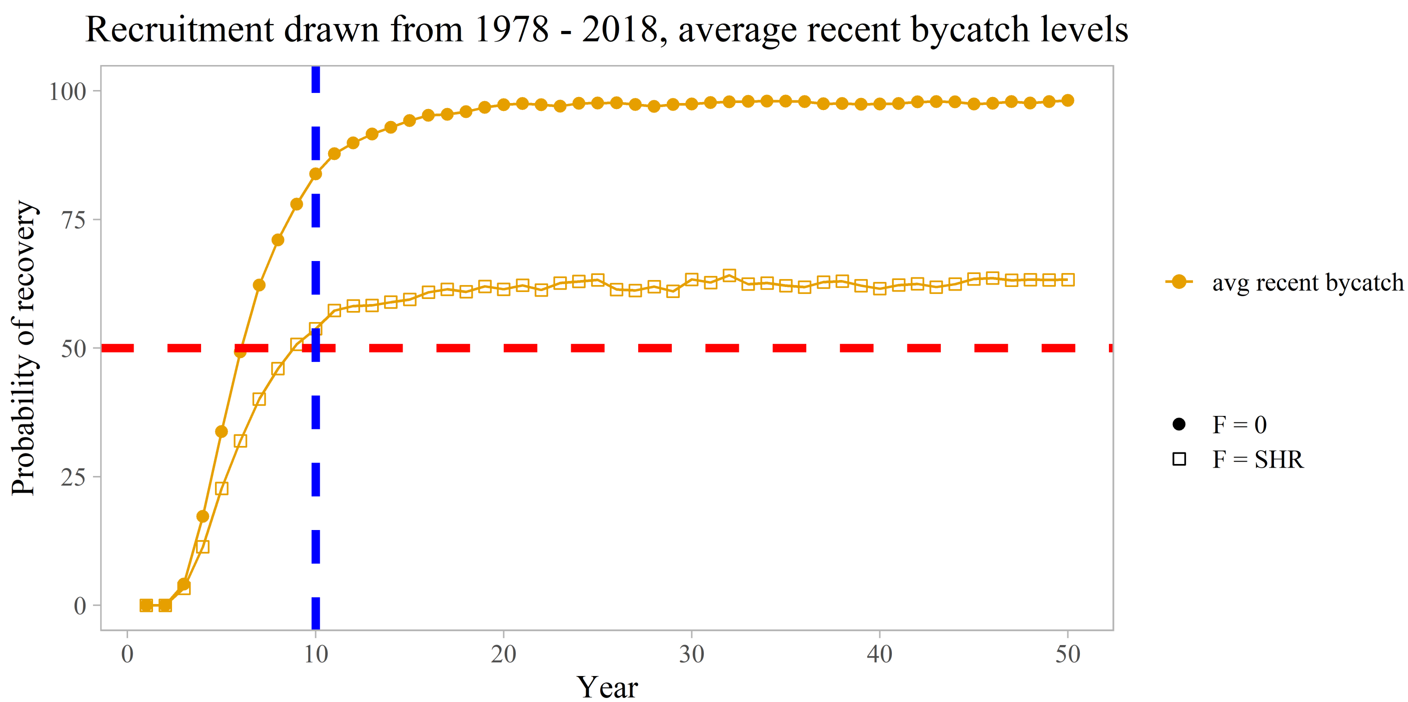


Figure 3: Probability of recovery with random recruitment from 1978 to 2018 under different fishing mortalities, min F = 0 and a max F equivalent to the state harvest rate (SHR). Projection 1.

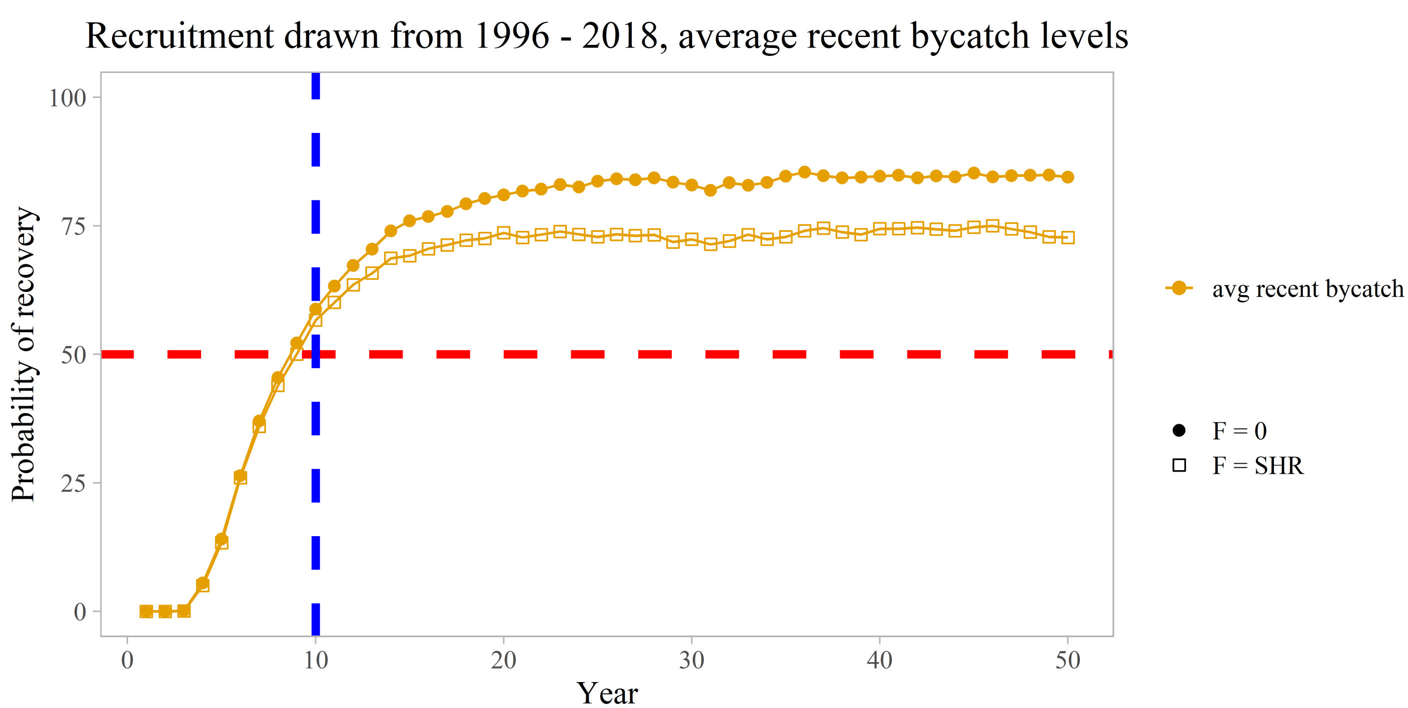


Figure 4: Probability of recovery with random recruitment from 1996 to 2018 under different fishing mortalities, min F = 0 and a max F equivalent to the state harvest rate (SHR). Projection 5.

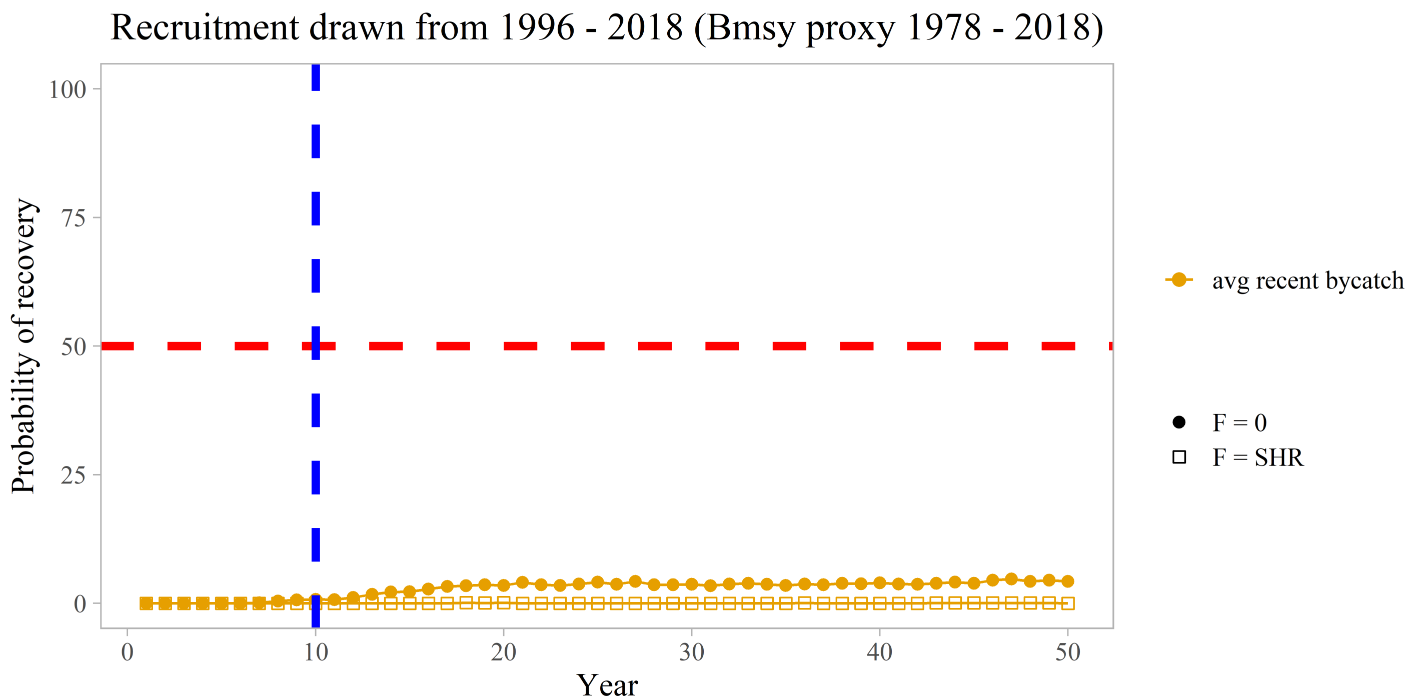


Figure 5: Probability of recovery with random recruitment from 1996 to 2018, while the Bmsy proxy is from 1978 to 2018, under different fishing mortalities, min F = 0 and a max F equivalent to the state harvest rate (SHR). Projection 4

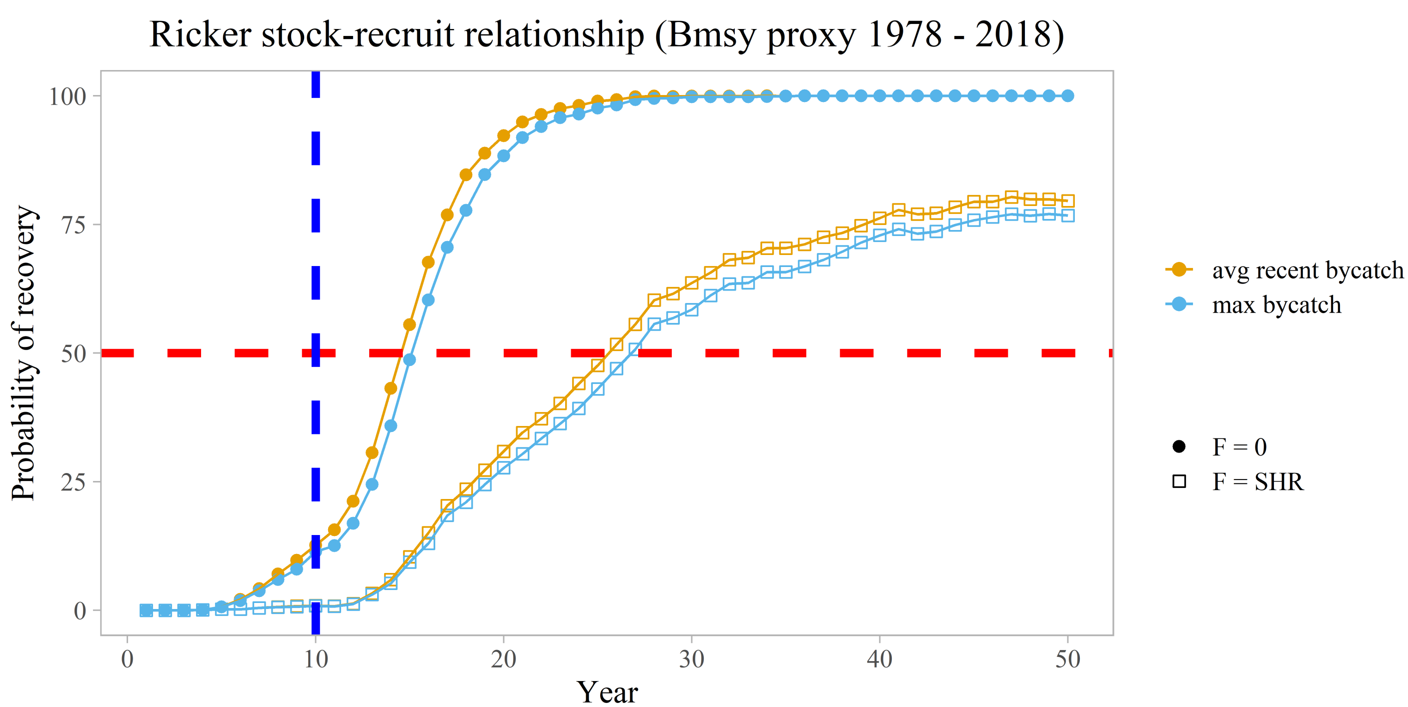


Figure 6: Comparisons of probability of recovery with ricker s-r relationshipusing the entire time series (1978-2018) under different bycatch levels, show as with a min F = 0 and a max F equivalent to the state harvest rate (SHR). Projection 2

Appendix D. Recruitment Breakpoint Analysis

Introduction

In 2018 SMBKC was declared overfished and a rebuilding plan was put into motion. On examination, it was clear that recruitment for SMBKC has been consistently lower in recent years. Thus, the crab Plan Team requested that the authors conduct a recruitment breakpoint analysis similar to that conducted for Bristol Bay red king crab in 2017 (Zheng et al. 2017) and eastern Bering Sea Tanner crab in 2013 (Stockhausen 2013). The R code based on these studies was adapted for this study (Jie Zheng, Buck Stockhausen pers. Comm.). The goal of this analysis was to objectively identify a change in stock productivity based on the recruitment time series. This could then be used to develop alternative rebuilding scenarios and also provide alternative B_{MSY} proxies. Results from assessment model 3 from 2018 (Ianelli and Zheng 2018) were used for this analysis.

Methods

The methods were the same as used for BBKRC (Zheng et al. 2017) which followed Punt et al. (2014) and Stockhausen (2013). Stock productivity is represented by ln(*R/MMB*), where *R* is recruitment and *MMB* is mature male biomass, with recruitment lagging to the brood year of mature biomass. Let y_t = ln(*R/MMB*) as estimated directly from the stock assessment model and fit externally to stock-recruitment relationships (with predictions as $\hat{y}_t$). For the Ricker stock-recruitment models,

$$\begin{aligned} \hat{y}_t &= \alpha_1 + \beta_1 \cdot MMB \qquad t < b, \\ \hat{y}_t &= \alpha_2 + \beta_2 \cdot MMB \qquad t \geq b, \end{aligned} \tag{1}$$

where α_1 and β_1 are the Ricker stock-recruit function parameters for the early period before the potential breakpoint in year *b* and α_2 and β_2 are the parameters for the period after the breakpoint in year *b*. For Beverton-Holt stock-recruitment models,

$$\begin{aligned} \hat{y}_t &= \alpha_1 - \log(1 + e^{\beta_1} \cdot MMB) \qquad t < b, \\ \hat{y}_t &= \alpha_2 + \log(1 + e^{\beta_2} \cdot MMB) \qquad t \geq b, \end{aligned} \tag{2}$$

where α_1 and β_1 are the Beverton-Holt stock-recruit function log-transformed parameters for the early period before the potential breakpoint in year *b* and α_2 and β_2 are the log-transformed parameters for the period after the breakpoint in year *b*.

A maximum likelihood approach was used to estimate stock-recruitment model and error parameters. Because y_t is measured with error, the negative log-likelihood function is

$$-\ln(L) = 0.5 \cdot \ln(|\mathbf{\Omega}|) + 0.5 \cdot \sum_t \sum_j (y_t - \hat{y}_t) \cdot \left[\mathbf{\Omega}^{-1}\right]_{t,j} \cdot (y_j - \hat{y}_j), \tag{3}$$

where Ω contains observation and process error as

$$\mathbf{\Omega} = \mathbf{O} + \mathbf{P}, \tag{4}$$

where **O** is the observation error covariance matrix estimated from the stock assessment model and **P** is the process error matrix and is assumed to reflect a first-order autoregressive process to have σ^2 on the diagonal and $\sigma^2 \rho^{|t-j|}$ on the off-diagonal elements. σ^2 represents process error variance and ρ represents the degree of autocorrelation.

For each candidate breakpoint year *b*, the negative log likelihood value of equation (3) was minimized with respect to the six model parameters: α_1, β_1, α_2, β_2, $\ln(\sigma)$ and $\tan(\rho)$. The minimum time span considered as a potential regime was 5 years. Each brood year from 1983 to 2005 was evaluated as a potential breakpoint *b* using time series of ln(R/MMB) and MMB for brood years 1978-2010. A model with no breakpoint was also evaluated. Models with different breakpoints were then ranked using AICc (AIC corrected for small sample size; Burnham and Anderson 2004),

$$AIC_c = -2 \cdot \ln(L) + \frac{2 \cdot k \cdot (k+1)}{n-k-1}, \qquad (5)$$

where *k* is the number of parameters and *n* is the number of observations. Using AICc, the model with the smallest AICc is regarded as the “best” model among the set of models evaluated. Different models can be compared in terms of θ_m, the relative probability (odds) that the model with the minimum AICc score is a better model than model *m*, where

$$\theta_m = \exp([(AICc_m - AICc_{\min})/2]. \qquad (6)$$

Results

Results are summarized in Tables D1-D4 and Figures D1-D6. Both Ricker and Beverton-Holt (B-H) models resulted in the same breakpoint brood year of 1989, which corresponded to recruitment year of 1996. The model without a breakpoint (i.e., a single period) was about 26 times less probable than the 1989 breakpoint model for the Ricker stock-recruitment relationship and 4 times less probable than the Beverton-Holt, which suggested a possible change in stock productivity from the early high period to the recent low period. Alternative breakpoint brood years of 1984-1988 for the Ricker model and of 1990 for Beverton-Holt model were also reasonably reported with relative odds less than 10.

Both Ricker and Beverton-Holt stock-recruitment models fitted the data poorly. Additionally, the fit to the breakpoint group with fewer data points was extremely poor for both models, especially the Ricker model. For example, the Ricker model with a breakpoint year of 1983 (Figure D1) fits the larger data group well (black line) but the fit to the smaller data group (red line) is poor, with an estimated intercept (α_1) that appears to be lower than the expected fit. This was the case for all breakpoint years with the data group (pre or post breakpoint) that had fewer data points. A sensitivity analysis was performed to determine the source of this lack of fit for both the Ricker and B-H models. For the Ricker model a breakpoint analysis that produced two independent regression (where the covariance matrix and ρ were set to 0) produced model fits that fit both data groups well, additionally this analysis produced the same breakpoint year of 1989, but suggested that 1990 was also a possibility. The poor model fit is primarily due to covariance and estimation of ρ in the analysis. The same analysis with the B-H model was performed but only the Ricker results are presented here for simplicity (Figures D8-D10).

Sensitivity analyses suggest that error within the model, specifically autocorrelation (ρ), produce poor fits to the stock-recruit relationships when the sample size for the data set is low. However, the resulting breakpoint year is still the same, suggesting strong evidence for a brood year breakpoint in 1989. The only other likely breakpoint year is 1990, with relative odds < 2 compared to 1989. These breakpoint brood years would produce breaks in recruitment in either 1996 or 1997.

Discussion

A recruitment breakpoint analysis was conducted on St Matthews blue king crab by Punt et al. (2014) with data from 1978 to 2010 to estimate a breakpoint brood year of 1993, corresponding to recruitment year of 1998, but this model used a 5-year lag and incorporated smaller size classes (20 - 90mm) than the current assessment model. The projections for recruitment from the Punt et al. (2014) model are substantially higher in the late 2000s than the current assessment model, which would greatly influence the breakpoint analysis results. The different time series of data may also explain the differences; however, both suggest a break in recruitment in the mid to late 1990s.

Time series of estimated mature male biomass during 1978-2017 (the entire time series) has been used to compute a B_{MSY} proxy. Using the 2018 assessment model the B_{MSY} proxy for 2018 is 3,478 t. The B_{MSY} proxy for the recent recruitment period (based on the break point analysis; 1996-2017) using the same model is 2,030 t (Table D5). The is approximately a 42% reduction (Figure D7). If the estimated breakpoint year is used to set the new recruitment time series, the estimated B_{MSY} proxy will be correspondingly lower than the current estimated value.

References

Burnham, K.P., and D.R. Anderson. 2004. Multimodal inference: understanding AIC and BIC in model selection. Sociological Methods & Research 33:261–304.

Punt, A.E., C.S. Szuwalski, and W. Stockhausen. 2014. An evaluation of stock-recruitment proxies and environmental change points for implementing the US Sustainable Fisheries Act. Fisheries Research 157:28-40.

Stockhausen, W.T. 2013 Recruitment Analysis for Stock Status Determination and Harvest Recommendations. Appendix to: 2013 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries in the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, Anchorage. pp.450-478.

Table D1. Results of the breakpoint analysis, with AICc and the relative probability (odds) against the Ricker stock-recruitment model being correct by breakpoint year. The model with no breakpoint is listed first in the table. The "best" model is shaded. Years are brood year.

Year	AICc	Odds
NA	1.474	26.124
1983	-0.187	11.384
1984	-1.498	5.913
1985	-0.975	7.679
1986	-1.449	6.059
1987	-1.141	7.066
1988	-1.784	5.124
1989	-5.052	1.000
1990	0.141	13.413
1991	2.586	45.564
1992	4.658	128.335
1993	4.621	125.992
1994	2.479	43.172
1995	5.339	180.461
1996	5.266	173.990
1997	4.137	98.931
1998	4.950	148.548
1999	7.258	471.115
2000	7.234	465.383
2001	5.509	196.408
2002	6.186	275.605
2003	4.537	120.830
2004	2.989	55.723
2005	6.716	359.120

Table D2. Parameter estimates and standard deviations for the Ricker stock-recruitment model with no breakpoint (first row) and the single breakpoint models (by year of breakpoint). The "best" model is shaded. Years are brood year.

Year	α_1	std.dev.	α_2	std.dev.	β_1	std.dev.	β_2	std.dev.	ln(σ)	std.dev.	tan(ρ)	std.dev.
			5.488	0.624			0.155	0.068	-0.099	0.373	6.493	5.311
1983	4.456	1.224	6.770	1.096	0.062	0.078	0.546	0.127	0.180	0.610	22.813	29.838
1984	4.834	0.989	6.862	0.970	0.080	0.058	0.632	0.138	0.064	0.570	20.324	24.984
1985	5.199	0.845	6.764	0.859	0.100	0.054	0.634	0.142	-0.044	0.523	15.556	17.804
1986	5.510	0.743	6.615	0.764	0.104	0.055	0.617	0.149	-0.166	0.474	11.401	12.175
1987	5.193	0.856	6.794	0.883	0.101	0.054	0.645	0.145	-0.031	0.530	15.858	18.137
1988	5.356	0.779	6.667	0.814	0.103	0.053	0.621	0.147	-0.131	0.520	13.543	15.341
1989	5.819	0.625	6.080	0.698	0.098	0.052	0.475	0.183	-0.521	0.495	6.231	7.556
1990	5.818	0.874	5.790	1.116	0.101	0.058	0.358	0.292	-0.594	0.654	3.776	7.050
1991	5.918	0.703	5.606	0.820	0.124	0.064	0.294	0.194	-0.581	0.433	2.791	3.540
1992	5.270	1.008	6.317	1.232	0.134	0.062	0.439	0.262	-0.031	0.696	10.149	15.757
1993	5.288	1.009	6.262	1.282	0.137	0.063	0.424	0.275	-0.040	0.691	9.514	15.029
1994	5.632	0.812	5.994	1.089	0.138	0.066	0.420	0.245	-0.289	0.512	5.086	6.549
1995	4.886	1.189	6.705	1.340	0.136	0.063	0.500	0.227	0.255	0.621	17.185	22.680
1996	4.949	1.110	6.683	1.273	0.136	0.063	0.513	0.236	0.208	0.597	15.375	20.228
1997	4.720	1.295	6.554	1.437	0.135	0.061	0.381	0.252	0.367	0.600	22.852	29.149
1998	4.997	1.047	5.658	1.435	0.141	0.062	0.068	0.427	0.201	0.551	15.742	19.015
1999	5.533	0.687	5.493	1.665	0.156	0.069	0.179	0.798	-0.129	0.438	6.011	6.144
2000	5.443	0.719	5.636	1.740	0.155	0.069	0.198	0.805	-0.067	0.472	6.998	7.404
2001	5.717	0.537	4.613	1.775	0.156	0.066	-0.078	0.803	-0.261	0.334	4.720	3.589
2002	5.657	0.553	4.553	1.799	0.156	0.066	-0.142	0.800	-0.239	0.366	5.149	4.225
2003	5.767	0.492	4.785	1.705	0.159	0.063	0.062	0.779	-0.343	0.323	4.474	3.254
2004	5.814	0.468	4.685	1.664	0.160	0.062	0.099	0.758	-0.384	0.301	4.213	2.864
2005	5.607	0.555	5.195	1.790	0.155	0.067	0.141	0.826	-0.227	0.378	5.190	4.365

Table D3. Results of the breakpoint analysis, with AICc and the relative probability (odds) against the Beverton-Holt stock-recruitment model being correct by breakpoint year. The model with no breakpoint is listed first in the table. The "best" model is shaded. Years are brood year.

Year	AICc	Odds
NA	-1.533	4.232
1983	4.103	70.852
1984	3.986	66.809
1985	4.005	67.459
1986	2.860	38.062
1987	3.925	64.830
1988	2.563	32.810
1989	-4.418	1.000
1990	-0.741	6.288
1991	0.740	13.187
1992	2.859	38.028
1993	2.630	33.923
1994	0.854	13.956
1995	4.237	75.741
1996	4.267	76.888
1997	1.905	23.605
1998	2.075	25.703
1999	3.956	65.817
2000	4.112	71.165
2001	2.937	39.540
2002	3.116	43.263
2003	0.877	14.121
2004	-0.855	5.939
2005	3.579	54.527

Table D4. Parameter estimates and standard deviations for the Beverton-Holt stock-recruitment model with no breakpoint (first row) and the single breakpoint models (by year of breakpoint). The "best" model is shaded. Years are brood year.

Year	α_1	std.dev.	α_2	std.dev.	β_1	std.dev.	β_2	std.dev.	ln(σ)	std.dev.	tan(ρ)	std.dev.
			11.908	34.104			5.800	34.131	-0.009	0.437	9.869	9.284
1983	11.694	NA	12.970	47.627	5.444	NA	6.914	47.639	-0.064	0.440	8.852	8.394
1984	5.572	2.004	16.904	327.946	-0.995	2.787	10.826	327.948	-0.048	0.461	9.257	9.254
1985	6.345	3.335	13.895	71.302	-0.097	4.202	7.862	71.309	-0.040	0.568	9.453	11.707
1986	7.533	NA	13.399	63.519	0.973	NA	7.500	63.531	-0.261	0.335	6.145	5.013
1987	5.981	1.683	16.024	219.692	-0.666	2.487	10.011	219.695	-0.134	0.472	7.647	7.894
1988	6.262	1.538	13.277	68.643	-0.711	2.287	7.383	68.656	-0.350	0.425	5.155	5.008
1989	7.068	1.875	11.864	69.327	-0.295	2.416	6.194	69.377	-0.751	0.300	2.896	2.154
1990	12.339	NA	11.704	NA	5.363	NA	5.993	NA	-0.722	0.336	2.646	2.383
1991	12.304	38.041	11.711	NA	5.419	38.076	5.985	NA	-0.653	0.356	2.588	2.578
1992	12.200	33.709	11.752	NA	5.608	33.730	5.917	NA	-0.420	0.496	4.429	5.120
1993	12.881	44.794	11.465	NA	6.344	44.807	5.636	NA	-0.369	0.430	4.791	4.774
1994	13.348	51.252	11.695	233.066	6.642	51.264	6.049	233.257	-0.446	0.310	3.715	2.753
1995	11.988	36.396	11.863	111.774	5.817	36.408	5.805	111.874	-0.058	0.518	8.939	9.881
1996	11.966	37.397	11.882	93.181	5.842	37.411	5.790	93.266	-0.020	0.527	9.588	11.563
1997	13.744	105.672	7.696	5.406	8.060	105.672	1.102	5.906	0.337	0.621	24.517	32.501
1998	12.980	58.869	5.748	1.618	7.151	58.870	-2.250	6.036	0.229	0.584	19.852	25.260
1999	13.405	47.136	11.393	NA	7.144	47.143	5.452	NA	-0.137	0.447	7.230	7.396
2000	14.297	98.747	5.732	1.989	8.272	98.752	-1.652	6.425	0.074	0.552	12.085	14.354
2001	12.041	31.917	11.731	NA	5.698	31.953	5.946	NA	-0.230	0.398	6.243	5.598
2002	13.694	52.456	5.888	NA	7.486	52.464	-0.604	NA	-0.162	0.425	7.790	7.064
2003	13.209	40.983	11.292	NA	6.789	40.995	5.706	NA	-0.349	0.371	5.920	4.824
2004	13.213	39.232	11.330	NA	6.749	39.244	5.911	NA	-0.392	0.349	5.678	4.409
2005	14.402	93.698	10.309	NA	8.150	93.706	4.447	NA	-0.158	0.432	7.808	7.191

Table D5. Estimates of B_{MSY} proxy using the entire time series and model suggested breakpoint years for recruitment.

Year	Basis for B_{MSY}	B_{MSY} proxy	MSST	Biomass (MMB_{mating})	B/B_{MSY}
2018/19	1978-2017	3.48	1.74	1.09	0.31
2018/19	1996-2017	2.03	1.015	1.08	0.53

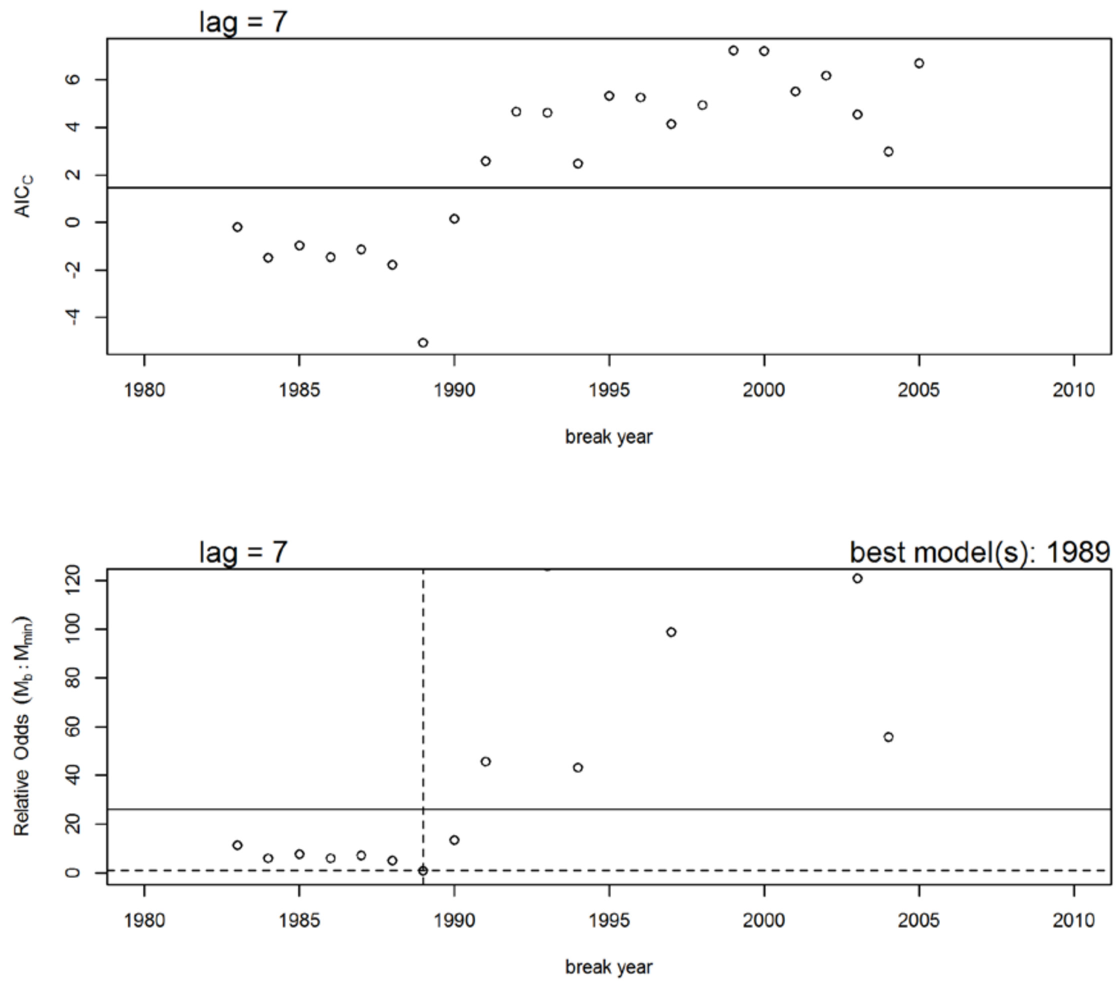


Figure D1. Results from the Ricker stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint model (horizontal solid line) relative to the model with the smallest AICc score. The dashed lines indicate the value for the model with the lowest AICc score (breakpoint in 1989). Not shown are 1-breakpoint models with high odds (>120) of being incorrect.

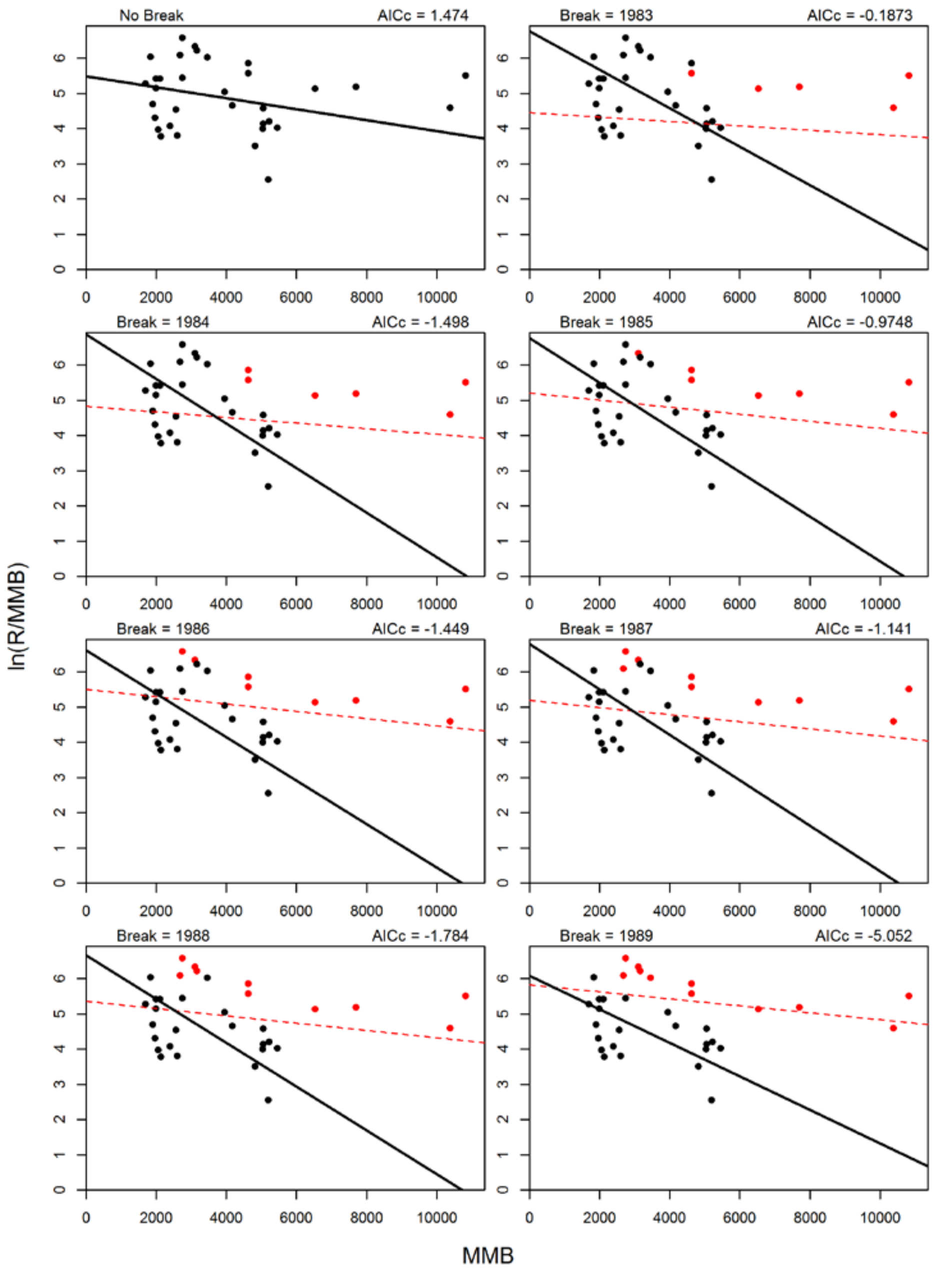


Figure D2. Fits for Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1978-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.

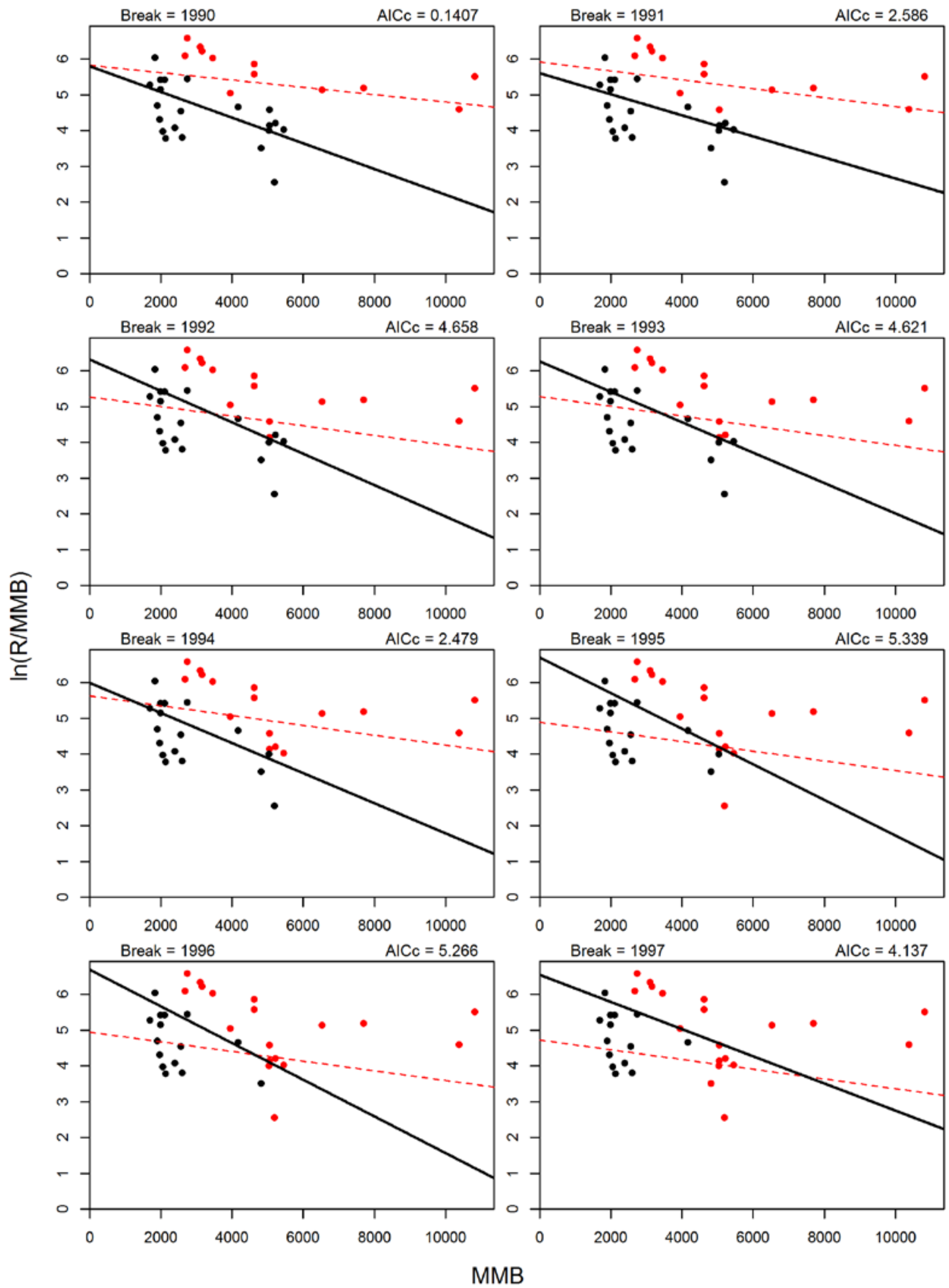


Figure D2. Continued.

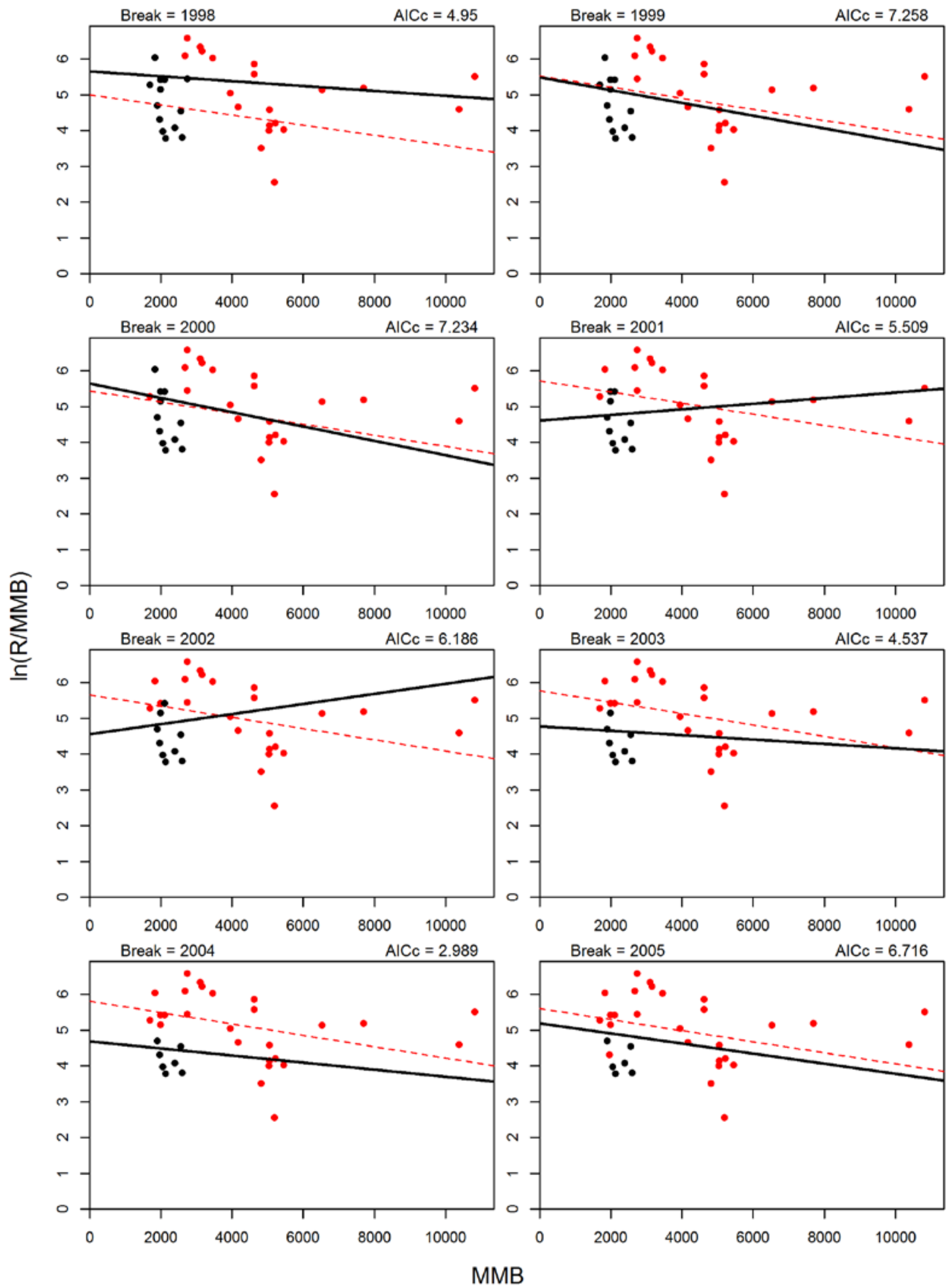


Figure D2. Continue.

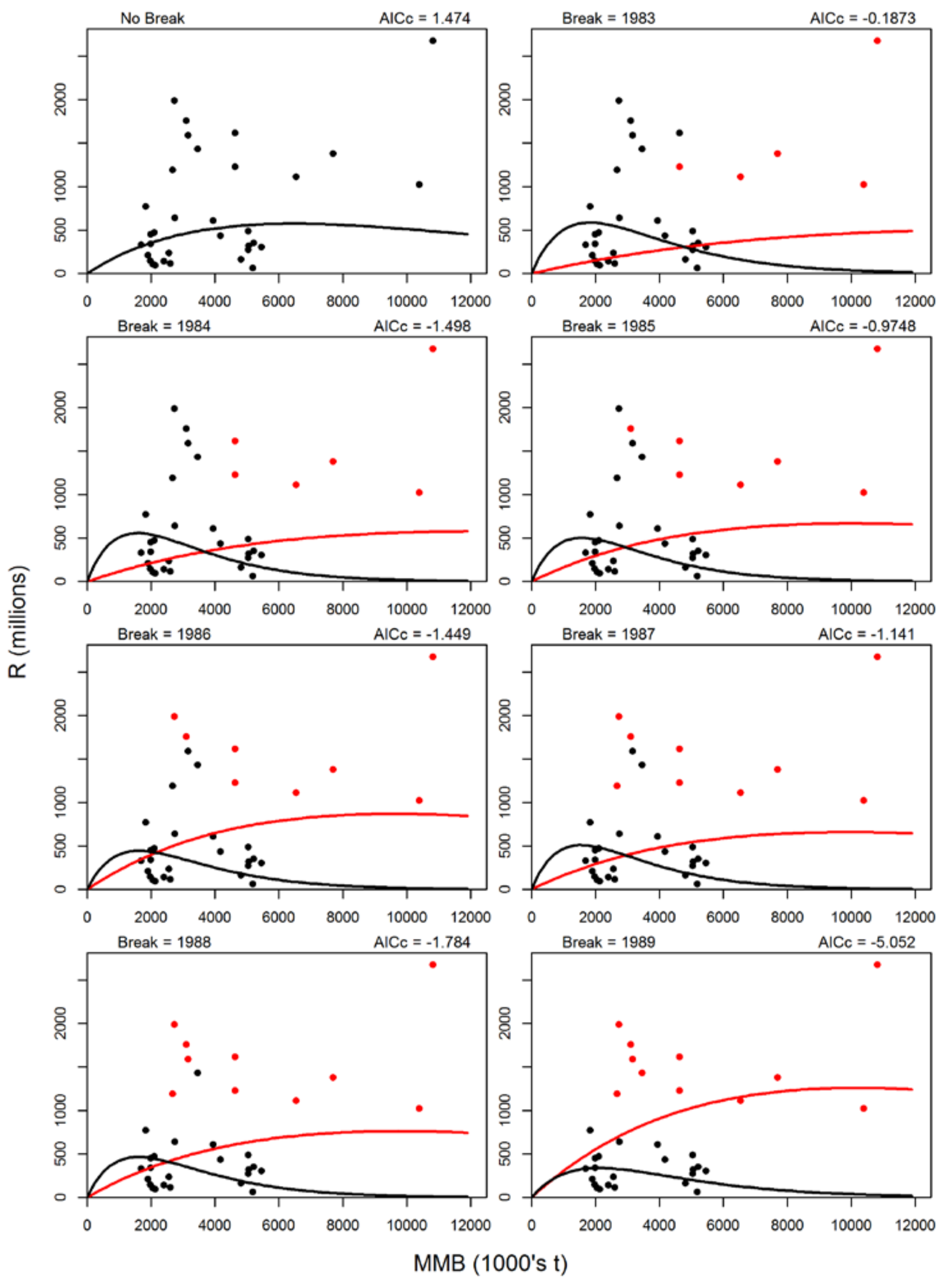
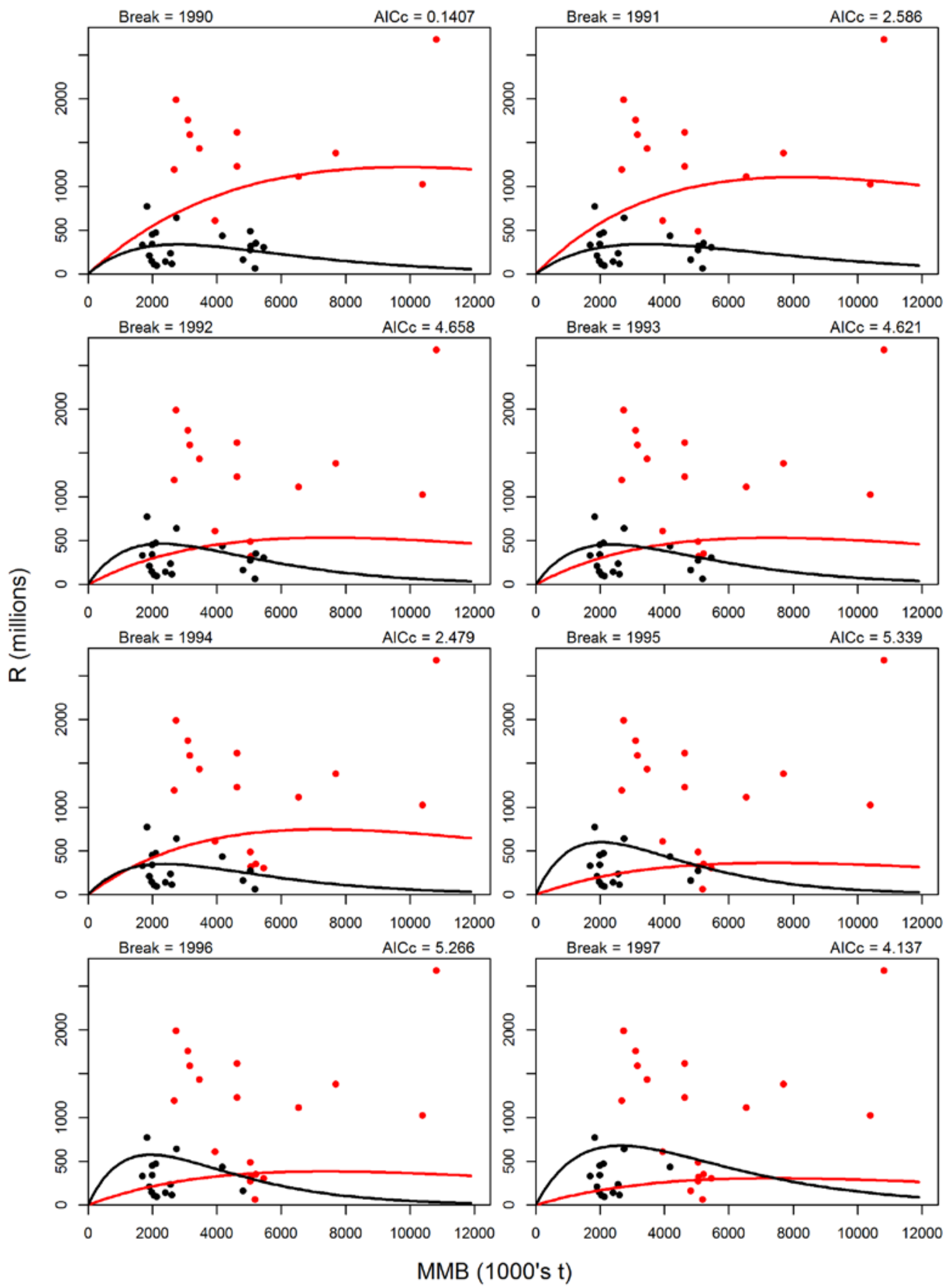


Figure D3. Fits on the arithmetic scale for Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1978-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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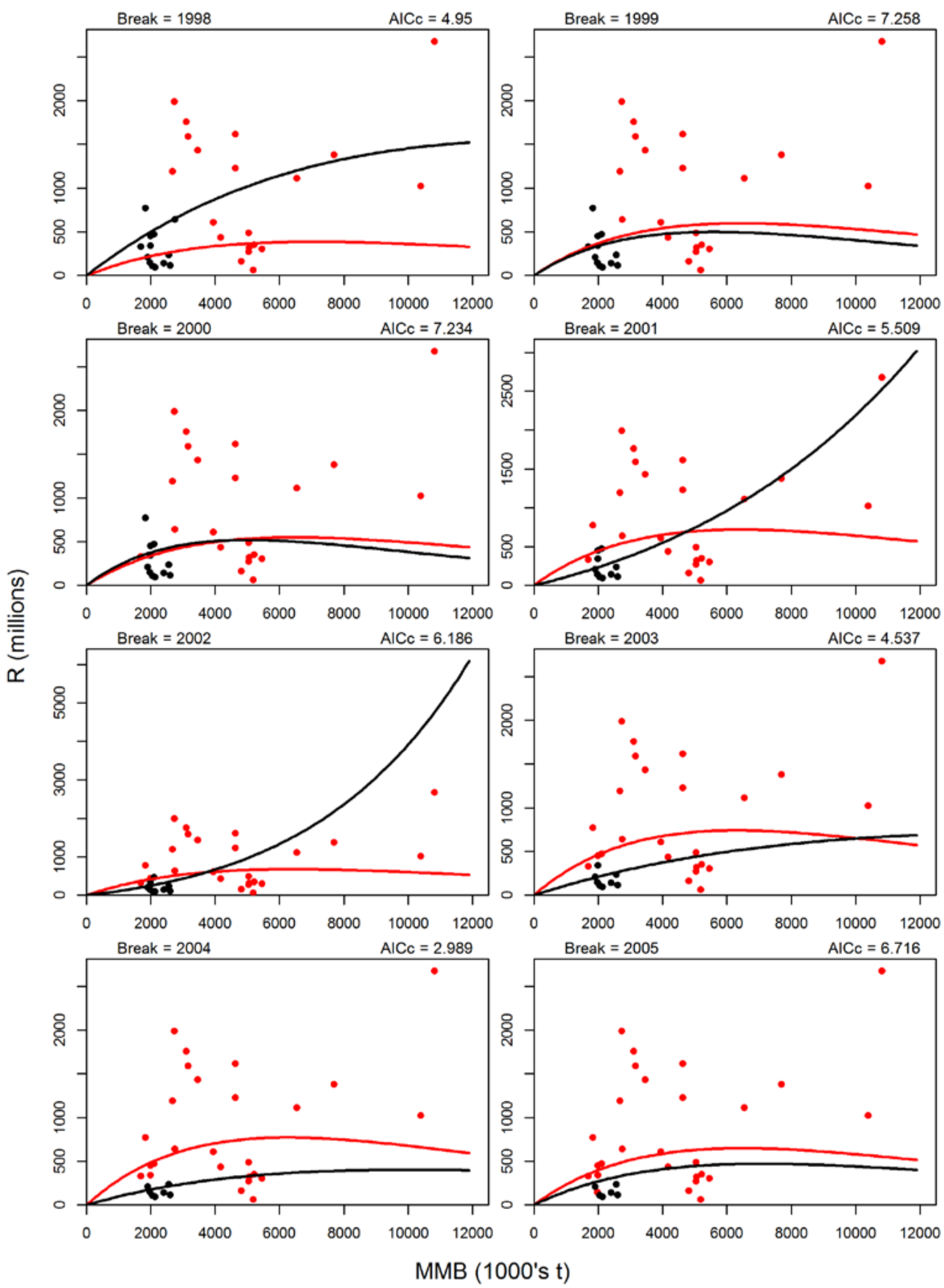

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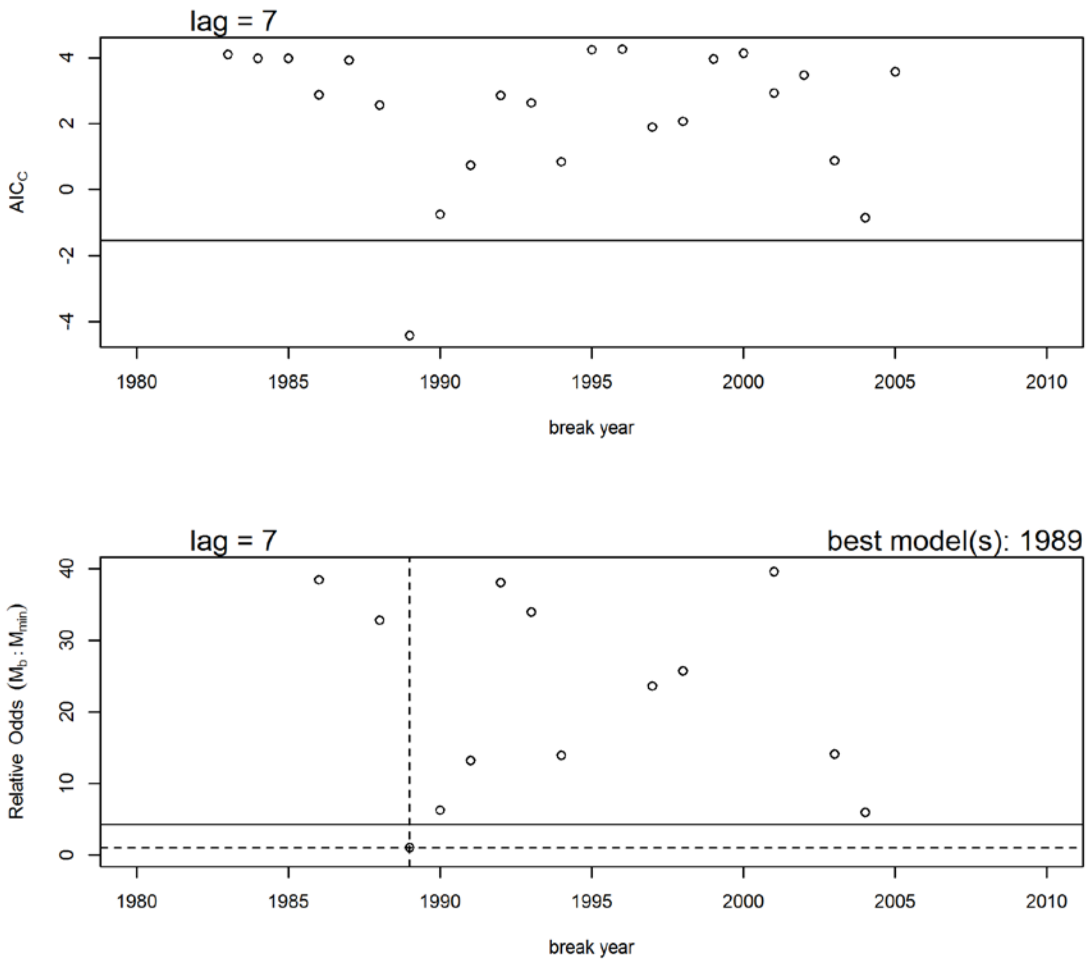


Figure D4. Results from the B-H stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint model (horizontal solid line) relative to the model with the smallest AICc score. The dashed lines indicate the value for the model with the lowest AICc score (breakpoint in 1989). Not shown are 1-breakpoint models with high odds (>40) of being incorrect.

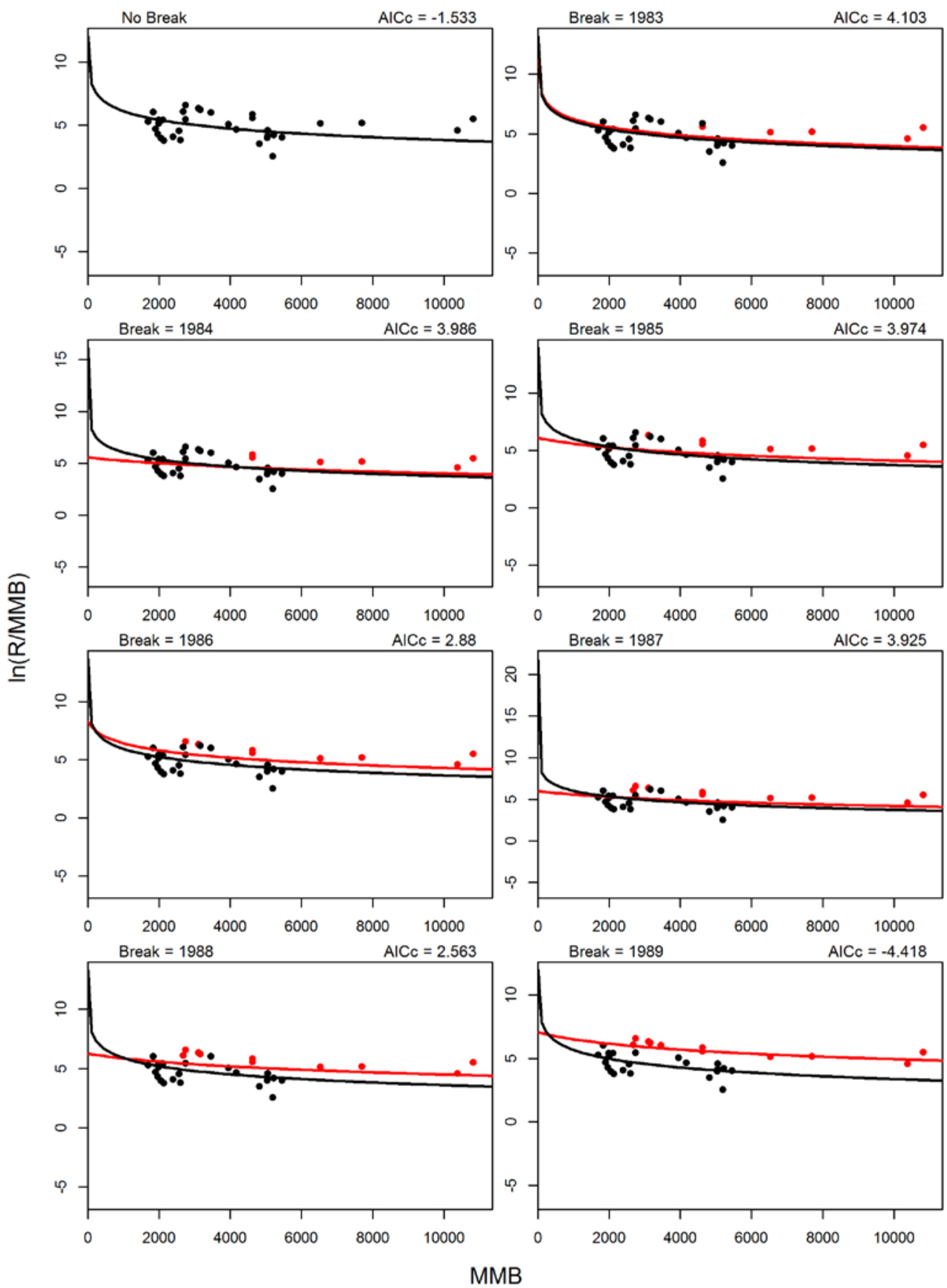
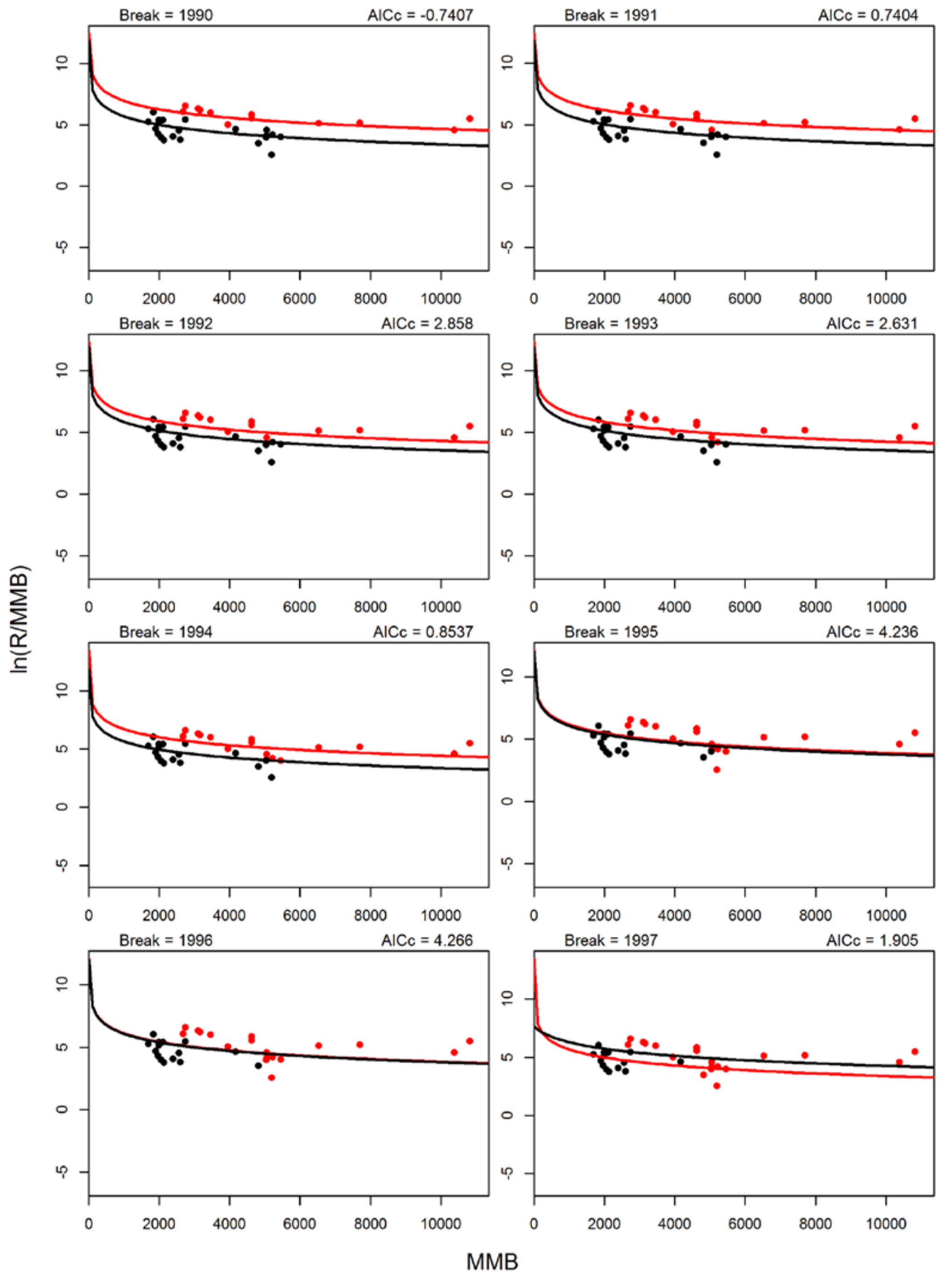


Figure D5. Fits for B-H models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1978-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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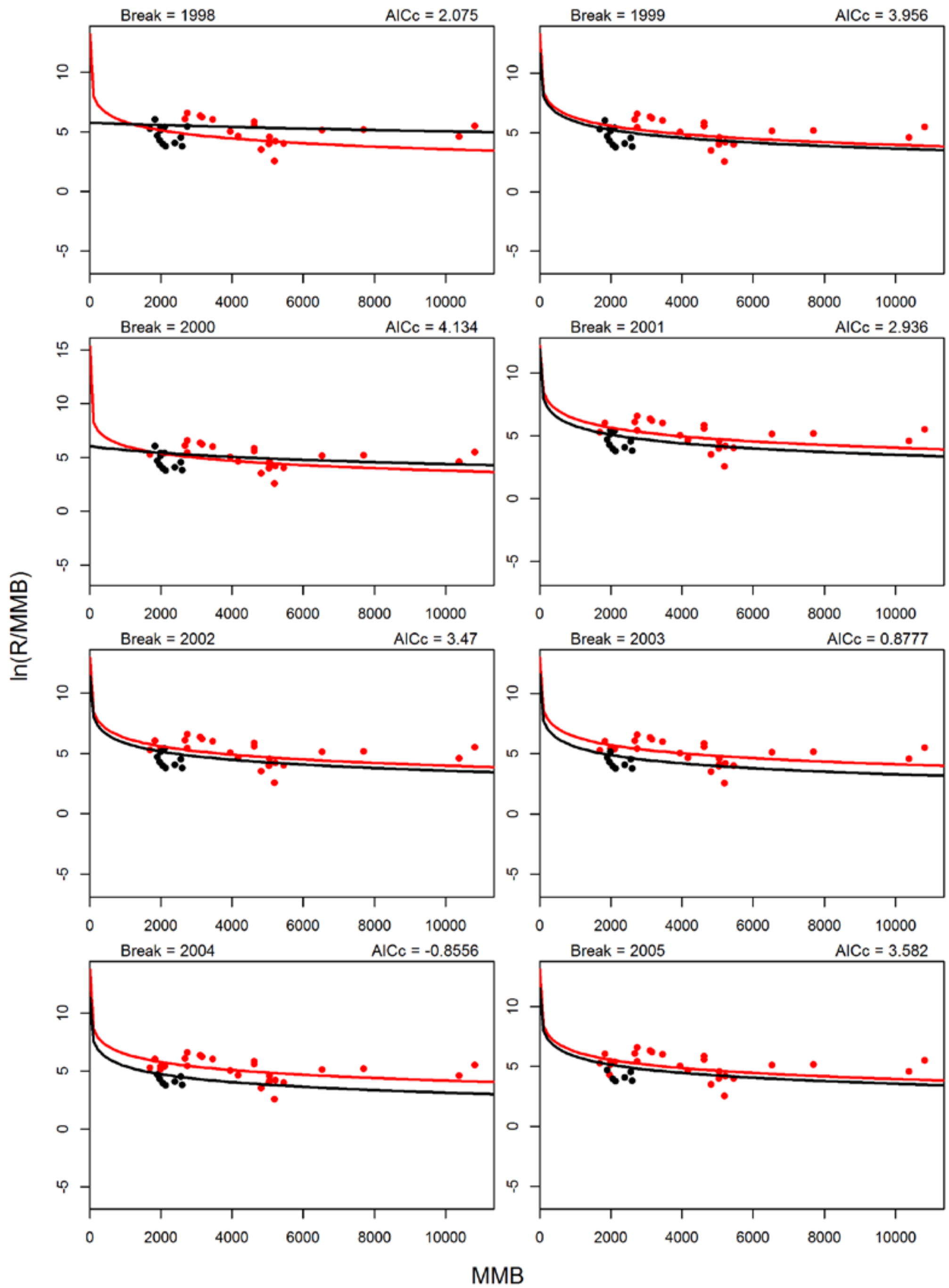

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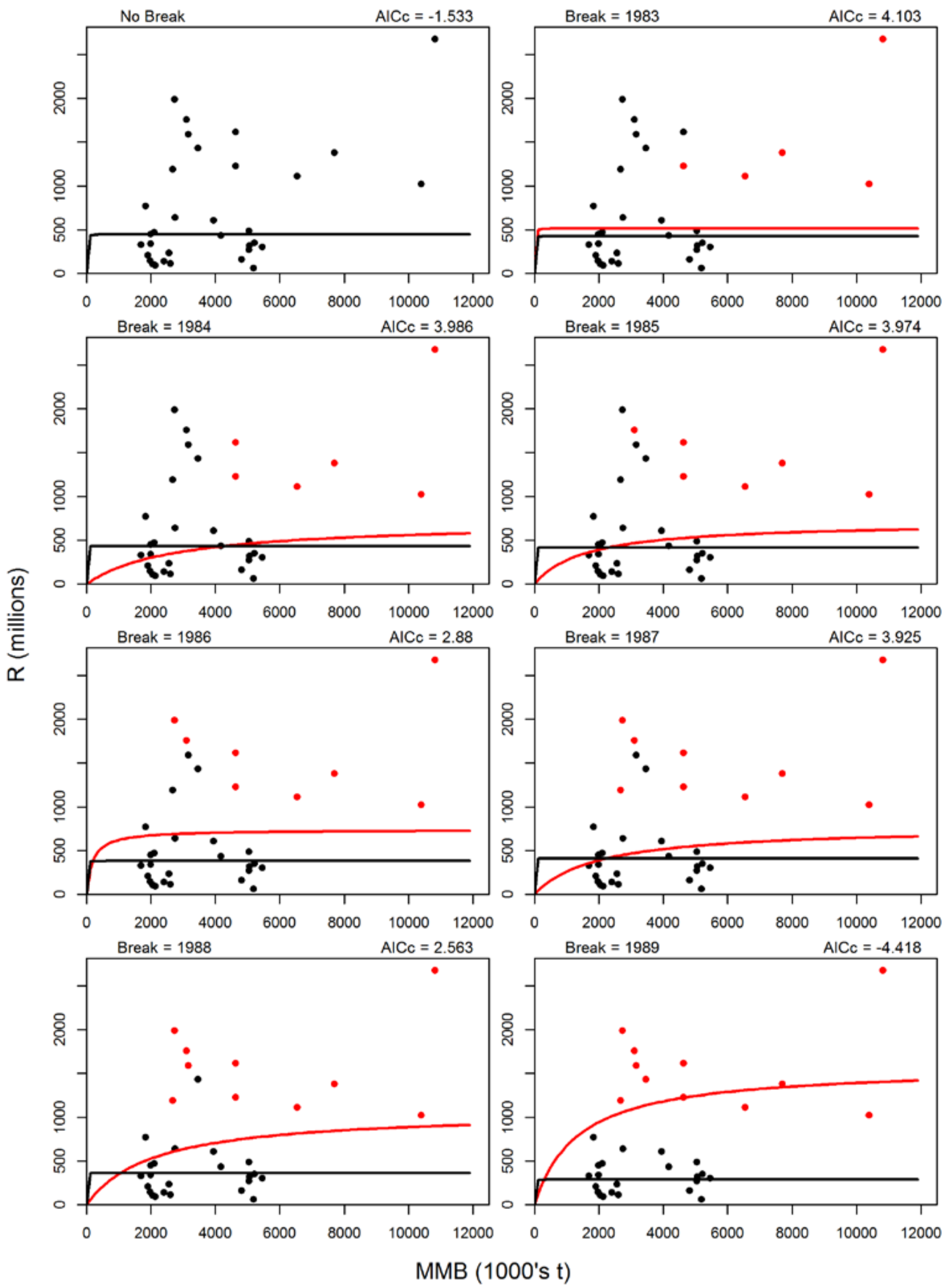
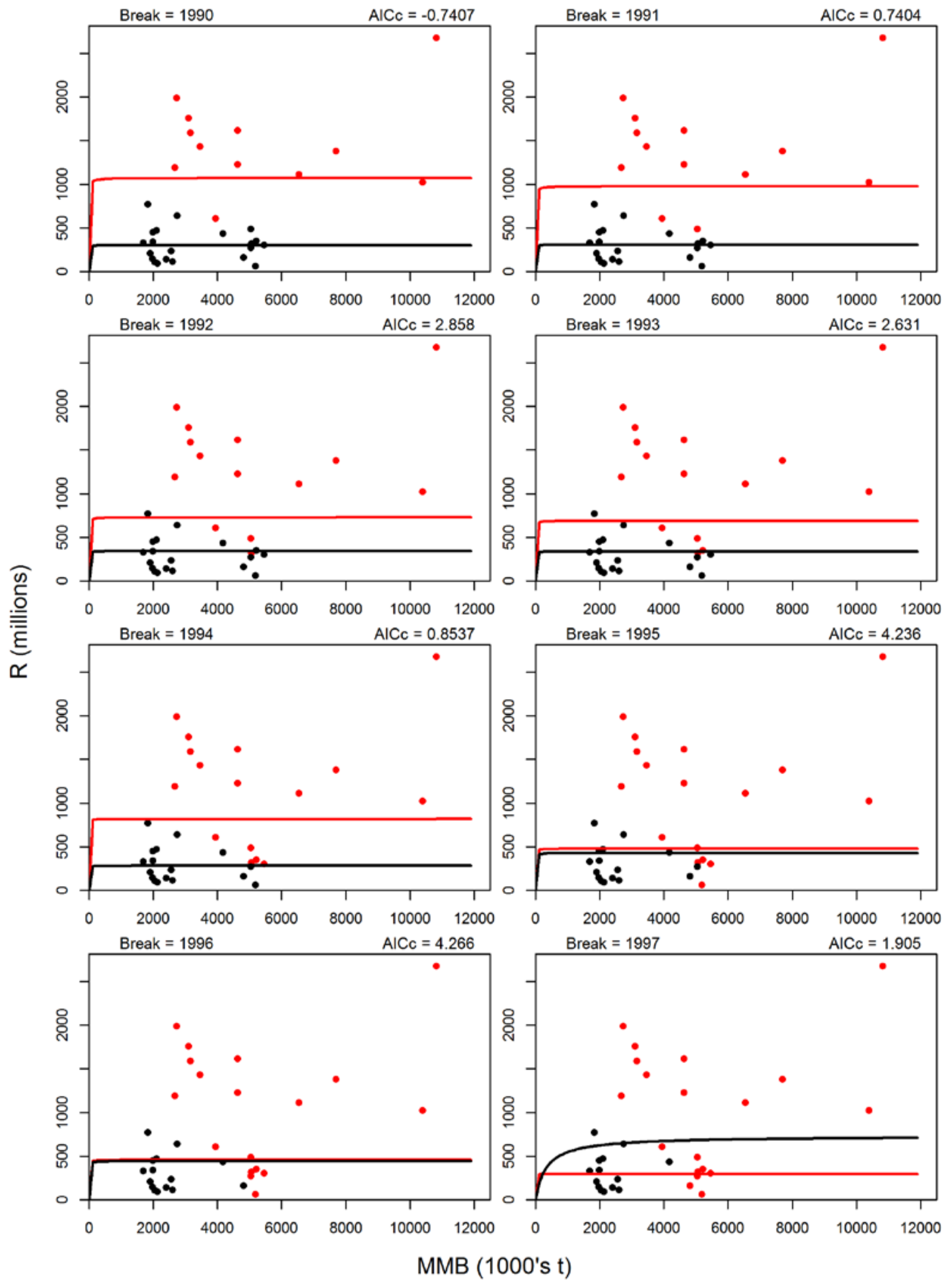


Figure D6. Fits on the arithmetic scale for B-H models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1978-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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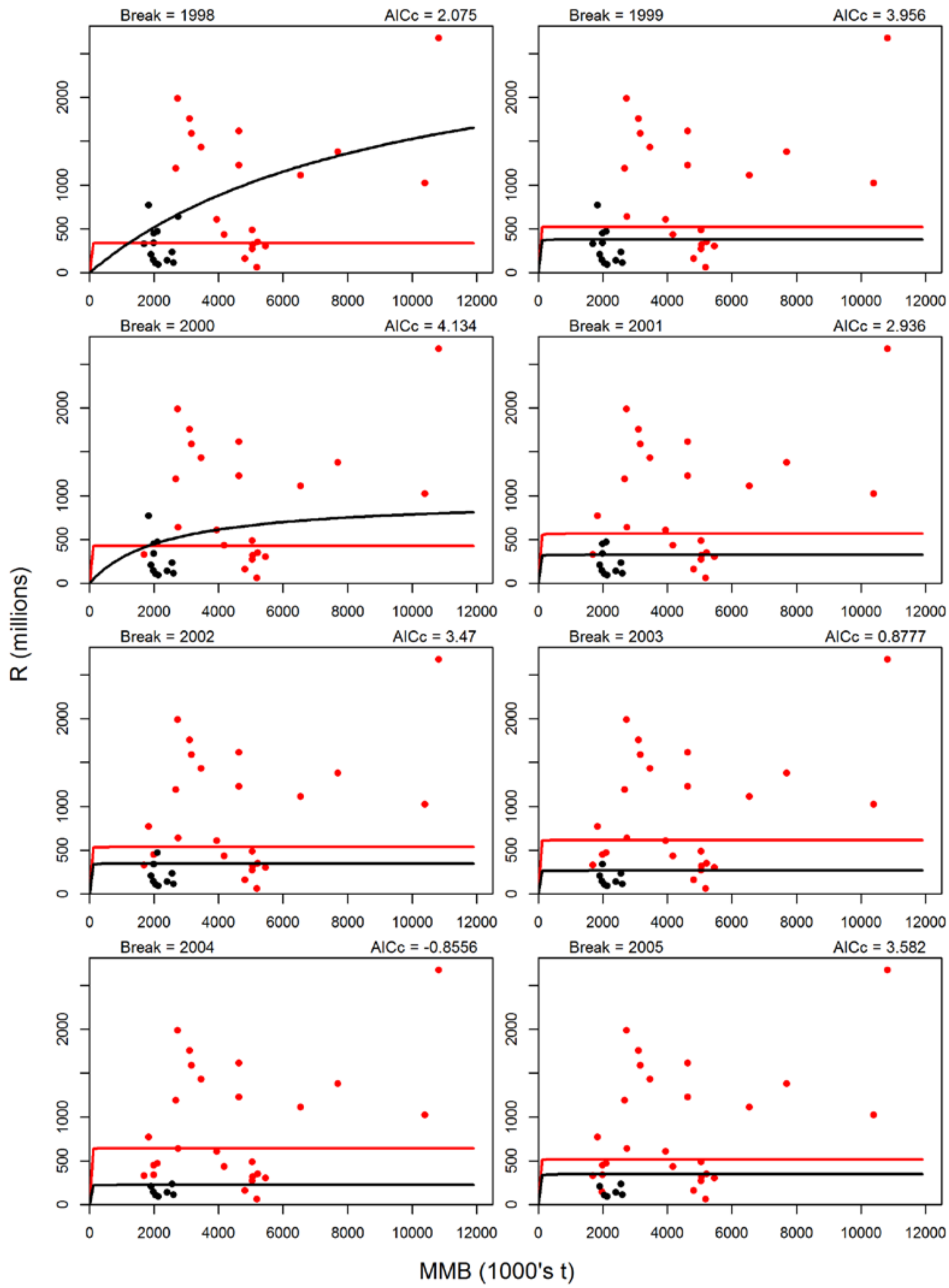

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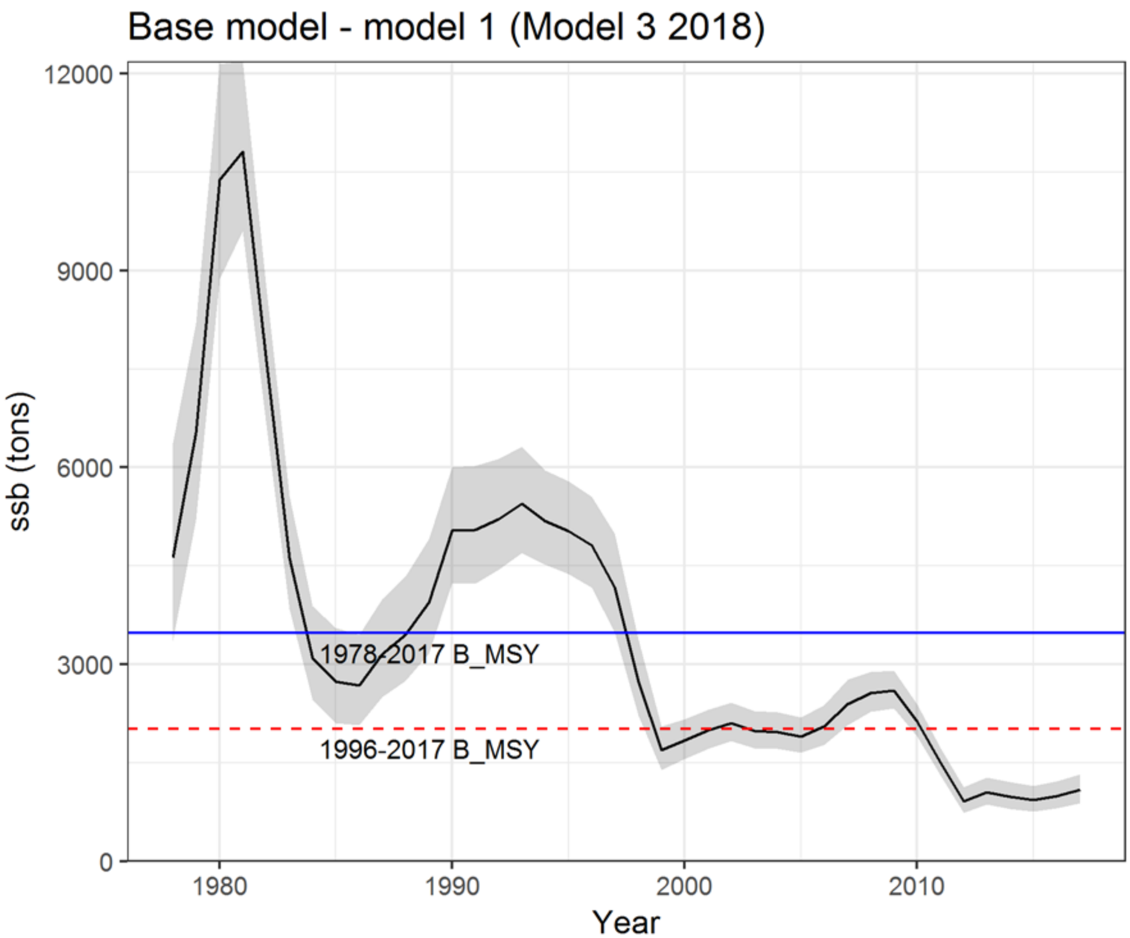

Figure D7. Computed B_{MSY} proxy (average mature male biomass) for the corresponding year ranges based on the 2018 assessment model with GMACS code updates.

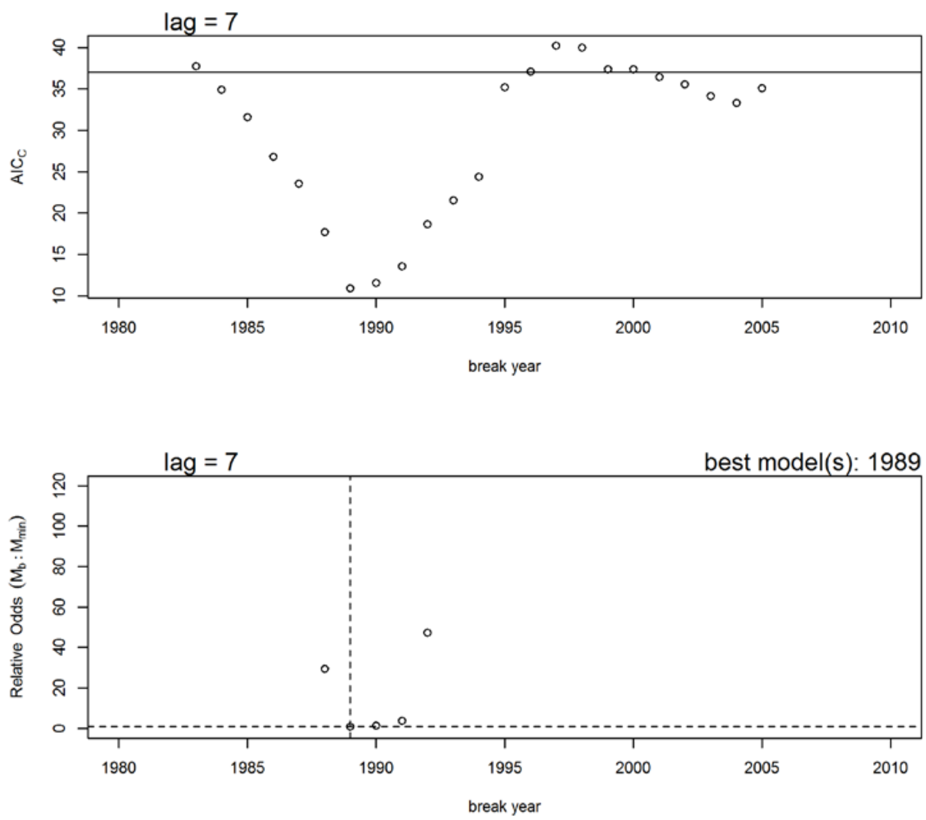

Figure D8. Results from the sensitivity analysis for Ricker stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint model (horizontal solid line) relative to the model with the smallest AICc score. The dashed lines indicate the value for the model with the lowest AICc score (breakpoint in 1989). Not shown are 1-breakpoint models with high odds (>120) of being incorrect.

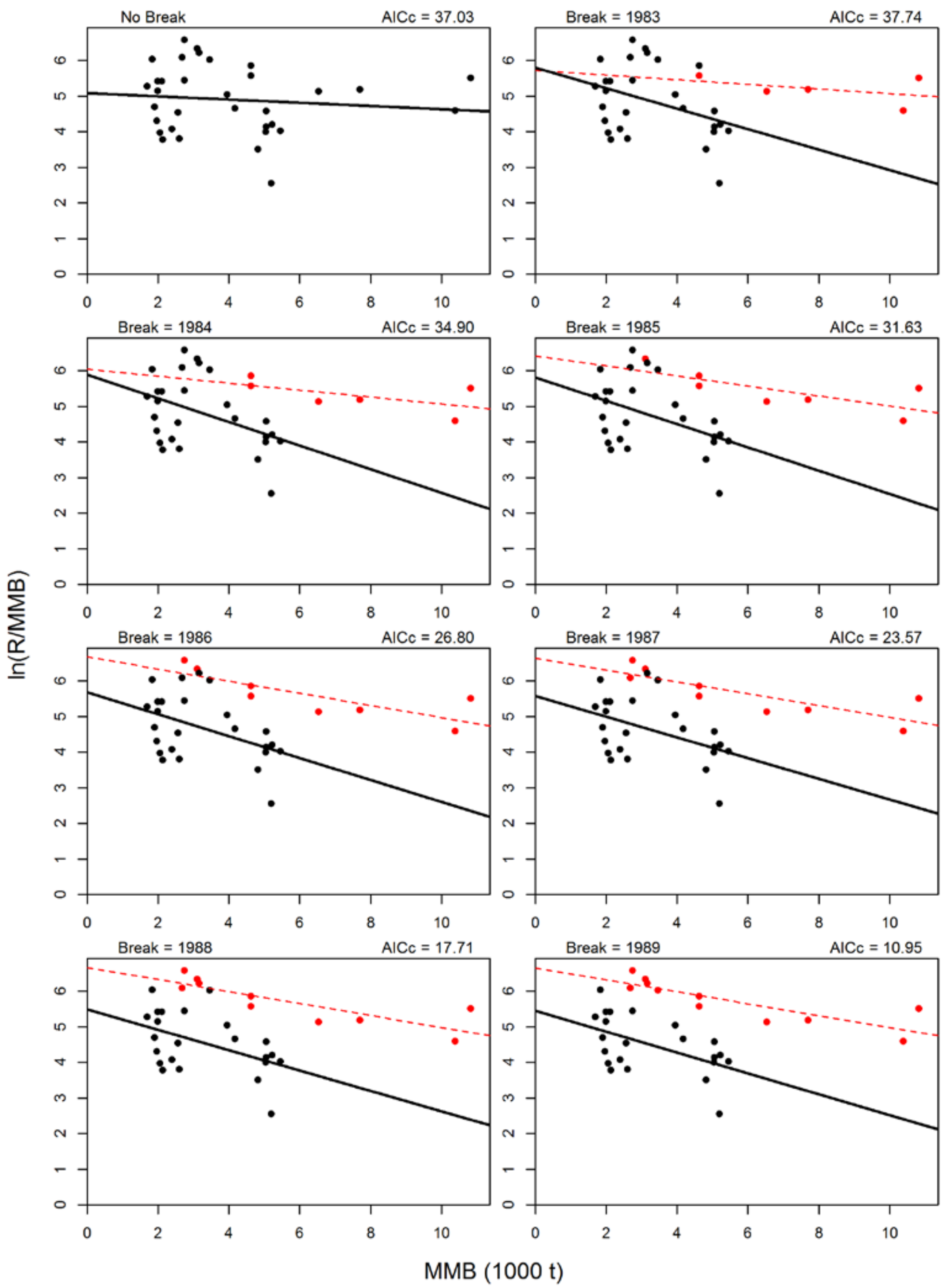

Figure D9. Fits for the sensitivity analysis using the Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1978-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.

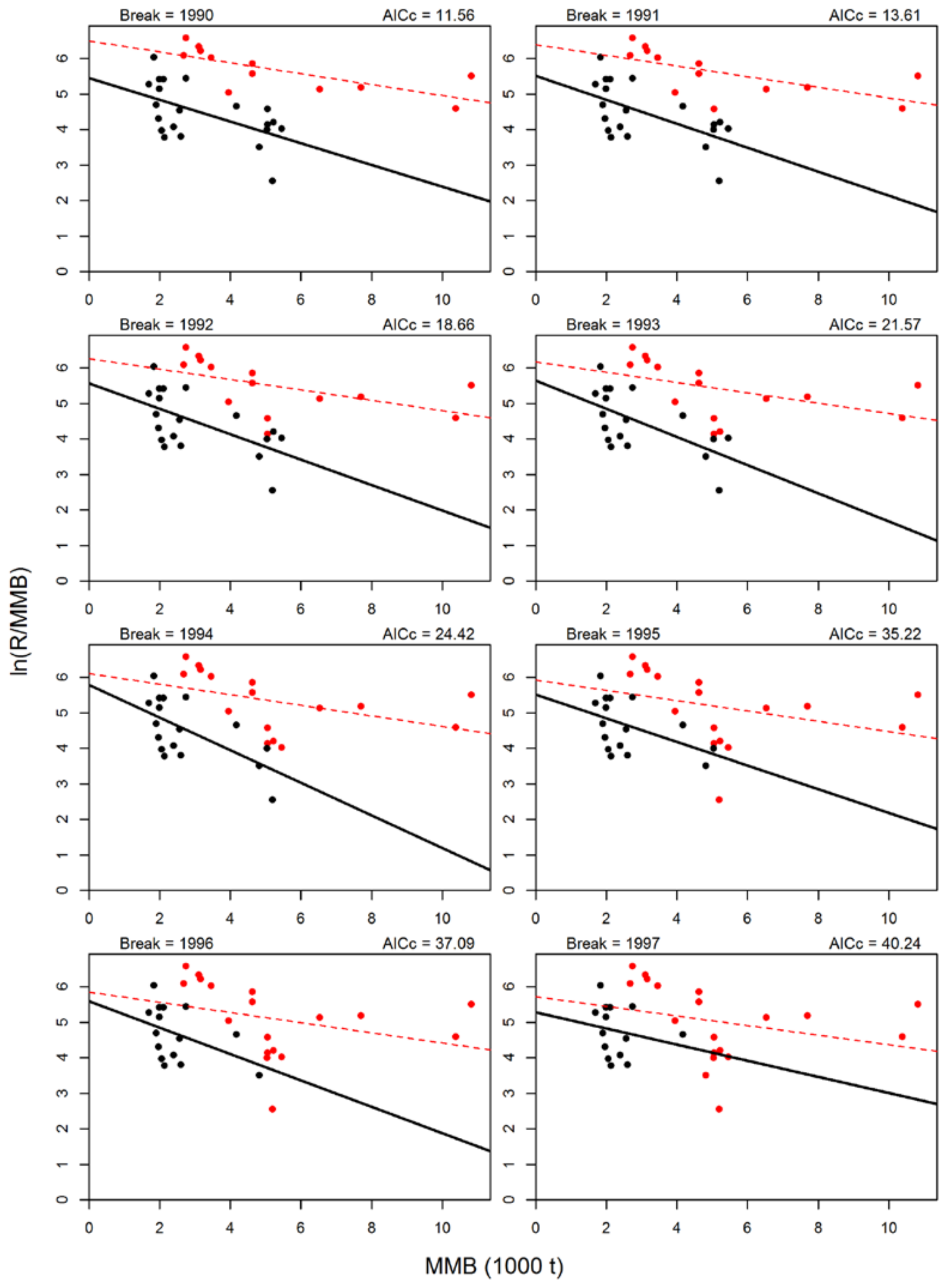

Figure D9. Continued.

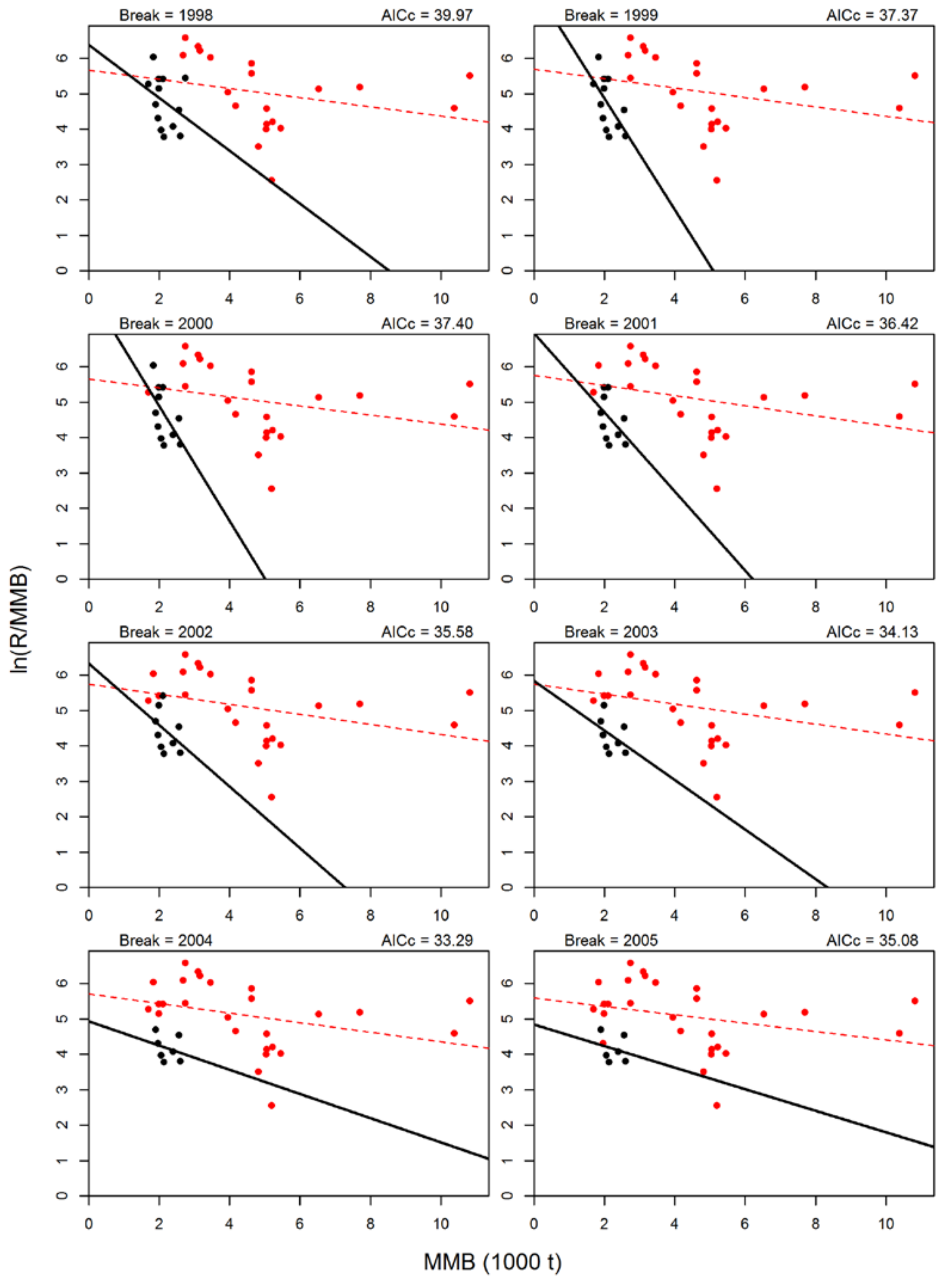

Figure D9. Continued.

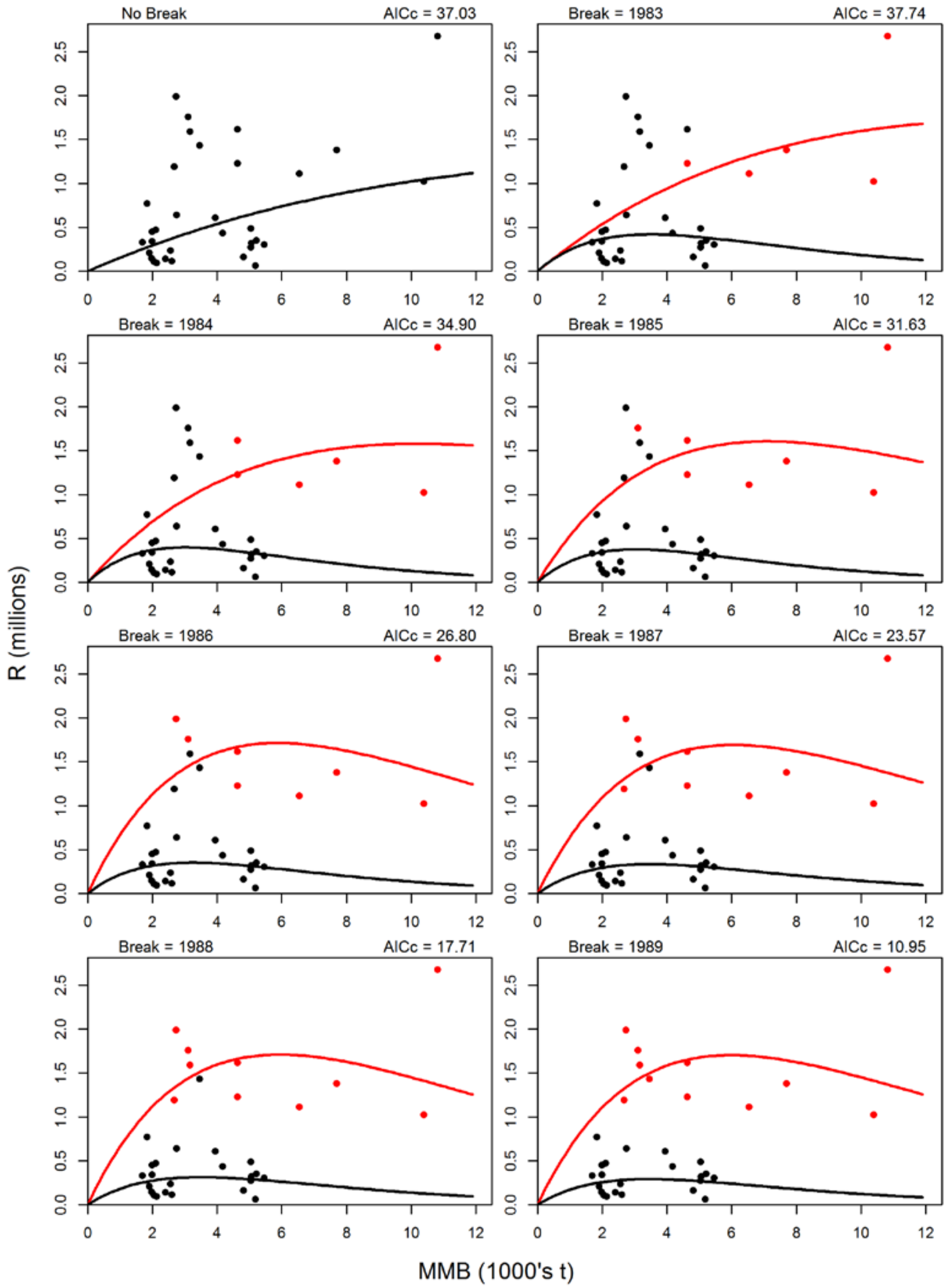

Figure D10. Fits on the arithmetic scale for the sensitivity analysis using the Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1978-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.

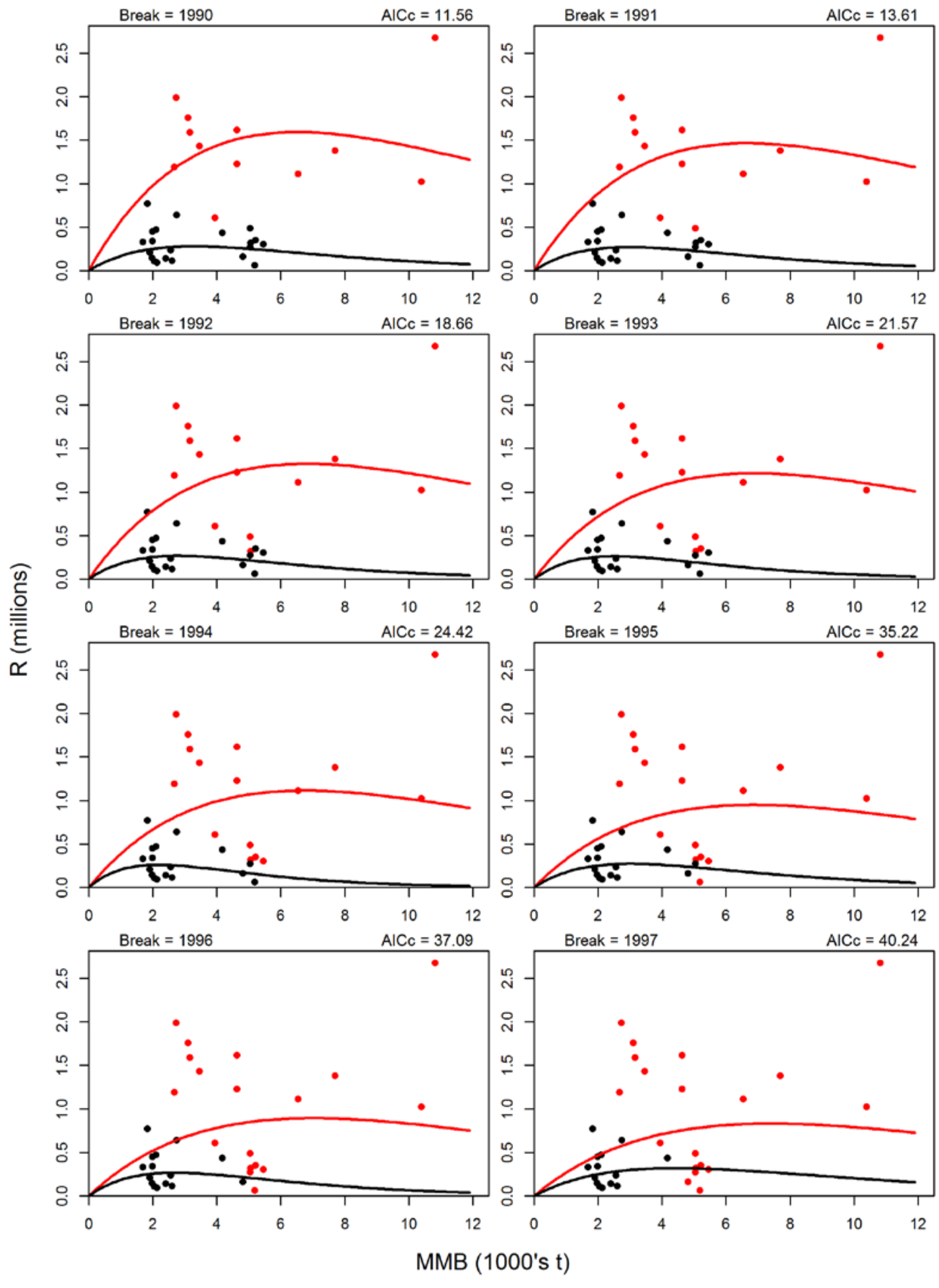

Figure D10. Continued.

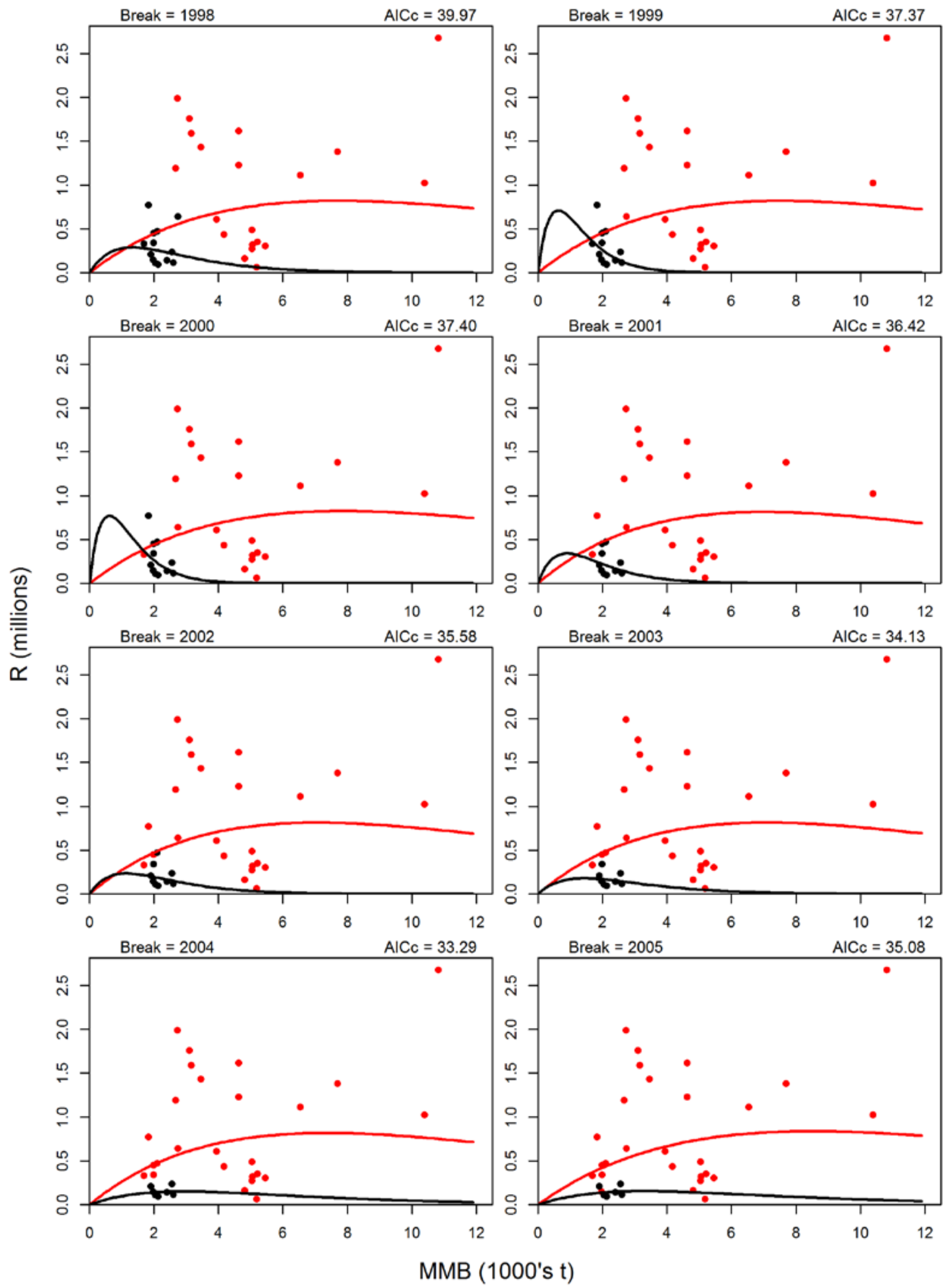

Figure D10. Continued.

Ecosystem and Socioeconomic Profile of the Saint Matthew Blue King Crab stock in the Bering Sea

Erin Fedewa, Brian Garber-Yonts, Kalei Shotwell and Katie Palof

September 2019

Executive Summary

National initiative and NPFMC recommendations suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for the Saint Matthew blue king crab (SMBKC) stock. Scores for stock assessment prioritization, habitat prioritization, climate vulnerability assessment, and data classification analysis were moderate to high. The SMBKC ESP follows the new standardized framework for evaluating ecosystem and socioeconomic considerations for SMBKC 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 SMBKC stock in the Bering Sea and present results of applying the ESP process through a metric and subsequent indicator assessment. Analysis of the ecosystem and socioeconomic metrics 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.

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 recruitment and the overfished declaration in 2018.
- Trend modeling for ecosystem indicators revealed poor conditions for SMBKC in recent years, attributed to above average bottom temperatures, a reduction in the cold pool extent, and an increase in mean benthic predator biomass in the St. Matthew Island management boundary.

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.

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 (Sigler et al., 2017; 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 Bering Sea Saint Matthew blue king crab (hereafter referred to as SMBKC) 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 four-step ESP process begins with an evaluation of the stock assessment classification results (Lynch et al., 2018) to assess the priority for conducting an ESP and the target ecosystem linkage level. Once it is established to conduct an ESP, the second step is a metric assessment. Metrics are quantitative stock-specific measures that identify vulnerability or resilience of the stock with respect to biological or socioeconomic processes. Where possible, evaluating these metrics by life history stage can highlight potential bottlenecks and lead to a mechanistic understanding of ecosystem or socioeconomic pressures on the stock. The third step is an indicator assessment where a time-series suite is created that represent the critical processes identified by the metric assessment. These indicators must be useful for stock assessment 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. The final step of the ESP is to report potential ecosystem and socioeconomic recommendations, data gaps, caveats, and future research priorities.

Justification

The national initiative prioritization scores for SMBKC are overall moderate to high primarily because the distribution of this stock depends greatly on habitat, there was increasing model development for this stock, and there is potential vulnerability to impacts of future ocean acidification. Also in 2018 the stock was declared overfished, warranting the Crab Plan Team to request an evaluation of ecosystem factors to inform the stock rebuilding plan. 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 SMBKC stock in order to identify data gaps and assess the priority for conducting an ESP. SMBKC is currently managed as a Tier 4 crab stock and as such, the new data classification scores characterize the stock as data-limited with insufficient life history, natural mortality and recruitment data. Both current and target data availability attribute levels for the SMBKC stock size composition attribute were classified as a 3, which adequately supports a size-structured stock assessment. However, catch, 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 survey extent/design to better understand the spatial extent of the stock, increases in stock specific growth and other life history information, and 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 SMBKC.

Data

Initially, information on SMBKC 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. The form data serves 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 metrics and indicators for the SMBKC ESP were collected from surveys, regional reports, laboratory studies and the literature (Table 1). Information for the first year of life was collected primarily from laboratory studies completed at the Kodiak Fisheries Research Center (Long and Daly, 2017), Hatfield Marine Science Center (Stoner et al., 2013) and the Alutiiq Pride Shellfish Hatchery (Herter et al., 2011). Data for late-juvenile through adult BKC stages were derived from the annual NOAA eastern Bering Sea bottom trawl survey and the triannual Alaska Department of Fish and Game St. Matthew Pot Survey. The NOAA bottom trawl survey has been collected annually since 1975 and uses a standardized 376 station grid from Bristol Bay to northwest of St. Matthew Island. Data collected on the survey provides fishery-independent estimates of groundfish and crab abundances and biological data (Zacher et al., 2019). Due to the rocky substrate preferences of BKC, much of the habitat utilized by the SMBKC stock is untrawlable and biomass estimates are underrepresented using NOAA standardized survey gear. As a result, Alaska Department of Fish and Game has conducted the St. Matthew Pot Survey triannually since 1995. In addition to reporting spatial trends in CPUE, the pot survey provides biological data from areas not surveyed by the NOAA trawl survey and is better suited to sample nearshore areas where mature female BKC are concentrated (Watson, 2004; Pengilly and Vanek, 2014).

Information on BKC habitat use was derived from essential fish habitat (EFH) model output and maps (Laman et al., 2017) as well as a recent data rescue effort to recover historic cruise data across all life history stages of the Pribilof Islands BKC stock (Armstrong et al., 2015). 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. The Food Habits database consists of diet data collected from major groundfish species during the annual NOAA eastern Bering Sea bottom trawl survey.

Data used to generate socioeconomic metrics and indicators are derived from fishery-dependent sources, including commercial landings data for SMBKC collected in ADFG fish tickets (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 SMBKC 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 SMBKC. 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 SMBKC relate to other groundfish and crab stocks and highlights the potential vulnerabilities and data gaps for the stock. The 80th and 90th percentile rank areas are provided to highlight metrics that cross into these zones indicating a high level of vulnerability for SMBKC (Figure 1, yellow and red shaded area).

For SMBKC ecosystem metrics, latitude range, depth range, adult mobility, ocean acidification sensitivity and predator stressors fell within the 90th percentile rank of vulnerability, suggesting that BKC are habitat specialists and highly sensitive to changes in resource availability and habitat requirements. Additionally, predation pressure is very high during early life history stages and BKC are particularly vulnerable to predators after molting. Recruitment variability, temperature range, fecundity, habitat specificity, habitat dependence index and habitat vulnerability index fell within the 80th percentile rank when compared to other stocks in the groundfish and crab FMP's. SMBKC were also relatively resilient for breeding strategy index, hatch size and ecosystem value top-down and bottom-up. These initial results suggest that stage-based information regarding the implications of high predation, climate change, and habitat quality would be both valuable for the stock and would assist with subsequent indicator development. For the three applicable socioeconomic metrics, values indicated medium to low vulnerability.

SMBKC had numerous data gaps for ecosystem metrics, including growth rate, length at 50% maturity, maximum length, spawning duration, dispersal ELH, prey specificity and mean trophic level. The data quality was rated as medium to complete for all metrics with data available except for natural mortality, recruitment variability and ecosystem value top-down. The numerous data gaps highlight the need for additional studies to contribute to a better understanding of BKC 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. However, BKC early life history processes are not well understood and data has been provided primarily from laboratory studies (e.g. Stoner et al., 2013, Long and Daly, 2017). As a first attempt to synthesize distribution, habitat usage and phenology of BKC across all life stages, we created a baseline life history conceptual model which is detailed in Figure 2. In the conceptual model figure, abiotic and biotic processes were identified by each life stage from the lead author and relevant papers. The main categories of the primary ecosystem processes influencing BKC life stages were identified as water temperature, larval transport and retention, habitat suitability and impact of predation. Details on why these processes were highlighted in the conceptual model and the potential relationship between these processes and the different life stages are described below.

BKC larval development consists of four zoeal stages and one glaucothoe stage, after which larvae metamorphose and settle as stage C1 benthic juveniles (Persselin, 2006). Cultivation experiments reported a 91.7% survival rate of BKC larvae from hatching to C1 stage at 6°C with increased mortality at rearing temperatures greater than 9°C (Stevens et al., 2005; Stevens et al., 2008a). While BKC larvae exhibit an upper thermal tolerance in captivity, cooler water temperatures could, in turn, slow development rates and increase mortality due to both increased larval transport and larval stage duration (Loher, 2014). Dispersal pathways of SMBKC larvae are currently unknown but advection and dispersal rates may be a significant driver of recruitment dynamics, as observed in other EBS crab stocks (Rosenkranz et al., 1998; Richar et al., 2015; Daly et al., 2018). Transport to favorable settlement grounds in the nearshore waters of St. Matthew Island is most likely dependent on high localized retention rates of BKC larvae although studies are needed to identify relationships between oceanographic conditions, larval transport and recruitment success.

During the early juvenile stages, successful settlement requires shallow, nearshore waters (<50m) and hard substrate such as shell hash, gravel or rock due to the reliance of BKC on crypsis to evade predation (Armstrong et al., 1985; Daly and Long, 2014). Survival in juvenile BKC is linked to mollusk shell abundance, including mussels (*Modiolus modiolus*), scallops (*Chlamys* sp.), rock oysters (*Pododesmus macrochisma*), and hairy tritons (*Fusitriton oregonensis*) (Chilton et al., 2011; Palacios and Armstrong, 1985). Unlike RKC, juvenile BKC lack a heavy covering of carapace spines and do not form pods to offer protection from predation, emphasizing the role of habitat complexity in BKC survival (Stevens, 2014). In addition, juvenile BKC molt several times a year during early benthic instar stages and are especially vulnerable to predation while soft. Pacific cod have been shown to predate heavily on soft-shell female red king crab (Livingston, 1989) and are likely also a key predator on juvenile BKC. Early juvenile BKC appear to have a broad range of temperature tolerance, indicated by relatively high survival over the range of temperatures tested (1.5 to 12 °C) in a laboratory experiment (Stoner et al., 2013). This is likely advantageous during the juvenile stage when BKC utilize relatively shallow habitats more prone to temperature fluctuations.

Late juvenile and adult BKC are less reliant on habitat with complex substrate, however a suite of habitat variables can be used to predict SMBKC distribution and identify vulnerabilities associated with suitable habitat characteristics. EFH models suggest that the probability of mature BKC abundance is highest over coarser sediments and lower maximum tidal currents (Laman et al., 2017). Temperature and depth likely also represent vulnerabilities given that mature female BKC migrate to relatively shallow, nearshore waters south of St. Matthew Island during the spring and summer months when bottom temperatures reach their maximum (Pengilly and Vanek, 2014). BKC exhibit reduced growth rates at 12°C and above, with feeding ration increasing with temperature up to 6°C (Long and Daly, 2017). In addition to temperature effects on BKC physiology, laboratory studies have demonstrated temperature-mediated shifts in hatch timing and embryo development (Stevens et al., 2008b). The biannual molt and reproductive strategy characteristic of BKC in contrast to most other *Paralithodes* spp. suggests that energetic restrictions imposed by temperature or prey conditions may be a limitation in reproductive dynamics (Webb, 2014; Jensen et al., 1985). However, adult BKC are generalists and as such, it is hypothesized that benthic prey abundances may not play an important role in life history processes.

Socioeconomic Processes

As discussed in more historical detail in Leon et al. (2017), the commercial SMBKC fishery began in 1977, with 10 vessels harvesting 1.2 million pounds (including deadloss), increasing to 22 vessels in 1978, harvesting 2.0 million pounds, and declining over the next two years to 2 active vessels in 1980. Over the next three years, the fishery increased from 31 active vessels in 1981 harvesting 4.6 million pounds to 164 vessels landing 9.5 million pounds in 1983, the largest annual catch volume in the fishery to-date and the first year of management under a declared GHL, which began at 8 million pounds. In subsequent seasons through 1997, the GHL varied from 0.5 million to 5.0 million pounds, with an active fleet varying between 31 and 174 vessels and total landings varying between 1.0 million pounds in 1986 (exceeding the preseason declared GHL range of 0.2 – 0.5 million by 100%) to 4.6 million pounds in 1997. With the initial year of the CDQ program in 1998, the fishery opened with a GHL of 5.0 million pounds, with 1.0 million pounds allocated as CDQ quota in addition to 4.0 million pounds in the general allocation fishery; the latter was prosecuted by 131 active vessels harvesting 2.9 million pounds before the fishery was closed inseason, however, only one active vessel harvested CDQ and total 1998 catch cannot be reported due to confidentiality of the CDQ catch.

The stock declined following the 1998 season, being declared overfished by NMFS in 1999 based on the results of the summer trawl survey, and the fishery was closed from the 1999 to 2008/09 seasons, with a rebuilding plan being implemented beginning in 2000. The fishery reopened for the 2009/10 season under the CR program and TAC management (both of which began in 2005 for the 2005/06 crab season), with a combined TAC of 1.67 million pounds (90% issued as IFQ allocation and 10% as CDQ), and with 7 active vessels harvesting 0.46 million pounds (39% of the TAC). The fishery remained open over the next three seasons, increasing to 2.4 million pounds TAC in 2011/12, with 18 active vessels harvesting 1.9 million pounds (80% of the TAC), and 1.63 million pounds TAC in 2012/13, with 17 active vessels harvesting 1.62 million pounds, approaching full utilization of the TAC for the first time under the CR program. Due to low abundance in the 2013 survey, the fishery was closed for 2013/14, and opened for the next two seasons with substantially reduced TACs relative to previous open seasons, at 0.66 million pounds in 2014/15 and 0.41 million pounds in 2015/16, and the number of active vessels during the two most recent seasons reduced to 4 and 3 vessels, respectively, with a catch of 0.11 million pounds in 2015/16 and utilization of the available catch limit declining to 26%, the lowest level in the fishery to-date. The fishery has been closed during each of the last three crab seasons, beginning in 2016/17.

Over the 1977 to 1998 period, the SMBKC fishery was prosecuted during open seasons that varied in length and timing, with the earliest opening on June 7 in 1977, growing later over subsequent seasons to August 1 in 1982, September 1 in 1985, and September 16 in 1991, and September 15 from 1993 through 1998. Prior to 1982, SMBKC openings ranged from approximately 5 to 9 weeks, with the latest closing on September 3 after 19 days in both 1978 and 1980. Over subsequent years prior to 2005, openings in the fishery were limited to shorter spans of 1 to 11 days, with the latest closing in 1998 on September 26. With the implementation of the CR program, the regulatory season for SMBKC was shifted to October 15 through February 1, with active fishing typically during years when the fishery opened occurring within a period of 4-5 weeks beginning October 15, with final landings for the respective seasons occurring during early- to mid-November. Over the more recent history of the SMBKC fishery, active vessels have prosecuted the SMBKC fishery in the period preceding active fishing in the other rationalized crab fisheries (most commonly the Bristol Bay RKC and Bering Sea snow crab fisheries, with some vessels also fishing in the Bering Sea Tanner crab fisheries) and groundfish, with SMBKC contributing a component to associated vessels' fishing portfolio, and comprising a small to moderate proportion of total annual ex-vessel revenue for most vessels active in SMBKC during a given year.

Indicators Assessment

Indicator Suite

We first provide information on how we selected the indicators for this third step of the ESP process and then provide results on the indicators analysis.

Ecosystem Indicators

Very few studies have linked environmental 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 red and blue king crab stocks in the early 1970's corresponded with low temperatures. However, recruitment trends are not consistently explained by temperatures or decadal-scale environmental variability (Zheng and Kruse, 2006). Furthermore, groundfish predation has been hypothesized as a mechanism driving recruitment variability. SMBKC recruitment was positively correlated with Pacific cod biomass, opposite of the hypothesized directionality of predation effects on recruitment (Zheng and Kruse, 2006). The lack of general or biologically meaningful relationships supporting recruitment hypotheses for SMBKC in these studies may be attributed to analyses using basin-scale indicators that are not relevant to the small spatial scale of the SMBKC management area.
When selecting a suite of indicators for the SMBKC ESP, efforts were instead focused on developing spatially explicit indicators bounded by the SMBKC management area. These indicators are described below.

Bottom temperature and cold pool indicators representing environmental conditions during the summer survey period are likely drivers of juvenile and adult BKC distribution, timing of the reproductive cycle and larval transport. BKC females move inshore in late spring to hatch eggs, molt and mate (Armstrong et al., 1981). These inshore movements may be triggered by warming bottom temperatures, suggesting that cold years in the Bering Sea have the potential to delay mating migrations, embryo development and hatching as demonstrated in laboratory studies (Stevens et al., 2008b). Temperature-mediated shifts in hatch timing could subsequently result in BKC larvae mismatches with prey resources, or increase the probability of advection away from favorable nursery grounds. 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).

An indicator representing the cold pool extent (<2°C) is not only important in driving BKC distributions, but also in driving distributions of major predators of BKC. Pacific cod and several flatfish species typically avoid temperatures less than 1° C (Kotwicki and Lauth, 2013), suggesting that years with a large cold pool extent around St. Matthew Island may offer BKC a refuge from predation.

A SMBKC pre-recruit biomass index effectively tracks the number of males that will likely enter the fishery the following year. Small catches of these sub-legal BKC are often a reliable indicator of impending declines in mature male biomass and may be useful as an early indicator of stock recovery for the SMBKC rebuilding plan. Likewise, a male bycatch indicator tracks mortality in trawl and fixed gear fisheries and fluctuations in bycatch rates may necessitate different regulations on groundfish fisheries or area closures to limit BKC mortality due to bycatch.

Estimates of benthic predator biomass (i.e. Pacific cod, sablefish, Pacific halibut, skates, sculpin, octopus and assorted flatfish) and invertebrate biomass (i.e. brittle stars, sea stars, sea cucumber, bivalves, non-commercial crab species, shrimp and polychaetes) provide information on the relative fluctuations of these foraging guilds (BSAI ESR, 2018). Increases in benthic predator biomass may represent increased mortality events due to predation on BKC. Although no studies on BKC diet and foraging ecology exist to date, species included in the invert biomass indicator are important prey sources for other EBS commercial crab species, and therefore likely prey of BKC as well. Increases in invert biomass may suggest optimal foraging conditions for BKC. It is, however, important to note that bottom trawl survey methods result in very low catchability of polychaetes, which are recognized as an important prey source for EBS crab species. Furthermore, increases in highly mobile benthic foragers such as hermit crabs and sea stars may, instead, suggest increased competition for benthic resources. A better understanding of benthic production and foraging ecology in the Bering Sea, and specifically, the St. Matthew Island region, is necessary to refine foraging guild indicators and their impacts on SMBKC.

Socioeconomic Indicators

Indicators reported for applicable socioeconomic metrics are derived from fishery-dependent sources that represent full enumeration of commercial landings captured in ADFG fish tickets, and ADFG and NMFS observer program data that support reliable estimates of fishing effort in the SMBKC fishery and bycatch in groundfish fisheries, respectively. Due to the intermittent opening of the targeted SMBKC fishery over the last 20 years, however, substantial gaps in the time-series for most socioeconomic indicators indicate zero (0) values when no fishery occurred, and the small number of vessels or processors participating in the fishery during some recent openings prevents reporting the value of some indicators for those years to protect confidentiality of associated landings and/or catch and effort data. The socioeconomic indicators reported below were selected in part on the basis of maximal length of time-series available[1], however, discontinuities in some data series due to changes in data collection methods limit reporting of indicator values to 1991 and later. Also, because the most recent fishery-dependent data sources 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), socioeconomic indicators are limited to providing retrospective information. Although relative to other crab and groundfish stocks, SMBKC is not data-poor with regard to most socioeconomic dimensions relevant to the fishery, the time-series gaps in socioeconomic indicators reported below may limit the ability to identify trends or movements in the indicators contemporaneous with reported ecosystem indicators and other factors considered in the SMBKC assessment. Combined with other functional limitations, this may substantially diminish the utility of these or other potential socioeconomic indicators for many of the purposes envisioned for the ESP.

The socioeconomic indicators reported below can be grouped into two broad, interrelated categories: 1) those addressing dimensions of commercial value, constituent demand and community dependence, and 2) indicators related to the relative quantity and efficiency of fishing effort. The latter set of indicators are reported in the assessment and are included in Figure 4 to support visual comparison of the relative values and trends in the respective sets of indicators.

Commercial value and constituent demand indicators

Ex-vessel price per pound, 1991-2015 ($2018)

Ex-vessel prices are revenue per pound of retained SMBKC catch, delivered live and sold to processors. 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.

SMB exvessel revenue share (% of total exvessel revenue)

This indicator represents the proportion of total annual ex-vessel revenue from all crab and groundfish landings for vessels active in the SMBKC fishery during a given calendar year that is produced from the SMBKC fishery. The reported values are calculated as the vessel-level mean SMBKC revenue share over the set of vessels active in the fishery for the year. Revenue share provides an indicator of the relative income dependence of participating vessels on the SMBKC 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.

Processors active in fishery

The number of processors (buyers) of SMBKC landings during the year; this provides an indicator of the density of the market for SMBKC landings.

Local Quotient of SMB landed catch in Saint Paul

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.

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[1]As one of the eight FMP crab stocks included in the Crab Rationalization Program, substantial additional data are available for the SMBKC fishery that are collected by NMFS in several mandatory reporting data collections that were initiated in 2005 to monitor the performance and effects of the management program, including the ownership of CR crab harvesting and processing quota share (QS) and the quantity and value of QS transfers between buyers and sellers, and vessel and plant operating cost, quota lease activity and value, and employment data reported by crab fishing and processing sector participants in the Crab Economic Data Report (EDR) program. Although these and other CR program-specific data collections provide substantial additional data to support a variety of socioeconomic indicators of potential utility for the purpose of the ESP (many of which are reported in BSAI Crab Economic Status Reports produced annually by AFSC (Garber-Yonts and Lee, 2019), the associated data series are only available beginning 2005 or more recent, and are largely subject to the same intermittency as other fishery-dependent data available for the SMBKC fishery.

TAC Utilization (%)

The percentage of the available catch allocation (GHL or TAC) that was harvested by participating vessels (including catch discarded as deadloss at the landing). Underutilization of the available TAC indicates a low value of expected returns from fishing SMBKC relative to alternative fishing targets, or idling the vessel.

Fishing effort

Vessels active in fishery

Total Potlifts

CPUE (no. of crabs per potlift - mean)

SMBKC male bycatch biomass (1000t)

Indicator Monitoring Analysis

The suite of indicators for SMBKC is monitored using a series 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 only report the results of the first stage indicator testing procedure for SMBKC. The first stage is a simple assessment of the trend and variance of the most recent year and a traffic-light evaluation of the most current year of data when available (Tables 2-3). The traffic-light ranking of the current year is based on the 20th and 80th percentiles of the time series and the color of blue, yellow, or red related to being below, within, or above the two percentiles (Caddy et al., 2015).

Ecosystem indicator trends suggest poor environmental conditions during the past 5 years for the SMBKC stock. Summer bottom water temperatures in the St. Matthew management area were at an all-time high in 2018 while the cold pool did not extend into the management area. Similar conditions were observed during 2019 summer survey operations. SMBKC pre-recruit biomass has also been on a steady decline since the mid-1990's and the 2017 recruitment estimate is the third lowest in the 41 year time-series, following the lowest previously observed in 2016. Results of a recent breakpoint analysis suggest a SMBKC recruitment regime shift around 1996, corresponding with a 1989 brood year (Palof et al., 2019). Interestingly, there is empirical evidence for a 1989 regime shift in the North Pacific which was attributed to declines in Bering Sea groundfish recruitment and overall decreases in marine productivity (Hare and Mantua, 2000). Synchronous declines in time-lagged SMBKC recruitment suggest that ELH stages of BKC may have been negatively affected by these basin-scale ecological changes. Furthermore, warmer than average bottom temperatures in the St. Matthew Island management area in recent years correspond with low recruitment, suggesting that temperature may have an indirect effect on BKC early life history processes and survival to recruitment. In past years, trawl survey station R-24, on the northwest corner of St. Matthew Island, has been characterized by large catches of mature male BKC (Zacher et al., 2019). In 2018 and 2019, BKC catches were very low at R-24, corresponding with bottom temperatures nearing the upper limit of BKC thermal requirements. These observations may suggest that BKC habitat quality is decreasing as shallow, nearshore habitats warm to 6°C and above.

Benthic predator biomass was at an all-time high in 2016, attributed to high catches of Pacific cod surrounding St. Matthew Island. Likewise, in 2016 benthic invert biomass was up from previous years, characterized by high catches of several sea star species (*Ctenodiscus crispatus, Gorgonocephalus eucnemis and Leptasterias polaris*) as well as *Hyas coarctatus and Pagarus trigonocheirus*. 2016 biomass increases in highly mobile decapods and echinoderms may suggest increased competition for food resources available for juvenile and adult BKC. Both benthic predator and benthic invert biomasses have since declined, although remain above-average.

As a full suite of indicators is developed in the coming years, bayesian adaptive sampling (BAS) will be used for the second stage modeling application to quantify the association between hypothesized predictors and SMBKC along with the strength of support for each hypothesis.

Recommendations

In initial projections for the SMBKC rebuilding plan, recruitment appears to drive recovery time of the stock so we emphasize a concerted focus on developing a better understanding of early life history processes and the continued development of indicators relevant to larval and juvenile SMBKC. Developing an EFH habitat indicator for SMBKC should also be prioritized, as metric assessment results highlighted several vulnerabilities related to habitat. These updated indicators may then be used in second and third stage testing and modeling.

With these future priorities in mind, we provide the following set of considerations:

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 poor conditions for SMBKC in recent years attributed to above average bottom temperatures, a reduction in the cold pool extent, and an increase in mean benthic predator biomass in the St. Matthew management boundary.

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. 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 the development of a larval retention indicator. Furthermore, additional groundfish stomach data outside of the summer survey time series would help to refine our understanding of predation pressure across life history stages of SMBKC. Likewise, spring bottom temperatures prior to the summer bottom trawl survey may help to understand SMBKC distribution in relation to survey catchability.

As noted above, 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.

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Literature Cited

Armstrong, D., Incze, L., Wencker, D., and Armstrong, J. 1981. Distribution and abundance of decapod crustacean larvae in the southeastern Bering Sea with emphasis on commercial species.: 53. 479-878 pp.

Armstrong, D. A., Armstrong, J. L., Palacios, R., Williams, G., Jensen, G. C., and Pearson, W. 1985. Early life history of juvenile blue king crab, *Paralithodes platypus*, around the Pribilof Islands. *In* Proceedings of the International King Crab Symposium, pp. 211-229. Ed. by S. K. Davis, F. Gaffney, J. McCrary, A. J. Paul, and R. S. Otto. Alaska Sea Grant College Program, University of Alaska Fairbanks, Anchorage, AK.

Armstrong, D.A., W.C. Long, J. Armstrong, P.S. McDonald. 2015. Blue king crab, habitat, and the ecosystem: Data rescue from the 1980s. NPRB Project 1321 Final Report. North Pacific Research Board.

Caddy, J.F. 2015. The traffic light procedure for decision making: its rapid extension from fisheries to other sectors of the economy. Glob. J. of Sci. Front. Res: 1 Mar. Sci. 15(1), 30 pp.

Chilton, E., Swiney, K., Urban, D.J., and Munk E.J. 2011. Ecosystem considerations for Bering Sea and Aleutian Islands king and tanner crab species *In* Stock Assessment and Fishery Evaluation

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

Daly, B., and Long, W. C. 2014. Intra-guild predation among early benthic phase red and blue king crabs: Evidence for a habitat-mediated competitive advantage. Journal of Experimental Marine Biology and Ecology, 451: 98-104.

Daly, B., A.J. Hermann, C. Parada, S. Hinckley, T.H. Loher, and D.A. Armstrong. 2018. Impacts of climate change on red king crab larval advection in Bristol Bay: implications for recruitment variability. NPRB Project 1402 Final Report. North Pacific Research Board.

Dorn, M. W., C. J. Cunningham, M. T. Dalton, B. S. Fadely, B. L. Gerke, A. B. Hollowed, K. K.

Garber-Yonts, B., and J. Lee. 2019. Stock Assessment and Fishery Evaluation Report for King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions: Economic Status of the BSAI Crab Fisheries, 2018. NPFMC, April, 2019. 178 p. https://www.fisheries.noaa.gov/webdam/download/91792918.

Hare, S.R. and M.J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography, 47: 103-145.

Herter, H., Daly, B., Swingle, J. S., and Lean, C. 2011. Morphometrics, fecundity, and hatch timing of blue king crabs (*Paralithodes platypus*) from the Bering Strait, Alaska, USA. Journal of Crustacean Biology, 31: 304-312.

Holsman, J. H. Moss, O. A. Ormseth, W. A. Palsson, P. A. Ressler, L. A. Rogers, M. A. Sigler, P. J. Stabeno, and M. Szymkowiak. 2018. A climate science regional action plan for the Gulf of Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-376, 58 p.

Jensen, G. C., Armstrong, D. A., and Williams, G. 1985. Reproductive biology of blue king crab, *Paralithodes platypus*, in the Pribilof Islands *In* Proceedings of the International King Crab Symposium, 5th edn, pp. 109-121. Ed. by S. K. Davis, F. Gaffney, J. McCrary, A. J. Paul, and R. S. Otto. Alaska Sea Grant College Program, University of Alaska Fairbanks, Anchorage, AK.

Kotwicki, S., and Lauth, R. R. 2013. Detecting temporal trends and environmentally-driven changes in the spatial distribution of bottom fishes and crabs on the eastern Bering Sea shelf. Deep-Sea Research Part Ii-Topical Studies in Oceanography, 94: 231-243.

Laman, E. A., C. N. Rooper, S. C. Rooney, K. A. Turner, D. W. Cooper, and M. Zimmermann. 2017. Model-based Essentail Fish Habitat Definitions for Bering Sea Groundfish Species. U.S. Dep. Commer., NOAA Tech Memo. doi:10.7289/V5/TM-AFSC-357

Leon, J. M., J. Shaishnikoff, E. Nichols, and M. Westphal. 2017. Annual management report for shellfish fisheries of the Bering Sea–Aleutian Islands Management Area, 2015/16. Alaska Department of Fish and Game, Fishery Management Report No. 17-10, Anchorage. 188 p.

Livingston, P. 1989. Interannual trends in Pacific cod, *Gadus macrocephalus*, predation on three commercially important crab species in the eastern Bering Sea. Fishery Bulletin, 87: 807-827.

Loher, T. 2014. Modeling Larval Advection and Spatial Population Structure in King Crabs: Interactions among Life-History Requirements, Extrinsic Forcing, and Source-Sink Dynamics, *In* King Crabs of the World : Biology and Fisheries Management. Ed. by B. G. Stevens. CRC Press LLC.

Long, W. C., and Daly, B. 2017. Upper thermal tolerance in red and blue king crab: sublethal and lethal effects. Marine Biology, 164: 162.

Lynch, P. D., R. D. Methot, and J. S. Link (eds.). 2018. Implementing a Next Generation Stock Assessment Enterprise. An Update to the NOAA Fisheries Stock Assessment Improvement Plan. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-183, 127 p. doi: 10.7755/TMSPO.183

Palacios, R., and Armstrong, D. 1985. Community analysis applied to characterization of blue king crab habitat around the Pribilof Islands. *In* Proceedings of the International King Crab Symposium, pp. 193-209. Ed. by B. Melteff. University of Alaska Sea Grant Program, Anchorage, AK, USA.

Pengilly, D., and Vanek, V. 2014. Results of the 2013 triennial St. Matthew Island blue king crab pot survey. ICES Document 14-35: No. 14-35. 81 pp.

Palof, K., Zheng, J., Ianelli, J. 2019. St. Matthew Island Blue King Crab Stock Assessment *In* Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Persselin, S. 2006. Cultivation of king crab larvae at the Kodiak Fisheries Research Center, Kodiak, Alaska. *In* Alaska Crab Stock Enhancement and Rehabilitation: Workshop Proceedings, pp. 9-13. Ed. by B. Stevens. Alaska Sea Grant College Program AKSG-06-04.

Richar, J. I., Kruse, G. H., Curchitser, E., and Hermann, A. J. 2015. Patterns in connectivity and retention of simulated Tanner crab (*Chionoecetes bairdi*) larvae in the eastern Bering Sea. Progress in Oceanography, 138: 475-485.

Rosenkranz, G., Tyler, A., Kruse, G., and Niebauer, H. 1998. Relationship between wind and year class strength of Tanner crabs in the southeastern Bering Sea. Alaska Fishery Research Bulletin, 5: 18-24.

Siddon, E., and S., Zador. 2018. Ecosystem Status Report 2018: Status of the Bering Sea marine ecosystem. *In* Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501. 215 p.

Sigler, M. F., M. P. Eagleton, T. E. Helser, J. V. Olson, J. L. Pirtle, C. N. Rooper, S. C. Simpson, and R.P. Stone. 2017. Alaska Essential Fish Habitat Research Plan: A Research Plan for the National Marine Fisheries Service's Alaska Fisheries Science Center and Alaska Regional Office. AFSC Processed Rep. 2015-05, 22 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Stevens, B. G., Persselin, S., and Matweyou, J. 2008a. Survival of blue king crab *Paralithodes platypus* Brandt, 1850, larvae in cultivation: effects of diet, temperature and rearing density. Aquaculture Research: 390-397.

Stevens, B. G., Persselin, S. L., and Matweyou, J. A. 2005. Cultivation of blue king crab larvae, *Paralithodes platypus*: effects of diet, temperature, and density. *In* Larvi '05 - Fish & Shellfish Larviculture Symposium, pp. 485-488. Ed. by C. I. Hendry, G. Van Stappen, M. Wille, and P. Sorgeloos. European Aquaculture Society, Gent, Belgium.

Stevens, B. G., Swiney, K. M., and Buck, L. 2008b. Thermal effects on embryonic development and hatching for blue king crab *Paralithodes platypus* (Brandt, 1850) held in the laboratory, and a method for predicting dates of hatching. Journal of Shellfish Research, 27: 1255-1263.

Stevens, B.G. 2014. Biology and Ecology of Juvenile King Crabs, *In* King Crabs of the World: Biology and Fisheries Management. Ed. by B. G. Stevens. CRC Press LLC.

Stoner, A. W., Copeman, L. A., and Ottmar, M. L. 2013. Molting, growth, and energetics of newly-settled blue king crab: Effects of temperature and comparisons with red king crab. Journal of Experimental Marine Biology and Ecology, 442: 10-21.

Watson, L. J. 2004. Project operational plan for the 2004 Triennial St. Matthew Island blue king crab survey. ICES Document 4K04-26. 55 pp.

Webb, J. 2014. Reproductive Ecology of Commercially Important Lithodid Crabs, *In* King Crabs of the World: Biology and Fisheries Management. Ed. by B. G. Stevens. CRC Press LLC.

Zacher, L.S., Richar J.I., and Foy R.J. 2019. The 2019 Eastern Bering Sea Continental Shelf Trawl Survey: Results for Commercial Crab Species. U.S. Dep. Commer., NOAA Tech Memo.

Zheng, J., and Kruse, G. 2000. Recruitment patterns of Alaskan crabs in relation to decadal shifts in climate and physical oceanography. ICES Journal of Marine Science, 57: 438.

Zheng, J., and Kruse, G. H. 2006. Recruitment variation of eastern Bering Sea crabs: Climate-forcing or top-down effects? Progress in Oceanography, 68: 184-204.

Table 1. List of data sources used in the SMBKC ESP evaluation. Please see the SMBKC SAFE document (Palof et al., 2019), the NOAA EBS Trawl Survey: Results for Commercial Crab Species Technical Memo (Zacher et al., 2019) 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 collected from key groundfish species on the EBS bottom trawl survey	1987-2018	EBS annual
	ADF&G St. Matthew Island Pot Survey	Pot survey for blue king crab in the standard EBS bottom trawl survey area offshore and the nearshore area south and west of St. Matthew Island	1995-2018	St. Matthew Island Management Area, triannual
	Essential Fish Habitat Models	Habitat suitability MaxEnt models for describing essential fish habitat of groundfish and crab in Alaska, EFH 2017 Update	1970-2016	Alaska
	Historic Pribilof Island BKC Cruise Data	Data from zooplankton tows, beam trawl and rock dredge samples and side scan sonar to examine BKC processes across life history stages	1983-1984	Pribilof Islands, EBS
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	1992-2018	Alaska
	ADF&G Crab Observer program data	SMBKC catch and effort data (number of active vessels, total pots lifted, and CPUE), sourced from ADF&G Annual Fishery Management Report	1980-2017	Alaska

Table 2. First stage ecosystem indicator analysis for SMBKC including indicator title and short description. The recent five-year trend (up, down, or stable) and recent five-year mean (greater than (+), less than (-) or within 1 standard deviation (·) of long-term mean) are provided following the ESR methods. Fill is based on 2019 conditions for SMBKC relative to the 20th and 80th percentiles of the time series (yellow = average, blue = good, red = poor, no fill = no current year data). NA = data gap.

Title	Description	Trend	Mean
Summer Bottom Temperature	Average bottom temperature (°C) over all hauls within the SMBKC management boundary of the RACE Bering Sea shelf bottom trawl survey	**Up**	•
Proportion Cold Pool	Proportion of RACE Bering Sea shelf bottom trawl survey stations within the SMBKC management boundary less than 2°C	**Down**	**-**
SMBKC Pre-recruit Biomass	Model estimates for SMBKC recruitment. Includes male crab (105-119 mm CL) that will likely enter the fishery the following year.	**Stable**	•
Benthic Predator Biomass	Combined biomass (1,000t) of benthic predators within the SMBKC management boundary on the RACE Bering Sea shelf bottom trawl survey	**Stable**	+
Benthic Invert Biomass	Combined biomass (1,000t) of benthic invertebrates within the SMBKC management boundary on the RACE Bering Sea shelf bottom trawl survey	**Stable**	+

Table 3. First stage socioeconomic indicator analysis for SMBKC including indicator title and short description. The recent five-year trend (up, down, or stable) and recent five-year mean (greater than (+), less than (-) or within 1 standard deviation (·) of long-term mean) are provided following the ESR methods. Fill is based on most recent conditions for SMBKC relative to the 20th and 80th percentiles of the time series (yellow = average, blue = good, red = poor, no fill = no current year data). NA = data gap.

Title	Description	Trend	Mean
Vessels active in fishery	Annual count of crab vessels that delivered commercial landings of SMBKC to processors[2]	**Stable**	**-**
TAC Utilization	Percentage of the annual SMBKC TAC (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing.	**Down**	•
Total Potlifts	Fishing effort, as measured by estimated number of crab pots lifted by vessels during the SMBKC fishery	**Down**	•
CPUE	Fishing effort efficiency, as measured by estimated mean number of retained SMBKC per potlift	**Down**	•
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.	**Down**	•
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.	**Down**	•
Processors active in fishery	Total number of crab processors that purchased landings of SMBKC from delivering vessels during the calendar year.	**Down**	•
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.	**Down**	•
SMBKC Male Bycatch in Groundfish Fishery	Incidental bycatch biomass estimates of male SMBKC (tons) in trawl and fixed gear fisheries	**Stable**	•

[2]Includes crab catcher/processors that harvested and processed SMBKC catch on-board.

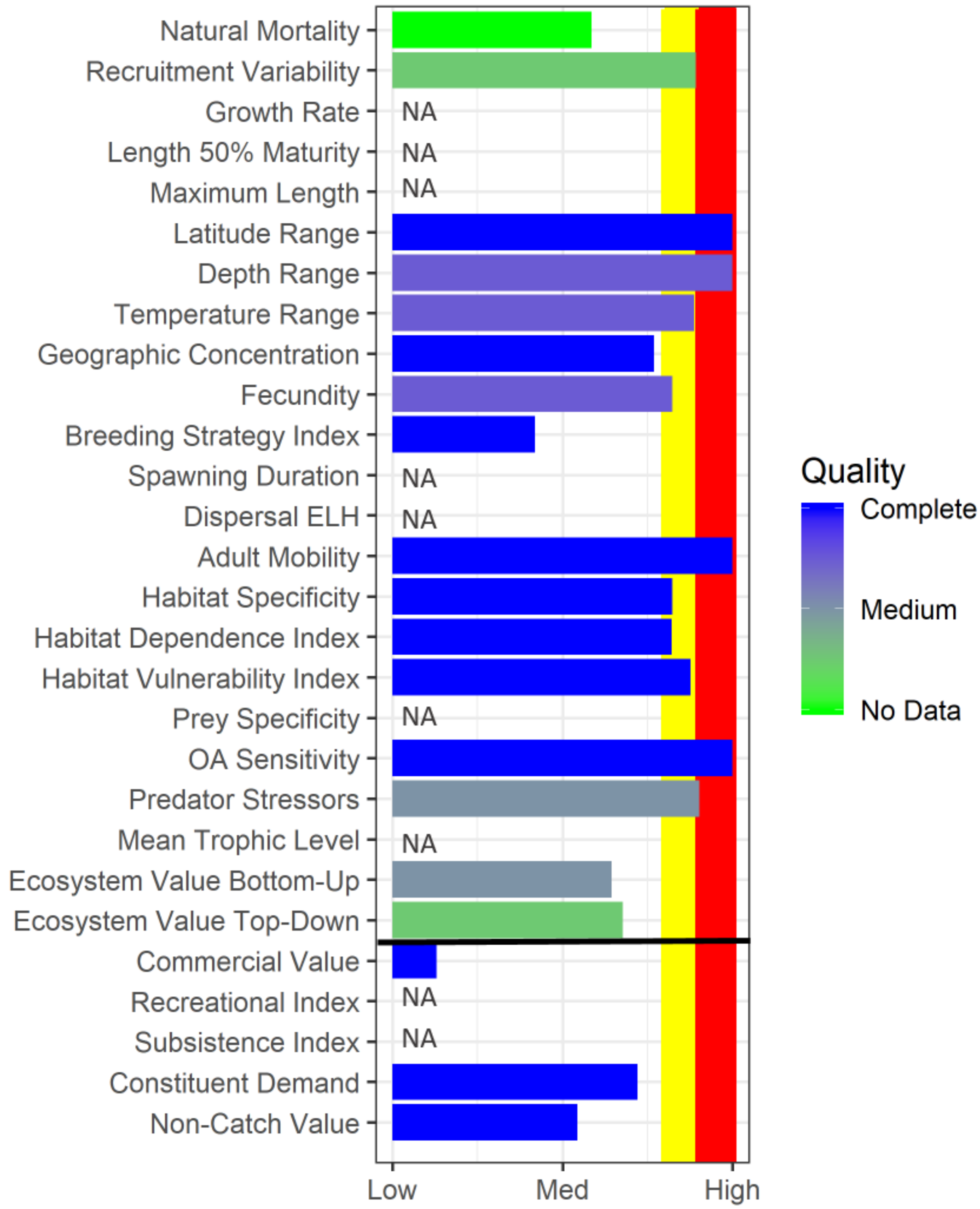


Figure 1. Baseline metrics for SMBKC graded as percentile rank over all groundfish and crab stocks in the FMP. Red bar indicates 90th percentile, yellow bar indicates 80th percentile. Higher rank values indicate a vulnerability and color of the horizontal bar describes data quality of the metric (see Shotwell et al., *In Review*, for more details on the metric definitions). Ecosystem indicators above and socioeconomic indicators below the horizontal black line.

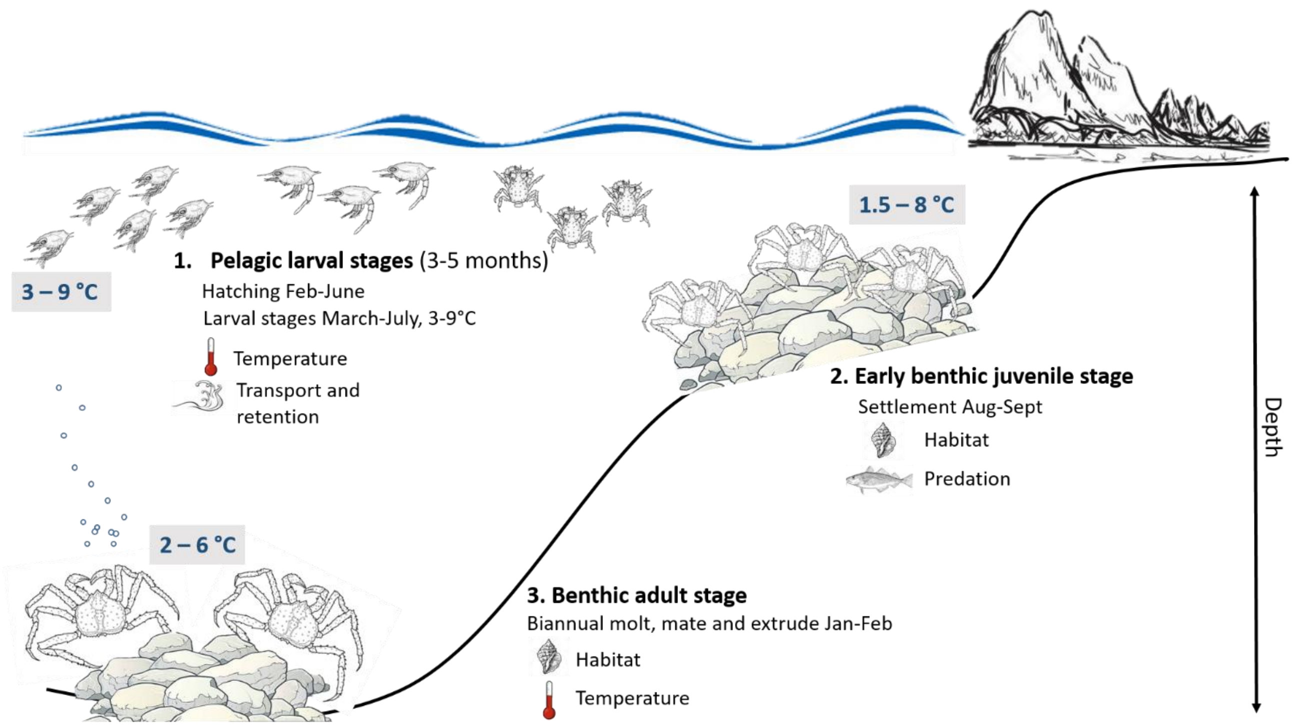


Figure 2. Conceptual diagram of phenological information by life history stage for SMBKC and processes likely affecting survival in each stage. Thermal requirements by life history stage were determined from BKC laboratory studies (Stoner et al., 2013, Stevens et al., 2008a, Stevens et al., 2008b).

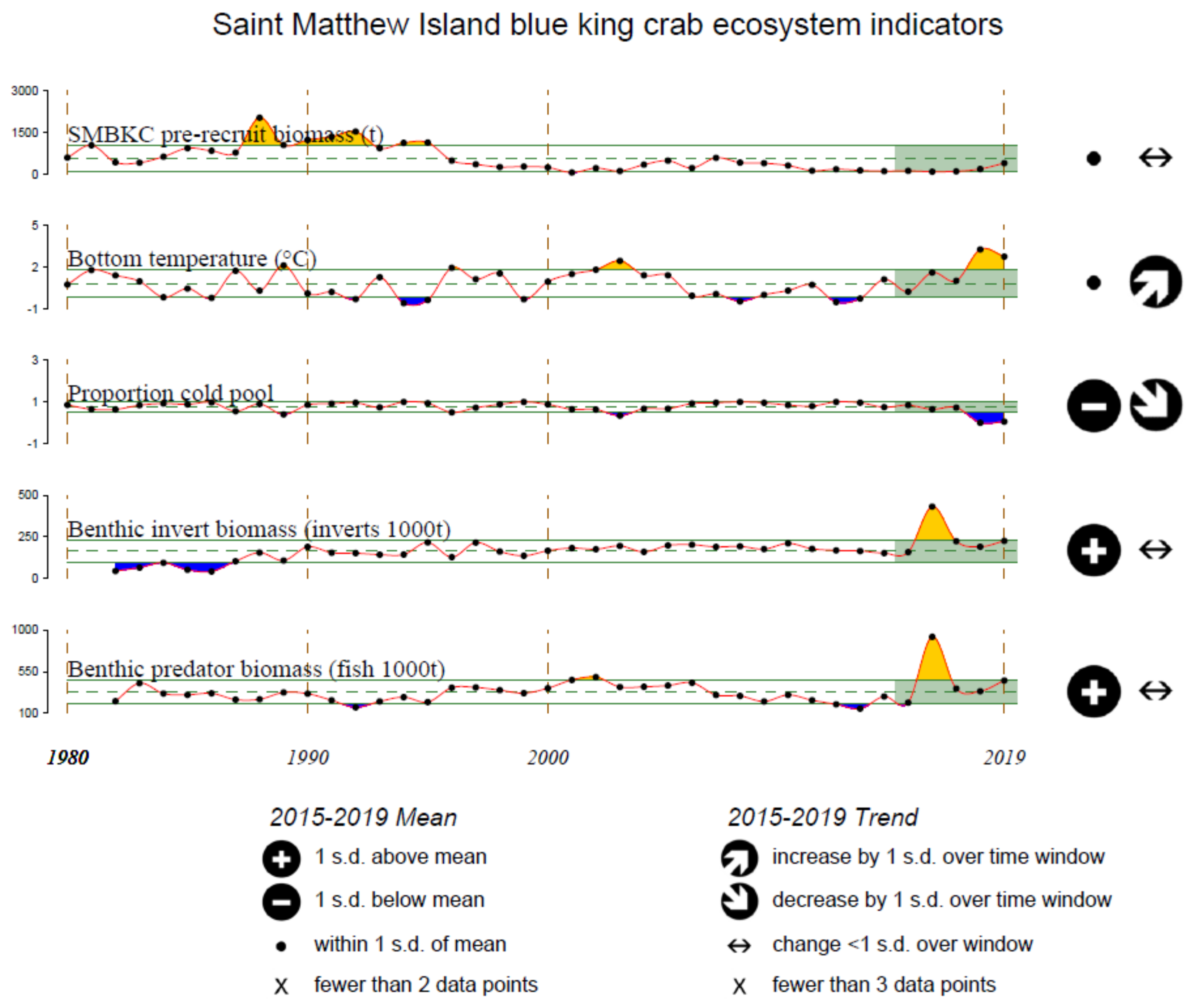


Figure 3. Selected ecosystem indicators for SMBKC with time series ranging from 1980 – 2019. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent five years for mean and trend analysis.

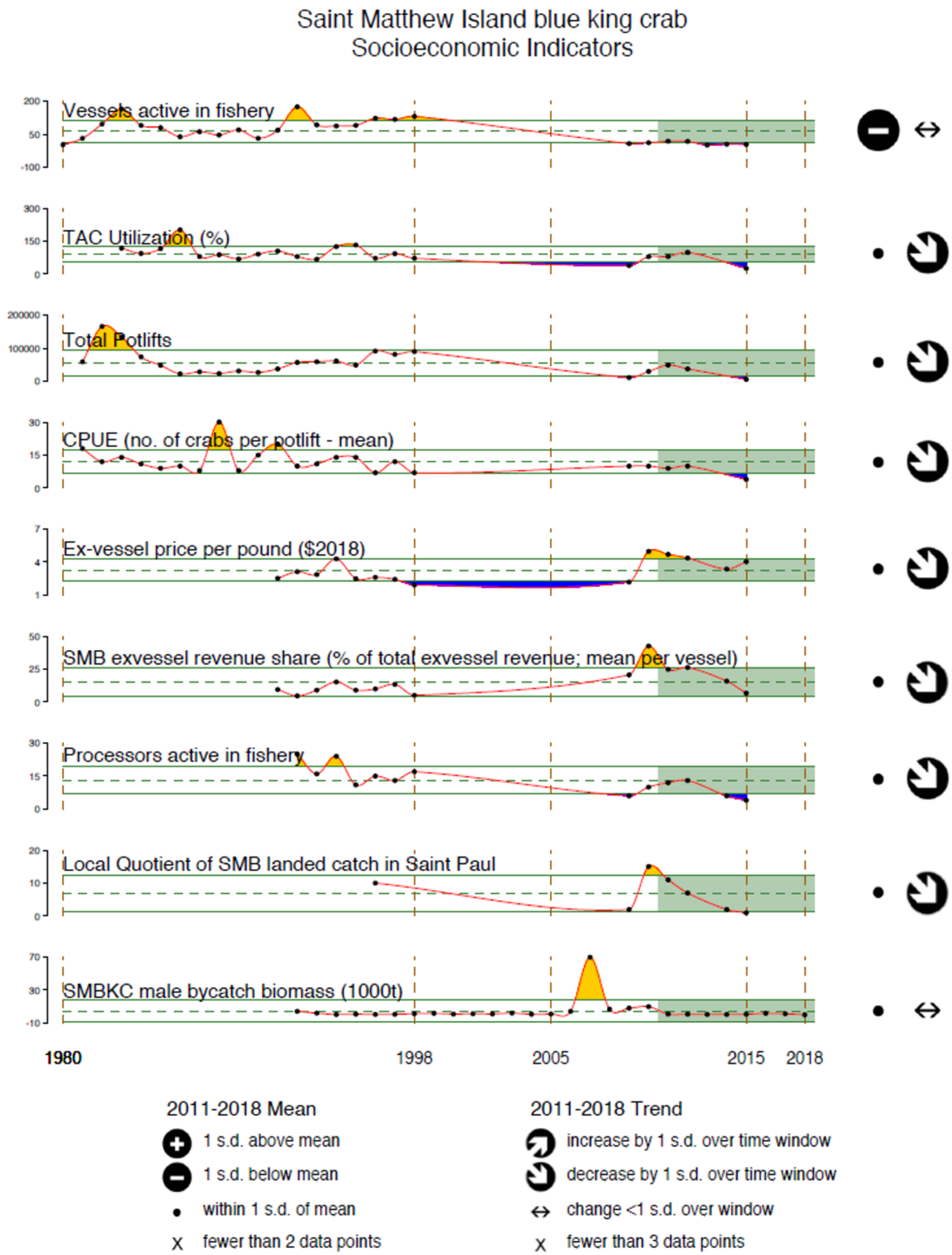


Figure 4. Selected socioeconomic indicators for SMBKC with time series ranging from 1980 – 2019. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of time series. For mean and trend analysis, the light green shaded area represents the most recent eight year period, which includes the most recent five year period (2011-2015) of open fisheries in more than two successive years.

Appendix C. Rebuilding analysis for St. Matthew blue king crab

Introduction

In 2018 the MMB for SMBKC fell below 50% of the B_{MSY} proxy or the MSST, using average mature male biomass from 1978-2017. The stock was determined to be overfished (but overfishing is not occurring since the fishery has been closes the last two years) and a rebuilding plan is to be implemented within 2 years. This document summarizes the projections performed on the 2019 assessment model and their associated rebuilding probabilities for the stock using the projections module developed for GMACS (A.Punt pers Comm). All projections presented here are performed on the base or reference model with 2019 data, results include projections that look at a alternative regime time frame for reference point calculations.

Regime shifts

Model output in 2018 (using the reference model) of both biomass and recruitment suggest a shift from higher levels in the first have of the time series to lower levels in the recent regime. These trends warranted an examination of the modeled data to determine if a regime shift has occurred.

Recruitment breakpoint analysis

Upon examination it was clear that recruitment for SMBKC has been consistently lower in recent years. Thus, the crab Plan Team requested that the authors conduct a recruitment breakpoint analysis similar to that conducted for Bristol Bay red king crab in 2017 (Zheng et al. 2017) and eastern Bering Sea Tanner crab in 2013 (Stockhausen 2013). The goal of this analysis was to objectively identify a change in stock productivity based on the recruitment time series. This could then be used to develop alternative rebuilding scenarios and also provide alternative BMSY proxies. Results from assessment model 3 from 2018, which is the base or reference model (Ianelli and Zheng 2018), were used for this analysis. These results were presented at the May 2019 crab Plan Team meeting, the details of this analysis can be found in Appendix D.

Both Ricker and Beverton-Holt (B-H) models resulted in the same breakpoint brood year of 1989, which corresponded to recruitment year of 1996. The model without a breakpoint (i.e., a single period) was about 26 times less probable than the 1989 breakpoint model for the Ricker stock-recruitment relationship and 4 times less probable than the Beverton-Holt, which suggested a possible change in stock productivity from the early high period to the recent low period.

STARS method

The "Sequential t-Test Analysis of Regime Shifts (STARS)" method was suggested as a alternative analysis that could be used to determine of the St.Matthew blue king crab stock has undergone a regime shift (Rodionov and Overland 2005). The advantage of this method is that it can be performed on any time series and does not rely on a stock recruitment relationship. This method identifies discontinuity in a time-series and allows for early detection of a regime shift and subsequent monitoring of changes in its magnitude over time (Rodionov 2004).

Detection of discontinuity is accomplished by sequentially testing whether a new mean recruitment value within a time-series represents a statistically significant deviation from the mean value of the current 'regime.' As data are added to the time-series, the hypothesis of a new 'regime' (i.e. time block) is either confirmed or rejected based on the Student's t-test (Rodionov and Overland 2005). The STARS method is well documented in the literature and has been applied previously to physical and biological indices (Mueter et al. 2007; Reid et al. 2016; Marty 2008; Conversi et al. 2010; Menberg et al. 2014; Blamey et al. 2012; Lindegren et al. 2010; Howard et al. 2007). An R script (STARS.R; Seddon et al. 2011; http://esapubs.org/archive/ecol/E095/262/suppl-1.php) that is equivalent to the v3-2 excel add-in tool (http://www. beringclimate.noaa.gov/regimes), and references the methods from Rodionov 2004 and 2006, was used to run the STARS method on the recruitment time series from the accepted 2018 model output.

Several parameters within the STARS method need specification prior to application to determine the breaks in the recruitment time series. Two parameters, the p-value (the probability level for significance between 'regime' means) and the cutoff length (the approximate minimum number of years within a regime) control the magnitude and scale of the regimes to be detected, or how strong a change in the recruitment needs to be detected. If regimes are longer than the cutoff length, they will be detected. There is a reduced probability of detection for regimes shorter than the cutoff length, but the regimes may still be detected if the shift is of sufficient magnitude (Rodionov 2004). In addition, Huber's weight parameter determines the weight assigned to outliers and thus the magnitude of the average values of each regime (Huber 1964). Finally, the user determines whether to account for autocorrelation and specifies the associated subsample size needed. For this study, a p-value of 0.05 was chosen, which is well within the range of other studies that have applied the STARS method. A range of cutoff values from 5 to 20 were specified within the STARS method to explore the sensitivity, but all values produced the same significant break year of 1996. The default value of one for Huber's weight parameter, and autocorrelation were included (Newman et al. 2003). Two frameworks are available within the STARS method to estimate autocorrelation (Rodionov 2004): the MPK (Marriott-Pope and Kendall) and the IPN4 (Inverse Proportionality with 4 corrections). The two frameworks break the time series into subsamples, estimate bias-corrected first-order autocorrelation for each subsample and then use the median value of all estimates. The two frameworks produce very similar results and only in certain instances (small subsample size) does the IPN4 method significantly outperform the MPK method (Rodionov 2004). Therefore, the IPN4 method was used in this analysis with the suggested subsample size of m=(l+1)/3, where l is the cutoff length.

This parameterization resulted in two potential time blocks: 1978-1995 and 1996–2017, corresponding to a break in 1996 which is the same year as the recruitment breakpoint analysis that was performed in May 2019.

Rebuilding projections

The rebuilding projections were performed using the projection module coded into GMACS in early 2019 (A. Punt per Comm). A preliminary analysis of the rebuilding projections performed at the January crab plan team meeting by A.Punt concluded that bycatch mortality in this fishery was minor and that the rebuilding timeline was mostly dependent on assumptions of recruitment for the stock.

Initial rebuilding projections presented at the May CPT meeting (June SSC meeting) included recruitment options of: Ricker, or Beverton-Holt stock recruit relationship and "random" recruitment. Stock-recruitment models (Ricker, Beverton-Holt) typically fit poorly for crab stocks, and this holds true for SMBKC. Projections using these stock recruitment relationships were still provided for initial review since they scale recruitment to the current status of the stock. The "random"" recruitment option resamples historical recruitment estimates randomly, from a designated period for each projection iteration, such as the entire time series 1978 to 2018 as one example. This option assumes that recruitment is unrelated to stock size, but also relies on choosing the random draws from a biologically and environmentally representative time frame of past recruitment.

Projections were performed to look at a range of combinations of recruitment, bycatch mortality, and implementation of the state harvest policy to determine the probability of recovery for each scenario. Rebuilding time under any of the projection combinations is insensitive to the average values for recent (2013 - 2017 or 2014 - 2018) bycatch. As a sensitivity analysis the projections presented here were also performed using the maximum observed bycatch value, corresponding to year 2007. The implementation of the state harvest policy in the projections (version "d") affected rebuilding times in some projections, but with a much smaller affect of increasing T_{min} than projections at F = M (0.18), therefore the projections presented here use the state of Alaska harvest policy as the upper bound for fishing mortality.

The projections considered in May produced a range of T_{min} values, however, the decision tackled at this meeting was which option is the most biologically and environmentally plausible. The recruitment breakpoint analysis and the STARS method suggested that recent recruitment (1996-2017) differed from the early part of the time series.

Both the CPT and SSC recommendations from the May meeting were to proceed with "random" recruitment projections that drew from two recruitment time periods:

1) the entire time series, 1978 to 2018
2) the current regime, 1996 to 2018

These projections use the state harvest policy as the upper fishing mortality and included average recent bycatch mortality (2014 - 2018). Additionally, sensitivity on T_{min} values to higher bycatch mortality are included to help inform the rebuilding time frame (using maximum observed bycatch in 2007, which is 10 times here than recent bycatch levels).

The important decision points that are needed to move forward with the rebuilding plan are to adapt a consensus on:

- the current state of the stock (reference point time frame),
- the corresponding expectations on future recruitment, and
- the expectations for future bycatch mortality.

Recommendations from the Sept. 2019 CPT meeting were to consider projections that were presented in May in addition to those initially presented in this document. Therefore, this document was updated to also include additional projections: projection 4 - random recruitment from recent years (1996-2018) with the current reference point time frame (1978-2018) and projection 2 - ricker stock-recruit relationship using entire time series (Tables 1 and 2).

Table 1: Projections performed with associated recruitment assumptions.

Projection	recruitment	B_{MSY} proxy	recruitment years
1	random recruitment	1978-2018	1978-2018
2	ricker	1978-2018	
4	random recruitment	1978-2018	1996-2018
5	random recruitment	1996-2018	1996-2018

Table 2: Versions for each of the projections.

Version	Bycatch mortality	SOA harvest policy
d	present (2014-2018)	yes
aa	max value (2007)	yes

Results

Bycatch mortality

Rebuilding time under any of the projection combinations is insensitive to the average values for recent (2014 - 2018) bycatch. A sensitivity analysis to larger bycatch levels was performed using the maximum observed bycatch value, corresponding to year 2007 in the model input (Figures 1 and 2).

Random recruitment entire time series (1978 - 2018)

Projections using "random" recruitment (projection 1) resampled from the entire time series (1978-2018) implied environmental conditions as being equal to this period. Under this hypothesis the probability of recovery produces, under average recent bycatch levels, a $T_{min} = 6.05$ years under no directed fishery mortality (F = 0), and a $T_{min} = 9.0$ years when the state harvest policy is implemented (Figure 3). The recruitment breakpoint analysis performed on this stock (Appendix D) suggested that recruitment conditions equal to the full period are unlikely and overly optimistic.

Random recruitment from current regime (1996 - 2018)

The recruitment breakpoint analysis suggested that a shift occurred in 1996. Both the "random" recruitment time period and the time period to calculate the B_{MSY} proxy should reflect this (Table 3). Projection 5 matches these two time frames, and under average recent bycatch levels, has a $T_{min} = 9.0$ years for the probability of recovery to this new/current B_{MSY} proxy under no directed fishery mortality (F = 0), and a T_{min} a little over 9.0 years under the state harvest policy implementation (Figure 4). The consistencies in these T_{min} values is due to the state harvest policy thresholds being based on past periods rather than having adopted to changes in B_{MSY} proxy years.

Projection 4 uses recruitment from the recent regime but keeps the reference point time frame for the entire time series of data (1978-2018). Although this is a mis-match of the reference point and recruitment time frame it encompasses expectations for the recruitment of the stock with respect to the environment and the current stock status (Figure 5).

Ricker stock-recruit relationship (1978 - 2018)

While the stock-recruit relationship for St. Matt's blue king crab is weak, it still provides an estimate of recruitment potential that responds to the status of the mature male biomass, therefore it is also presented here for comparison (Figure 6). The benefit of this projection is that it incorporates the stock status into the recruitment considerations without changing the time frame to draw either recruitment or the B_{MSY} proxy.

Discussion

The projections initially considered here produced T_{min} values that fell between 6 and a little over 11 years (Tables 4 and 5), however, the question remains which option is the most biologically and environmentally plausible. The recruitment breakpoint analysis (Appendix D) suggested that recent recruitment (1996-2018) differed from the early part of the time series. Recruitment success for SMBKC, as with many crab species, is driven by environmental conditions. In the Bering Sea recent environmental conditions appear to be unfavorable for recruitment success for this stock, which may be due to the longer larval duration of blue king crab.

Projections that include average recent bycatch levels have a T_{min} value less than 10 years under no directed fishing (F = 0). These values increased with maximum bycatch levels, however these projections assume that these high bycatch levels would persist annually throughout the 50 year projection. Even with increased bycatch to higher levels in some years the rebuilding time frame would not be expected to increase dramatically (Table 5).

Assuming that recent trends in recruitment and biomass represent a current environmental "regime", the most biologically and environmental plausible projection would be projection 5, which suggests the stock would rebuild in less than 10 years to a more representative B_{MSY} that is based on current recruitment conditions. However, if adjusting the reference point time frame is not considered valid the projections suggest a rebuilding time frame < 10 years to the current B_{MSY} proxy levels, with large assumptions on upcoming recruitment variability. When the reference point time frame or B_{MSY} proxy years are kept to the entire time series the probability of recovery of the stock ranges from >100 years (assuming recent recruitment) to less than 10 years if recruitment is allowed to be randomly draw from the entire time series. Overall, the CPT and the author feel that these two outlooks are more pessimistic and more optimistic, respectively, than the reality for this stock. Projection 2, which uses a stock-recruit relationship, provides some intermediate reference for T_{min}.

According to the federal rebuilding framework if T_{min} exceeds 10 years, then the method for determining a T_{max} would be defined by one of three options. These are: T_{min} plus one generation time, time to rebuild to B_{msy} if fished at 75% of MFMT, or T_{min} multiplied by two. The rough generation time calculated for this stock, assuming a recruitment age of 7 years, is approximately 14 years. The CPT entertained estimates of T_{max} that reflected these, while also stressing the important of recruitment assumptions for this stock.

Tables

Table 3: B_{MSY} proxy options for 2018 model 3, all Tier 4b.

Year	Basis for B_{MSY}	B_{MSY} proxy	MSST	Biomass(MMB_{mating})	B/B_{MSY}	F_{OFL}	M
2019/20	1978-2018	3.48	1.74	1.08	0.31	0.042	0.18
2019/20	1996-2018	2.05	1.025	1.04	0.51	0.082	0.18

Table 4: T_{min} for each projection version d with no directed fishing (F=0) and average recent bycatch.

Projection	recruitment	B_{MSY} proxy	recruitment yrs	T_{min}
1	random recruitment	1978-2018	1978-2018	6.05 years
2	ricker	1978-2018	1978-2018	14.5 years
4	random recruitment	1978-2018	1996-2018	>100 years
5	random recruitment	1996-2018	1996-2018	9.0 years

Table 5: T_{min} for each projection version aa with maximum observed bycatch.

Projection	recruitment	B_{MSY} proxy	recruitment yrs	F level	T_{min}
1	random recruitment	1978-2018	1978-2018	F = 0	6.5 years
1	random recruitment	1978-2018	1978-2018	F = SHR	11.0 years
5	random recruitment	1996-2018	1996-2018	F = 0	11.25 years
5	random recruitment	1996-2018	1996-2018	F = SHR	13.0 years

Figures

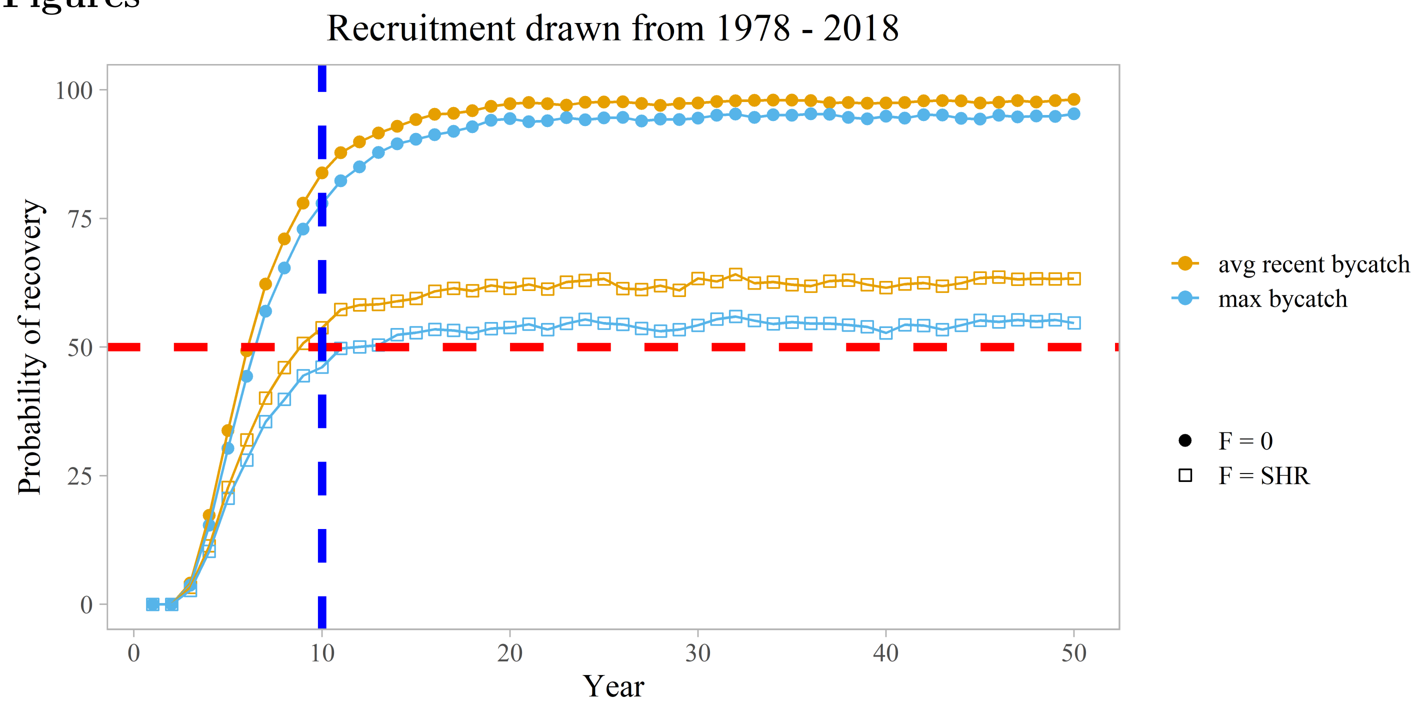


Figure 1: Comparisons of probability of recovery with random recruitment from 1978 to 2018 under different bycatch levels, show as with a min F = 0 and a max F equivalent to the state harvest rate (SHR).

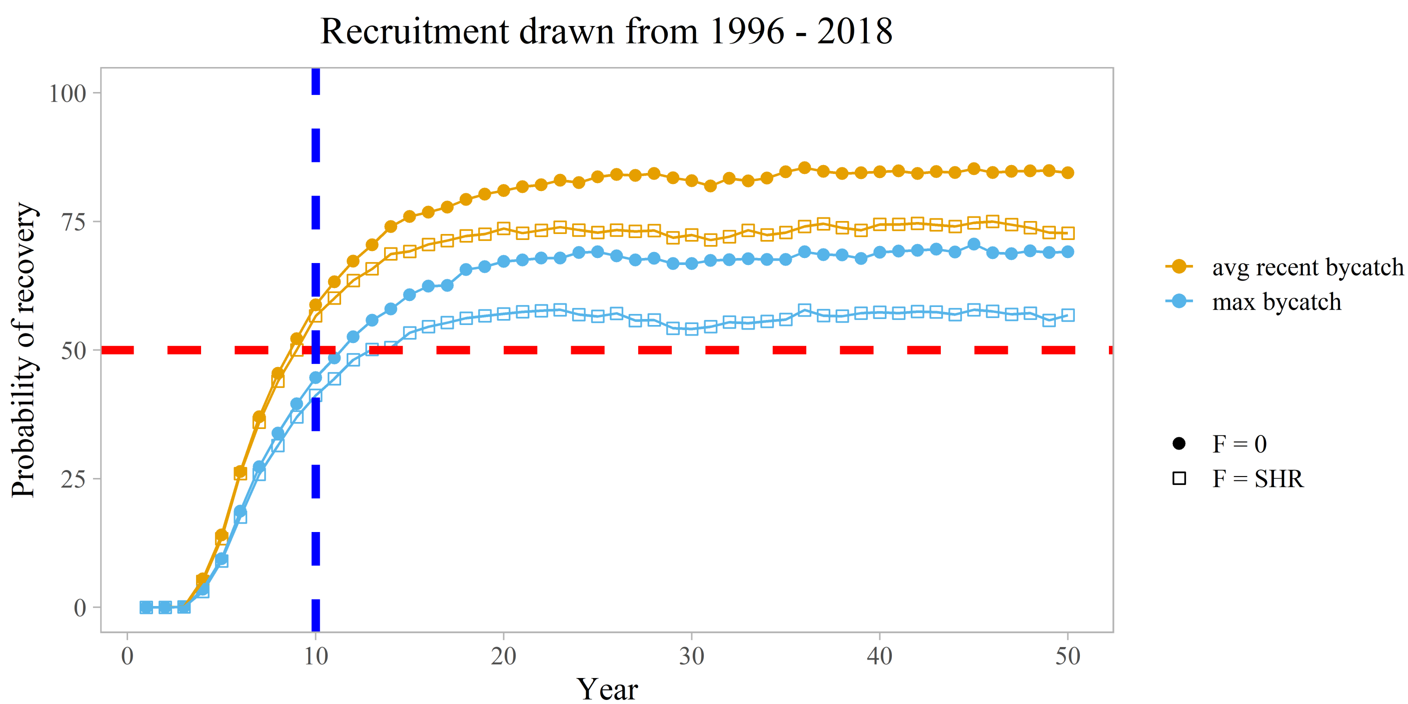


Figure 2: Comparisons of probability of recovery with random recruitment from 1996 to 2018 under different bycatch levels, show as with a min F = 0 and a max F equivalent to the state harvest rate (SHR).

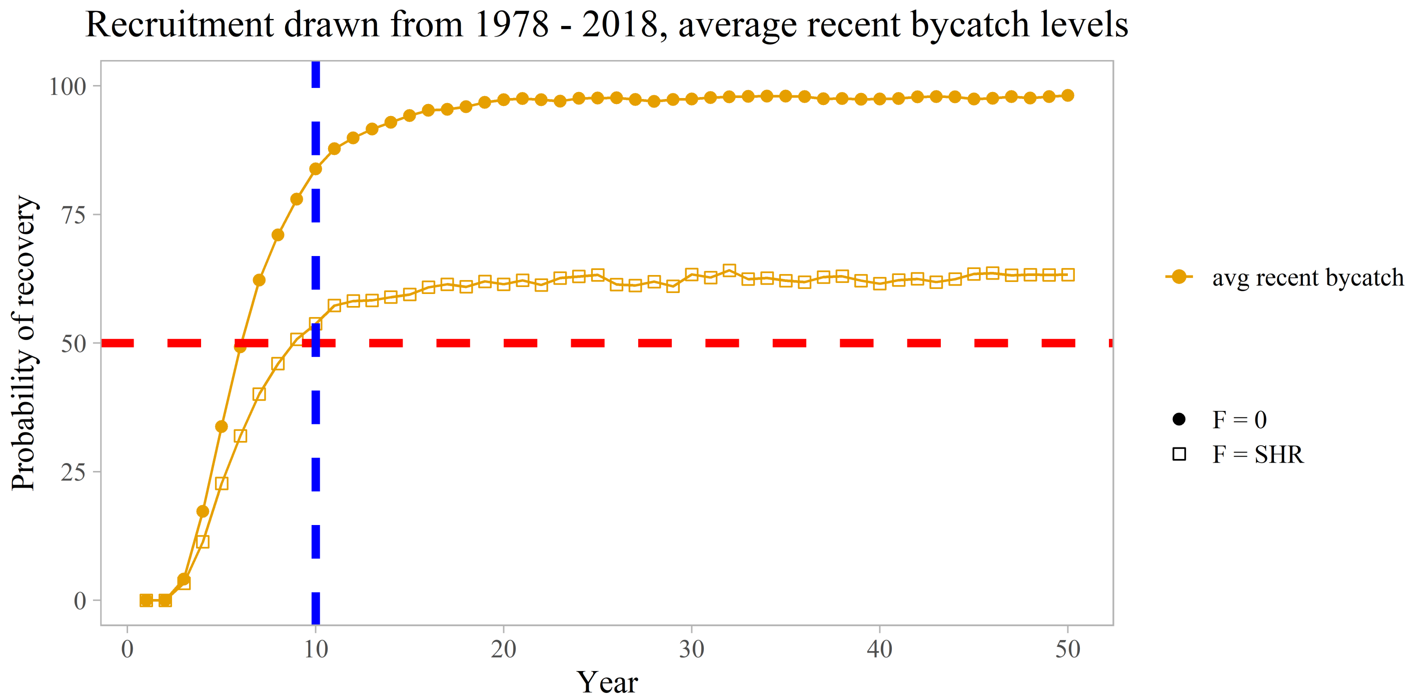


Figure 3: Probability of recovery with random recruitment from 1978 to 2018 under different fishing mortalities, min F = 0 and a max F equivalent to the state harvest rate (SHR). Projection 1.

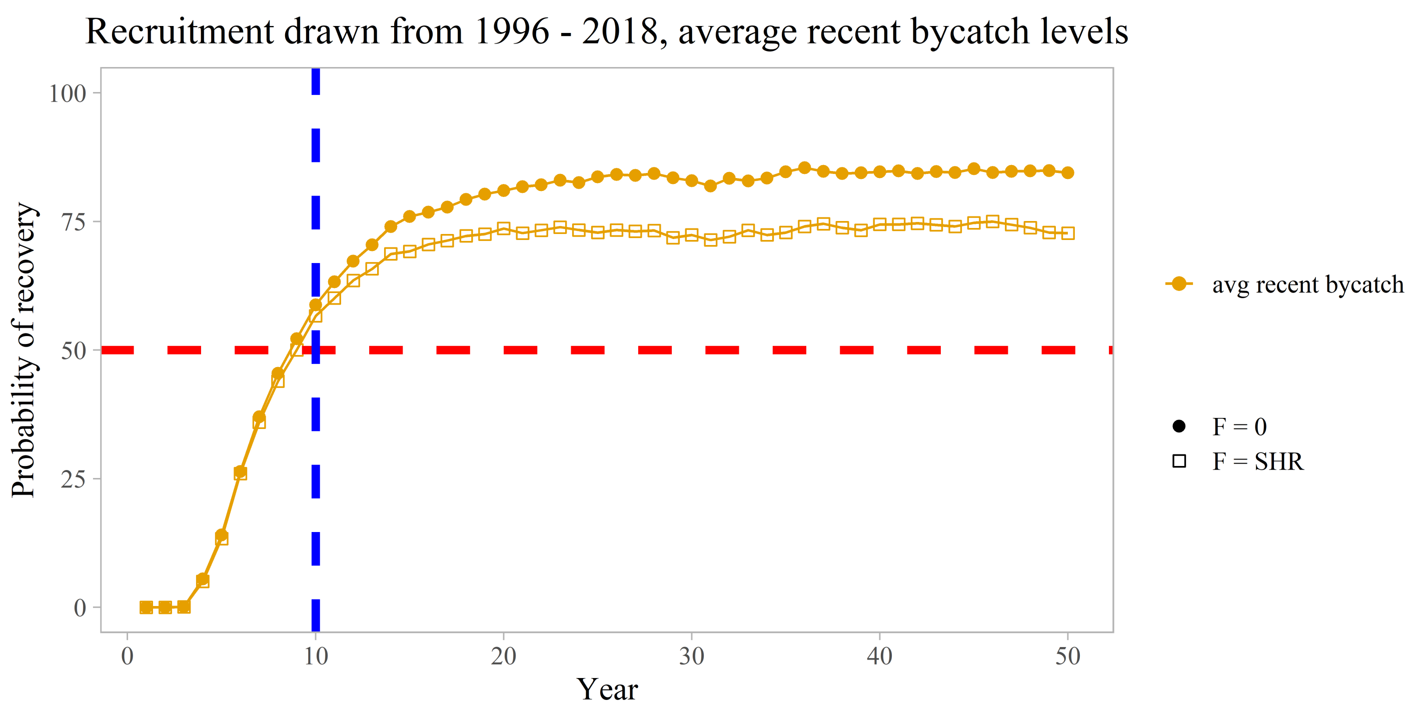


Figure 4: Probability of recovery with random recruitment from 1996 to 2018 under different fishing mortalities, min F = 0 and a max F equivalent to the state harvest rate (SHR). Projection 5.

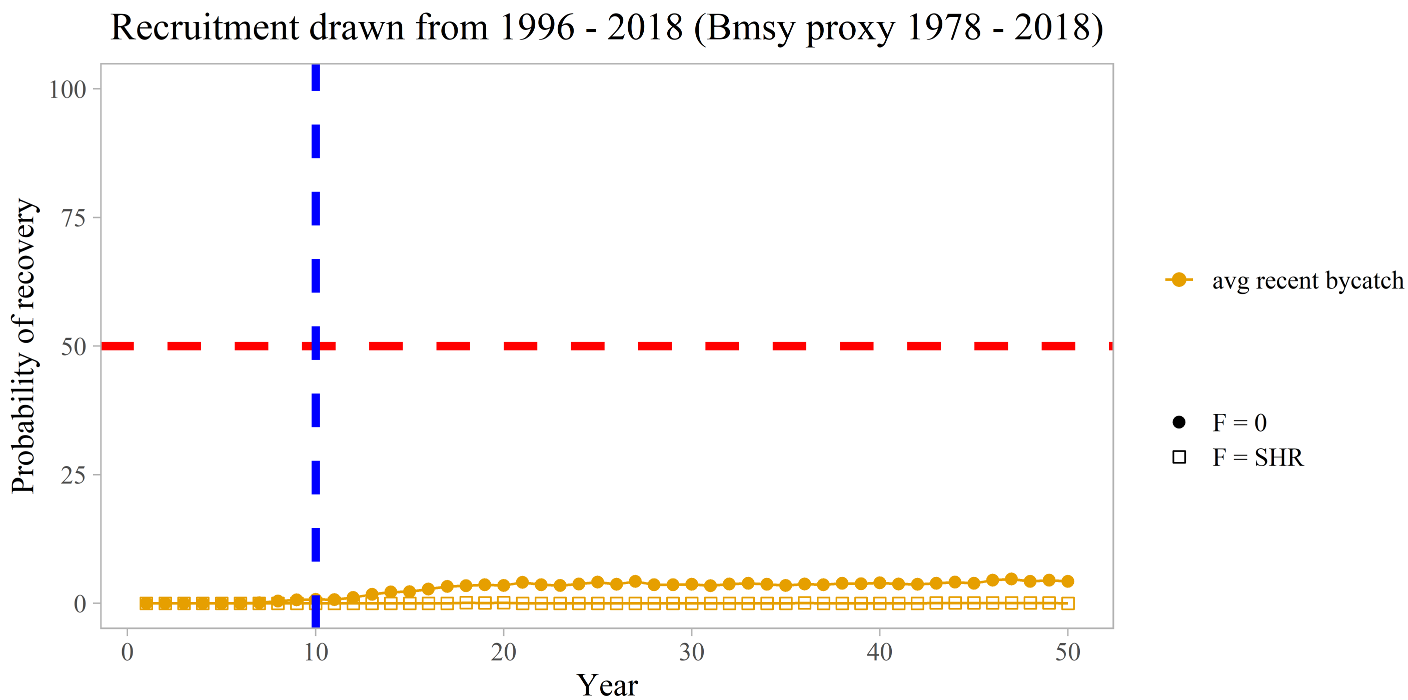


Figure 5: Probability of recovery with random recruitment from 1996 to 2018, while the Bmsy proxy is from 1978 to 2018, under different fishing mortalities, min F = 0 and a max F equivalent to the state harvest rate (SHR). Projection 4

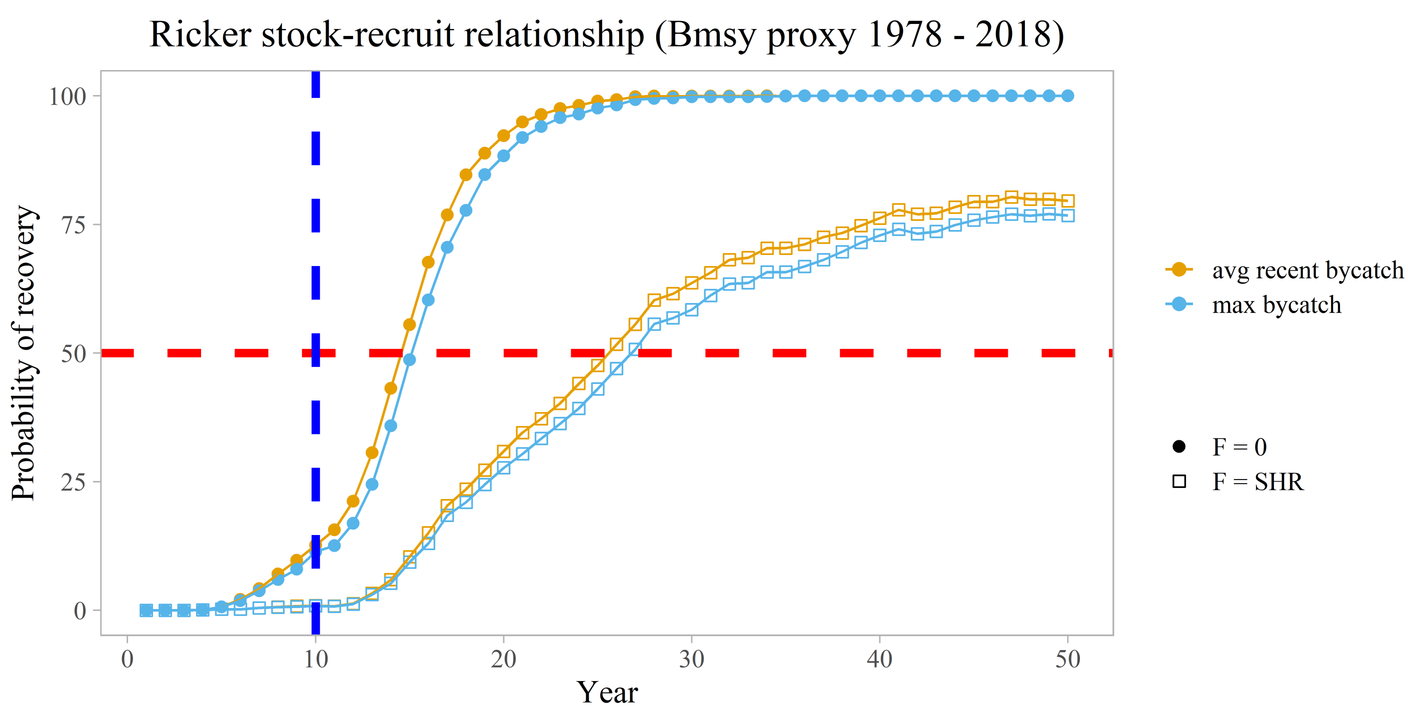


Figure 6: Comparisons of probability of recovery with ricker s-r relationshipusing the entire time series (1978-2018) under different bycatch levels, show as with a min F = 0 and a max F equivalent to the state harvest rate (SHR). Projection 2

Appendix D. Recruitment Breakpoint Analysis

Introduction

In 2018 SMBKC was declared overfished and a rebuilding plan was put into motion. On examination, it was clear that recruitment for SMBKC has been consistently lower in recent years. Thus, the crab Plan Team requested that the authors conduct a recruitment breakpoint analysis similar to that conducted for Bristol Bay red king crab in 2017 (Zheng et al. 2017) and eastern Bering Sea Tanner crab in 2013 (Stockhausen 2013). The R code based on these studies was adapted for this study (Jie Zheng, Buck Stockhausen pers. Comm.). The goal of this analysis was to objectively identify a change in stock productivity based on the recruitment time series. This could then be used to develop alternative rebuilding scenarios and also provide alternative B_{MSY} proxies. Results from assessment model 3 from 2018 (Ianelli and Zheng 2018) were used for this analysis.

Methods

The methods were the same as used for BBKRC (Zheng et al. 2017) which followed Punt et al. (2014) and Stockhausen (2013). Stock productivity is represented by ln(*R/MMB*), where *R* is recruitment and *MMB* is mature male biomass, with recruitment lagging to the brood year of mature biomass. Let $y_t = \ln(R/MMB)$ as estimated directly from the stock assessment model and fit externally to stock-recruitment relationships (with predictions as $\hat{y}_t$). For the Ricker stock-recruitment models,

$$\begin{aligned} \hat{y}_t &= \alpha_1 + \beta_1 \cdot MMB \qquad t < b, \\ \hat{y}_t &= \alpha_2 + \beta_2 \cdot MMB \qquad t \geq b, \end{aligned} \tag{1}$$

where α_1 and β_1 are the Ricker stock-recruit function parameters for the early period before the potential breakpoint in year *b* and α_2 and β_2 are the parameters for the period after the breakpoint in year *b*. For Beverton-Holt stock-recruitment models,

$$\begin{aligned} \hat{y}_t &= \alpha_1 - \log(1 + e^{\beta_1} \cdot MMB) \qquad t < b, \\ \hat{y}_t &= \alpha_2 + \log(1 + e^{\beta_2} \cdot MMB) \qquad t \geq b, \end{aligned} \tag{2}$$

where α_1 and β_1 are the Beverton-Holt stock-recruit function log-transformed parameters for the early period before the potential breakpoint in year *b* and α_2 and β_2 are the log-transformed parameters for the period after the breakpoint in year *b*.

A maximum likelihood approach was used to estimate stock-recruitment model and error parameters. Because y_t is measured with error, the negative log-likelihood function is

$$-\ln(L) = 0.5 \cdot \ln(|\mathbf{\Omega}|) + 0.5 \cdot \sum_t \sum_j (y_t - \hat{y}_t) \cdot \left[\mathbf{\Omega}^{-1}\right]_{t,j} \cdot (y_j - \hat{y}_j), \tag{3}$$

where Ω contains observation and process error as

$$\mathbf{\Omega} = \mathbf{O} + \mathbf{P}, \tag{4}$$

where **O** is the observation error covariance matrix estimated from the stock assessment model and **P** is the process error matrix and is assumed to reflect a first-order autoregressive process to have σ^2 on the diagonal and $\sigma^2 \rho^{|t-j|}$ on the off-diagonal elements. σ^2 represents process error variance and ρ represents the degree of autocorrelation.

For each candidate breakpoint year b, the negative log likelihood value of equation (3) was minimized with respect to the six model parameters: α_1, β_1, α_2, β_2, $\ln(\sigma)$ and $\tan(\rho)$. The minimum time span considered as a potential regime was 5 years. Each brood year from 1983 to 2005 was evaluated as a potential breakpoint b using time series of ln(R/MMB) and MMB for brood years 1978-2010. A model with no breakpoint was also evaluated. Models with different breakpoints were then ranked using AICc (AIC corrected for small sample size; Burnham and Anderson 2004),

$$AIC_c = -2 \cdot \ln(L) + \frac{2 \cdot k \cdot (k+1)}{n-k-1}, \qquad (5)$$

where k is the number of parameters and n is the number of observations. Using AICc, the model with the smallest AICc is regarded as the “best” model among the set of models evaluated. Different models can be compared in terms of θ_m, the relative probability (odds) that the model with the minimum AICc score is a better model than model m, where

$$\theta_m = \exp([(AICc_m - AICc_{\min})/2]. \qquad (6)$$

Results

Results are summarized in Tables D1-D4 and Figures D1-D6. Both Ricker and Beverton-Holt (B-H) models resulted in the same breakpoint brood year of 1989, which corresponded to recruitment year of 1996. The model without a breakpoint (i.e., a single period) was about 26 times less probable than the 1989 breakpoint model for the Ricker stock-recruitment relationship and 4 times less probable than the Beverton-Holt, which suggested a possible change in stock productivity from the early high period to the recent low period. Alternative breakpoint brood years of 1984-1988 for the Ricker model and of 1990 for Beverton-Holt model were also reasonably reported with relative odds less than 10.

Both Ricker and Beverton-Holt stock-recruitment models fitted the data poorly. Additionally, the fit to the breakpoint group with fewer data points was extremely poor for both models, especially the Ricker model. For example, the Ricker model with a breakpoint year of 1983 (Figure D1) fits the larger data group well (black line) but the fit to the smaller data group (red line) is poor, with an estimated intercept (α_1) that appears to be lower than the expected fit. This was the case for all breakpoint years with the data group (pre or post breakpoint) that had fewer data points. A sensitivity analysis was performed to determine the source of this lack of fit for both the Ricker and B-H models. For the Ricker model a breakpoint analysis that produced two independent regression (where the covariance matrix and ρ were set to 0) produced model fits that fit both data groups well, additionally this analysis produced the same breakpoint year of 1989, but suggested that 1990 was also a possibility. The poor model fit is primarily due to covariance and estimation of ρ in the analysis. The same analysis with the B-H model was performed but only the Ricker results are presented here for simplicity (Figures D8-D10).

Sensitivity analyses suggest that error within the model, specifically autocorrelation (ρ), produce poor fits to the stock-recruit relationships when the sample size for the data set is low. However, the resulting breakpoint year is still the same, suggesting strong evidence for a brood year breakpoint in 1989. The only other likely breakpoint year is 1990, with relative odds < 2 compared to 1989. These breakpoint brood years would produce breaks in recruitment in either 1996 or 1997.

Discussion

A recruitment breakpoint analysis was conducted on St Matthews blue king crab by Punt et al. (2014) with data from 1978 to 2010 to estimate a breakpoint brood year of 1993, corresponding to recruitment year of 1998, but this model used a 5-year lag and incorporated smaller size classes (20 - 90mm) than the current assessment model. The projections for recruitment from the Punt et al. (2014) model are substantially higher in the late 2000s than the current assessment model, which would greatly influence the breakpoint analysis results. The different time series of data may also explain the differences; however, both suggest a break in recruitment in the mid to late 1990s.

Time series of estimated mature male biomass during 1978-2017 (the entire time series) has been used to compute a B_{MSY} proxy. Using the 2018 assessment model the B_{MSY} proxy for 2018 is 3,478 t. The B_{MSY} proxy for the recent recruitment period (based on the break point analysis; 1996-2017) using the same model is 2,030 t (Table D5). The is approximately a 42% reduction (Figure D7). If the estimated breakpoint year is used to set the new recruitment time series, the estimated B_{MSY} proxy will be correspondingly lower than the current estimated value.

References

Burnham, K.P., and D.R. Anderson. 2004. Multimodal inference: understanding AIC and BIC in model selection. Sociological Methods & Research 33:261–304.

Punt, A.E., C.S. Szuwalski, and W. Stockhausen. 2014. An evaluation of stock-recruitment proxies and environmental change points for implementing the US Sustainable Fisheries Act. Fisheries Research 157:28-40.

Stockhausen, W.T. 2013 Recruitment Analysis for Stock Status Determination and Harvest Recommendations. Appendix to: 2013 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries in the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, Anchorage. pp.450-478.

Table D1. Results of the breakpoint analysis, with AICc and the relative probability (odds) against the Ricker stock-recruitment model being correct by breakpoint year. The model with no breakpoint is listed first in the table. The "best" model is shaded. Years are brood year.

Year	AICc	Odds
NA	1.474	26.124
1983	-0.187	11.384
1984	-1.498	5.913
1985	-0.975	7.679
1986	-1.449	6.059
1987	-1.141	7.066
1988	-1.784	5.124
1989	-5.052	1.000
1990	0.141	13.413
1991	2.586	45.564
1992	4.658	128.335
1993	4.621	125.992
1994	2.479	43.172
1995	5.339	180.461
1996	5.266	173.990
1997	4.137	98.931
1998	4.950	148.548
1999	7.258	471.115
2000	7.234	465.383
2001	5.509	196.408
2002	6.186	275.605
2003	4.537	120.830
2004	2.989	55.723
2005	6.716	359.120

Table D2. Parameter estimates and standard deviations for the Ricker stock-recruitment model with no breakpoint (first row) and the single breakpoint models (by year of breakpoint). The "best" model is shaded. Years are brood year.

Year	α_1	std.dev.	α_2	std.dev.	β_1	std.dev.	β_2	std.dev.	ln(σ)	std.dev.	tan(ρ)	std.dev.
			5.488	0.624			0.155	0.068	-0.099	0.373	6.493	5.311
1983	4.456	1.224	6.770	1.096	0.062	0.078	0.546	0.127	0.180	0.610	22.813	29.838
1984	4.834	0.989	6.862	0.970	0.080	0.058	0.632	0.138	0.064	0.570	20.324	24.984
1985	5.199	0.845	6.764	0.859	0.100	0.054	0.634	0.142	-0.044	0.523	15.556	17.804
1986	5.510	0.743	6.615	0.764	0.104	0.055	0.617	0.149	-0.166	0.474	11.401	12.175
1987	5.193	0.856	6.794	0.883	0.101	0.054	0.645	0.145	-0.031	0.530	15.858	18.137
1988	5.356	0.779	6.667	0.814	0.103	0.053	0.621	0.147	-0.131	0.520	13.543	15.341
1989	5.819	0.625	6.080	0.698	0.098	0.052	0.475	0.183	-0.521	0.495	6.231	7.556
1990	5.818	0.874	5.790	1.116	0.101	0.058	0.358	0.292	-0.594	0.654	3.776	7.050
1991	5.918	0.703	5.606	0.820	0.124	0.064	0.294	0.194	-0.581	0.433	2.791	3.540
1992	5.270	1.008	6.317	1.232	0.134	0.062	0.439	0.262	-0.031	0.696	10.149	15.757
1993	5.288	1.009	6.262	1.282	0.137	0.063	0.424	0.275	-0.040	0.691	9.514	15.029
1994	5.632	0.812	5.994	1.089	0.138	0.066	0.420	0.245	-0.289	0.512	5.086	6.549
1995	4.886	1.189	6.705	1.340	0.136	0.063	0.500	0.227	0.255	0.621	17.185	22.680
1996	4.949	1.110	6.683	1.273	0.136	0.063	0.513	0.236	0.208	0.597	15.375	20.228
1997	4.720	1.295	6.554	1.437	0.135	0.061	0.381	0.252	0.367	0.600	22.852	29.149
1998	4.997	1.047	5.658	1.435	0.141	0.062	0.068	0.427	0.201	0.551	15.742	19.015
1999	5.533	0.687	5.493	1.665	0.156	0.069	0.179	0.798	-0.129	0.438	6.011	6.144
2000	5.443	0.719	5.636	1.740	0.155	0.069	0.198	0.805	-0.067	0.472	6.998	7.404
2001	5.717	0.537	4.613	1.775	0.156	0.066	-0.078	0.803	-0.261	0.334	4.720	3.589
2002	5.657	0.553	4.553	1.799	0.156	0.066	-0.142	0.800	-0.239	0.366	5.149	4.225
2003	5.767	0.492	4.785	1.705	0.159	0.063	0.062	0.779	-0.343	0.323	4.474	3.254
2004	5.814	0.468	4.685	1.664	0.160	0.062	0.099	0.758	-0.384	0.301	4.213	2.864
2005	5.607	0.555	5.195	1.790	0.155	0.067	0.141	0.826	-0.227	0.378	5.190	4.365

Table D3. Results of the breakpoint analysis, with AICc and the relative probability (odds) against the Beverton-Holt stock-recruitment model being correct by breakpoint year. The model with no breakpoint is listed first in the table. The "best" model is shaded. Years are brood year.

Year	AICc	Odds
NA	-1.533	4.232
1983	4.103	70.852
1984	3.986	66.809
1985	4.005	67.459
1986	2.860	38.062
1987	3.925	64.830
1988	2.563	32.810
1989	-4.418	1.000
1990	-0.741	6.288
1991	0.740	13.187
1992	2.859	38.028
1993	2.630	33.923
1994	0.854	13.956
1995	4.237	75.741
1996	4.267	76.888
1997	1.905	23.605
1998	2.075	25.703
1999	3.956	65.817
2000	4.112	71.165
2001	2.937	39.540
2002	3.116	43.263
2003	0.877	14.121
2004	-0.855	5.939
2005	3.579	54.527

Table D4. Parameter estimates and standard deviations for the Beverton-Holt stock-recruitment model with no breakpoint (first row) and the single breakpoint models (by year of breakpoint). The "best" model is shaded. Years are brood year.

Year	α_1	std.dev.	α_2	std.dev.	β_1	std.dev.	β_2	std.dev.	ln(σ)	std.dev.	tan(ρ)	std.dev.
			11.908	34.104			5.800	34.131	-0.009	0.437	9.869	9.284
1983	11.694	NA	12.970	47.627	5.444	NA	6.914	47.639	-0.064	0.440	8.852	8.394
1984	5.572	2.004	16.904	327.946	-0.995	2.787	10.826	327.948	-0.048	0.461	9.257	9.254
1985	6.345	3.335	13.895	71.302	-0.097	4.202	7.862	71.309	-0.040	0.568	9.453	11.707
1986	7.533	NA	13.399	63.519	0.973	NA	7.500	63.531	-0.261	0.335	6.145	5.013
1987	5.981	1.683	16.024	219.692	-0.666	2.487	10.011	219.695	-0.134	0.472	7.647	7.894
1988	6.262	1.538	13.277	68.643	-0.711	2.287	7.383	68.656	-0.350	0.425	5.155	5.008
1989	7.068	1.875	11.864	69.327	-0.295	2.416	6.194	69.377	-0.751	0.300	2.896	2.154
1990	12.339	NA	11.704	NA	5.363	NA	5.993	NA	-0.722	0.336	2.646	2.383
1991	12.304	38.041	11.711	NA	5.419	38.076	5.985	NA	-0.653	0.356	2.588	2.578
1992	12.200	33.709	11.752	NA	5.608	33.730	5.917	NA	-0.420	0.496	4.429	5.120
1993	12.881	44.794	11.465	NA	6.344	44.807	5.636	NA	-0.369	0.430	4.791	4.774
1994	13.348	51.252	11.695	233.066	6.642	51.264	6.049	233.257	-0.446	0.310	3.715	2.753
1995	11.988	36.396	11.863	111.774	5.817	36.408	5.805	111.874	-0.058	0.518	8.939	9.881
1996	11.966	37.397	11.882	93.181	5.842	37.411	5.790	93.266	-0.020	0.527	9.588	11.563
1997	13.744	105.672	7.696	5.406	8.060	105.672	1.102	5.906	0.337	0.621	24.517	32.501
1998	12.980	58.869	5.748	1.618	7.151	58.870	-2.250	6.036	0.229	0.584	19.852	25.260
1999	13.405	47.136	11.393	NA	7.144	47.143	5.452	NA	-0.137	0.447	7.230	7.396
2000	14.297	98.747	5.732	1.989	8.272	98.752	-1.652	6.425	0.074	0.552	12.085	14.354
2001	12.041	31.917	11.731	NA	5.698	31.953	5.946	NA	-0.230	0.398	6.243	5.598
2002	13.694	52.456	5.888	NA	7.486	52.464	-0.604	NA	-0.162	0.425	7.790	7.064
2003	13.209	40.983	11.292	NA	6.789	40.995	5.706	NA	-0.349	0.371	5.920	4.824
2004	13.213	39.232	11.330	NA	6.749	39.244	5.911	NA	-0.392	0.349	5.678	4.409
2005	14.402	93.698	10.309	NA	8.150	93.706	4.447	NA	-0.158	0.432	7.808	7.191

Table D5. Estimates of B_{MSY} proxy using the entire time series and model suggested breakpoint years for recruitment.

Year	Basis for B_{MSY}	B_{MSY} proxy	MSST	Biomass (MMB_{mating})	B/B_{MSY}
2018/19	1978-2017	3.48	1.74	1.09	0.31
2018/19	1996-2017	2.03	1.015	1.08	0.53

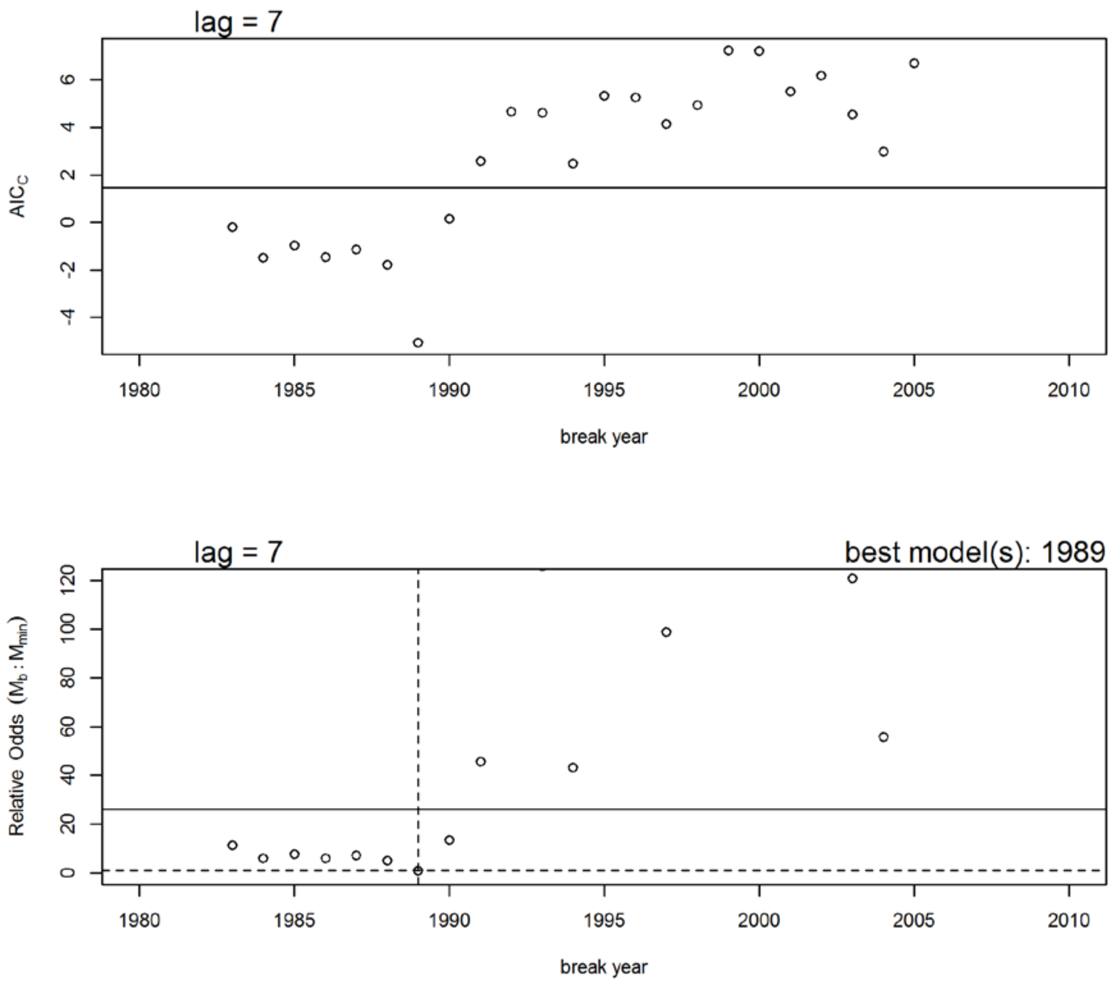


Figure D1. Results from the Ricker stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint model (horizontal solid line) relative to the model with the smallest AICc score. The dashed lines indicate the value for the model with the lowest AICc score (breakpoint in 1989). Not shown are 1-breakpoint models with high odds (>120) of being incorrect.

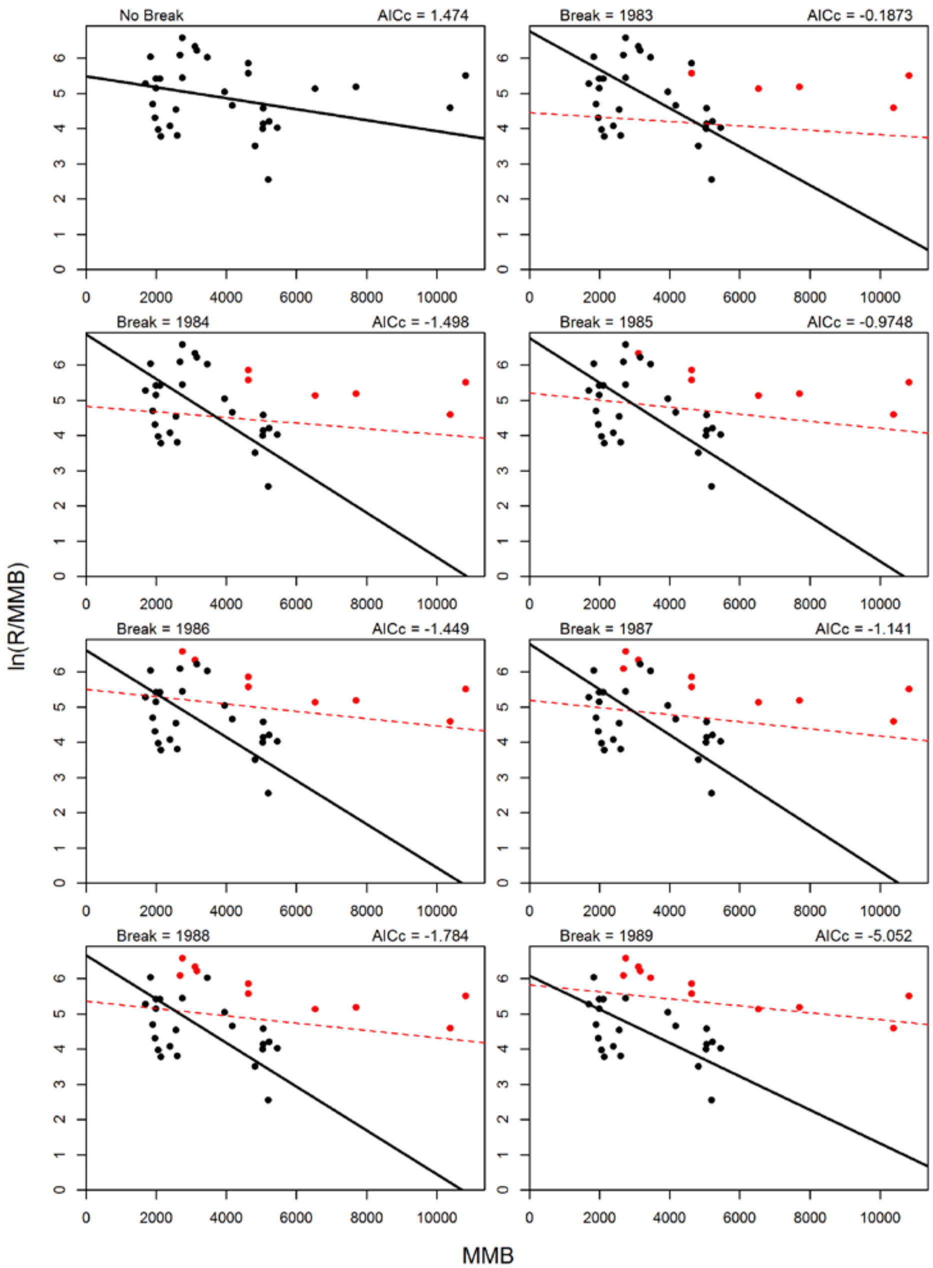
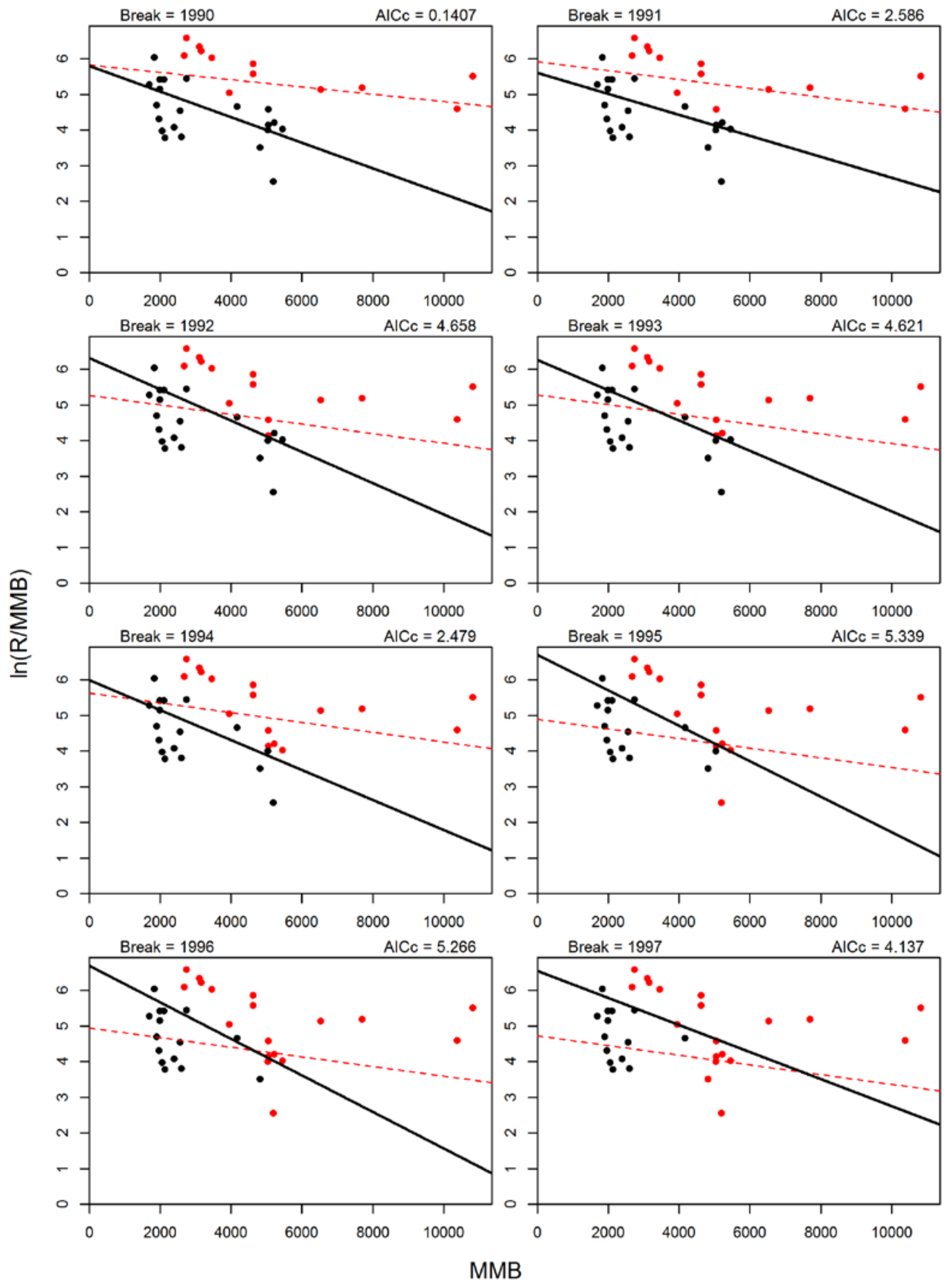


Figure D2. Fits for Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1978-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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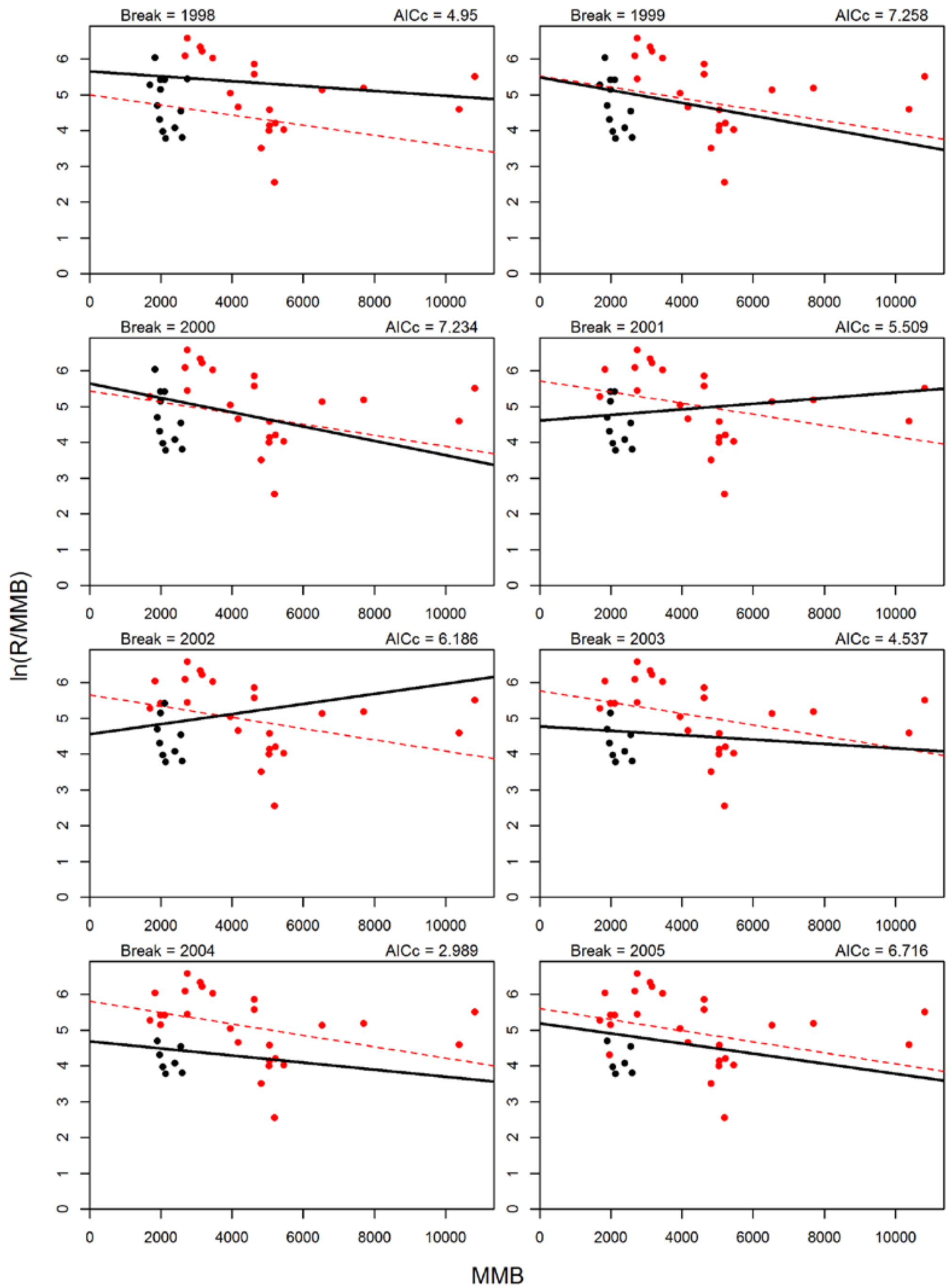

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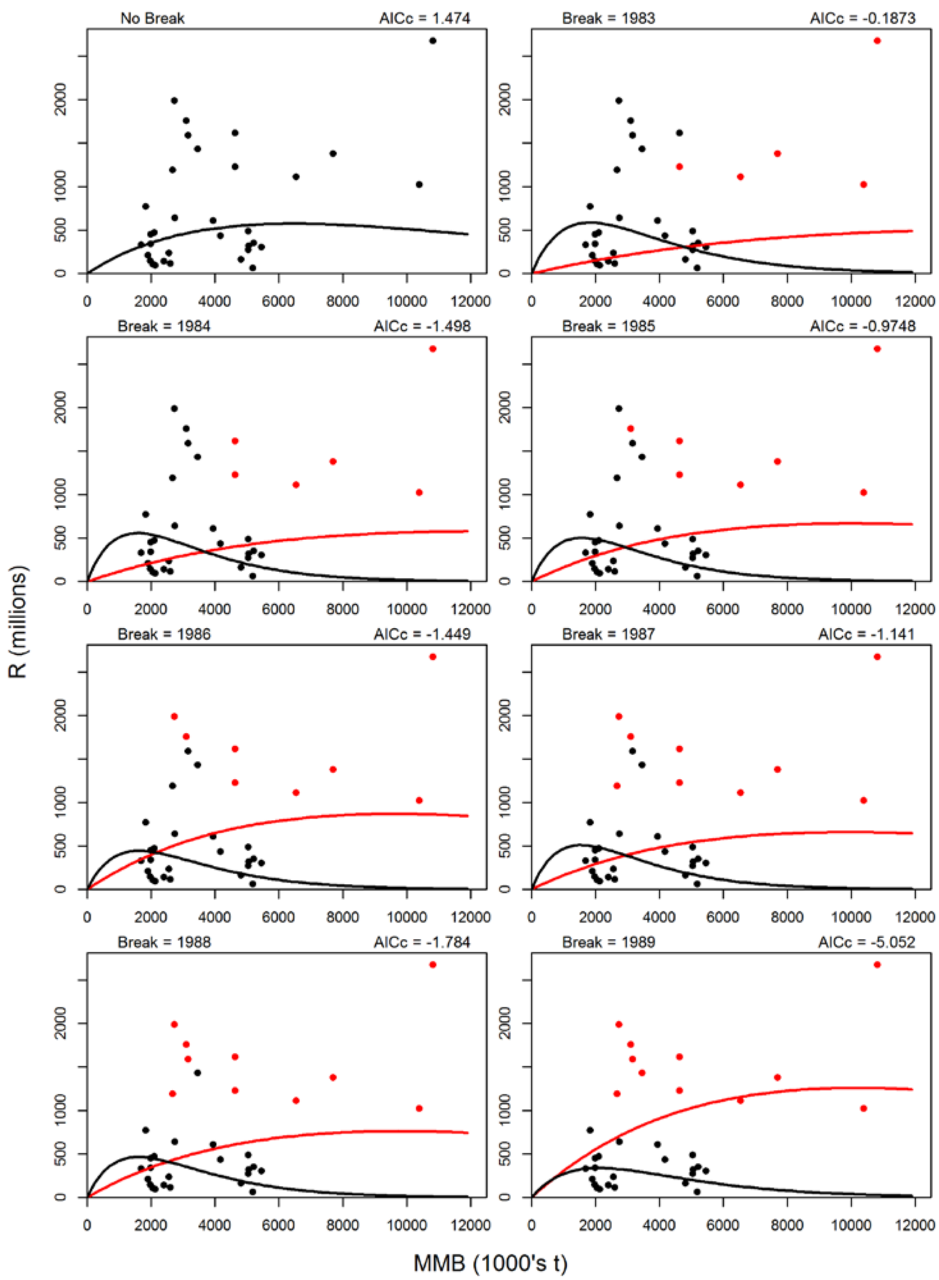
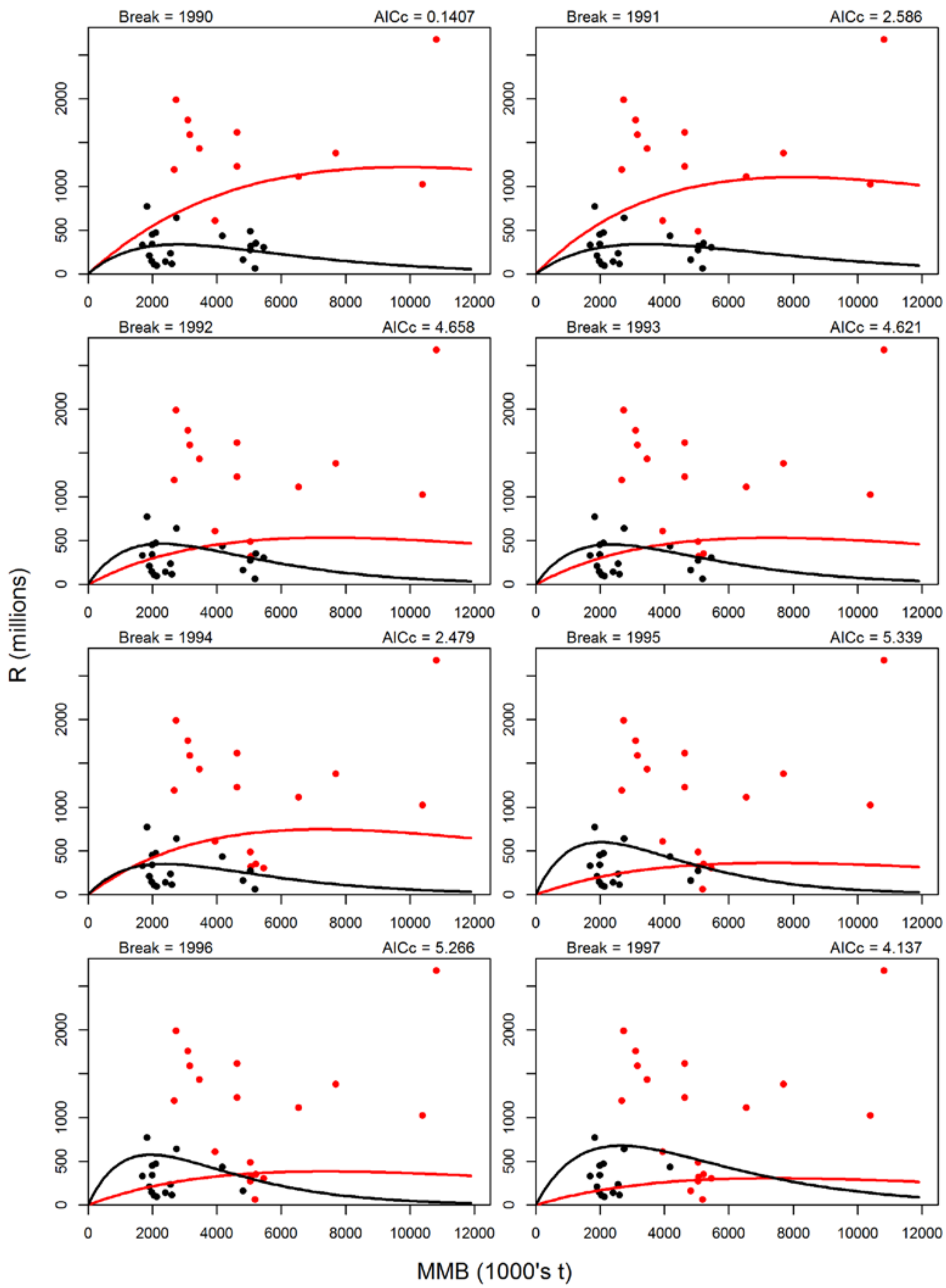


Figure D3. Fits on the arithmetic scale for Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1978-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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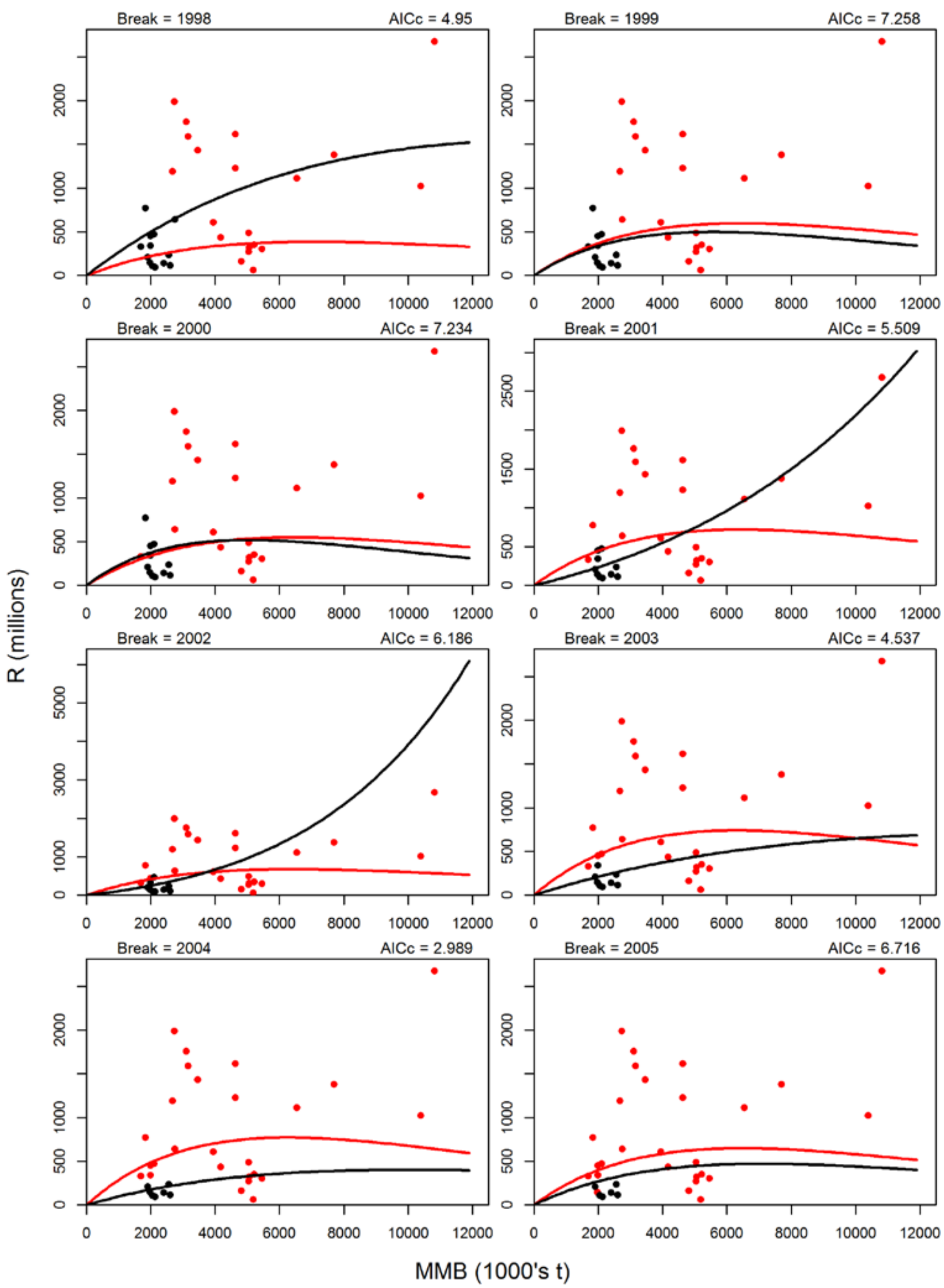

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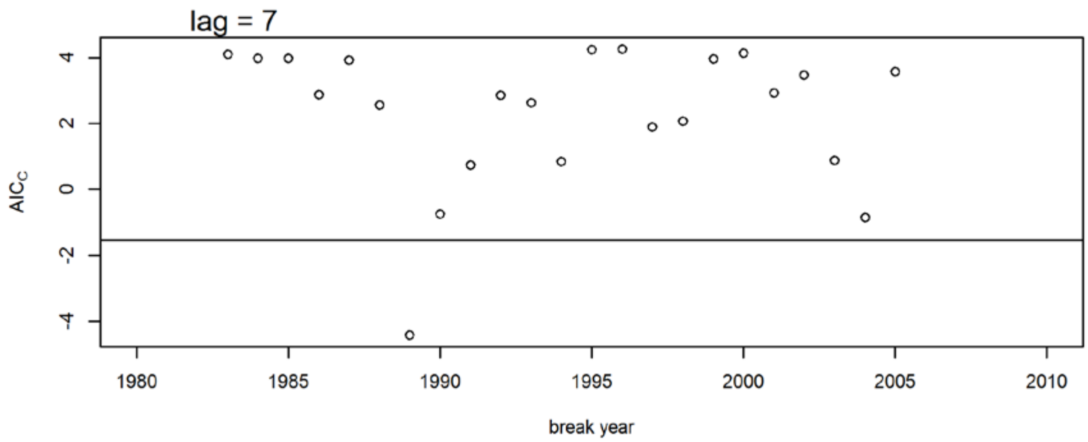


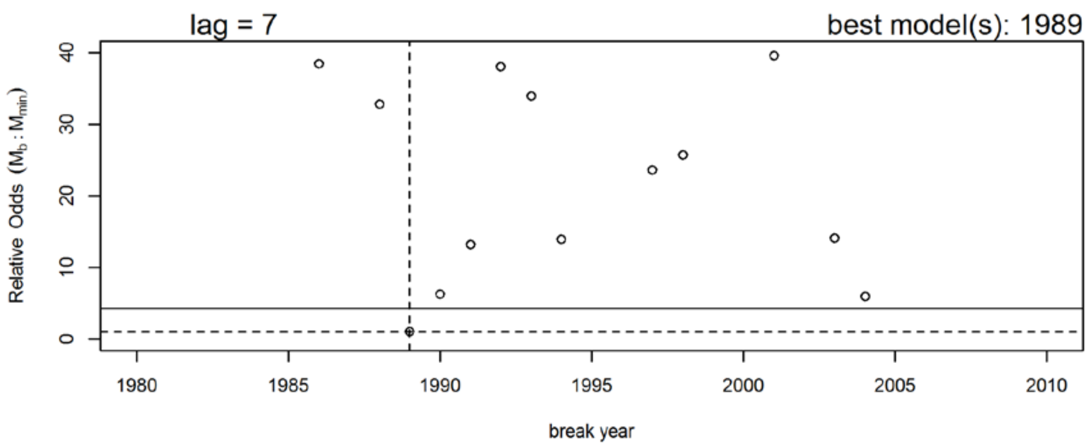


Figure D4. Results from the B-H stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint model (horizontal solid line) relative to the model with the smallest AICc score. The dashed lines indicate the value for the model with the lowest AICc score (breakpoint in 1989). Not shown are 1-breakpoint models with high odds (>40) of being incorrect.

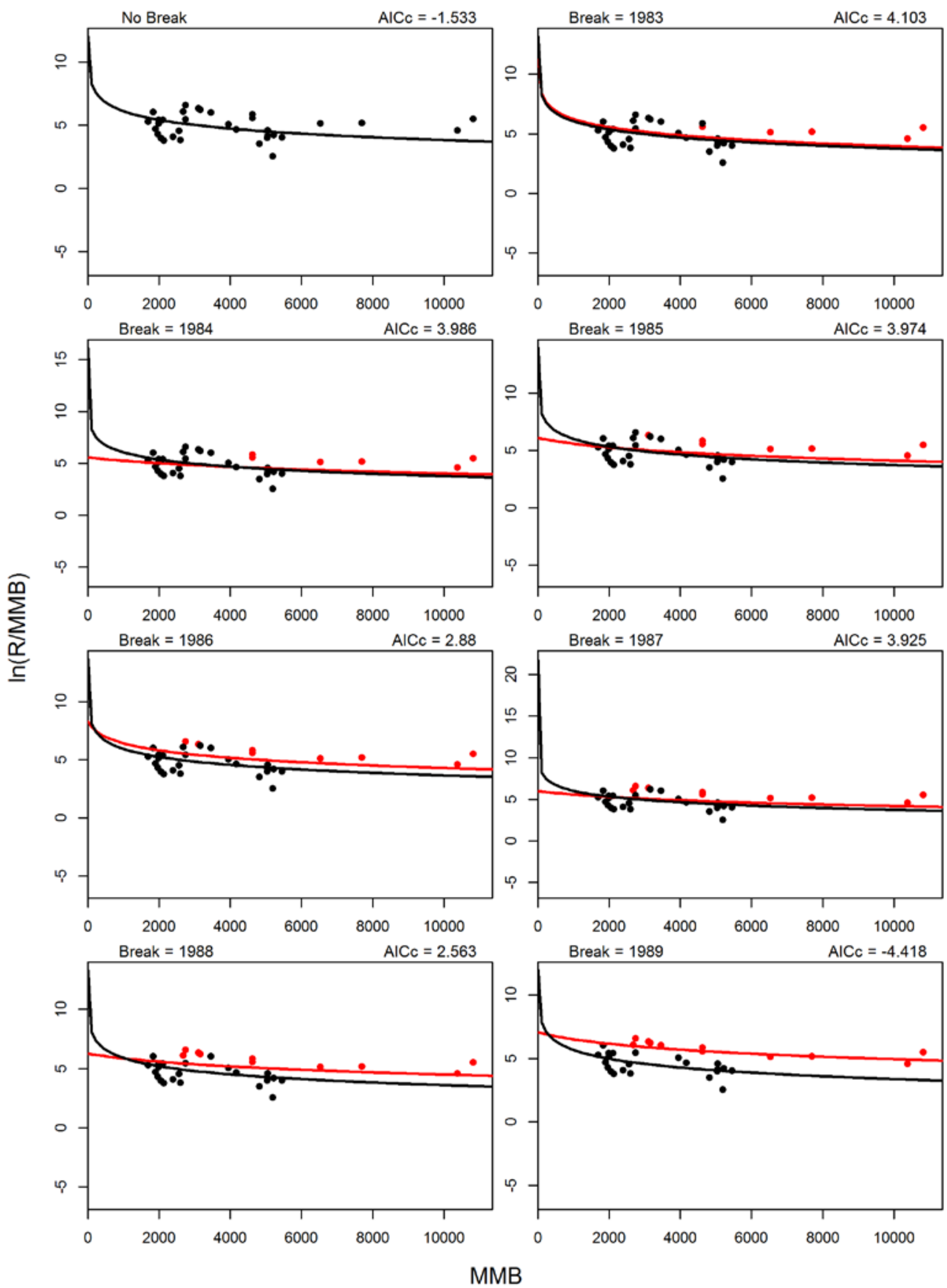
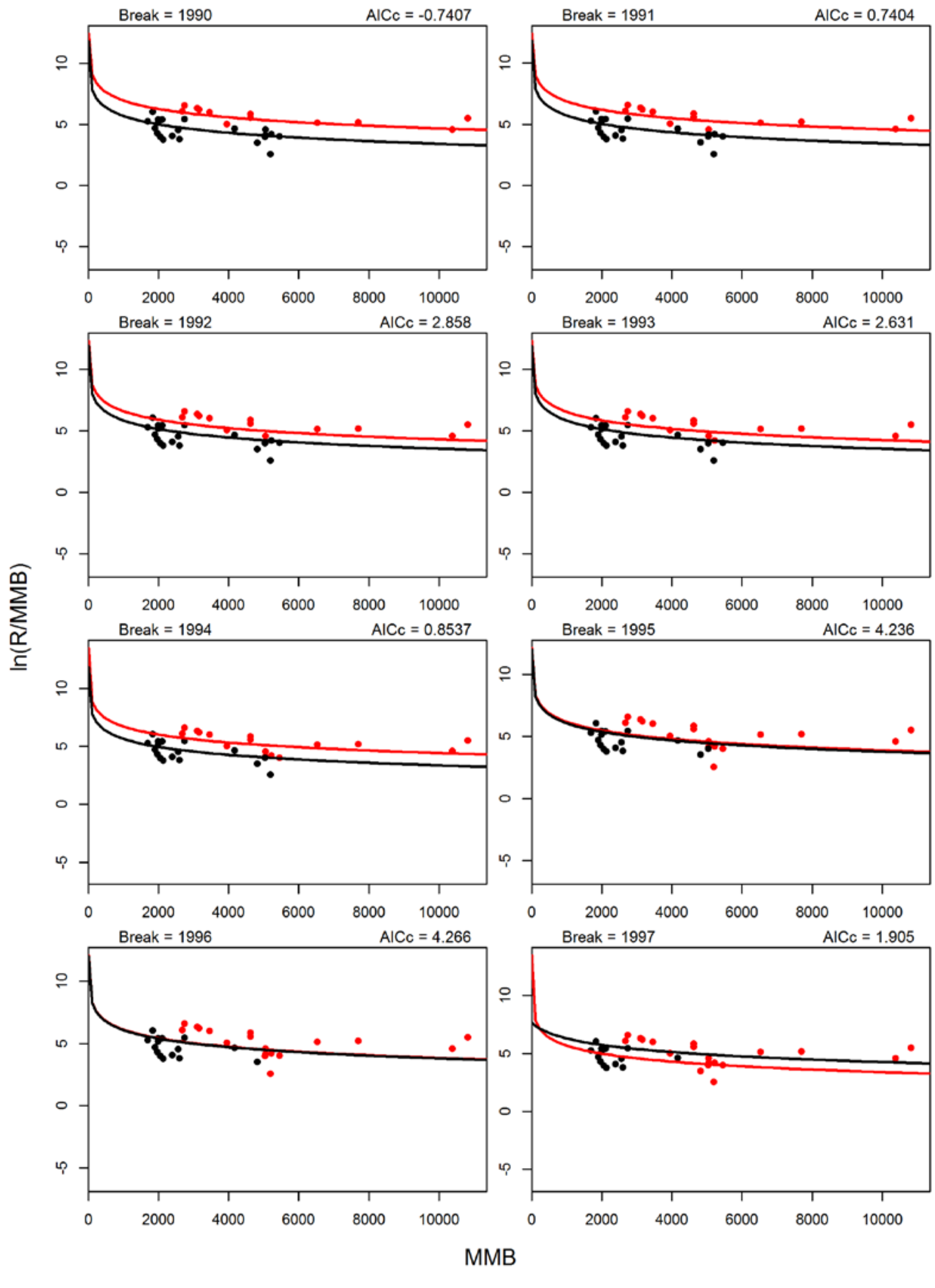


Figure D5. Fits for B-H models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1978-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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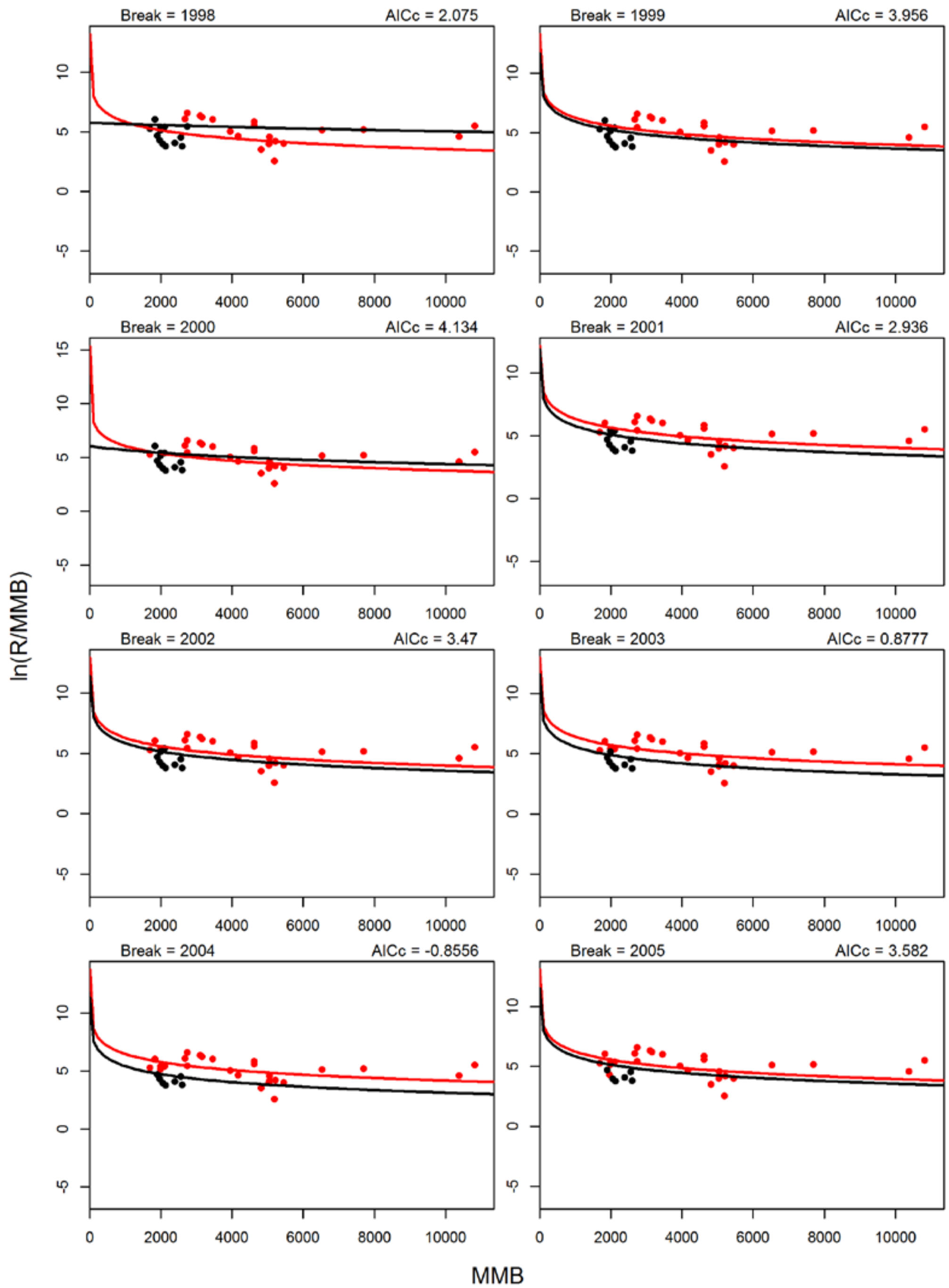

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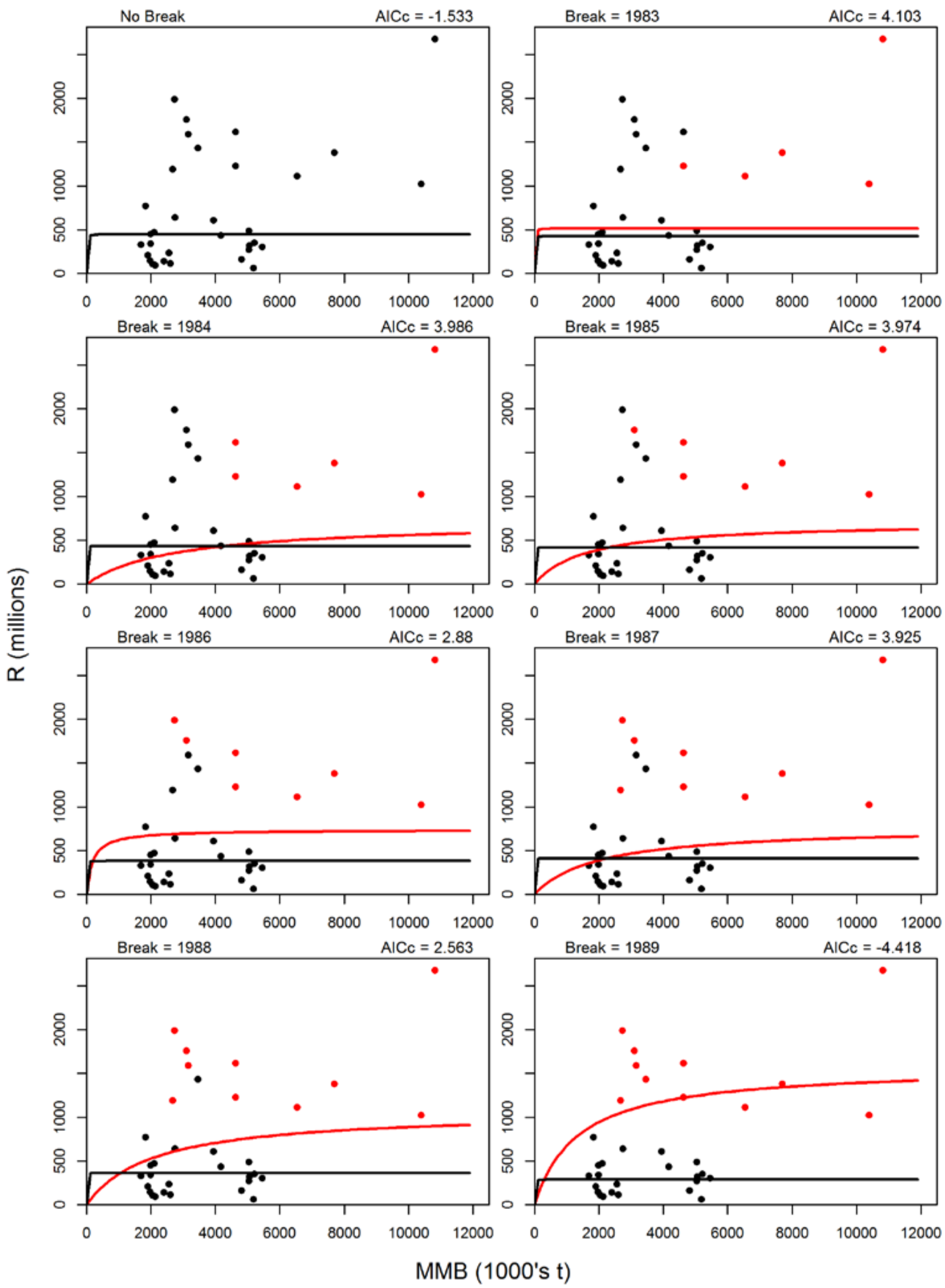
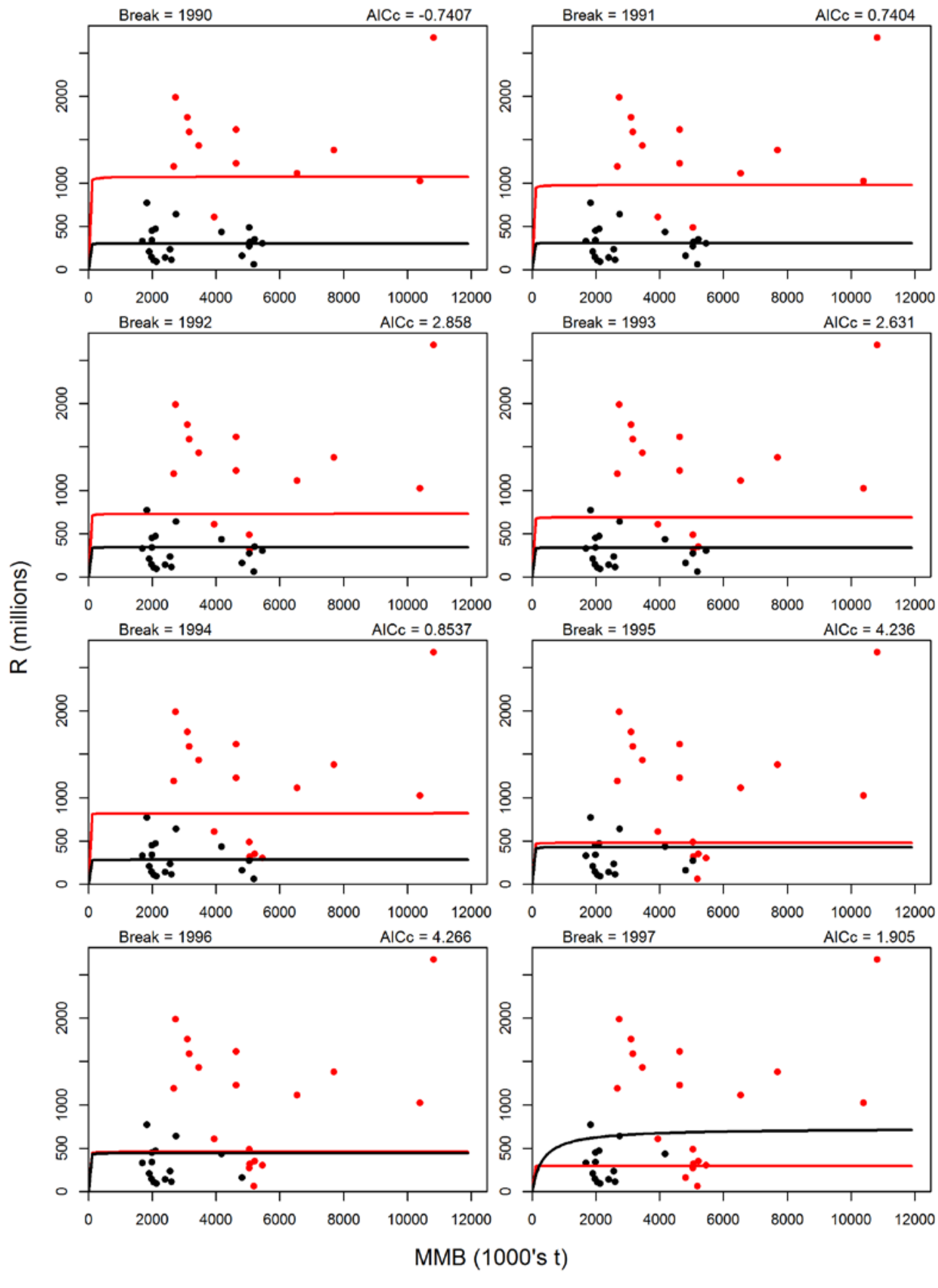


Figure D6. Fits on the arithmetic scale for B-H models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1978-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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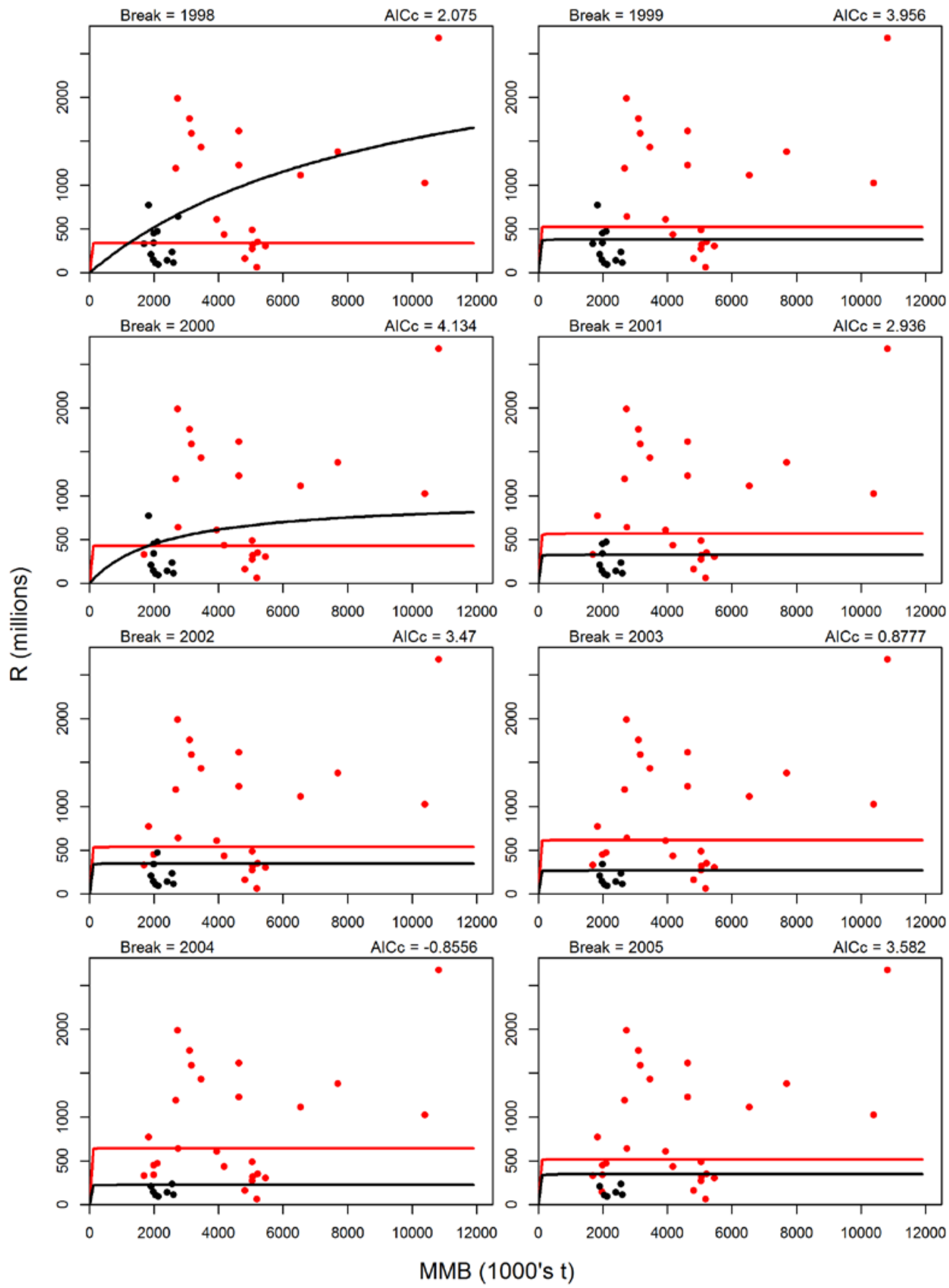

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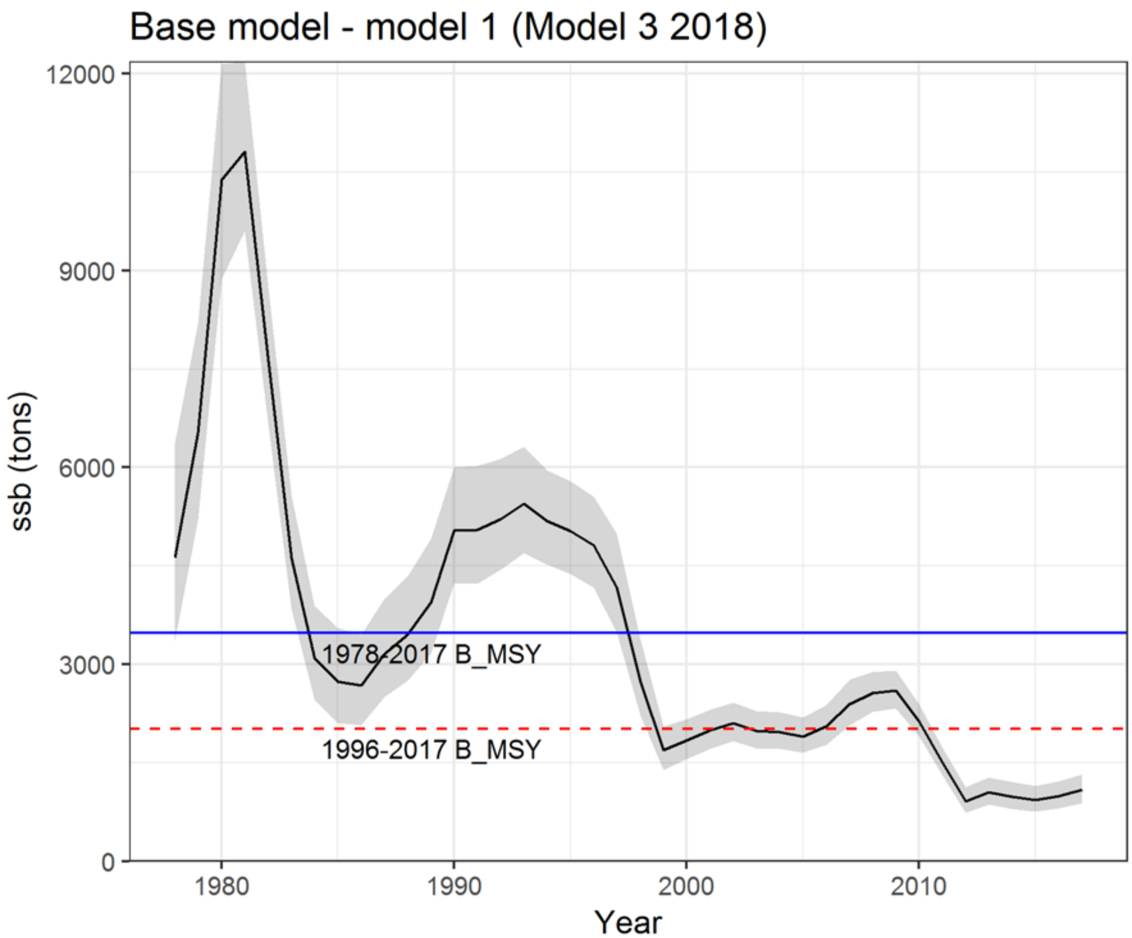

Figure D7. Computed B_{MSY} proxy (average mature male biomass) for the corresponding year ranges based on the 2018 assessment model with GMACS code updates.

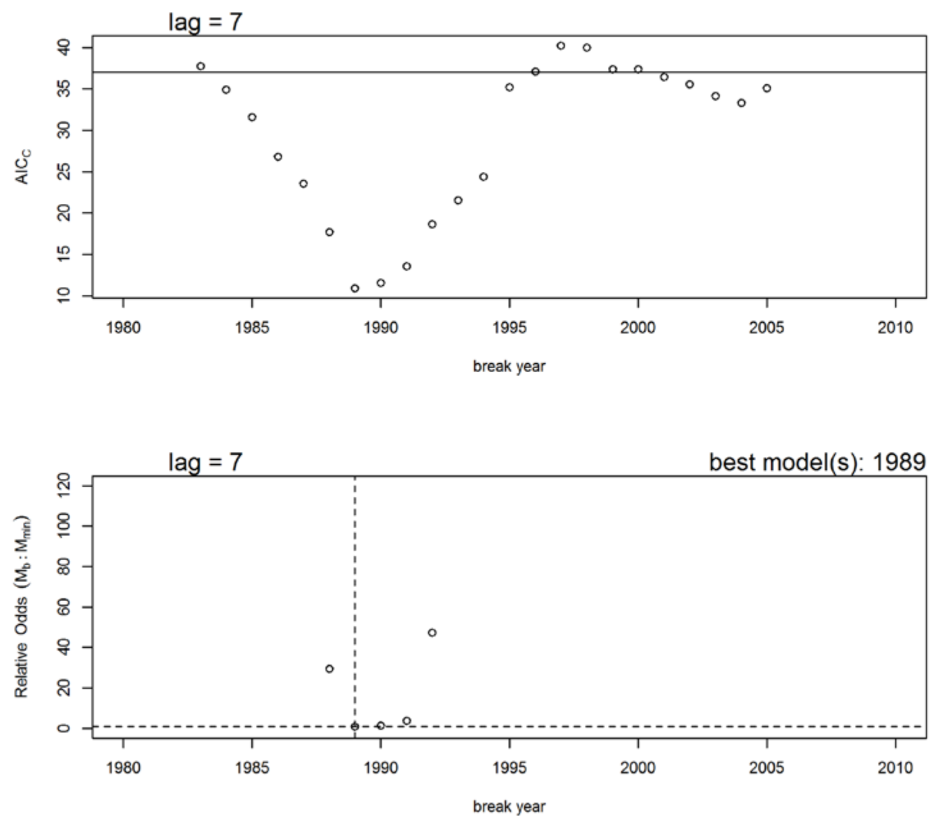

Figure D8. Results from the sensitivity analysis for Ricker stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint model (horizontal solid line) relative to the model with the smallest AICc score. The dashed lines indicate the value for the model with the lowest AICc score (breakpoint in 1989). Not shown are 1-breakpoint models with high odds (>120) of being incorrect.

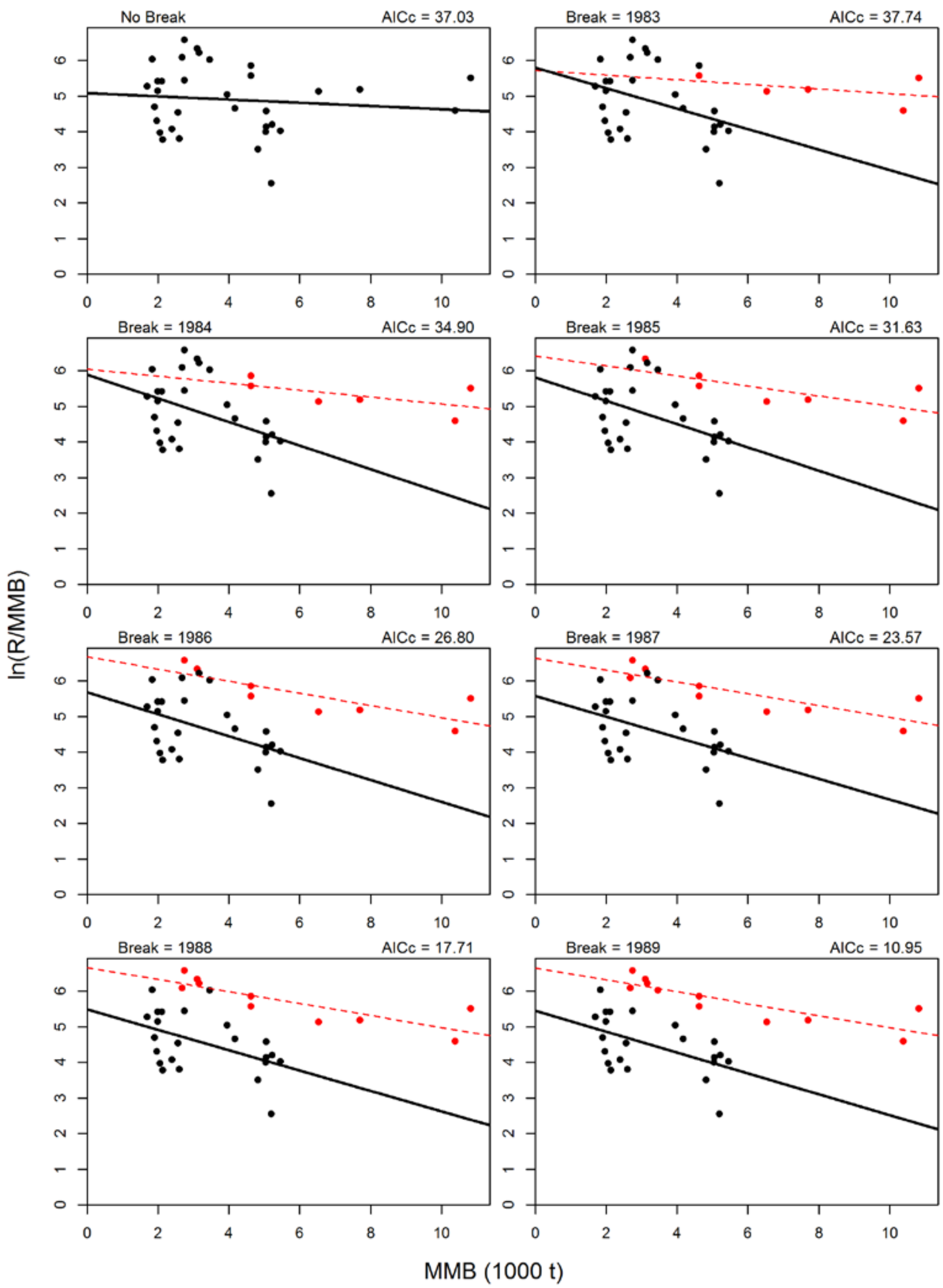

Figure D9. Fits for the sensitivity analysis using the Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1978-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.

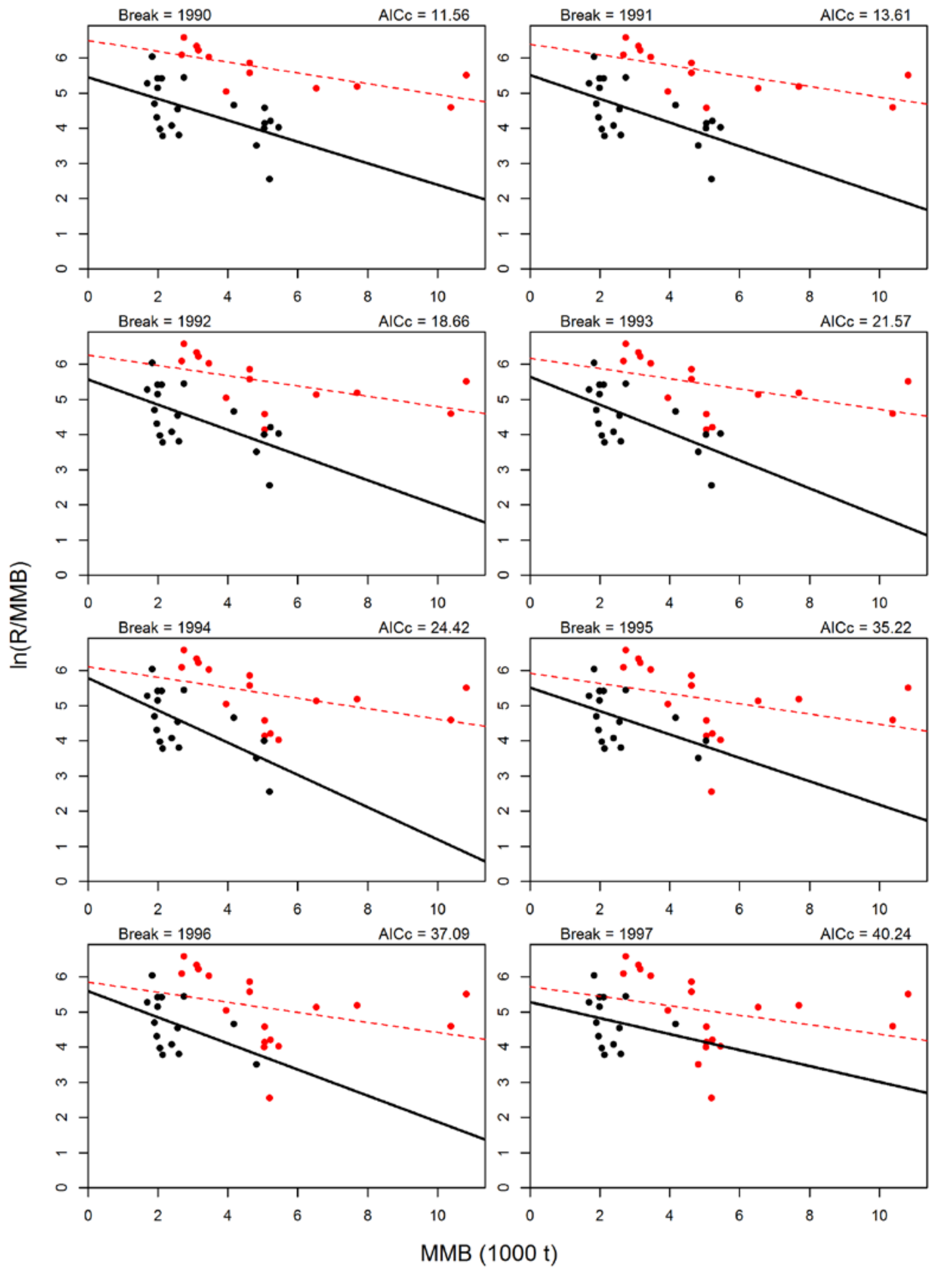

Figure D9. Continued.

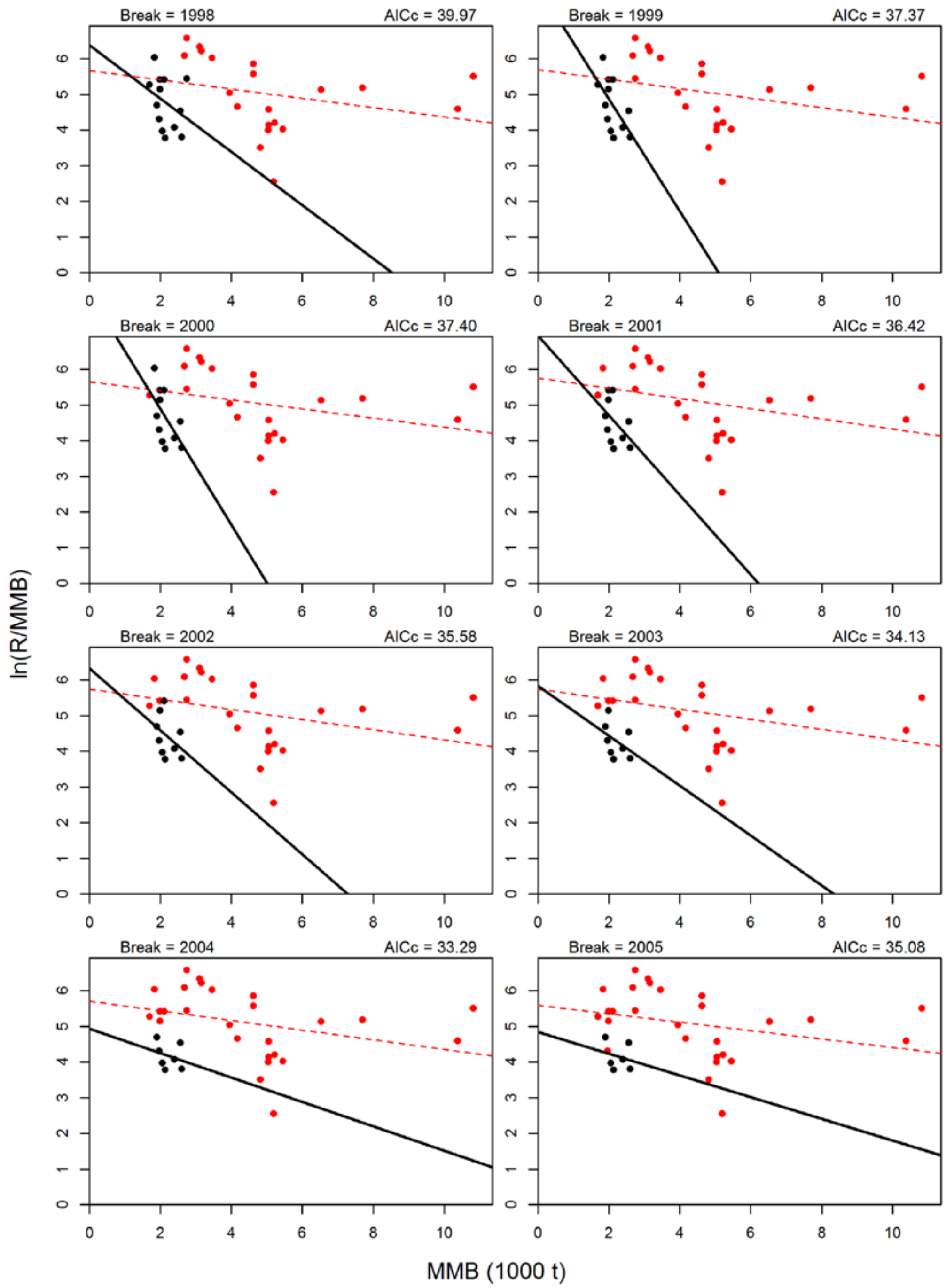

Figure D9. Continued.

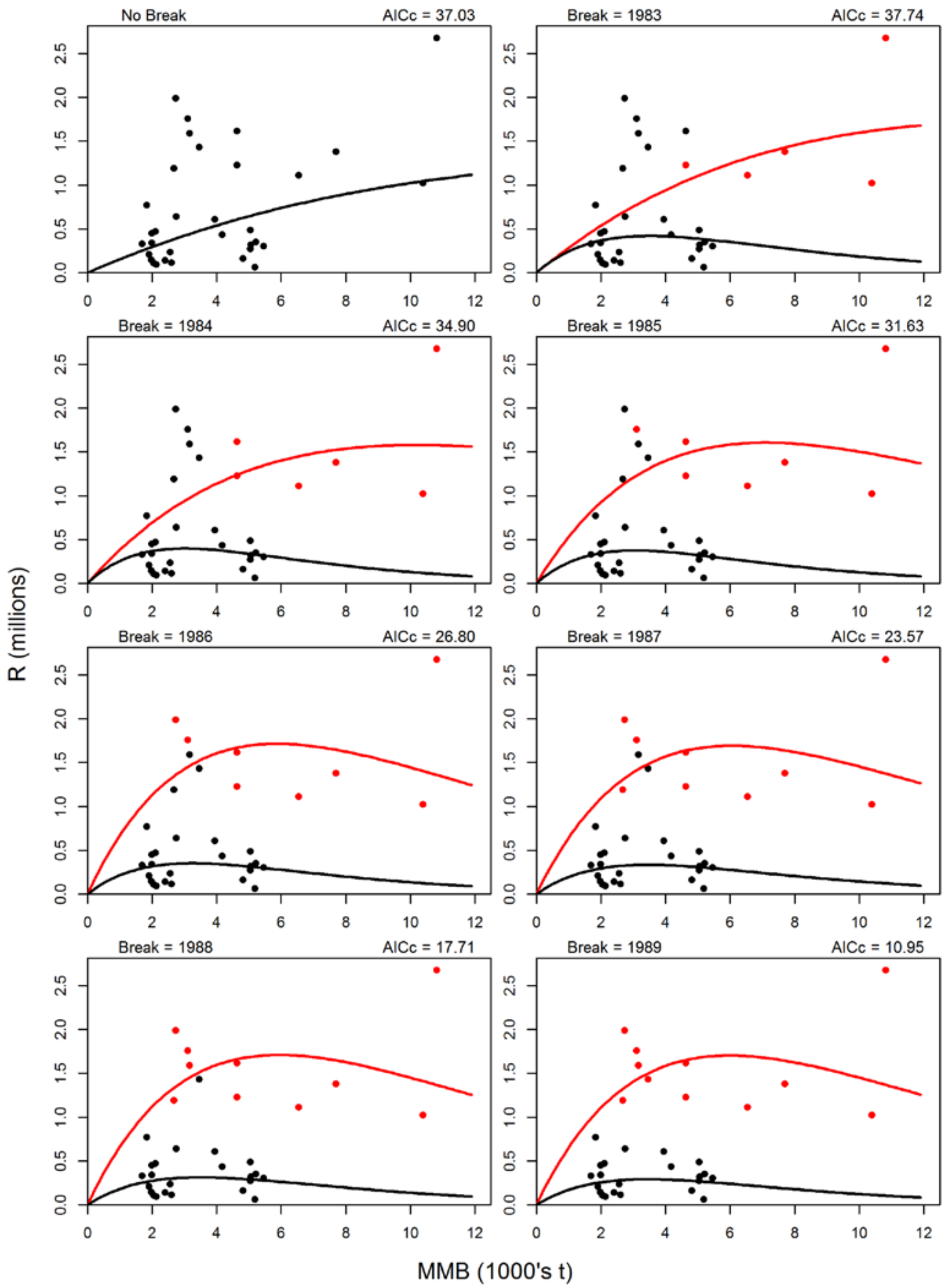

Figure D10. Fits on the arithmetic scale for the sensitivity analysis using the Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1978-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.

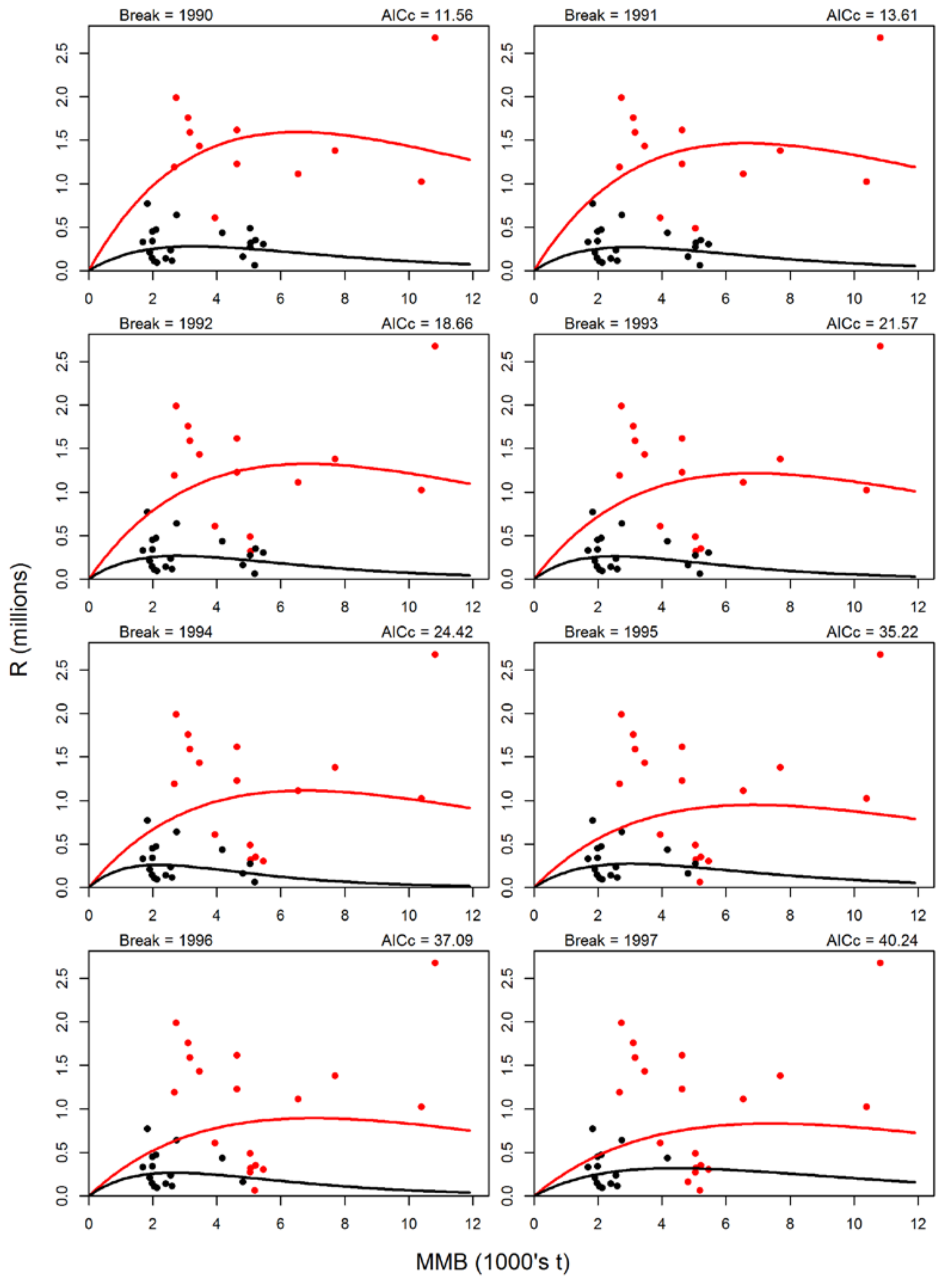

Figure D10. Continued.

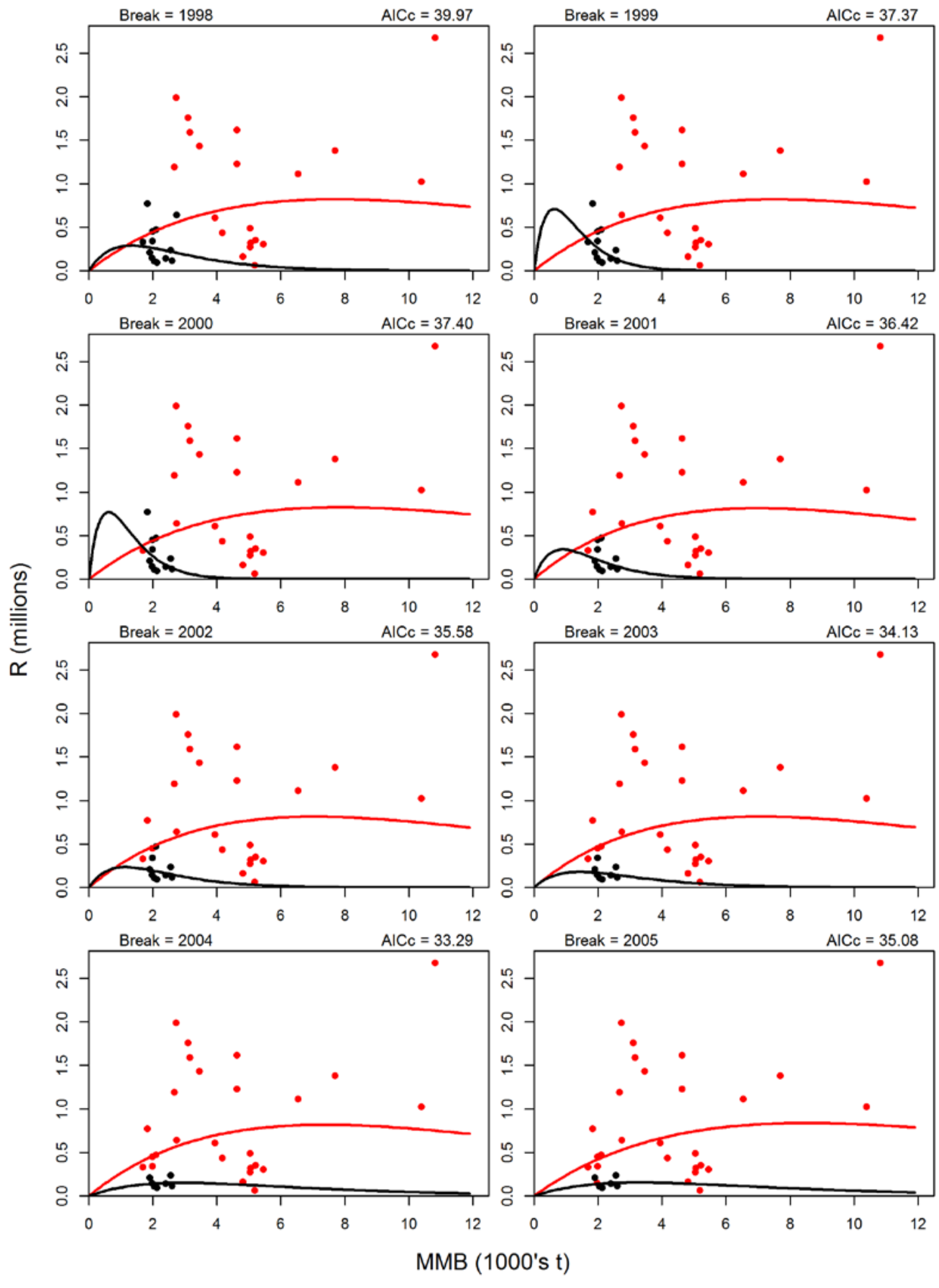

Figure D10. Continued.

Ecosystem and Socioeconomic Profile of the Saint Matthew Blue King Crab stock in the Bering Sea

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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 Saint Matthew blue king crab (SMBKC) stock. Scores for stock assessment prioritization, habitat prioritization, climate vulnerability assessment, and data classification analysis were moderate to high. The SMBKC ESP follows the new standardized framework for evaluating ecosystem and socioeconomic considerations for SMBKC 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 SMBKC stock in the Bering Sea and present results of applying the ESP process through a metric and subsequent indicator assessment. Analysis of the ecosystem and socioeconomic metrics 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.

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 recruitment and the overfished declaration in 2018.
- Trend modeling for ecosystem indicators revealed poor conditions for SMBKC in recent years, attributed to above average bottom temperatures, a reduction in the cold pool extent, and an increase in mean benthic predator biomass in the St. Matthew Island management boundary.

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.

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 (Sigler et al., 2017; 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 Bering Sea Saint Matthew blue king crab (hereafter referred to as SMBKC) 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 four-step ESP process begins with an evaluation of the stock assessment classification results (Lynch et al., 2018) to assess the priority for conducting an ESP and the target ecosystem linkage level. Once it is established to conduct an ESP, the second step is a metric assessment. Metrics are quantitative stock-specific measures that identify vulnerability or resilience of the stock with respect to biological or socioeconomic processes. Where possible, evaluating these metrics by life history stage can highlight potential bottlenecks and lead to a mechanistic understanding of ecosystem or socioeconomic pressures on the stock. The third step is an indicator assessment where a time-series suite is created that represent the critical processes identified by the metric assessment. These indicators must be useful for stock assessment 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. The final step of the ESP is to report potential ecosystem and socioeconomic recommendations, data gaps, caveats, and future research priorities.

Justification

The national initiative prioritization scores for SMBKC are overall moderate to high primarily because the distribution of this stock depends greatly on habitat, there was increasing model development for this stock, and there is potential vulnerability to impacts of future ocean acidification. Also in 2018 the stock was declared overfished, warranting the Crab Plan Team to request an evaluation of ecosystem factors to inform the stock rebuilding plan. 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 SMBKC stock in order to identify data gaps and assess the priority for conducting an ESP. SMBKC is currently managed as a Tier 4 crab stock and as such, the new data classification scores characterize the stock as data-limited with insufficient life history, natural mortality and recruitment data. Both current and target data availability attribute levels for the SMBKC stock size composition attribute were classified as a 3, which adequately supports a size-structured stock assessment. However, catch, 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 survey extent/design to better understand the spatial extent of the stock, increases in stock specific growth and other life history information, and 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 SMBKC.

Data

Initially, information on SMBKC 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. The form data serves 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 metrics and indicators for the SMBKC ESP were collected from surveys, regional reports, laboratory studies and the literature (Table 1). Information for the first year of life was collected primarily from laboratory studies completed at the Kodiak Fisheries Research Center (Long and Daly, 2017), Hatfield Marine Science Center (Stoner et al., 2013) and the Alutiiq Pride Shellfish Hatchery (Herter et al., 2011). Data for late-juvenile through adult BKC stages were derived from the annual NOAA eastern Bering Sea bottom trawl survey and the triannual Alaska Department of Fish and Game St. Matthew Pot Survey. The NOAA bottom trawl survey has been collected annually since 1975 and uses a standardized 376 station grid from Bristol Bay to northwest of St. Matthew Island. Data collected on the survey provides fishery-independent estimates of groundfish and crab abundances and biological data (Zacher et al., 2019). Due to the rocky substrate preferences of BKC, much of the habitat utilized by the SMBKC stock is untrawlable and biomass estimates are underrepresented using NOAA standardized survey gear. As a result, Alaska Department of Fish and Game has conducted the St. Matthew Pot Survey triannually since 1995. In addition to reporting spatial trends in CPUE, the pot survey provides biological data from areas not surveyed by the NOAA trawl survey and is better suited to sample nearshore areas where mature female BKC are concentrated (Watson, 2004; Pengilly and Vanek, 2014).

Information on BKC habitat use was derived from essential fish habitat (EFH) model output and maps (Laman et al., 2017) as well as a recent data rescue effort to recover historic cruise data across all life history stages of the Pribilof Islands BKC stock (Armstrong et al., 2015). 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. The Food Habits database consists of diet data collected from major groundfish species during the annual NOAA eastern Bering Sea bottom trawl survey.

Data used to generate socioeconomic metrics and indicators are derived from fishery-dependent sources, including commercial landings data for SMBKC collected in ADFG fish tickets (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 SMBKC 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 SMBKC. 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 SMBKC relate to other groundfish and crab stocks and highlights the potential vulnerabilities and data gaps for the stock. The 80th and 90th percentile rank areas are provided to highlight metrics that cross into these zones indicating a high level of vulnerability for SMBKC (Figure 1, yellow and red shaded area).

For SMBKC ecosystem metrics, latitude range, depth range, adult mobility, ocean acidification sensitivity and predator stressors fell within the 90th percentile rank of vulnerability, suggesting that BKC are habitat specialists and highly sensitive to changes in resource availability and habitat requirements. Additionally, predation pressure is very high during early life history stages and BKC are particularly vulnerable to predators after molting. Recruitment variability, temperature range, fecundity, habitat specificity, habitat dependence index and habitat vulnerability index fell within the 80th percentile rank when compared to other stocks in the groundfish and crab FMP's. SMBKC were also relatively resilient for breeding strategy index, hatch size and ecosystem value top-down and bottom-up. These initial results suggest that stage-based information regarding the implications of high predation, climate change, and habitat quality would be both valuable for the stock and would assist with subsequent indicator development. For the three applicable socioeconomic metrics, values indicated medium to low vulnerability.

SMBKC had numerous data gaps for ecosystem metrics, including growth rate, length at 50% maturity, maximum length, spawning duration, dispersal ELH, prey specificity and mean trophic level. The data quality was rated as medium to complete for all metrics with data available except for natural mortality, recruitment variability and ecosystem value top-down. The numerous data gaps highlight the need for additional studies to contribute to a better understanding of BKC 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. However, BKC early life history processes are not well understood and data has been provided primarily from laboratory studies (e.g. Stoner et al., 2013, Long and Daly, 2017). As a first attempt to synthesize distribution, habitat usage and phenology of BKC across all life stages, we created a baseline life history conceptual model which is detailed in Figure 2. In the conceptual model figure, abiotic and biotic processes were identified by each life stage from the lead author and relevant papers. The main categories of the primary ecosystem processes influencing BKC life stages were identified as water temperature, larval transport and retention, habitat suitability and impact of predation. Details on why these processes were highlighted in the conceptual model and the potential relationship between these processes and the different life stages are described below.

BKC larval development consists of four zoeal stages and one glaucothoe stage, after which larvae metamorphose and settle as stage C1 benthic juveniles (Persselin, 2006). Cultivation experiments reported a 91.7% survival rate of BKC larvae from hatching to C1 stage at 6°C with increased mortality at rearing temperatures greater than 9°C (Stevens et al., 2005; Stevens et al., 2008a). While BKC larvae exhibit an upper thermal tolerance in captivity, cooler water temperatures could, in turn, slow development rates and increase mortality due to both increased larval transport and larval stage duration (Loher, 2014). Dispersal pathways of SMBKC larvae are currently unknown but advection and dispersal rates may be a significant driver of recruitment dynamics, as observed in other EBS crab stocks (Rosenkranz et al., 1998; Richar et al., 2015; Daly et al., 2018). Transport to favorable settlement grounds in the nearshore waters of St. Matthew Island is most likely dependent on high localized retention rates of BKC larvae although studies are needed to identify relationships between oceanographic conditions, larval transport and recruitment success.

During the early juvenile stages, successful settlement requires shallow, nearshore waters (<50m) and hard substrate such as shell hash, gravel or rock due to the reliance of BKC on crypsis to evade predation (Armstrong et al., 1985; Daly and Long, 2014). Survival in juvenile BKC is linked to mollusk shell abundance, including mussels (*Modiolus modiolus*), scallops (*Chlamys* sp.), rock oysters (*Pododesmus macrochisma*), and hairy tritons (*Fusitriton oregonensis*) (Chilton et al., 2011; Palacios and Armstrong, 1985). Unlike RKC, juvenile BKC lack a heavy covering of carapace spines and do not form pods to offer protection from predation, emphasizing the role of habitat complexity in BKC survival (Stevens, 2014). In addition, juvenile BKC molt several times a year during early benthic instar stages and are especially vulnerable to predation while soft. Pacific cod have been shown to predate heavily on soft-shell female red king crab (Livingston, 1989) and are likely also a key predator on juvenile BKC. Early juvenile BKC appear to have a broad range of temperature tolerance, indicated by relatively high survival over the range of temperatures tested (1.5 to 12 °C) in a laboratory experiment (Stoner et al., 2013). This is likely advantageous during the juvenile stage when BKC utilize relatively shallow habitats more prone to temperature fluctuations.

Late juvenile and adult BKC are less reliant on habitat with complex substrate, however a suite of habitat variables can be used to predict SMBKC distribution and identify vulnerabilities associated with suitable habitat characteristics. EFH models suggest that the probability of mature BKC abundance is highest over coarser sediments and lower maximum tidal currents (Laman et al., 2017). Temperature and depth likely also represent vulnerabilities given that mature female BKC migrate to relatively shallow, nearshore waters south of St. Matthew Island during the spring and summer months when bottom temperatures reach their maximum (Pengilly and Vanek, 2014). BKC exhibit reduced growth rates at 12°C and above, with feeding ration increasing with temperature up to 6°C (Long and Daly, 2017). In addition to temperature effects on BKC physiology, laboratory studies have demonstrated temperature-mediated shifts in hatch timing and embryo development (Stevens et al., 2008b). The biannual molt and reproductive strategy characteristic of BKC in contrast to most other *Paralithodes* spp. suggests that energetic restrictions imposed by temperature or prey conditions may be a limitation in reproductive dynamics (Webb, 2014; Jensen et al., 1985). However, adult BKC are generalists and as such, it is hypothesized that benthic prey abundances may not play an important role in life history processes.

Socioeconomic Processes

As discussed in more historical detail in Leon et al. (2017), the commercial SMBKC fishery began in 1977, with 10 vessels harvesting 1.2 million pounds (including deadloss), increasing to 22 vessels in 1978, harvesting 2.0 million pounds, and declining over the next two years to 2 active vessels in 1980. Over the next three years, the fishery increased from 31 active vessels in 1981 harvesting 4.6 million pounds to 164 vessels landing 9.5 million pounds in 1983, the largest annual catch volume in the fishery to-date and the first year of management under a declared GHL, which began at 8 million pounds. In subsequent seasons through 1997, the GHL varied from 0.5 million to 5.0 million pounds, with an active fleet varying between 31 and 174 vessels and total landings varying between 1.0 million pounds in 1986 (exceeding the preseason declared GHL range of 0.2 – 0.5 million by 100%) to 4.6 million pounds in 1997. With the initial year of the CDQ program in 1998, the fishery opened with a GHL of 5.0 million pounds, with 1.0 million pounds allocated as CDQ quota in addition to 4.0 million pounds in the general allocation fishery; the latter was prosecuted by 131 active vessels harvesting 2.9 million pounds before the fishery was closed inseason, however, only one active vessel harvested CDQ and total 1998 catch cannot be reported due to confidentiality of the CDQ catch.

The stock declined following the 1998 season, being declared overfished by NMFS in 1999 based on the results of the summer trawl survey, and the fishery was closed from the 1999 to 2008/09 seasons, with a rebuilding plan being implemented beginning in 2000. The fishery reopened for the 2009/10 season under the CR program and TAC management (both of which began in 2005 for the 2005/06 crab season), with a combined TAC of 1.67 million pounds (90% issued as IFQ allocation and 10% as CDQ), and with 7 active vessels harvesting 0.46 million pounds (39% of the TAC). The fishery remained open over the next three seasons, increasing to 2.4 million pounds TAC in 2011/12, with 18 active vessels harvesting 1.9 million pounds (80% of the TAC), and 1.63 million pounds TAC in 2012/13, with 17 active vessels harvesting 1.62 million pounds, approaching full utilization of the TAC for the first time under the CR program. Due to low abundance in the 2013 survey, the fishery was closed for 2013/14, and opened for the next two seasons with substantially reduced TACs relative to previous open seasons, at 0.66 million pounds in 2014/15 and 0.41 million pounds in 2015/16, and the number of active vessels during the two most recent seasons reduced to 4 and 3 vessels, respectively, with a catch of 0.11 million pounds in 2015/16 and utilization of the available catch limit declining to 26%, the lowest level in the fishery to-date. The fishery has been closed during each of the last three crab seasons, beginning in 2016/17.

Over the 1977 to 1998 period, the SMBKC fishery was prosecuted during open seasons that varied in length and timing, with the earliest opening on June 7 in 1977, growing later over subsequent seasons to August 1 in 1982, September 1 in 1985, and September 16 in 1991, and September 15 from 1993 through 1998. Prior to 1982, SMBKC openings ranged from approximately 5 to 9 weeks, with the latest closing on September 3 after 19 days in both 1978 and 1980. Over subsequent years prior to 2005, openings in the fishery were limited to shorter spans of 1 to 11 days, with the latest closing in 1998 on September 26. With the implementation of the CR program, the regulatory season for SMBKC was shifted to October 15 through February 1, with active fishing typically during years when the fishery opened occurring within a period of 4-5 weeks beginning October 15, with final landings for the respective seasons occurring during early- to mid-November. Over the more recent history of the SMBKC fishery, active vessels have prosecuted the SMBKC fishery in the period preceding active fishing in the other rationalized crab fisheries (most commonly the Bristol Bay RKC and Bering Sea snow crab fisheries, with some vessels also fishing in the Bering Sea Tanner crab fisheries) and groundfish, with SMBKC contributing a component to associated vessels' fishing portfolio, and comprising a small to moderate proportion of total annual ex-vessel revenue for most vessels active in SMBKC during a given year.

Indicators Assessment

Indicator Suite

We first provide information on how we selected the indicators for this third step of the ESP process and then provide results on the indicators analysis.

Ecosystem Indicators

Very few studies have linked environmental 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 red and blue king crab stocks in the early 1970's corresponded with low temperatures. However, recruitment trends are not consistently explained by temperatures or decadal-scale environmental variability (Zheng and Kruse, 2006). Furthermore, groundfish predation has been hypothesized as a mechanism driving recruitment variability. SMBKC recruitment was positively correlated with Pacific cod biomass, opposite of the hypothesized directionality of predation effects on recruitment (Zheng and Kruse, 2006). The lack of general or biologically meaningful relationships supporting recruitment hypotheses for SMBKC in these studies may be attributed to analyses using basin-scale indicators that are not relevant to the small spatial scale of the SMBKC management area.
When selecting a suite of indicators for the SMBKC ESP, efforts were instead focused on developing spatially explicit indicators bounded by the SMBKC management area. These indicators are described below.

Bottom temperature and cold pool indicators representing environmental conditions during the summer survey period are likely drivers of juvenile and adult BKC distribution, timing of the reproductive cycle and larval transport. BKC females move inshore in late spring to hatch eggs, molt and mate (Armstrong et al., 1981). These inshore movements may be triggered by warming bottom temperatures, suggesting that cold years in the Bering Sea have the potential to delay mating migrations, embryo development and hatching as demonstrated in laboratory studies (Stevens et al., 2008b). Temperature-mediated shifts in hatch timing could subsequently result in BKC larvae mismatches with prey resources, or increase the probability of advection away from favorable nursery grounds. 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).

An indicator representing the cold pool extent (<2°C) is not only important in driving BKC distributions, but also in driving distributions of major predators of BKC. Pacific cod and several flatfish species typically avoid temperatures less than 1° C (Kotwicki and Lauth, 2013), suggesting that years with a large cold pool extent around St. Matthew Island may offer BKC a refuge from predation.

A SMBKC pre-recruit biomass index effectively tracks the number of males that will likely enter the fishery the following year. Small catches of these sub-legal BKC are often a reliable indicator of impending declines in mature male biomass and may be useful as an early indicator of stock recovery for the SMBKC rebuilding plan. Likewise, a male bycatch indicator tracks mortality in trawl and fixed gear fisheries and fluctuations in bycatch rates may necessitate different regulations on groundfish fisheries or area closures to limit BKC mortality due to bycatch.

Estimates of benthic predator biomass (i.e. Pacific cod, sablefish, Pacific halibut, skates, sculpin, octopus and assorted flatfish) and invertebrate biomass (i.e. brittle stars, sea stars, sea cucumber, bivalves, non-commercial crab species, shrimp and polychaetes) provide information on the relative fluctuations of these foraging guilds (BSAI ESR, 2018). Increases in benthic predator biomass may represent increased mortality events due to predation on BKC. Although no studies on BKC diet and foraging ecology exist to date, species included in the invert biomass indicator are important prey sources for other EBS commercial crab species, and therefore likely prey of BKC as well. Increases in invert biomass may suggest optimal foraging conditions for BKC. It is, however, important to note that bottom trawl survey methods result in very low catchability of polychaetes, which are recognized as an important prey source for EBS crab species. Furthermore, increases in highly mobile benthic foragers such as hermit crabs and sea stars may, instead, suggest increased competition for benthic resources. A better understanding of benthic production and foraging ecology in the Bering Sea, and specifically, the St. Matthew Island region, is necessary to refine foraging guild indicators and their impacts on SMBKC.

Socioeconomic Indicators

Indicators reported for applicable socioeconomic metrics are derived from fishery-dependent sources that represent full enumeration of commercial landings captured in ADFG fish tickets, and ADFG and NMFS observer program data that support reliable estimates of fishing effort in the SMBKC fishery and bycatch in groundfish fisheries, respectively. Due to the intermittent opening of the targeted SMBKC fishery over the last 20 years, however, substantial gaps in the time-series for most socioeconomic indicators indicate zero (0) values when no fishery occurred, and the small number of vessels or processors participating in the fishery during some recent openings prevents reporting the value of some indicators for those years to protect confidentiality of associated landings and/or catch and effort data. The socioeconomic indicators reported below were selected in part on the basis of maximal length of time-series available[1], however, discontinuities in some data series due to changes in data collection methods limit reporting of indicator values to 1991 and later. Also, because the most recent fishery-dependent data sources 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), socioeconomic indicators are limited to providing retrospective information. Although relative to other crab and groundfish stocks, SMBKC is not data-poor with regard to most socioeconomic dimensions relevant to the fishery, the time-series gaps in socioeconomic indicators reported below may limit the ability to identify trends or movements in the indicators contemporaneous with reported ecosystem indicators and other factors considered in the SMBKC assessment. Combined with other functional limitations, this may substantially diminish the utility of these or other potential socioeconomic indicators for many of the purposes envisioned for the ESP.

The socioeconomic indicators reported below can be grouped into two broad, interrelated categories: 1) those addressing dimensions of commercial value, constituent demand and community dependence, and 2) indicators related to the relative quantity and efficiency of fishing effort. The latter set of indicators are reported in the assessment and are included in Figure 4 to support visual comparison of the relative values and trends in the respective sets of indicators.

Commercial value and constituent demand indicators

Ex-vessel price per pound, 1991-2015 ($2018)

Ex-vessel prices are revenue per pound of retained SMBKC catch, delivered live and sold to processors. 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.

SMB exvessel revenue share (% of total exvessel revenue)

This indicator represents the proportion of total annual ex-vessel revenue from all crab and groundfish landings for vessels active in the SMBKC fishery during a given calendar year that is produced from the SMBKC fishery. The reported values are calculated as the vessel-level mean SMBKC revenue share over the set of vessels active in the fishery for the year. Revenue share provides an indicator of the relative income dependence of participating vessels on the SMBKC 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.

Processors active in fishery

The number of processors (buyers) of SMBKC landings during the year; this provides an indicator of the density of the market for SMBKC landings.

Local Quotient of SMB landed catch in Saint Paul

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.

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[1]As one of the eight FMP crab stocks included in the Crab Rationalization Program, substantial additional data are available for the SMBKC fishery that are collected by NMFS in several mandatory reporting data collections that were initiated in 2005 to monitor the performance and effects of the management program, including the ownership of CR crab harvesting and processing quota share (QS) and the quantity and value of QS transfers between buyers and sellers, and vessel and plant operating cost, quota lease activity and value, and employment data reported by crab fishing and processing sector participants in the Crab Economic Data Report (EDR) program. Although these and other CR program-specific data collections provide substantial additional data to support a variety of socioeconomic indicators of potential utility for the purpose of the ESP (many of which are reported in BSAI Crab Economic Status Reports produced annually by AFSC (Garber-Yonts and Lee, 2019), the associated data series are only available beginning 2005 or more recent, and are largely subject to the same intermittency as other fishery-dependent data available for the SMBKC fishery.

TAC Utilization (%)

The percentage of the available catch allocation (GHL or TAC) that was harvested by participating vessels (including catch discarded as deadloss at the landing). Underutilization of the available TAC indicates a low value of expected returns from fishing SMBKC relative to alternative fishing targets, or idling the vessel.

Fishing effort

Vessels active in fishery

Total Potlifts

CPUE (no. of crabs per potlift - mean)

SMBKC male bycatch biomass (1000t)

Indicator Monitoring Analysis

The suite of indicators for SMBKC is monitored using a series 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 only report the results of the first stage indicator testing procedure for SMBKC. The first stage is a simple assessment of the trend and variance of the most recent year and a traffic-light evaluation of the most current year of data when available (Tables 2-3). The traffic-light ranking of the current year is based on the 20th and 80th percentiles of the time series and the color of blue, yellow, or red related to being below, within, or above the two percentiles (Caddy et al., 2015).

Ecosystem indicator trends suggest poor environmental conditions during the past 5 years for the SMBKC stock. Summer bottom water temperatures in the St. Matthew management area were at an all-time high in 2018 while the cold pool did not extend into the management area. Similar conditions were observed during 2019 summer survey operations. SMBKC pre-recruit biomass has also been on a steady decline since the mid-1990's and the 2017 recruitment estimate is the third lowest in the 41 year time-series, following the lowest previously observed in 2016. Results of a recent breakpoint analysis suggest a SMBKC recruitment regime shift around 1996, corresponding with a 1989 brood year (Palof et al., 2019). Interestingly, there is empirical evidence for a 1989 regime shift in the North Pacific which was attributed to declines in Bering Sea groundfish recruitment and overall decreases in marine productivity (Hare and Mantua, 2000). Synchronous declines in time-lagged SMBKC recruitment suggest that ELH stages of BKC may have been negatively affected by these basin-scale ecological changes. Furthermore, warmer than average bottom temperatures in the St. Matthew Island management area in recent years correspond with low recruitment, suggesting that temperature may have an indirect effect on BKC early life history processes and survival to recruitment. In past years, trawl survey station R-24, on the northwest corner of St. Matthew Island, has been characterized by large catches of mature male BKC (Zacher et al., 2019). In 2018 and 2019, BKC catches were very low at R-24, corresponding with bottom temperatures nearing the upper limit of BKC thermal requirements. These observations may suggest that BKC habitat quality is decreasing as shallow, nearshore habitats warm to 6°C and above.

Benthic predator biomass was at an all-time high in 2016, attributed to high catches of Pacific cod surrounding St. Matthew Island. Likewise, in 2016 benthic invert biomass was up from previous years, characterized by high catches of several sea star species (*Ctenodiscus crispatus, Gorgonocephalus eucnemis and Leptasterias polaris*) as well as *Hyas coarctatus and Pagarus trigonocheirus*. 2016 biomass increases in highly mobile decapods and echinoderms may suggest increased competition for food resources available for juvenile and adult BKC. Both benthic predator and benthic invert biomasses have since declined, although remain above-average.

As a full suite of indicators is developed in the coming years, bayesian adaptive sampling (BAS) will be used for the second stage modeling application to quantify the association between hypothesized predictors and SMBKC along with the strength of support for each hypothesis.

Recommendations

In initial projections for the SMBKC rebuilding plan, recruitment appears to drive recovery time of the stock so we emphasize a concerted focus on developing a better understanding of early life history processes and the continued development of indicators relevant to larval and juvenile SMBKC. Developing an EFH habitat indicator for SMBKC should also be prioritized, as metric assessment results highlighted several vulnerabilities related to habitat. These updated indicators may then be used in second and third stage testing and modeling.

With these future priorities in mind, we provide the following set of considerations:

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 poor conditions for SMBKC in recent years attributed to above average bottom temperatures, a reduction in the cold pool extent, and an increase in mean benthic predator biomass in the St. Matthew management boundary.

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. 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 the development of a larval retention indicator. Furthermore, additional groundfish stomach data outside of the summer survey time series would help to refine our understanding of predation pressure across life history stages of SMBKC. Likewise, spring bottom temperatures prior to the summer bottom trawl survey may help to understand SMBKC distribution in relation to survey catchability.

As noted above, 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.

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We would like to thank all the crab stock assessment authors for their timely response to requests and questions regarding their data, report summaries, and manuscripts. We also thank all attendees and presenters at the AFSC sponsored ESP Data workshop (May, 2019) for their valuable insight on the development of the SMBKC ESP and their collective efforts in summarizing data sources and time series for future indicator development. Lastly, we thank the Crab Plan Team for supporting the development of this report and future reports.

Literature Cited

Armstrong, D., Incze, L., Wencker, D., and Armstrong, J. 1981. Distribution and abundance of decapod crustacean larvae in the southeastern Bering Sea with emphasis on commercial species.: 53. 479-878 pp.

Armstrong, D. A., Armstrong, J. L., Palacios, R., Williams, G., Jensen, G. C., and Pearson, W. 1985. Early life history of juvenile blue king crab, *Paralithodes platypus*, around the Pribilof Islands. *In* Proceedings of the International King Crab Symposium, pp. 211-229. Ed. by S. K. Davis, F. Gaffney, J. McCrary, A. J. Paul, and R. S. Otto. Alaska Sea Grant College Program, University of Alaska Fairbanks, Anchorage, AK.

Armstrong, D.A., W.C. Long, J. Armstrong, P.S. McDonald. 2015. Blue king crab, habitat, and the ecosystem: Data rescue from the 1980s. NPRB Project 1321 Final Report. North Pacific Research Board.

Caddy, J.F. 2015. The traffic light procedure for decision making: its rapid extension from fisheries to other sectors of the economy. Glob. J. of Sci. Front. Res: 1 Mar. Sci. 15(1), 30 pp.

Chilton, E., Swiney, K., Urban, D.J., and Munk E.J. 2011. Ecosystem considerations for Bering Sea and Aleutian Islands king and tanner crab species *In* Stock Assessment and Fishery Evaluation

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

Daly, B., and Long, W. C. 2014. Intra-guild predation among early benthic phase red and blue king crabs: Evidence for a habitat-mediated competitive advantage. Journal of Experimental Marine Biology and Ecology, 451: 98-104.

Daly, B., A.J. Hermann, C. Parada, S. Hinckley, T.H. Loher, and D.A. Armstrong. 2018. Impacts of climate change on red king crab larval advection in Bristol Bay: implications for recruitment variability. NPRB Project 1402 Final Report. North Pacific Research Board.

Dorn, M. W., C. J. Cunningham, M. T. Dalton, B. S. Fadely, B. L. Gerke, A. B. Hollowed, K. K.

Garber-Yonts, B., and J. Lee. 2019. Stock Assessment and Fishery Evaluation Report for King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions: Economic Status of the BSAI Crab Fisheries, 2018. NPFMC, April, 2019. 178 p. https://www.fisheries.noaa.gov/webdam/download/91792918.

Hare, S.R. and M.J. Mantua. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography, 47: 103-145.

Herter, H., Daly, B., Swingle, J. S., and Lean, C. 2011. Morphometrics, fecundity, and hatch timing of blue king crabs (*Paralithodes platypus*) from the Bering Strait, Alaska, USA. Journal of Crustacean Biology, 31: 304-312.

Holsman, J. H. Moss, O. A. Ormseth, W. A. Palsson, P. A. Ressler, L. A. Rogers, M. A. Sigler, P. J. Stabeno, and M. Szymkowiak. 2018. A climate science regional action plan for the Gulf of Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-376, 58 p.

Jensen, G. C., Armstrong, D. A., and Williams, G. 1985. Reproductive biology of blue king crab, *Paralithodes platypus*, in the Pribilof Islands *In* Proceedings of the International King Crab Symposium, 5th edn, pp. 109-121. Ed. by S. K. Davis, F. Gaffney, J. McCrary, A. J. Paul, and R. S. Otto. Alaska Sea Grant College Program, University of Alaska Fairbanks, Anchorage, AK.

Kotwicki, S., and Lauth, R. R. 2013. Detecting temporal trends and environmentally-driven changes in the spatial distribution of bottom fishes and crabs on the eastern Bering Sea shelf. Deep-Sea Research Part Ii-Topical Studies in Oceanography, 94: 231-243.

Laman, E. A., C. N. Rooper, S. C. Rooney, K. A. Turner, D. W. Cooper, and M. Zimmermann. 2017. Model-based Essentail Fish Habitat Definitions for Bering Sea Groundfish Species. U.S. Dep. Commer., NOAA Tech Memo. doi:10.7289/V5/TM-AFSC-357

Leon, J. M., J. Shaishnikoff, E. Nichols, and M. Westphal. 2017. Annual management report for shellfish fisheries of the Bering Sea–Aleutian Islands Management Area, 2015/16. Alaska Department of Fish and Game, Fishery Management Report No. 17-10, Anchorage. 188 p.

Livingston, P. 1989. Interannual trends in Pacific cod, *Gadus macrocephalus*, predation on three commercially important crab species in the eastern Bering Sea. Fishery Bulletin, 87: 807-827.

Loher, T. 2014. Modeling Larval Advection and Spatial Population Structure in King Crabs: Interactions among Life-History Requirements, Extrinsic Forcing, and Source-Sink Dynamics, *In* King Crabs of the World : Biology and Fisheries Management. Ed. by B. G. Stevens. CRC Press LLC.

Long, W. C., and Daly, B. 2017. Upper thermal tolerance in red and blue king crab: sublethal and lethal effects. Marine Biology, 164: 162.

Lynch, P. D., R. D. Methot, and J. S. Link (eds.). 2018. Implementing a Next Generation Stock Assessment Enterprise. An Update to the NOAA Fisheries Stock Assessment Improvement Plan. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-F/SPO-183, 127 p. doi: 10.7755/TMSPO.183

Palacios, R., and Armstrong, D. 1985. Community analysis applied to characterization of blue king crab habitat around the Pribilof Islands. *In* Proceedings of the International King Crab Symposium, pp. 193-209. Ed. by B. Melteff. University of Alaska Sea Grant Program, Anchorage, AK, USA.

Pengilly, D., and Vanek, V. 2014. Results of the 2013 triennial St. Matthew Island blue king crab pot survey. ICES Document 14-35: No. 14-35. 81 pp.

Palof, K., Zheng, J., Ianelli, J. 2019. St. Matthew Island Blue King Crab Stock Assessment *In* Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306 Anchorage, AK 99501.

Persselin, S. 2006. Cultivation of king crab larvae at the Kodiak Fisheries Research Center, Kodiak, Alaska. *In* Alaska Crab Stock Enhancement and Rehabilitation: Workshop Proceedings, pp. 9-13. Ed. by B. Stevens. Alaska Sea Grant College Program AKSG-06-04.

Richar, J. I., Kruse, G. H., Curchitser, E., and Hermann, A. J. 2015. Patterns in connectivity and retention of simulated Tanner crab (*Chionoecetes bairdi*) larvae in the eastern Bering Sea. Progress in Oceanography, 138: 475-485.

Rosenkranz, G., Tyler, A., Kruse, G., and Niebauer, H. 1998. Relationship between wind and year class strength of Tanner crabs in the southeastern Bering Sea. Alaska Fishery Research Bulletin, 5: 18-24.

Siddon, E., and S., Zador. 2018. Ecosystem Status Report 2018: Status of the Bering Sea marine ecosystem. *In* Stock Assessment and Fishery Evaluation Report, North Pacific Fishery Management Council, 605 W 4th Ave, Suite 306, Anchorage, AK 99501. 215 p.

Sigler, M. F., M. P. Eagleton, T. E. Helser, J. V. Olson, J. L. Pirtle, C. N. Rooper, S. C. Simpson, and R.P. Stone. 2017. Alaska Essential Fish Habitat Research Plan: A Research Plan for the National Marine Fisheries Service’s Alaska Fisheries Science Center and Alaska Regional Office. AFSC Processed Rep. 2015-05, 22 p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Stevens, B. G., Persselin, S., and Matweyou, J. 2008a. Survival of blue king crab *Paralithodes platypus* Brandt, 1850, larvae in cultivation: effects of diet, temperature and rearing density. Aquaculture Research: 390-397.

Stevens, B. G., Persselin, S. L., and Matweyou, J. A. 2005. Cultivation of blue king crab larvae, *Paralithodes platypus*: effects of diet, temperature, and density. *In* Larvi '05 - Fish & Shellfish Larviculture Symposium, pp. 485-488. Ed. by C. I. Hendry, G. Van Stappen, M. Wille, and P. Sorgeloos. European Aquaculture Society, Gent, Belgium.

Stevens, B. G., Swiney, K. M., and Buck, L. 2008b. Thermal effects on embryonic development and hatching for blue king crab *Paralithodes platypus* (Brandt, 1850) held in the laboratory, and a method for predicting dates of hatching. Journal of Shellfish Research, 27: 1255-1263.

Stevens, B.G. 2014. Biology and Ecology of Juvenile King Crabs, *In* King Crabs of the World: Biology and Fisheries Management. Ed. by B. G. Stevens. CRC Press LLC.

Stoner, A. W., Copeman, L. A., and Ottmar, M. L. 2013. Molting, growth, and energetics of newly-settled blue king crab: Effects of temperature and comparisons with red king crab. Journal of Experimental Marine Biology and Ecology, 442: 10-21.

Watson, L. J. 2004. Project operational plan for the 2004 Triennial St. Matthew Island blue king crab survey. ICES Document 4K04-26. 55 pp.

Webb, J. 2014. Reproductive Ecology of Commercially Important Lithodid Crabs, *In* King Crabs of the World: Biology and Fisheries Management. Ed. by B. G. Stevens. CRC Press LLC.

Zacher, L.S., Richar J.I., and Foy R.J. 2019. The 2019 Eastern Bering Sea Continental Shelf Trawl Survey: Results for Commercial Crab Species. U.S. Dep. Commer., NOAA Tech Memo.

Zheng, J., and Kruse, G. 2000. Recruitment patterns of Alaskan crabs in relation to decadal shifts in climate and physical oceanography. ICES Journal of Marine Science, 57: 438.

Zheng, J., and Kruse, G. H. 2006. Recruitment variation of eastern Bering Sea crabs: Climate-forcing or top-down effects? Progress in Oceanography, 68: 184-204.

Table 1. List of data sources used in the SMBKC ESP evaluation. Please see the SMBKC SAFE document (Palof et al., 2019), the NOAA EBS Trawl Survey: Results for Commercial Crab Species Technical Memo (Zacher et al., 2019) 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 collected from key groundfish species on the EBS bottom trawl survey	1987-2018	EBS annual
	ADF&G St. Matthew Island Pot Survey	Pot survey for blue king crab in the standard EBS bottom trawl survey area offshore and the nearshore area south and west of St. Matthew Island	1995-2018	St. Matthew Island Management Area, triannual
	Essential Fish Habitat Models	Habitat suitability MaxEnt models for describing essential fish habitat of groundfish and crab in Alaska, EFH 2017 Update	1970-2016	Alaska
	Historic Pribilof Island BKC Cruise Data	Data from zooplankton tows, beam trawl and rock dredge samples and side scan sonar to examine BKC processes across life history stages	1983-1984	Pribilof Islands, EBS
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	1992-2018	Alaska
	ADF&G Crab Observer program data	SMBKC catch and effort data (number of active vessels, total pots lifted, and CPUE), sourced from ADF&G Annual Fishery Management Report	1980-2017	Alaska

Table 2. First stage ecosystem indicator analysis for SMBKC including indicator title and short description. The recent five-year trend (up, down, or stable) and recent five-year mean (greater than (+), less than (-) or within 1 standard deviation (·) of long-term mean) are provided following the ESR methods. Fill is based on 2019 conditions for SMBKC relative to the 20th and 80th percentiles of the time series (yellow = average, blue = good, red = poor, no fill = no current year data). NA = data gap.

Title	Description	Trend	Mean
Summer Bottom Temperature	Average bottom temperature (°C) over all hauls within the SMBKC management boundary of the RACE Bering Sea shelf bottom trawl survey	**Up**	•
Proportion Cold Pool	Proportion of RACE Bering Sea shelf bottom trawl survey stations within the SMBKC management boundary less than 2°C	**Down**	**-**
SMBKC Pre-recruit Biomass	Model estimates for SMBKC recruitment. Includes male crab (105-119 mm CL) that will likely enter the fishery the following year.	**Stable**	•
Benthic Predator Biomass	Combined biomass (1,000t) of benthic predators within the SMBKC management boundary on the RACE Bering Sea shelf bottom trawl survey	**Stable**	**+**
Benthic Invert Biomass	Combined biomass (1,000t) of benthic invertebrates within the SMBKC management boundary on the RACE Bering Sea shelf bottom trawl survey	**Stable**	**+**

Table 3. First stage socioeconomic indicator analysis for SMBKC including indicator title and short description. The recent five-year trend (up, down, or stable) and recent five-year mean (greater than (+), less than (-) or within 1 standard deviation (·) of long-term mean) are provided following the ESR methods. Fill is based on most recent conditions for SMBKC relative to the 20th and 80th percentiles of the time series (yellow = average, blue = good, red = poor, no fill = no current year data). NA = data gap.

Title	Description	Trend	Mean
Vessels active in fishery	Annual count of crab vessels that delivered commercial landings of SMBKC to processors[2]	**Stable**	**-**
TAC Utilization	Percentage of the annual SMBKC TAC (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing.	**Down**	•
Total Potlifts	Fishing effort, as measured by estimated number of crab pots lifted by vessels during the SMBKC fishery	**Down**	•
CPUE	Fishing effort efficiency, as measured by estimated mean number of retained SMBKC per potlift	**Down**	•
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.	**Down**	•
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.	**Down**	•
Processors active in fishery	Total number of crab processors that purchased landings of SMBKC from delivering vessels during the calendar year.	**Down**	•
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.	**Down**	•
SMBKC Male Bycatch in Groundfish Fishery	Incidental bycatch biomass estimates of male SMBKC (tons) in trawl and fixed gear fisheries	**Stable**	•

[2]Includes crab catcher/processors that harvested and processed SMBKC catch on-board.

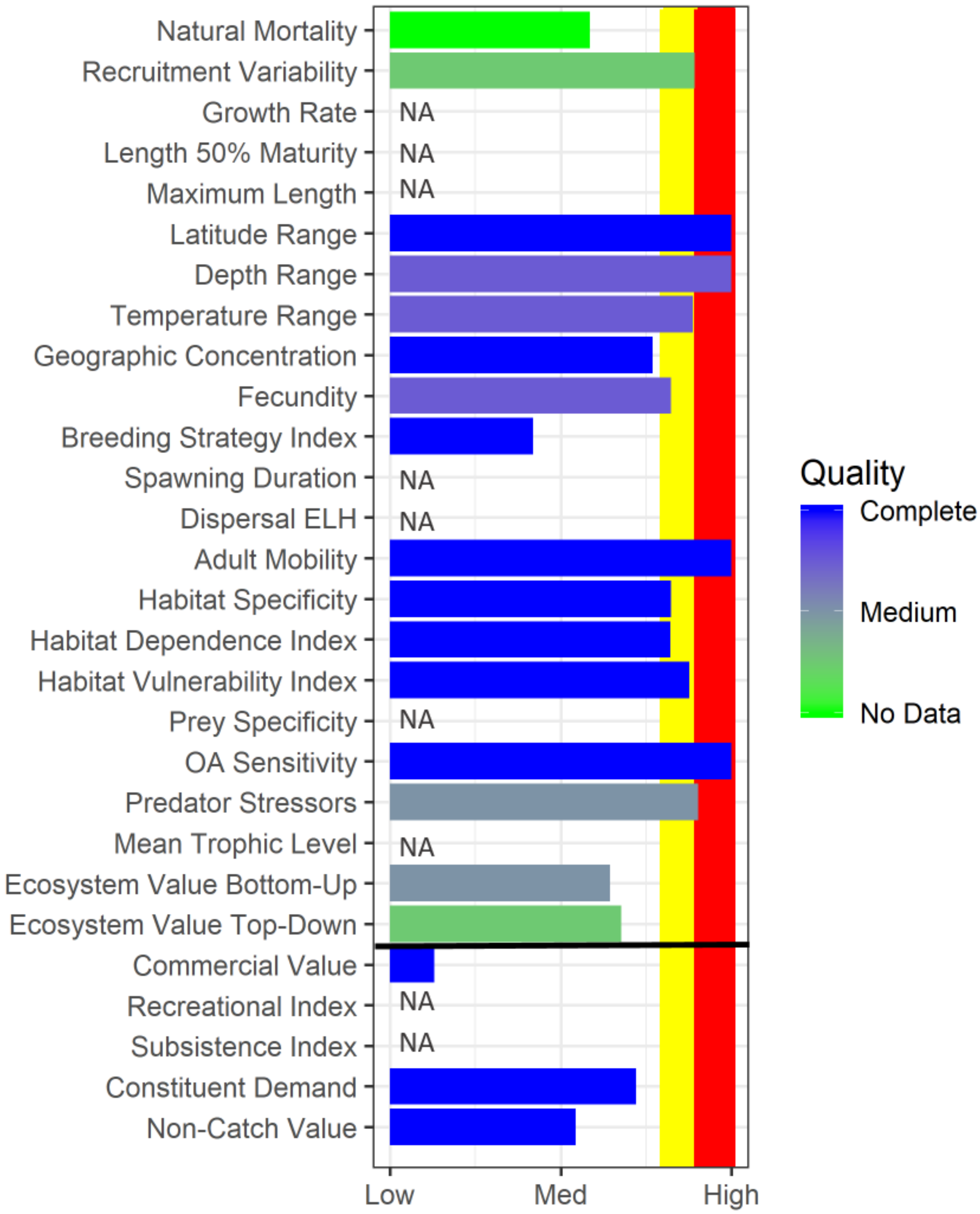

Figure 1. Baseline metrics for SMBKC graded as percentile rank over all groundfish and crab stocks in the FMP. Red bar indicates 90th percentile, yellow bar indicates 80th percentile. Higher rank values indicate a vulnerability and color of the horizontal bar describes data quality of the metric (see Shotwell et al., *In Review*, for more details on the metric definitions). Ecosystem indicators above and socioeconomic indicators below the horizontal black line.

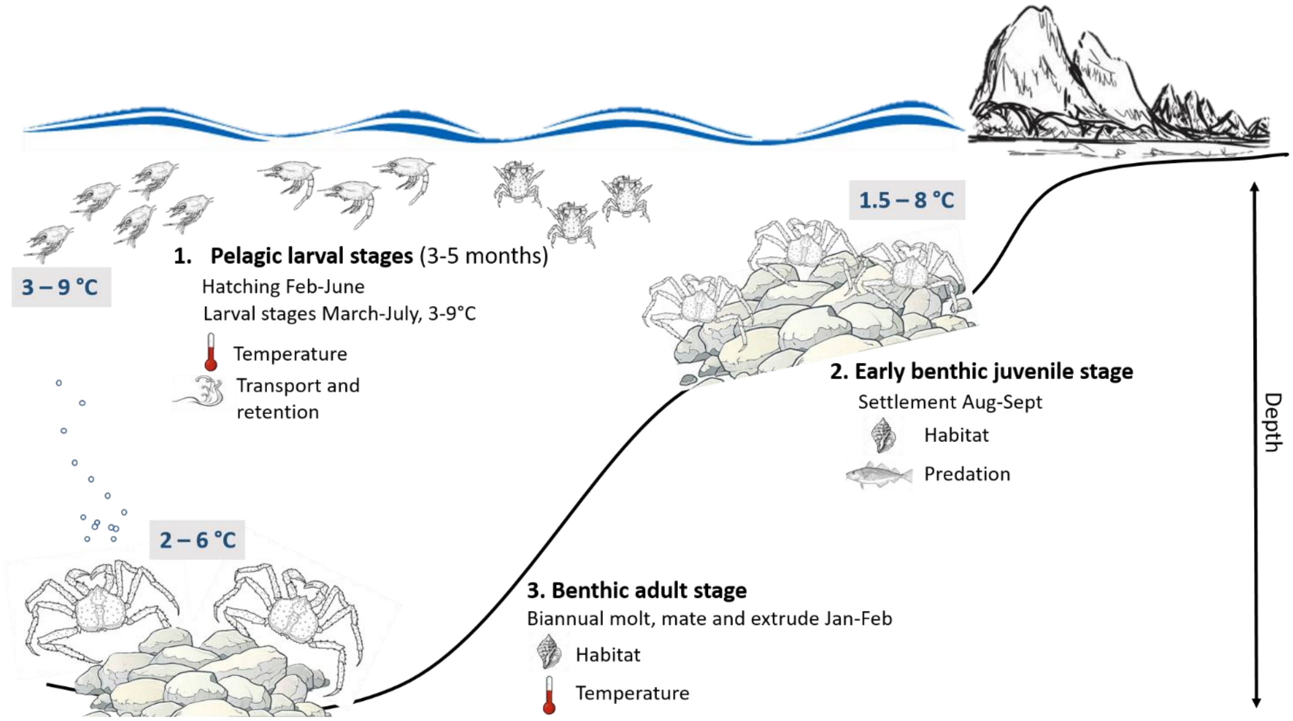

Figure 2. Conceptual diagram of phenological information by life history stage for SMBKC and processes likely affecting survival in each stage. Thermal requirements by life history stage were determined from BKC laboratory studies (Stoner et al., 2013, Stevens et al., 2008a, Stevens et al., 2008b).

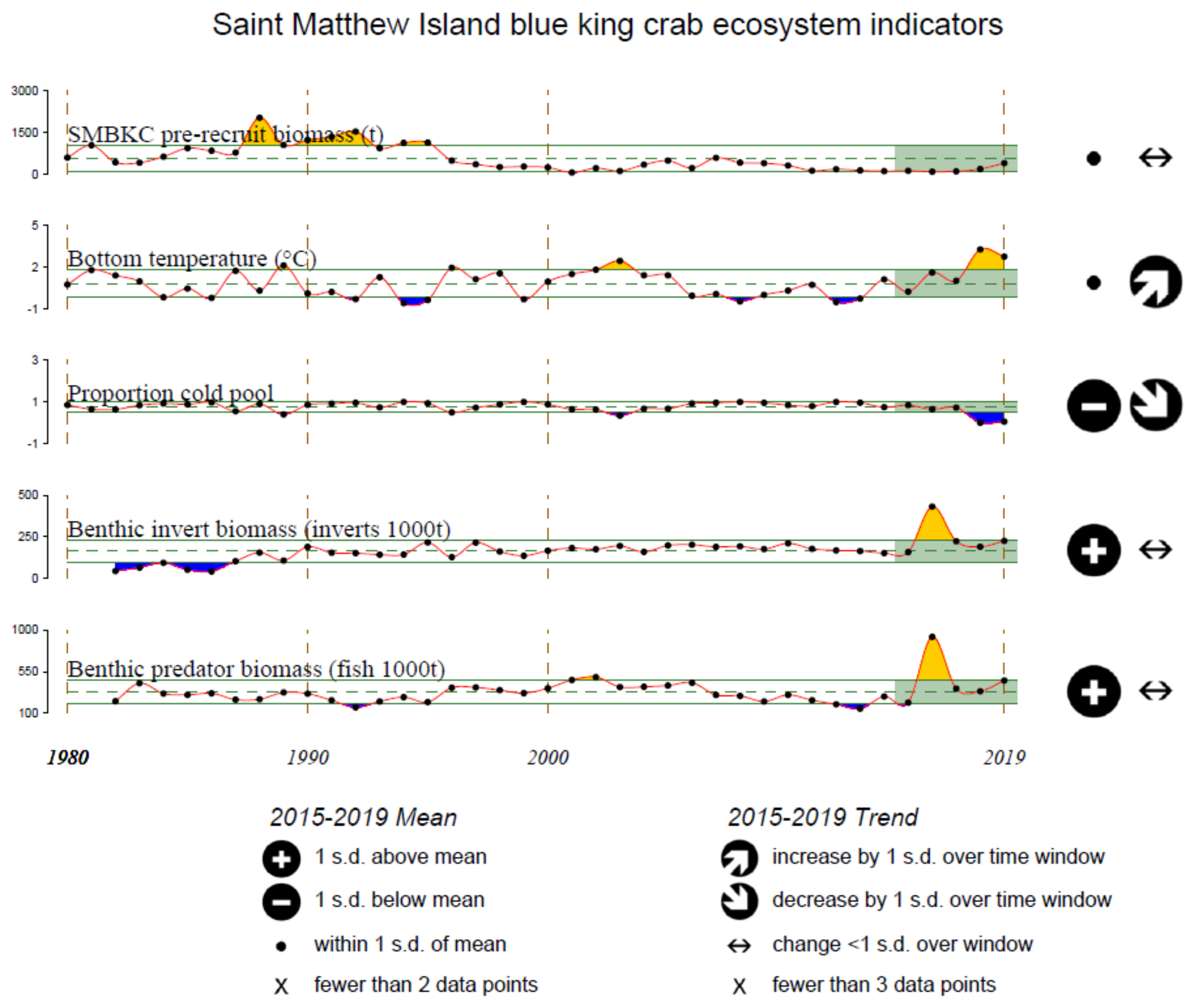

Figure 3. Selected ecosystem indicators for SMBKC with time series ranging from 1980 – 2019. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is mean of time series. Light green shaded area represents most recent five years for mean and trend analysis.

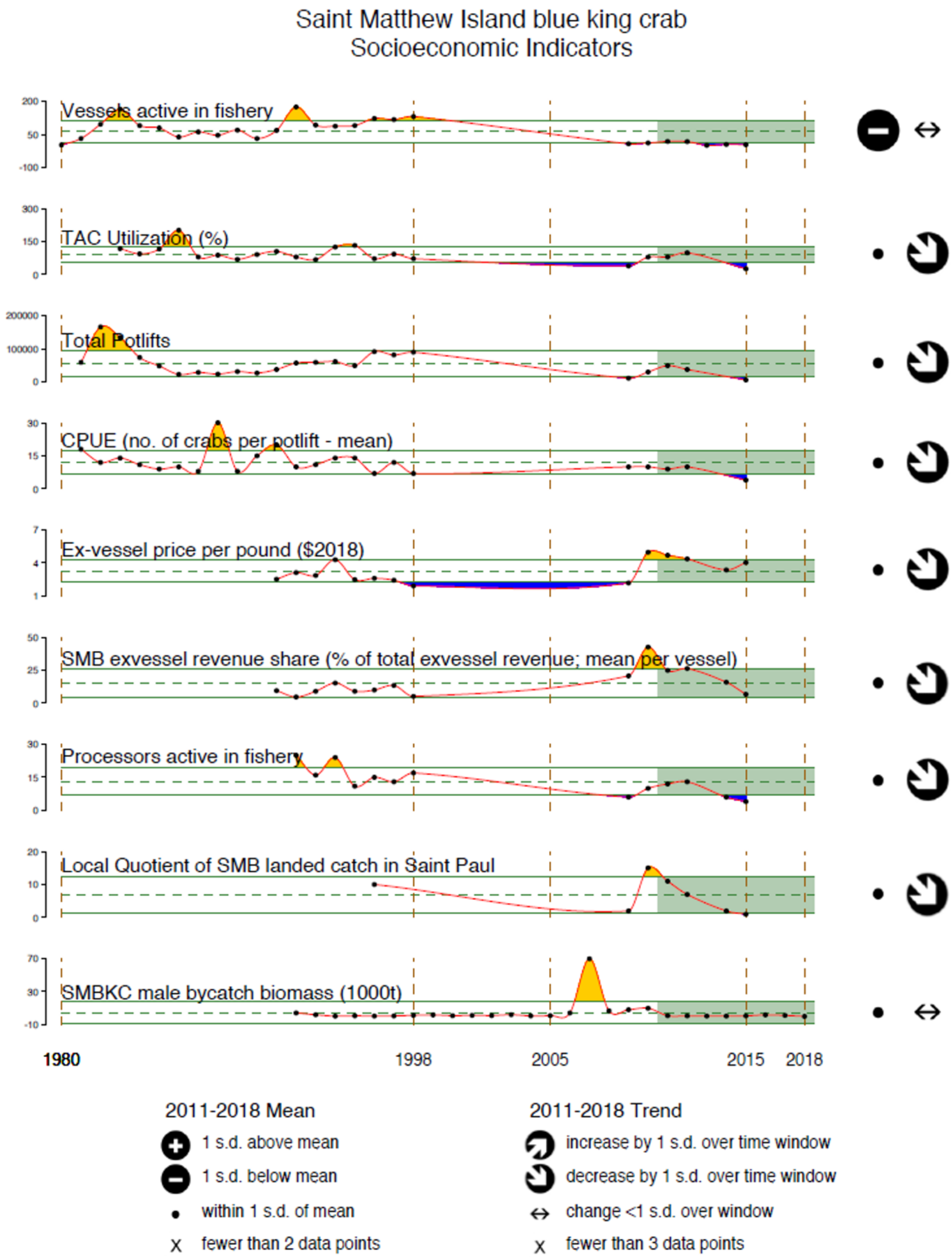

Figure 4. Selected socioeconomic indicators for SMBKC with time series ranging from 1980 – 2019. Upper and lower solid green horizontal lines are 90th and 10th percentiles of time series. Dotted green horizontal line is the mean of time series. For mean and trend analysis, the light green shaded area represents the most recent eight year period, which includes the most recent five year period (2011-2015) of open fisheries in more than two successive years.

7 Norton Sound Red King Crab

Fishery information relative to OFL setting

The Norton Sound red king crab (NSRKC) stock supports three main fisheries: summer commercial, winter commercial, and winter subsistence. The summer commercial fishery, which accounts for most of the catch, reached a peak in the late 1970s at a little over 2.9 million lb. retained catch. Retained catches since 1982 have been below 0.5 million lb., averaging 0.3 million lb., including several low years in the 1990s. As the crab population rebounded, retained catches have increased to around 0.5 million lb. in recent years, but were around 0.3 million lb. in 2018.

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, but none of these surveys have been conducted every year. The assessment is based on a male-only length-based model of male crab abundance that combines multiple sources of data. A maximum likelihood approach was used to estimate abundance, recruitment, and selectivity and catchability of the commercial pot gear. The model has been updated to include the following data: total catch, catch length composition, discard length composition data from the 2018 summer commercial fishery, and 2018 winter commercial and subsistence catch. New trend data in the assessment included 2018 ADFG survey in Norton Sound. In addition, the standardized commercial catch CPUE indices were updated to include data for 1977-2018. The current model assumes a constant M=0.18 yr^{-1} for all length classes except the the > 123mm CL length-class, which had an estimated value of 0.583 yr^{-1}. Logistic functions are used to describe fishery and survey selectivities, except for a dome-shaped function examined for the winter pot fishery.

The assessment author envaulted eight model alternatives, a base model (model 18.0) that assumes fixed retention selectivity and uses retention and discards length-composition data to estimate total catch selectivity, and several other models that incorporate different stanzas (1987-1994 and 2012-2018) of size composition data from the summer and winter commercial fisheries and estimate separate retention selectivities for the summer and winter fisheries.

The CPT recommended model 18.2b which estimates commercial fishery retention selectivity using summer commercial 2012-2018 total catch length composition data, 1987-1994 summer commercial fishery discard length composition data, and 2015-2018 winter commercial fishery retention length composition data. Estimating retention selectivity did not change fit to population dynamics, but improved fits of commercial retention and tag recovery data that inform the size transition matrix and molt probabilities. Estimating separate retention selectivities for the summer and winter fisheries did not improve the model fit.

Stock biomass and recruitment trends

Mature male biomass was estimated to be at an historic low in 1982 following a sharp decline from the peak biomass in 1977. The MMB then exhibited an increase from a low in 1997 to a peak in 2010, before showing minor declines and increases close to the $B_{MSY\ \mathrm{proxy}}$. The stock is currently estimated to be on a downward trend. Estimated recruitment was weak during the late 1970s and high during the early 1980s, with a slight downward trend from 1983 to 1993. Estimated recruitment has generally been variable, with a slight decrease in the last 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 $B_{MSY\ \mathrm{proxy}}$, calculated as the average of mature male biomass on February 1 during 1980-2019 was 4.57 million lb. The estimated

2019 mature male biomass on February 1 using Model 18.2b is 3.12 million lb., which is below the $B_{MSY\ proxy}$ for this stock, placing Norton Sound red king crab in status category 4b. The $F_{MSY\ proxy}$ is M =0.18 yr^{-1} and the F_{OFL}=0.118yr^{-1}, because the 2019 mature male biomass is less than $B_{MSY\ proxy}$, with the CPT choosing the default of gamma =1.0.

The CPT recommends that the OFL for 2019 be set according to model 18.2b, for which the calculated OFL is 0.24 million lb. (0.11 thousand t). The team recommends that the ABC for 2019 be set below the maximum permissible ABC. The team recommends that the SSC-endorsed buffer of 20% from the OFL be used to set the ABC at 0.19 million lb. (0.09 thousand t). The OFL is a retained catch OFL although a total catch OFL is computed as part of the assessment. The recommendation of an ABC less than the maximum permissible is recommended due to concern about model specification and unresolved competing hypotheses about whether the lack of large male crab in the fisheries and surveys is from increased natural mortality or movement out of the area.

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	Retain catch ABC
2015	1.09	2.33	0.18	0.18	0.24	0.33	0.26
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	TBD	TBD	TBD	0.11	0.09

1: Summer commercial fishery

2: Summer commercial fishery, winter commercial fishery and subsistence fishery

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 Catch[1]	Total Catch[2]	Retained Catch OFL	Retain catch ABC
2015	2.41	5.13	0.39	0.40	0.52	0.72	0.58
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	TBD	TBD	TBD	0.24	0.19

Total retained catch during 2018 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 Model-Based Stock Assessment

May 2019 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 crab rationalization in 2005/06. 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.

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, is expected to be implemented for 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 on-board observer program, and towards a $500,000 goal in 2015/16 to 2018/19 in order to fund an on-board observer program and stock survey.

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). Total retained catch in 2018/19 was 2,965 t (6,535,586 lb): 1,830 t (4,034,242 lb) from the EAG fishery, which included cost-recovery catch, 1,135 t (2,501,344 lb), and 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 AIGKC 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 2018/19 was 240 t (528,954 lb) for EAG and 140 t (309,038 lb) for WAG. Discarded catch also occurs during fixed-gear and trawl groundfish fisheries but is small relative to that during the directed fishery. Groundfish fisheries are a minor contributor to total fishery discard mortality, 8 t (17,275 lb) for EAG and 2 t (5,046 lb) for WAG in 2018/19. 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) fisheries in August 2018, by vessels that were quota fishing. During the survey work, adjustments were made to a portion of the gear so escape mechanisms were no longer functional. However, for the purpose of catch accounting for 2018/19, it was assumed that bycatch mortality that occurred during the survey was accounted for by reported discards for the 2018/19 EAG 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 2014 and 2015, highest in 2015-2016; and lowest in 1986. The model recruitment for WAG was high during 1984 to 1986, highest in 1985, and lowest in 2011. A declining trend in recruitment was observed since the early-1990s in WAG.

5. Management performance

The 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 for the second season in 2018/19. 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.

Among the five common scenarios for EAG and WAG, the last three scenarios considered the recently concluded fisheries data. We recommend two scenarios form the last three scenarios: scenario 19_1 (re-evaluation of observer CPUE indices after reducing the number of gear codes); and scenario 19_2a for EAG (scenario 19_1 plus considering year and area interaction factor during 2005/06 to 2018/19), and scenario 19_2 for WAG (scenario 19_1 plus considering year and area interaction factor during 1995/96 to 2018/19).

Scenario 19_0 is the base scenario with the knife edge male maturity at 111 mm CL, an *M* of 0.21yr^{-1}, and the addition of 2018/19 data. Scenarios 19_1 and 19_2a or 19_2 are modifications from the base scenario.

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]
2015/16	N/A	N/A	2.853	2.729	3.076	5.69	4.26
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[c]	5.880	17.848	2.883	2.965	3.355	5.514	4.136
2018//19[d]	5.881	16.095				5.264	3.948.
2018/19e	5.880	16.000				5.189	3.892
2019/20[f]		15.978				5.263	3.947
2019/20[g]		**15.944**				**5.249**	**3.937**
2019/20[h]		**13.861**				**4.380**	**3.285**

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]
2015/16	N/A	N/A	6.290	6.016	6.782	12.53	9.40
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[c]	12.964	39.348	6.356	6.536	7.396	12.157	9.118
2018//19[d]	12.965	35.483				11.606	8.704
2018/19[e]	12.964	35.274				11.440	8.580
2019/20[f]		35.225				11.603	8.702
2019/20[g]		**35.150**				**11.572**	**8.679**
2019/20[h]		**30.558**				**9.656**	**7.242**

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. 2018/19 accepted scenario, up to 2016/17 data.
d. 18_0 base scenario, up to 2017/18 data.
e. 18_1 scenario: 18_0 modified with number of gear codes reduced for observer CPUE standardization, up to 2017/18 data.
f. 19_0 scenario: same as 18_0, up to 2018/19 data.
g. 19_1 scenario: same as 18_1, up to 2018/19 data.
h. 19_2 scenario: same as 19_1 with Year and Area interaction in the observer CPUE standardization, up to 2018/19 data.

Since the 2018/19 total catch of 3,355 t (7.396 million lb) is below the OFL catch of 5,514 t (12.157 million lb), "overfishing" did not occur in the Aleutian Islands golden king crab fishery in 2018/19.

The NPFMC approved model 19_1 (line item g) for 2019/20 OFL and ABC setting.

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 2019. The terminal year mature male biomass was projected by an additional year to determine OFL and ABC for the 2019/20 season. The Tier 3 approach uses a constant annual natural mortality (*M*) and the mean number of recruits for the period 1987 – 2012 for OFL and ABC calculation. An *M* of 0.21 yr^{-1} previously derived from the combined data (Siddeek *et al.* 2018) was used.

We provide the OFL and ABC estimates for EAG and WAG separately and combined (i.e., for the entire Aleutian Islands, AI) for five scenarios 18_0, 18_1, 19_0, 19_1, and 19_2 (or 19_2a) in the following six tables. We treat scenario 19_0 as the base scenario for EAG and WAG.

EAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in millions of pounds. For 18_... scenarios, Current MMB = MMB on 15 Feb. 2019; and for 19_... scenarios, Current MMB = MMB on 15 Feb. 2020.

Scenario	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)
EAG18_0	3a	14.982	23.682	1.58	0.644	1987–2012	0.644	8.141	7.978	6.106
EAG18_1	3a	14.958	23.327	1.56	0.644	1987–2012	0.644	7.928	7.770	5.946
EAG19_0	3a	14.517	22.561	1.55	0.660	1987–2012	0.660	7.564	7.522	5.673
EAG19_1	3a	14.516	22.494	1.55	0.660	1987–2012	0.660	7.536	7.494	5.652
EAG19_2a	3a	14.629	18.587	1.27	0.640	1987–2012	0.640	5.856	5.811	4.392

Biomass in 1000 t; total OFL and ABC for the next fishing season in t.

Scenario	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)
EAG18_0	3a	6.796	10.742	1.58	0.644	1987–2012	0.644	3,692.810	3,618.954	2,769.608
EAG18_1	3a	6.785	10.581	1.56	0.644	1987–2012	0.644	3,596.260	3,524.335	2,697.195
EAG19_0	3a	6.585	10,234	1.55	0.660	1987–2012	0.660	3,430.984	3,412.054	2,573.238
EAG19_1	3a	6.584	10.203	1.55	0.660	1987–2012	0.660	3,418.287	3,399.176	2,563.715
EAG19_2a	3a	6.635	8.431	1.27	0.640	1987–2012	0.640	2,656.254	2,635.769	1,992.190

WAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in millions of pounds. For 18_... scenarios, Current MMB = MMB on 15 Feb. 2019; and for 19_ … scenarios, Current MMB = MMB on 15 Feb. 2020.

Scenario	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)
WAG18_0	3a	11.365	11.801	1.04	0.596	1987–2012	0.596	3.465	3.395	2.598
WAG18_1	3a	11.451	11.947	1.04	0.596	1987–2012	0.596	3.512	3.442	2.634
WAG19_0	3a	11.412	12.664	1.11	0.600	1987–2012	0.600	4.039	4.024	3.029
WAG19_1	3a	11.412	12.656	1.11	0.600	1987–2012	0.600	4.036	4.021	3.027
WAG19_2	3a	11.406	11.971	1.05	0.600	1987–2012	0.600	3.800	3.779	2.850

Biomass in 1000 t; total OFL and ABC for the next fishing season in t.

Scenario	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)
WAG18_0	3a	5.155	5.353	1.04	0.596	1987–2012	0.596	1,571.490	1,540.060	1,178.618
WAG18_1	3a	5.194	5.419	1.04	0.596	1987–2012	0.596	1,593.020	1,561.160	1,194.765
WAG19_0	3a	5.176	5.744	1.11	0.600	1987–2012	0.600	1,831.940	1,825.151	1,373.955
WAG19_1	3a	5.176	5.741	1.11	0.600	1987–2012	0.600	1,830.847	1,823.914	1,373.135
WAG19_2	3a	5.174	5.430	1.05	0.600	1987–2012	0.600	1,723.882	1,714.360	1,292.912

Aleutian Islands (AI)
Total OFL and ABC for the next fishing season in millions of pounds.

Scenario	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
18_0	11.606	11.373	8.704
18_1	11.440	11.212	8.580
19_0	11.603	11.546	8.702
19_1	11.572	11.515	8.679
19_2	9.656	9.590	7.242

Aleutian Islands (AI)
Total OFL and ABC for the next fishing season in t.

Scenario	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
18_0	5,264.30	5,159.01	3,948.23
18_1	5,189.28	5,085.50	3,891.96
19_0	5,262.92	5,237.21	3,947.19
19_1	5,249.13	5,223.09	3,936.85
19_2	4,380.14	4,350.13	3,285.10

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 2017, proposed changes to OFL and ABC calculation under model–based Tier 3 assessment were accepted.

2. *Changes to input data*
   - Commercial fisheries data were updated with values from the most recent observer and fish ticket data for 2018/19: 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 (1981/82–2018/19), total catch (1990/91–2018/19), and groundfish bycatch (1989/90–2018/19) biomass and size compositions.

- Fish ticket retained CPUE were standardized by the generalized linear model (GLM) with the lognormal link function 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 R square criterion and CAIC (modified AIC), separately for 1995/96–2004/05 (pre-rationalization) and 2005/06–2018/19 (post-rationalization) periods. A Year and Area interaction factor was considered in one scenario to estimate a set of CPUE indices.

3. *Changes to assessment methodology*
   None

4. *Changes to assessment results*
   As expected, the addition of the 2018/19 data changed the OFL and ABC estimates, but changes in parameter or abundance estimates were not dramatic.

B. Response to May 2018 CPT comments

Selected Comments relevant for this assessment:

Comment 2:
Reanalyze chela measurement data for AIGKC using new analytical techniques developed for snow crab and Tanner crab.

Response:
We are currently collecting more chela measurement data from the observer, dockside retained catch, and independent survey (in EAG) sampling. The first set of extended data will not be available for completing the revised analysis for the May 2019 CPT meeting. However, we will complete the re-analysis for the May 2020 CPT presentation.

We are also collecting additional length-weight data during the 2018/19 fishing season from the independent survey sampling which covers all sizes and both regions. These data will enable us to update the length-weight relationship separately for EAG and WAG. We will complete this analysis for the May 2020 CPT presentation.

Comment 3:
Work on appropriate statistical models for analysis of ADF&G cooperative pot survey that reflect the nested sampling design of vessels, strings within vessel, and pots within strings and consider the use of random effects as appropriate.

Response:
We have completed the cooperative survey for four fishing seasons (2015/16, 2016/17, 2017/18, and 2018/19) in the EAG region. We also extended the survey for the first time in the WAG region in 2018/19. However, the time series is not long enough to provide meaningful results. We will follow the random effects approach and present preliminary results at the May 2020 CPT meeting as per CPT recommendation.

Comment 5:
Continue exploration of year-area interactions using appropriate analytical methods and develop area weights using fishing footprint calculations.

Response:
We investigated the Year and Area interaction effect on the observer CPUE indices calculation in this report. Scenarios 19_2 (WAG) and 19_2a (EAG) considered the interaction term in the CPUE standardization. Appendix B provides the details.

Comment 6:
A standard set of plots should be prepared to summarize the B0 calculations for each model-based crab assessment, including AIGKC. Plot 1 should compare dynamic B0 and the estimated time series of mature male biomass. Plot 2 should plot the B0 depletion ratio, MMB/B0. Plot 3 should plot the estimated recruitment time series. These plots should be collated and used to develop recommendations on the use of B0 in Bering Sea crab assessments at the September 2018 CPT meeting for subsequent SSC review. This should be flagged as a general recommendation applicable to all assessed stocks.

Response:
B0 analysis is done for the three scenarios, 19_0, 19_1, and 19_2 (or 19_2a). See Figures C.1 (EAG) and C.2 (WAG) in Appendix C.

Response to June 2018 SSC comments:
Selected Comments relevant for this assessment:

Comment 1:
The SSC reminds all stock assessment authors to implement the guidelines for model numbering for consistency and easier version tracking over time. The authors should use their best estimate of catch for current and future years to get the best estimate of projected ABC/OFLs. The groundfish stock assessment authors have adopted methods to do this, such as using the 3-year average ratio of catch/TAC.

Response:
We followed CPT suggested model numbering. For example, When the base scenario 18_0, which is the 2018 model with up to 2017/18 data, is used with up to 2018/19 data, we labeled the model as 19_0. Because we are using the currently completed fishery data (2018/19) this time, the recommended approach is not needed.

Comment 2:
There is continued high uncertainty about maturity. Using knife-edge maturity, as currently implemented, was an interim fix due to problems with estimating maturity at size. We support and encourage efforts to obtain additional chela measurements to improve the parameterization of maturity in the model as a probabilistic function of size (e.g., logistic).

Response:
We will be developing a logistic maturity curve with the additional data analysis (see our response to CPT comment #2).

Comment 3:
We encourage the co-operative survey to be continued and endorse further work to include this independent survey into the model. The SSC specifically endorses the CPT recommendation to use nested random effects for strings within vessels and for pots within strings in a mixed-effects model. The SSC also requests the authors to include a brief description of the cooperative survey in the document, including the area sampled, size composition, and a summary of trends in CPUE.

Response:
We will provide a description of the survey in consultation with the independent survey project leader.

Comment 5:
The CPT noted that the year effect is not appropriate as an abundance index in the presence of interactions and recommended use of the "fishing footprint" as a measure of area, then use of area weights to compute the annual abundance index. The SSC supports this recommendation but notes that, like the VAST analyses, the 'fishing footprint' needs to be clearly defined and a rationale for how it is quantified needs to be developed before further pursuing year-area interactions in the model.

Response:
We identified the fishing footprints based on the observer pot sampling locations in the 1995/96 to 2018/19 database. We used a geostatistical package in R to allocate the fishing footprints to 30X30 nmi cell grids for Year and Area interaction investigation (see Appendix B). Please see our response to CPT comment #5.

Response to January 2019 CPT comments

Comment 1:
The projection for the 2018/19 fishing year should be based on setting the retained catch to the 2018/19 TAC (because catches closely mimic the TACs for AIGKC) and assuming that groundfish bycatch for 2018/19 equals the recent three-year mean groundfish bycatch. The assumed removals should be listed in Table 2 (with annotations that the catches concerned are assumed). No catch composition data for the 2018/19 fishing year should be generated based on averaged past data.

Response:
Because we are using the currently completed fishery data (2018/19), this recommendation is no longer needed.

Comment 2:
Scenario 18_1a should be dropped because the suggested approach for adjusting pot bycatch is plausible at the individual pot level, but not at the total bycatch level.

Response:
We have dropped this scenario in the current analysis.

Comment 3:
Add a new scenario based on a revised definition of "area" when conducting the CPUE standardization – consideration should be given to including an interaction between year and the revised area definition in the standardization model. If an area*year interaction is supported, the final index should be an area-weighted index

Response:
We investigated the Year and Area interaction effect on observer CPUE indices calculation. We identified scenarios 19_2 (WAG) and 19_2a (EAG) that include observer CPUE indices estimated considering Year and Area interaction. Appendix B provides the details.

In relation to the results presented, the CPT requested the following:

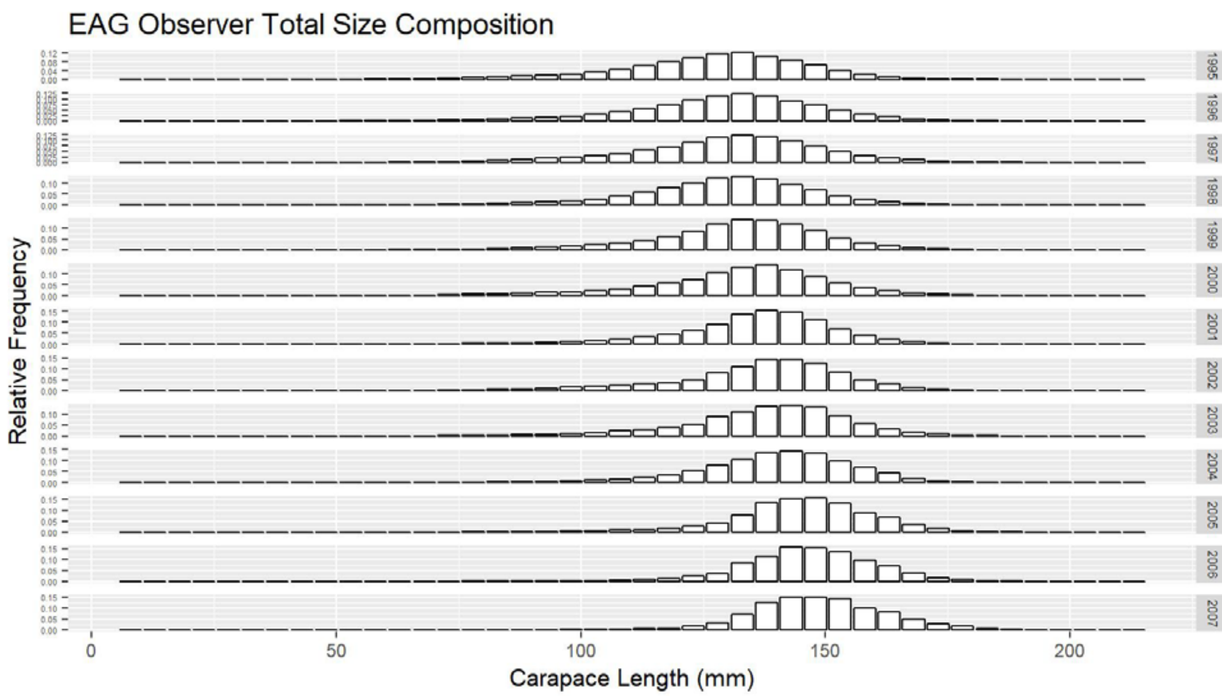
Comment 4:
The next assessment should report results from the May 2017, September 2017, and May 2018 assessments as well as those from the new scenarios to enable an evaluation of the impact of changes to the model and the data.

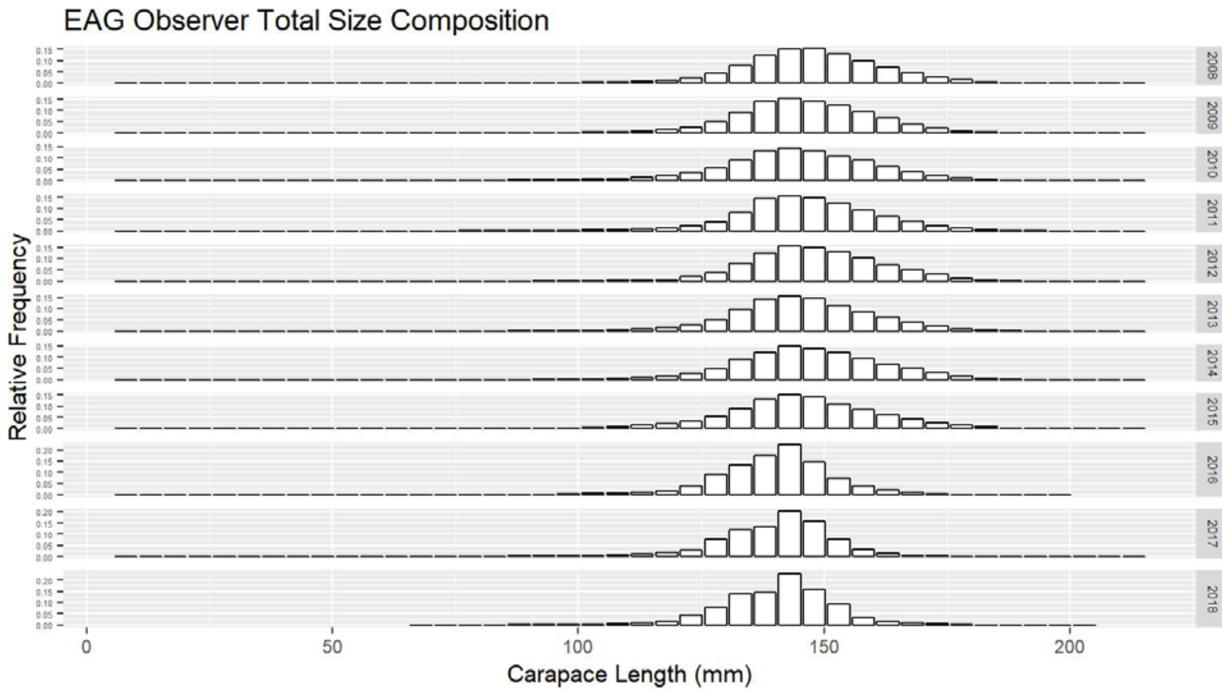
Response:
We have identified the progression of years in the previous and current model scenarios appropriately. For example, see Figure 26 for comparison of MMB time series estimates that include up to 2016/17, 2017/18,

and 2018/19 data and Figures B.2 and B.3 in Appendix B for input CPUE indices based on up to 2015/16, 2016/17, 2017/18, and 2018/19 data.

Comment 5:
The increase in MMB in the last year of the assessment for the EAG is caused by a large recruitment three years ago, but this increase is not reflected in the standardized CPUE – the analysts should identify what in the data (e.g. the length-compositions) are the cause of the increased recruitment. Showing the fits to the length-composition data may help identify whether there is a basis in the data for higher estimated recruitment.

Response:
We provide the observer collected relative total size compositions to justify the possibility of high recruitment to wider size groups until 2015 in EAG and then the total catch size range narrowing down during 2016 to 2018.





Comment 6:
The results of the three scenarios are hard to distinguish in the figures. Whether they are actually different needs to be checked.

Response:
Scenarios 19_0 and 19_1 result are largely indistinguishable because only the gear codes were reduced in the CPUE standardization. Therefore, we identified scenario 19_1 with orange points for differentiation in most of the plots.

Comment 7:
The time-trajectories for dynamic B_0 should be clearly labelled in figures such as 17 and 18.

Response:
Done. See Figures C.1 (EAG) and C.2 (WAG) in Appendix C.

Comment 8:
The survey data will not be included in the assessment formally until the 2020 assessment. However, there would be value in plotting the length-composition data from the survey as it may provide evidence in support of the large estimated recent recruitment.

Response:
We have not yet analyzed the survey data.

Response to February 2019 SSC comments

Comment 1:
Exploration of geostatistical models (e.g., VAST) for spatial analysis of the NMFS and ADF&G survey information,

Response:

We have postponed analysis of observer data using VAST pending the May 2019 presentation by the developer on applicability of VAST to crab stocks to the CPT.

Comment 2:
removing one dataset at a time from the model to identify the source of the large estimated recruitment three years ago; the CPUE time series does not show this increase and the source of information for this large recruitment estimate should be identified,

Response:

We have done the retrospective analysis on MMB (Figure 23 for EAG and Figure 41 for WAG). Peeling off the data set year-by-year shows some spread on MMB time series for EAG but not for WAG, which may suggest influx of the large recruitment in recent years. When we added the new data set 2018/19, the recruitment pulse did not disappear (see Figure14).

Comment 3:
exploring the use of the industry survey for purposes other than stock assessment modeling, such as length compositions

Response:
Please see our response to January 2019 CPT comment #8.

Comment 4:
pursuing other CPT recommendations, including a comparison with the May 2017, September 2017, and May 2018 assessments to assess the impact of incremental model and data changes. This type of retrospective comparison among assessment results has been reported in some groundfish assessments and, if routinely reported, would provide useful information on the development of the assessment model.

Response:
Please see our responses to January 2019 CPT comments #4.

Response to some of the June 2018 CIE comments:

We have not completely addressed all the comments made by the reviewers. We addressed some in this report.

A. Comment by Yong Chen:

Specific recommendations:
Short Term:

Comment A.1:
More in-depth and structured diagnosis of relative importance of different likelihood functions for different input data sets and how they should be weighted in model fitting. A careful examination of potential temporal trends in residual distribution may be also needed.

Response:
Because size frequency likelihoods consume a large part of the total likelihood, for all scenarios we objectively weighted the length composition data by the Francis' re-weighting method. We also examined the temporal trends in size compositions fit by bubble plots (Figures 19, 20, 37, and 38). We validated the error model used in the CPUE standardization by the QQ plot.

Comment A.2:
Multiple model configurations were used over the time, which reflect different assumptions on the fishery dynamics. I recommend analyzing among-model variations to better understand the structural uncertainty and possible management implications of making changes to the models over the time.

Response:
Because the AIGKC model was recently approved for OFL and ABC calculations, the model has not been changed during the last three years since implementation. Only new data points have been added. Therefore, the comment is not strictly applicable to the AIGKC model.

Comment A.3:
I suggest that the assessment model structure be kept relatively stable over time. If a new model or new model configurations/parametrizations need to be used, it should be run in parallel to the old model to identify changes in stock assessment outcomes resulting from changes in model configurations. i.e., New scenarios should be run in parallel to the old one.

Response:
We have kept the assessment model structure relatively stable since the acceptance of the model. We are showing the time trends in input CPUE indices (Figures B.2 and B.3), recruitment (Figures 14 and 32), fishing mortality (Figures 25 and 43), and mature male biomasses (Figure 26) in parallel as a result of changes in model configurations and expansion of input data sources over time.

Comment A.4:
Retrospective analysis should be done for all scenarios.

Response:
We did the retrospective analysis for all scenarios: 19_0, 19_1, and 19_2 (or 19_2a).

Comment A.5:
The current models estimate model parameters using maximum likelihood function and is not a full Bayesian model. Uncertainty estimates may not be reliable (tend to be under-estimated), which limits the full consideration of uncertainty in stock assessment and management. A full Bayesian model may be more desirable.

Response:
This is debatable for the length-based models. We have not undertaken this step yet.

Comment A.6:
VAST type analysis should be carried out for index estimation to capture autocorrelation over space and time of independent survey data.

Response:
The VAST developer will present the applicability of VAST to crab stocks at the May 2019 CPT meeting. We will discuss its applicability at the CPT meeting and follow the CPT guidance.

Comment A.7:
Jittering should be done to evaluate the sensitivity of model convergence.

Response:
Done for scenarios 19_1 and 19_2 (or 19_2a).

Long-term:

Comment A.8:
Given strong seasonality of fishery and life history, a model with season as its time step may better capture the dynamics of fishery and life history. A comparative study may be needed for evaluating possible differences in stock assessments using “year” and “season” as time steps.

Response:
A good suggestion. We will investigate this in the near future.

Comment A.9:
Given the importance of the survey data in the assessment, I suggest conducting an extensive computer simulation study based on past data to evaluate the effectiveness of the current survey designs capturing the spatio-temporal dynamics of the stocks.

Response:
A good suggestion. We have not investigated this aspect yet.

Comment A.10:
There is a need to evaluate temporal and spatial variability in key life history parameters such as weight-at-length and maturity-at-length. Mixed-effect model can be used for analysis.

Response:
A good suggestion. We are currently collecting data on weight-at-length and maturity-at-length over time and space. We will consider using an appropriate model to analyze these data.

Comment A.11:
Constant discard mortality over time and space may not be biologically realistic.

Response:
We will investigate how best to capture this aspect. We presented our first thought at the January 2019 CPT meeting by weighting the mortality rate by overall landing, but this approach was not accepted by the CPT.

Comment A.12:
Survey for AIGKC should be extended to WAG and more information on small crab need to be collected, for the WAG area.

Response:
We extended the survey to WAG in 2018.

Comment A.13:
It is likely that outliers may exist in fisheries data, which may introduce biases in stock assessment results because of log-normal and multinomial likelihood functions tend to be sensitive to outliers in data. Using robust likelihood functions may be more appropriate. Some simulation studies can be done to evaluate possible impacts of using different likelihood functions in the absence and presence of outliers in various input data sets.

Response:
A good thought. We used the robust likelihood function for the length composition data sets. We will investigate its applicability to other likelihood components.

B. Comments by John Neilson:

Comment B.1:
Bycatch mortality may vary over season.

Response:
See our response to comment #A.11.

Comment B.2:
Past models' projections should have been compared with the current estimates and trends of MMB.

Response:
Yes, we did in this report. See our response to comment #A.3.

Comment B.3:
However, there are so many degrees of freedom associated with Gear in the CPUE standardization. Consulting with fishing industry could help obtain realistic and sensible ways of combining gear types that have essentially similar selectivity.

Response:
We reduced the number of gear codes in scenarios 18_1, 19_1, and 19_2 (or 19_2a) with the industry consultation.

Comment B.4:
The CPUE standardization attempts to deal with the issue of reduction in number of vessels by considering vessels stayed in the fishery for a long time period.

Response:
Agree.

Comment B.5:
The fishery independent survey is not truly independent index because the survey does not standardize for soak time and depth. But useful for the model and sampling young crabs. The industry survey offers the best hope to avoid problems with the changes in the area fished or number of vessels over time. Can test the gear power as well. The coverage should also expand to WAG.

Response:
Agree. We extended the independent survey to WAG in 2018.

Comment B.6:
Estimate maturity outside the model.

Response:
We did.

C. Comments by Rauf Kalida:

Comment C.1:
Breakpoint analysis is a good approach. Spatial and temporal changes in maturity should also be investigated to improve maturity breakpoint.

Response:
With the additional data currently being collected we will investigate spatio-temporal changes in maturity. Several other recommendations, such as tagging experiments with DST and PIT tags, larval distribution study, crab ageing, have been made by Rauf in the CIE report, which will be addressed in the future.

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 the Alaska Department of Fish and Game (ADF&G) to manage the golden king crab fishery in the areas east and west of 174°W longitude as two distinct stocks. That re-designation of management areas was intended to more accurately reflect golden king crab stock distribution, coherent with the longitudinal pattern in fishery production prior to 1996/97 (Figure 3). The longitudinal pattern in fishery production relative to 174° W longitude since 1996/97 is similar to that observed prior to the change in management area definition, although there have been some changes in the longitudinal pattern in fishery production within the areas east and west of 174° W longitude (Figure 4).

Commercial fishing for golden king crab in the Aleutian Islands Area typically occurs at depths of 100–275 fathoms (183–503 m). Pots sampled by at-sea fishery observers in 2013/14 were fished at an average depth of 176 fathoms (322 m; N=499) in the area east of 174° W longitude and 158 fathoms (289 m; N=1,223) for the area west of 174° W longitude (Gaeuman 2014).

3. 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 one time, 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, pages 9–14). 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, non-standardized CPUE and average weight in the Aleutian Islands golden king crab fishery.

The fisheries in 1996/97–1997/98 were managed with 1,452 t (3,200,000 lb) for EAG and 1,225 t (2,700,000 lb) for WAG (Table 1). During 1998/99–2004/05 the fisheries were managed with 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 with 1,014 t (2,235,000 lb) while keeping the TAC for EAG at the same level as that in the previous season.

During 1996/97–2018/19 the annual retained catch during commercial fishing (including cost-recovery fishing that occurred during 2013/14–2018/19) has averaged 2% below the annual GHL/TACs. During 1996/97–2018/19, 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 implementation of the Crab Rationalization program was implementation of a community development quota (CDQ) fishery for golden king crab in the eastern Aleutians (i.e., 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 IFQ fishery.

Golden king crab may be commercially fished only with king crab pots (defined in 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, must have at least four escape rings of five and one-half inches minimum inside diameter installed on the vertical plane or at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized golden king crab (5 AAC 34.625 (b)). Prior to the regulation requiring an escape mechanism on pots, some participants in the Aleutian Islands golden king crab fishery voluntarily sewed escape rings (typically 139 mm or 5.5 inches) into their gear or, more rarely, included panels with escape mesh (Beers 1992). 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 that, "… the golden king crab fleet has modified their gear to allow for small crab sorting," and provided a written statement from Lance Nylander, of Dungeness Gear Works in Seattle, who "believes he makes all the gear for the golden king crab harvesting fleet," saying that, "Since 1999, DGW has installed 9[-inch] escape web on the door of over 95% of Golden Crab pot orders we manufactured." A study to estimate the contact-selection curve for male golden king crab that was conducted aboard one vessel commercial fishing for golden king crab during the 2012/13 season and showed that 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.

Additional management measures include only males of a minimum size may be retained by the commercial golden king crab fishery in the Aleutian Islands Area. By State regulation (5 AAC 34.620 (b)), the minimum legal-size limit is 6.0-inches (152.4 mm) carapace width (CW), including spines, 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 (Appendix C). 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 fishermen, 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 2011/12–2018/19 (an increasing trend in EAG and a decreasing trend in WAG). Sharp increases in CPUE were observed since 2016 in WAG and 2017 in EAG.

6. Brief description of the annual ADF&G harvest strategy:

In March 2019, the BOF accepted 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), as approved by the BOF in March 2019:

(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 $(0.15)x(MMA_E/MMA_{E,(1985\text{-}2017)})x(MMA_E)$ 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 $(0.15)x(MMA_E)$ 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 $(0.20)x(MMA_W/MMA_{W,(1985\text{-}2017)})x(MMA_W)$ or 25 percent of LMA_W, whichever is less; and

(3) if MMA_W is greater than 100 percent of $MMA_{W,(1985\text{-}2017)}$, 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) $MMA_{E,(1985\text{-}2017)}$ 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) $MMA_{W,(1985\text{-}2017)}$ 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 also has authority to annually receive receipts of $500,000 through cost-recovery fishing on Aleutian Islands golden king crab. The retained catch from that cost-recovery fishing is not counted against attainment of the annually-established TAC.

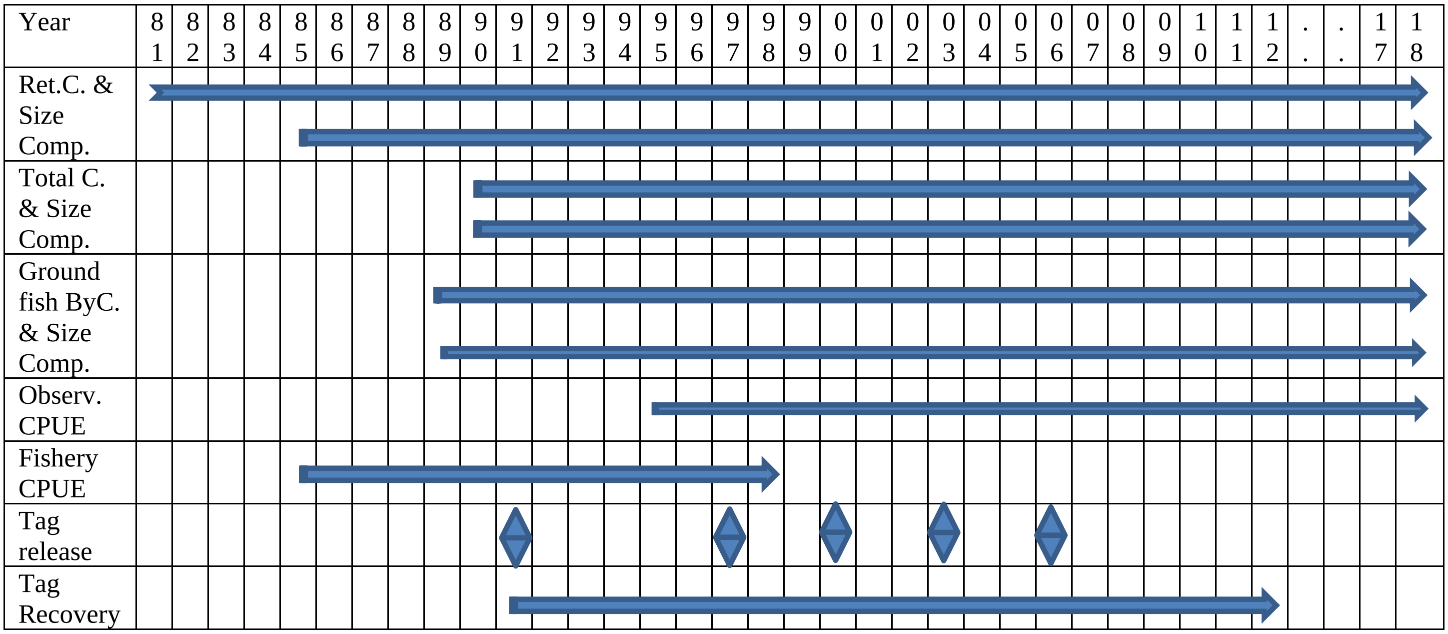
7. Summary of the history of the basis and estimates of MMB_{MSY} or proxy MMB_{MSY}:

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 2018/19 information. The details are given in the graphic 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 1981/82–2018/19 (Table 1). Estimated total catch weight for 1990/91–2018/19 (Table 2a).

b. Bycatch and discards:

Retained catch, bycatch mortality (male and female of all sizes included) separated by the crab fishery and groundfish fishery, and total fishery mortality for 1981/82–2018/19 (Table 2). Crab fishery discards are available after observer sampling was established in 1988/89. Some observer data exist for the 1988/89–1989/90 seasons, but those data are not considered reliable. Table 2 provides crab fishery discards and groundfish fishery bycatch for 1991/92–2018/19 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 1985/86–2018/19 (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 available (Figures 9 to 11 for EAG; and 27 to 29 for WAG).

e. Survey biomass estimates:

They are not available for the area because no systematic surveys, covering the entire fishing area, have occurred.

f. Survey catch–at–length:

They are 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 length-based model.

- **Weight-at-length**: Male length-weight relationship: $W = aL^b$ where a = $3.7255*10^{-4}$, b = 3.0896 (updated estimates).

- **Natural mortality**: Previously model estimated fixed natural mortality value, 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 to recapture data from these surveys were used.

Data from the independent pot surveys conducted during 2015 to 2017 in EAG and 2018 in both EAG and WAG were not used in the current assessment. We plan to use them in the 2020 model.

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 (pre-rationalization) and 2005/06–2018/19 (post-raqtionalization).

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 covering all areas, 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}. The M value was the combined estimates for EAG and WAG (Siddeek *et al.* 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 in Appendix A) and logistic selectivity patterns (Equation A.9 in Appendix A) 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 with the first author.

3. Model Selection and Evaluation

a. Description of alternative model configurations:

We considered five scenarios for EAG and WAG (Table T1). We presented OFL and ABC results for all scenarios separately for EAG, WAG, and the entire AI in the executive summary tables. We considered scenario 19_0 as the base scenario. 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 in Appendix A).

ii) Observer CPUE indices for 1995/96–2018/19.

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 2005/06–2018/19, and a single set of logistic retention curve parameters.

vi) Full selectivity (selectivity =1.0) for groundfish (trawl) 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 of Appendix A.

Best estimate of parameter values for scenarios 19_1 and 19_2 (or 19_2a) 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; a constant 50% knife-edge maturity size of 111 mm CL was used for MMB calculation; two catchability and two sets of logistic total selectivity curves were used for the pre- and post-rationalization periods; and a common *M* based on the estimate from the combined EAG and WAG data was used . Changes from scenario 19_0 specifications are highlighted by the shaded text.

Scenario	**Size-composition weighting**	**CPUE data type**	Natural mortality (*M* yr^{-1})
18_0	Stage-1: Number of days/trips Stage-2: Francis method	Observer data from 1995/96–2017/18; Fish Ticket data from 1985/86–1998/99; and number of gear codes were not reduced for observer CPUE standardization.	0.21
18_1	Stage-1: Number of days/trips Stage-2: Francis method	Observer data from 1995/96–2017/18; Fish Ticket data from 1985/86–1998/99; and number of gear codes were reduced for observer CPUE standardization.	0.21
19_0	Stage-1: Number of days/trips Stage-2: Francis method	Observer data from 1995/96–2018/19; Fish Ticket data from 1985/86–1998/99; and number of gear codes were not reduced for observer CPUE standardization.	0.21
19_1	Stage-1: Number of days/trips Stage-2: Francis method	Observer data from 1995/96–2018/19; Fish Ticket data from 1985/86–1998/99; and number of gear codes were reduced for observer CPUE standardization.	0.21
19_2a (EAG) or 19_2 (WAG)	Stage-1: Number of days/trips Stage-2: Francis method	Observer data from 1995/96–2018/19; Fish Ticket data from 1985/86–1998/99; Year and Area interaction factor was considered & number of gear codes were reduced for observer CPUE standardization.	0.21

b. Progression of results:

The OFL and ABC estimates are like those estimated by the 2018 model.

c. Label the approved model from the previous year as model 0:

Following the September CPT suggestion, we used the notation 19_0 for the base model which came from the previous approved assessment model, 18_0.

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). The five scenarios also considered different configuration of parameters to select parsimonious models. The detailed results of the five scenarios 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 and number of fishing trips for groundfish size composition (note: we did not use the groundfish size composition in the model fit) for all 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 scenarios 19_0, 19_1, and 19_2 (or 19_2a) 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 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 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 scenarios 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 scenarios 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 to 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 scenarios. 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 of Appendix A). 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 scenarios. The numbers of estimable parameters are listed in Table A1 of Appendix A.

   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 all scenarios are summarized respectively 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 scenarios 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 all scenarios are summarized in Tables 9 to 11 for EAG and Tables 18 to 20 for WAG.

      d. The recruitment estimates for those scenarios 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 all scenarios are summarized in Table 12 for EAG and Table 21 for WAG. Scenario 19_2a has the minimum total negative log likelihood for EAG whereas scenario 19_2 has the minimum for WAG. Thus, the input observer CPUE indices with Year and Area interaction appears to have influenced the overall fit.

4. Graphs of estimates:

a. Selectivity:

Total selectivity and retention curves of the pre- and post-rationalization periods for all scenarios 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 six scenarios (2017 assessment time series of MMB estimates were included for comparison) are depicted in Figures 26 for EAG and WAG. Mature male biomass tracked the CPUE trends well for all scenarios for EAG and WAG. The biomass variance was estimated using the Burnham *et al.* (1987) suggested formula (Equation A.14 in Appendix A). We determined the mature male biomass values on 15 February each year and considered the 1987–2012 time series of recruits 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 four scenarios is shown in Figures 25 and 43 for EAG and WAG, respectively. 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 scenarios 19_1 and 19_2 (or 19_2a) for EAG and WAG in Figure 44. The 2018 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 for four scenarios are illustrated in Figure 14 for EAG and in Figure 32 for WAG. 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 four scenarios.

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 for three scenarios are illustrated in Figures 17 and 35 for EAG and WAG, respectively. The 1981/82–1984//85 retained catch plots for four scenarios 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 did not consider the pot survey data for the analysis.

i. CPUE index data:

The model predicted CPUE vs. input CPUE indices for three scenarios are shown in Figure 24 for EAG and Figure 42 for WAG. Scenario 19_2 (or 19_2a) predictions dipped lower than other predictions in recent three years. The CPUE variance was estimated using the Burnham *et al.* (1987) suggested formula (Equation A.14 in Appendix A).

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 for four scenarios are depicted in Figures 16 and 34 for EAG and WAG, respectively. 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 scenarios [19_1 and 19_2a (EAG) and 19_2 (WAG)]. The retained catch bubble plots do not appear to exhibit major pronounced patterns among residuals for the selected scenarios.

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 scenarios 19_0, 19_1, and 19_2 (or 19_2a).

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.

6. Retrospective and historical analysis:

The retrospective fits for scenarios 19_0, 19_1, and 19_2 (or 19_2a) are shown in Figure 23 for EAG and in Figure 41 for WAG. The retrospective fits were prepared for the whole time series 1961 to 2018. The retrospective patterns 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 values are also given in the figures.

Mohn rho (ρ) formula modified by Deroba (2014) is as follows:

$$Mohn\ \rho = \frac{\sum_{n=1}^{x} \frac{\left[\widehat{MMB}_{y=T-n,T-n} - \widehat{MMB}_{y=T-n,T}\right]}{\widehat{MMB}_{y=T-n,T}}}{x}$$

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 =2018.

The low values (<<1.0) of Mohn rho indicate no severe model misspecification. 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 is better when the molt probability model is included. Therefore, we included a molt probability sub-model for the size transition matrix calculation in all scenarios.

8. Conduct 'jitter analysis':

We conducted jitter analysis on scenarios 19_1 and 19_2 (or 19_2a). The results indicated that global convergence was achieved for most runs.

F. Calculation of the OFL

1. Specification of the Tier level:

Aleutian Islands golden king crab was elevated to Tier 3 level in 2017 for OFL and ABC determination. In the following section, we provide the methods 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. Growth transition matrix is fixed and estimated using tagging data with the molt probability sub-model.

c. Total fishery selectivity and retention curves are length dependent and the 2005/06–2018/19 period selectivity estimates are used.

d. Groundfish bycatch fishery selectivity is kept constant at 1.0 for all length groups.

e. Model estimated recruits (in millions of crab) are averaged for the time period 1987– 2012.

f. Model estimated groundfish bycatch mortality values are averaged for the period 2009/10 – 2018/19 (10 years).

g. A knife-edge 50% maturity size is used for MMB estimation.

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 adding a constant number of annual recruits. Once the stock dynamics were 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 that produces the 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} is determined using Equation A.28 in Appendix A. The OFL is estimated by an iterative procedure accounting for intervening total removals (see Appendix A for the formulas).

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:

See Management Performance table below. The OFL and ABC values for 2018/19 in the table below are the recommended values. The TACs for 2015/16 to 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 catch.

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]
2015/16	N/A	N/A	2.853	2.729	3.076	5.69	4.26
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[c]	5.880	17.848	2.883	2.965	3.355	5.514	4.136
2018//19[d]	5.881	16.095				5.264	3.948.
2018/19e	5.880	16.000				5.189	3.892
2019/20[f]		15.978				5.263	3.947
2019/20[g]		**15.944**				**5.249**	**3.937**
2019/20[h]		**13.861**				**4.380**	**3.285**

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]
2015/16	N/A	N/A	6.290	6.016	6.782	12.53	9.40
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[c]	12.964	39.348	6.356	6.536	7.396	12.157	9.118
2018//19[d]	12.965	35.483				11.606	8.704
2018/19[e]	12.964	35.274				11.440	8.580
2019/20[f]		35.225				11.603	8.702
2019/20[g]		**35.150**				**11.572**	**8.679**
2019/20[h]		**30.558**				**9.656**	**7.242**

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. 2018/19 accepted scenario, up to 2016/17 data.
d. 18_0 base scenario, up to 2017/18 data.
e. 18_1 scenario: 18_0 modified with number of gear code reduced for observer CPUE standardization, up to 2017/18 data.
f. 19_0 scenario: same as 18_0, up to 2018/19 data.
g. 19_1 scenario: same as 18_1, up to 2018/19 data.
h. 19_2 scenario: same as 19_1 with Year and Area interaction in the observer CPUE standardization, up to 2018/19 data.

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 scenarios [19_0, 19_1, and 19_2 (& 19_2a)]:

Scenario 19_0:

EAG: 3,279 t (7.229 million lb)

WAG: 1,739 t (3.834 million lb)

AI: 5,018 t (11.063 million lb).

Scenario 19_1:

EAG: 3,267 t (7.202 million lb)

WAG: 1,738 t (3.831 million lb)

AI: 5,005 t (11.033 million lb).

Scenario 19_2a (EAG) & 19_2 (WAG):

EAG: 2,522 t (5.560 million lb)

WAG: 1,633 t (3.600 million lb)

AI: 4,155 t (9.160 million lb).

G. *Calculation of ABC*

1. 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 scenarios 19_0, 19_1, and 19_2 (& 19_2a):

Scenario 19_0:

EAG: ABC = 2,573 t (5.673 million lb)

WAG: ABC = 1,374 t (3.029 million lb)

AI: ABC = 3,947 t (8.702 million lb).

Scenario 19_1:

EAG: ABC = 2,564 t (5.652 million lb)

WAG: ABC = 1,373 t (3.027 million lb)

AI: ABC = 3,937 t (8.679 million lb).

Scenario 19_2a (EAG) & 19_2 (WAG):

EAG: ABC = 1,992 t (4.392 million lb)

WAG: ABC = 1,293 t (2.850 million lb)

AI: ABC = 3.285 t (7.242 million lb).

2. List of variables related to scientific uncertainty:

- Model relied 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 (1987–2012) 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.

3. List of additional uncertainties for alternative sigma-b.

We recommend a buffer of 25% to account for additional uncertainties.

4. Author recommended ABC:

Authors recommend two ABC options based on 25% buffer on the OFL under scenarios 19_1 and 19_2 (or 19_2a).

H. Rebuilding Analysis

Not applicable. This stock has not been declared overfished.

I. Data Gaps and Research Priorities

1. The recruit abundances were estimated from 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 the possibility 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 used the estimated *M* from the previous model. However, an independent estimate of *M* is needed for comparison, which could be achieved with tagging experiments.

3. An extensive tagging study will also provide independent estimates of molting probability and growth. We used the 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 experimentally-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 the 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. The independent survey collected length weight data during 2018, which will be analyzed during the next assessment cycle.

7. We have recently included male maturity data in the model to determine a maturity curve for MMB estimation. The maturity data available to us were collected in 1984 and 1991. 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. We will analyze the additional data and plan to continue data collection for another season before deciding on continuing this type of data collection.

8. Morphometric measurements provide morphometric maturity size. 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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K. Literature Cited

Adams, C.F., and A.J. Paul. 1999. Phototaxis and geotaxis of light-adapted zoeae of the golden king crab *Lithodes aequispinus* (Anomura: Lithodidae) in the laboratory. Journal of Crustacean Biology. 19(1): 106-110.

ADF&G (Alaska Department of Fish and Game). 2002. Annual management report for the shellfish fisheries of the Westward Region, 2001. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K02–54, Kodiak, Alaska.

Barnard, D.R., and R. Burt. 2004. Summary of the 2002 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K04–27, Kodiak, Alaska.

Barnard, D.R., R. Burt, and H. Moore. 2001. Summary of the 2000 mandatory shellfish observer program database for the open access fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K01–39, Kodiak, Alaska.

Beers, D.E. 1992. Annual biological summary of the Westward Region shellfish observer database, 1991. Alaska Department of Fish and game, Division of Commercial Fisheries, Regional Information Report 4K92-33, Kodiak.

Blau, S.F., and D. Pengilly. 1994. Findings from the 1991 Aleutian Islands golden king crab survey in the Dutch Harbor and Adak management areas including analysis of recovered tagged crabs. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 4K94-35, Kodiak.

Blau, S.F., L.J. Watson, and I. Vining. 1998. The 1997 Aleutian Islands golden king crab survey. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 4K98-30, Kodiak.

Bowers, F.R., M. Schwenzfeier, S. Coleman, B.J. Failor-Rounds, K. Milani, K. Herring, M. Salmon, and M. Albert. 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea, and the Westward Region's shellfish observer program, 2006/07. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Fishery Management Report No. 08-02, Anchorage, Alaska.

Bowers, F.R., M. Schwenzfeier, K. Herring, M. Salmon, J. Shaishnikoff, H. Fitch, J. Alas, and B. Baechler. 2011. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea, and the Westward Region's shellfish observer program, 2009/10. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Fishery Management Report No. 11-05, Anchorage, Alaska.

Bozdogan, H. 1987. Model selection and Akaike's Information Criterion (AIC): The general theory and its analytical extensions. Psychometrika, 52, 345-370.

Burnham, K.P., D.R. Anderson, G.C. White, C. Brownie, and K.H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society, Monograph 5, 437p.

Burnham, K.P. and D.R. Anderson. 2002. Model Selection and Multimodal Inference, A practical Information- Theoretic Approach. 2nd edition. Springer-Verlag, NY, 488p.

Daly, B., M.S.M. Siddeek, M. Stichert, S. Martell, and J. Zheng. 2019. Recommended harvest strategy for Aleutian Islands golden king crab. Alaska Department of Fish and Game, Fishery Manuscript Series No. 19-03, Anchorage.

Deroba, J.J. 2014. Evaluating the consequences of adjusting fish stock assessment estimates of biomass for retrospective patterns using Mohn's rho. *North American Journal of Fisheries Management* 34:380-390.

Feenstra, J., A. Linnane, M. Haddon, and A. Punt. (unpublished, 2019). Impacts on CPUE from vessel fleet composition changes in an Australian lobster (*Jasus edwardsii*) fishery. New Zealand Journal of Marine and Freshwater Research.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. *Optim. Methods Softw.* 27:233-249.

Fox, J., and S. Weisberg. 2011. An R Companion to Applied Regression. Second edition. Sage Publications, Inc. 449 p.

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. *Canadian Journal of. Fisheries and Aquatic Sciences* 68: 1124–1138.

Francis, R.I.C.C. 2017. Revisiting data weighting in fisheries stock assessment models. *Fisheries Research* 192: 5-15.

Gaeuman, W.B. 2014. Summary of the 2013/2014 Mandatory Crab Observer Program Database for the Bering Sea/Aleutian Islands commercial crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 14-49, Anchorage.

Gaeuman, W.B. 2011. Summary of the 2009/10 mandatory crab observer program database for the BSAI commercial crab fisheries. Fishery Data Series No. 11-04. Alaska Department of Fish and Game, Kodiak.

Hartill, T. 2012. Annual management report for the community development quota and Adak Community Allocation crab fisheries in the Bering Sea and Aleutian Islands, 2010/11. Pages 177–194 in Fitch, H., M. Schwenzfeier, B. Baechler, T. Hartill, M. Salmon, M. Deiman, E. Evans, E. Henry, L. Wald, J. Shaishnikoff, and K. Herring. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the Westward Region's Shellfish Observer Program, 2010/11. Alaska Department of Fish and Game, Fishery Management Report No. 12-22, Anchorage.

Hilsinger, J., C. Siddon, and L. Hulbert. 2016. Cooperative red king crab survey in the Adak area, 2015. Anchorage., Alaska Department of Fish and Game, Fishery Data Series No. 16-18.

Hiramoto, K. 1985. Overview of the golden king crab, *Lithodes aequispina*, fishery and its fishery biology in the Pacific waters of Central Japan. Pages 297-315, In: Proceedings of the International King Crab Symposium. Alaska Sea Grant College Program, AK-SG-85-12, Fairbanks, Alaska.

Jewett, S.C., N.A. Sloan, and D.A. Somerton. 1985. Size at sexual maturity and fecundity of the fjord-dwelling golden king crab *Lithodes aequispina* Benedict from northern British Columbia. *Journal of Crustacean Biology* 5: 377–385.

Koeneman, T.M., and D.V. Buchanan. 1985. Growth of the golden king crab, *Lithodes aequispina*, in Southeast Alaskan waters. Pages 281-297, In: Proceedings of the International King Crab Symposium. Alaska Sea Grant College Program, AK-SG-85-12, Fairbanks, Alaska.

Kruse, G.H., L.C. Byrne, F.C. Funk, S.C. Matulich, and J. Zheng. 2000. Analysis of minimum size limit for the red king crab fishery in Bristol Bay, Alaska. *N. Am. J. Fish. Manage.* 20:307-319.

Leon, J. M., J. Shaishnikoff, E. Nichols, and M. Westphal. 2017. Annual management report for shellfish fisheries of the Bering Sea–Aleutian Islands management area, 2015/16. Alaska Department of Fish and Game, Fishery Management Report No. 17-10, Anchorage.

Maunder, M.N., and A.E. Punt. 2004. Standardizing catch and effort data: a review of recent approaches. *Fisheries Research* 70: 141-159.

Mohn, R. 1999. The retrospective problem in sequential population analysis: An investigation using cod fishery and simulated data. *ICES Journal of Marine Science* 56:473-488.

Moore, H., L.C. Byrne, and M.C. Schwenzfeier. 2000. Summary of the 1999 mandatory shellfish observer program database for the open access fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K00–50, Kodiak, Alaska.

Morrison, R., R.K. Gish, and M. Ruccio. 1998. Annual management report for the shellfish fisheries of the Aleutian Islands. Pages 82–139 in ADF&G. Annual management report for the shellfish fisheries of the Westward Region. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K98-39, Kodiak.

National Marine Fisheries Service (NMFS). 2004. Bering Sea Aleutian Islands Crab Fisheries Final Environmental Impact Statement. National Marine Fisheries Service, Alaska Region, Juneau, August 2004.

North Pacific Fishery Management Council (NPFMC). 2007a. Initial Review Draft: Environmental Assessment for proposed Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions. 17 January 2007. North Pacific Fishery Management Council, Anchorage.

North Pacific Fishery Management Council (NPFMC). 2007b. Public Review Draft: Environmental Assessment for proposed Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions. 14 November 2007. North Pacific Fishery Management Council, Anchorage.

Otto, R.S., and P.A. Cummiskey. 1985. Observations on the reproductive biology of golden king crab (*Lithodes aequispina*) in the Bering Sea and Aleutian Islands. Pages 123-135 In: Proceedings of the International King Crab Symposium. Alaska Sea Grant College Program, AK-SG-85-12, Fairbanks, Alaska.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Shirley, T.C., and S. Zhou. 1997. Lecithotrophic development of the golden king crab *Lithodes aequispinus* (Anomura: Lithodidae). *J. Crust. Biol.* 17(2):207-216.

Siddeek, M.S.M. 2002. Review of biological reference points used in Bering Sea and Aleutian Islands (king and Tanner) crab management. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 5J02-06, Juneau, Alaska.

Siddeek, M.S.M., D.R. Barnard, L.J. Watson, and R.K. Gish. 2005. A modified catch-length analysis model for golden king crab (*Lithodes aequispinus*) stock assessment in the eastern Aleutian Islands. Pages 783-805 in Fisheries assessment and management in data limited situations, Alaska Sea Grant College Program, AK-SG-05-02, Fairbanks, Alaska.

Siddeek, M.S.M., J. Zheng, and D. Pengilly. 2015. Aleutian Islands Golden King Crab (*Lithodes aequispinus*) Model-Based Stock Assessment in Fall 2015. Draft report submitted for the September 2015 Crab Plan Team Meeting. North Pacific Fishery Management Council, Anchorage, Alaska.

Siddeek, M.S.M., J. Zheng, A.E. Punt, and V. Vanek. 2016a. Estimation of size-transition matrices with and without moult probability for Alaska golden king crab using tag–recapture data. *Fisheries Research* 180:161-168.

Siddeek, M.S.M., J. Zheng, and D. Pengilly 2016b. Standardizing CPUE from the Aleutian Islands golden king crab observer data. In: T.J. Quinn II, J.L. Armstrong, M.R. Baker, J. Heifetz, and D. Witherell (eds.), Assessing and Managing Data-Limited Fish Stocks. Alaska Sea Grant, University of Alaska Fairbanks, Alaska, USA, pp. 97-116.

Siddeek, M.S.M., J. Zheng, C. Siddon, B. Daly, J. Runnebaum, and M.J. Westphal. 2018. Aleutian Islands Golden king crab model-based stock assessment in Spring 2018. CRAB2018SAFE chapter. North Pacific Fishery Management Council, Anchorage, Alaska.

Somerton, D.A., and R.S. Otto. 1986. Distribution and reproductive biology of the golden king crab, *Lithodes aequispina*, in the Eastern Bering Sea. *Fishery Bulletin* 81(3): 571-584.

Starr, P.J. 2012. Standardized CPUE analysis exploration: using the rock lobster voluntary logbook and observer catch sampling programmes. New Zealand Fisheries Assessment Report 2012/34, 75 p.

Vanek, V., D. Pengilly, and M.S.M. Siddeek. 2013. A study of commercial fishing gear selectivity during the 2012/13 Aleutian Islands golden king crab fishery east of 174° W longitude. Alaska Department of Fish and Game, Division of Sport Fish and Commercial Fisheries, Fishery Data Series No. 13-41.

Von Szalay, P.G., C.N. Roper, N.W. Raring, and M.H. Martin. 2011. Data report: 2010 Aleutian Islands bottom trawl survey. U.S. Dep. Commerce., NOAA Technical Memorandum NMFS-AFSC-215.

Watson, L.J. 2004. The 2003 triennial Aleutian Islands golden king crab survey and comparisons to the 1997 and 2000 surveys (revised October 17, 2005). Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K04-42, Kodiak. [Revised 10/17/2005].

Watson, L.J. 2007. The 2006 triennial Aleutian Islands golden king crab survey. Alaska Department of Fish and Game, Fishery Management Report No. 07-07, Anchorage.

Watson, L.J., and R.K. Gish. 2002. The 2000 Aleutian Islands golden king crab survey and recoveries of tagged crabs in the 1997–1999 and 2000–2002 fishing seasons. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K02-6, Kodiak.

Watson, L.J., D. Pengilly, and S.F. Blau. 2002. Growth and molting of golden king crabs (*Lithodes aequispinus*) in the eastern Aleutian Islands, Alaska. Pages 169-187 *in* Crabs in cold water regions: biology, management, and economics, Alaska Sea Grant College Program, AK-SG-02-01, Fairbanks, Alaska.

Webb. J. 2014. Reproductive ecology of commercially important Lithodid crabs. Pages 285-314 *in* B.G. Stevens (ed.). King Crabs of the World: Biology and Fisheries Management. CRC Press, Taylor & Francis Group, New York.

Table 1. Commercial fishery history for the Aleutian Islands golden king crab fishery 1981/82–2018/19: 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 – 2018/19, 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]

Crab Fishing Season	Vessels		GHL/TAC		Harvest[a]		Crab[b]		Pot Lifts		CPUE[b]		Average Weight[c]	
1995/96	28		–		3,157		1,582,333		293,021		5		2.0[f]	
	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]

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
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]
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]

Note:

a. Includes deadloss.
b. Number of crab per pot lift.
c. Average weight of landed crab, including deadloss.
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 – 2018/19, 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

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 (1990/91–2018/19). 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	1,623	3,684
1991/92	5,899	2,565
1992/93	5,580	1,517
1993/94	NA	2,814
1994/95	2,017	4,942
1995/96	3,734	2,128
1996/97	2,059	1,763
1997/98	2,548	1,793
1998/99	2,797	1,085
1999/00	2,280	2,087
2000/01	2,555	2,228
2001/02	2,097	2,133
2002/03	1,800	1,889
2003/04	1,816	1,855
2004/05	1,619	1,874
2005/06	1,717	1,786
2006/07	1,615	1,542
2007/08	1,791	1,602
2008/09	1,790	1,721
2009/10	1,750	1,667
2010/11	1,735	1,580
2011/12	1,748	1,506
2012/13	1,919	1,812
2013/14	1,818	1,895
2014/15	1,939	1,583
2015/16	2,099	1,548
2016/17	2,218	1,545
2017/18	2,035	1,155
2018/19	2,643	1,507

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 Scenario19_1) for the EAG and WAG golden king crab stocks, 1985/86–2018/19. 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	2.17	11.83	13.00	26.67	106,281	108,533	138	340		
1991/92	8.20	7.40	17.56	7.07	42.16	17.26	133,428	101,429	377	857		
1992/93	8.40	5.90	10.44	4.24	34.84	11.35	133,778	69,443	199	690		
1993/94	7.80	4.40	5.91	12.75	23.50	21.25	106,890	127,764	31	174		
1994/95	5.90	4.10	4.66	6.62	18.43	19.52	191,455	195,138	127	1,270		
1995/96	5.90	4.70	6.03	6.03	20.36	17.30	177,773	115,248	6,388	5,598	1.00	1.16
1996/97	6.50	6.10	6.02	5.90	16.71	14.85	113,460	99,267	8,360	7,194	0.94	1.01
1997/98	7.30	6.60	7.99	6.72	20.66	15.54	106,403	86,811	4,670	3,985	0.87	1.03
1998/99	8.90	11.40	9.82	9.43	28.27	23.09	83,378	35,975	3,616	1,876	1.00	1.08
1999/00	9.00	6.30	10.28	6.09	23.27	14.83	79,129	107,040	3,851	4,523	0.92	0.93
2000/01	9.90	7.00	10.40	6.46	26.77	16.76	71,551	101,239	5,043	4,740	0.82	0.87
2001/02	11.70	6.50	11.73	6.04	23.60	14.70	62,639	105,512	4,626	4,454	1.04	0.83
2002/03	12.40	8.40	12.70	7.47	23.54	17.37	52,042	78,979	3,980	2,509	1.10	0.90
2003/04	10.90	10.20	11.34	9.33	20.04	18.21	58,883	66,236	3,960	3,334	0.97	1.09
2004/05	18.30	12.10	18.34	11.14	29.36	22.44	34,848	56,846	2,206	2,619	1.44	1.17
2005/06	25.40	21.20	29.52	23.83	38.44	36.16	24,569	30,116	1,193	1,365	0.99	1.17
2006/07	24.80	19.60	25.13	24.01	33.41	33.47	26,195	26,870	1,098	1,183	0.81	1.14
2007/08	28.00	20.00	31.10	21.04	40.38	32.46	22,653	29,950	998	1,082	0.91	1.00
2008/09	27.30	22.40	29.97	24.50	38.36	38.11	24,466	26,200	613	979	0.90	1.14
2009/10	25.90	23.70	26.60	26.55	35.78	34.08	26,298	26,489	408	892	0.73	1.25
2010/11	26.00	20.90	26.40	22.41	36.95	29.12	25,851	29,994	436	867	0.76	1.06
2011/12	37.30	23.40	39.48	23.69	52.25	31.04	17,915	26,326	361	837	1.09	1.10
2012/13	33.02	20.57	37.82	22.86	47.49	30.80	20,827	32,716	438	1,109	1.05	1.07
2013/14	33.67	16.42	35.94	16.94	46.34	25.00	21,388	41,835	499	1,223	1.03	0.82
2014/15	42.29	15.29	47.01	15.28	59.91	22.64	17,002	41,548	376	1,137	1.34	0.72
2015/16	39.41	14.97	43.19	15.80	58.77	22.23	19,376	41,108	478	1,296	1.27	0.76
2016/17	32.45	14.29	36.89	16.75	52.58	24.43	24,470	38,118	617	1,060	1.06	0.85
2017/18	31.46	16.81	35.18	19.28	53.40	25.53	25,516	30,885	585	760	1.02	0.96
2018/19	36.80	19.83	41.57	22.85	62.97	30.61	25,553	29,156	475	688	1.25	1.16

Table 4. Time series of GLM estimated CPUE indices and coefficient of variations (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	1.66	0.06
1986/87	1.30	0.06
1987/88	0.97	0.06
1988/89	1.06	0.05
1989/90	1.05	0.04
1990/91	0.96	0.05
1991/92	0.84	0.05
1992/93	0.89	0.05
1993/94	0.91	0.06
1994/95	0.78	0.05
1995/96	0.71	0.05
1996/97	0.81	0.05
1997/98	1.10	0.05
1998/99	1.31	0.06

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 scenario 19_0 model 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	51				
1988/89	352	293				
1989/90	792	659			9	4
1990/91	163	136	22	12	13	6
1991/92	140	117	48	26	NA	NA
1992/93	49	41	41	23	2	1
1993/94	340	283	NA	NA	2	1
1994/95	319	266	34	19	4	2
1995/96	879	732	1,117	613	5	2
1996/97	547	455	509	280	4	2
1997/98	538	448	711	390	8	4
1998/99	541	450	574	315	15	7
1999/00	463	386	607	333	14	6
2000/01	436	363	495	272	16	7
2001/02	488	406	510	280	13	6
2002/03	406	338	438	241	15	7
2003/04	405	337	416	228	17	8
2004/05	280	233	299	164	10	5
2005/06	266	221	232	127	12	6
2006/07	234	195	143	79	14	6
2007/08	199	166	134	74	17	8
2008/09	197	164	113	62	15	7
2009/10	170	142	95	52	16	7
2010/11	183	152	108	59	26	12
2011/12	160	133	107	59	13	6
2012/13	187	156	99	54	18	8
2013/14	193	161	122	67	17	8
2014/15	168	140	99	54	16	7
2015/16	190	158	125	69	10	5
2016/17	223	186	155	85	12	6
2017/18	213	177	133	73	12	6
2018/19	218	182	234	128	9	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 scenario 19_1 model 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	51				
1988/89	352	293				
1989/90	792	659			9	4
1990/91	163	136	22	12	13	6
1991/92	140	117	48	26	NA	NA
1992/93	49	41	41	23	2	1
1993/94	340	283	NA	NA	2	1
1994/95	319	266	34	19	4	2
1995/96	879	732	1,117	614	5	2
1996/97	547	455	509	280	4	2
1997/98	538	448	711	391	8	4
1998/99	541	450	574	316	15	7
1999/00	463	385	607	334	14	6
2000/01	436	363	495	272	16	7
2001/02	488	406	510	280	13	6
2002/03	406	338	438	241	15	7
2003/04	405	337	416	229	17	8
2004/05	280	233	299	164	10	5
2005/06	266	221	232	128	12	6
2006/07	234	195	143	79	14	6
2007/08	199	166	134	74	17	8
2008/09	197	164	113	62	15	7
2009/10	170	142	95	52	16	7
2010/11	183	152	108	59	26	12
2011/12	160	133	107	59	13	6
2012/13	187	156	99	54	18	8
2013/14	193	161	122	67	17	8
2014/15	168	140	99	54	16	7
2015/16	190	158	125	69	10	5
2016/17	223	186	155	85	12	6
2017/18	213	177	133	73	12	6
2018/19	218	181	234	129	9	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 scenario 19_2a model 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	51				
1988/89	352	292				
1989/90	792	658			9	4
1990/91	163	135	22	13	13	6
1991/92	140	116	48	28	NA	NA
1992/93	49	41	41	24	2	1
1993/94	340	282	NA	NA	2	1
1994/95	319	265	34	20	4	2
1995/96	879	730	1,117	661	5	2
1996/97	547	454	509	301	4	2
1997/98	538	447	711	421	8	4
1998/99	541	449	574	340	15	7
1999/00	463	384	607	359	14	6
2000/01	436	362	495	293	16	7
2001/02	488	405	510	302	13	6
2002/03	406	337	438	259	15	7
2003/04	405	336	416	246	17	8
2004/05	280	232	299	177	10	5
2005/06	266	221	232	137	12	6
2006/07	234	194	143	85	14	6
2007/08	199	165	134	79	17	8
2008/09	197	164	113	67	15	7
2009/10	170	141	95	56	16	7
2010/11	183	152	108	64	26	12
2011/12	160	133	107	63	13	6
2012/13	187	155	99	59	18	8
2013/14	193	160	122	72	17	8
2014/15	168	139	99	59	16	7
2015/16	190	158	125	74	10	5
2016/17	223	185	155	92	12	6
2017/18	213	177	133	79	12	6
2018/19	218	181	234	138	9	4

Table 8. Parameter estimates and coefficient of variations (CV) with the 2018 MMB (MMB estimated on 15 Feb 2019) for scenarios 19_0, 19_1, and 19_2a for the golden king crab data from the EAG, 1985/86–2018/19. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 19_0		**Scenario 19_1**		**Scenario 19_2a**		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.54	0.006	2.54	0.006	2.54	0.006	1.0, 4.5
ω_2 (growth incr. slope)	-8.24	0.208	-8.24	0.21	-8.25	0.21	-12.0-5.0
log_a (molt prob. slope)	-2.51	0.023	-2.51	0.02	-2.49	0.02	-4.61-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.001	4.95	0.001	3.869,5.05
σ (growth variability std)	3.68	0.03	3.68	0.03	3.68	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.38	0.02	3.38	0.02	3.39	0.02	0.,4.4
log_ total sel deltaθ, 2005–18	2.98	0.03	2.98	0.03	2.96	0.03	0.,4.4
log_ ret. sel deltaθ, 1985–18	1.86	0.02	1.86	0.02	1.86	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.834	0.00	4.834	0.003	4.83	0.003	4.0,5.0
log_tot sel θ_{50}, 2005–18	4.923	0.002	4.923	0.002	4.92	0.002	4.0,5.0
log_ret. sel θ_{50}, 1985–18	4.915	0.0003	4.915	0.0003	4.92	0.0003	4.0,5.0
log_β_r (rec.distribution par.)	-1.077	0.17	-1.077	0.17	-1.06	0.17	-12.0, 12.0
logq2 (catchability 1995–04)	-0.55	0.13	-0.550	0.13	-0.52	0.15	-9.0, 2.25
logq3 (catchability 2005–18)	-0.77	0.16	-0.766	0.16	-0.79	0.19	-9.0, 2.25
log_mean_rec (mean rec.)	0.85	0.05	0.847	0.05	0.84	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.97	0.07	-0.973	0.07	-1.00	0.07	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.21	0.09	-9.207	0.09	-9.21	0.09	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.04	0.39	0.043	0.39	0.05	1.01	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.04	0.43	0.040	0.43	0.04	0.44	0.0,1.0
2018 MMB	11,562	0.21	11,520	0.21	9,126	0.29	

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 scenario 19_0 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 2019 are restricted to 1985–2019. 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} =22,467 $MMB_{35\%}$=6,585			
1985	1.69	9,527	0.04	9,563	0.06
1986	1.01	7,295	0.04	8,122	0.04
1987	4.23	6,702	0.05	6,352	0.04
1988	3.60	6,760	0.05	5,292	0.05
1989	2.01	5,914	0.06	4,755	0.07
1990	2.96	6,006	0.05	4,296	0.07
1991	3.49	6,108	0.04	4,566	0.06
1992	2.26	6,040	0.04	4,406	0.05
1993	2.16	6,180	0.03	4,445	0.05
1994	2.43	5,707	0.03	4,865	0.04
1995	2.29	5,121	0.04	4,427	0.04
1996	2.22	5,219	0.04	3,832	0.04
1997	3.00	5,470	0.05	3,957	0.04
1998	2.73	6,027	0.05	4,052	0.05
1999	2.86	6,670	0.06	4,468	0.05
2000	2.65	7,240	0.06	5,093	0.06
2001	1.99	7,535	0.06	5,679	0.06
2002	2.48	7,757	0.07	6,164	0.07
2003	2.152	7,967	0.07	6,451	0.07
2004	1.88	7,980	0.07	6,638	0.07
2005	2.81	8,016	0.07	6,766	0.08
2006	2.16	8,228	0.07	6,659	0.08
2007	2.085	8,224	0.07	6,781	0.08
2008	3.09	8,349	0.07	6,912	0.08
2009	2.03	8,614	0.07	6,863	0.08
2010	1.89	8,458	0.07	7,110	0.07
2011	2.25	8,241	0.06	7,211	0.07
2012	2.01	8,037	0.07	7,009	0.07
2013	1.75	7,646	0.07	6,777	0.07
2014	3.16	7,518	0.09	6,488	0.08
2015	4.03	8,157	0.11	6,121	0.09
2016	4.77	9,392	0.14	6,199	0.11
2017	4.05	10,933	0.18	6,942	0.14
2018	2.57	11,562	0.21	8,382	0.18
2019	2.33				

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 scenario 19_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 2017 are restricted to 1985–2019. 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} =22,465 $MMB_{35\%}$=6,584			
1985	1.69	9,527	0.04	9,564	0.06
1986	1.01	7,295	0.04	8,122	0.04
1987	4.23	6,702	0.05	6,351	0.04
1988	3.60	6,760	0.05	5,292	0.05
1989	2.01	5,914	0.06	4,755	0.07
1990	2.96	6,006	0.05	4,296	0.07
1991	3.49	6,108	0.04	4,565	0.06
1992	2.26	6,039	0.04	4,406	0.05
1993	2.15	6,179	0.03	4,444	0.05
1994	2.43	5,706	0.03	4,865	0.04
1995	2.29	5,120	0.04	4,426	0.04
1996	2.22	5,219	0.04	3,831	0.04
1997	3.00	5,471	0.05	3,957	0.04
1998	2.74	6,030	0.05	4,052	0.05
1999	2.86	6,675	0.06	4,469	0.05
2000	2.65	7,247	0.06	5,097	0.06
2001	2.00	7,545	0.06	5,685	0.06
2002	2.48	7,767	0.07	6,172	0.07
2003	2.15	7,977	0.07	6,460	0.07
2004	1.88	7,990	0.07	6,648	0.07
2005	2.80	8,023	0.07	6,775	0.08
2006	2.16	8,231	0.07	6,668	0.08
2007	2.08	8,225	0.07	6,785	0.08
2008	3.09	8,349	0.07	6,913	0.08
2009	2.03	8,613	0.07	6,863	0.08
2010	1.89	8,458	0.07	7,109	0.07
2011	2.25	8,243	0.06	7,210	0.07
2012	2.00	8,036	0.07	7,009	0.07
2013	1.75	7,639	0.07	6,777	0.07
2014	3.15	7,506	0.09	6,485	0.08
2015	4.02	8,139	0.11	6,113	0.09
2016	4.76	9,365	0.14	6,185	0.11
2017	4.04	10,898	0.18	6,921	0.14
2018	2.57	11,520	0.21	8,353	0.18
2019	2.33				

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 scenario 19_2a 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 2017 are restricted to 1985–2019. Equilibrium MMBeq and MMB35% 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} =22,596 $MMB_{35\%}$=6,635			
1985	1.68	9,532	0.04	9,589	0.06
1986	1.01	7,289	0.04	8,122	0.04
1987	4.21	6,691	0.05	6,339	0.04
1988	3.63	6,751	0.05	5,275	0.05
1989	2.01	5,913	0.06	4,736	0.07
1990	2.99	6,013	0.05	4,285	0.07
1991	3.48	6,124	0.04	4,558	0.06
1992	2.24	6,044	0.04	4,410	0.05
1993	2.15	6,171	0.03	4,450	0.05
1994	2.47	5,702	0.04	4,856	0.04
1995	2.34	5,151	0.04	4,410	0.04
1996	2.29	5,298	0.05	3,834	0.04
1997	3.14	5,626	0.05	3,998	0.05
1998	2.91	6,301	0.06	4,146	0.05
1999	3.02	7,073	0.06	4,650	0.06
2000	2.83	7,763	0.06	5,393	0.06
2001	2.13	8,160	0.07	6,094	0.07
2002	2.60	8,449	0.07	6,687	0.07
2003	2.23	8,690	0.08	7,052	0.08
2004	1.94	8,698	0.08	7,286	0.08
2005	2.82	8,696	0.08	7,424	0.08
2006	2.18	8,843	0.08	7,298	0.09
2007	2.14	8,785	0.07	7,365	0.08
2008	3.01	8,844	0.07	7,433	0.08
2009	1.91	8,977	0.07	7,337	0.08
2010	1.81	8,677	0.07	7,496	0.07
2011	2.11	8,322	0.07	7,463	0.07
2012	1.83	7,953	0.07	7,131	0.07
2013	1.63	7,404	0.08	6,761	0.07
2014	2.85	7,109	0.10	6,318	0.08
2015	3.41	7,432	0.13	5,817	0.10
2016	3.59	8,058	0.18	5,700	0.13
2017	3.38	8,855	0.24	6,063	0.17
2018	2.53	9,126	0.29	6,817	0.24
2019	2.31				

Table 12. Negative log-likelihood values of the fits for scenarios (Sc) 19_0 (base), 19_1 (observer CPUE with reduced number of gear codes), and 19_2a (observer CPUE 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	**Sc 19_0**	**Sc 19_1**	**Sc 19_2a**
Number of free parameters	146	146	146
Retlencomp	-1251.82	-1251.74	-1250.70
Totallencomp	-1363.48	-1363.84	-1380.79
Observer cpue	-3.88	-3.55	4.03
RetdcatchB	7.35	7.36	7.82
TotalcatchB	22.53	22.53	22.80
GdiscdcatchB	0.00	0.00	0.00
Rec_dev	7.55	7.53	6.42
Pot F_dev	0.01	0.01	0.01
Gbyc_F_dev	0.03	0.03	0.03
Tag	2692.49	2692.48	2692.15
Fishery cpue	-2.2896	-2.2935	-2.835
RetcatchN	0.0065	0.0065	0.0048
Total	108.50	108.52	98.94

Table 13. Time series of 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 selected by R square criteria.

Year	**CPUE Index**	**CV**
1985/86	2.16	0.06
1986/87	1.78	0.04
1987/88	1.33	0.05
1988/89	1.47	0.03
1989/90	1.25	0.03
1990/91	0.88	0.04
1991/92	0.70	0.04
1992/93	0.59	0.04
1993/94	0.71	0.06
1994/95	0.86	0.04
1995/96	0.80	0.04
1996/97	0.84	0.03
1997/98	0.72	0.03
1998/99	0.99	0.04

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 scenario 19_0 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	249			7	5
1990/91	205	100	190	98	6	4
1991/92	102	50	104	54	1	1
1992/93	76	37	94	48	3	2
1993/94	378	184	62	32	NA	NA
1994/95	367	178	119	61	2	1
1995/96	705	343	907	467	5	4
1996/97	817	397	1061	546	8	6
1997/98	984	478	1116	574	6	4
1998/99	613	298	638	328	14	10
1999/00	915	445	1155	594	18	13
2000/01	1029	500	1205	620	11	8
2001/02	898	436	975	502	11	8
2002/03	628	305	675	347	16	12
2003/04	688	334	700	360	8	6
2004/05	449	218	488	251	9	7
2005/06	337	164	220	113	6	4
2006/07	337	164	321	165	14	10
2007/08	276	134	257	132	17	12
2008/09	318	155	258	133	19	14
2009/10	362	176	292	150	24	17
2010/11	328	159	222	114	13	9
2011/12	295	143	252	130	14	10
2012/13	288	140	241	124	18	13
2013/14	327	159	236	121	17	12
2014/15	305	148	219	113	18	13
2015/16	287	139	243	125	10	7
2016/17	392	191	253	130	12	9
2017/18	299	145	222	114	10	7
2018/19	328	159	318	164	5	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 scenario 19_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	249			7	5
1990/91	205	100	190	98	6	4
1991/92	102	50	104	54	1	1
1992/93	76	37	94	48	3	2
1993/94	378	184	62	32	NA	NA
1994/95	367	178	119	61	2	1
1995/96	705	342	907	468	5	4
1996/97	817	397	1061	547	8	6
1997/98	984	478	1116	575	6	4
1998/99	613	298	638	329	14	10
1999/00	915	444	1155	596	18	13
2000/01	1029	500	1205	621	11	8
2001/02	898	436	975	503	11	8
2002/03	628	305	675	348	16	12
2003/04	688	334	700	361	8	6
2004/05	449	218	488	252	9	7
2005/06	337	164	220	113	6	4
2006/07	337	164	321	166	14	10
2007/08	276	134	257	133	17	12
2008/09	318	154	258	133	19	14
2009/10	362	176	292	151	24	17
2010/11	328	159	222	114	13	9
2011/12	295	143	252	130	14	10
2012/13	288	140	241	124	18	13
2013/14	327	159	236	122	17	12
2014/15	305	148	219	113	18	13
2015/16	287	139	243	125	10	7
2016/17	392	190	253	130	12	9
2017/18	299	145	222	114	10	7
2018/19	328	159	318	164	5	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 scenario 19_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	139				
1989/90	513	249			7	5
1990/91	205	99	190	102	6	4
1991/92	102	49	104	56	1	1
1992/93	76	37	94	50	3	2
1993/94	378	183	62	33	NA	NA
1994/95	367	178	119	64	2	1
1995/96	705	342	907	485	5	4
1996/97	817	396	1061	568	8	6
1997/98	984	477	1116	597	6	4
1998/99	613	297	638	341	14	10
1999/00	915	444	1155	618	18	13
2000/01	1029	499	1205	645	11	8
2001/02	898	435	975	522	11	8
2002/03	628	305	675	361	16	12
2003/04	688	334	700	375	8	6
2004/05	449	218	488	261	9	7
2005/06	337	163	220	118	6	4
2006/07	337	163	321	172	14	10
2007/08	276	134	257	138	17	12
2008/09	318	154	258	138	19	14
2009/10	362	176	292	156	24	18
2010/11	328	159	222	119	13	10
2011/12	295	143	252	135	14	10
2012/13	288	140	241	129	18	13
2013/14	327	159	236	126	17	12
2014/15	305	148	219	117	18	13
2015/16	287	139	243	130	10	7
2016/17	392	190	253	135	12	9
2017/18	299	145	222	119	10	7
2018/19	328	159	318	170	5	4

Table 17. Parameter estimates and coefficient of variations (CV) with the 2018 MMB (MMB estimated on 15 Feb 2019) for scenarios 19_0, 19_1, and 19_2 for the golden king crab data from the WAG, 1985/86–2018/19. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 19_0		**Scenario 19_1**		**Scenario 19_2**		
Parameter	Estimate	CV	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.54	0.01	2.54	0.01	2.54	0.01	1.0, 4.5
ω_2 (growth incr. slope)	-7.63	0.22	-7.63	0.22	-7.67	0.22	-12.0-5.0
log_a (molt prob. slope)	-2.63	0.03	-2.63	0.03	-2.63	0.03	-4.61-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.001	4.95	0.001	3.869,5.05
σ (growth variability std)	3.69	0.03	3.69	0.03	3.69	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.41	0.01	3.41	0.01	3.42	0.01	0.,4.4
log_ total sel deltaθ, 2005–18	2.86	0.02	2.86	0.02	2.85	0.02	0.,4.4
log_ ret. sel deltaθ, 1985–18	1.79	0.02	1.79	0.02	1.79	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.868	0.002	4.868	0.002	4.871	0.002	4.0,5.0
log_tot sel θ_{50}, 2005–18	4.902	0.001	4.902	0.001	4.899	0.001	4.0,5.0
log_ret. sel θ_{50}, 1985–18	4.916	0.0002	4.916	0.0002	4.916	0.0002	4.0,5.0
log_β_r (rec.distribution par.)	-1.024	0.16	-1.024	0.16	-1.019	0.16	-12.0, 12.0
logq2 (catchability 1995–04)	-0.046	1.40	-0.047	1.36	-0.062	1.04	-9.0, 2.25
logq3 (catchability 2005–18)	-0.387	0.23	-0.387	0.23	-0.409	0.28	-9.0, 2.25
log_mean_rec (mean rec.)	0.718	0.06	0.718	0.06	0.717	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.693	0.09	-0.693	0.09	-0.702	0.09	-15.0, -0.01
log_mean_Fground (GF byc. F)	-8.356	0.10	-8.356	0.10	-8.358	0.10	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.021	0.34	0.022	0.34	~0.000	387.19	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.013	0.66	0.013	0.65	0.014	0.58	0.0,1.0
2018 MMB	6,332	0.15	6,328	0.15	5,947	0.21	

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 scenario 19_0 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 2017 are restricted to 1985–2019. 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} =17,941 $MMB_{35\%}$=5,176			
1985	4.03	10,539	0.05	8,712	0.09
1986	3.57	8,206	0.05	8,238	0.07
1987	2.66	7,606	0.04	5,888	0.06
1988	1.76	6,497	0.04	5,582	0.04
1989	2.37	4,418	0.04	4,964	0.04
1990	1.91	4,049	0.05	3,113	0.05
1991	1.66	3,801	0.05	2,772	0.05
1992	2.11	3,975	0.04	2,668	0.06
1993	1.57	4,581	0.03	2,821	0.05
1994	1.97	3,895	0.03	3,434	0.03
1995	1.88	3,905	0.03	2,792	0.03
1996	1.72	3,914	0.04	2,749	0.03
1997	1.87	3,986	0.04	2,794	0.04
1998	1.90	4,310	0.03	2,875	0.04
1999	2.24	4,345	0.04	3,156	0.03
2000	2.49	4,504	0.04	3,098	0.04
2001	2.51	4,929	0.05	3,106	0.04
2002	2.44	5,450	0.05	3,424	0.05
2003	1.72	5,733	0.05	3,918	0.05
2004	2.25	5,804	0.06	4,371	0.05
2005	2.34	6,092	0.06	4,523	0.06
2006	2.46	6,638	0.05	4,674	0.06
2007	1.71	6,832	0.05	5,120	0.06
2008	1.50	6,643	0.05	5,434	0.06
2009	1.92	6,276	0.05	5,499	0.05
2010	1.61	6,012	0.05	5,156	0.05
2011	1.18	5,531	0.05	4,871	0.05
2012	1.90	4,965	0.05	4,551	0.05
2013	2.40	4,816	0.06	3,965	0.05
2014	1.88	5,038	0.07	3,536	0.06
2015	2.32	5,307	0.08	3,680	0.07
2016	2.48	5,855	0.09	3,942	0.08
2017	1.79	6,323	0.12	4,360	0.09
2018	1.86	6,332	0.15	4,913	0.11
2019	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 scenario 19_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 2017 are restricted to 1985–2019. 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} =17,940 $MMB_{35\%}$=5,176			
1985	4.03	10,544	0.05	8,719	0.09
1986	3.57	8,210	0.05	8,243	0.07
1987	2.66	7,610	0.04	5,892	0.06
1988	1.76	6,500	0.04	5,585	0.04
1989	2.37	4,420	0.04	4,968	0.04
1990	1.91	4,050	0.05	3,115	0.05
1991	1.66	3,802	0.05	2,774	0.05
1992	2.10	3,975	0.04	2,669	0.06
1993	1.56	4,579	0.03	2,822	0.05
1994	1.98	3,893	0.03	3,433	0.03
1995	1.88	3,904	0.03	2,789	0.03
1996	1.71	3,914	0.04	2,747	0.03
1997	1.87	3,985	0.04	2,794	0.04
1998	1.90	4,309	0.03	2,874	0.04
1999	2.24	4,344	0.04	3,155	0.03
2000	2.49	4,504	0.04	3,097	0.04
2001	2.51	4,931	0.05	3,105	0.04
2002	2.44	5,452	0.05	3,425	0.05
2003	1.72	5,734	0.05	3,919	0.05
2004	2.25	5,805	0.06	4,372	0.05
2005	2.34	6,095	0.06	4,523	0.06
2006	2.46	6,643	0.05	4,674	0.06
2007	1.71	6,836	0.05	5,123	0.06
2008	1.50	6,647	0.05	5,438	0.06
2009	1.92	6,278	0.05	5,502	0.05
2010	1.61	6,013	0.05	5,159	0.05
2011	1.18	5,534	0.05	4,872	0.05
2012	1.90	4,970	0.05	4,553	0.05
2013	2.40	4,822	0.06	3,968	0.05
2014	1.88	5,041	0.07	3,541	0.06
2015	2.32	5,308	0.08	3,684	0.07
2016	2.48	5,854	0.10	3,944	0.08
2017	1.79	6,320	0.12	4,359	0.09
2018	1.86	6,328	0.15	4,911	0.12
2019	2.05				

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 scenario 19_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 2017 are restricted to 1985–2019. 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} =17,932 $MMB_{35\%}$=5,174			
1985	3.91	10,658	0.05	8,868	0.09
1986	3.60	8,275	0.05	8,374	0.07
1987	2.64	7,667	0.04	5,966	0.06
1988	1.75	6,538	0.04	5,632	0.04
1989	2.38	4,452	0.04	5,000	0.04
1990	1.91	4,086	0.05	3,138	0.05
1991	1.66	3,836	0.05	2,799	0.05
1992	2.04	3,987	0.04	2,694	0.05
1993	1.54	4,552	0.03	2,842	0.05
1994	2.01	3,853	0.03	3,424	0.03
1995	1.88	3,876	0.03	2,748	0.03
1996	1.71	3,890	0.04	2,708	0.03
1997	1.89	3,971	0.04	2,764	0.04
1998	1.92	4,315	0.04	2,848	0.04
1999	2.28	4,378	0.04	3,141	0.03
2000	2.55	4,579	0.04	3,104	0.04
2001	2.553	5,048	0.05	3,142	0.04
2002	2.49	5,603	0.05	3,500	0.05
2003	1.72	5,901	0.06	4,029	0.05
2004	2.29	5,973	0.06	4,510	0.06
2005	2.393	6,276	0.06	4,667	0.06
2006	2.43	6,824	0.06	4,823	0.07
2007	1.70	6,987	0.05	5,282	0.06
2008	1.50	6,771	0.05	5,583	0.06
2009	1.90	6,375	0.05	5,620	0.05
2010	1.61	6,081	0.05	5,251	0.05
2011	1.20	5,589	0.05	4,938	0.05
2012	1.90	5,021	0.05	4,597	0.05
2013	2.35	4,850	0.07	4,007	0.06
2014	1.80	5,015	0.08	3,573	0.07
2015	2.22	5,207	0.10	3,686	0.08
2016	2.30	5,649	0.14	3,887	0.10
2017	1.68	6,001	0.18	4,225	0.13
2018	1.83	5,947	0.21	4,669	0.17
2019	2.05				

Table 21. Negative log-likelihood values of the fits for scenarios (Sc) 19_0 (base), 19_1 (observer CPUE with reduced number of gear codes), and 19_2 (observer CPUE 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	**Sc 19_0**	**Sc 19_1**	**Sc 19_2**
Number of free parameters	146	146	146
Retlencomp	-1204.90	-1204.75	-1205.02
Totallencomp	-1511.17	-1511.61	-1518.91
Observer cpue	-12.08	-11.23	-6.10
RetdcatchB	4.90	4.93	5.51
TotalcatchB	45.31	45.31	45.56
GdiscdcatchB	0.00	0.00	0.00
Rec_dev	4.65	4.65	4.62
Pot F_dev	0.03	0.03	0.03
Gbyc_F_dev	0.04	0.04	0.04
Tag	2694.37	2694.36	2694.14
Fishery cpue	-9.6898	-9.7218	-9.2786
RetcatchN	0.0022	0.0021	0.0017
Total	11.45	12.00	10.60

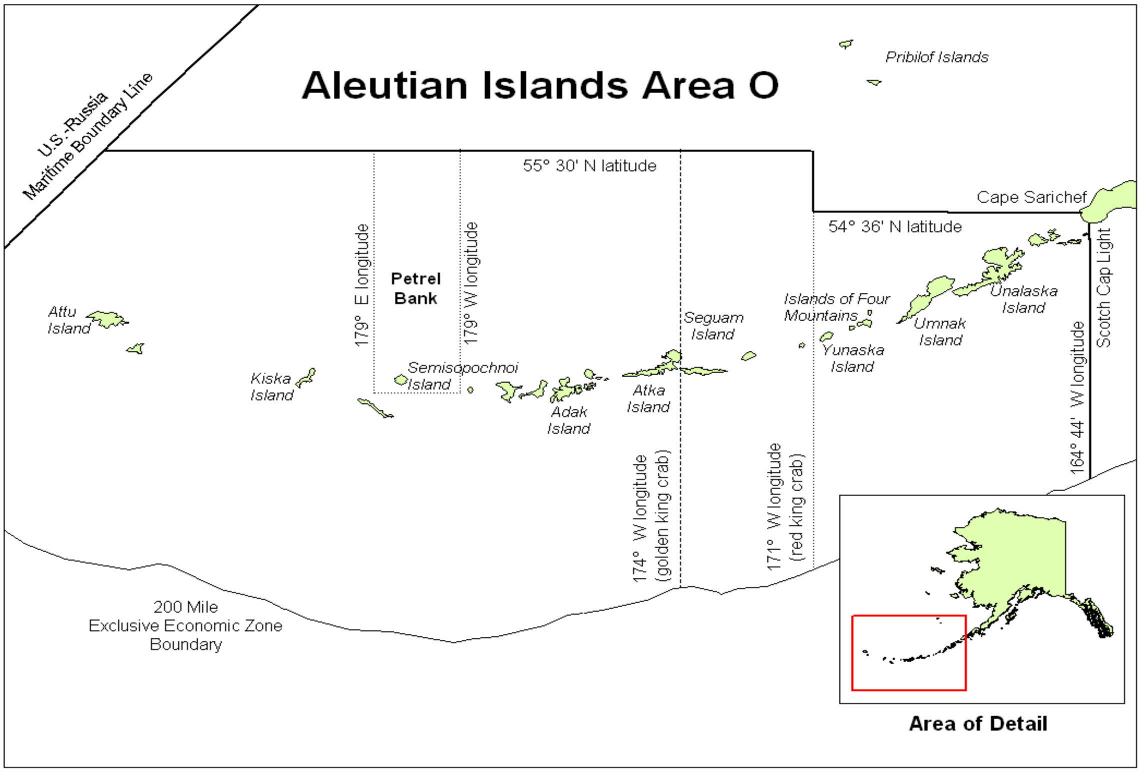


Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Leon *et al.* 2017).

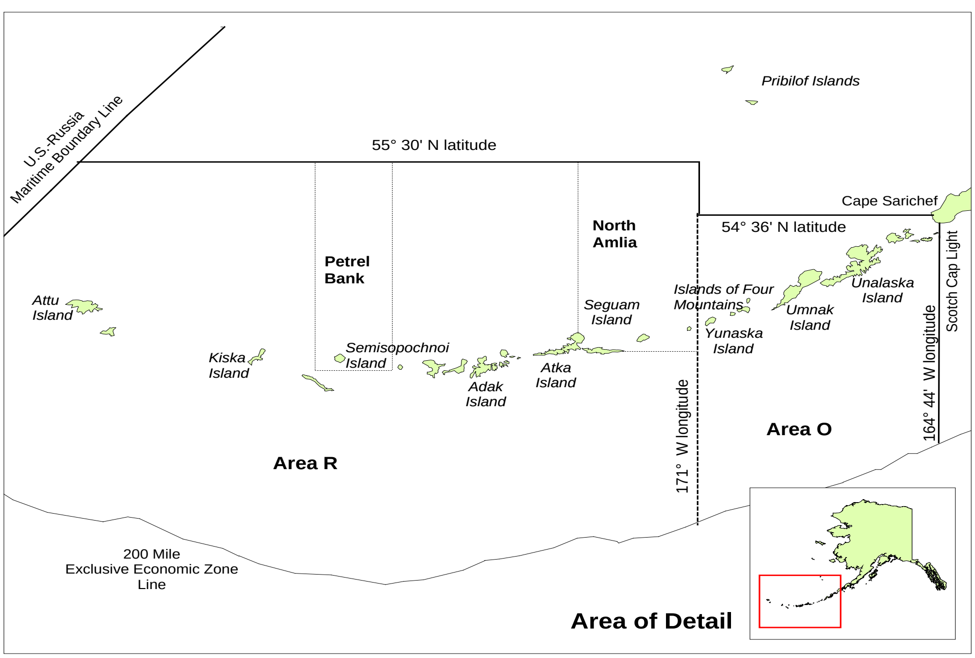


Figure 2. Adak (Area R) and Dutch Harbor (Area O) king crab registration area and districts, 1984/85–1995/96 seasons (Leon *et al.* 2017).

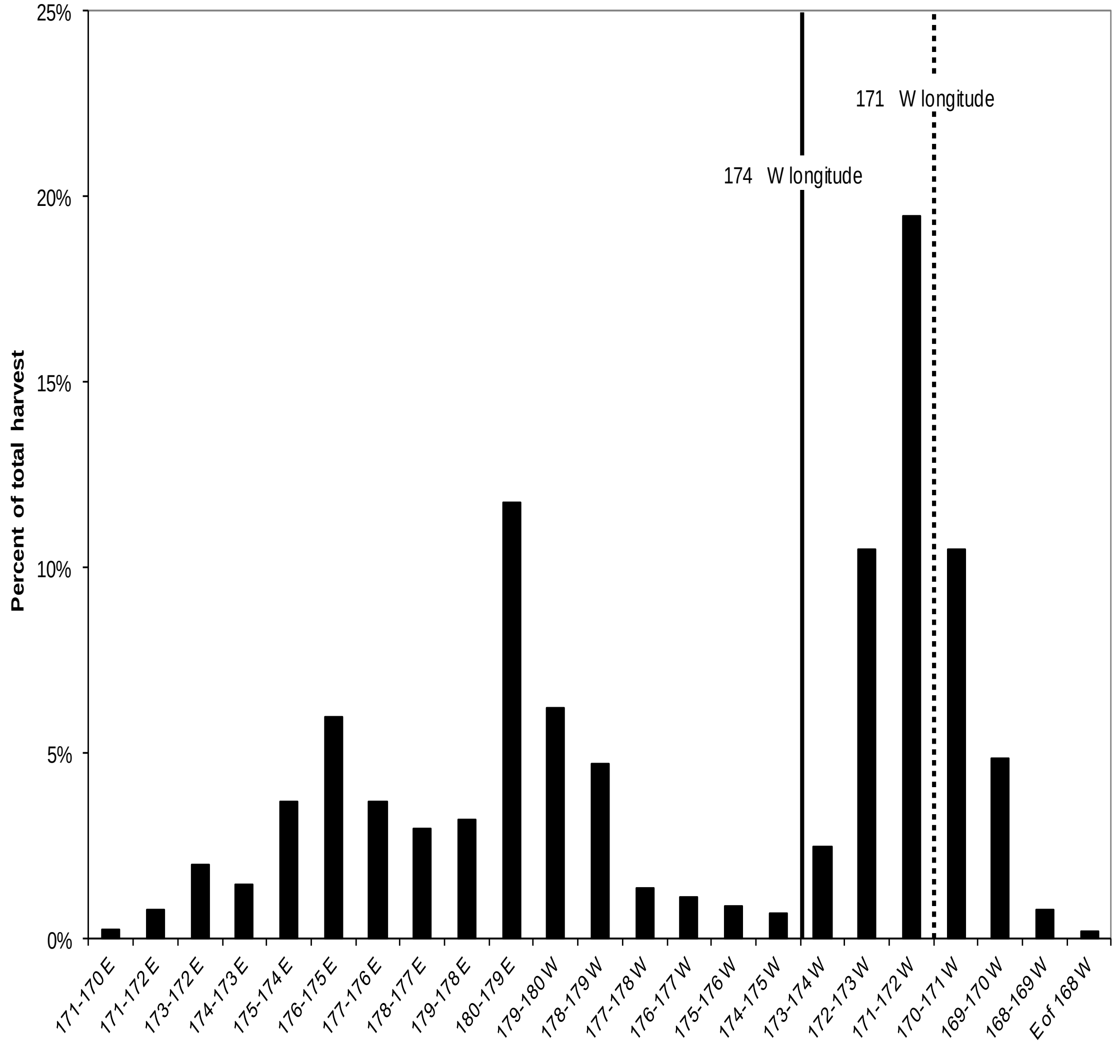


Figure 3. Percent of total 1981/82–1995/96 golden king crab retained catch weight (harvest) from one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor 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).

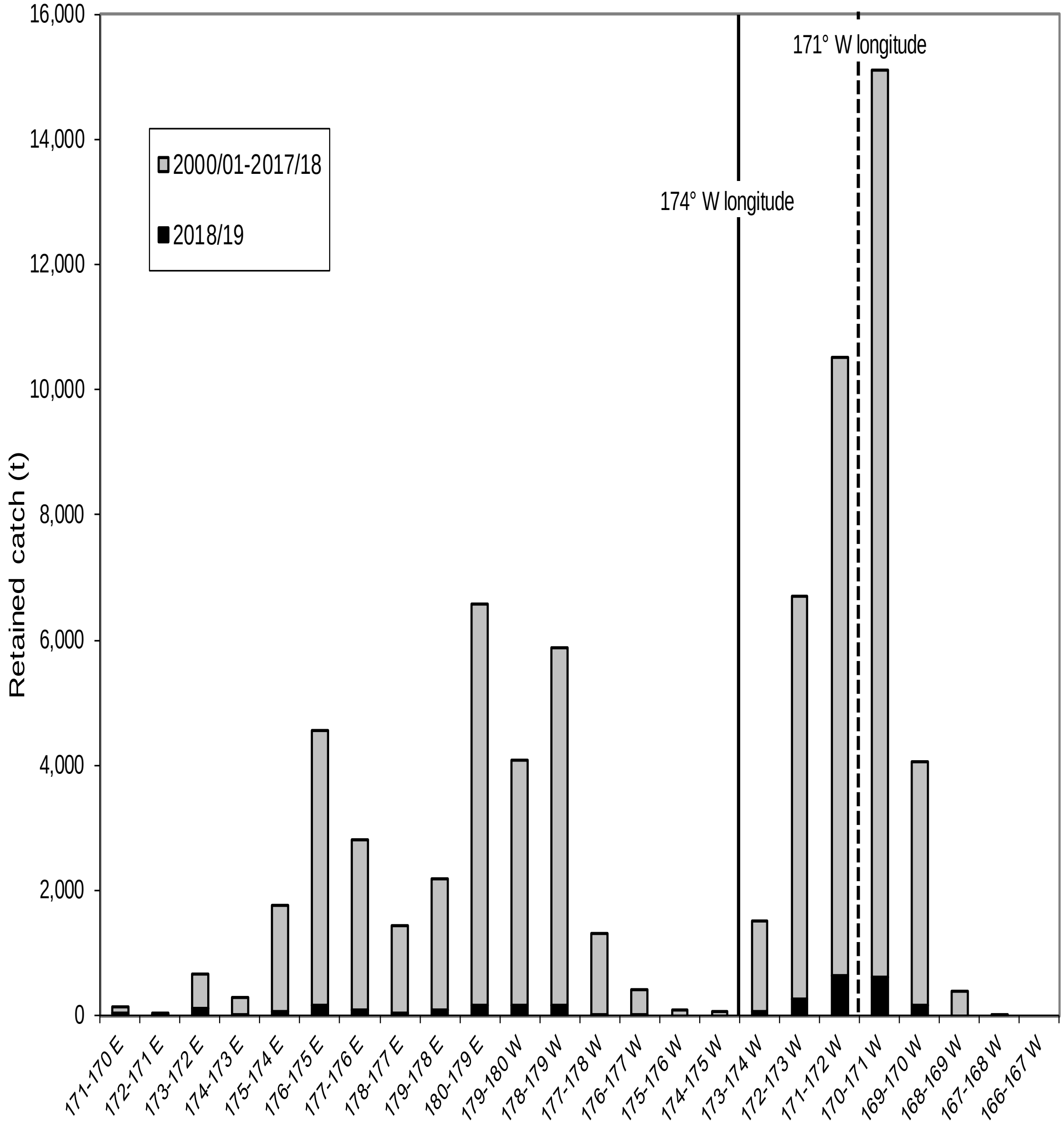


Figure 4. Retained catch (t) of golden king crab within one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2018/19commercial fishery seasons; solid line denotes the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden king 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).

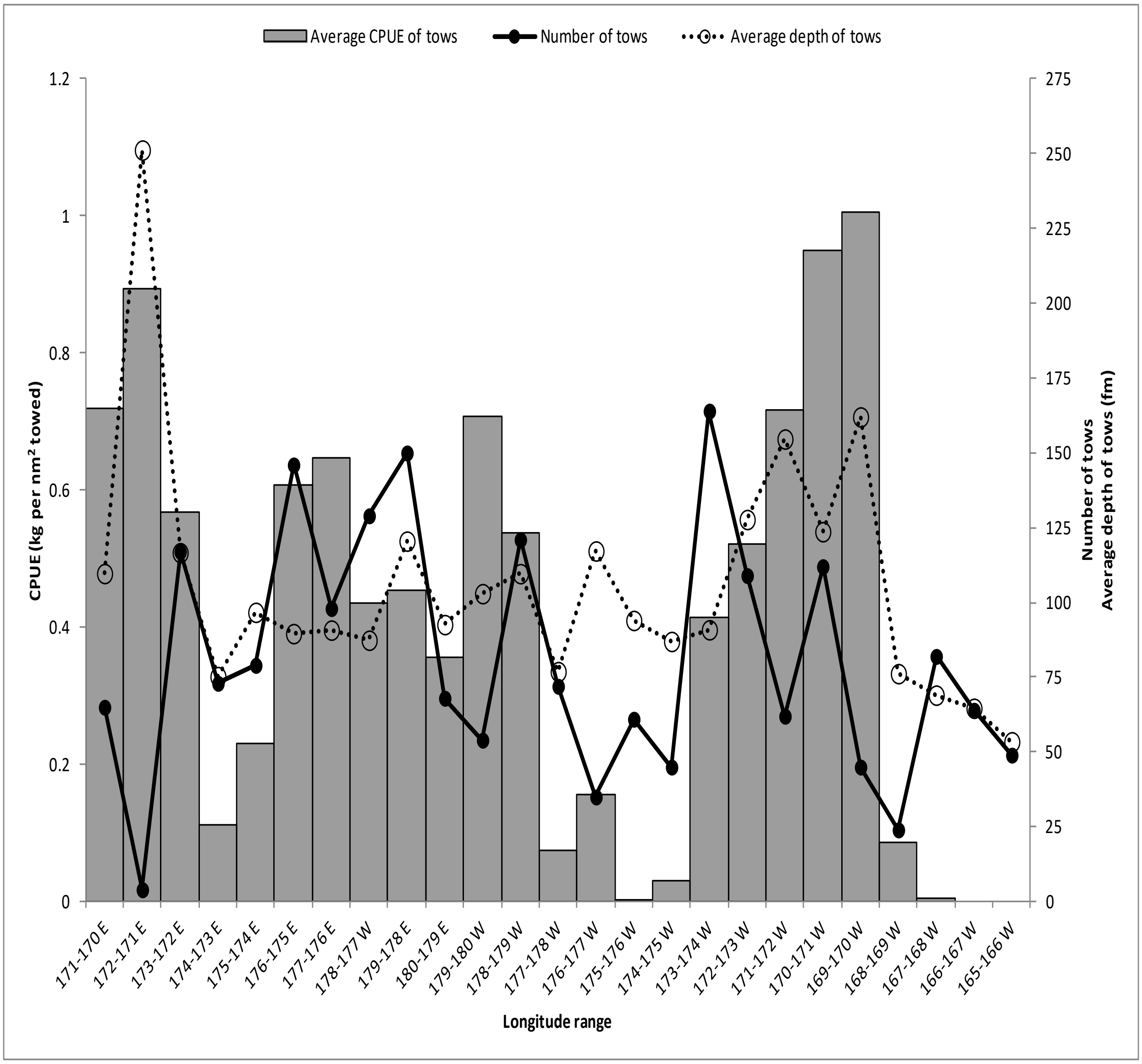


Figure 5. Average golden king crab CPUE (kg/nm2) for tows, number of tows, and average depth of tows from one-degree longitude intervals during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys; preliminary summary of data obtained on 1 April 2013 from http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm.

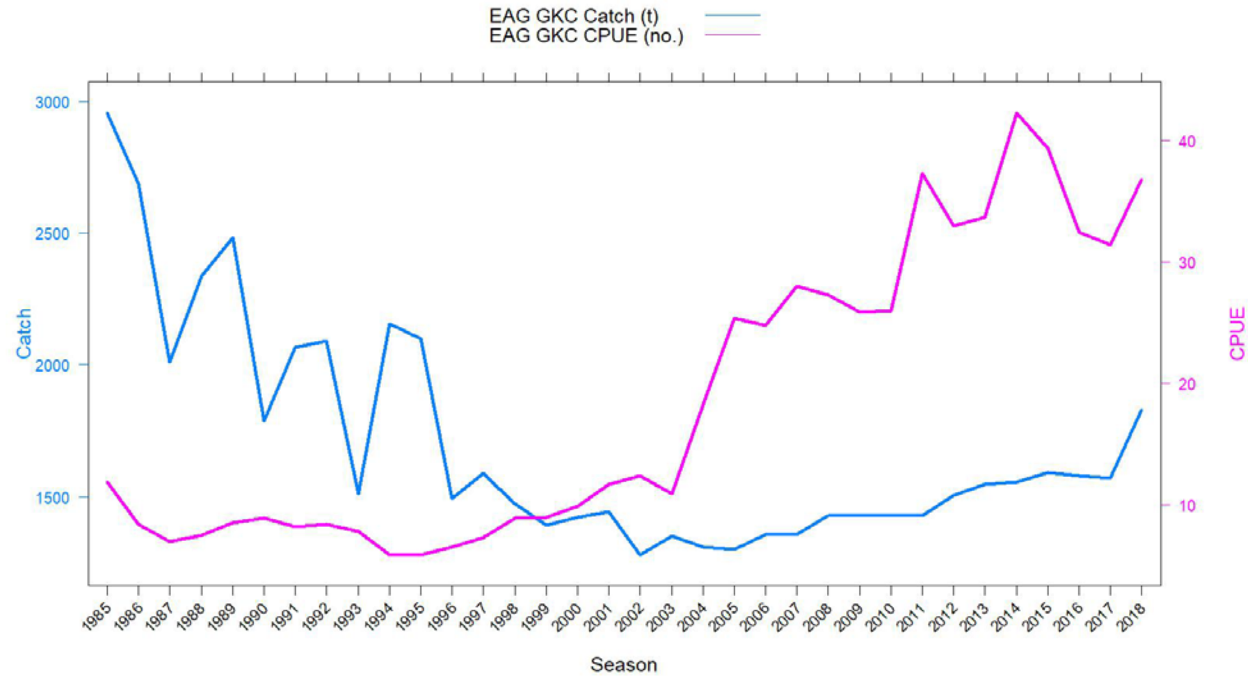


Figure 6. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the EAG, 1985/86–2018/19 fisheries (note: 1985 refers to the 1985/86 fishing year).

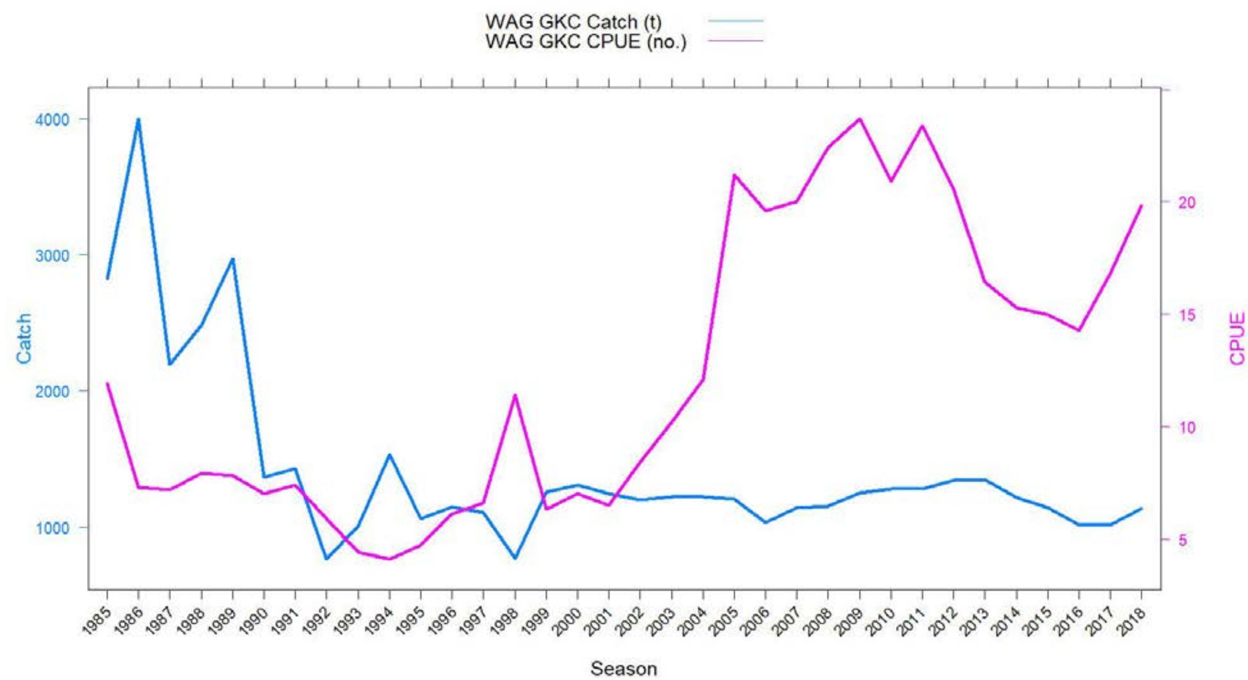


Figure 7. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the WAG, 1985/86–2018/19 fisheries (note: 1985 refers to the 1985/86 fishing year).

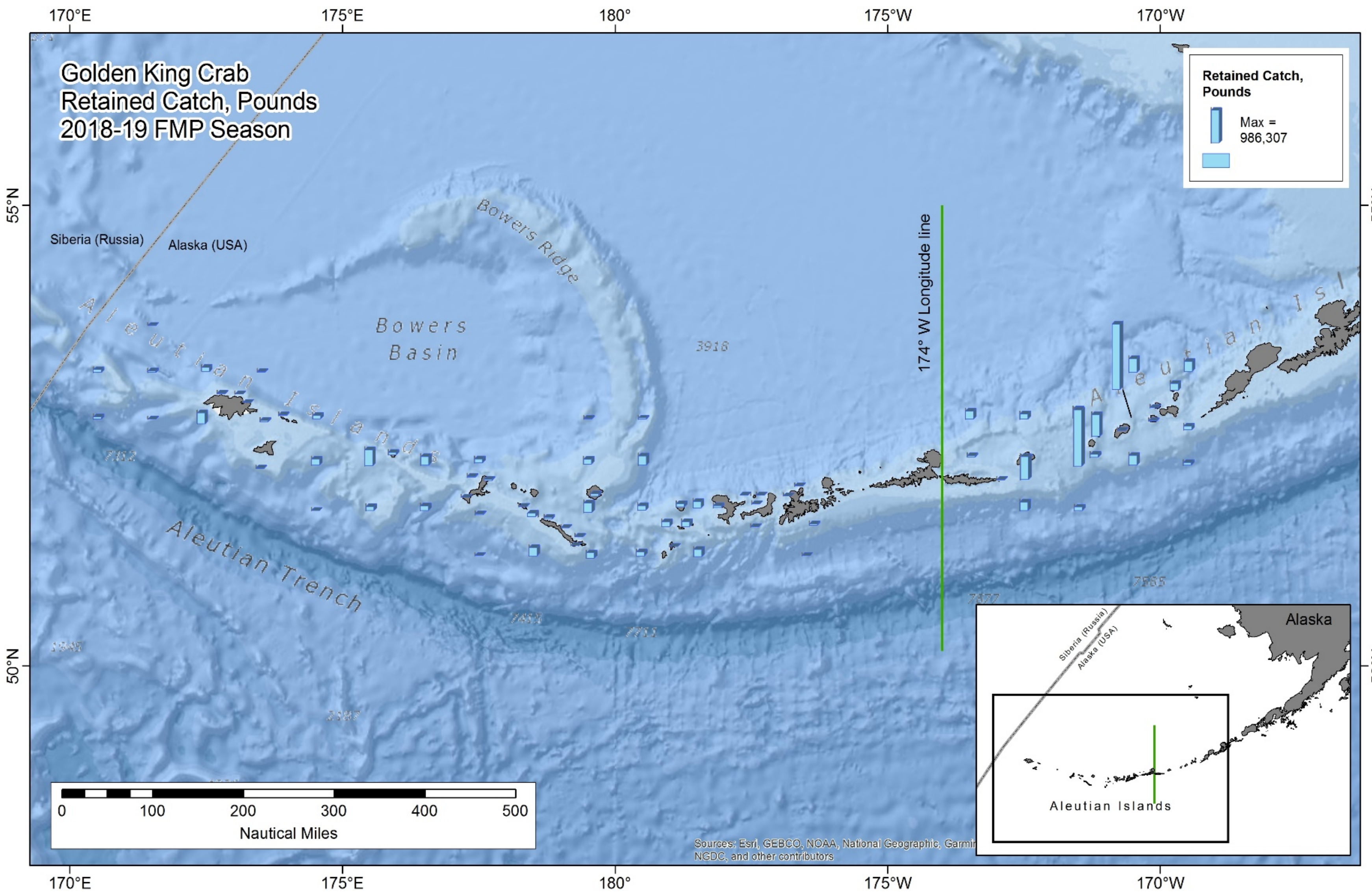


Figure 8. Catch distribution by statistical area.in 2018/19.

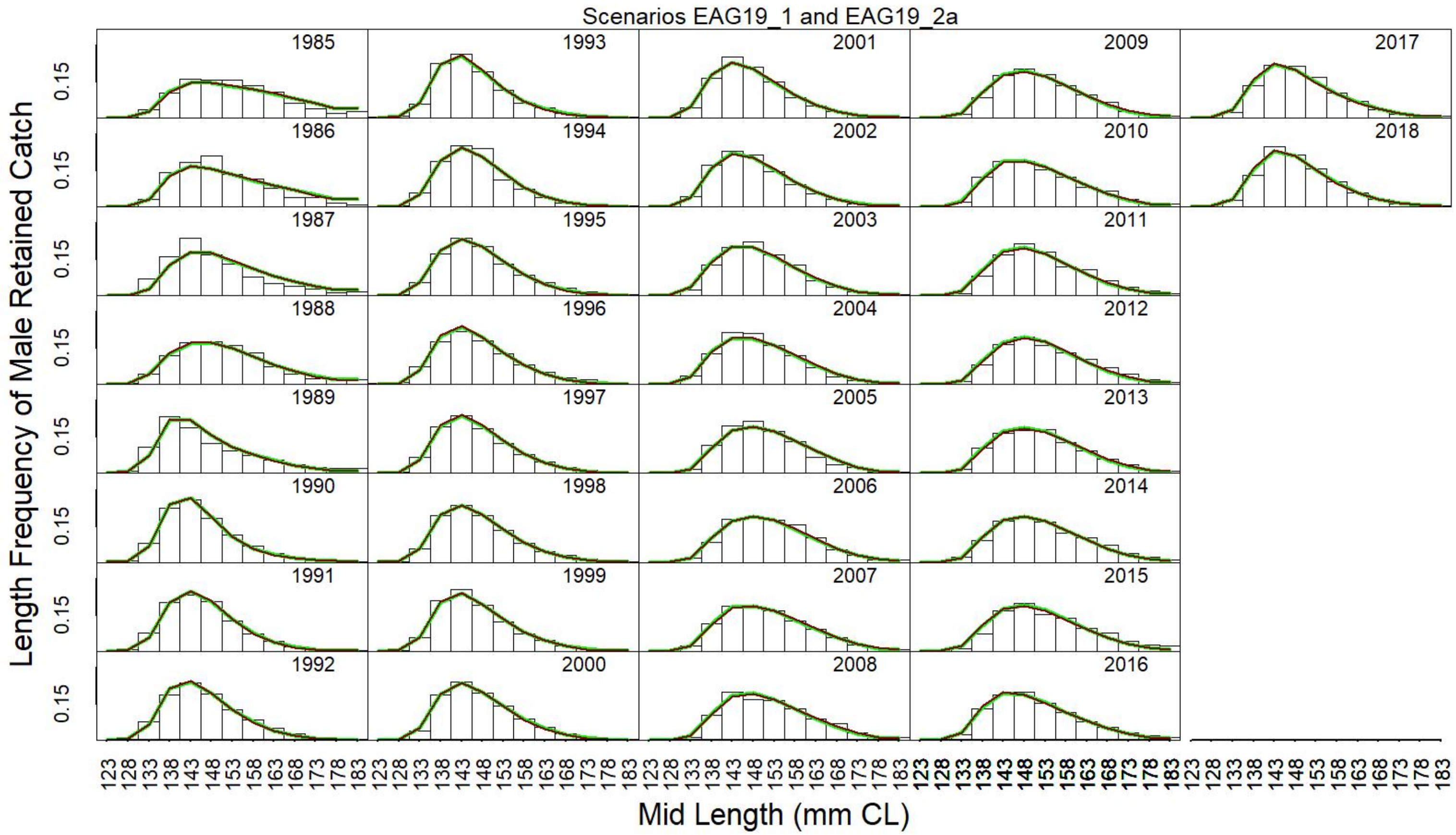


Figure 9. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions under scenarios 19_1 (green line) and 19_2a (dark red line) for golden king crab in the EAG, 1985/86 to 2018/19. This color scheme is used in all other figures.

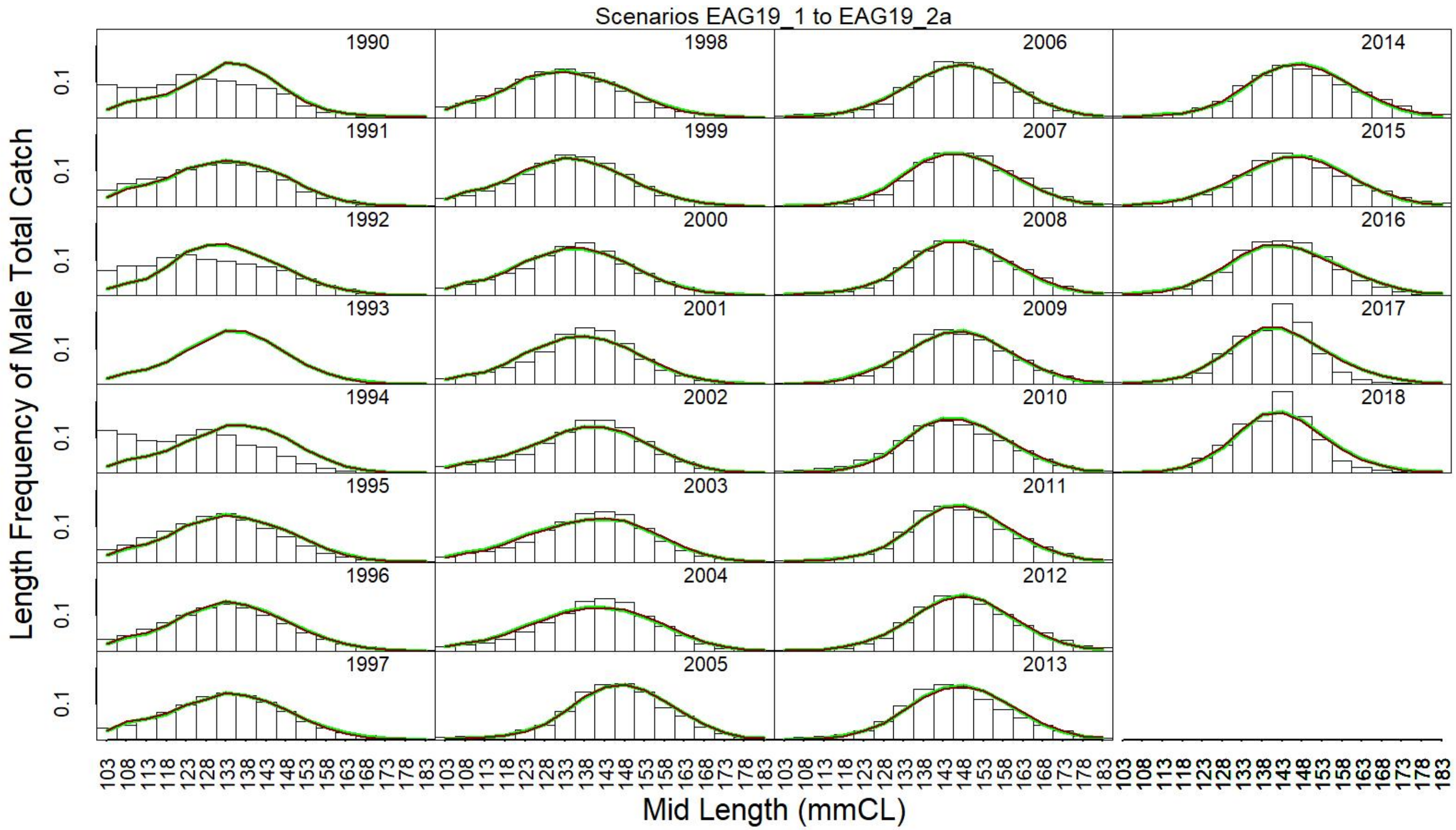


Figure 10. Predicted (line) vs. observed (bar) total catch relative length frequency distributions under scenarios 19_1 (green line) and 19_2a (dark red line) for golden king crab in the EAG, 1990/91 to 2018/19.

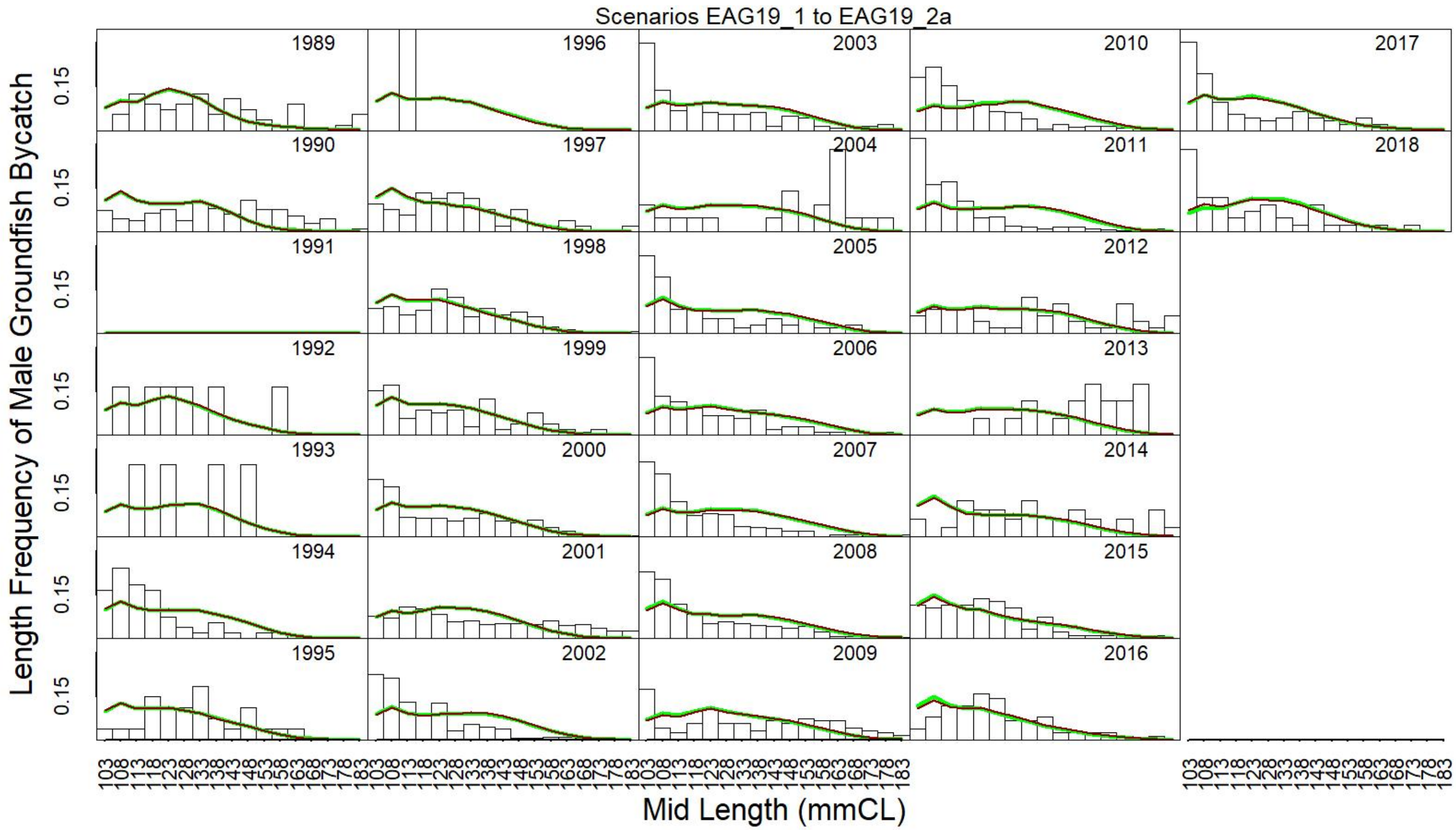


Figure 11. Predicted (line) vs. observed (bar) groundfish discarded bycatch relative length frequency distributions under scenarios 19_1 (green line) and 19_2a (dark red line) for golden king crab in the EAG, 19989/90 to 2018/19.

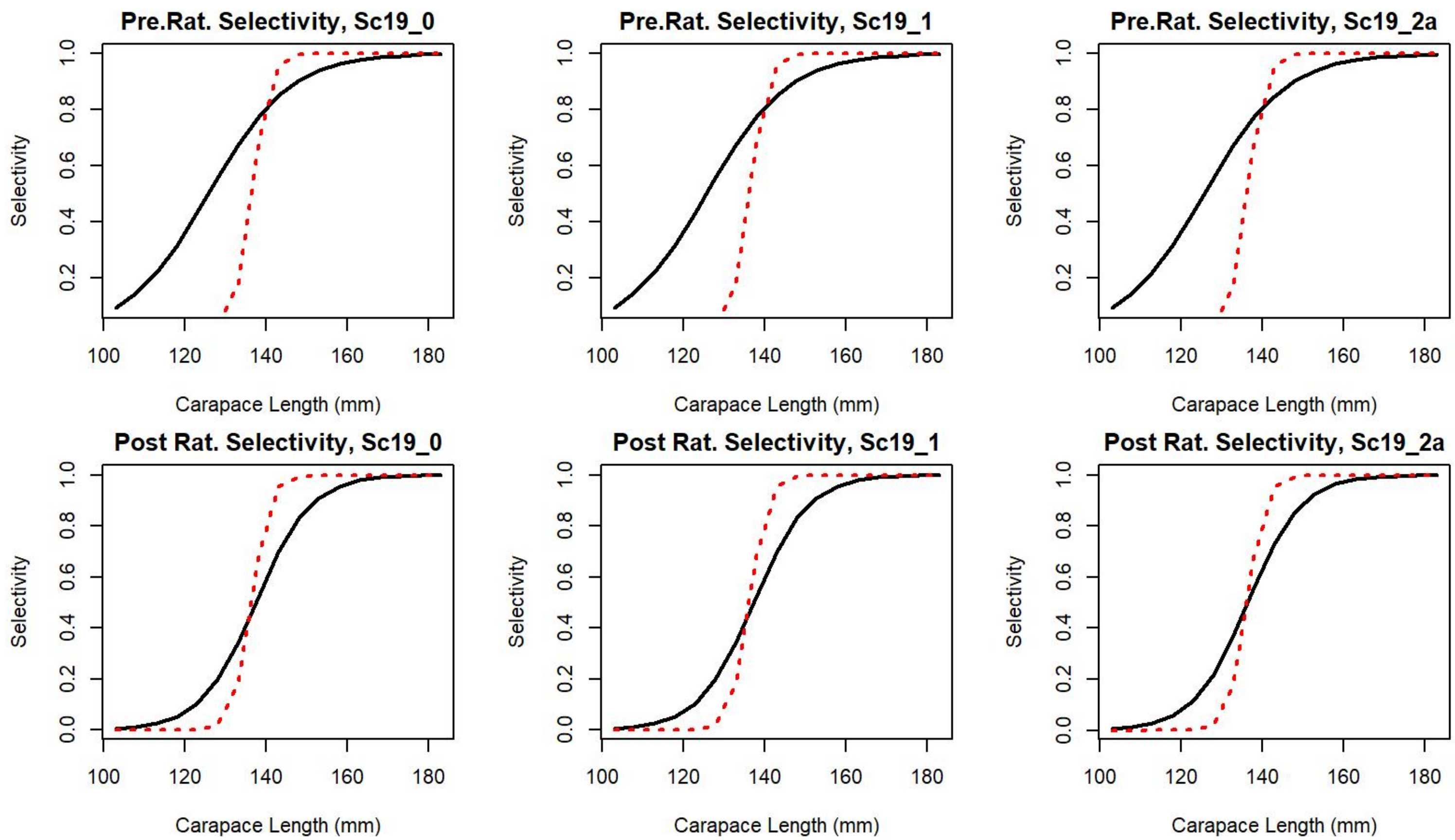


Figure 12. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios 19_0, 19_1, and 19_2a model fits to golden king crab data in the EAG.

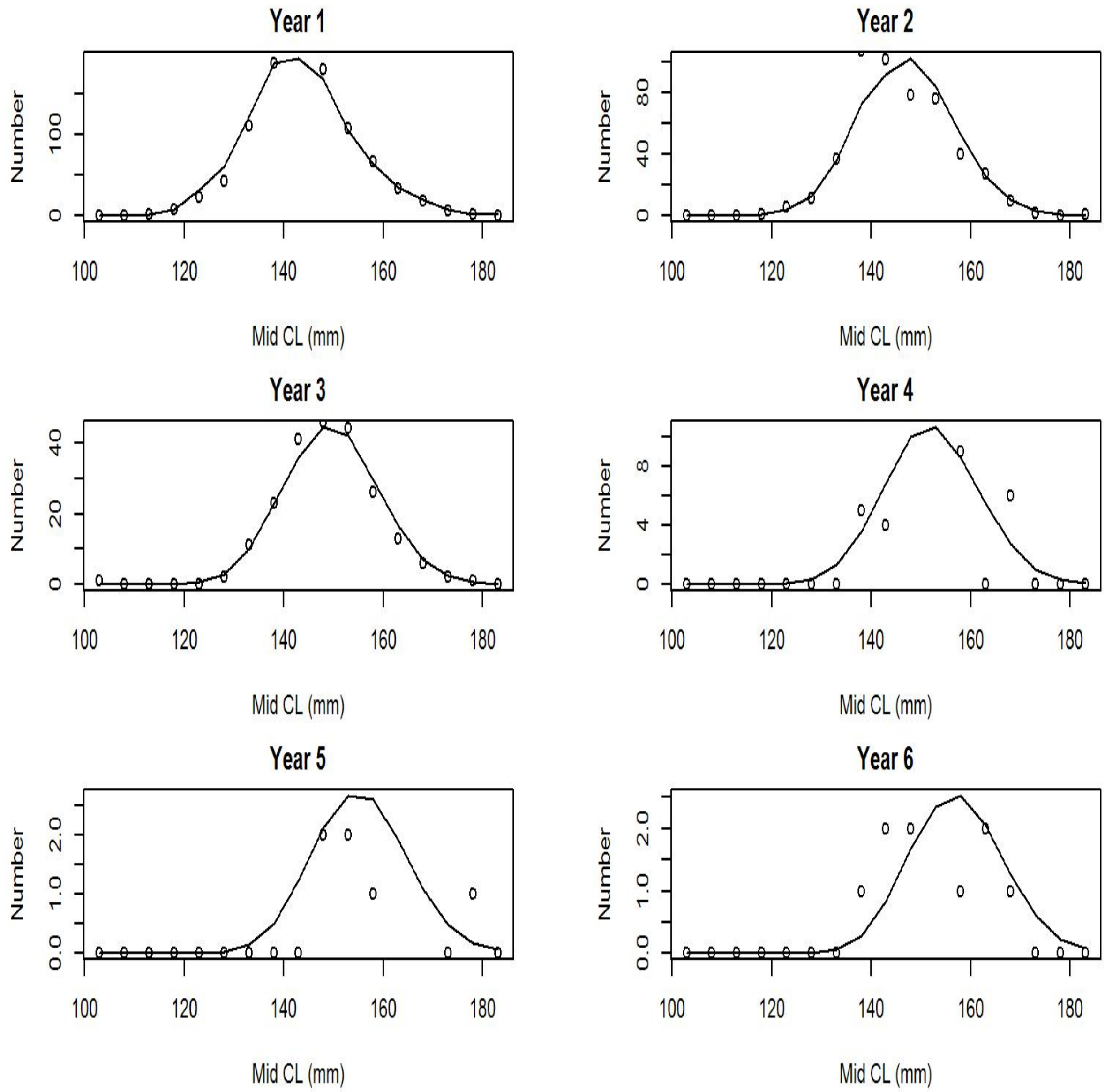


Figure 13. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 post tagging under scenario 19_1 for EAG golden king crab.

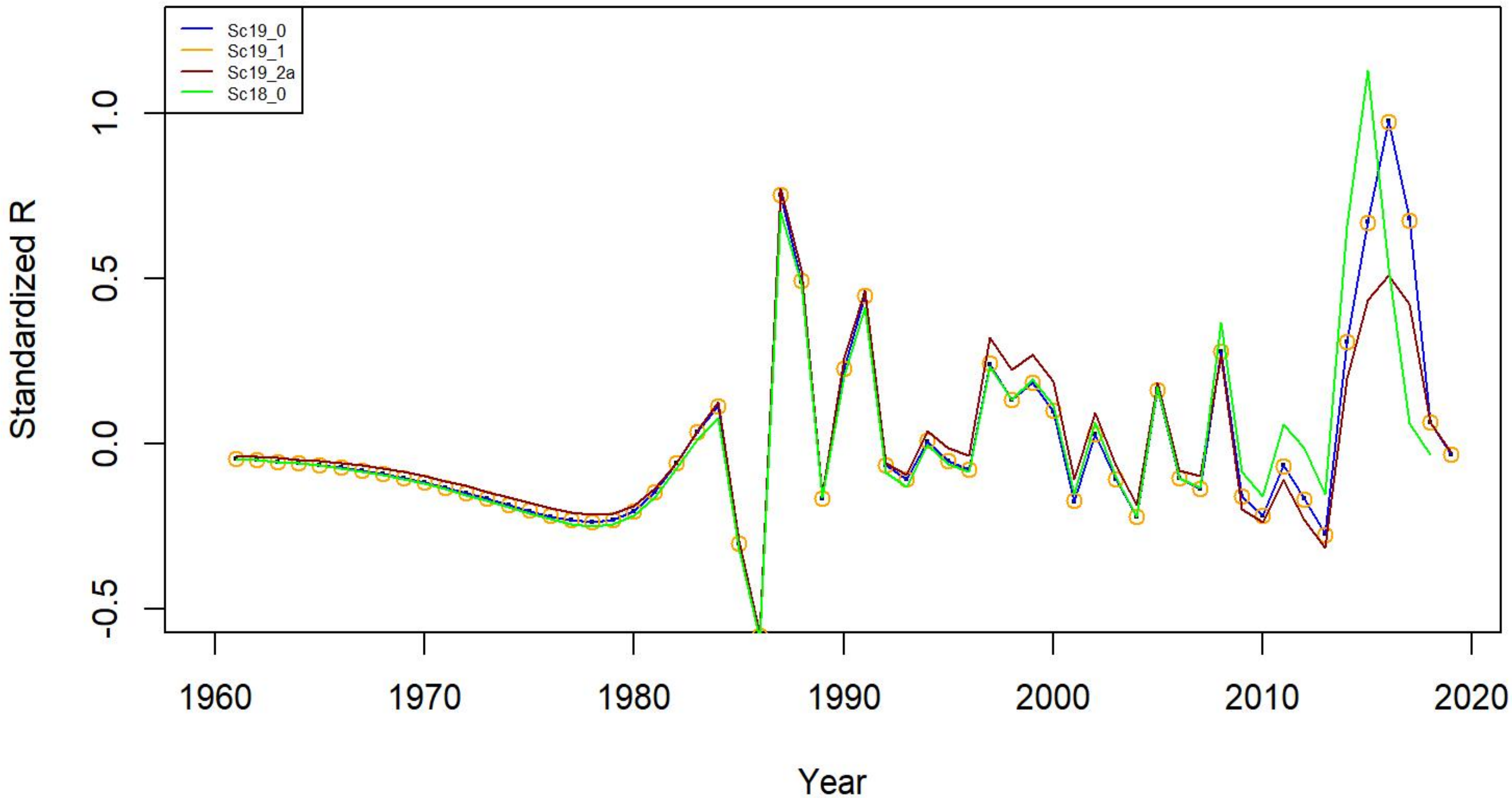


Figure 14. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2a for EAG golden king crab data, 1961–2019. The numbers of recruits are standardized using (R-mean R)/mean R for comparing different scenarios' results.

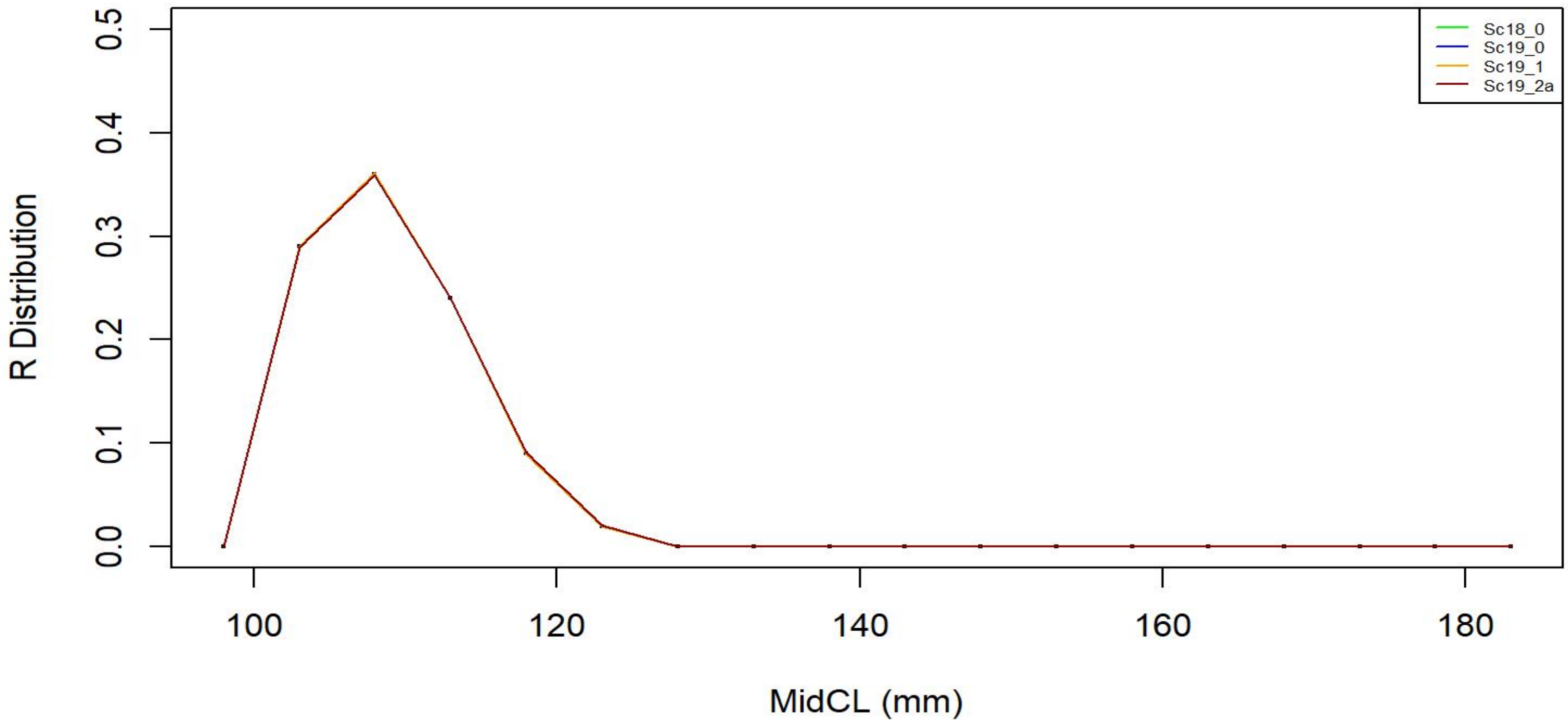


Figure 15. Recruit size distribution to the assessment model under scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2a for EAG golden king crab.

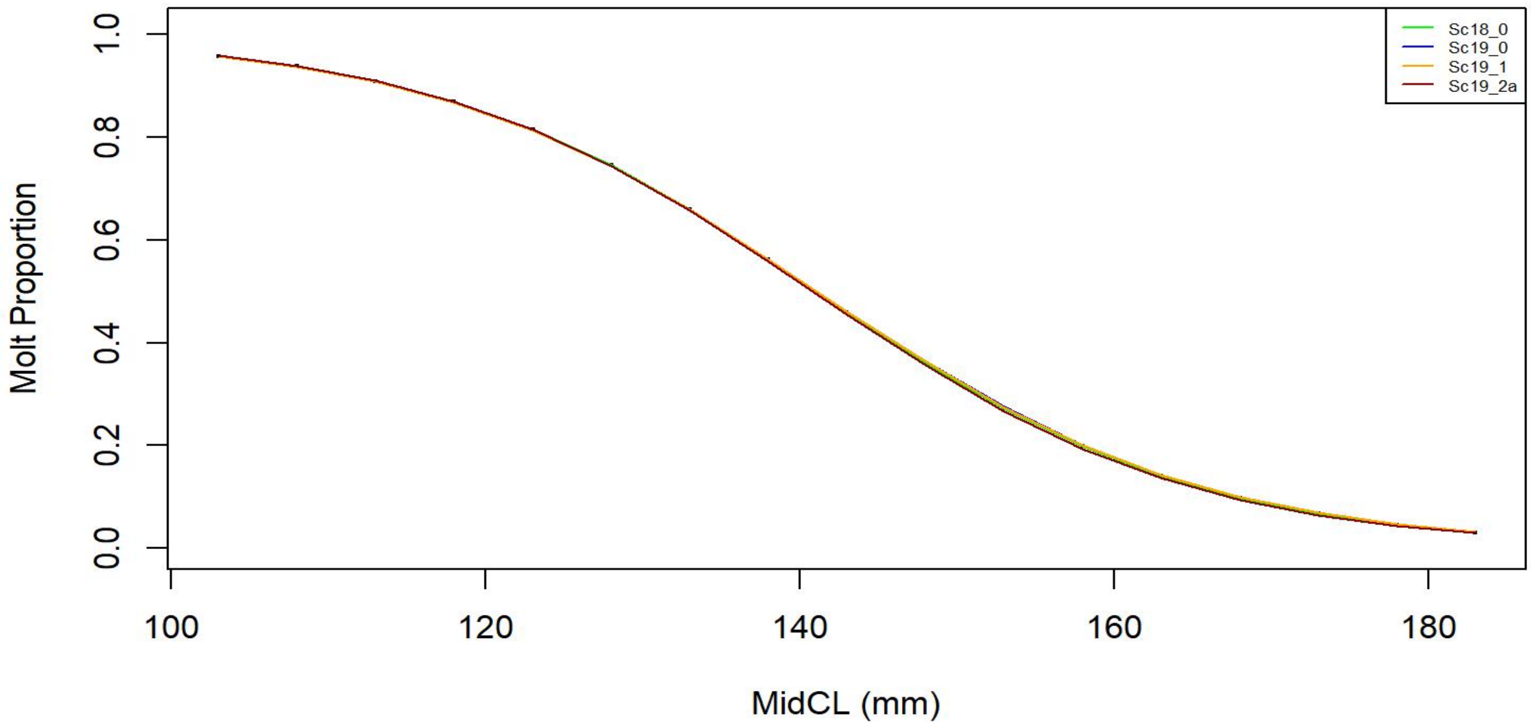


Figure 16. Estimated molt probability vs. carapace length of golden king crab for scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2a for EAG golden king crab.

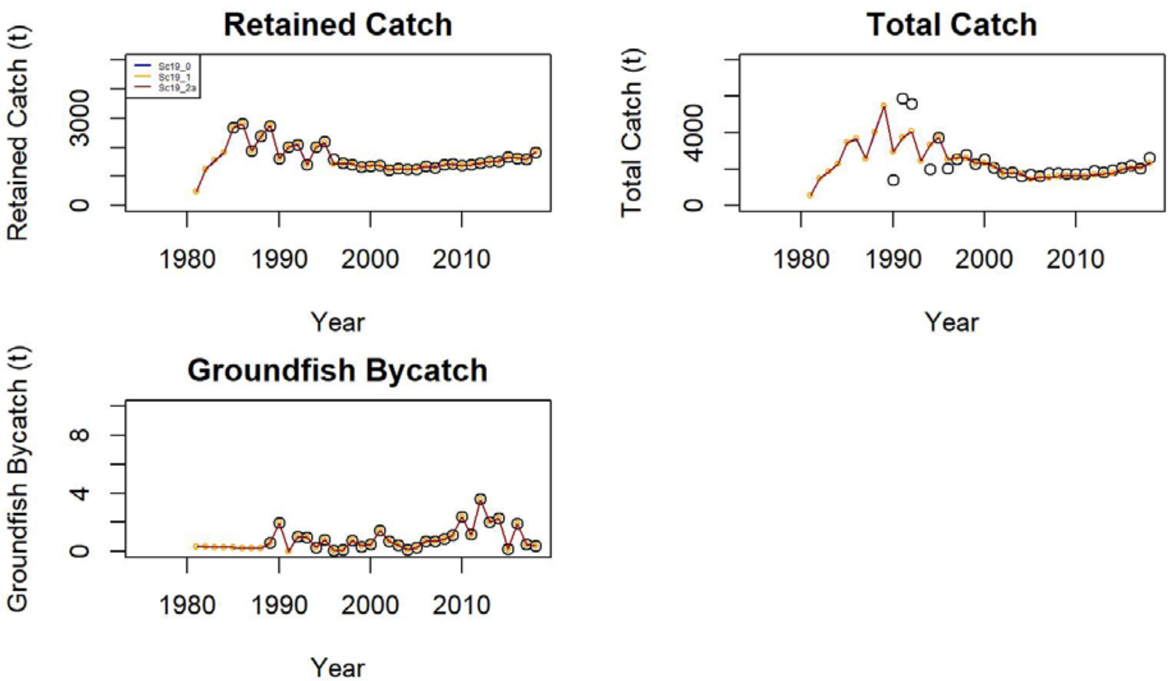


Figure 17. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right in), and groundfish bycatch (bottom left) of golden king crab for scenarios 19_0, 19_1, and 19_2a fits in EAG, 1981/82–2018/19.

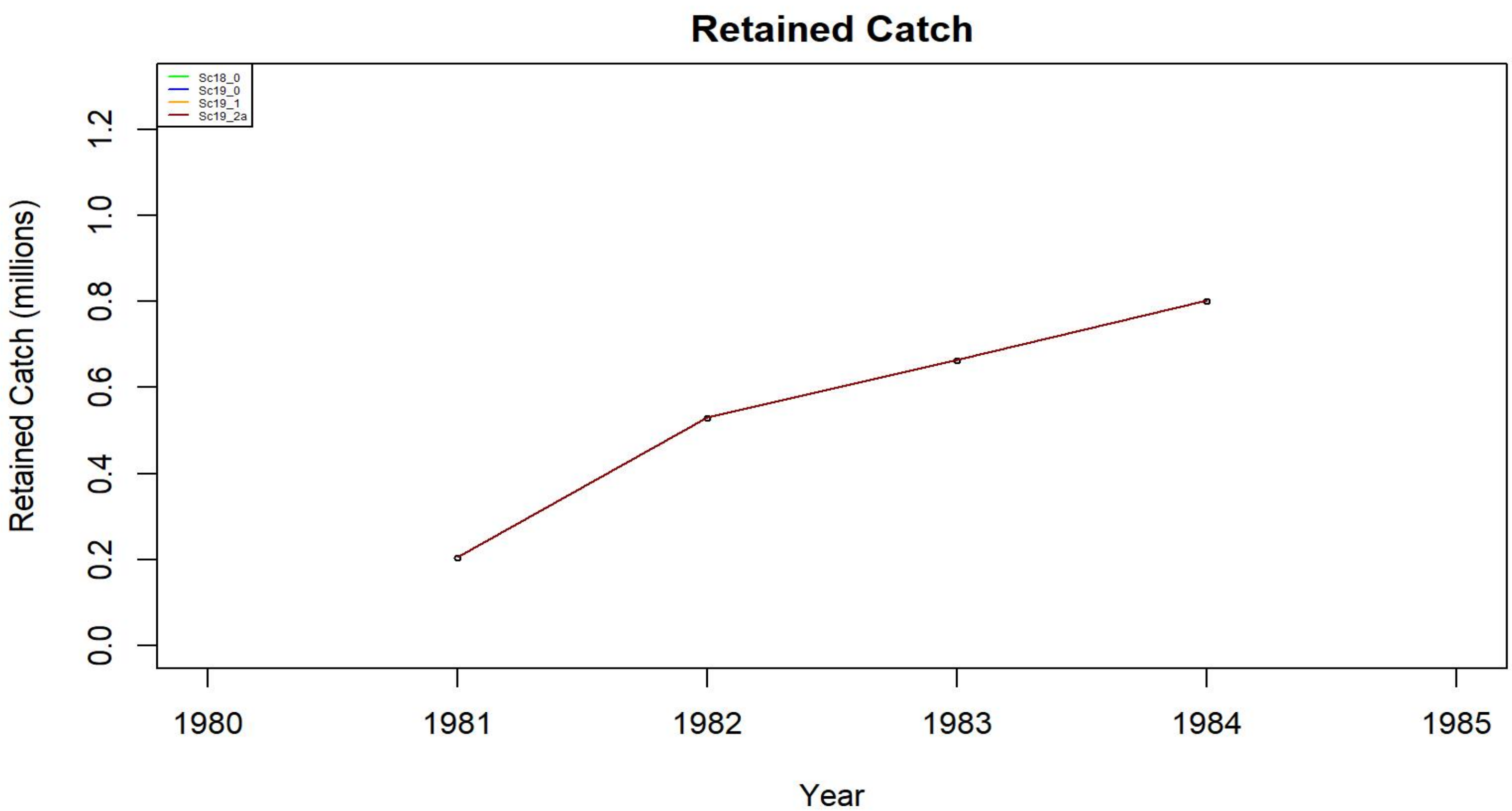


Figure 18. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2a for golden king crab fits in the EAG, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period were in number of crabs.

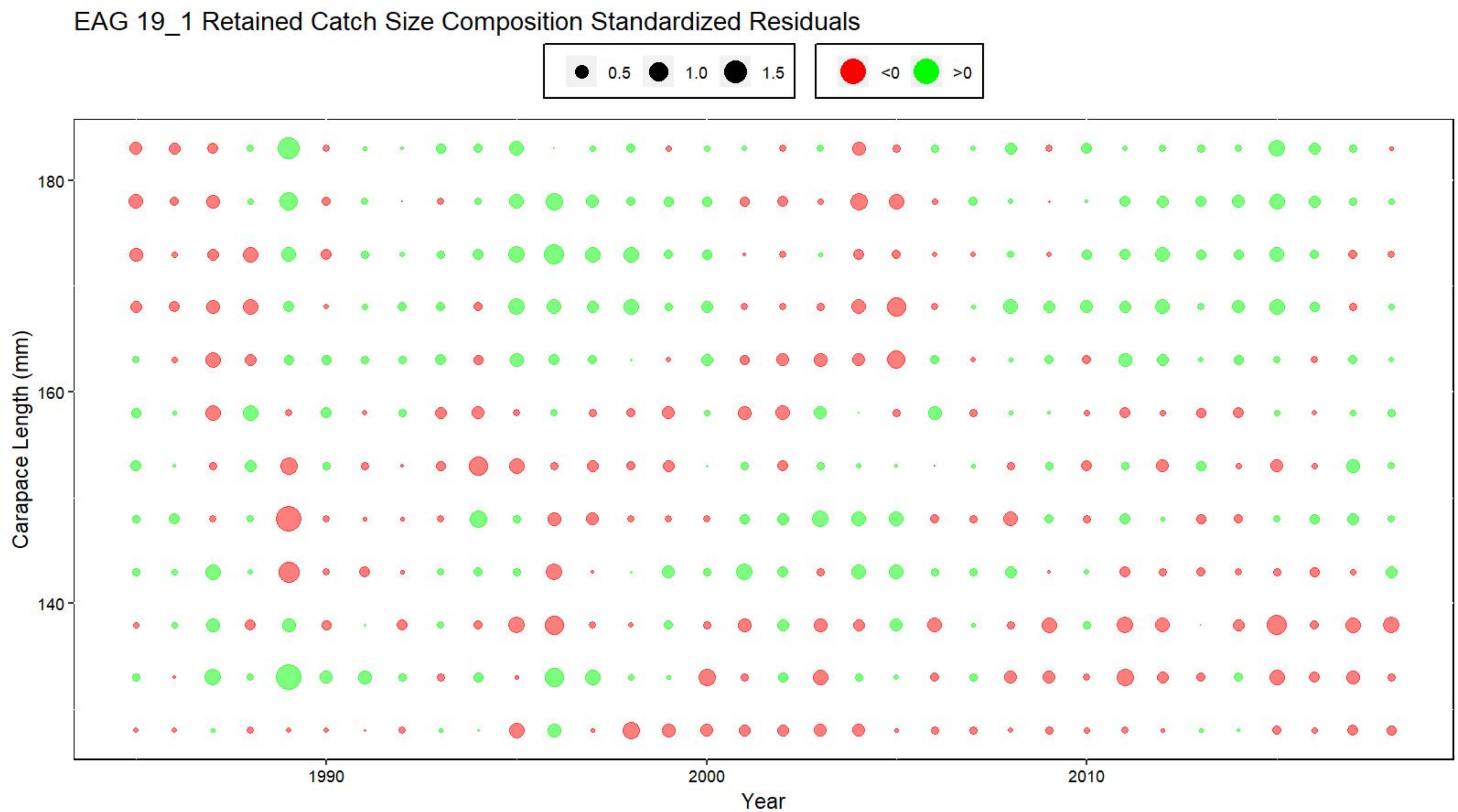


Figure 19. Bubble plot of standardized residuals of retained catch length composition for scenario 19_1 fit for EAG golden king crab, 1985/86–2018/19. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

Figure 20. Bubble plot of standardized residuals of total catch length composition for scenario 19_1 fit for EAG golden king crab, 1990/91–2018/19. 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.

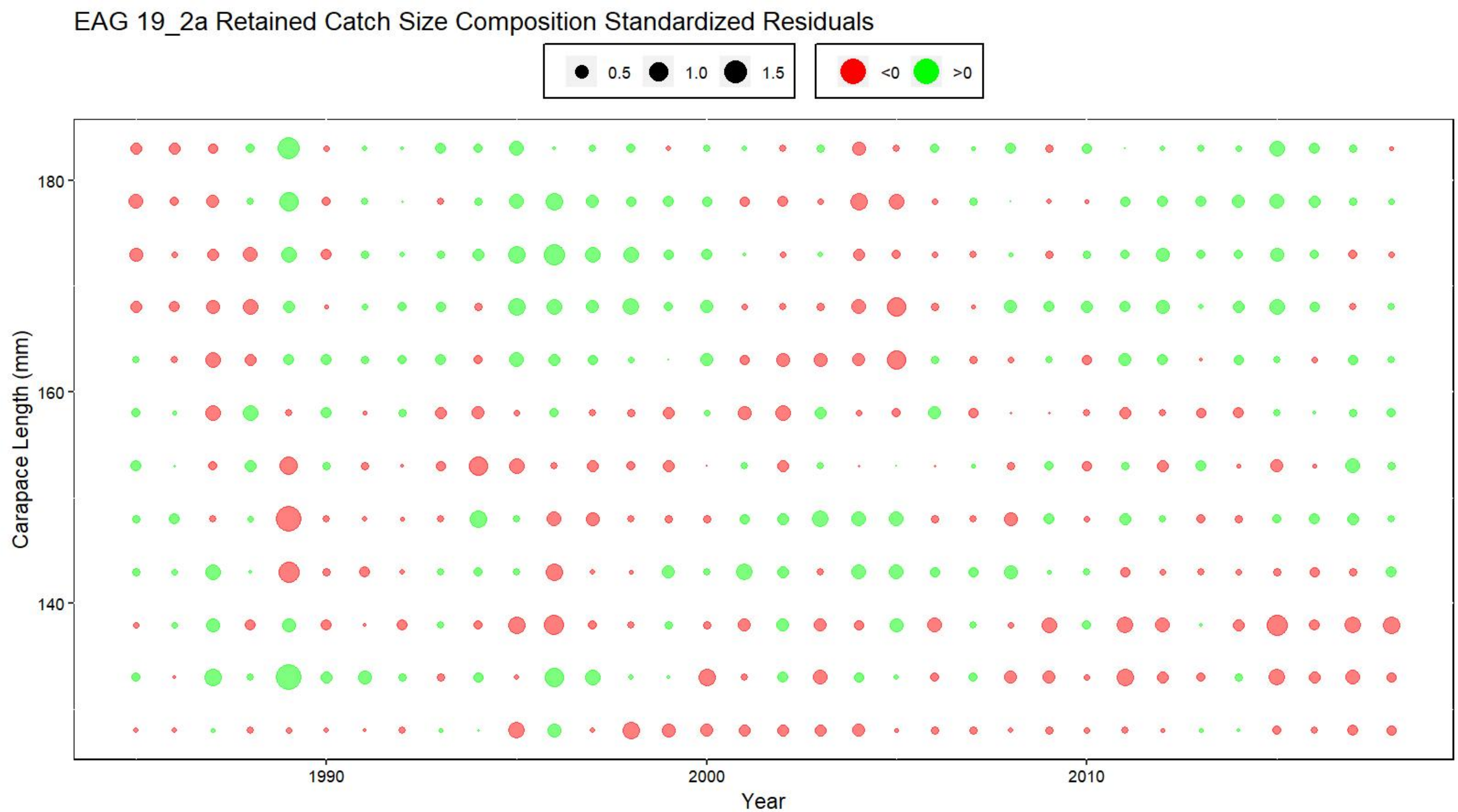


Figure 21. Bubble plot of standardized residuals of retained catch length composition for scenario 19_2a fit for EAG golden king crab, 1985/86–2018/19. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

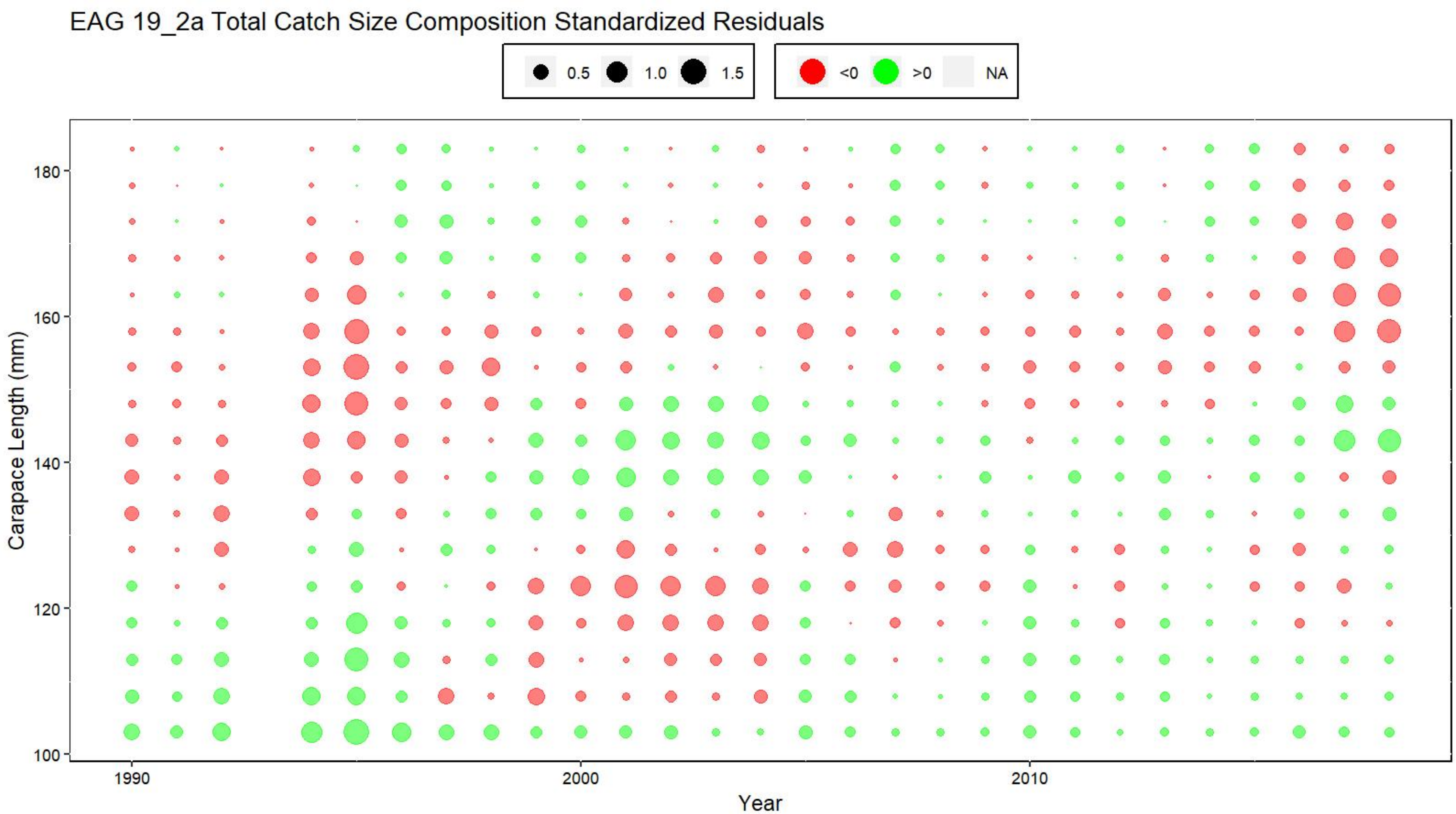
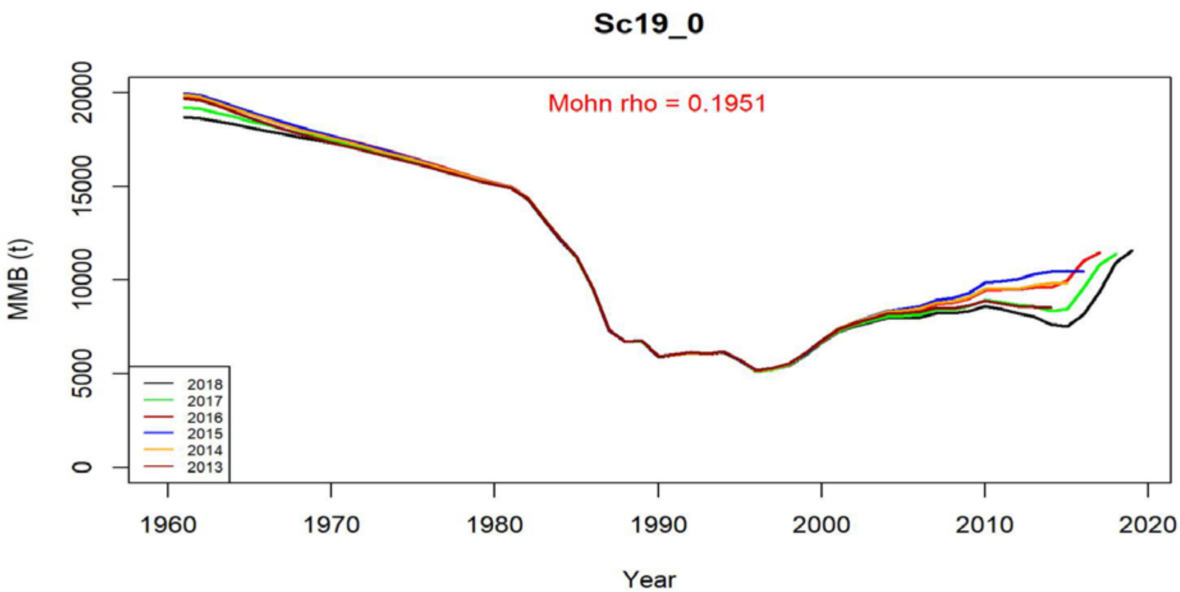
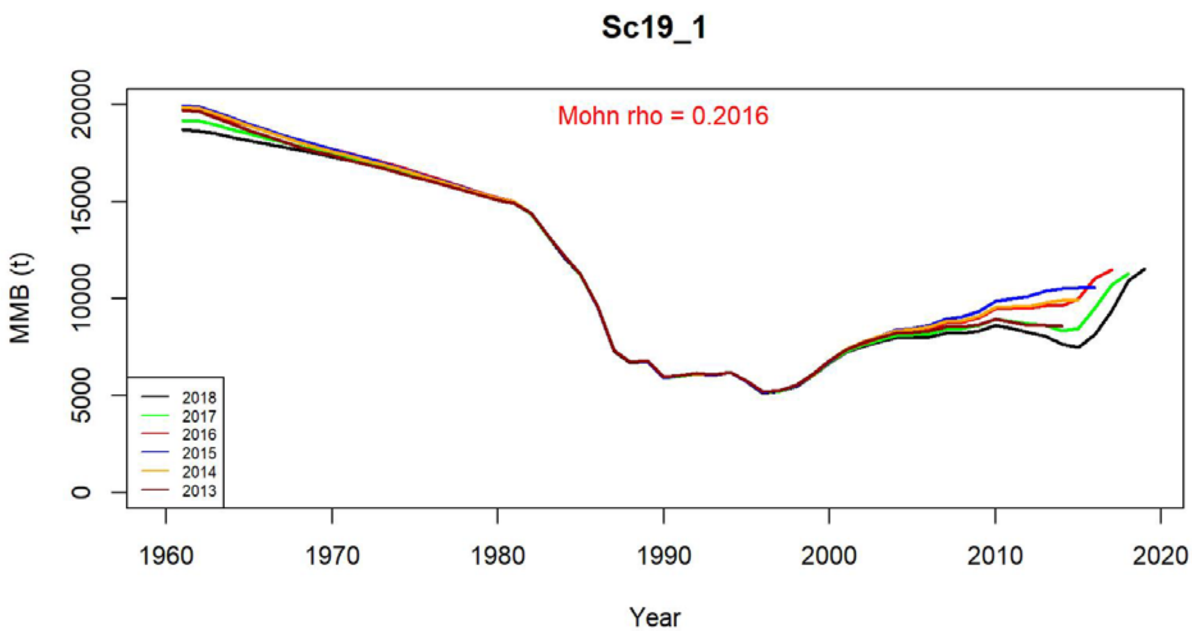


Figure 22. Bubble plot of standardized residuals of total catch length composition for scenario 19_2a fit for EAG golden king crab, 1990/91–2018/19. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Sc19_0
Mohn rho = 0.1951
MMB (t)
Year
2018
2017
2016
2015
2014
2013


Sc19_1
Mohn rho = 0.2016
MMB (t)
Year
2018
2017
2016
2015
2014
2013

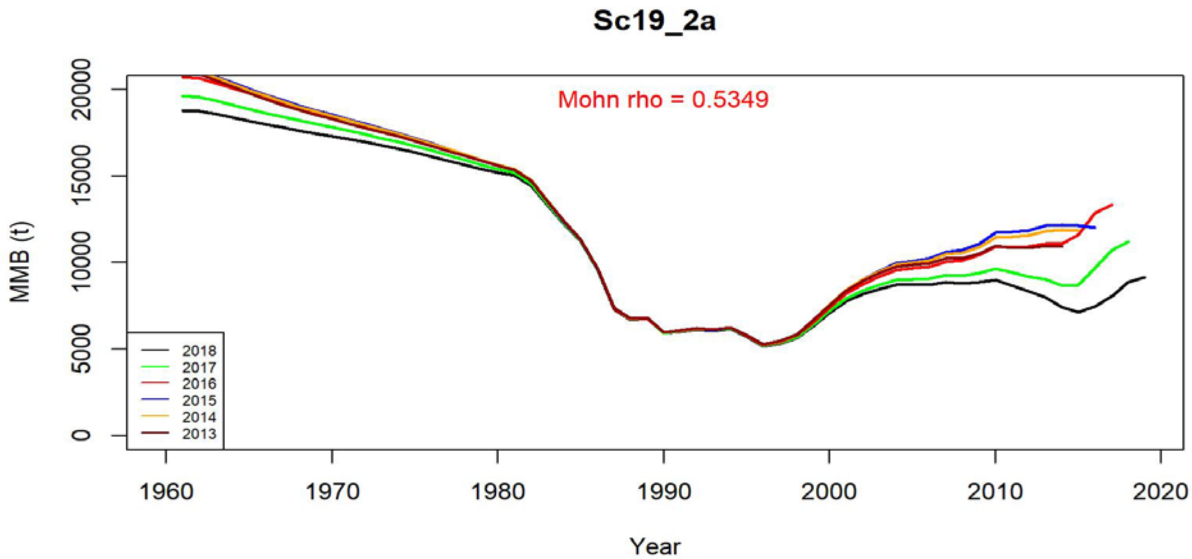


Figure 23. Retrospective fits of MMB by the model following removal of terminal year data under scenarios 19_0, 19_1 and 19_2a for golden king crab in the EAG, 1960/61–2018/19.

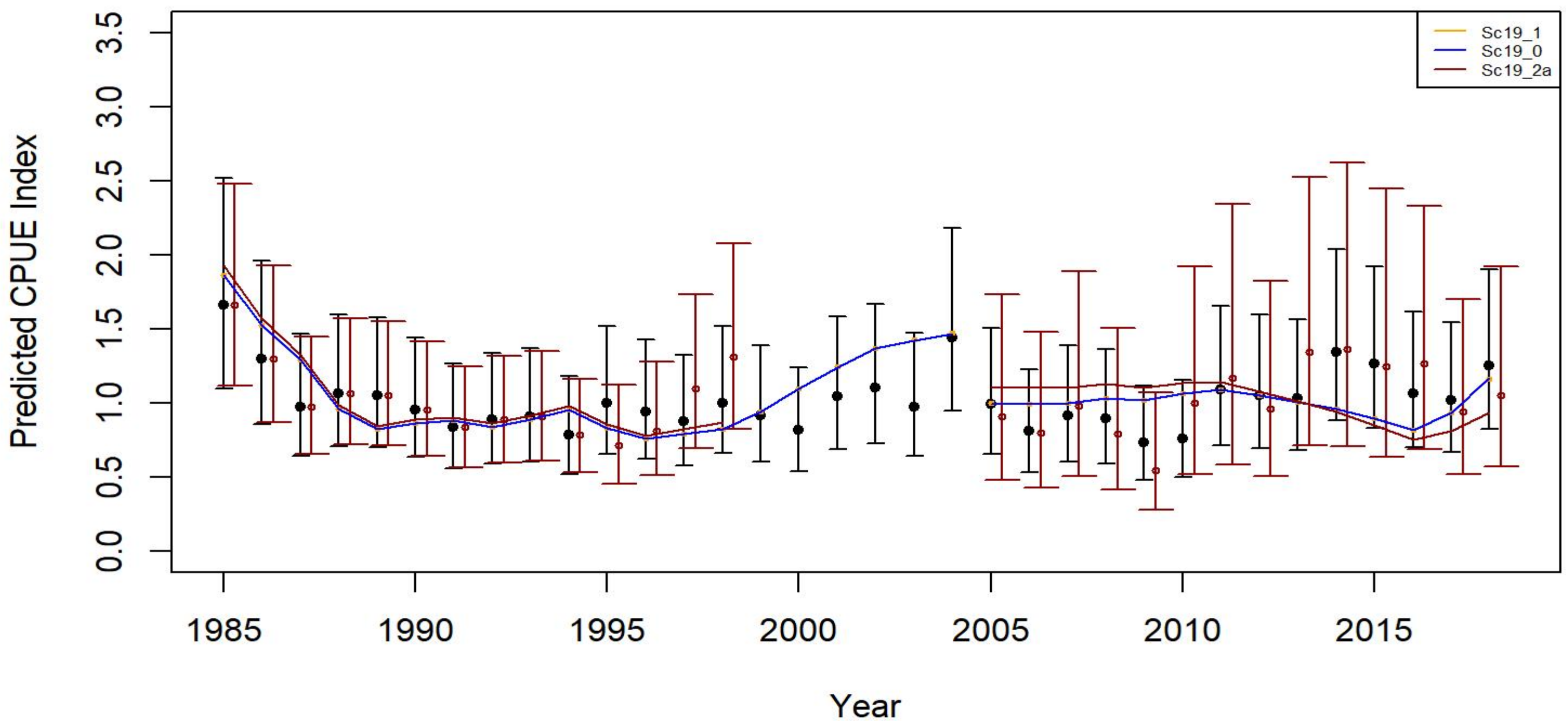


Figure 24. Comparison of input CPUE indices (closed circles with +/- 2 SE for Sc19_1 and Sc19_2a) with predicted CPUE indices (colored solid lines) under scenarios 19_0, 19_1, and 19_2a for EAG golden king crab data, 1985/86–2018/19. Model estimated additional standard error was added to each input standard error.

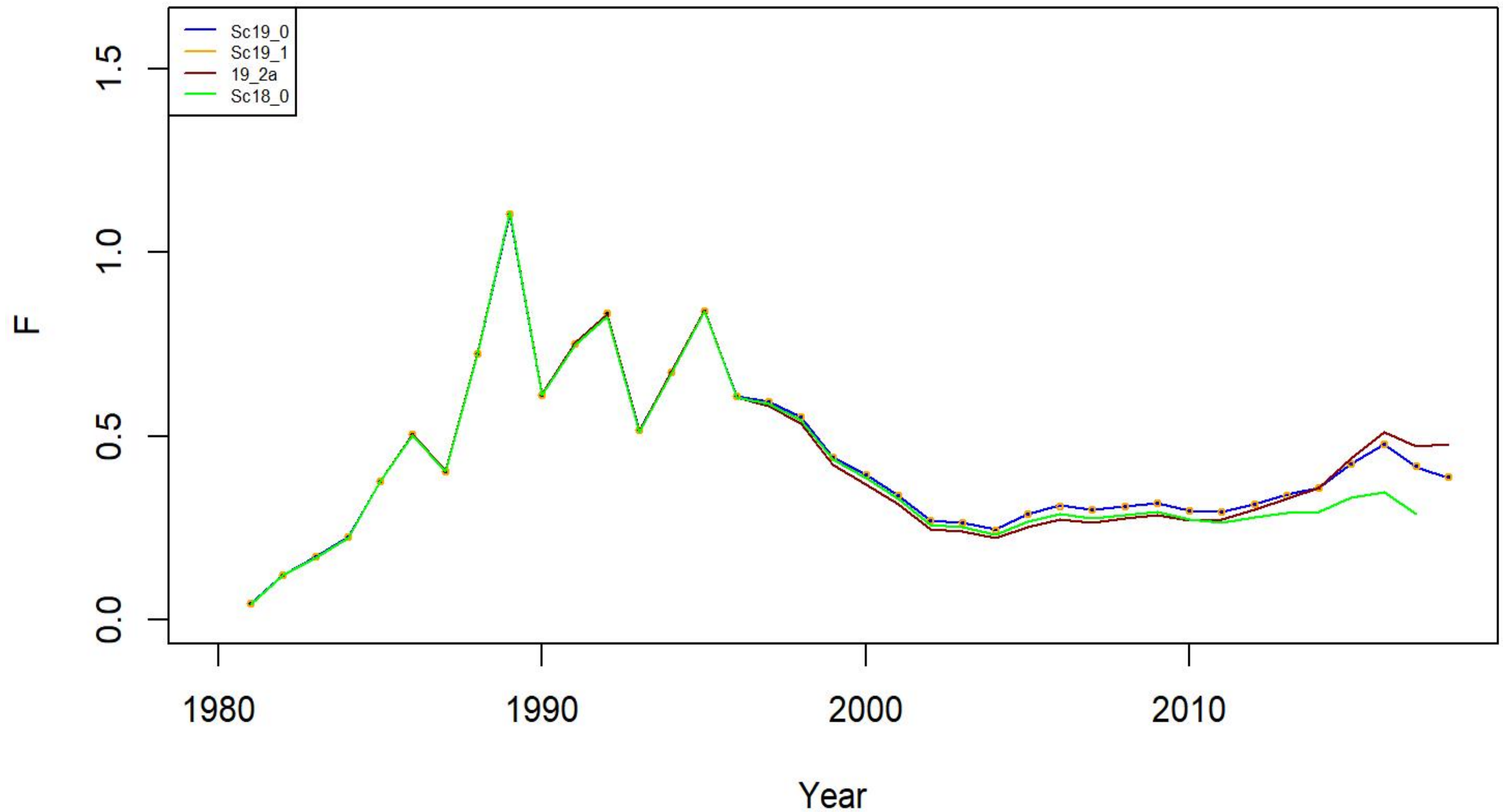
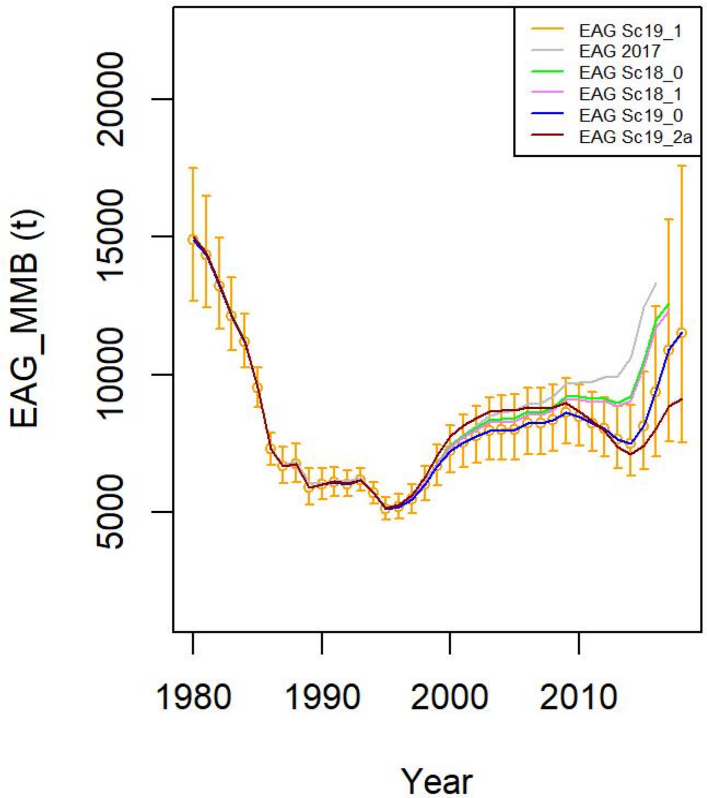


Figure 25. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios 18_0, 19_0, 19_1, and 19_2a model fits in the EAG, 1981/82–2018/19.



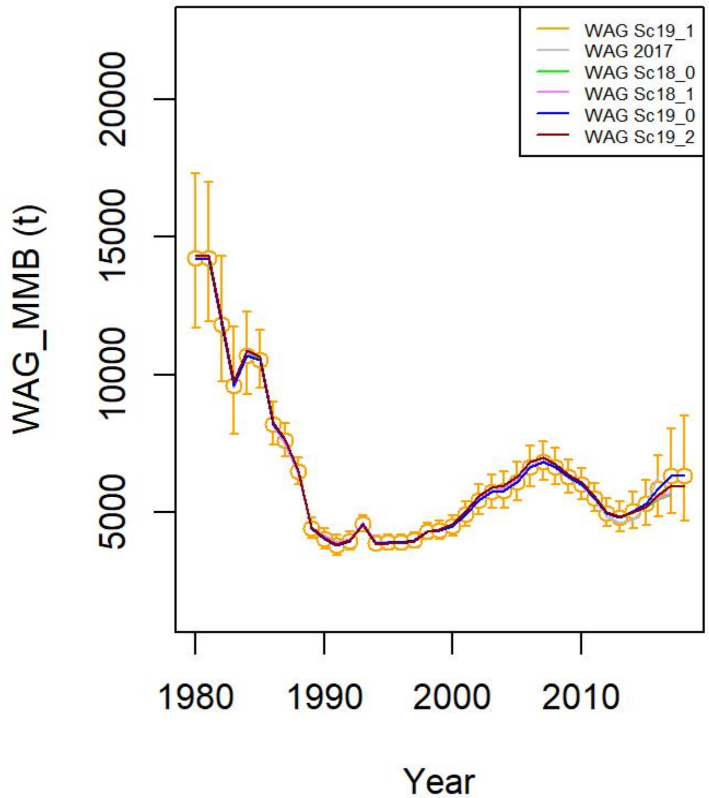


Figure 26. Trends in golden king crab mature male biomass for scenarios EAG 2017 (up to 2016/17 data), 18_0 and 18_1 (up to 2017/18 data), and 19_0, 19_1, 19_2a (EAG), or 19_2 (WAG) (up to 2018/19 data) fits to EAG (left) and WAG (right) data, 1960/61–2018/19. Scenario 19_1 estimate has two standard error confidence limits.

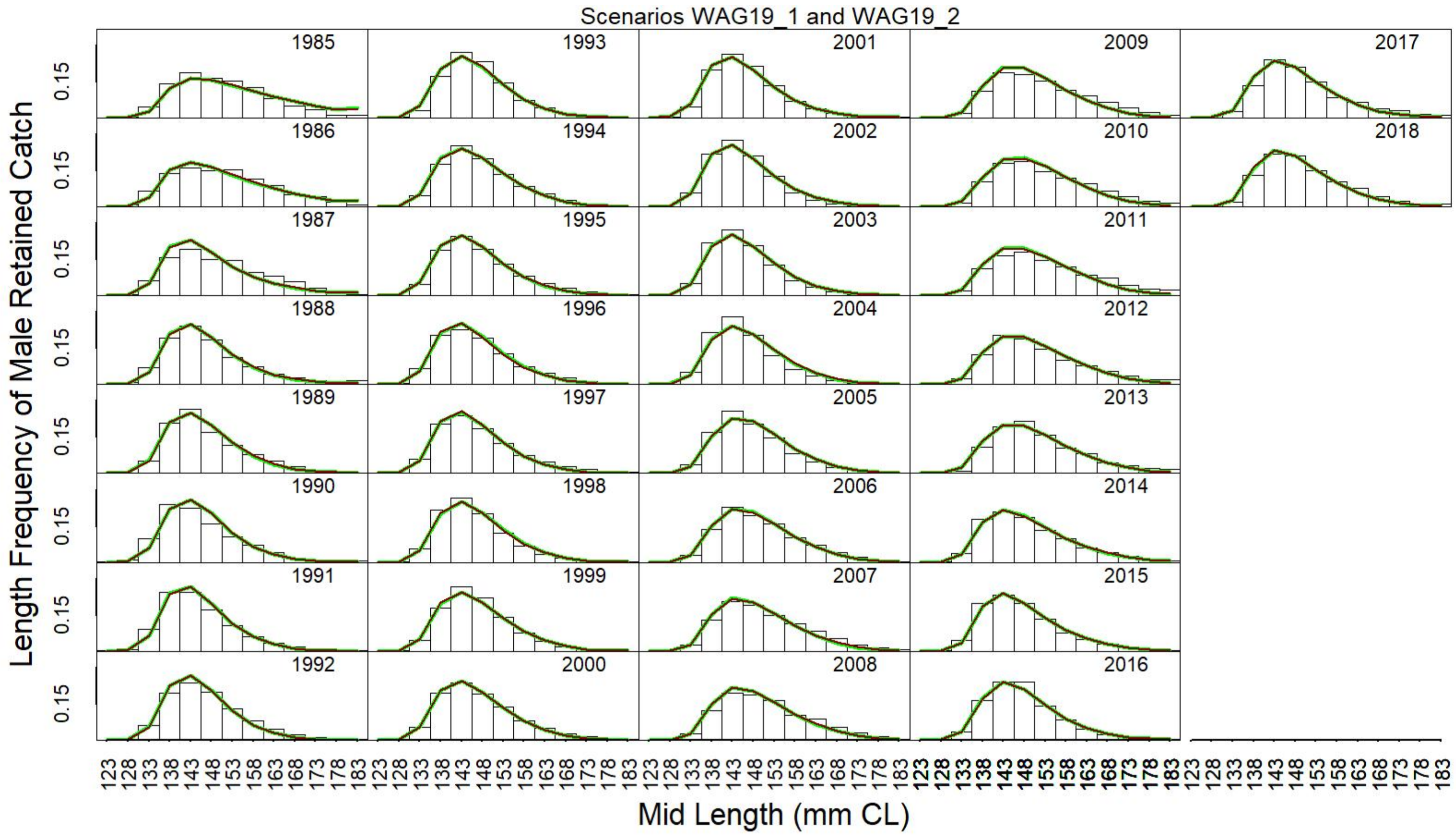


Figure 27. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions under scenarios 19_1 (green line) and 19_2 (dark red line) for golden king crab in the WAG, 1985/86 to 2018/19. This color scheme is used in all other graphs.

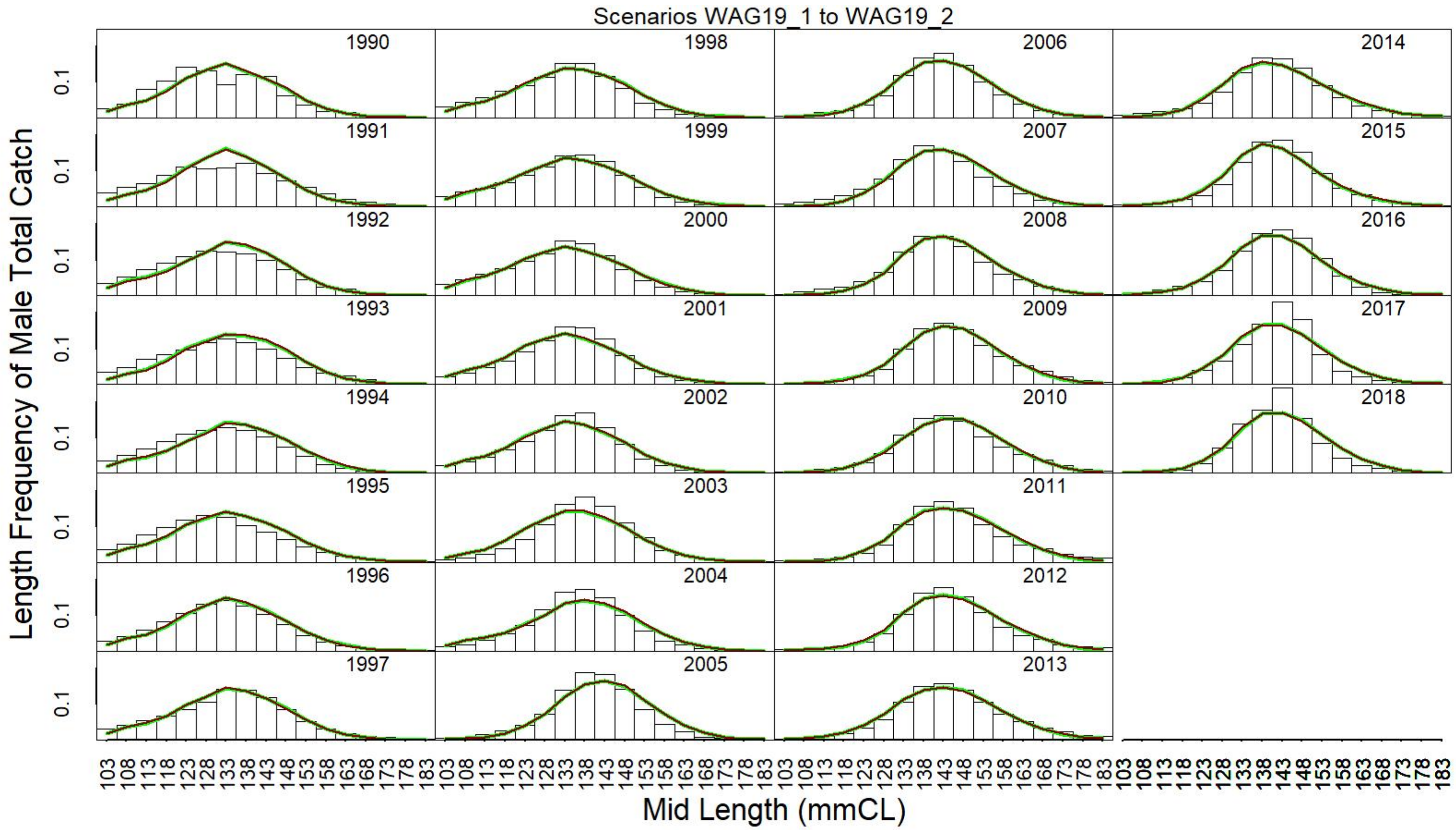


Figure 28. Predicted (line) vs. observed (bar) total catch relative length frequency distributions under scenarios 19_1 (green line) and 19_2 (dark red line) for golden king crab in the WAG, 1990/91 to 2018/19.

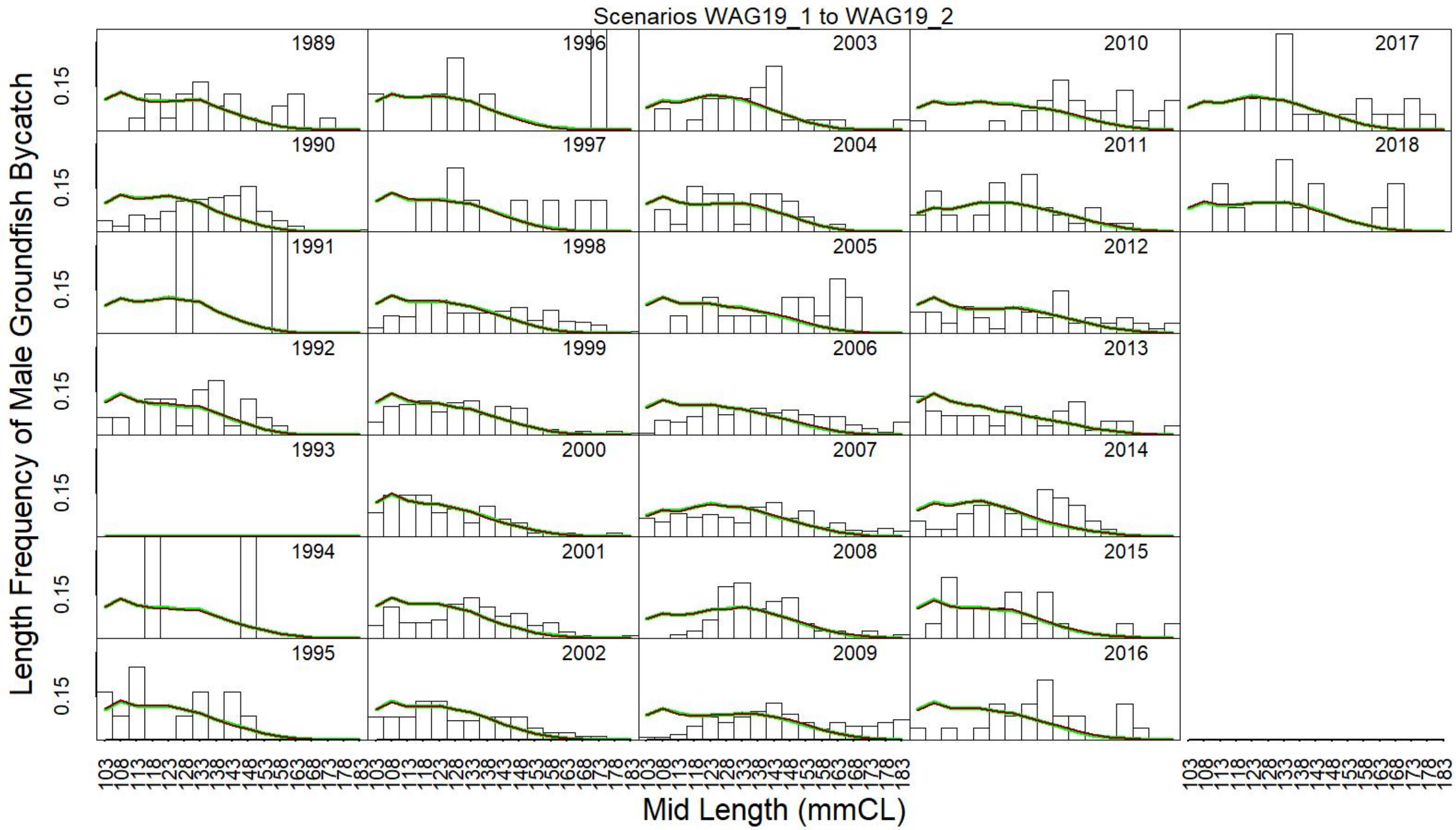


Figure 29. Predicted (line) vs. observed (bar) groundfish discarded bycatch relative length frequency distributions under scenarios 19_1 (green line) and 19_2 (dark red line) for golden king crab in the WAG, 19989/90 to 2018/19.

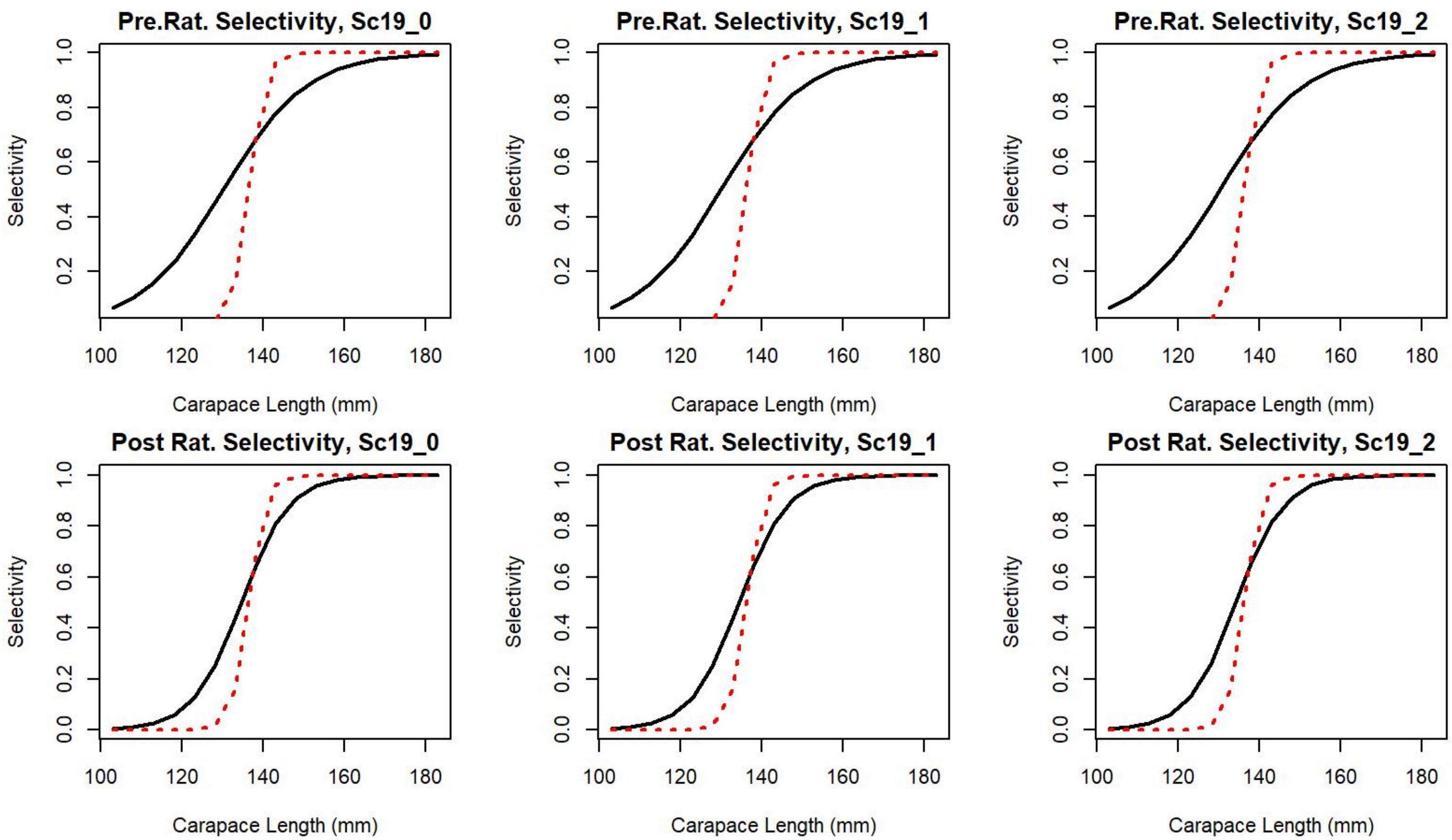


Figure 30. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios 19_0, 19_1, and 19_2 model fits to golden king crab data in the WAG.

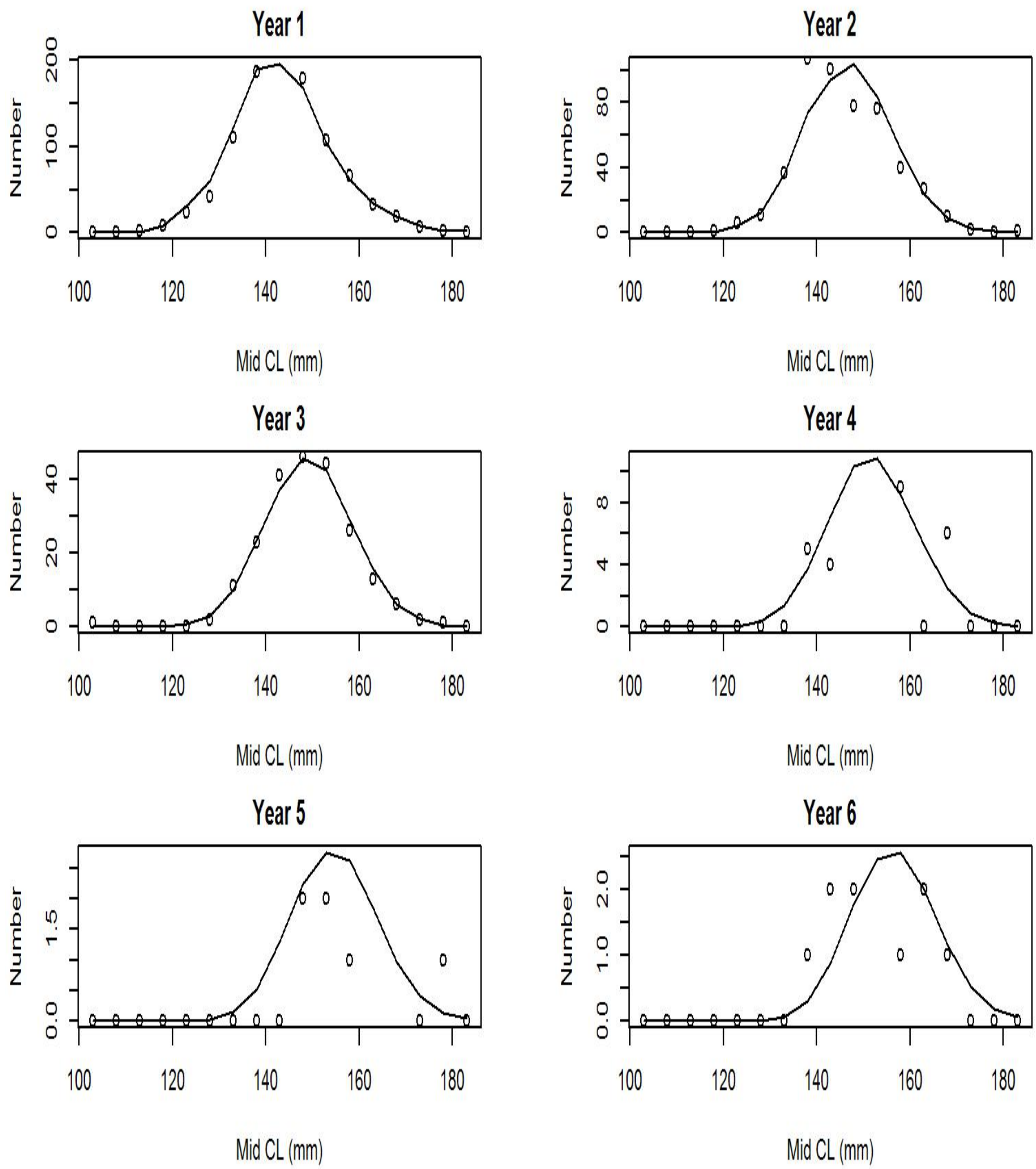


Figure 31. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 post tagging under scenario 19_1 for WAG golden king crab.

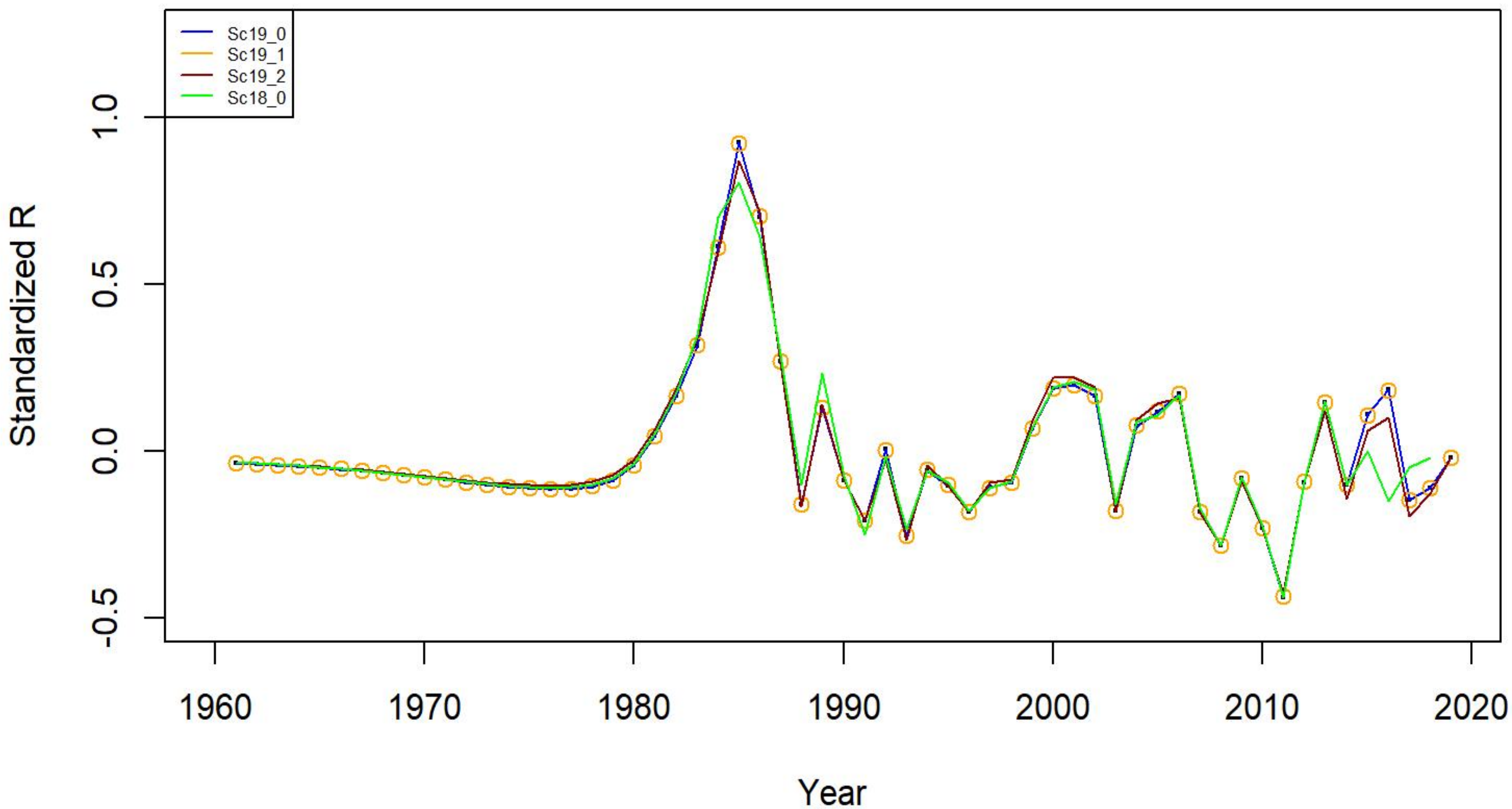


Figure 32. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2 for WAG golden king crab data, 1961–2019. The numbers of recruits are standardized using (R-mean R)/mean R for comparing different scenarios' results.

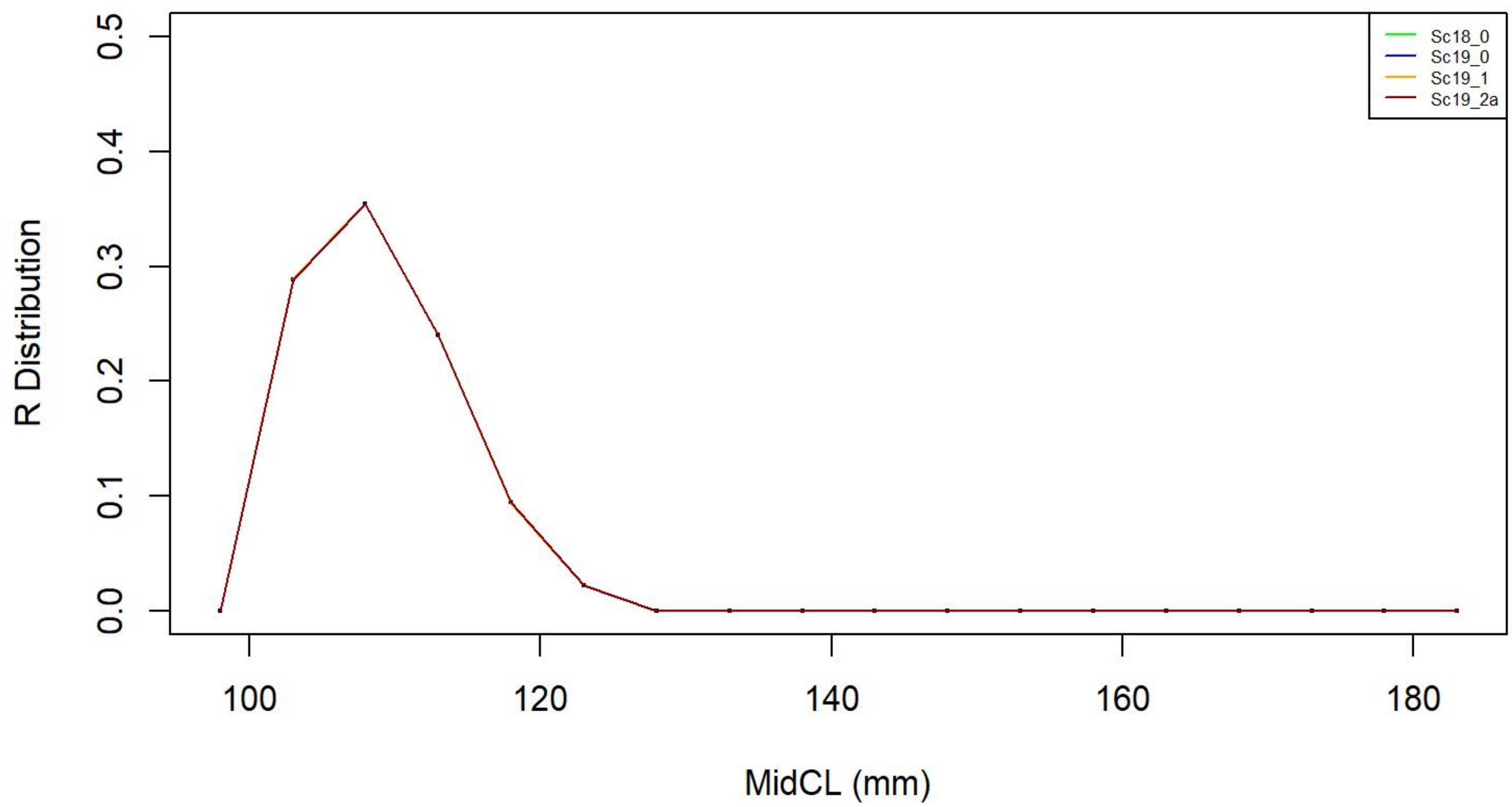


Figure 33. Recruit size distribution to the assessment model under scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2 for WAG golden king crab.

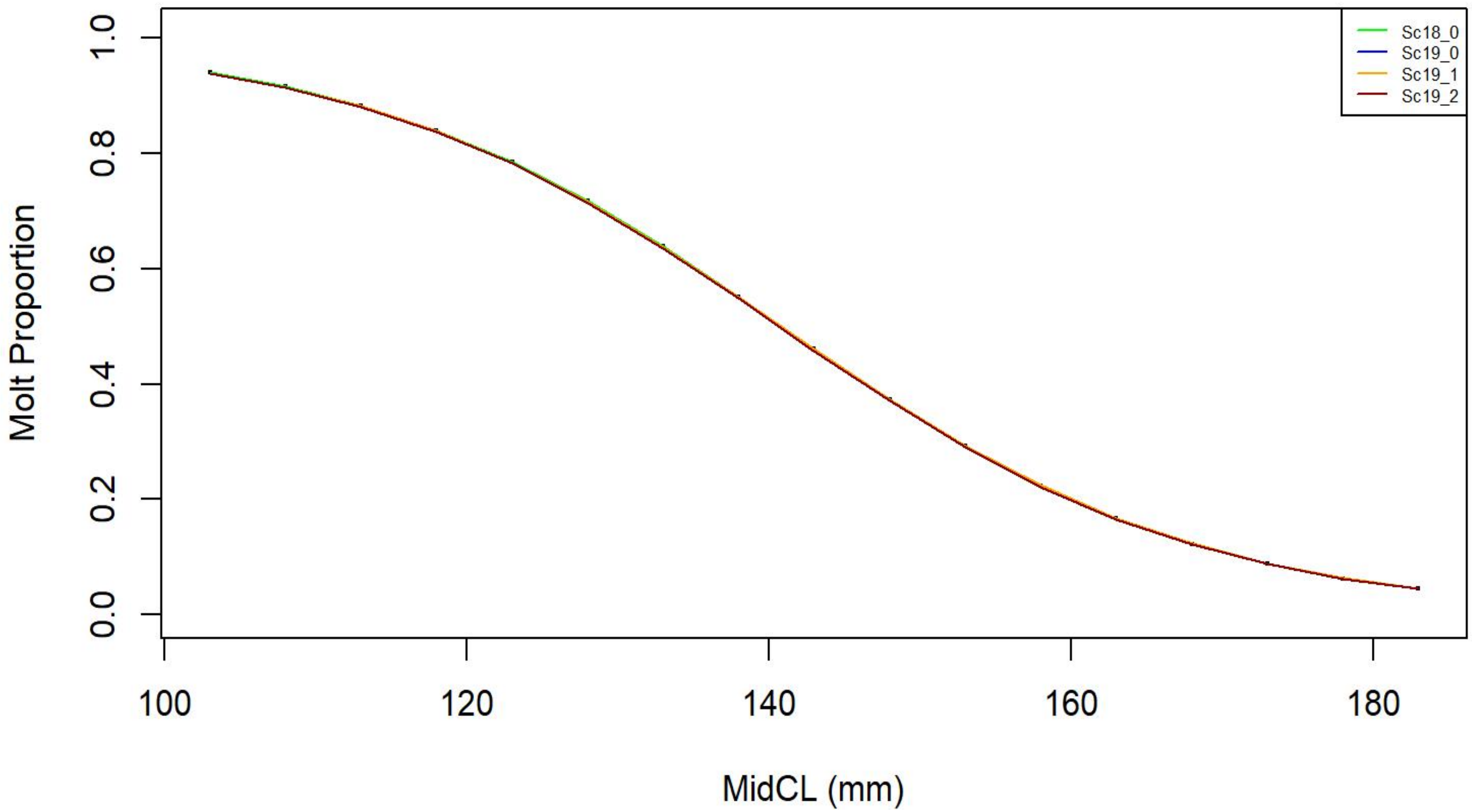


Figure 34. Estimated molt probability vs. carapace length of golden king crab for scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2 for WAG golden king crab.

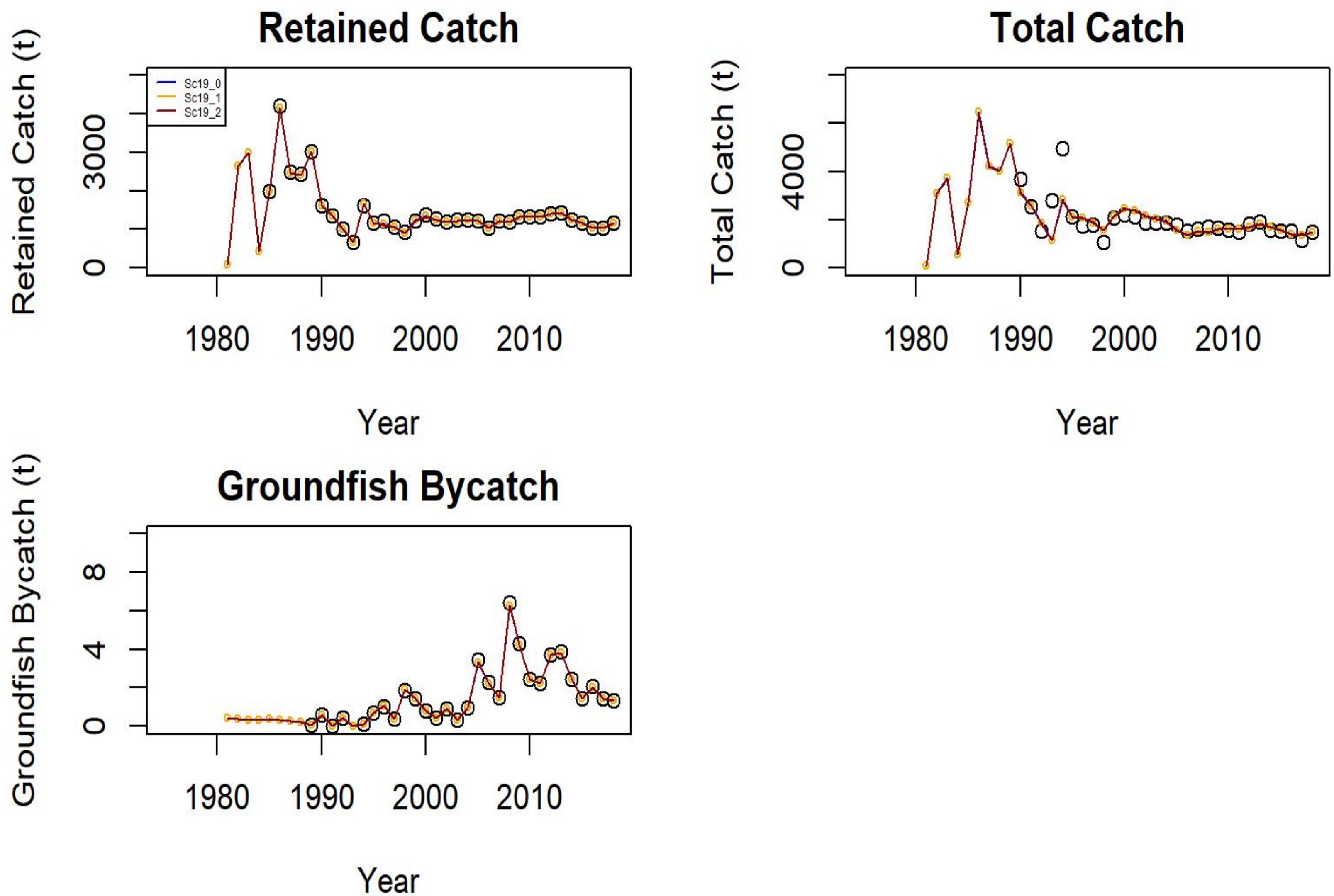


Figure 35. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right in), and groundfish bycatch (bottom left) of golden king crab for scenarios 19_0, 19_1, and 19_2 fits in WAG, 1981/82–2018/19.

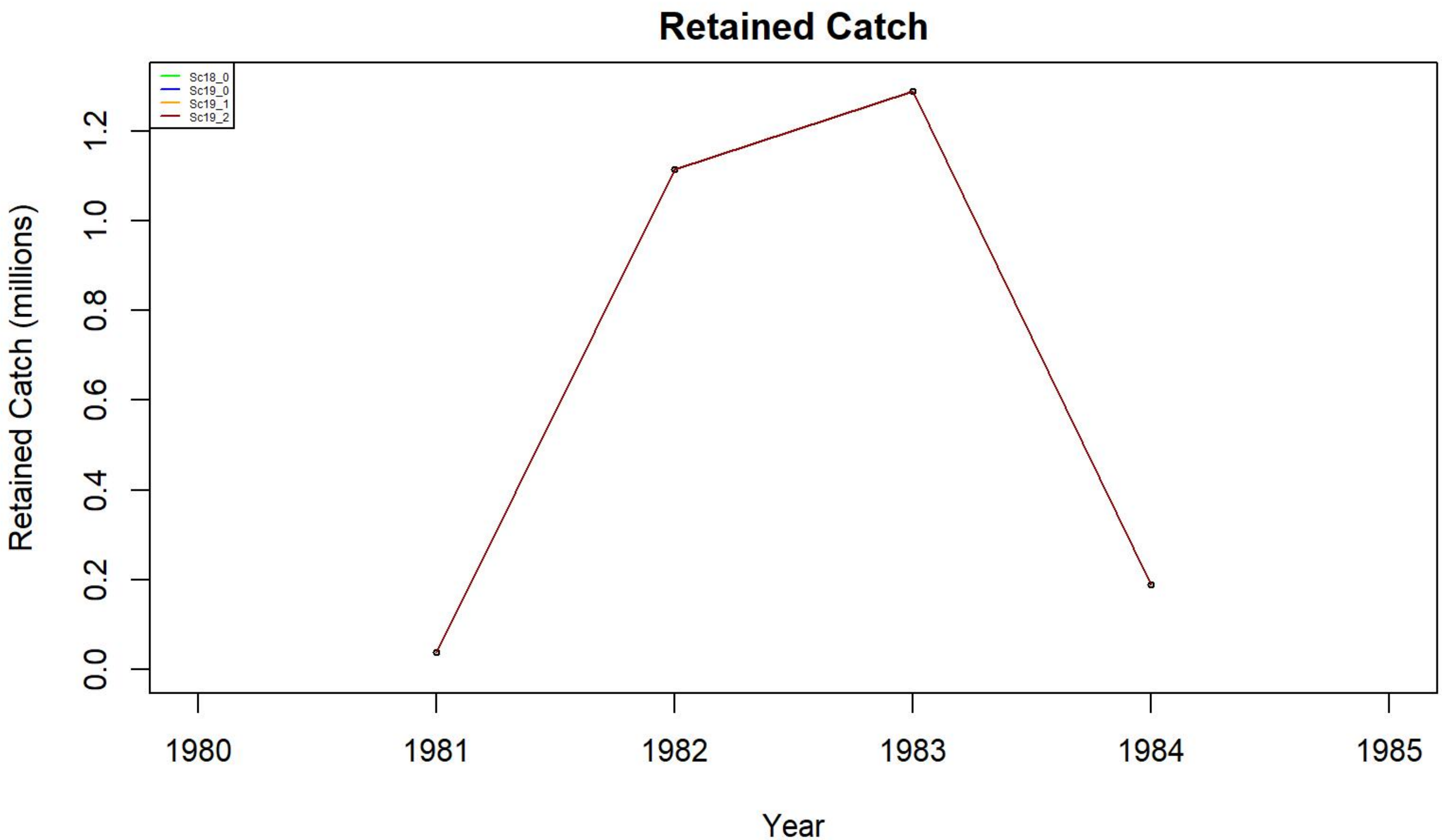


Figure 36. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios (Sc) 18_0 (up to 2017/18 data, green curve), 19_0 (up to 2018/19 data), 19_1, and 19_2 for golden king crab fits in the WAG, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period were in number of crabs.

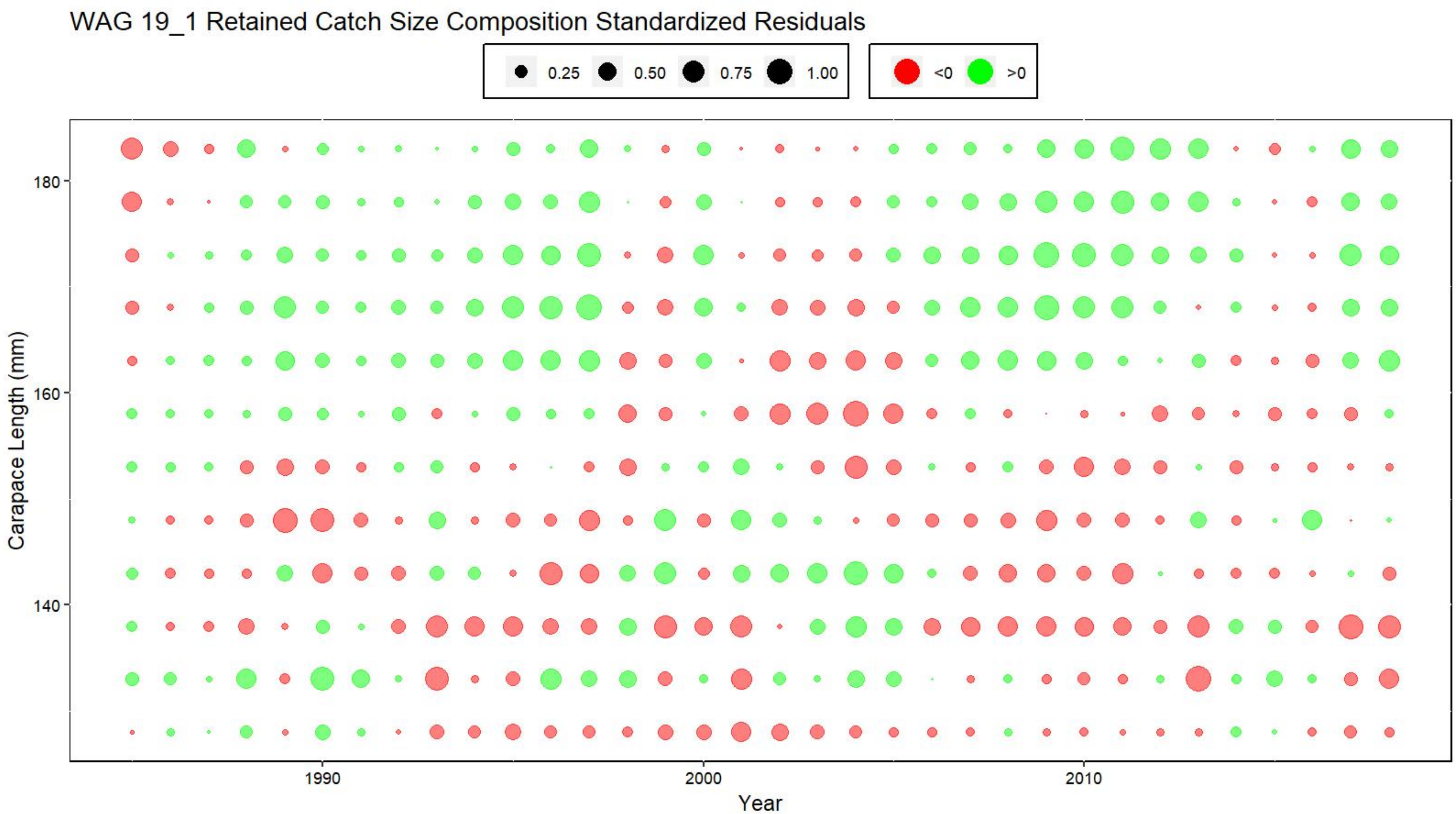


Figure 37. Bubble plot of standardized residuals of retained catch length composition for scenario 19_1 fit for WAG golden king crab, 1985/86–2018/19. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

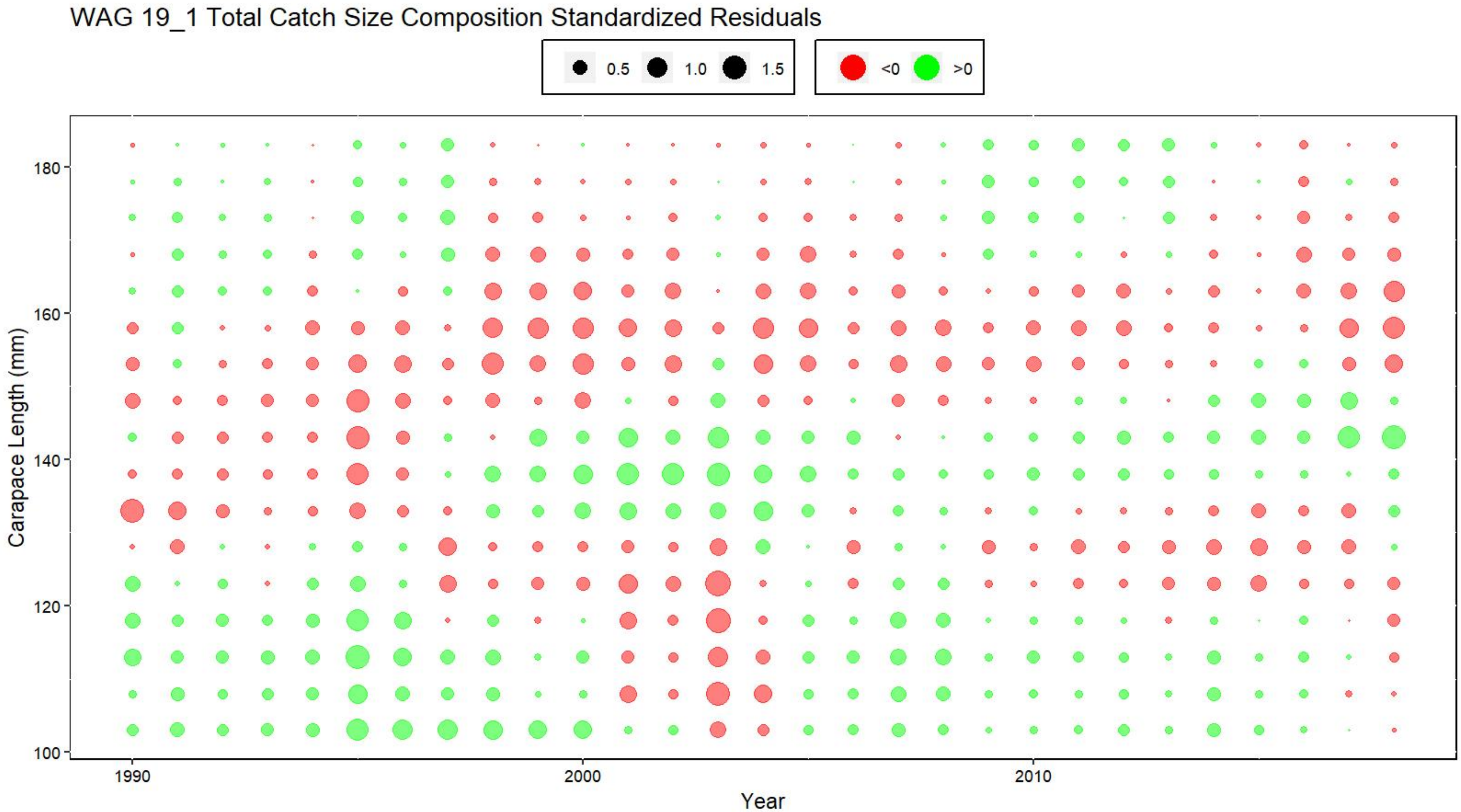


Figure 38. Bubble plot of standardized residuals of total catch length composition for scenario 19_1 fit for WAG golden king crab, 1990/91–2018/19. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

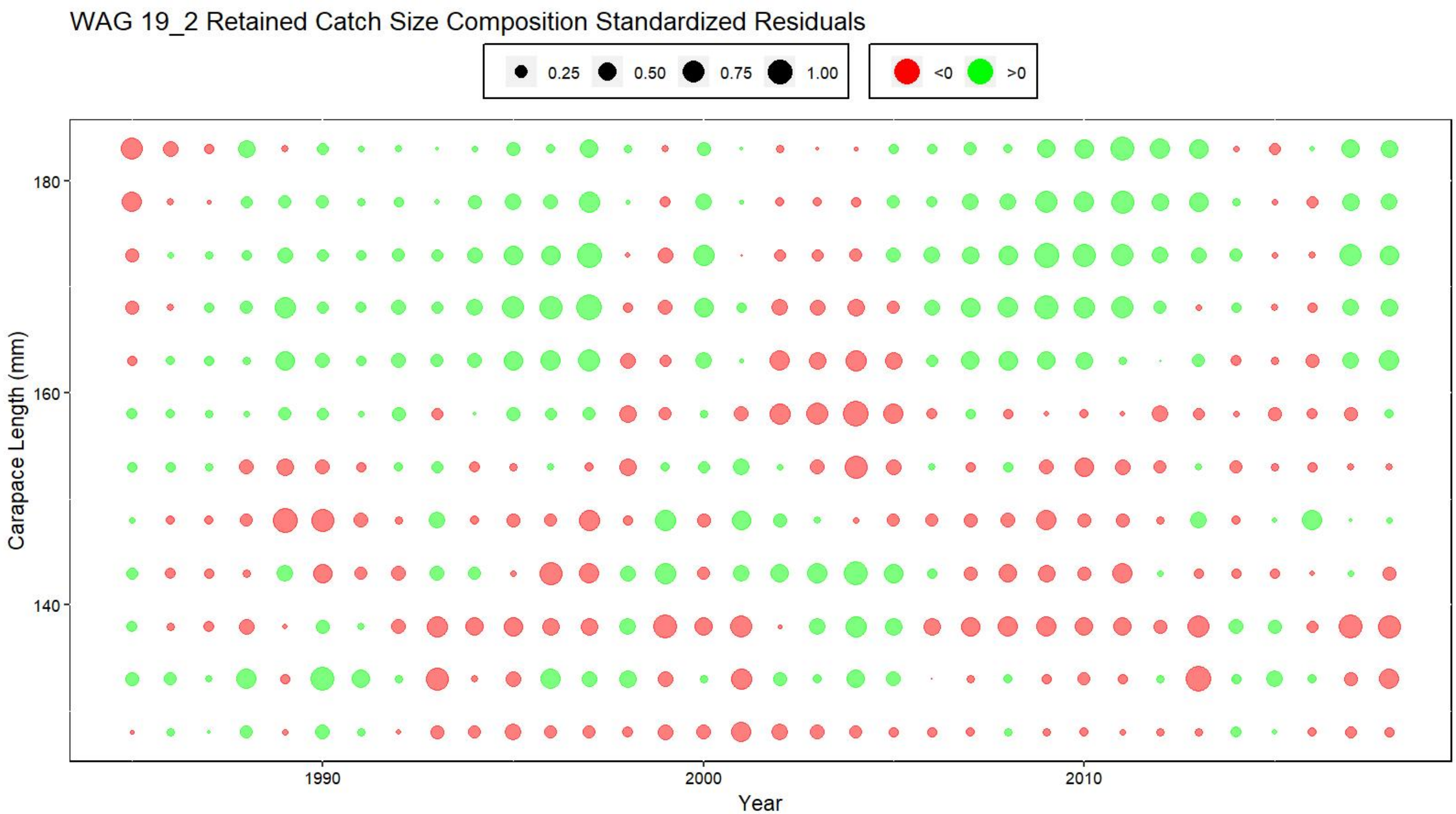


Figure 39. Bubble plot of standardized residuals of retained catch length composition for scenario 19_2 fit for WAG golden king crab, 1985/86–2018/19. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

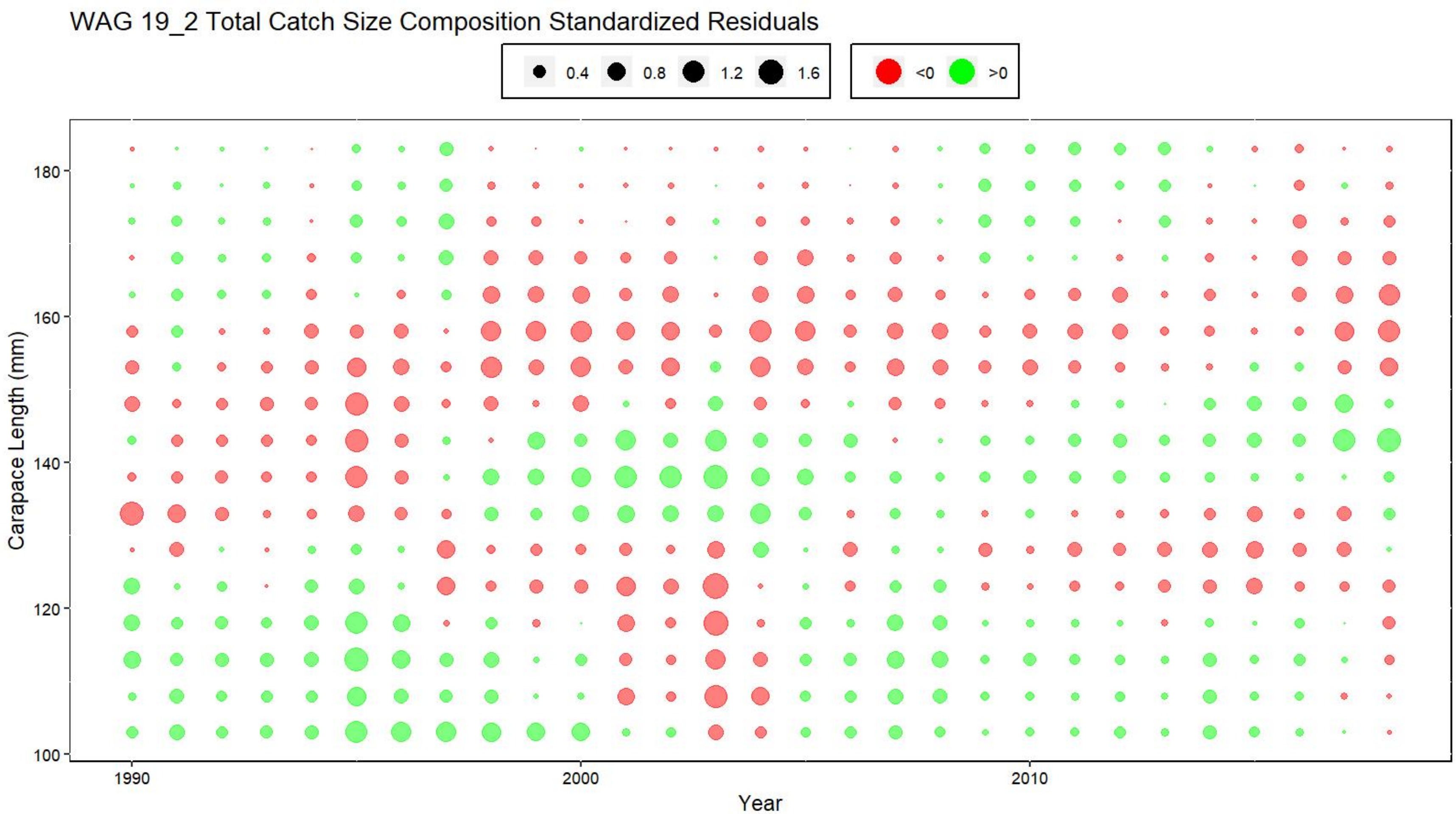
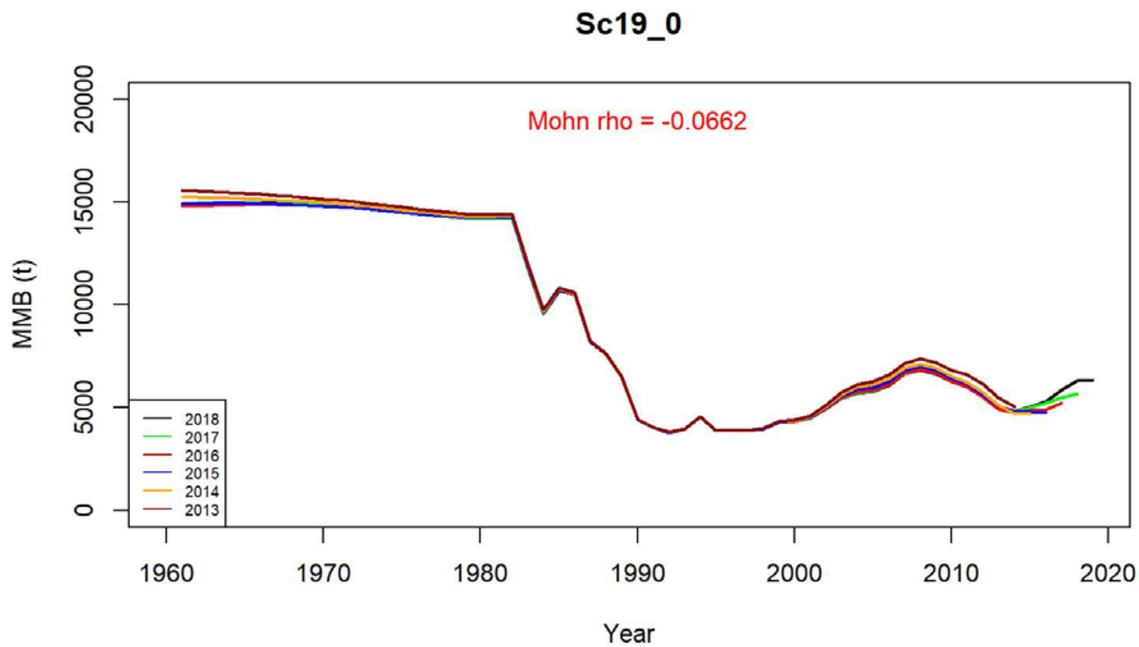
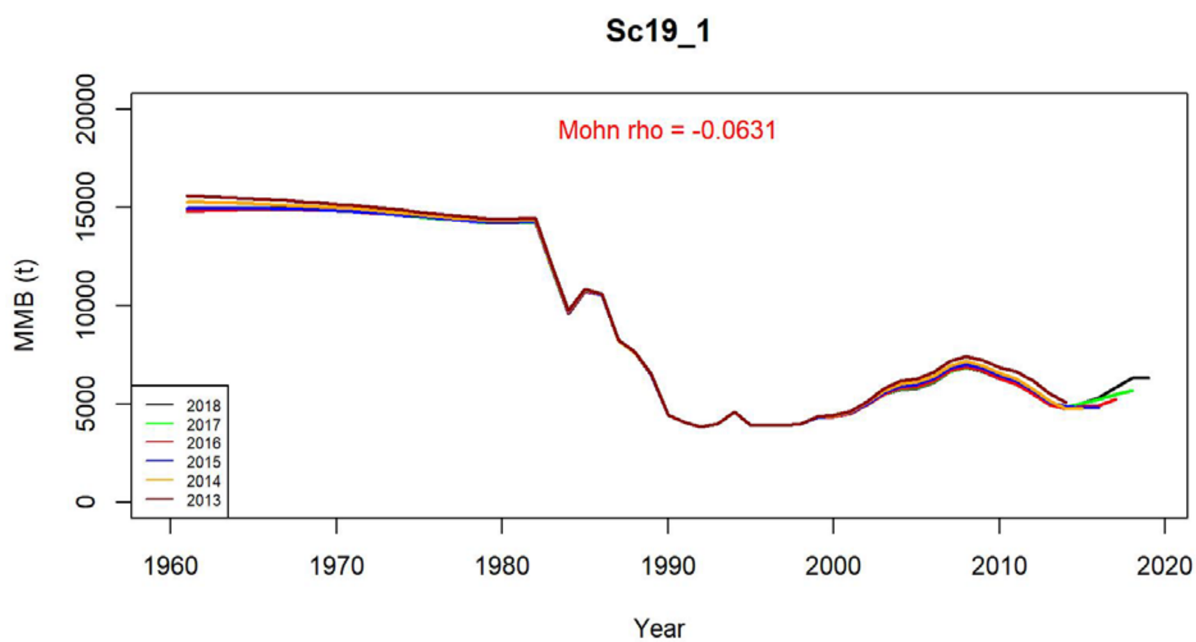


Figure 40. Bubble plot of standardized residuals of total catch length composition for scenario 19_2 fit for WAG golden king crab, 1990/91–2018/19. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Sc19_0
Mohn rho = -0.0662
MMB (t)
Year
2018
2017
2016
2015
2014
2013


Sc19_1
Mohn rho = -0.0631
MMB (t)
Year
2018
2017
2016
2015
2014
2013

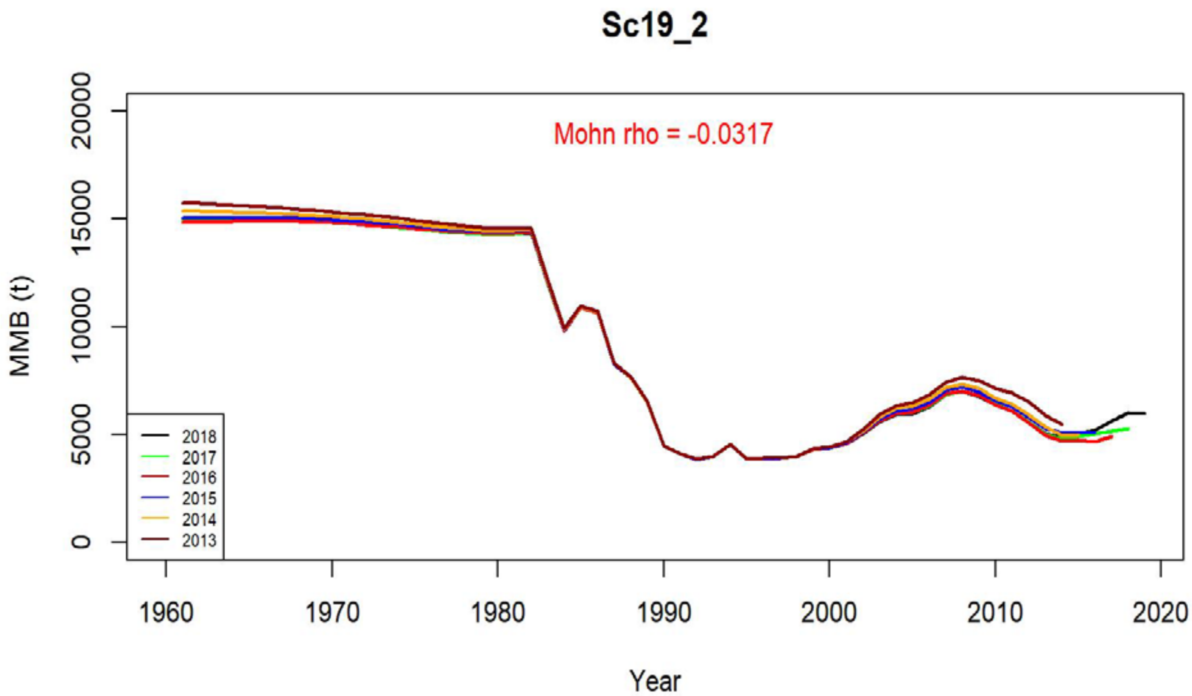


Figure 41. Retrospective fits of MMB by the model following removal of terminal year data under scenarios 19_0, 19_1 and 19_2 for golden king crab in the WAG, 1960/61–2018/19.

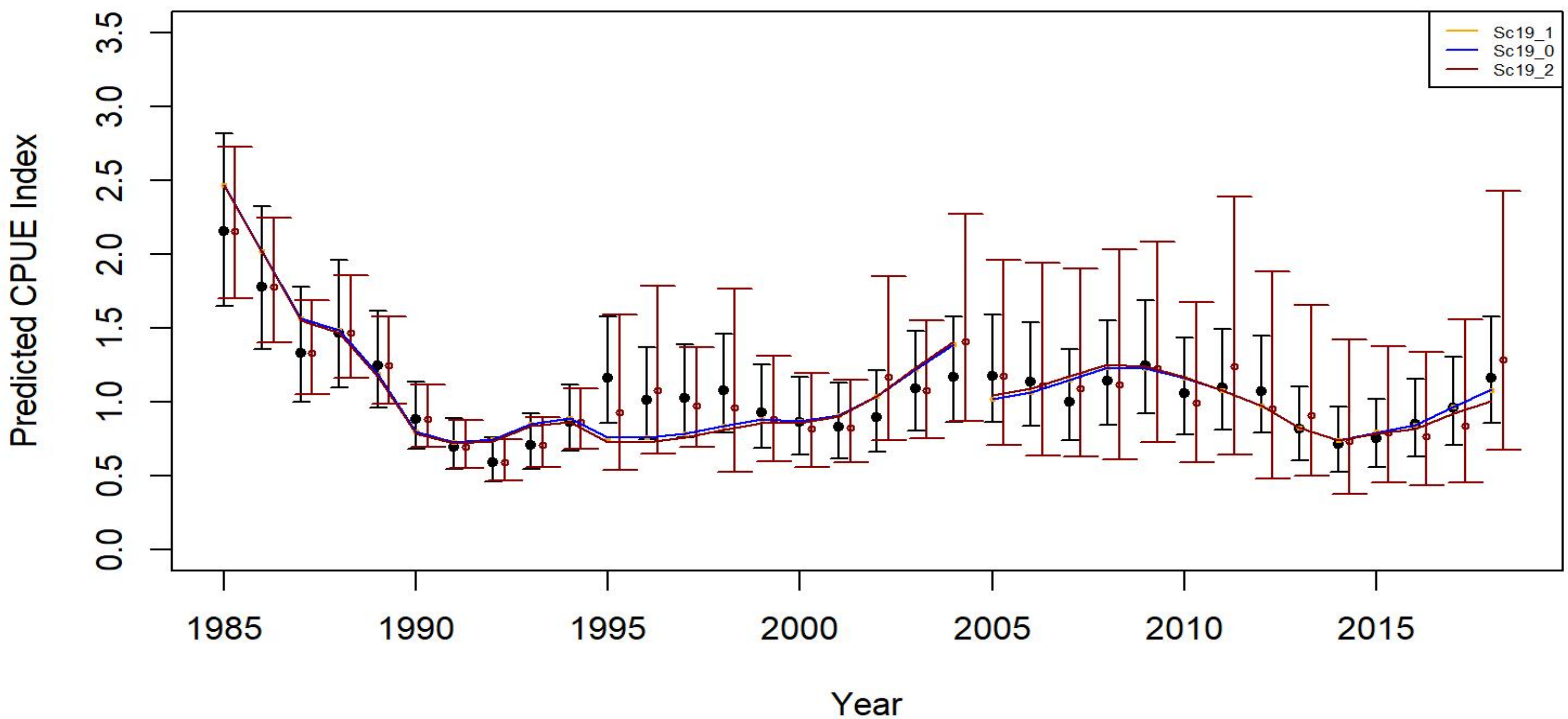


Figure 42. Comparison of input CPUE indices (closed circles with +/- 2 SE for Sc19_1 and 19_2) with model predicted CPUE indices (colored solid lines) under scenarios 19_0, 19_1, and 19_2 for WAG golden king crab data, 1985/86–2018/19. Model estimated additional standard error was added to each input standard error.

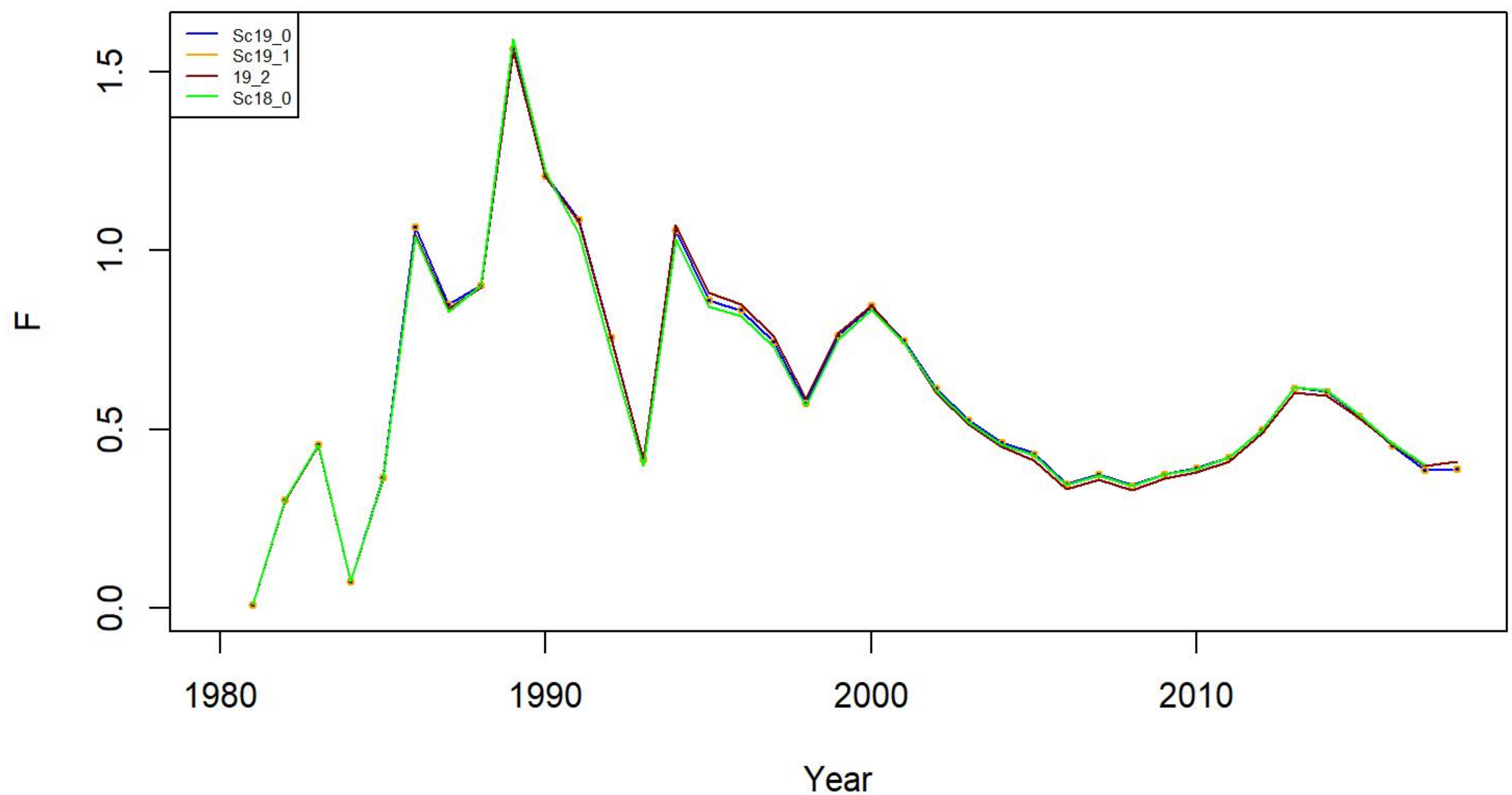


Figure 43. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios 18_0, 19_0, 19_1, and 19_2 model fits in the WAG, 1981/82–2018/19.

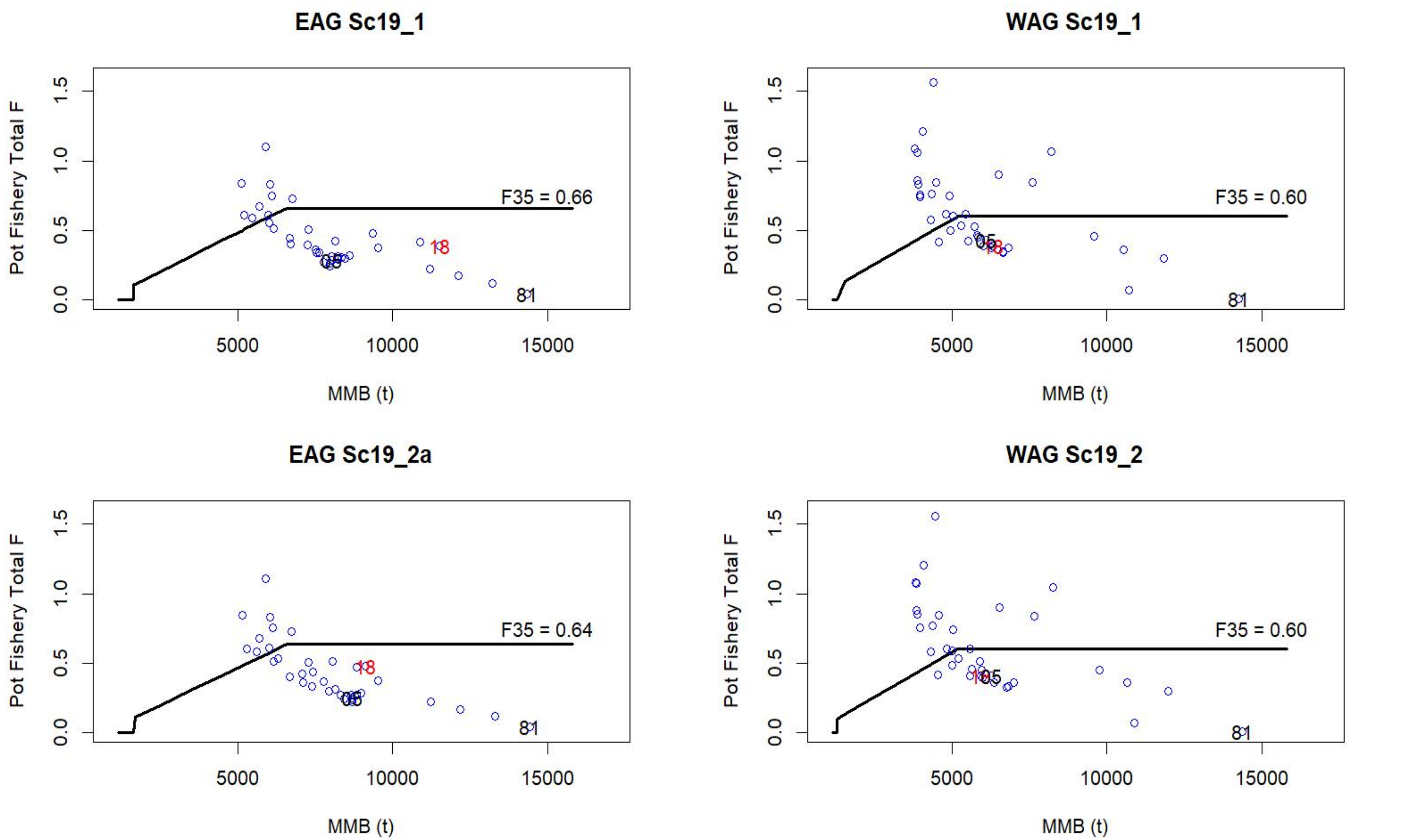


Figure 44. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1981/82–2018/19 under scenarios 19_1 and 19_2a (or19_2) for EAG and WAG. Average recruitment from 1987 to 2012 was used to estimate $MMB_{35\%}$.

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:

$$N_{t+1,j} = \sum_{i=1}^{j}[N_{t,i}e^{-M} - (\hat{C}_{t,i} + \widehat{D}_{t,i} + \widehat{Tr}_{t,i})e^{(y_t-1)M}]X_{i,j} + R_{t+1,j} \qquad \text{(A.1)}$$

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 $(\hat{T}_{t,i\;temp})$ 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

$$\hat{T}_{t,j,temp} = \frac{F_t s_{t,j}^T}{Z_{t,j}} N_{t,j}e^{-y_t M}(1 - e^{-Z_{t,j}}) \qquad \text{(A.2a)}$$

$$\hat{C}_{t,j} = \frac{F_t s_{t,j}^T s_{t,j}^r}{Z_{t,j}} N_{t,j}e^{-y_t M}(1 - e^{-Z_{t,j}}) \qquad \text{(A.2b)}$$

$$\widehat{D}_{t,j} = 0.2(\hat{T}_{t,j,temp} - \hat{C}_{t,j}) \qquad \text{(A.2c)}$$

$$\widehat{Tr}_{t,j} = 0.65\frac{F_t^{Tr} s_j^{Tr}}{Z_{t,j}} N_{t,j}e^{-y_t M}(1 - e^{-Z_{t,j}}) \qquad \text{(A.2d)}$$

$$\hat{T}_{t,j} = \hat{C}_{t,j} + \widehat{D}_{t,j} \qquad \text{(A.2e)}$$

where $Z_{t,j}$ is total fishery-related mortality on animals in length-class *j* during year *t*:

$$Z_{t,j} = F_t s_{t,j}^T s_{t,j}^r + 0.2F_t s_{t,j}^T(1 - s_{t,j}^r) + 0.65\, F_t^{Tr} s_j^{Tr} \qquad \text{(A.3)}$$

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 – 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 when $j>i$:

$$m_i = \frac{1}{1 + e^{c(\tau_i - d)}} \tag{A.8}$$

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:

$$S_i = \frac{1}{1 + e^{\left[-ln\,(19)\frac{\tau_i - \theta_{50}}{\theta_{95} - \theta_{50}}\right]}} \tag{A.9}$$

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 ($\theta_{95} - \theta_{50}$) 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

$$gamma(x|\alpha_r, \beta_r) = \frac{x^{\alpha_r - 1} e^{\frac{x}{\beta_r}}}{\beta_r{}^{\alpha_r}\,\Gamma_{(\alpha_r)}} \tag{A.10}$$

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:

$$LL_r^{catch} = \lambda_r \sum_t \{\ell\mathrm{n}(\sum_j \hat{C}_{t,j} w_j + c) - \ell\mathrm{n}(\sum_j C_{t,j} w_j + c)\}^2 \tag{A.11a}$$

$$LL_T^{catch} = \lambda_T \sum_t \{ln\,(\sum_j \hat{T}_{t,j} w_j + c) - ln\,(\sum_j T_{t,j} w_j + c)\}^2 \tag{A.11b}$$

$$LL_{GD}^{catch} = \lambda_{GD} \sum_t \{ln\,(\sum_j \widehat{Tr}_{t,j} w_j + c) - ln\,(\sum_j Tr_{t,j} w_j + c)\}^2 \tag{A.11c}$$

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 – 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:

$$LL_r^{CPUE} = \lambda_{r,CPUE}\left\{0.5\sum_t ln\left[2\pi\left(\sigma_{r,t}^2+\sigma_e^2\right)\right]+\sum_t\frac{\left(ln(CPUE_t^r+c)-ln(\widehat{CPUE}_t^r+c)\right)^2}{2\left(\sigma_{r,t}^2+\sigma_e^2\right)}\right\} \qquad \text{(A.12)}$$

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 $CPUE_t^r$:

$$\widehat{CPUE}_t^r = q_k\sum_j S_j^T S_j^r\left(N_{t,j}-0.5\left[\widehat{C_{t,j}}+\widehat{D_{t,j}}+\widehat{Tr_{t,j}}\right]\right)e^{-y_tM} \qquad \text{(A.13)}$$

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 retained catch rate indices.

Following Burnham *et al.* (1987), we computed the ln(CPUE) variance by:

$$\sigma_{r,t}^2 = \ln\left(1+CV_{r,t}^2\right) \qquad \text{(A.14)}$$

Length-composition data
The length-composition data are included in the likelihood function using the robust normal for proportions likelihood, i.e., generically:

$$LL_r^{LF} = 0.5\sum_t\sum_j \ell n(2\pi\sigma_{t,j}^2)-\sum_t\sum_j \ell n\left[\exp\left(-\frac{(P_{t,j}-\hat{P}_{t,j})^2}{2\sigma_{t,j}^2}\right)+0.01\right] \qquad \text{(A.15)}$$

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.:

$$\hat{L}_{t,j}^r = \frac{\hat{C}_{t,j}}{\sum_j^n \hat{C}_{t,j}}$$

$$\hat{L}_{t,j}^T = \frac{\hat{T}_{t,j}}{\sum_j^n \hat{T}_{t,j}}$$

$$\hat{L}_{t,j}^{GF} = \frac{\widehat{Tr}_{t,j}}{\sum_j^n \widehat{Tr}_{t,j}} \qquad \text{(A.16)}$$

$\sigma_{t,j}^2$ is the variance of $P_{t,j}$:

$$\sigma^2_{t,j} = \left[(1 - P_{t,j}) P_{t,j} + \frac{0.1}{n} \right] / S_t \tag{A.17}$$

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:

$$lnL = \lambda_{y,tag} \sum_j \sum_t \sum_y \sum_i \rho_{j,t,y,i} ln\hat{\rho}_{j,t,y,i} \tag{A18}$$

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:

$$\underline{\hat{\rho}}_{j,t,y} \propto \underline{s}^T [\mathbf{X}]^y \underline{Z}^{(j)} \tag{A19}$$

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):

$$P_1 = \lambda_F \sum_t (\ell nF_t - \ell n\bar{F})^2 \tag{A.20}$$

$$P_2 = \lambda_{F^{Tr}} \sum_t (\ell nF_t^{Tr} - \ell n\bar{F}^{Tr})^2$$

(A.21)

$$P_3 = \lambda_R \sum_t (\ell n\varepsilon_t)^2 \tag{A.22}$$

$$\mathrm{P}_5 = \lambda_{\mathrm{posfn}} * \mathrm{fpen} \tag{A.23}$$

Standardized Residual of Length Composition

$$\mathrm{Std.Res}_{t,j} = \frac{P_{t,j} - \widehat{P_{t,j}}}{\sqrt{2\sigma_{t,j}^2}} \tag{A.24}$$

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:

$$\mathrm{MMB}_t = \sum_{j=\mathrm{mature\ size}}^{n}\{N_{j,t}e^{-y'M} - (\hat{C}_{j,t} + \hat{D}_{j,t} + \widehat{Tr}_{j,t})e^{(y_t - y')M}\}w_j \tag{A.27}$$

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* $MMB_{current} > 0.25MMB_{35\%}$,

$$F_{OFL} = F_{35\%} \frac{\left(\frac{MMB_{current}}{MMB_{35\%}} - \alpha\right)}{(1-\alpha)} \tag{A.28}$$

If,
$MMB_{current} \leq 0.25MMB_{35\%}$,

$F_{OFL} = 0.$

where α is a parameter, $\mathrm{MMB}_{\mathrm{current}}$ 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	1981–2018 (estimated)
Mean pot fishery fishing mortality, $\overline{F}$	1 (estimated)
Groundfish fishery, F_t^{Tr}	1989–2018 (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, $\text{delta}\theta^{\text{T}}$	2 (1981–2004; 2005+) (estimated)
Pot fishery retention, θ_{50}^{r}	1 (1981+) (estimated)
Pot fishery retention selectivity difference, $\text{delta}\theta^{\text{r}}$	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, $\overline{L}_R$	1 (pre-specified, 110 mmCL)
Distribution to length-class, β_r	1 (estimated)
Median recruitment, $\overline{\text{R}}$	1 (estimated)
Recruitment deviations, ε_t	59 (1961–2019) (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 scenario for EAG and WAG.

Weight	Scenario 19_0	Scenario 19_1	Scenario 19_2 (or 19_2a)
Catch:			
Retained catch for 1981–1984 and/or 1985–2018, λ_r	500 (0.032)	500	500
Total catch for 1990–2018, 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 –2018, λ_{GD}	0.2 (3.344)	0.2	0.2
Catch-rate:			
Observer legal size crab catch-rate for 1995–2018, $\lambda_{r,CPUE}$	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 1995/96–2018/19. The 1990/91–2018/19 observer database consists of 115,118 records and that of 1995/96–2018/19 contains 110,843 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 –2018/19.

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 2005/06–2018/19, 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 GLM 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 ($R^2 < 0.01$) (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 three sets of CPUE indices for model input scenarios, 19_0 (original gear codes), 19_1 (reduced number of gear codes), and 19_2 (WAG) or 19_2a (EAG) [reduced number of gear codes and Year:Area interaction].

For year and area interaction analysis, we designed the areas in to 30X30nmi grids as follows:

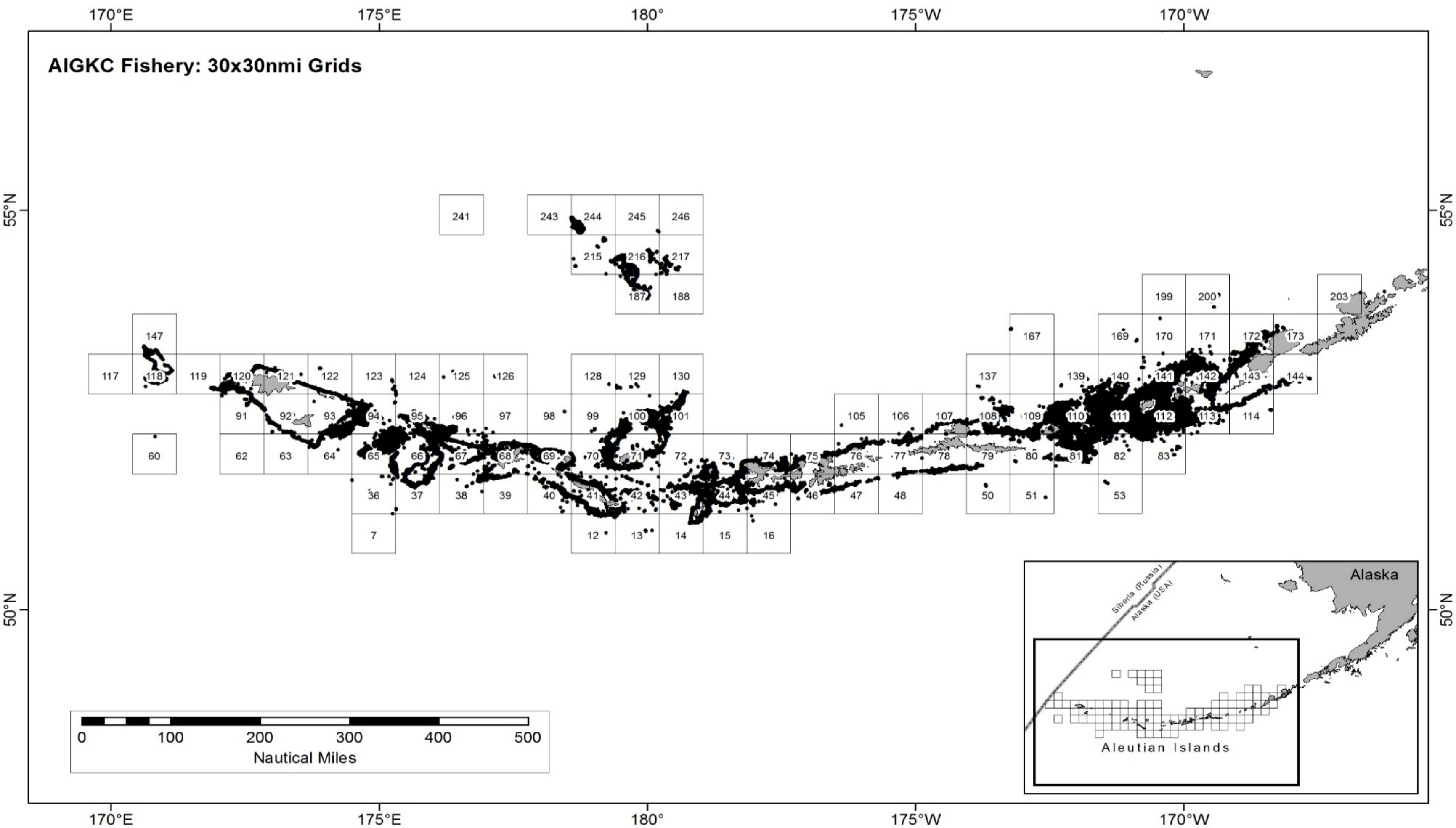


Figure B.1. The 1995/96 to 2018/19 observer pot samples enmeshed in 30X30nmi grids for the Aleutian Islands golden king crab.

To add a column of actual fishing location cell (i.e., foot print) in the 1995/96 to 2018/19 observer database, we used a geostatistical software available in R with the following lines of codes. It allocates an observer sampled pot location with a given latitude and longitude to the nearest Cell.

```
distancem<- vector(mode = "numeric", length = 106)
 library(geosphere)
   for(i  in 1:length(potsample1$Latitude))
    {distancem<- distGeo(potsample1[i,12:11],potsample2[,6:5])
    potsample1$GridCell[i]<- potsample2$FID[which.min(distancem)]   }
```

where "potsample1" is the original observer data base and "potsample2" is a set of Lat and Long centroids of 30X30nmi grids based on 1995_2017 observer data foot prints, and FID is a Cell number identified by a grid.

In the observer CPUE standardization, we identified the Area by the fishing foot print Cell ID#.

a. Observer CPUE index by GLM:

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

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year_{y_i}} \qquad \text{(B.2)}$$

where Year is a factorial variable.

The maximum set of model terms offered to the stepwise selection procedure was:

$$\ln\,(\mathrm{CPUE_I}) = \mathrm{Year_{y_i}} + \mathrm{ns}(\mathrm{Soak_{si}}, \mathrm{df}) + \mathrm{Month_{m_i}} + \mathrm{Vessel_{vi}} + \mathrm{Captain_{ci}} + \mathrm{Area_{ai}} + \mathrm{Gear_{gi}} + \mathrm{ns}(\mathrm{Depth_{di}}, \mathrm{df}), \qquad \text{(B.3)}$$

where Soak is in unit of days and is numeric; Month, Area (GridCell) 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).

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=5)),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:

Scenario 19_0:

Initial selection by stepAIC:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Month + Area$$

AIC=205012

Final selection by stepCPUE:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Month \qquad \text{(B.4)}$$

for the 1995/96–2004/05 period [θ=1.38, $R^2 = 0.2201$]

Initial selection by stepAIC:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 9) + Month + Vessel$$

AIC=68144

Final selection by stepCPUE:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 9) \qquad \text{(B.5)}$$

for the 2005/06–2018/19 period [$\theta = 2.33,\ R^2 = 0.1157$].

Scenario 19_1:

Initial selection by stepAIC:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Month + Area$$

AIC=204999

Final selection by stepCPUE:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + Month \qquad \text{(B.6)}$$

for the 1995/96–2004/05 period [θ=1.38, $R^2 = 0.2203$]

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Gear} + \text{ns}(\text{Soak}, 9) + Month$
AIC=68132

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Gear} + \text{ns}(\text{Soak}, 9) \quad \text{(B.7)}$$

for the 2005/06–2018/19 period [$\theta = 2.33$, $R^2 = 0.1135$].

The final models for WAG were:

Scenario 19_0:

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{ns}(\text{Soak}, 8) + \text{Gear} + Area + Month$

AIC=179337

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{ns}(\text{Soak}, 8) + Gear + Area \quad \text{(B.8)}$$

for the 1995/96–2004/05 period [θ=1.0, $R^2 = 0.1874$]

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Vessel} + \text{ns}(\text{Depth}, 2) + \text{Month} + \text{ns}(\text{Soak}, 9)$

AIC=96308

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{ns}(\text{Soak}, 5) \quad \text{(B.9)}$$

for the 2005/06–2018/19 period [$\theta = 1.15$, $R^2 = 0.0470$, Soak forced in].

Scenario 19_1:

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{ns}(\text{Soak}, 8) + \text{Gear} + Area + Month$

AIC=179340

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{ns}(\text{Soak}, 8) + \text{Gear} + \text{Area} \quad \text{(B.10)}$$

for the 1995/96–2004/05 period [θ=1.0, $R^2 = 0.1864$]

Initial selection by stepAIC:

$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{Vessel} + \text{ns}(\text{Depth}, 2) + \text{Month} + \text{ns}(\text{Soak}, 5)$ AIC=96286

Final selection by stepCPUE:

$$\ln(\text{CPUE}) = \text{Year} + \text{Gear} + \text{ns}(\text{Soak}, 5) \quad \text{(B.11)}$$

for the 2005/06–2018/19 period [$\theta = 1.15,\ R^2 = 0.0468$, Soak forced in].

Year and Area interaction GLM:

We assumed the null model to be

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year_{y_i}}:\mathrm{Area_{ai}} \qquad \text{(B.12)}$$

The maximum set of model terms offered to the stepwise selection procedure was:

$\ln(\mathrm{CPUE_I}) = \mathrm{Year_{y_i}}: Area_{ai} + \mathrm{ns(Soak_{si}, df)} + \mathrm{Month_{m_i}} + \mathrm{Vessel_{vi}} + \mathrm{Captain_{ci}} + \mathrm{Area_{ai}} + \mathrm{Gear_{gi}} + \mathrm{ns(Depth_{di}, df)}$. (B.13)

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(1.0),data=datacore)
 wpotsampleoutAIC<-stepAIC(glm.object,scope=list(upper=
~(Year:Area+ns(SoakDays,df=8)+Month+Vessel+Captain+Area+Gear+ns(Depth,df=10)),lower=~Year:
Area),family= negative.binomial(1.0),direction="forward",trace=9,k=log(nrow(datacore))+1.0)
```

Step 2:

```
glm.object<- glm(Legals~Year:Area,family = negative.binomial(1.0),data=datacore)
 wpotsampleout<-stepCPUE(glm.object,scope=list(upper=
~(Captain+ns(SoakDays,df=8)+Gear+Area+Month+Year:Area),lower=                    ~Year:Area),family=
negative.binomial(1.0),direction="forward",trace=9,r2.change=0.01)
```

The final interaction effect models for EAG were:

Scenario 19_2:

Initial selection by stepAIC:

$$\ln(\mathrm{CPUE}) = \mathrm{Gear} + \mathrm{Captain} + \mathrm{Month} + \mathrm{ns(Soak, 4)} + Area + Year: Area$$

AIC=205530

Final selection by stepCPUE:

$$\ln(\mathrm{CPUE}) = \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns(Soak, 4)} + Year: Area \qquad \text{(B.14)}$$

for the 1995/96–2004/05 period [θ=1.38, $R^2 = 0.2368$]

Initial selection by stepAIC:

$$\ln(\mathrm{CPUE}) = \mathrm{Vessel} + \mathrm{Gear} + \mathrm{ns(Soak, 9)} + Year: Area$$

AIC=69116

Final selection by stepCPUE:

$$\ln(\mathrm{CPUE}) = \ \mathrm{ns}(\mathrm{Soak}, 9) + Gear + Year{:}\, Area \tag{B.15}$$

for the 2005/06–2018/19 period [$\theta = 2.33,\ \mathrm{R}^2 = 0.1463$].

The final interaction effect models for WAG were:

Scenario 19_2:

Initial selection by stepAIC:

$$\ln(\mathrm{CPUE}) = \ \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 8) + Gear + \ Area + Month + Year{:}\, Area$$

AIC=181206

Final selection by stepCPUE:

$$\ln(\mathrm{CPUE}) = \ \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 8) + \mathrm{Gear} + Year{:}\, Area \tag{B.16}$$

for the 1995/96–2004/05 period [θ=1.0, $\mathrm{R}^2 = 0.2103$]

Initial selection by stepAIC:

$$\ln(\mathrm{CPUE}) = \ \mathrm{Vessel} + \mathrm{Area} + \mathrm{Gear} + \ \mathrm{ns}(\mathrm{Depth}, 2) + ns(Soak, 5) + \ Year{:}\, Area$$

AIC=98649

Final selection by stepCPUE:

$$\ln(\mathrm{CPUE}) = \mathrm{Vessel} + Year{:}\, Area + ns(Soak, 5) \tag{B.17}$$

for the 2005/06–2018/19 period [$\theta = 1.15,\ \mathrm{R}^2 = 0.1125, \mathrm{Soak\ forced\ in}$].

Steps:

1. We removed the zero interaction factor cells based on the estimated bivariate correlation matrix (Zeros and NAs producing interaction factor levels were removed. Information is available with the first author).
2. We did not include the Year factor on its own in the GLM.
3. The Year coefficient (as CPUE index for an Year) was determined from the Year:Area coefficients as follows:

$$Index_{yi} = \sum_i e^{coefficient\ (Year_i:\, Area_i)}\ X\ Area_i \tag{B.18}$$

Where *i* is the number of Grid Cell (fishing footprints) in $Year_i$

The indices were rescaled by the geometric mean of estimated Index_{yi} values separately for the pre- and post-rationalization periods. The variance of ln(indexi) was estimated as the mean value of GLM estimated standard deviation ^2 for each year (this is because we assumed each Cell has the same area, 30X30nmi).

4. For EAG, the estimated variances were substantially high for the pre-rationalization period (Table B.2). Therefore, we modified Scenario 19_2 to 19_2a where pre-rationalization period's indices were omitted; instead, used the extended Fish Ticket CPUE indices (1985-1998).

Table B.2. Comparison of CPUE indices and variances of log CPUE between EAG and WAG for scenario 19_2.

Year	EAG CPUE Index 19_2	Variance (ln(CPUE))	WAG CPUE Index 19_2	Variance (ln(CPUE))
1995	0.8796	0.9656	0.9291	0.0725
1996	0.6943	0.9651	1.0757	0.0645
1997	0.7232	0.9045	0.9771	0.0283
1998	0.9321	0.9045	0.9623	0.0918
1999	0.8269	0.9275	0.8855	0.0384
2000	0.8824	0.9170	0.8203	0.0358
2001	1.3353	0.9591	0.8227	0.0275
2002	1.2385	0.9623	1.1716	0.0523
2003	1.1646	0.9049	1.0789	0.0328
2004	1.7285	0.8996	1.4085	0.0574
2005	0.9103	0.0539	1.1771	0.0649
2006	0.7970	0.0457	1.1095	0.0782
2007	0.9785	0.0589	1.0932	0.0764
2008	0.7926	0.0540	1.1148	0.0899
2009	0.5490	0.0630	1.2306	0.0695
2010	0.9999	0.0571	0.9935	0.0686
2011	1.1685	0.0709	1.2384	0.1084
2012	0.9646	0.0520	0.9521	0.1160
2013	1.3463	0.0491	0.9121	0.0893
2014	1.3650	0.0572	0.7339	0.1101
2015	1.2458	0.0639	0.7906	0.0769
2016	1.2662	0.0434	0.7636	0.0788
2017	0.9440	0.0371	0.8403	0.0958
2018	1.0498	0.0420	1.2837	0.1020

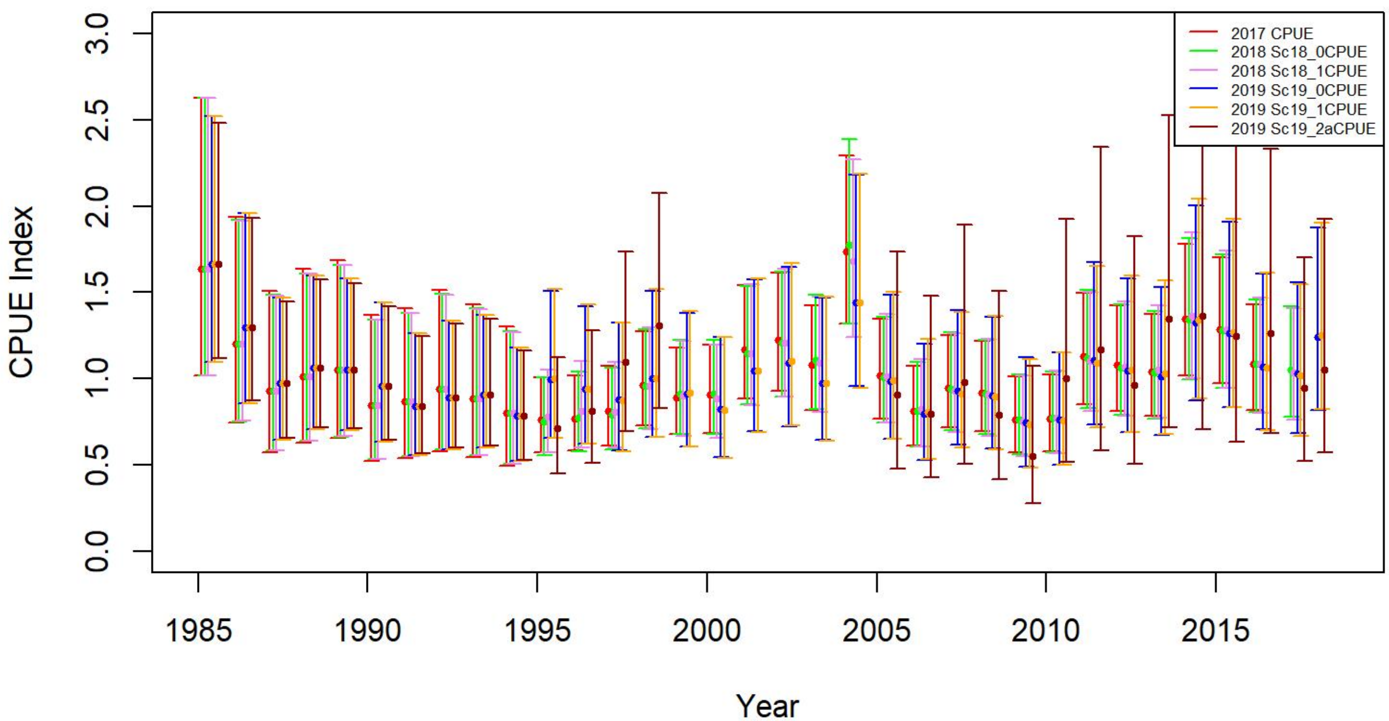


Figure B.2. Comparison of input CPUE indices for scenarios 2016 (ADF&G area codes grouped into 10 groups, up to 2015/16 data), 2017 (ADF&G area codes not grouped, up to 2016/17 data), 2018 Sc 18_0 (Lat and Long position of observed pot, up to 2017/18 data), 2018 Sc18_1 (Lat and Long position of observed pot, reduced number of gear codes, , up to 2017/18 data), 2019 Sc 19_0 (Grid Cell position of observed pot, up to 2018/19 data), 2019 Sc 19_1 (Grid Cell position of observed pot, reduced number of gear codes, up to 2018/19 data), and 2019 Sc 19_2a (Grid Cell position of observed pot, reduced number of gear codes, fish ticket CPUE indices extended up to 1998/99, pre rationalization period observer CPUE indices ignored, up to 2018/19 data) for EAG golden king crab. Model estimated additional standard error was added to each input standard error for 2-standard error confidence interval determination.

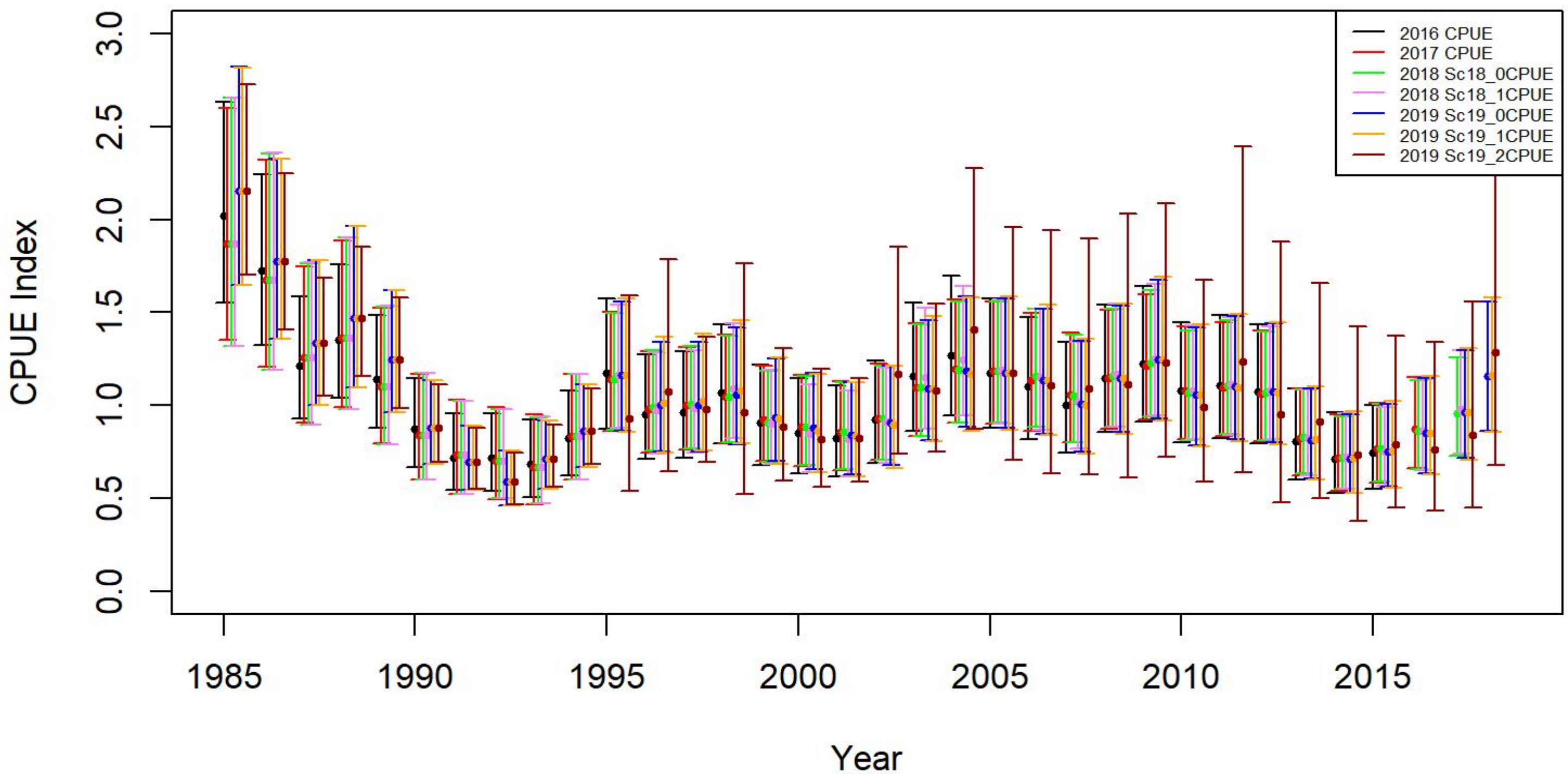


Figure B.3. Comparison of input CPUE indices for scenarios 2016 (ADF&G area codes grouped into 10 groups, up to 2015/16 data), 2017 (ADF&G area codes not grouped, up to 2016/17 data), 2018 Sc 18_0 (Lat and Long position of observed pot, up to 2017/18 data), 2018 Sc18_1 (Lat and Long position of observed pot, reduced number of gear codes, , up to 2017/18 data), 2019 Sc 19_0 (Grid Cell position of observed pot, up to 2018/19 data), 2019 Sc 19_1 (Grid Cell position of observed pot, reduced number of gear codes, up to 2018/19 data), and 2019 Sc 19_2 (Grid Cell position of observed pot, reduced number of gear codes, up to 2018/19 data) for WAG golden king crab. Model estimated additional standard error was added to each input standard error for 2-standard error confidence interval determination.

Fish Ticket CPUE index:

We also fitted the lognormal GLM 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 for EAG was:

Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Vessel} + \mathrm{Month}$
AIC=25805

Final selection by stepCPUE:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Vessel} + \mathrm{Month}$ (B.19)
for the 1985/86–1998/99 period [$R^2 = 0.3700$]

and that for WAG was:

Initial selection by stepAIC:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Vessel} + \mathrm{Area}$
AIC= 11110

Final selection by stepCPUE
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Vessel},\ R^2 = 0.3679$ (B.20)

The R^2 for the fish ticket data fits are much higher compared to that for observer data fits

Figures B.6 and B.7 depict the trends in nominal and standardized CPUE indices for the fish ticket CPUE time series for EAG and WAG, respectively.

Figures B.4 and B.7 depict the trends in nominal and standardized CPUE indices for the observer and Fish Ticket CPUE time series for EAG and WAG, respectively.

Note: For brevity we did not present the diagnostic figures for the fits in this document. They are available with the first author.

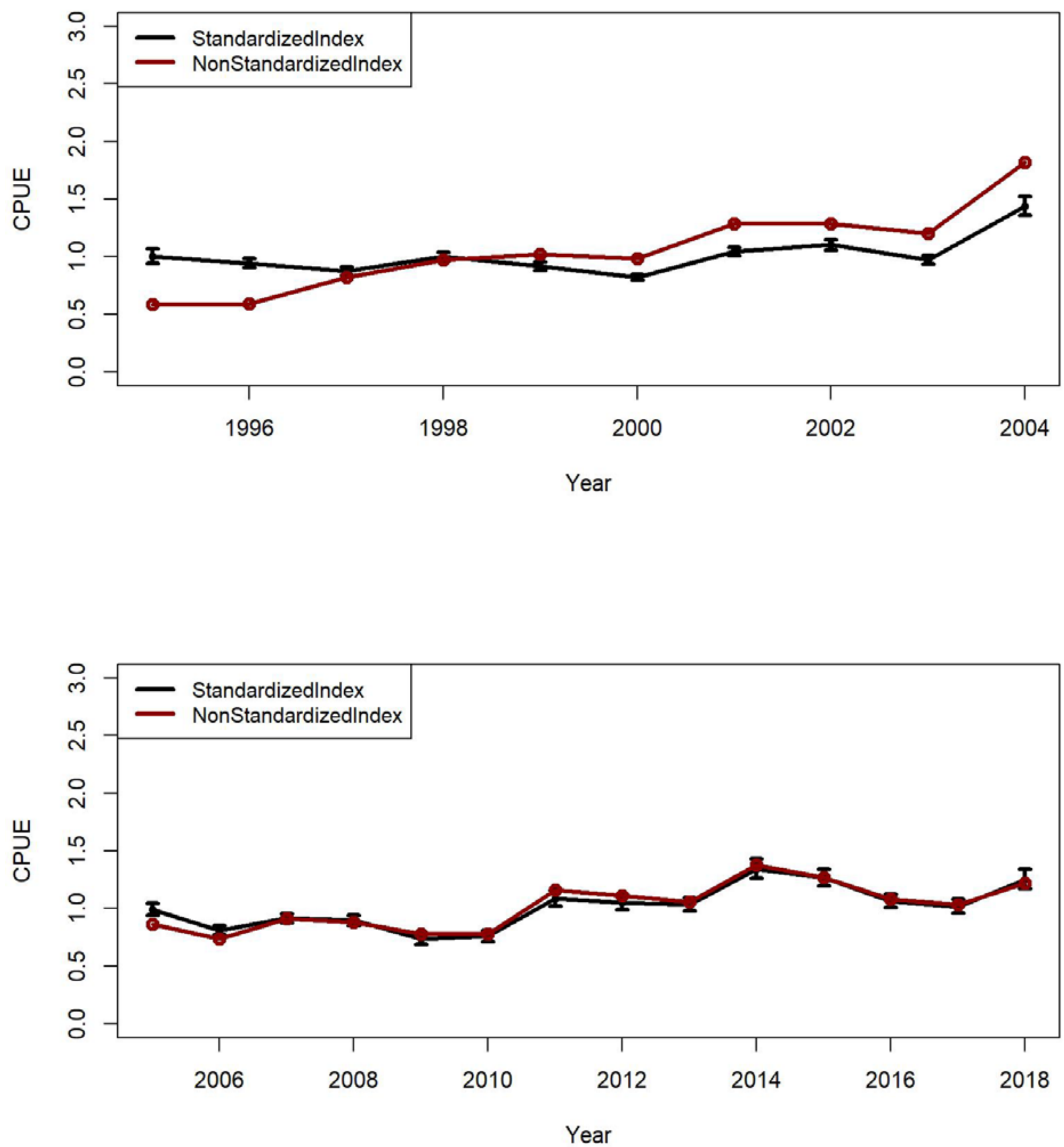
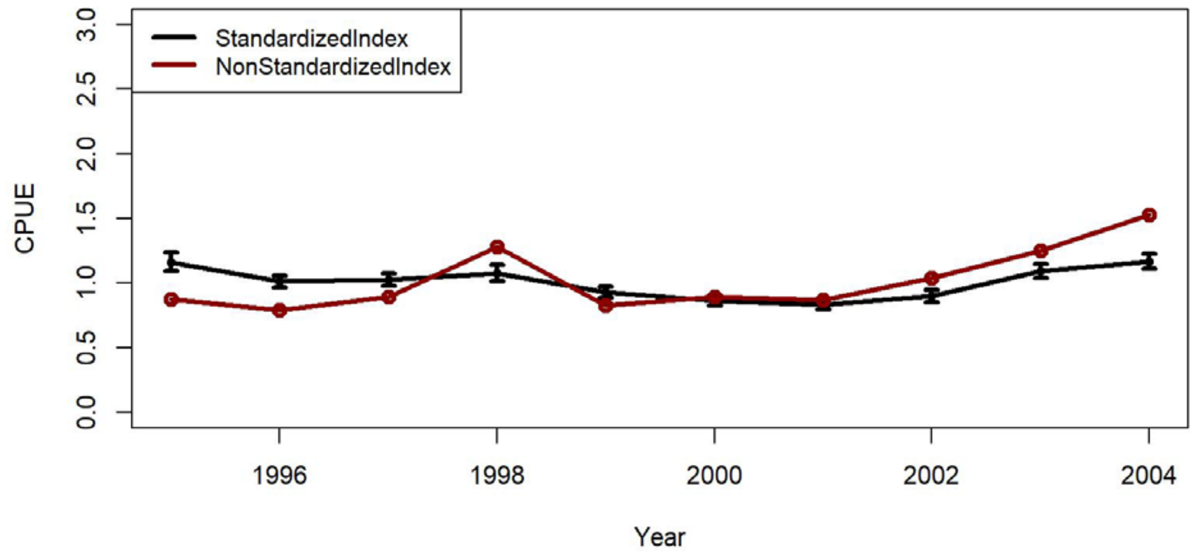


Figure B.4. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from EAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05, and bottom panel: 2005/06–2018/19. Standardized indices: black line and non-standardized indices: red line. Scenario 19_1.



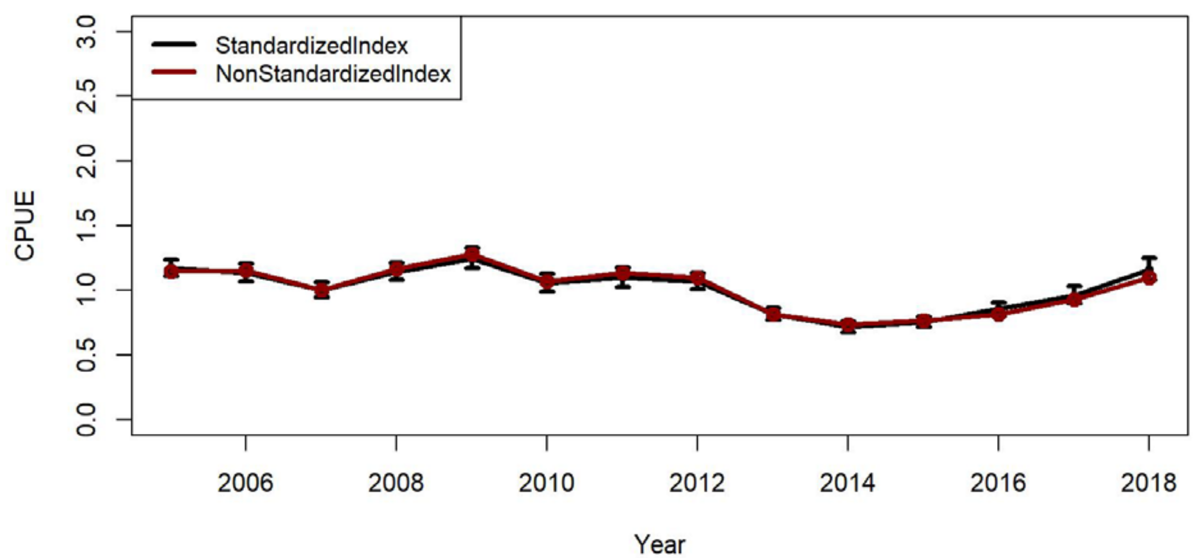


Figure B.5. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from WAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05, and bottom panel: 2005/06–2018/19. Standardized indices: black line and non-standardized indices: red line. Scenario 19_1.

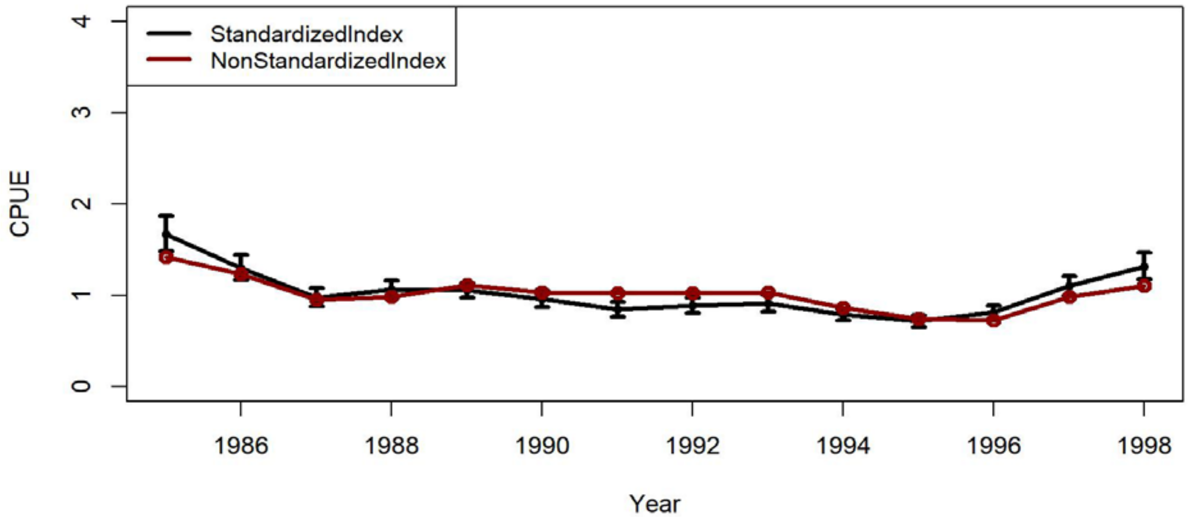


Figure B.6. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG. The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line.

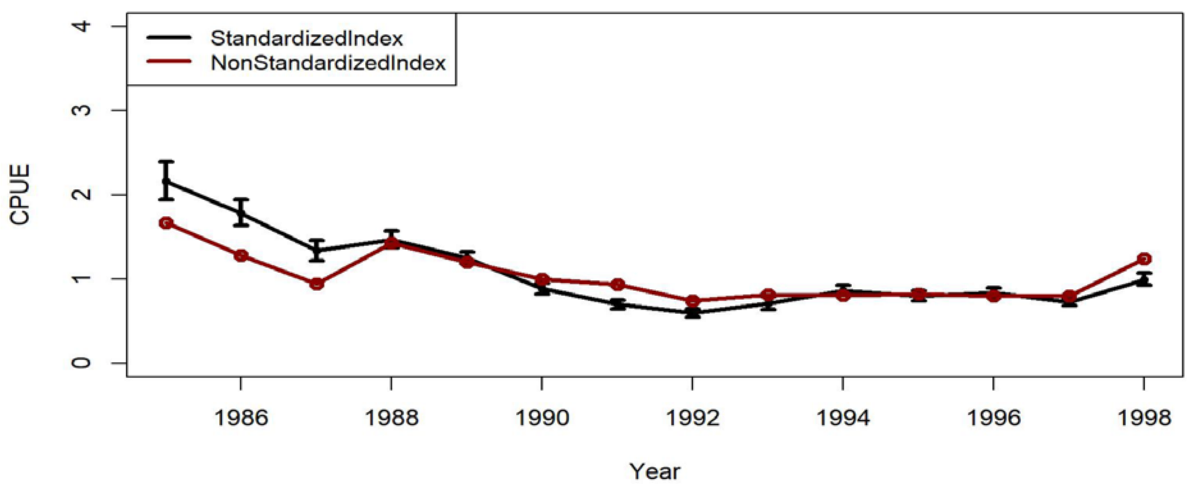


Figure B.7. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG. The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line.

Appendix C. B0 Analysis

For proper B0 analysis, a stock-recruitment relationship and impacts of environmental factors on recruitment are needed. We did not establish a stock-recruitment relationship for Aleutian Islands golden king crab. Furthermore, the impacts of environmental factors on recruitment have not been studied in the Aleutian Islands areas. Therefore, we approached the B0 analysis in a simple way. We computed the time series of B0 values using the same recruitment time series estimated by the assessment model scenarios (Sc.) 19_0, 19_1, and 19_2a (for EAG) or 19_2 (for WAG) and setting all directed and bycatch fishing mortality to zero. Following figures compare the time series of estimated B0 and MMB with fishing, MMB ratio (MMB/B0), and number of recruits for the three scenarios separately for EAG and WAG. It is clear that the fishery has a great impact on the biomass dynamics with MMB dropping precipitously with the onset of significant fishery removals in 1981:

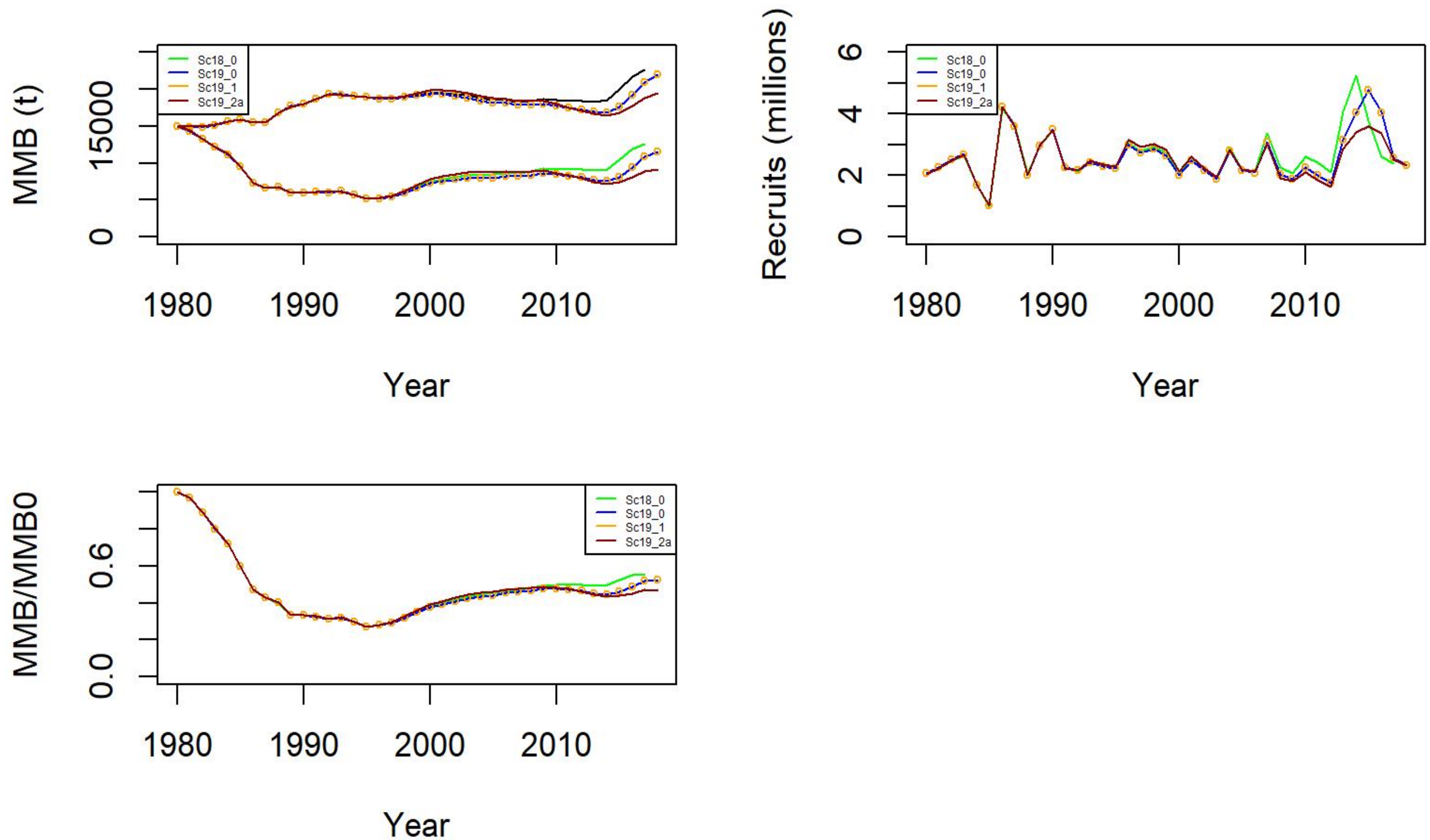


Figure C.1. Comparison of estimated B0 (t) with MMB (top left), estimated number of recruits (top right), and MMB/B0 ratio (bottom left) for scenarios (Sc.) 18_0 (green line, up to 2017/18 data), 19_0 (up to 2018/19 data), 19_1, and 19_2a model fits in the EAG.

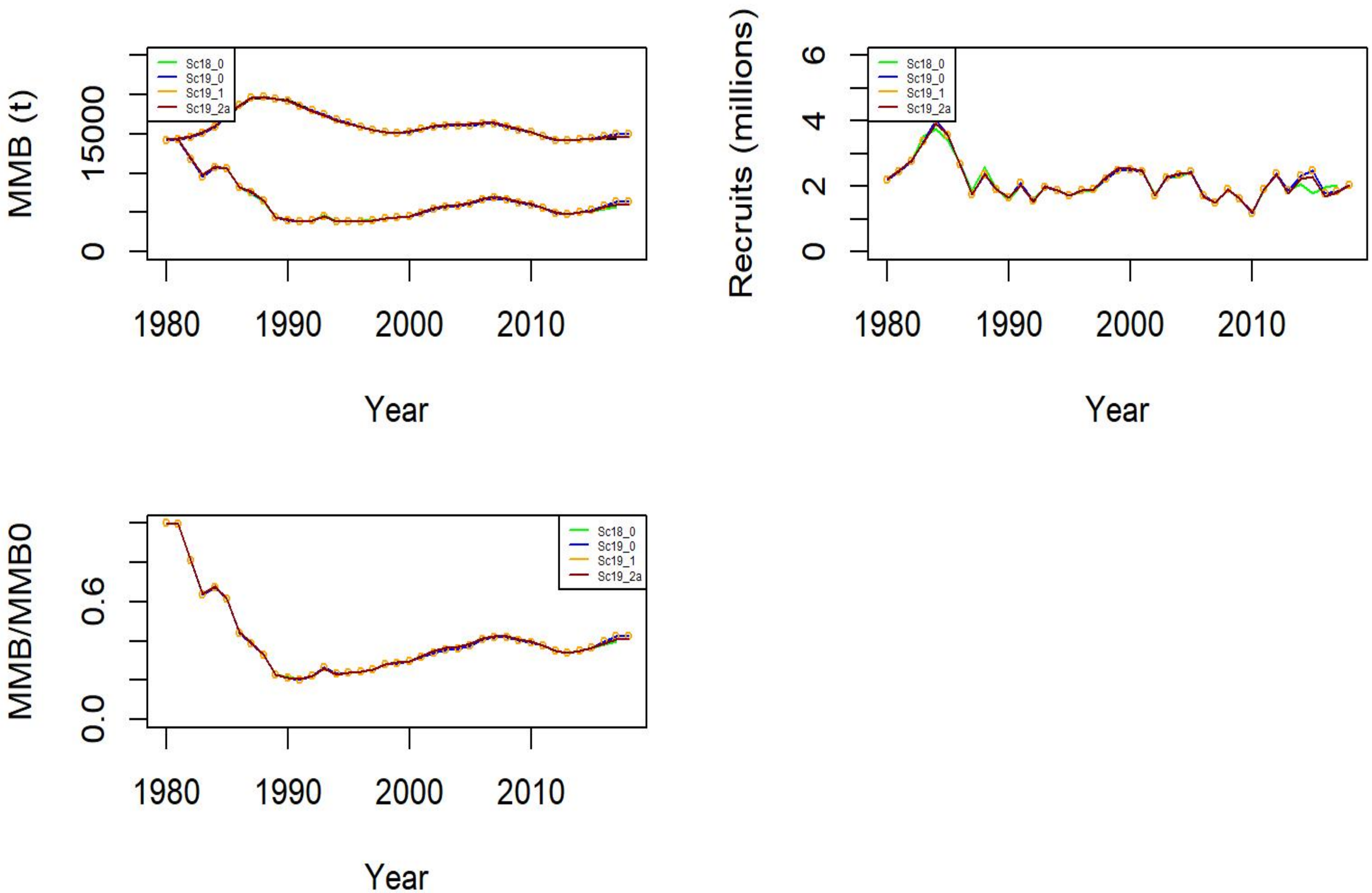


Figure C.2. Comparison of estimated B0 (t) with MMB (top left), estimated number of recruits (top right), and MMB/B0 ratio (bottom left) for scenarios (Sc.) 18_0 (green line, up to 2017/18 data), 19_0 (up to 2018/19 data), 19_1, and 19_2a model fits in the WAG.

Appendix D: Jittering

Jittering of scenarios 19_1 and 19_2 (or 19_2a) parameter estimates:
We followed the Stock Synthesis approach to do 100 jitter runs of scenarios *19_1 and 19_2 or 19_2a* 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:
>
> $$temp = 0.5 * rdev * Jitterfactor * \ln\left(\frac{P_{\max} - P_{\min} + 0.0000002}{P_{val} - P_{\min} + 0.0000001} - 1\right), \tag{D.1}$$
>
> with the final jittered initial parameter value back transformed as:
>
> $$P_{new} = P_{\min} + \frac{P_{\max} - P_{\min}}{1.0 + \exp(-2.0\, temp)}, \tag{D.2}$$
>
> 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 19_1 in Tables D.1 and D.2; and 19_2a and 19_2 in Tables D.3 and D.4 for EAG and WAG, respectively. Almost all runs converged to the highest log likelihood values for EAG. On the other hand, some jitter runs for WAG scenario 19_1 produced smaller objective function value whereas some runs for WAG scenario 19_2 produced larger objective function values compared to the base estimate (run 0). However, those fits with smaller objective function values predicted extremely large groundfish bycatches in certain years, consequently we ignored those runs. We concluded from jitter results that optimization of 19_1 and 19_2 (or 19_2a) models achieved global minima.

Table D.1. Results from 100 jitter runs for scenario 19_1 for EAG. Jitter run 0 corresponds to the original optimized estimates. Note: B_{MSY} reference points were based on average recruitment for 1987–2012.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**108.5244**	**0.00019844**	**6,584**	**3,418**	**10,203**
1	108.5244	0.00003765	6,584	3,418	10,203
2	108.5244	0.00006024	6,584	3,418	10,203
3	108.5244	0.00006469	6,584	3,418	10,203
4	108.5244	0.00085722	6,584	3,418	10,203
5	108.5244	0.00010202	6,584	3,418	10,203
6	108.5244	0.00002813	6,584	3,418	10,203
7	108.5244	0.00007841	6,584	3,418	10,203
8	108.5244	0.00002810	6,584	3,418	10,203
9	108.5244	0.00010359	6,584	3,418	10,203
10	108.5244	0.00019743	6,584	3,418	10,203
11	108.5244	0.00010534	6,584	3,418	10,203
12	108.5244	0.00020649	6,584	3,418	10,203
13	108.5244	0.00023738	6,584	3,418	10,203
14	108.5244	0.00008070	6,584	3,418	10,203
15	108.5244	0.00074843	6,584	3,418	10,203
16	108.5244	0.00013616	6,584	3,418	10,203
17	108.5244	0.00011527	6,584	3,418	10,203
18	108.5244	0.00003540	6,584	3,418	10,203
19	108.5244	0.00003587	6,584	3,418	10,203
20	108.5244	0.00023851	6,584	3,418	10,203
21	108.5244	0.00009878	6,584	3,418	10,203
22	108.5244	0.00002835	6,584	3,418	10,203
23	108.5244	0.00007482	6,584	3,418	10,203
24	108.5244	0.00020804	6,584	3,418	10,203
25	108.5244	0.00008940	6,584	3,418	10,203
26	108.5244	0.00046323	6,584	3,418	10,203
27	108.5244	0.00018521	6,584	3,418	10,203
28	108.5244	0.00020666	6,584	3,418	10,203
29	108.5244	0.00002508	6,584	3,418	10,203
30	108.5244	0.00010483	6,584	3,418	10,203
31	108.5244	0.00012694	6,584	3,418	10,203
32	108.5244	0.00006304	6,584	3,418	10,203
33	108.5244	0.00011522	6,584	3,418	10,203
34	108.5244	0.00013291	6,584	3,418	10,203
35	108.5244	0.00001389	6,584	3,418	10,203
36	108.5244	0.00001315	6,584	3,418	10,203

37	108.5244	0.00000710	6,584	3,418	10,203
38	108.5244	0.00009928	6,584	3,418	10,203
39	108.5244	0.00017745	6,584	3,418	10,203
40	108.5244	0.00009716	6,584	3,418	10,203
41	108.5244	0.00025232	6,584	3,418	10,203
42	108.5244	0.00015306	6,584	3,418	10,203
43	108.5244	0.00004956	6,584	3,418	10,203
44	108.5244	0.00019774	6,584	3,418	10,203
45	108.5244	0.00001779	6,584	3,418	10,203
46	108.5244	0.00003405	6,584	3,418	10,203
47	108.5244	0.00009371	6,584	3,418	10,203
48	108.5244	0.00012506	6,584	3,418	10,203
49	108.5244	0.00010105	6,584	3,418	10,203
50	108.5244	0.00005369	6,584	3,418	10,203
51	108.5244	0.00003462	6,584	3,418	10,203
52	108.5244	0.00013454	6,584	3,418	10,203
53	108.5244	0.00037256	6,584	3,418	10,203
54	108.5244	0.00004734	6,584	3,418	10,203
55	108.5244	0.00006217	6,584	3,418	10,203
56	108.5244	0.00010582	6,584	3,418	10,203
57	108.5244	0.00027120	6,584	3,418	10,203
58	108.5244	0.00009683	6,584	3,418	10,203
59	108.5244	0.00007260	6,584	3,418	10,203
60	108.5244	0.00101527	6,584	3,418	10,203
61	108.5244	0.00033784	6,584	3,418	10,203
62	108.5244	0.00008491	6,584	3,418	10,203
63	108.5244	0.00001370	6,584	3,418	10,203
64	108.5244	0.00003530	6,584	3,418	10,203
65	108.5244	0.00005301	6,584	3,418	10,203
66	108.5244	0.00007408	6,584	3,418	10,203
67	108.5244	0.00040697	6,584	3,418	10,203
68	108.5244	0.00007171	6,584	3,418	10,203
69	108.5244	0.00000551	6,584	3,418	10,203
70	108.5244	0.00016844	6,584	3,418	10,203
71	108.5244	0.00001833	6,584	3,418	10,203
72	108.5244	0.00014056	6,584	3,418	10,203
73	108.5244	0.00007077	6,584	3,418	10,203
74	108.5244	0.00002829	6,584	3,418	10,203
75	108.5244	0.00003979	6,584	3,418	10,203
76	108.5244	0.00018708	6,584	3,418	10,203
77	108.5244	0.00028434	6,584	3,418	10,203
78	108.5244	0.00048770	6,584	3,418	10,203
79	108.5244	0.00006920	6,584	3,418	10,203

80	108.5244	0.00005676	6,584	3,418	10,203
81	108.5244	0.00010013	6,584	3,418	10,203
82	108.5244	0.00016680	6,584	3,418	10,203
83	108.5244	0.00000654	6,584	3,418	10,203
84	108.5244	0.00018383	6,584	3,418	10,203
85	108.5244	0.00006973	6,584	3,418	10,203
86	108.5244	0.00012976	6,584	3,418	10,203
87	108.5244	0.00000915	6,584	3,418	10,203
88	108.5244	0.00015539	6,584	3,418	10,203
89	108.5244	0.00009303	6,584	3,418	10,203
90	108.5244	0.00054451	6,584	3,418	10,203
91	108.5244	0.00008850	6,584	3,418	10,203
92	108.5244	0.00055446	6,584	3,418	10,203
93	108.5244	0.00022993	6,584	3,418	10,203
94	108.5244	0.00004575	6,584	3,418	10,203
95	108.5244	0.00056284	6,584	3,418	10,203
96	108.5244	0.00015610	6,584	3,418	10,203
97	108.5244	0.00016861	6,584	3,418	10,203
98	108.5244	0.00010544	6,584	3,418	10,203
99	108.5244	0.00010761	6,584	3,418	10,203
100	108.5244	0.00003920	6,584	3,418	10,203

Table D.2 Results from 100 jitter runs for scenario 19_1 for WAG. Jitter run 0 corresponds to the original optimized estimates. Note: B_{MSY} reference points were based on average recruitment for 1987–2012.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**12.0048**	**0.00018382**	**5,176**	**1,831**	**5,741**
1	12.0048	0.00020306	5,176	1,831	5,741
2	12.0048	0.00022315	5,176	1,831	5,741
3	12.0048	0.00006551	5,176	1,831	5,741
4	14.2432	0.00046758	5,532	1,912	5,910
5	12.0048	0.00012866	5,176	1,831	5,741
6	12.0048	0.00000595	5,176	1,831	5,741
7	9.9980	0.00015851	5,670	1,929	5,997
8	12.0048	0.00001447	5,176	1,831	5,741
9	9.9980	0.00017029	5,670	1,929	5,997
10	12.0048	0.00072925	5,176	1,831	5,741
11	12.0048	0.00054967	5,176	1,831	5,741
12	12.0048	0.00010234	5,176	1,831	5,741
13	12.0048	0.00005552	5,176	1,831	5,741
14	12.0048	0.00015787	5,176	1,831	5,741
15	12.0048	0.00012732	5,176	1,831	5,741
16	12.0048	0.00001726	5,176	1,831	5,741
17	12.0048	0.00009354	5,176	1,831	5,741
18	12.0048	0.00020537	5,176	1,831	5,741
19	12.0048	0.00008776	5,176	1,831	5,741
20	12.0048	0.00010251	5,176	1,831	5,741
21	12.0048	0.00004000	5,176	1,831	5,741
22	12.0048	0.00015839	5,176	1,831	5,741
23	12.0048	0.00019508	5,176	1,831	5,741
24	12.0048	0.00018912	5,176	1,831	5,741
25	12.0048	0.00014118	5,176	1,831	5,741
26	12.0048	0.00009186	5,176	1,831	5,741
27	12.0048	0.00003851	5,176	1,831	5,741
28	12.0048	0.00003228	5,176	1,831	5,741
29	12.0048	0.00009755	5,176	1,831	5,741
30	12.0048	0.00004661	5,176	1,831	5,741
31	12.0048	0.00001021	5,176	1,831	5,741
32	12.0048	0.00047176	5,176	1,831	5,741
33	14.2432	0.00001721	5,532	1,912	5,910
34	NA	NA	NA	NA	NA
35	12.0048	0.00034421	5,176	1,831	5,741
36	12.0048	0.00008064	5,176	1,831	5,741

37	12.0048	0.00031788	5,176	1,831	5,741
38	12.0048	0.00020530	5,176	1,831	5,741
39	12.0048	0.00032915	5,176	1,831	5,741
40	12.0048	0.00015036	5,176	1,831	5,741
41	12.0048	0.00003404	5,176	1,831	5,741
42	NA	NA	NA	NA	NA
43	8.9832	0.00003104	5,760	1,909	5,985
44	9.9980	0.00005094	5,670	1,929	5,997
45	12.0048	0.00008802	5,176	1,831	5,741
46	12.0048	0.00020453	5,176	1,831	5,741
47	8.9832	0.00038883	5,760	1,909	5,985
48	12.0048	0.00006047	5,176	1,831	5,741
49	NA	NA	NA	NA	NA
50	12.0048	0.00005564	5,176	1,831	5,741
51	12.0048	0.00031332	5,176	1,831	5,741
52	12.0048	0.00016600	5,176	1,831	5,741
53	12.0048	0.00006754	5,176	1,831	5,741
54	12.0048	0.00011545	5,176	1,831	5,741
55	12.0048	0.00026613	5,176	1,831	5,741
56	12.0048	0.00015730	5,176	1,831	5,741
57	12.0048	0.00011702	5,176	1,831	5,741
58	12.0048	0.00008183	5,176	1,831	5,741
59	12.0048	0.00035406	5,176	1,831	5,741
60	12.0048	0.00008772	5,176	1,831	5,741
61	12.0048	0.00007139	5,176	1,831	5,741
62	12.0048	0.00004616	5,176	1,831	5,741
63	12.0048	0.00019302	5,176	1,831	5,741
64	12.0048	0.00007680	5,176	1,831	5,741
65	14.0510	0.00000970	5,669	1,935	5,970
66	12.0048	0.00008575	5,176	1,831	5,741
67	8.9832	0.00005520	5,760	1,909	5,985
68	12.0048	0.00008454	5,176	1,831	5,741
69	12.0048	0.00016487	5,176	1,831	5,741
70	12.0048	0.00001696	5,176	1,831	5,741
71	12.0048	0.00010773	5,176	1,831	5,741
72	12.0048	0.00044903	5,176	1,831	5,741
73	12.0048	0.00005129	5,176	1,831	5,741
74	12.0048	0.00013604	5,176	1,831	5,741
75	12.0048	0.00000918	5,176	1,831	5,741
76	9.9980	0.00022635	5,670	1,929	5,997
77	12.0048	0.00011279	5,176	1,831	5,741
78	8.9832	0.00002840	5,760	1,909	5,985
79	12.0048	0.00017031	5,176	1,831	5,741

80	9.9980	0.00007145	5,670	1,929	5,997
81	9.9980	0.00002225	5,670	1,929	5,997
82	12.0048	0.00032589	5,176	1,831	5,741
83	12.0048	0.00023430	5,176	1,831	5,741
84	12.0048	0.00024683	5,176	1,831	5,741
85	12.0048	0.00009399	5,176	1,831	5,741
86	12.0048	0.00015281	5,176	1,831	5,741
87	12.0048	0.00019518	5,176	1,831	5,741
88	12.0048	0.00012389	5,176	1,831	5,741
89	12.0048	0.00017609	5,176	1,831	5,741
90	12.0048	0.00004449	5,176	1,831	5,741
91	12.0048	0.00017768	5,176	1,831	5,741
92	12.0048	0.00004224	5,176	1,831	5,741
93	12.0048	0.00001789	5,176	1,831	5,741
94	12.0048	0.00010999	5,176	1,831	5,741
95	9.9980	0.00005282	5,670	1,929	5,997
96	12.0048	0.00005739	5,176	1,831	5,741
97	12.0048	0.00000249	5,176	1,831	5,741
98	12.0048	0.00010971	5,176	1,831	5,741
99	12.0048	0.00012626	5,176	1,831	5,741
100	12.0048	0.00008679	5,176	1,831	5,741

Table D.3. Results from 100 jitter runs for scenario 19_2a for EAG. Jitter run 0 corresponds to the original optimized estimates. Note: B_{MSY} reference points were based on average recruitment for 1987–2012.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**98.9350**	**0.00220451**	**6,635**	**2,656**	**8,431**
1	98.9350	0.00005061	6,635	2,656	8,431
2	98.9350	0.00025215	6,635	2,656	8,431
3	98.9350	0.00001897	6,635	2,656	8,431
4	98.9350	0.00047266	6,635	2,656	8,431
5	98.9350	0.00008656	6,635	2,656	8,431
6	98.9350	0.00026322	6,635	2,656	8,431
7	98.9350	0.00001076	6,635	2,656	8,431
8	98.9350	0.00014052	6,635	2,656	8,431
9	98.9350	0.00027672	6,635	2,656	8,431
10	98.9350	0.00025903	6,635	2,656	8,431
11	98.9350	0.00010192	6,635	2,656	8,431
12	98.9350	0.00005431	6,635	2,656	8,431
13	98.9350	0.00013773	6,635	2,656	8,431
14	98.9350	0.00062415	6,635	2,656	8,431
15	98.9350	0.00030986	6,635	2,656	8,431
16	98.9350	0.00012384	6,635	2,656	8,431
17	98.9350	0.00010802	6,635	2,656	8,431
18	98.9350	0.00000473	6,635	2,656	8,431
19	98.9350	0.00008735	6,635	2,656	8,431
20	98.9350	0.00017034	6,635	2,656	8,431
21	98.9350	0.00009046	6,635	2,656	8,431
22	98.9350	0.00006774	6,635	2,656	8,431
23	98.9350	0.00004319	6,635	2,656	8,431
24	98.9350	0.00016437	6,635	2,656	8,431
25	98.9350	0.00008285	6,635	2,656	8,431
26	98.9350	0.00014131	6,635	2,656	8,431
27	98.9350	0.00005240	6,635	2,656	8,431
28	98.9350	0.00008080	6,635	2,656	8,431
29	98.9350	0.00003179	6,635	2,656	8,431
30	98.9350	0.00032008	6,635	2,656	8,431
31	98.9350	0.00008112	6,635	2,656	8,431
32	98.9350	0.00027994	6,635	2,656	8,431
33	98.9350	0.00027537	6,635	2,656	8,431
34	98.9350	0.00004613	6,635	2,656	8,431
35	98.9350	0.00027592	6,635	2,656	8,431
36	98.9350	0.00009002	6,635	2,656	8,431

37	98.9350	0.00005911	6,635	2,656	8,431
38	98.9350	0.00098377	6,635	2,656	8,431
39	98.9350	0.00025026	6,635	2,656	8,431
40	98.9350	0.00007010	6,635	2,656	8,431
41	98.9350	0.00050483	6,635	2,656	8,431
42	98.9350	0.00020079	6,635	2,656	8,431
43	98.9350	0.00007397	6,635	2,656	8,431
44	98.9350	0.00001915	6,635	2,656	8,431
45	98.9350	0.00002672	6,635	2,656	8,431
46	98.9350	0.00002425	6,635	2,656	8,431
47	98.9350	0.00011851	6,635	2,656	8,431
48	98.9350	0.00015965	6,635	2,656	8,431
49	98.9350	0.00035529	6,635	2,656	8,431
50	98.9350	0.00001112	6,635	2,656	8,431
51	98.9350	0.00004687	6,635	2,656	8,431
52	98.9350	0.00013227	6,635	2,656	8,431
53	98.9350	0.00025765	6,635	2,656	8,431
54	98.9350	0.00004983	6,635	2,656	8,431
55	98.9350	0.00004199	6,635	2,656	8,431
56	98.9350	0.00042957	6,635	2,656	8,431
57	98.9350	0.00005388	6,635	2,656	8,431
58	98.9350	0.00004797	6,635	2,656	8,431
59	98.9350	0.00021588	6,635	2,656	8,431
60	98.9350	0.00035240	6,635	2,656	8,431
61	98.9350	0.00015409	6,635	2,656	8,431
62	98.9350	0.00004914	6,635	2,656	8,431
63	98.9350	0.00002380	6,635	2,656	8,431
64	98.9350	0.00007796	6,635	2,656	8,431
65	98.9350	0.00001817	6,635	2,656	8,431
66	98.9350	0.00005540	6,635	2,656	8,431
67	98.9350	0.00016910	6,635	2,656	8,431
68	98.9350	0.00011864	6,635	2,656	8,431
69	98.9350	0.00014533	6,635	2,656	8,431
70	98.9350	0.00003525	6,635	2,656	8,431
71	98.9350	0.00023926	6,635	2,656	8,431
72	98.9350	0.00002570	6,635	2,656	8,431
73	98.9350	0.00006938	6,635	2,656	8,431
74	98.9350	0.00004828	6,635	2,656	8,431
75	98.9350	0.00001484	6,635	2,656	8,431
76	98.9350	0.00007852	6,635	2,656	8,431
77	98.9350	0.00012094	6,635	2,656	8,431
78	98.9350	0.00002564	6,635	2,656	8,431
79	98.9350	0.00015410	6,635	2,656	8,431

80	98.9350	0.00003088	6,635	2,656	8,431
81	98.9350	0.00003733	6,635	2,656	8,431
82	98.9350	0.00002000	6,635	2,656	8,431
83	98.9350	0.00032593	6,635	2,656	8,431
84	98.9350	0.00019526	6,635	2,656	8,431
85	98.9350	0.00021407	6,635	2,656	8,431
86	98.9350	0.00032090	6,635	2,656	8,431
87	98.9350	0.00012003	6,635	2,656	8,431
88	98.9350	0.00015566	6,635	2,656	8,431
89	98.9350	0.00007121	6,635	2,656	8,431
90	98.9350	0.00002203	6,635	2,656	8,431
91	98.9350	0.00005271	6,635	2,656	8,431
92	98.9350	0.00037249	6,635	2,656	8,431
93	98.9350	0.00009763	6,635	2,656	8,431
94	98.9350	0.00033723	6,635	2,656	8,431
95	98.9350	0.00015707	6,635	2,656	8,431
96	98.9350	0.00022095	6,635	2,656	8,431
97	98.9350	0.00005962	6,635	2,656	8,431
98	98.9350	0.00015658	6,635	2,656	8,431
99	98.9350	0.00011312	6,635	2,656	8,431
100	98.9350	0.00001896	6,635	2,656	8,431

Table D.4 Results from 100 jitter runs for scenario 19_2 for WAG. Jitter run 0 corresponds to the original optimized estimates. Note: B_{MSY} reference points were based on average recruitment for 1987–2012.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**10.5983**	**0.00082425**	**5,174**	**1,724**	**5,430**
1	10.5983	0.00011058	5,174	1,724	5,430
2	10.5983	0.00010558	5,174	1,724	5,430
3	10.5983	0.00026167	5,174	1,724	5,430
4	10.5983	0.00040994	5,174	1,724	5,430
5	10.5983	0.00011106	5,174	1,724	5,430
6	10.5983	0.00010598	5,174	1,724	5,430
7	10.5983	0.00014270	5,174	1,724	5,430
8	10.5983	0.00004026	5,174	1,724	5,430
9	10.5983	0.00024259	5,174	1,724	5,430
10	15.2881	0.00011151	5,471	1,770	5,584
11	10.5983	0.00024071	5,174	1,724	5,430
12	10.5983	0.00002014	5,174	1,724	5,430
13	10.5983	0.00021256	5,174	1,724	5,430
14	10.5983	0.00007823	5,174	1,724	5,430
15	10.5983	0.00006527	5,174	1,724	5,430
16	10.5983	0.00013656	5,174	1,724	5,430
17	12.2552	0.00010209	5,542	1,791	5,650
18	10.5983	0.00029437	5,174	1,724	5,430
19	12.2552	0.00010219	5,542	1,791	5,650
20	12.2552	0.00008522	5,542	1,791	5,650
21	10.5983	0.00011096	5,174	1,724	5,430
22	10.5983	0.00018497	5,174	1,724	5,430
23	10.5983	0.00006415	5,174	1,724	5,430
24	10.5983	0.00007716	5,174	1,724	5,430
25	10.5983	0.00012036	5,174	1,724	5,430
26	10.5983	0.00003911	5,174	1,724	5,430
27	10.5983	0.00011934	5,174	1,724	5,430
28	10.5983	0.00012605	5,174	1,724	5,430
29	10.5983	0.00019706	5,174	1,724	5,430
30	15.2881	0.00002597	5,471	1,770	5,584
31	10.5983	0.00004627	5,174	1,724	5,430
32	10.5983	0.00005286	5,174	1,724	5,430
33	10.5983	0.00013577	5,174	1,724	5,430
34	10.5983	0.00018601	5,174	1,724	5,430
35	10.5983	0.00041979	5,174	1,724	5,430
36	10.5983	0.00015026	5,174	1,724	5,430

37	10.5983	0.00020795	5,174	1,724	5,430
38	10.5983	0.00020491	5,174	1,724	5,430
39	10.5983	0.00034183	5,174	1,724	5,430
40	10.5983	0.00035498	5,174	1,724	5,430
41	10.5983	0.00062835	5,174	1,724	5,430
42	10.5983	0.00006200	5,174	1,724	5,430
43	10.5983	0.00016800	5,174	1,724	5,430
44	10.5983	0.00005308	5,174	1,724	5,430
45	10.5983	0.00003170	5,174	1,724	5,430
46	10.5983	0.00024692	5,174	1,724	5,430
47	10.5983	0.00007671	5,174	1,724	5,430
48	10.5983	0.00022411	5,174	1,724	5,430
49	10.5983	0.00013150	5,174	1,724	5,430
50	10.5983	0.00009045	5,174	1,724	5,430
51	15.6088	0.00004377	5,596	1,824	5,681
52	10.5983	0.00003371	5,174	1,724	5,430
53	10.5983	0.00022699	5,174	1,724	5,430
54	12.2552	0.00014177	5,542	1,791	5,650
55	10.5983	0.00032630	5,174	1,724	5,430
56	10.5983	0.00029168	5,174	1,724	5,430
57	10.5983	0.00035747	5,174	1,724	5,430
58	10.5983	0.00002259	5,174	1,724	5,430
59	10.5983	0.00030140	5,174	1,724	5,430
60	10.5983	0.00006033	5,174	1,724	5,430
61	10.5983	0.00017884	5,174	1,724	5,430
62	12.2552	0.00009428	5,542	1,791	5,650
63	10.5983	0.00012856	5,174	1,724	5,430
64	10.5983	0.00008975	5,174	1,724	5,430
65	10.5983	0.00035089	5,174	1,724	5,430
66	10.5983	0.00038820	5,174	1,724	5,430
67	10.5983	0.00011772	5,174	1,724	5,430
68	10.5983	0.00013030	5,174	1,724	5,430
69	10.5983	0.00005639	5,174	1,724	5,430
70	10.5983	0.00014941	5,174	1,724	5,430
71	10.5983	0.00049187	5,174	1,724	5,430
72	10.5983	0.00008074	5,174	1,724	5,430
73	10.8981	0.00017206	5,674	1,826	5,695
74	10.5983	0.00000739	5,174	1,724	5,430
75	10.5983	0.00013654	5,174	1,724	5,430
76	10.5983	0.00002294	5,174	1,724	5,430
77	10.5983	0.00019720	5,174	1,724	5,430
78	10.5983	0.00007537	5,174	1,724	5,430
79	10.5983	0.00040316	5,174	1,724	5,430

80	10.5983	0.00016887	5,174	1,724	5,430
81	10.5983	0.00012809	5,174	1,724	5,430
82	10.5983	0.00017558	5,174	1,724	5,430
83	10.5983	0.00011734	5,174	1,724	5,430
84	10.5983	0.00008249	5,174	1,724	5,430
85	10.5983	0.00026630	5,174	1,724	5,430
86	10.5983	0.00026680	5,174	1,724	5,430
87	10.5983	0.00022976	5,174	1,724	5,430
88	10.5983	0.00077521	5,174	1,724	5,430
89	10.5983	0.00012832	5,174	1,724	5,430
90	10.5983	0.00013345	5,174	1,724	5,430
91	10.8981	0.00049018	5,674	1,826	5,695
92	10.8981	0.00032380	5,674	1,826	5,695
93	10.5983	0.00024174	5,174	1,724	5,430
94	10.5983	0.00013448	5,174	1,724	5,430
95	10.5983	0.00023735	5,174	1,724	5,430
96	10.5983	0.00019920	5,174	1,724	5,430
97	10.5983	0.00005063	5,174	1,724	5,430
98	10.5983	0.00010792	5,174	1,724	5,430
99	10.5983	0.00033559	5,174	1,724	5,430
100	10.5983	0.00060659	5,174	1,724	5,430

Pribilof Islands Golden King Crab

– 2017 Tier 5 Assessment

2017 Crab SAFE Report Chapter (May 2017)

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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, and 2015) to 155 t (341,908 lb) in 1995, when seven vessels made landings. The fishery is not rationalized. There is no state harvest strategy in regulation. A guideline harvest level (GHL) was first established for the fishery in 1999 at 91 t (200,000 lb). The GHL was reduced to 68 t (150,000 lb) for 2000–2014 and reduced to 59 t (130,000 lb) in 2015. No vessels participated in the directed fishery and no landings were made during 2006–2009. Catch data from 2003–2005 and 2010–2014 cannot be reported here under the confidentiality requirements of State of Alaska (SOA) statute Sec. 16.05.815. The 2003 and 2004 fisheries were closed by emergency order to manage the 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. Discarded (non-retained) catch has occurred in the directed golden king crab fishery and in the eastern Bering Sea snow crab fishery and in the Bering Sea grooved Tanner crab fishery. Estimates of annual total fishery mortality during 2001–2015 due to crab fisheries range from 0 t to 73 t, with an average of 24 t. There was no discarded catch during crab fisheries in 2015/16. Discarded catch also occurs in Bering Sea groundfish fisheries. Estimates of annual fishery mortality during 1991/92–2015/16 due to groundfish fisheries range from <1 t to 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 2016). Total fishery mortality in groundfish fisheries during the 2016 crab fishing year was 0.24 t.

3. Stock biomass:

Stock biomass (all sizes, both sexes) of golden king crab have been estimated for the Pribilof Canyon area using the area-swept technique applied to data obtained from the erstwhile biennial eastern Bering Sea upper continental slope trawl survey performed by NMFS-AFSC in 2002, 2004, 2008, 2010, 2012, and 2016 (Hoff and Britt 2003, 2005, 2009, 2011; Hoff 2013, 2016). See Appendices A1–A3 for summaries of the slope survey as they pertain to data on and estimates of Pribilof Island golden king crab stock biomass. Complete data on size-sex composition of survey catch are available only from the 2008–2016 biennial surveys (C. Armistead, NMFS-AFSC, Kodiak). Biomass estimates by sex and size class from the 2008, 2010, and 2012 surveys were presented in a May 2013 (Gaeuman 2013a) report to the Crab Plan Team and biomass estimates of mature males from the 2008–2012 biennial surveys were presented in a September 2013 (Gaeuman 2013b) report to the Crab Plan Team. Biomass estimates from the 2016 survey have not been presented to the Crab Plan Team prior to this report.

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 in 2012 to 897 t in 2016, and from 256 t in 2012 to 475 t 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; Appendices A2 and A3). No vessels participated in the 2015 or 2016 directed fisheries (i.e., retained catch= 0 t; 0 lb) and no bycatch was observed in crab fisheries in these years; 0.24 t of fishery mortality occurred during groundfish fisheries in 2016. Overfishing did not occur in 2016. The GHL for the 2018 season has yet to be established (M.Stichert, ADF&G, Kodiak, *pers. comm.*, 1 April 2017). The 2018 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
2013	N/A	N/A	68	Conf. [c]	Conf. [c]	91	82
2014	N/A	N/A	68	Conf. [c]	Conf. [c]	91	82
2015	N/A	N/A	59	0	1.92	91	68
2016	N/A	N/A	59	0	0.24	91	68
2017	N/A	N/A	59			93	70
2018	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 2013 and 2014 because the directed fishery is confidential.
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
2013	N/A	N/A	150,000	Conf.[c]	Conf.[c]	0.20	0.18
2014	N/A	N/A	150,000	Conf.[c]	Conf.[c]	0.20	0.18
2015	N/A	N/A	130,000	0	0.004	0.20	0.15
2016	N/A	N/A	130,000	0	<0.001	0.20	0.15
2017	N/A	N/A	130,000			0.20	0.15
2018						0.20	0.15

a. Guideline harvest level.
b. Total retained catch plus estimated bycatch mortality of discarded catch during crab fisheries and groundfish fisheries. Estimates of annual bycatch mortality during 1991/92–2016 groundfish fisheries are ≤19,480 lb, with an average of 5,098 lb.
c. Confidential under Sec. 16.05.815 (SOA statute). GHL not attained.

6. **<u>Basis for the OFL and ABC</u>:** The values for 2018 are the author's recommendation.

Calendar Year	**Tier**	**Years to define Average catch (OFL)**	**Natural Mortality[b]**	**Buffer**
2013	5	1993–1998[a]	0.18 yr^{-1}	10%
2014	5	1993–1998[a]	0.18 yr^{-1}	10%
2015	5	1993–1998[a]	0.18 yr^{-1}	25%
2016	5	1993–1998[a]	0.18 yr^{-1}	25%
2017	5	1993–1998[a]	0.18 yr^{-1}	25%
2018	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. **<u>PDF of the OFL:</u>**

Sampling distribution of the recommended Tier 5 OFL was estimated by bootstrapping. The standard deviation of the estimated sampling distribution of the recommended OFL (Alternative 1) is 23 t (CV = 0.25; section G.1).

8. **<u>Basis for the ABC recommendation:</u>**

A 25% buffer on the OFL, the default; i.e., ABC = (1-0.25)·OFL. This is a data-poor stock.

9. **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 avoid exceeding the ABC. The GHL remained at 59 t (130,000 lb) in 2016 and 2017. The GHL for the 2018 has yet to be established.

2. Changes to the input data:
- Retained catch and discarded catch data have been updated with the results for the 2016 directed fishery, during which no vessels participated, and bycatch in other crab fisheries in 2016, which was zero.
- Discarded catch estimates from groundfish fisheries have been listed by calendar year from 2009 to 2016, including 0.24 t of bycatch mortality for 2016.

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 2013–2017 Tier 5 OFLs; computations applied directly to data and estimates expressed in metric units resulted in minor changes in results due to rounding used in previous assessments.

B. Responses to SSC and CPT Comments

- **Responses to the most recent two sets of SSC and CPT comments on assessments in general (and relevant to this assessment):**
  - CPT, May 2016: *None pertaining to a Tier 5 assessment*.
  - SSC, June 2016: *None pertaining to a Tier 5 assessment*.
  - CPT, September 2016: None pertaining to a Tier 5 assessment.
  - SSC, October 2015: *None.*

- **Responses to the most recent two sets of SSC and CPT comments specific to the assessment:**
  - CPT, May 2016:
    - *"A Tier 4 assessment based on a random effects model was presented at the September 2015 meeting. Information on mature and legal male biomass from the slope trawl surveys was only available for three years (2008, 2010, and 2012), and the model runs did not appear to be able to estimate a process error term with the available data. A slope trawl survey is planned for the summer of 2016 and the CPT will re-evaluate the model with the new survey results in January or May 2017………"*
      - Response: The author has conducted the preliminary model analysis with the 2016 survey included, and includes those results in an updated discussion paper.
  - SSC, June 2016:

- *"In June 2015, the SSC requested that the author approach the harvester about whether they would voluntarily allow confidential data to be presented in assessments. However, this was not done. The SSC reiterates this request."*
    - Still not done. No directed fishery since 2014. Waivers have been obtained from harvesters for the confidential seasons and discussions are in progress as to which processor waivers are needed (M. Westphal, ADF&G, Dutch Harbor, *pers. comm.*, 14 April 2017).
- "*Finally, the SSC reiterates last year's request for NMFS to assess the feasibility to provide groundfish PSC data for PIGKC by calendar year*".
    - Groundfish bycatch data for PIGKC is provided by NMFS-AFSC by calendar year from 2009 to 2016, and is included in this assessment.
- "*A Tier 4 assessment based on a random effects model was presented to the CPT in September 2015, but it was unable to estimate process error. That Tier 4 assessment was based on 5 years of slope trawl surveys. The plan is to reevaluate the random effects model after results from the 2016 slope trawl survey become available in 2017. The SSC looks forward to a future Tier 4 assessment.*"
    - Not done. The author reran the model with 2016 slope survey data with an associated discussion paper. However, the author does not present this in relation to a Tier 4 or modified Tier 5 assessment. The previous analyst (Gaeuman) has since left the department, dirupting continuity in this process.

- CPT, September 2015 and 2016:
    - "*The CPT recommends the random effects model be re-evaluated after results from the 2016 slope survey are available.*"
        - Response: See above.
- SSC, October 2015:
    - *"The SSC concurs with the CPT recommendation"* ["*that the random effects model be re-evaluated after results from the 2016 slope survey are available*"]
        - Response: Okay. See above.

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. They are frequently found on coral bottom (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). Biomass estimates from the 2016 slope survey have not been presented to the Crab Plan Team prior to this document. Results of the 2002–2016 biennial eastern Bering Sea continental slope trawl surveys show that the biomass, number, and density (in number per area and in weight per area) of golden king crab on the eastern Bering Sea continental slope are higher in the southern areas than in the northern areas (Gaeuman 2013a, 2013b; Haaga et al. 2009; Hoff 2013, 2016; Hoff and Britt 2003, 2005, 2009, 2011; Pengilly 2015). 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). Most of the commercial fishery catches for golden king crab have occured in the Pribilof Canyon area (Neufeld and Barnard 2003; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006; Leon et al. 2017). Similar to previous year's biomass, the 2016 survey shows biomass was highest in survey subarea 2.

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; 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 2 years or less and that females carry embryos for less than two years with a prolonged period in which they remain in barren condition (Watson et al. 2002). From laboratory studies of golden king crab collected from Prince William Sound, Paul and Paul (2001b) estimated a 20-month reproductive cycle with a 12-month clutch brooding period.

Numerous observations on clutch and embryo condition of mature female golden king crab captured during surveys have been consistent with asynchronous, aseasonal reproduction (Otto and Cummiskey 1985; Hiramoto 1985; Sloan 1985; Somerton and Otto 1986; Blau and Pengilly 1994; Blau et al. 1998; Watson et al. 2002). Based on data from Japan (Hiramoto and Sato 1970), McBride et al. (1982) suggested that spawning of golden king crab in the Bering Sea and Aleutian Islands occurs predominately during the summer and fall.

The success of asynchronous and aseasonal spawning of golden king crab may be facilitated by fully 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. <u>Brief summary of management history</u>:

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, 1 vessel fished in each of 2010 and 2012–2014, and 2 vessels fished in 2011.

The fishery is not rationalized and has been managed inseason to a guideline harvest level (GHL) since 1999. The GHL for 1999 was 91 t (200,000 lb), whereas the GHL for 2000–2014 was 68 t (150,000 lb). Following the reduction of ABC from 82 t for 2014 to 68 t for 2015, the GHL was reduced in 2015 to 59 t (130,000 lb).

Catch statistics for 2003–2005 and 2010–2014 are confidential under Sec. 16.05.815 of SOA statutes. It can be noted, however, that the 2003 and 2004 fisheries were closed by emergency order to manage the fishery retained catch towards the GHL, whereas the 2005 and 2010–2014 fisheries were not closed by emergency order. With regard to 2004, “Catch rates during the 2004 fishery were among the highest on record, and the fishery was the shortest ever at approximately three weeks in duration” (Bowers et al. 2005).

A summary of relevant fishery regulations and management actions pertaining to the Pribilof District golden king crab fishery is provided below.

Only males of a minimum legal size may be retained. By State of Alaska regulation (**5 AAC 34.920 (a)**), the minimum legal size limit for Pribilof District golden king crab is 5.5-inches (140 mm) carapace width (CW), including spines. A carapace length (CL) ≥124 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007). Golden king crab may be commercially fished only with king crab pots (as defined in 5 AAC 34.050); pots used to take golden king crab in Registration Area Q (Bering Sea) may be longlined (5 AAC 34.925(f)). Pots used to fish for golden king crab in the Pribilof District must have at least four escape rings of no less than five and one-half inches inside diameter installed on the vertical plane or at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized golden king crab (5 AAC 34.925 (c)) and the sidewall “…must contain an opening equal to or exceeding 18 inches in length... The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread.” (5 AAC 39.145(1)). There is a pot limit of 40 pots for vessels ≤125-feet LOA and of 50 pots for vessels >125-feet LOA (5 AAC 34.925 (e)(1)(B)). Golden king crab can be harvested from 1 January through 31 December only under conditions of a permit issued by the commissioner of ADF&G (**5 AAC 34.910 (b)(3)**). Since 2001, those conditions have included the carrying of a fisheries observer.

D. Data

1. Summary of new information:

1. Retained catch and estimated discarded catch during the 2016 directed fishery (no effort and no catch), estimated discarded catch during other crab fisheries in 2016 (no catch), and the estimated discarded catch in groundfish fisheries during 2016 have been added.

2. Data presented as time series:

a. Total catch and b. Information on bycatch and discards:

- The 1981/82–1983/84, 1984–2016 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 1993–2016 time series of weight of retained catch and estimated weight of discarded catch and estimated weight of fishery mortality of Pribilof golden king crab during the directed fishery and all other crab fisheries are given in Table 2. Discarded catch of Pribilof golden king crab occurs mainly in the directed golden king crab fishery, when prosecuted, and to a lesser extent in the Bering Sea snow crab fishery

and the Bering Sea grooved Tanner crab fishery when prosecuted. Because the Bering Sea snow crab fishery is largely prosecuted between January and May and the Bering Sea grooved Tanner crab fishery is prosecuted with a calendar year season, discarded catch in the crab fisheries can be estimated on a calendar year basis to align with the calendar-year season for Pribilof District golden king crab. Observer data on size distributions and estimated catch numbers of discarded catch were used to estimate the weight of discarded catch of golden king crab by applying a weight-at-length estimator (see below). Observers were first deployed to collect discarded catch data during the Pribilof District golden king crab fishery in 2001 and during the Bering Sea grooved Tanner crab fishery in 1994. Retained catch or observer data are confidential for at least one of the crab fisheries in 1999–2001, 2003–2005, and 2010−2014. Following Siddeek et al. (2014), the bycatch mortality rate of golden king crab captured and discarded during Aleutian Islands golden king crab fishery was assumed to be 0.2. Following Foy (2013), bycatch mortality rate of king crab during the snow crab fishery was assumed to be 0.5. The bycatch mortality rate during the grooved Tanner crab fishery was also assumed to be 0.5.

- The groundfish fishery discarded catch data are grouped into crab fishery years from 1991/92–2008/09, and by calendar years from 2009–2016. The 1991/92–2016 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 2009–2016 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 Appendices A2-A3 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 Appendices A1–A3 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 = 0.001424 and B = 2.781 for females.

c. Natural mortality rate:

The default natural mortality rate assumed for king crab species by NPFMC (2007) is M=0.18. Note, however, natural mortality was not used for OFL estimation because this stock belongs to Tier 5.

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

- Standardized bottom trawl surveys to assess the groundfish and invertebrate resources of the eastern Bering Sea upper continental slope were performed in 2002, 2004, 2008, 2010, 2012, and 2016 (Hoff and Britt 2003, 2005, 2009, 2011; Haaga et al. 2009, Gaeuman 2013a, 2013b; Hoff 2016). Data and analysed results pertaining to golden king crab from the 2008–2016 EBS upper continental slope surveys are provided in Appendices A1–A3, 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) and Pengilly (2015) presented assessment-modelling approaches for this stock to the Crab Plan Team using data from the biennial NMFS EBS continental slope survey Appendices A2 and A3). However, following the cancellation of the 2014 slope survey, this stock continued to be managed as a Tier 5 stock for 2017, 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 2018.

Additionally, NPFMC (2007) states that for estimating the OFL of Tier 5 stocks, “The time period selected for computing the average catch, hence the OFL, should be based on the best scientific information available and provide the required risk aversion for stock conservation and utilization goals.” Given that a total-catch OFL is to be used, alternative configurations for the Tier 5 model are limited to: 1) alternative time periods for computing the average total-catch mortality; and 2) alternative approaches for estimating the discarded catch component of the total catch mortality during that period.

With regard to choosing from alternative time periods for computing average annual catch to compute the OFL, NPFMC (2007) suggested using the average retained catch over the years 1993 to 1999 as the estimated OFL for Pribilof District golden king crab. Years post-1984 were chosen based on an assumed 8-year lag between hatching and growth to legal size after the 1976/77 “regime shift”. With regard to excluding data from years 1985 to 1992 and years after 1999, NPFMC (2007) states, “The excluded years are from 1985 to 1992 and from 2000 to 2005 for Pribilof Islands golden king crab when the fishing effort was less than 10% of the average or the GHL was set below the previous average catch.” In 2008 the CPT and SSC endorsed the approach of estimating OFL as the average retained catch during 1993–1999 for setting a retained-catch OFL for 2009. However, in May 2009 the CPT set a retained-catch OFL for 2010, but using the average retained catch during 1993–1998; 1999 was excluded because it was the first year that a preseason GHL was established for the fishery. In May 2010, the CPT established a total-catch OFL computed as a function of the average retained catch during 1993–1998, a ratio-based estimate of the bycatch mortality during the directed fishery of that period, and an estimate of the “background” bycatch mortality due to other fisheries. Other time periods, extending into years post-1999, had been considered for computing the average retained catch in the establishment of the 2009, 2010, 2011 OFLs, but those time periods were rejected by the CPT and the SSC. Hence the period for calculating the retained-catch portion of the Tier 5 total-catch OFL for this stock has been firmly established by the CPT and SSC at 1993–1998 (the CPT said “this freezes the time frame...”). For the 2012 and the 2013 OFLs, the CPT and SSC recommended the period 2001–2010 for calculating the ratio-based estimate of the bycatch mortality during the 1993–1998 directed fishery, the period 1994–1998 for calculating the estimated bycatch mortality due to non-directed crab fisheries during 1993–1998, and the period 1992/93–1998/99 for calculating the estimated bycatch mortality due to groundfish fisheries during 1993–1998.

Two alternative approaches for determination of the 2013 OFL were presented to the CPT and SSC in May–June 2013. Alternative 1 was the status quo approach (i.e., the approach used to establish the 2012 total-catch OFL). Alternative 2 was the same as Alternative 1 except that it used updated discarded catch data from crab fisheries in 2011. Alternative 2 was presented specifically to allow the CPT and the SSC to clarify whether the 2013 and subsequent OFLs should be computed using data collected after 2010, or if the time periods for data used to calculate the 2013 and subsequent OFLs should be “frozen” at the years used to calculate the 2012 OFL. The CPT and the SSC both recommended Alternative 1, clarifying that Tier 5 OFLs for future years should be computed using only data collected through 2010. Following that recommendation from CPT and the SSC, only one alternative was presented for computing the 2014–2017 Tier 5 OFLs (i.e., the Alternative 1 that was presented in 2013). The 2018 Tier 5 OFL recommended here uses the same approach as used for the 2013–2017 Tier 5 OFLs.

3. <u>Model Selection and Evaluation</u>:

a. <u>*Description of alternative model configurations*</u>

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.,

$$OFL_{2018} = (1+R_{2001–2010})*RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,92/93–98/99},$$

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).

The estimated average annual bycatch mortality in non-directed fisheries during 1994–1998 is used to estimate the average annual bycatch mortality in non-directed fisheries during 1993–1998 because there are no discarded catch data available for the non-directed fisheries during 1993.

The estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99 is used to estimate the average annual bycatch mortality in groundfish fisheries during 1993–1998 because 1992/93–1998/99 is the shortest time period of crab fishery years that encompasses calendar years 1993–1998.

Statistics on the data and estimates used to calculate $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$ are provided in Table 5; the column means in Table 5 are the calculated values of $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$. Using the calculated values of $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$, the calculated value of OFL_{2018} is,

$$OFL_{2018} = (1+0.052)*78.80 \text{ t} + 6.09 \text{ t} + 3.79 \text{ t} = 93 \text{ t } (204{,}527 \text{ lbs}).$$

b. ***Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed:*** See the table, below.

Model	**Retained-vs.Total-catch**	**Time Period**	**Resulting OFL (t)**
Recommended/status quo	Total-catch	1993–1998	93

This is recommended as being the best approach with the limited data available and follows the advice of the CPT and SSC to “freeze” the period for calculation of the OFL at the time period that was established for the 2012 OFL and uses the computations recommended by the CPT and SSC in 2013.

c. ***Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models:*** See Section E, above.

d. ***Convergence status and convergence criteria for the base-case model (or proposed base-case model):*** Not applicable.

e. ***Table (or plot) of the sample sizes assumed for the compositional data:*** Not applicable.

f. ***Do parameter estimates for all models make sense, are they credible?:***

The time period used for determining the OFL was established by the SSC in June 2012. Retained catch data come from fish tickets and annual retained catch is considered a known (not estimated) value. Estimates of discarded catch from crab fisheries data are generally considered credible (e.g., Byrne and Pengilly 1998; Gaeuman 2011, 2013c, 2014), but may have greater uncertainty in a small, low effort fishery such as the Pribilof golden king crab fishery. Estimates of bycatch mortality are estimates of discarded catch times an assumed bycatch mortality rate. The assumed bycatch mortality rates (i.e., 0.2 for crab fisheries, 0.5 for fixed-gear groundfish fisheries, and 0.8 for trawl groundfish fisheries) have not been estimated from data.

g. ***Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty:*** See section E.3.c, above.

h. ***Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach):*** Not applicable.

i. ***Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented:*** See section E.3.c, above.

4. Results (best model(s)):

a. List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties: Not applicable.

b. Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons): See Tables 2–5.

c. Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible): Information requested for this subsection is not applicable to a Tier 5 stock.

d. Evaluation of the fit to the data: Not applicable for Tier 5 stock.

e. Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments): Not applicable for Tier 5 stock.

f. Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.): For this assessment, the major uncertainties are:

- Whether the time period is "representative of the production potential of the stock" and if it serves to "provide the required risk aversion for stock conservation and utilization goals." Or whether any such time period exists.
  - Only a period of 6 years is used to compute the OFL, 1993–1998. The SSC has noted its uneasiness with that situation ("6 years of data are very few years upon which to base these catch specifications." June 2011 SSC minutes).
- No data on discarded catch due to the directed fishery are available from the period used to compute the OFL. Estimation of the OFL rests on the assumption that data on the ratio of discarded catch to retained catch from post-2000 can be used to accurately estimate that ratio in 1993–1998.
- The bycatch mortality rates used in estimation of total catch. Bycatch mortality is unknown and no data that could be used to estimate the bycatch mortality of this stock are known to the author. Hence, only the values that are assumed for other BSAI king crab stock assessments are considered in this assessment. The estimated OFL increases (or decreases) relative to the bycatch mortality rates assumed: doubling the assumed bycatch mortality rates increases the OFL estimate by a factor of 1.15; halving the assumed bycatch mortality rates decreases the OFL estimate by a factor of 0.92.

F. Calculation of the OFL

1. **Specification of the Tier level and stock status level for computing the OFL:**
   - Recommended as Tier 5, total-catch OFL estimated by estimated average total catch over a specified period.
   - Recommended time period for computing retained-catch OFL: 1993–1998.
     - This is the same time period that was used to establish OFL for 2010–2017. The time period 1993–1998 provides the longest continuous time period through 2016 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. No vessels participated in the 2016 directed fishery and no bycatch was observed in crab fisheries in 2016; therefore total catch in 2016 was zero. Although 0.24 t of fishery mortality occurred during groundfish fisheries in 2016, this level of fishery mortality does not exceed the 2016 OFL. As such, overfishing did not occur in 2016. Values for the 2018 OFL and ABC are the author's recommendations.

Management Performance Table (values in t)

Calendar Year	MSST	Biomass (MMB)	GHL[a]	Retained Catch	Total Catch[b]	OFL	ABC
2013	N/A	N/A	68	Conf. [c]	Conf. [c]	91	82
2014	N/A	N/A	68	Conf. [c]	Conf. [c]	91	82
2015	N/A	N/A	59	0	1.92	91	68
2016	N/A	N/A	59	0	0.24	91	68
2017	N/A	N/A	59			93	70
2018	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 2013 and 2014 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
2013	N/A	N/A	150,000	Conf.[c]	Conf.[c]	0.20	0.18
2014	N/A	N/A	150,000	Conf.[c]	Conf.[c]	0.20	0.18
2015	N/A	N/A	130,000	0	0.004	0.20	0.15
2016	N/A	N/A	130,000	0	<0.001	0.20	0.15
2017	N/A	N/A	130,000			0.20	0.15
2018	N/A	N/A				0.20	0.15

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 2018 (70 t); see G.4, below.

5. <u>Recommended F_{OFL}, OFL total catch and the retained portion for the coming year</u>: See sections ***F.3*** and ***F.4***, above; no F_{OFL} is recommended for a Tier 5 stock.

G. Calculation of ABC

1. PDF of OFL. A bootstrap estimates of the sampling distribution (assuming no error in estimation of discarded catch) of the status quo Alternative 1 OFL is shown in Figure 2 (1,000 samples drawn with replacement independently from each of the four columns of values in Table 5 to calculate $R_{2001\text{-}2010}$, $RET_{1993\text{-}1998}$, $BM_{NC,1994\text{-}1998}$, $BM_{GF,92/93\text{-}98/99}$, and OFL_{2016}). The mean and CV computed from the 1,000 replicates are 92 t and 0.25, respectively. Note that generated sampling distribution and computed standard deviation are meaningful as measures in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Sections E.2 and E.4.f).

2. List of variables related to scientific uncertainty.

- Bycatch mortality rate in each fishery that discarded catch occurs. Note that for Tier 5 stocks, an increase in an assumed bycatch mortality rate will increase the OFL (and hence the ABC), but has no effect on the retained-catch portion of the OFL or the retained-catch portion of the ABC.
- Estimated discarded catch and bycatch mortality for each fishery that discarded catch occurred in during 1993–1998.
- The time period to compute the average catch under the assumption of representing "a time period determined to be representative of the production potential of the stock."
- Stock size in 2018 is unknown.

3. List of additional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

5. **Author recommended ABC.** 25% buffer on OFL; i.e., ABC = (1-0.25)·(93 t) = 70 t (153,395 lb).

H. Rebuilding Analyses

Not applicable; this stock has not been declared overfished.

I. Data Gaps and Research Priorities

Data from the 2008–2012 biennial NMFS-AFSC eastern Bering Sea upper continental slope trawl surveys have been examined for their utility in determining overfishing levels and stock status by Gaeuman (2103a, 2013b) and Pengilly (2015). Cancellation of the survey that was scheduled for 2014 raised uncertainties on the prospects for obtaining fishery-independent survey data on this stock in the future; however, a slope survey was conducted in summer 2016. Those data are included in an updated discussion paper presented to the CPT.

J. Literature Cited

Barnard, D. R., and R. Burt. 2004. Alaska Department of Fish and Game summary of the 2002 mandatory shellfish observer program database for the general and CDQ crab fisheries. Alaska Department of Fish and Game, Regional Information Report No. 4K04-27, Kodiak.

Barnard, D. R., and R. Burt. 2006. Alaska Department of Fish and Game summary of the 2005 mandatory shellfish observer program database for the non-rationalized crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 06-36, Anchorage.

Blau, S. F., and D. Pengilly. 1994. Findings from the 1991 Aleutian Islands golden king crab survey in the Dutch Harbor and Adak management areas including analysis of recovered tagged crabs. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 4K94-35, Kodiak.

Blau, S. F., L. J. Watson, and I. Vining. 1998. The 1997 Aleutian Islands golden king crab survey. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 4K98-30, Kodiak.

Bowers, F.B., B. Failor-Rounds, and M.E. Cavin. 2005. Annual management report for the commercial shellfish fisheries of the Bering Sea, 2004. Pages 71–186 *in* Bowers, F.R., K.L. Bush, M. Schwenzfeier, J. Barnhart, M. Bon, M.E. Cavin, S. Coleman, B. Failor-Rounds, K. Milani, and M. Salmon. 2005. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the Westward Region's Shellfish Observer Program, 2004. Alaska Department of Fish and Game, Fishery Management Report No. 05-51, Anchorage.

Burt, R., and D. R. Barnard. 2005. Alaska Department of Fish and Game summary of the 2003 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 05-05, Anchorage.

Burt, R., and D. R. Barnard. 2006. Alaska Department of Fish and Game summary of the 2004 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 06-03, Anchorage.

Byrne, L. C., and D. Pengilly. 1998. Evaluation of CPUE estimates for the 1995 crab fisheries of the Bering Sea and Aleutian Islands based on observer data. Pages 61–74 *in*: Fishery stock assessment models, edited by F. Funk, T.J. Quinn II, J. Heifetz, J.N. Iannelli, J.E. Powers, J.F. Schweigert, P.J. Sullivan, and C.-I Zhang, Alaska Sea Grant College Program Report No. AK-SG-98-01, University of Alaska Fairbanks, 1998.

Foy, R. J., 2013. 2013 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Red King Crab Fisheries of the Bering Sea and Aleutian Islands Regions. *in*: Stock Assessment and fishery Evaluation report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions: 2013 Crab SAFE. NPFMC, Anchorage, September 2013.

Gaeuman, W. B. 2011. Summary of the 2010/2011 Mandatory Crab Observer Program Database for the Bering Sea/Aleutian Islands commercial crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 11-73, Anchorage.

Gaeuman, W. B. 2013a. Pribilof Islands golden king crab Tier 4 stock assessment considerations. Report to the North Pacific Fishery Management Council Bering Sea-Aleutian Island Crab Plan Team, 30 April – 3 May 2013 meeting, Anchorage, AK.

Gaeuman, W. B. 2013b. Alternative Pribilof Islands golden king crab stock assessment strategy. Report to the North Pacific Fishery Management Council Bering Sea-Aleutian Island Crab Plan Team, 17–20 September 2013 meeting, Seattle, WA.

Gaeuman, W. B. 2013c. Summary of the 2011/2012 Mandatory Crab Observer Program Database for the Bering Sea/Aleutian Islands commercial crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 13-21, Anchorage.

Gaeuman, W. B. 2014. Summary of the 2013/14 Mandatory Crab Observer Program Database for the Bering Sea/Aleutian Islands commercial crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 14-49, Anchorage.

Haaga, J. A., S. Van Sant, and G. R. Hoff. 2009. Crab abundance and depth distribution along the continental slope of the eastern Bering Sea. Poster presented at the 25th Lowell Wakefield Fisheries Symposium (Biology and Management of Exploited Crab Populations under Climate Change), Anchorage, AK, March 2009. Available online at: ftp://ftp.afsc.noaa.gov/posters/pJHaaga01_ebs-crab.pdf

Hiramoto, K. 1985. Overview of the golden king crab, *Lithodes aequispina*, fishery and its fishery biology in the Pacific waters of Central Japan. *in*: Proc. Intl. King Crab Symp., University of Alaska Sea Grant Rpt. 85-12, Fairbanks.

Hiramoto, K., and S. Sato. 1970. Biological and fisheries survey on an anomuran crab, *Lithodes aequispina* Benedict, off Boso Peninsula and Sagami Bay, central Japan. Jpn. J. Ecol. 20:165-170. In Japanese with English summary.

Hoff, G. R. 2013. Results of the 2012 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-258.

Hoff, G. R. 2016. Results of the 2016 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-339.

Hoff, G. R., and L. Britt. 2003. Results of the 2002 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-141.

Hoff, G .R., and L. Britt. 2005. Results of the 2004 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-156.

Hoff, G. R., and L. Britt. 2009. Results of the 2008 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-197.

Hoff, G. R., and L. Britt. 2011. Results of the 2010 eastern Bering Sea upper continental slope survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-224.

Jewett, S. C., Sloan, N. A., and Somerton, D. A. 1985. Size at sexual maturity and fecundity of the fjord-dwelling golden king crab *Lithodes aequispina* Benedict from northern British Columbia. Journal of Crustacean Biology 5(3):377-385.

Leon, J. M., J. Shaishnikoff, E. Nichols, and M. Westphal. 2017. Annual management report for shellfish fisheries of the Bering Sea–Aleutian Islands management area, 2015/16. Alaska Department of Fish and Game, Fishery Management Report No. 17-10, Anchorage.

McBride, J., D. Fraser, and J. Reeves. 1982. Information on the distribution and biology of the golden (brown) king crab in the Bering Sea and Aleutian Islands area. NOAA, NWAFC Proc. Rpt. 92-02.

National Marine Fisheries Service (NMFS). 2004. Bering Sea Aleutian Islands Crab Fisheries Final Environmental Impact Statement. DOC, NOAA, National Marine Fisheries Service, AK Region, P.O. Box 21668, Juneau, AK 99802-1668, August 2004.

Neufeld, G., and D. R. Barnard. 2003. Alaska Department of Fish and Game summary of the 2001 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 4K03-2, Kodiak.

North Pacific Fishery Management Council (NPFMC). 2007. Public Review Draft: Environmental Assessment for proposed Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions. 14 November 2007. North Pacific Fishery Management Council, Anchorage.

Nyblade, C.F. 1987. Phylum or subphylum Crustacea, class Malacostraca, order Decopoda, Anomura. *in*: M.F. Strathman (ed.), Reproduction and development of marine invertebrates on the northern Pacific Coast. Univ. Wash. Press, Seattle, pp.441-450.

Otto, R. S., and P. A. Cummiskey. 1985. Observations on the reproductive biology of golden king crab (*Lithodes aequispina*) in the Bering Sea and Aleutian Islands. Pages 123–136 *in* Proceedings of the International King Crab Symposium. University of Alaska Sea Grant Report No. 85-12, Fairbanks.

Paul, A. J., and J. M. Paul. 2000. Changes in chela heights and carapace lengths in male and female golden king crabs *Lithodes aequispinus* after molting in the laboratory. Alaska Fishery Research Bulletin 6:70–77.

Paul, A. J., and J. M. Paul. 2001a. Growth of juvenile golden king crabs *Lithodes aequispinus* in the laboratory. Alaska Fishery Research Bulletin 8: 135–138.

Paul, A. J., and J. M. Paul. 2001b. The reproductive cycle of golden king crab *Lithodes aequispinus* (Anomura: Lithodidae). Journal of Shellfish Research 20:369–371.

Pengilly, D. 2015. Discussion paper for September 2015 Crab Plan Team meeting: Random effects approach to modelling NMFS EBS slope survey area-swept estimates for Pribilof Islands golden king crab. Report to the North Pacific Fishery Management Council Bering Sea-Aleutian Island Crab Plan Team, 14-17 September 2015 meeting, Seattle, WA.

Shirley, T. C., and S. Zhou . 1997. Lecithotrophic development of the golden king crab *Lithodes aequispinus* (Anomura: Lithodidae). Journal of Crustacean Biology 17:207–216.

Siddeek, M. S. M., J. Zheng, and D. Pengilly. 2014. Aleutian Islands golden king crab (*Lithodes aequispinus*) model-based stock assessment in spring 2015. http://www.npfmc.org/wp-content/PDFdocuments/membership/PlanTeam/Crab/May2015/AIGKC.pdf

Sloan, N.A. 1985. Life history characteristics of fjord-dwelling golden king crabs *Lithodes aequispina*. Mar. Ecol. Prog. Ser. 22:219-228.

Somerton, D. A., and R.S. Otto. 1986. Distribution and reproductive biology of the golden king crab, *Lithodes aequispina*, in the eastern Bering Sea. Fish. Bull. 84:571-584.

Watson, L. J., D. Pengilly, and S. F. Blau. 2002. Growth and molting probability of golden king crabs (*Lithodes aequispinus*) in the eastern Aleutian Islands, Alaska. Pages 169–187 *in* 2002. A. J. Paul, E. G. Elner, G. S. Jamieson, G. H. Kruse, R. S. Otto, B. Sainte-Marie, T. C. Shirley, and D. Woodby (eds.). Crabs in coldwater regions: Biology, Management, and Economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks.

Webb. J. 2014. Reproductive ecology of commercially important Lithodid crabs. Pages 285–314 *in* B.G. Stevens (ed.): King Crabs of the World: Biology and Fisheries Management. CRC Press, Taylor & Francis Group, New York.

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Table 1a. Commercial fishery history for the Pribilof District golden king crab fishery, 1981/82 through 2016: 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	–	–

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 2016: 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	–	–

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, 1993–2016, 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

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 2009-2016 are listed by calendar year.

Crab fishing year (1991/92–2008/09) or Calendar year (2009-2016)	Bycatch in groundfish fisheries (no mortality rate applied) Fixed	Trawl	Total	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	0.60	0.53	1.13	0.73
2015	0.81	1.89	2.70	1.92
2016	0.23	0.16	0.39	0.24
Average	1.70	1.83	3.53	2.31

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	0.60	0.53
2015	2015/16	0.00	0.00	0.00	0.812	1.890
2016	2016/17	0.00	0.00	0.00	0.231	0.158

a. Year convention for retained weights in directed fishery, 1984-2016, estimates of discarded bycatch weights in directed, non-directed crab fisheries, and grounfish (2009-2016).

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 $RET_{1993\text{-}1998}$ (**t**) and estimates used in calculation of $R_{2001\text{-}2010}$ (ratio, t:t), $BM_{NC,1994\text{-}1998}$ (**t**), and $BM_{GF,92/93\text{-}98/99}$ (**t**) for calculation of the recommended (status quo Alternative 1) Pribilof Islands golden king crab Tier 5 2018 OFL (**t**); values under $RET_{1993\text{-}1998}$ are from Table 1, values under $R_{2001\text{-}2010}$ were computed from the retained catch data and the directed fishery discarded catch estimates in Table 2 (assumed bycatch mortality rate = 0.2), values under $BM_{NC,1994\text{-}1998}$ were computed from the non-directed crab fishery discarded catch estimates in Table 2 (assumed bycatch mortality rate = 0.5) and values under $BM_{GF,92/93\text{-}98/99}$ are from Table 3.

Calendar Year[a]	Crab Fishing Year[b]	$RET_{1993\text{-}1998}$	$R_{2001\text{-}2010}$	$BM_{NC,1994\text{-}1998}$	$BM_{GF,92/93\text{-}98/99}$
1993	1992/93	30.60			8.84
1994	1993/94	40.36		2.48	7.96
1995	1994/95	155.09		8.14	2.70
1996	1995/96	149.24		1.29	1.72
1997	1996/97	81.31		2.03	0.71
1998	1997/98	16.20		16.50	1.06
1999	1998/99				3.53
2000	1999/00				
2001	2000/01		0.054		
2002	2001/02		0.056		
2003	2002/03		conf.		
2004	2003/04		conf.		
2005	2004/05		conf.		
2006	2005/06				
2007	2006/07				
2008	2007/08				
2009	2008/09				
2010	2009/10		conf.		
	N	6	6	5	7
	Mean	78.80	0.052	6.09	3.79
	S.E.M	24.84	0.004	2.87	1.25
	CV	0.32	0.07	0.47	0.33

a. Year convention corresponding with values under $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, and $BM_{NC,1994\text{-}1998}$.
b. Year convention corresponding with values under $BM_{GF,92/93\text{-}98/99}$.

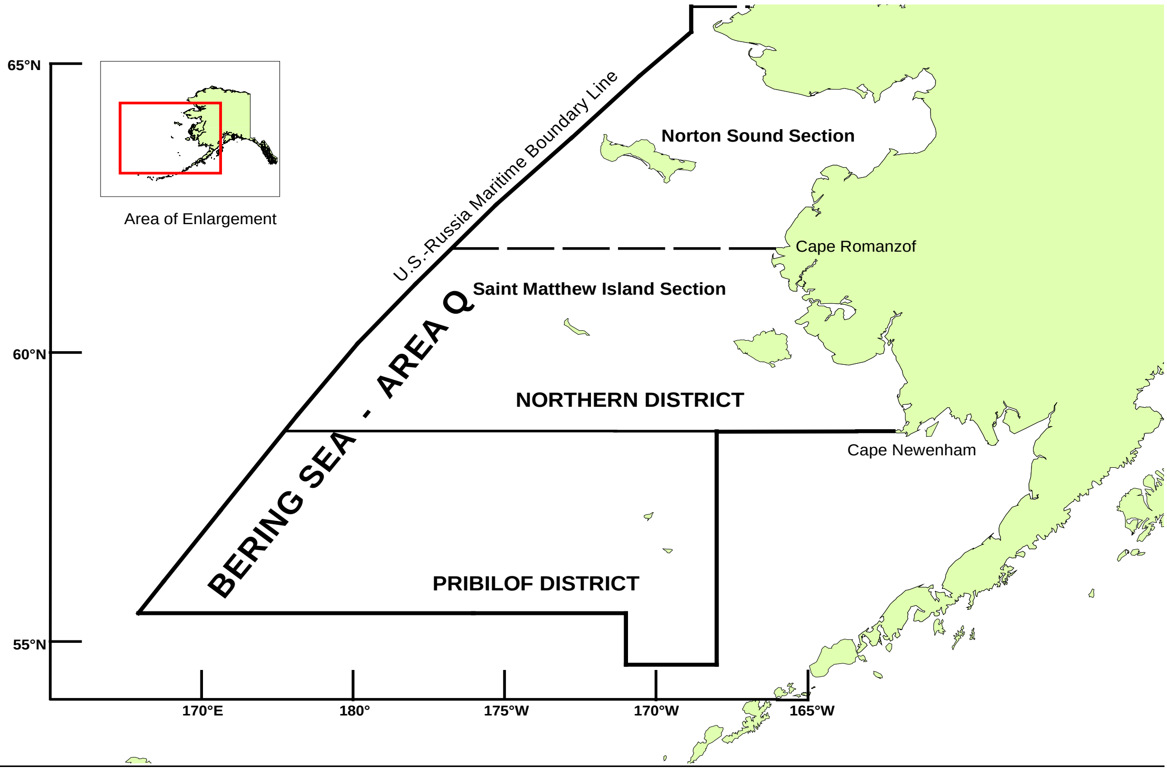

Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District (from Figure 2-4 *in* Leon et al. 2017).

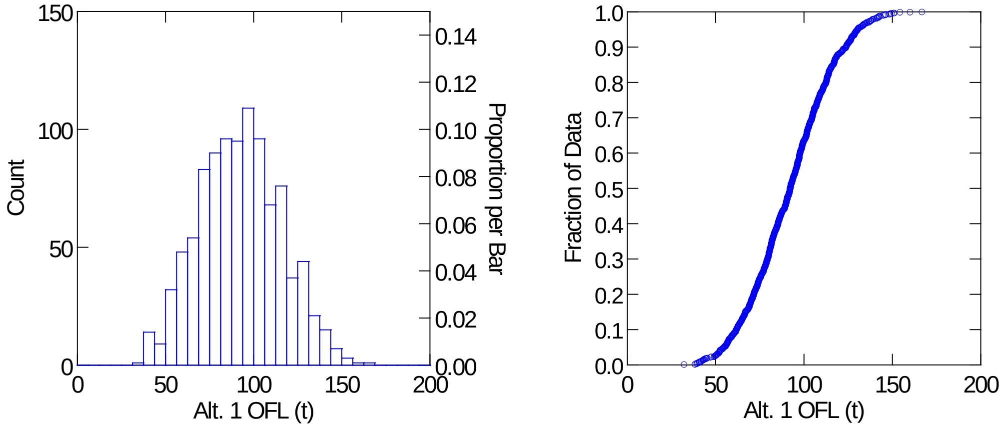

Figure 2. Bootstrapped estimates of the sampling distribution of the 2017 Alternative 1 Tier 5 OFL (total catch, t) for the Pribilof Islands golden king crab stock; histogram on left, quantile plot on right.

Western Aleutian Islands Red King Crab
– 2017 Tier 5 Assessment
2017 Crab SAFE Report Chapter (May 2017)

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Executive Summary

1. **<u>Stock</u>:**

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. **<u>Catches</u>:**

The domestic fishery has been prosecuted since 1960/61 and was opened every year through the 1995/96 crab fishing year. Peak retained catch occurred in 1964/65 at 9,613 t (21,193,000 lb). During the early years of the fishery through the late 1970s, most or all of the retained catch was harvested in the area between 172° W longitude and 179°15' W longitude. As the annual retained catch decreased into the mid-1970s and the early-1980s, the area west of 179°15' W longitude began to account for a larger portion of the retained catch. Retained catch during the 10-year period 1985/86–1994/95 averaged 428 t (942,940 lb), but the retained catch in 1995/96 was only 18 t (38,941 lb). The fishery has been opened only occasionally during 1996/97 to present. There was an exploratory fishery with a low guideline harvest level (GHL) in 1998/99, three commissioner’s permit fisheries in limited areas during 2000/01–2002/03 to allow for ADF&G-Industry surveys, and two commercial fisheries with a GHL of 227 t (500,000 lb) in 2002/03 and 2003/04. Most of the retained catch since 1990/91 was harvested in the Petrel Bank area (between 179° W longitude and 179° E longitude); in 2002/03 and 2003/04 the commercial fishery was opened only in the Petrel Bank area. Retained catch in the last two years with commercial fishing was 229 t (505,642 lb) in 2002/03 and 217 t (479,113 lb) in 2003/04. The fishery has been closed during 2004/05–2015/16. Discarded (non-retained) catch of red king crab occurs in the directed red king crab fishery (when prosecuted), in the Aleutian Islands golden king crab fishery, and in groundfish fisheries. Estimated annual weight of bycatch mortality due to crab fisheries during 1995/96–2015/16 averaged 1 t. Estimated annual weight of bycatch mortality due to groundfish fisheries during 1993/94–2015/16 averaged 9 t. Estimated weight of annual total fishery mortality during 1995/96–2015/16 averaged 36 t; the average annual retained catch during that period was 27 t (60,006 lb). A cooperative red king crab survey was performed by the Aleutian Islands King Crab Foundation (an industry group) and ADF&G in the Adak area in September 2015 (Hilsinger et al. 2016a), which resulted in an estimated bycatch mortality of 0.16 t (346 lb). Estimated total fishery mortality in 2015/16 resulted from groundfish fisheries (1.19 t) and the cooperative survey (0.16 t). 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 (Hilsinger and Siddon 2016b); however, those results and fishery mortality are not included here.

3. <u>Stock biomass</u>:
Estimates of past or present stock biomass are not available for this Tier 5 assessment.

4. <u>Recruitment</u>:
Estimates of recruitment trends and current levels relative to virgin or historic levels are not available for this Tier 5 assessment.

5. <u>Management performance</u>:
Overfishing did not occur during 2015/16 because the 2015/16 estimated total catch (1.3 t; 2,964 lb) did not exceed the Tier 5 OFL established for 2015/16 (56 t; 0.12-million lb). The 2015/16 estimated total catch did not exceed the ABC established for 2015/16 (34 t; 0.07-million lb). No determination has yet been made for a fishery opening or harvest level, if opened, for 2017/18. The OFL and ABC values for 2017/18 in the tables below are the author's status quo, Alternative 1 recommended values.

Management Performance Table (values in t)

Fishing Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch	Total Catch	OFL	ABC
2012/13	N/A	N/A	Closed	0	<1	56	34
2013/14	N/A	N/A	Closed	0	<1	56	34
2014/15	N/A	N/A	Closed	0	<1	56	34
2015/16	N/A	N/A	Closed	0	1.3	56	34
2016/17	N/A	N/A	Closed	0		56	34
2017/18	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
2012/13	N/A	N/A	Closed	0	624	123,867	74,320
2013/14	N/A	N/A	Closed	0	732	123,867	74,320
2014/15	N/A	N/A	Closed	0	474	123,867	74,320
2015/16	N/A	N/A	Closed	0	2,964	123,867	74,320
2016/17	N/A	N/A	Closed	0		123,867	74,320
2017/18	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 for 2017/18 are the author's recommended values.

Year	Tier	Years to define Average catch (OFL)	Natural Mortality	Buffer
2012/13	5	1995/96-2007/08[a]	0.18[b]	40%
2013/14	5	1995/96-2007/08[a]	0.18[b]	40%
2014/15	5	1995/96-2007/08[a]	0.18[b]	40%
2015/16	5	1995/96-2007/08[a]	0.18[b]	40%
2016/17	5	1995/96-2007/08[a]	0.18[b]	40%
2017/18	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 less than the ABC that was recommended by the SSC for 2012/13 – 2016/17. The recommended ABC of 14 t for 2017/18 is lowered because and the industry has not expressed interest in a small test fishery during 2017/18 and because the stock is severely depressed as indicated by the 2016 Petrel survey (CPT minutes for May 2017).

   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 2015/16 have been added, but were not entered into the calculation of the recommended 2017/18 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 2010/11–2016/17 OFLs.

B. Responses to SSC and CPT Comments

1. **Responses to the most recent two sets of SSC and CPT comments on assessments in general:**
    - CPT, May 2016: *None pertaining to a Tier 5 assessment*.
    - SSC, June 2016: *None pertaining to a Tier 5 assessment*.
    - CPT, September 2016 (via September 2015 SAFE Introduction chapter): *None pertaining to a Tier 5 assessment*.
    - SSC, October 2015: *None pertaining to a Tier 5 assessment*.
2. **Responses to the most recent two sets of SSC and CPT comments specific to the assessment:**
    - CPT, May 2016: *None.*
    - SSC, June 2015: "*The industry expressed no desire to pursue a red king crab fishery in the Adak area at this time. However, the Petrel Bank region will be surveyed during September 2016.*"
        - Response: *The Petrel survey was conducted in November 2016 and showed very little RKC (ave CPUE=0.11).*
    - "*The SSC also appreciates the addition of size frequency data in Appendices A1-A4. The SSC requests plotting these data to enable visualization of progression of size modes in next year's assessment.*"
        - Response: Done. See appendix A5.
    - CPT, September 2016: *None*.
    - SSC, October 2016: *None*.

C. Introduction

1. **Scientific name:** *Paralithodes camtschaticus*, Tilesius, 1815

2. **Description of general distribution:**

The general distribution of red king crab is summarized by NMFS (2004):

> Red king crab are widely distributed throughout the BSAI, GOA, Sea of Okhotsk, and along the Kamchatka shelf up to depths of 250 m. Red king crab are found from eastern Korea around the Pacific rim to northern British Columbia and as far north as Point Barrow (page 3-27).
>
> Most red and blue king crab fisheries occur at depths from 50-200 m, but red king crab fisheries in the Aleutian Islands sometimes extend to 300 m.
>
> Red king crab is native to waters of 300 m or less extending from eastern Korea, the northern coast of the Japan Sea, Hokkaido, the Sea of Okhotsk, through the eastern Kamchatkan Peninsula, the Aleutian Islands, the Bering Sea, the GOA, and the Pacific Coast of North America as far south as Alice Arm in British Columbia. They are not found north of the Kamchatkan Peninsula on the Asian Pacific Coast. In North America red king crab range includes commercial fisheries in Norton Sound and sparse populations extending through the Bering Straits as far east as Barrow on the northern coast of Alaska. Red king crab have been acclimated to Atlantic Ocean waters in Russia and northern Norway. In the Bering Sea, red king crab are found near the Pribilof Islands and east through Bristol Bay; but north of Bristol Bay (58 degrees 39 minutes) they are associated with the mainland of Alaska and do not extend to offshore islands such as St. Matthew or St. Laurence Islands.

Commercial fishing for WAI red king crab during the most recent two years that the fishery was prosecuted (2002/03 and 2003/04) was opened only in the Petrel Bank area (i.e., between 179° W longitude and 179° E longitude; Baechler and Cook 2014). Fishery effort during those two years typically occurred at depths of 60–90 fathoms (110–165 m); average depth of pots fished in the Aleutian Islands area during 2002/03 was 68 fathoms (124 m; Barnard and Burt 2004) and during 2003/04 was 82 fathoms (151 m; Burt and Barnard 2005). In the 580 pot lifts sampled by observers in the Aleutian Islands golden king crab fishery during 1996/97–2006/07 that contained 1 or more red king crab, depth was recorded for 578 pots (ADF&G observer database, Dutch Harbor, April 2008). Of those, the deepest recorded depth was 266 fathoms (486 m) and 90% of pot lifts had recorded depths of 100–200 fathoms (183–366 m); no red king crab were present in any of the 6,465 pot lifts sampled during the 1996/97–2006/07 Aleutian Islands golden king crab fishery with depths >266 fathoms (486 m).

In this chapter we will refer to the area west of 171° W longitude within the Aleutian Islands king crab Registration Area O as the “Western Aleutian Islands” (WAI). The Aleutian Islands king crab Registration Area O is described by Baechler and Cook (2014, page 7) as follows (see also Figure 1):

> “The Aleutian Islands king crab Registration Area O has as its eastern boundary the longitude of Scotch Cap Light (164° 44' W longitude), its northern boundary a line from Cape Sarichef (54° 36' N latitude) to 171° W longitude, north to 55° 30' N latitude, and as its western boundary the Maritime Boundary Agreement Line as that line is described in the text of and depicted in the annex to the Maritime Boundary Agreement between the United States and the Union of Soviet Socialist Republics signed in Washington, June 1, 1990. Area O encompasses both the waters of the Territorial Sea (0-3 nautical miles) and waters of the Exclusive Economic Zone (3-200 nautical miles).”

From 1984/85 until the March 1996 Alaska Board of Fisheries meeting, the Aleutian Islands king crab Registration Area O as currently defined had been subdivided at 171° W longitude into the historic Adak Registration Area R and the Dutch Harbor Registration Area O. The geographic boundaries of the WAI red king crab stock are defined here by the boundaries of the historic Adak Registration Area R; i.e., the current Aleutian Islands king crab Registration Area O, west of 171° W longitude. Note that in March 2014 the Alaska Board of Fisheries established two districts for management of commercial fisheries for red king crab in the waters of the Aleutian Islands west of 171° W longitude: 1) the Adak District, 171º to 179º W longitude; and the Petrel District, west of 179º W longitude.

3. 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 (Grant et al. 2014).

We know of no analyses of genetic relationships among red king crab from different locations within the WAI. However, given the expansiveness of the WAI and the canyons between some islands that are deep (>1,000 m) relative to the depth zone restrictions of red king crab (see above), at least some weak structuring within the WAI red king crab stock would be expected. A summary of total retained catch by 1-degree longitude groupings during 1985/86–1995/96 (years for which state statistical area definitions allow for grouping by 1-degree longitude and for which catch distribution was not affected by area closures and openings; see Section C.5) shows that catch and, presumably, distribution of legal-sized male red king crab is not evenly distributed across the Aleutian Islands, with most catch during that period having come from Petrel Bank, followed by the vicinity of Adak, Atka, and Amlia Islands (Figure 2). Note that the 1-degree longitude grouping of catch does not portray the spatial gaps in catch that are apparent in a closer inspection of the 1985/86–1995/96 catch data by state statistical areas. For example, no catch was reported during 1985/86–1995/96 from the two statistical areas (795102 and 795132) that include Amchitka Pass (Amchitka Pass lies between Petrel Bank and the Delarof Is; see Figure 2).

McMullen and Yoshihara (1971) reported the following on male red king crab that were tagged in February 1970 on the Bering Sea and Pacific Ocean sides of Atka Island and recovered in the subsequent fishery:

> "Fishermen landing tagged crabs were questioned carefully concerning the location of recapture. In no instance did crabs migrate through ocean passes between the Pacific Ocean and Bering Sea."

4. **<u>Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology)</u>:**

Red king crab eggs are fertilized externally and the clutch of fertilized eggs (embryos) are carried under the female's abdominal flap until hatching. Male king crab fertilize eggs by passing spermatophores from the fifth periopods to the gonopores and coxae of the female's third periopods; the eggs are fertilized during ovulation and attach to the female's pleopodal setae (Nyblade 1987, McMullen 1967). Females are generally mated within hours after molting (Powell and Nickerson 1965), but may mate up to 13 days after molting (McMullen 1969). Males must wait at least 10 days after completing a molt before mating (Powell et al. 1973), but, unlike females, do not need to molt prior to mating (Powell and Nickerson 1965).

Wallace et al. (1949, page 23) described the "egg laying frequency" of red king crab:

> "Egg laying normally takes place once a year and only rarely are mature females found to have missed an egg laying cycle. The eggs are laid in the spring immediately following shedding [i.e., molting] and mating and are incubated for a period of nearly a year. Hatching of the eggs does not occur until the following spring just prior to moulting [i.e., molting] season."

McMullen and Yoshihara (1971) reported that from 804 female red king crab (79–109-mm CL) collected during the 1969/70 commercial fishery in the western Aleutians, "Female king crab in the western Aleutians appeared to begin mating at 83 millimeters carapace length and virtually all females appeared to be mature at 102 millimeters length." Blau (1990) estimated size at maturity for WAI red king crab females as the estimated CL at which 50% of females are mature (SM50; as evidenced by presence of clutches of eggs or empty) according to a logistic regression: 89-mm CL (SD = 2.6 mm). Size at maturity has not been estimated for

WAI male red king crab. However, because the estimated SM50 for WAI red king crab females is the same as that estimated for Bristol Bay red king crab females (Otto et al. 1990), the estimated maturity schedule used for Bristol Bay red king crab males (see SAFE chapter on Bristol Bay red king crab) could be applied to males in the WAI stock as a proxy.

Few data are available on the molting and mating period for red king crab specifically in the WAI. Among the red king crab captured by ADF&G staff for tagging on the south side of Amlia Island (173° W longitude to 174° W longitude) in the first half of April 1971, males and females were molting, females were hatching embryos, and mating was occurring (McMullen and Yoshihara 1971). The spring mating period for red king crab is known to last for several months, however. For example, although mating activity in the Kodiak area apparently peaks in April, mating pairs in the Kodiak area have been documented from January through May (Powell et al. 2002). Due to the timing of the commercial fishery within a year, little data on reproductive condition of WAI red king crab females have been collected by at-sea fishery observers that can be used for evaluating the mating period. For example, of the 3,211 mature females that were examined during the 2002/03 and 2003/04 red king crab fisheries in the Petrel Bank area, which were prosecuted in late October, only 10 were scored as “hatching” (ADF&G observer database, Dutch Harbor, April 2008).

Data on mating pairs of red king crab collected from the Kodiak area during March–May of 1968 and 1969 showed that size of the females in the pairs increased from March to May, indicating that females tend to release their larvae and mate later in the mating season with increasing body size (Powell et al. 2002). Size of the males in those mating pairs did not increase with later sampling periods, but did show a decreasing trend in estimated time since last molt. In all the data on mating pairs collected from the Kodiak area during 1960–1984, the proportion of males that were estimated to have not recently molted prior to mating decreased monthly over the mating period (Powell et al. 2002). Those data suggest that males that do not molt early in the mating period have an advantage in mating early in the mating period, when primiparous females and smaller, multiparous females tend to ovulate, and that males that do molt early in the mating period likely participate later in the mating period, likely mating with the larger females.

Current knowledge of red king crab reproductive biology, including male and female maturation, migration, mating dynamics, and potential effects of exploitation on reproductive potential, is summarized by Webb (2014).

5. Brief summary of management history:

A complete summary of the management history through 2011/12 is provided by Baechler and Cook (2014, pages 7–13). The domestic fishery for red king crab in the WAI began in 1960/61. Retained catch of red king crab in the Aleutians west of 172° W longitude averaged 5,259 t (11,595,068 lb) during 1960/61–1975/76, with a peak retained catch of 9,613 t (21,193,000 lb) in 1964/65 (Tables 1a and 1b, Figure 3). Guideline harvest levels (GHL; sometimes expressed as ranges, with an upper and lower GHL) for the fishery were established in most years since 1973/74. The fishery was closed in 1976/77 in the area west of 172º W longitude, but was reopened for each year during 1977/78–1995/96. Average retained catch during 1977/78–1995/96 (for the area west of 172º W longitude prior to 1984/85 and for the area west of 171º W longitude since 1984/85) was 470 t (1,036,659 lb); the peak retained catch during that period occurred in 1983/84 at 899 t (1,981,579 lb). During the mid-to-late 1980s, significant portions of the catch during the WAI red king crab fishery occurred west of 179º E longitude or east of 179º W longitude, whereas most of the retained catch was harvested from the Petrel Bank area (179° W longitude to 179° W longitude) during 1990/91–1994/95 (Figure 4). Retained catch and fishery CPUE (retained crab per pot lift) declined from 1993/94 to 1994/95 and 1995/96; retained catch in 1994/95 and, especially, 1995/96 was far below the lower GHL established. Due to concerns about the low stock level and poor recruitment indicated by results of the fishery in 1994/95–1995/96, the fishery was closed in 1996/97–1997/98. During 1998/99–2003/04 the fishery was opened only in restricted areas, either as an open fishery managed under a GHL or as an ADF&G-Industry survey conducted as a commissioner's permit fishery (Table 2); peak retained catch during that period was 229 t (505,642 lb) harvested from the Petrel Bank area in 2002/03. The fishery has been closed during 2004/05–2015/16.

Only males of a minimum legal size may be retained by the commercial red king crab fishery in the WAI. By State of Alaska regulation (**5 AAC 34.620 (a)**), the minimum legal size limit is 6.5-inches (165 mm) carapace width (CW), including spines. A carapace length (CL) ≥138 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007). Except for the years 1968–1970, the minimum size has been 6.5-inches CW since 1950; in 1968 there was a "first-season" minimum size of 6.5-inches CW and a "second-season" minimum size of 7.0-inches and in 1969–1970 the minimum size was 7.0-inches CW (Donaldson and Donaldson 1992).

Red king crab may be commercially fished only with king crab pots (as defined in **5 AAC 34.050**). Pots used to fish for red king crab in the WAI must, since 1996, have at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized red king crab and may not be longlined (**5 AAC 34.625 (e)**). The sidewall of the pot "…must contain an opening equal to or exceeding 18 inches in length... The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread." (**5 AAC 39.145(1)**).

The WAI red king crab fishery west of 179° W longitude has been managed since 2005/06 under the Crab Rationalization program (50 CFR Parts 679 and 680). The WAI red king crab fishery in the area east of 179° W longitude was not included in the Crab Rationalization program (Baechler and Cook 2014). In March 2014 the Alaska Board of Fisheries established two red king crab management districts in state regulations for the Aleutian Islands west of 171° W longitude (the Adak District, 171º to 179º W longitude; and the Petrel District, west of 179º W longitude) and some notable differences in regulations exist between the two districts. The red king crab commercial fishing season in the Adak District is August 1 to February 15, unless closed by emergency order (**5 AAC 34.610 (a) (1)**); the red king crab commercial fishing season in the Petrel is October 15 to February 15, unless closed by emergency order (**5 AAC 34.610 (a) (2)**). Only vessels 60 feet or less in overall length may participate in the commercial red king crab fishery within the state waters of the Adak District (**5 AAC 34.610 (d)**); no vessel size limit is established for federal waters in the Adak District or for state or federal waters in the Petrel District. Federal waters in the Adak District are opened to commercial red king crab fishing only if the season harvest level established by ADF&G for the Adak District is 250,000 lb or more (**5 AAC 34.616 (a) (2)**); there is no comparable regulation for the Petrel District. In the Adak District, pots commercially fished for red king crab may only be deployed and retrieved between 8:00 AM and 5:59 PM each day (**5 AAC 34.625 (g) (2)**) and the following pot limits pertain: 10 pots per vessel for vessels fishing within state waters (**5 AAC 34.625 (g) (1) (A)**); and 15 pots per vessel for vessels fishing in federal waters (**5 AAC 34.625 (g) (1) (B)**). In the Petrel District there is no regulation pertaining to periods for operation of gear and a pot limit of 250 pots per vessel (**5 AAC 34.625 (d)**). See also "6. Brief description of the annual ADF&G harvest strategy," below.

6. Brief description of the annual ADF&G harvest strategy:

Prior to the March 2014 Alaska Board of Fisheries meeting, when the board adopted a harvest strategy for the Adak District only, there was no harvest strategy in state regulation for WAI red king crab. Following results of the January/February and November 2001 ADF&G-Industry pot surveys for red king crab in the Petrel Bank area, which produced high catch rates of legal males (CPUE = 28), but low catches of females and sublegal males, ADF&G opened the fishery in 2002/03 and 2003/04 with a GHL of 227 t (500,000 lb); that GHL was established as the minimum GHL that could be managed inseason, given expected participation and effort (Baechler and Cook 2014). The fishery was closed in 2004/05 due to continued uncertainty on the status of pre-recruit legal males, a reduction in legal male CPUE from 18 in 2002/03 to 10 in 2003/04, and a strategy adopted by ADF&G to close the fishery before the CPUE of legal crab dropped below 10.

The harvest strategy for red king crab in the Adak District adopted by the Alaska Board of Fisheries in March 2014 is as follows:

> **5 AAC 34.616. Adak District red king crab harvest strategy.** (a) In the Adak District, based on the best scientific information available, if the department determines that there is a harvestable surplus of
>
> (1) red king crab available in the waters of Alaska in the Adak District, the commissioner may open, by emergency order, a commercial red king crab fishery only in the waters of Alaska in the Adak District under 5 AAC 34.610(a)(1);
>
> (2) at least 250,000 pounds of red king crab in the Adak District, the commissioner may open, by emergency order, a commercial red king crab fishery in the entire Adak District under 5 AAC 34.610(a)(1).
>
> (b) In the Adak District, during a season opened under 5 AAC 34.610(a)(1), the operator of a validly registered king crab fishing vessel shall
>
> (1) report each day to the department
>
> (A) the number of pot lifts;
>
> (B) the number of crab retained for the 24-hour fishing period preceding the report; and
>
> (C) any other information the commissioner determines is necessary for the management and conservation of the fishery, as specified in the vessel registration certificate issued under 5 AAC 34.020; and
>
> (2) complete and submit a logbook as prescribed and provided by the department.

7. **Summary of the history of B_{MSY}:** Not applicable for this Tier 5 stock.

D. Data

1. Summary of new information:

- Retained catch data from the 2015/16 directed fishery has been added; the fishery was closed and the retained catch was 0 t (0 lb).
- Data on discarded catch in crab and groundfish fisheries has been updated with data from the 2015/16 Aleutian Islands golden king crab fishery (no bycatch of WAI RKC) and the 2015/16 groundfish fisheries in reporting areas 541, 542, and 543 (Figure 5).

- Discarded catch during the cooperative industry-ADF&G survey in 2015. Data was available as number of crab caught per size/sex group (males: legal, pre recruit, or juvenile and females). Assumptions were made on the representative size (width) of each group, which were converted to length then weight. A bycatch mortality rate of 0.2 (as applied to crab fisheries) was applied to the estimated total weight caught.

2. <u>Data presented as time series</u>:

a. <u>Total catch</u> and b. <u>Information on bycatch and discards</u>:

- Annual retained catch weight for 1960/61–2015/16 (Tables 1a and 1b, Figure 3).
- Annual retained catch weight and estimated weights of discarded legal males, discarded sublegal males, and discarded females captured by commercial crab fisheries during 1995/96–2015/16 (Table 3). Observer data on size distributions and estimated catch numbers of discarded catch were used to estimate the weight of discarded catch of red king crab by applying a weight-at-length estimator (see below). Estimates of discarded catch prior to 1995/96 are not given due to non-existence of data or to limitations on sampling for discarded catch during the crab fisheries: prior to 1988/89 there was no fishery observer program for Aleutian Islands crab fisheries and observers were required only on vessels processing king crab at sea (including catcher-processor vessels) during 1988/89–1994/95; observer data from the Aleutian Islands prior to 1990/91 is considered unreliable; and the observer data from the directed WAI red king crab fishery in 1990/91 and 1992/93–1994/95 and golden king crab fishery in the 1993/94–1994/95 are confidential due to the limited number of observed vessels. During 1995/96–2004/05, observers were required on all vessels fishing for king crab in the Aleutian Islands area at all times that a vessel was fishing. With the advent of the Crab Rationalization program in 2005/06, all vessels fishing for golden king crab in the Aleutian Islands area are now required to carry an observer for a period during which 50% of the vessel's retained catch was obtained during each trimester of the fishery; observers continue to be required at all times on a vessel fishing in the red king crab fishery west of 179° W longitude. All red king crab that were captured and discarded during the Aleutian Islands golden king crab fishery west of 174° W longitude by a vessel while an observer was on board during 2001/02–2002/03 and 2004/05–2015/16 were counted and recorded for capture location and biological data.
- Annual estimated weight of discarded catch and estimated bycatch mortality in the WAI (reporting areas 541, 542, and 543; i.e., Aleutian Islands west of 170° W longitude; Figure 5) during federal groundfish fisheries by gear type (fixed or trawl) for 1993/94–2015/16 (Table 4). Following Foy (2012a, 2012b), the bycatch mortality rate of king crab captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crab captured by trawls during groundfish fisheries was assumed to be 0.8. Estimates of discarded catch by gear type for 1992/93 are available, but appear to be suspect because they are extremely low. Annual estimated weight of discarded catch during federal groundfish fisheries by reporting area (541, 542, and 543) for 1993/94–2015/16 is also presented in Table 5.
- Annual estimated weight of total fishery mortality for 1995/96–2015/16, partitioned into retained catch, estimated bycatch mortality during crab fisheries, and estimated bycatch mortality during federal groundfish fisheries (Table 6). Following Siddeek et al. (2011), the bycatch mortality rate of king crab captured and discarded during Aleutian Islands king crab fisheries was assumed to be 0.2; bycatch mortality in crab fisheries was estimated for Table 6 by applying that assumed bycatch mortality rate to

the estimates of discarded catch given in Table 3. The estimates of bycatch mortality in groundfish fisheries given in Table 6 are from Table 4.

- Table 7 summarizes the available data on retained catch weight and estimates of discarded catch weight.

c. ***Catch-at-length:*** Although not used in a Tier 5 assessment, available retained-catch size frequency sample data from 1960/61–2015/16 are summarized and presented (Appendices A1–A4).

d. Survey biomass estimates: Not available; there is no program for regular performance of standardized surveys sampling from the entirety of the stock range.

e. Survey catch at length: Not used in a Tier 5 assessment; none are presented.

f. ***Other data time series:*** Although not used in a Tier 5 assessment, available data on CPUE (retained crab per pot lift) from 1972/73–2015/16 directed fisheries are presented (Table 1, Figure 6).

3. Data which may be aggregated over time:

a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):

Not used in a Tier 5 assessment. Growth per molt was estimated for WAI male red king crab by Vining et al. (2002) based on information received from recoveries during commercial fisheries of tagged red king crab released in the Adak Island to Amlia Island area during the 1970s (see Table 5 in Pengilly 2009). Vining et al. (2002) used a logit estimator to estimate the probability as a function of carapace length (CL, mm) at release that a male WAI red king tagged and released in new-shell condition would molt within 8–14 months after release (see Tables 6 and 7 in Pengilly 2009).

b. Weight-at length or weight-at-age (by sex):

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female red king crab according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007) are: A = 0.000361 and B = 3.16 for males and A = 0.022863 and B = 2.23382 for females; note that although the estimated parameters, A and B, are those estimated for ovigerous females, those parameters were used to estimate the weight of all females without regard to reproductive status. Estimated weights in grams were converted to lb by dividing by 453.6.

c. ***Natural mortality rate:***

Not used in a Tier 5 assessment. NPFMC (2007) assumed a natural mortality rate of M = 0.18 for king crab species, but natural mortality rate has not been estimated specifically for red king crab in the WAI.

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

- Distribution of effort and catch during the 2006 ADF&G Petrel Bank red king crab pot survey (Gish 2007) and the 2009 ADF&G Petrel Bank red king crab pot survey (Gish 2010).
- Sex-size distribution of catch and distribution of effort and catch during the January/February 2001 and November 2001 ADF&G-Industry red king crab survey of the Petrel Bank area (Bowers et al. 2002) and ADF&G-Industry red king crab pot

survey conducted as a commissioner's permit fishery in November 2002 in the Adak Island and Atka-Amlia Islands areas (Granath 2003).

- Observer data on size distribution and geographic distribution of discarded catch of red king crab in the WAI red king crab fishery and the Aleutian Islands golden king crab fishery, 1988/89–2015/16 (ADF&G observer database).
- Summary of data collected by ADF&G WAI red king crab fishery observers or surveys during 1969–1987 (Blau 1993).

E. Analytic Approach

1. <u>History of modeling approaches for this stock</u>: This is a Tier 5 assessment.

2. <u>Model Description</u>: *Subsections a–i are not applicable to a Tier 5 assessment.*
There is no regular survey of this stock. No assessment model for the WAI red king crab stock exists and none is in development. The SSC in June 2010 recommended that: the WAI red king crab stock be managed as a Tier 5 stock; the OFL be specified as a total-catch OFL; the total-catch OFL be established as the estimated average annual weight of the retained catch and bycatch mortality in crab and groundfish fisheries over the period 1995/96–2007/08; and the period used for computing the Tier 5 total-catch OFL be fixed at 1995/96–2007/08.

Given the strong recommendations from the SSC in June 2010, Tier 5 total-catch OFLs would change only if retained catch data and estimates of discarded catch for the period 1995/96–2007/08 or assumed values of bycatch mortality rates used in the 2010 SAFE were revised. Given that no need has been shown to revise either the retained catch data or the discarded catch estimates for the period 1995/96–2007/08 or assumed values of bycatch mortality rates used in the 2010 SAFE, the recommended approach for establishing the 2017/18 OFL is the approach identified by the SSC in June 2010 and no alternative approaches are suggested by the author. Hence the recommended total-catch OFL for 2017/18 is computed according to the status quo "Alternative 1" approach as:

$$OFL_{2017/18} = RET_{95/96\text{-}07/08} + BM_{CF,\ 95/96\text{-}07/08} + BM_{GF,\ 95/96\text{-}07/08},$$

where,

- $RET_{95/96\text{-}07/08}$ is the average annual retained catch in the directed crab fishery during 1995/96–2007/08
- $BM_{CF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the directed and non-directed crab fisheries during 1995/96–2007/08, and
- $BM_{GF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the groundfish fisheries during 1995/96–2007/08.

Given the June 2010 SSC recommendations, items ***E.2 a–i*** are not applicable.

3. <u>Model Selection and Evaluation</u>:

a. *<u>Description of alternative model configurations</u>*
Not applicable; see section E.2.

b. *<u>Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed</u>:* None; see section A.4.

c. ***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 6.

c. ***Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible):*** Not applicable to a Tier 5 assessment.

d. ***Evaluation of the fit to the data:*** Not applicable to a Tier 5 assessment.

e. ***Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments):*** Not applicable to a Tier 5 assessment.

f. ***Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.):*** For a Tier 5 assessment, the major uncertainties are:

- Whether the time period is "representative of the production potential of the stock" and if it serves to "provide the required risk aversion for stock conservation and utilization goals." Or whether any such time period exists.
    - In this regard, the CPT (May 2011 minutes) noted that the OFL (56 t; 0.12-million lb) that was established for this stock by the SSC in June 2010 "could be considered biased high because of years of high exploitation" and questioned "whether the time frame used to compute the OFL is meaningful as an estimate of the productivity potential of this stock."
- The bycatch mortality rates used in estimation of total catch. Being as most (78%) of the estimated total mortality during 1995/96–2007/08 is due to the retained catch component, the total catch estimate is not severely sensitive to the assumed bycatch mortality rates. Doubling the assumed bycatch mortality during crab fisheries from 0.2 to 0.4 would increase the OFL by a factor of 1.02; halving that assumed rate from 0.2 to 0.1 would decrease the OFL by a factor of 0.99. Increasing the assumed bycatch mortality rate for all groundfish fisheries (regardless of gear type) to 1.0, would increase the OFL by a factor of 1.07.

F. Calculation of the OFL

1. <u>Specification of the Tier level and stock status level for computing the OFL:</u>

- Recommended as Tier 5, total-catch OFL computed as the estimated average annual total catch over a specified period.
- Recommended time period for computing retained-catch portion of the OFL: 1995/96–2007/08.
- Recommended time period for computing bycatch mortality due to crab fisheries: 1995/96–2007/08.
- Recommended time period for computing bycatch mortality due to groundfish fisheries: 1995/96–2007/08.
- Recommended bycatch mortality rates: 0.2 for crab fisheries; 0.5 for fixed-gear groundfish fisheries; 0.8 for trawl groundfish fisheries.
- Recommended OFL for 2017/18 is estimated by,

$$OFL_{2017/18} = RET_{95/96\text{-}07/08} + BM_{CF,\ 95/96\text{-}07/08} + BM_{GF,\ 95/96\text{-}07/08},$$

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,

$$OFL_{2017/18} = 43.97\ t + 1.36\ t + 10.86\ t = 56\ t\ (123{,}867\ lb).$$

2. <u>List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan</u>: Not applicable to Tier 5 assessment.

3. 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 2015/16 directed fishery and no bycatch was observed in crab fisheries in 2015/16. Total catch mortality in 2015/16 consists of what occurred during groundfish fisheries (1.19 t) and the cooperative industry-ADF&G survey (0.16 t). Overfishing did not occur in 2015/16. The OFL and ABC values for 2017/18 in the table below are the author's recommended values. The 2017/18 TAC has not yet been established.

Management Performance Table (values in t)

Fishing Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch	Total Catch	OFL	ABC
2012/13	N/A	N/A	Closed	0	<1	56	34
2013/14	N/A	N/A	Closed	0	<1	56	34
2014/15	N/A	N/A	Closed	0	<1	56	34
2015/16	N/A	N/A	Closed	0	1.3	56	34
2016/17	N/A	N/A	Closed			56	34
2017/18	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
2012/13	N/A	N/A	Closed	0	624	123,867	74,320
2013/14	N/A	N/A	Closed	0	732	123,867	74,320
2014/15	N/A	N/A	Closed	0	474	123,867	74,320
2015/16	N/A	N/A	Closed	0	2,964	123,867	74,320
2016/17	N/A	N/A	Closed			123,867	74,320
2017/18	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 7 (the sample means of 1,000 samples drawn with replacement from the 1995/96–2007/08 estimates of total fishery mortality in Table 6). The mean (56 t) and CV (0.42) computed from the 1,000 replicates are essentially the same as for the mean and CV of the 1995/96–2007/08 total catch estimates given in Table 6. Note that generated sampling distribution is meaningful as a measure in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Section E.4.f).

2. List of variables related to scientific uncertainty.

- The time period to compute the average catch relative to the assumption that it represents "a time period determined to be representative of the production potential of the stock."
- Bycatch mortality rate in each fishery that bycatch occurs. Note that for a Tier 5 assessment, an increase in an assumed bycatch mortality rate will increase the OFL (and hence the ABC), but has no effect on the retained catch portion of the OFL or the retained catch portion of the ABC.
- Estimated discarded catch and bycatch mortality during each fishery that bycatch occurred in during 1995/96–2007/08.

3. List of additional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

4. Author recommended ABC: 14 t. This is lower than the ABC that has been recommended by the author since the SSC recommended a 34 t ABC for 2012/13. The SSC's recommended ABC of 34 t for 2012/13 was determined as a value "sufficient to cover bycatch and the proposed test fishery catch" (June 2012 SSC meeting minutes, page 10). It provides a 40% buffer on the OFL of 56 t. However, the industry has not expressed interest in conducting a test fishery for 2017/18. Further, the 2016 Petrel survey indicated the stock is severely depressed. Thus, the author and CPT recommends increasing the buffer to 75%.

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.

J. Literature Cited

Alaska Department of Fish and Game (ADF&G). 1978. Westward Region shellfish report to the Alaska Board of Fisheries, April 1978. Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak.

Baechler, B., and C. Cook 2014. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, 2011/12. Pages 3–71 *in* Fitch, H., M. Schwenzfeier, B. Baechler, C. Trebesch, M. Salmon, M. Good, E. Aus, C. Cook, E. Evans, E. Henry, L. Wald, J. Shaishnikoff, and K. Herring. 2014. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the Westward Region's Shellfish Observer Program, 2011/12. Alaska Department of Fish and Game, Fishery Management Report No. 14-54, Anchorage.

Barnard, D. R., and R. Burt. 2004. Alaska Department of Fish and Game summary of the 2002 mandatory shellfish observer program database for the general and CDQ crab fisheries. Alaska Department of Fish and Game, Regional Information Report No. 4K04-27, Kodiak.

Blau, S. F. 1990. Size at maturity of female red king crabs (*Paralithodes camtschatica*) in the Adak Management Area, Alaska. Pages 105–116 *in* Proceedings of the International Symposium on King and Tanner Crabs, Anchorage, Alaska, USA, November 28–30, 1989. Alaska Sea Grant College Program Report No. 90-04, Fairbanks.

Blau, S. F. 1993. Overview of the red king crab surveys conducted in the Adak management area (R), Alaska 1969–1987. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K93-10, Kodiak.

Bowers, F. R., W. Donaldson, and D. Pengilly. 2002. Analysis of the January-February and November 2001 Petrel bank red king crab commissioner's permit surveys. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K02-11, Kodiak.

Burt, R. and D. R. Barnard. 2005. Alaska Department of Fish and Game summary of the 2003 mandatory shellfish observer program database for the general and CDQ fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 05-05, Anchorage. Alaska Department of Fish and Game, Division of Commercial Fisheries, Fishery Research Bulletin No. 92-02. Juneau.

Donaldson, W. E., and W. K. Donaldson. 1992. A review of the history and justification for size limits in Alaskan king, Tanner, and snow crab fisheries. Alaska Department of Fish and Game, Division of Commercial Fisheries, Fishery Research Bulletin No. 20-02, Juneau.

Foy, R. J., 2012a. 2012 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions. *in*: Stock Assessment and fishery Evaluation report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions: 2012 Crab SAFE. NPFMC, Anchorage, September 2012.

Foy, R. J., 2012b. 2012 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Red King Crab Fisheries of the Bering Sea and Aleutian Islands Regions. *in*: Stock Assessment and fishery Evaluation report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions: 2012 Crab SAFE. NPFMC, Anchorage, September 2012.

Gish, R. K. 2007. The 2006 Petrel Bank red king crab survey. Alaska Department of Fish and Game, Fishery Management Report No. 07-44, Anchorage.

Gish, R. K. 2010. The 2009 Petrel Bank red king crab pot survey: Results for red king crab. Alaska Department of Fish and Game, Regional Information Report No. 4K10-06, Kodiak.

Granath, K. 2003. Analysis of the November 2002 Adak, Atka, and Amlia Islands red king crab commissioner's permit survey. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 4K03-33, Kodiak.

Grant, W.S., D.A. Zelinina, and N.S. Mugue. 2014. Phylogeography of red king crab: implications for management and stock enhancement. Pages 47-72 *in* B.G. Stevens (ed.): King Crabs of the World: Biology and Fisheries Management. CRC Press, Taylor & Francis Group, New York.

Hilsinger, J., C. Siddon and L. Hulbert. 2016a. Cooperative red king crab survey in the Adak area, 2015. Anchorage., Alaska Department of Fish and Game, Fishery Data Series No. 16-18.

Hilsinger, J., and C. Siddon. 2016b. Cooperative red king crab survey in the Petrel Bank area, 2016. Alaska Department of Fish and Game, Regional Operational Plan ROP.CF.5J.2016.01, Juneau.

McMullen, J. 1967. Breeding king crabs *Paralithodes camtschatica* located in ocean environment. J. Fish. Res. Board. Can. 24(12): 2627–2628.

McMullen, J. 1969. Effects of delayed mating in the reproduction of king crab *Paralithodes camtschatica*. J. Fish. Res. Board. Can. 26(10): 2737–2740.

McMullen, J., and H. Yoshihara. 1971. King crab research: Alaska Peninsula-Aleutian Islands Area. *In*: ADF&G. 1971. King crab management report to the Board of Fish and Game, April 1971 meeting. Kodiak.

Moore, H., L.C. Byrne, and D. Connolly. 2000. Summary of the 1998 mandatory shellfish observer program database. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K00-21, Kodiak.

National Marine Fisheries Service (NMFS). 2004. Bering Sea Aleutian Islands Crab Fisheries Final Environmental Impact Statement. DOC, NOAA, National Marine Fisheries Service, AK Region, P.O. Box 21668, Juneau, AK 99802-1668, August 2004.

North Pacific Fishery Management Council (NPFMC). 2007. Public Review Draft: Environmental Assessment for proposed Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions. 14 November 2007. North Pacific Fishery Management Council, Anchorage.

Nyblade, C.F. 1987. Phylum or subphylum Crustacea, class Malacostraca, order Decopoda, Anomura. In: M.F. Strathman (ed), Reproduction and development of marine invertebrates on the northern Pacific Coast. Univ. Wash. Press, Seattle.

Otto, R. S., R. A. MacIntosh, and P. A. Cummiskey. 1990. Fecundity and other reproductive parameters of female red king crab (*Paralithodes camtschatica*) in Bristol Bay and Norton Sound, Alaska. Pages 65–90 *in* Proceedings of the International Symposium on King and Tanner Crabs, Anchorage, Alaska, USA, November 28–30, 1989. Alaska Sea Grant College Program Report No. 90-04, Fairbanks.

Pengilly, D. 2009. Adak red king crab: September 2009 Crab SAFE Report Chapter. Pages 605–644 *in*: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions (2009 Crab SAFE), September 2009. North Pacific Fishery Management Council, Anchorage, AK.

Powell, G. C., and R. B. Nickerson. 1965. Reproduction of king crabs *Paralithodes camtschatica* (Tilesius). J. Fish. Res. Board Can. 22(1):101–111.

Powell, G. C., D. Pengilly, and S. F. Blau. 2002. Mating pairs of red king crabs (*Paralithodes camtschaticus*) in the Kodiak Archipelago, Alaska, 1960–1984. Pages 225–245 *in* Crabs in cold-water regions: Biology, management, and economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks.

Powell, G. C., B. Shafford, and M. Jones. 1973. Reproductive biology of young adult king crabs *Paralithodes camtschaticus* (Tilesius) at Kodiak, Alaska. Proc. Natl. Shellfish. Assoc. 63:77–87.

Seeb, L., and C. Smith. 2005. Red king crab and snow-Tanner crab genetics. Bering Sea Crab Research II, Project 2. Final Comprehensive Performance Report for NOAA Award NA16FN2621. October 2005. ADF&G, Juneau.

Siddeek, M.S.M., D. Pengilly, and J. Zheng. 2011. Aleutian Islands golden king crab (*Lithodes aequispinus*) model based stock assessment. http://www.fakr.noaa.gov/npfmc/PDFdocuments/membership/PlanTeam/Crab/GKCModelBasedAssessWorkShopJan2012.pdf

Wallace, M. M., C. J. Pertuit, and A. R. Hvatum. 1949. Contribution to the biology of the king crab (*Paralithodes camtschatica* Tilesius). U. S. Fish Wildl. Serv. Fish. Leafl. 340.

Webb. J. 2014. Reproductive ecology of commercially important Lithodid crabs. Pages 285-314 In B.G. Stevens (ed.): King Crabs of the World: Biology and Fisheries Management. CRC Press, Taylor & Francis Group, New York.

Vining, I., S. F. Blau, and D. Pengilly. 2002. Growth of red king crabs from the central Aleutian Islands, Alaska. Pages 39–50 *in* Crabs in cold-water regions: Biology, management, and economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks.

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Table 1a. Commercial fishery history for the western Aleutian Islands red king crab commercial fishery, 1960/61–2015/16: number of vessels, guideline harvest level (GHL; established in lb, **converted to t**) for 1973/74–2004/05, total allowable catch (TAC; established in lb, **converted to t**) in the area west of 179° W longitude combined with GHL (established in lb, **converted to t**) in the area east of 179° W longitude for 2005/06–2015/16, weight of retained catch (Harvest; **t**), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (**kg**) of retained crab.

Crab fishing year	Area	Vessels	GHL/TAC	Harvest[a]	Crab[a]	Pots lifted	CPUE	Weight
1960/61	West of 172° W	4	-	941	NA	NA	NA	NA
1961/62	West of 172° W	8	-	2,773	NA	NA	NA	NA
1962/63	West of 172° W	9	-	3,631	NA	NA	NA	NA
1963/64	West of 172° W	11	-	8,121	NA	NA	NA	NA
1964/65	West of 172° W	18	-	9,613	NA	NA	NA	NA
1965/66	West of 172° W	10	-	5,858	NA	NA	NA	NA
1966/67	West of 172° W	10	-	2,668	NA	NA	NA	NA
1967/68	West of 172° W	22	-	6,410	NA	NA	NA	NA
1968/69	West of 172° W	30	-	7,303	NA	NA	NA	NA
1969/70	West of 172° W	33	-	8,172	NA	115,929	NA	2.5
1970/71	West of 172° W	35	-	7,283	NA	124,235	NA	NA
1971/72	West of 172° W	40	-	7,020	NA	46,011	NA	NA
1972/73	West of 172° W	43	-	8,493	3,461,025	81,133	43	2.5
1973/74	West of 172° W	41	9,072[b]	4,419	1,844,974	70,059	26	2.4
1974/75	West of 172° W	36	9,072[b]	1,259	532,298	32,620	16	2.4
1975/76	West of 172° W	20	6,804[b]	187	79,977	8,331	10	2.3
1976/77	West of 172° W	FC	FC	FC	FC	FC	FC	FC
1977/78	West of 172° W	12	113–1,134	411	160,343	7,269	22	2.6
1978/79	West of 172° W	13	227–1,361	366	149,491	13,948	11	2.4
1979/80	West of 172° W	18	227–1,361	212	82,250	9,757	8	2.6
1980/81	West of 172° W	17	227–1,361	644	254,390	20,914	12	2.5
1981/82	West of 172° W	46	227–1,361	748	291,311	40,697	7	2.6
1982/83	West of 172° W	72	227–1,361	772	284,787	66,893	4	2.7
1983/84	West of 172° W	106	227–1,361	899	298,958	60,840	5	3.0
1984/85	West of 171° W	64	680–1,361	588	196,276	48,642	4	3.0
1985/86	West of 171° W	35	227–907	394	156,097	29,095	5	2.5
1986/87	West of 171° W	33	227–680	323	126,204	29,189	4	2.6
1987/88	West of 171° W	71	227–680	551	211,692	43,433	5	2.6
1988/89	West of 171° W	73	454	711	266,053	64,334	4	2.7
1989/90	West of 171° W	56	771	502	193,177	54,213	4	2.6
1990/91	West of 171° W	7	NA	376	146,903	10,674	14	2.6
1991/92	West of 171° W	10	NA	431	165,356	16,636	10	2.6
1992/93	West of 171° W	12	NA	584	218,049	16,129	14	2.7
1993/94	West of 171° W	12	NA	317	119,330	13,575	9	2.7
1994/95	West of 171° W	20	454–680	89	30,337	18,146	2	2.9
1995/96	West of 171° W	4	454–680	18	6,880	1,986	3	2.6
1996/97–1997/98	West of 171° W	FC	FC	FC	FC	FC	FC	FC
1998/99	174°–179° W; west of 179° E	1	7	CF	CF	CF	CF	CF
1999/00	West of 171° W	FC	FC	FC	FC	FC	FC	FC
2000/01[c]	179° W–179° E	1	(Permit/Survey)	35	11,299	496	23	3.1
2001/02[d]	179° W–179° E	4	(Permit/Survey)	70	22,080	564	39	3.2
2002/03	179° W–179° E	33	227	229	68,300	3,786	18	3.4
2003/04	179° W–179° E	30	227	217	59,828	5,774	10	3.6
2004/05–2015/16	West of 171° W	FC	FC	FC	FC	FC	FC	FC

Note: NA = Not available, FC = fishery closed, CF = confidential.

[a] Deadloss included.

[b] GHL includes all king crab species. Golden king crab incidental to red king crab.

[c] January/February 2001 Petrel Bank survey.

[d] November 2001 Petrel Bank survey.

Table 1b. Commercial fishery history for the western Aleutian Islands red king crab commercial fishery, 1960/61–2015/16 number of vessels, guideline harvest level (GHL; **lb**) for 1973/74–2004/05, total allowable catch (TAC; **lb**) in the area west of 179° W longitude combined with GHL (**lb**) in the area east of 179° W longitude for 2005/06–2015/16, weight of retained catch (Harvest; **lb**), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (**lb**) of retained crab.

Crab fishing year	Area	Vessels	GHL/TAC	Harvest[a]	Crab[a]	Pots lifted	CPUE	Weight
1960/61	West of 172° W	4	-	2,074,000	NA	NA	NA	NA
1961/62	West of 172° W	8	-	6,114,000	NA	NA	NA	NA
1962/63	West of 172° W	9	-	8,006,000	NA	NA	NA	NA
1963/64	West of 172° W	11	-	17,904,000	NA	NA	NA	NA
1964/65	West of 172° W	18	-	21,193,000	NA	NA	NA	NA
1965/66	West of 172° W	10	-	12,915,000	NA	NA	NA	NA
1966/67	West of 172° W	10	-	5,883,000	NA	NA	NA	NA
1967/68	West of 172° W	22	-	14,131,000	NA	NA	NA	NA
1968/69	West of 172° W	30	-	16,100,000	NA	NA	NA	NA
1969/70	West of 172° W	33	-	18,016,000	NA	115,929	NA	6.5
1970/71	West of 172° W	35	-	16,057,000	NA	124,235	NA	NA
1971/72	West of 172° W	40	-	15,475,940	NA	46,011	NA	NA
1972/73	West of 172° W	43	-	18,724,140	3,461,025	81,133	43	5.4
1973/74	West of 172° W	41	20,000,000[b]	9,741,464	1,844,974	70,059	26	5.3
1974/75	West of 172° W	36	20,000,000[b]	2,774,963	532,298	32,620	16	5.2
1975/76	West of 172° W	20	15,000,000[b]	411,583	79,977	8,331	10	5.2
1976/77	West of 172° W	FC	FC	FC	FC	FC	FC	FC
1977/78	West of 172° W	12	0.25 - 2.5 million	905,527	160,343	7,269	22	5.7
1978/79	West of 172° W	13	0.5 - 3.0 million	807,195	149,491	13,948	11	5.4
1979/80	West of 172° W	18	0.5 - 3.0 million	467,229	82,250	9,757	8	5.7
1980/81	West of 172° W	17	0.5 - 3.0 million	1,419,513	254,390	20,914	12	5.6
1981/82	West of 172° W	46	0.5 - 3.0 million	1,648,926	291,311	40,697	7	5.7
1982/83	West of 172° W	72	0.5 - 3.0 million	1,701,818	284,787	66,893	4	6.0
1983/84	West of 172° W	106	0.5 - 3.0 million	1,981,579	298,958	60,840	5	6.6
1984/85	West of 171° W	64	1.5 - 3.0 million	1,296,385	196,276	48,642	4	6.6
1985/86	West of 171° W	35	0.5 - 2.0 million	868,828	156,097	29,095	5	5.6
1986/87	West of 171° W	33	0.5 - 1.5 million	712,543	126,204	29,189	4	5.7
1987/88	West of 171° W	71	0.5 - 1.5 million	1,213,892	211,692	43,433	5	5.7
1988/89	West of 171° W	73	1.0 million	1,567,314	266,053	64,334	4	5.9
1989/90	West of 171° W	56	1.7 million	1,105,971	193,177	54,213	4	5.7
1990/91	West of 171° W	7	NA	828,105	146,903	10,674	14	5.6
1991/92	West of 171° W	10	NA	951,278	165,356	16,636	10	5.8
1992/93	West of 171° W	12	NA	1,286,424	218,049	16,129	14	6.0
1993/94	West of 171° W	12	NA	698,077	119,330	13,575	9	5.9
1994/95	West of 171° W	20	1.0 - 1.5 million	196,967	30,337	18,146	2	6.5
1995/96	West of 171° W	4	1.0 - 1.5 million	38,941	6,880	1,986	3	5.7
1996/97–1997/98	West of 171° W	FC	FC	FC	FC	FC	FC	FC
1998/99	174°–179° W; west of 179° E	1	15,000	CF	CF	CF	CF	CF
1999/00	West of 171° W	FC	FC	FC	FC	FC	FC	FC
2000/01[c]	179° W–179° E	1	(Permit/Survey)	76,562	11,299	496	23	6.8
2001/02[d]	179° W–179° E	4	(Permit/Survey)	153,961	22,080	564	39	7.0
2002/03	179° W–179° E	33	500,000	505,642	68,300	3,786	18	7.4
2003/04	179° W–179° E	30	500,000	479,113	59,828	5,774	10	8.0
2004/05–2015/16	West of 171° W	FC	FC	FC	FC	FC	FC	FC

Note: NA = Not available, FC = fishery closed, CF = confidential.

[a] Deadloss included.

[b] GHL includes all king crab species. Golden king crab incidental to red king crab.

[c] January/February 2001 Petrel Bank survey.

[d] November 2001 Petrel Bank survey.

Table 2. A summary of relevant fishery activities and management measures pertaining to the Western Aleutian Islands red king crab fishery since 1996/97.

Crab fishing year	Fishery Activities and Management Measures
1996/97–1997/98	• Fishery closed.
1998/99	• GHL of 7 t (15,000 lb) for exploratory fishing with fishery closed in the Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) o 1 vessel
1999/00	• Fishery closed
2000/01	• Fishery closed • Catch retained during ADF&G-Industry survey of Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) conducted as commissioner's permit fishery, Jan–Feb 2001 o 1 vessel o Retained catch weight = 35 t (76,562 lb) o CPUE = 23 retained crab per pot lift
2001/02	• Fishery closed • Catch retained ADF&G-Industry survey of Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) conducted as commissioner's permit fishery, November 2001 o 4 vessels o Retained catch weight = 70 t (153,961 lb) o CPUE = 39 retained crab per pot lift
2002/03	• Fishery opened with GHL of 227 t (500,000 lb) restricted to Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) o 33 vessels o Retained catch weight = 229 t (505,642 lb) o CPUE = 18 retained crab per pot lift • ADF&G-Industry survey of the Adak, Atka, and Amlia Islands area conducted as a commissioner's permit fishery o 4 legal males captured in 1,085 pot lifts
2003/04	• Fishery opened with GHL of 227 t (500,000 lb) restricted to Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) o 30 vessels o Retained catch weight = 217 t (479,113) lb o 10 retained crab per pot lift
2004/05–2016/17	• 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, 1995/96–2015/16.

	WAI red king crab fishery				AI golden king crab fishery			
Crab fishing		Discarded						Total
year	Retained	Legal male	Sublegal male	Female	Legal male	Sublegal male	Female	Discarded
1995/96	17.66	0.00	9.38	12.53	0.00	0.93	0.14	22.98
1996/97	0.00	0.00	0.00	0.00	1.49	0.92	0.30	2.71
1997/98	0.00	0.00	0.00	0.00	0.08	0.26	0.08	0.42
1998/99[a]	2.68	–[a]	–[a]	–[a]	0.34	0.06	0.08	–[a]
1999/00	0.00	0.00	0.00	0.00	0.07	0.34	0.04	0.46
2000/01	34.73	0.00	0.35	0.17	0.17	0.12	0.02	0.83
2001/02	69.84	0.08	2.98	3.80	9.07	0.00	0.17	16.09
2002/03	229.36	0.75	2.73	7.91	9.86	0.16	0.23	21.65
2003/04	217.32	0.29	2.99	3.61	4.28	2.88	3.03	17.08
2004/05	0.00	0.00	0.00	0.00	0.97	0.10	0.00	1.07
2005/06	0.00	0.00	0.00	0.00	0.09	0.00	0.02	0.11
2006/07	0.00	0.00	0.00	0.00	0.15	0.05	0.02	0.22
2007/08	0.00	0.00	0.00	0.00	0.28	0.83	0.25	1.36
2008/09	0.00	0.00	0.00	0.00	0.10	0.01	0.04	0.15
2009/10	0.00	0.00	0.00	0.00	0.26	0.11	0.02	0.39
2010/11	0.00	0.00	0.00	0.00	1.96	0.08	0.04	2.07
2011/12	0.00	0.00	0.00	0.00	0.43	0.01	0.04	0.49
2012/13	0.00	0.00	0.00	0.00	0.40	0.03	0.02	0.44
2013/14	0.00	0.00	0.00	0.00	1.34	0.05	0.08	1.46
2014/15	0.00	0.00	0.00	0.00	0.24	0.01	0.03	0.28
2015/16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Average	27.22	0.06	0.92	1.40	1.56	0.34	0.23	4.51

a. Data on discarded catch of red king crab during the red king crab fishery not available (see Moore et al. 2000).

Table 4. Estimated annual weight (**t**) of discarded catch of red king crab (all sizes, males and females) and estimated annual bycatch mortality (**t**) during federal groundfish fisheries by gear type (fixed or trawl) in reporting areas 541, 542, and 543 (Aleutian Islands west of 170° W longitude), 1993/94–2015/16 (assumes bycatch mortality rate of 0.5 for fixed-gear fisheries and 0.8 for trawl fisheries).

Crab fishing	Discarded catch		Bycatch Mortality		
year	Fixed Gear	Trawl Gear	Fixed Gear	Trawl Gear	Total
1993/94	0.60	40.09	0.30	32.07	32.37
1994/95	1.36	10.34	0.68	8.27	8.95
1995/96	2.63	6.93	1.32	5.55	6.86
1996/97	1.30	20.26	0.65	16.21	16.86
1997/98	1.73	5.31	0.87	4.25	5.12
1998/99	4.60	20.65	2.30	16.52	18.82
1999/00	17.13	12.69	8.57	10.15	18.72
2000/01	1.22	6.30	0.61	5.04	5.65
2001/02	2.42	27.01	1.21	21.61	22.82
2002/03	5.12	33.12	2.56	26.50	29.06
2003/04	1.62	4.15	0.81	3.32	4.13
2004/05	0.36	5.86	0.18	4.69	4.87
2005/06	1.61	1.07	0.80	0.86	1.66
2006/07	3.08	0.28	1.54	0.22	1.76
2007/08	7.70	1.19	3.85	0.95	4.80
2008/09	4.89	4.67	2.44	3.73	6.18
2009/10	0.14	6.40	0.07	5.12	5.19
2010/11	0.04	1.99	0.02	1.59	1.61
2011/12	1.19	0.82	0.60	0.41	1.01
2012/13	0.01	0.24	0.00	0.19	0.19
2013/14	0.01	0.04	0.01	0.03	0.04
2014/15	0.00	0.11	0.00	0.09	0.09
2015/16	0.03	1.46	0.02	1.17	1.19
Average	2.56	9.17	1.28	7.33	8.61

Table 5. Estimated annual weight of discarded catch (**t**; not discounted by an assumed bycatch mortality rate) of red king crab in reporting areas 541, 542, and 543 (Aleutian Islands west of 170° W longitude) during federal groundfish fisheries (all gear types combined) by reporting area, 1993/94–2015/16.

Crab fishing	Reporting Area			
year	541	542	543	Total
1993/94	37.9893	2.6590	0.0372	40.6855
1994/95	10.7216	0.8718	0.1025	11.6959
1995/96	5.9520	1.8398	1.7763	9.5681
1996/97	1.9477	3.0890	16.5258	21.5624
1997/98	1.0061	3.9639	2.0770	7.0470
1998/99	6.7549	7.1659	11.3335	25.2542
1999/00	16.3416	8.0535	5.4227	29.8183
2000/01	1.7686	3.6541	2.0961	7.5192
2001/02	3.4750	24.0341	1.9250	29.4341
2002/03	10.9996	21.3098	5.9384	38.2483
2003/04	2.2294	3.5280	0.0163	5.7733
2004/05	0.5280	5.6803	0.0154	6.2237
2005/06	1.6057	0.0395	1.0333	2.6785
2006/07	2.9688	0.3869	0.0000	3.3557
2007/08	5.1233	3.0427	0.7248	8.8909
2008/09	1.1440	7.5455	0.8668	9.5563
2009/10	1.6719	3.7548	1.1136	6.5404
2010/11	0.2123	1.8162	0.0005	2.0289
2011/12	0.8768	1.1335	0.0000	2.0108
2012/13	0.1560	0.0903	0.0000	0.2463
2013/14	0.0000	0.0435	0.0118	0.0553
2014/15	0.0000	0.1148	0.0005	0.1152
2015/16	0.0000	0.8864	0.6102	1.4966
Average	4.9336	4.5523	2.2447	11.7307

Table 6. Estimated annual weight (**t**) of total fishery mortality to Western Aleutian Islands red king crab, 1995/96–2015/16, partitioned by source of mortality: retained catch, estimated bycatch mortality during crab fisheries, and estimated bycatch mortality during groundfish fisheries.

		Bycatch Mortality by Fishery Type		
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
Mean, 1995/96–2007/08	43.97	1.36	10.86	56.19
CV of mean	0.52	0.37	0.23	0.43
Mean, 1995/96–2015/16	27.22	0.90	7.46	35.58
CV of mean	0.54	0.37	0.25	0.45

a. No discarded catch data was available from the 1998/99 directed fishery for red king crab (see Table 2); bycatch mortality due to the 1998/99 crab fisheries was estimated by multiplying the retained catch for the 1998/99 directed red king crab fishery by the ratio of the 1995/96 bycatch mortality in crab fisheries to the 1995/96 retained catch.

Table 7. Annual retained catch weight (**t**) and estimates of annual discarded catch weight (**t**; not discounted for an assumed bycatch mortality rate) of Western Aleutian Islands red king crab available for a Tier 5 assessment; shaded, bold values are used in computation of the recommended (status quo) 2017/18 Tier 5 OFL.

	Retained catch weight	Discarded catch weight (estimated)		
	Fish tickets	Observer data: lengths, catch per sampled pot	Blend method; Catch Accounting System	
Crab Fishing Year	Directed fishery	Crab fisheries	Fixed gear, groundfish	Trawl gear, groundfish
1960/61	940.75	—	—	—
1961/62	2773.27	—	—	—
1962/63	3631.46	—	—	—
1963/64	8121.13	—	—	—
1964/65	9612.99	—	—	—
1965/66	5858.15	—	—	—
1966/67	2668.49	—	—	—
1967/68	6409.72	—	—	—
1968/69	7302.85	—	—	—
1969/70	8171.93	—	—	—
1970/71	7283.34	—	—	—
1971/72	7019.78	—	—	—
1972/73	8493.14	—	—	—
1973/74	4418.66	—	—	—
1974/75	1258.70	—	—	—
1975/76	186.69	—	—	—
1976/77	0.00	—	—	—
1977/78	410.74	—	—	—
1978/79	366.14	—	—	—
1979/80	211.93	—	—	—
1980/81	643.88	—	—	—
1981/82	747.94	—	—	—
1982/83	771.93	—	—	—
1983/84	898.83	—	—	—
1984/85	588.03	—	—	—
1985/86	394.09	—	—	—
1986/87	323.20	—	—	—
1987/88	550.61	—	—	—
1988/89	710.92	—	—	—
1989/90	501.66	—	—	—
1990/91	375.62	Confidential	—	—
1991/92	431.49	Confidential	—	—
1992/93	583.51	Confidential	—	—
1993/94	316.64	Confidential	0.60	40.09
1994/95	89.34	Confidential	1.36	10.34
1995/96	**17.66**	**22.98**	**2.63**	**6.93**
1996/97	**0.00**	**2.71**	**1.30**	**20.26**
1997/98	**0.00**	**0.42**	**1.73**	**5.31**
1998/99	**2.68**	**3.48**	**4.60**	**20.65**
1999/00	**0.00**	**0.46**	**17.13**	**12.69**
2000/01	**34.73**	**0.83**	**1.22**	**6.30**
2001/02	**69.84**	**16.09**	**2.42**	**27.01**
2002/03	**229.36**	**21.65**	**5.12**	**33.12**
2003/04	**217.32**	**17.08**	**1.62**	**4.15**
2004/05	**0.00**	**1.07**	**0.36**	**5.86**
2005/06	**0.00**	**0.11**	**1.61**	**1.07**
2006/07	**0.00**	**0.22**	**3.08**	**0.28**
2007/08	**0.00**	**1.36**	**7.70**	**1.19**
2008/09	0.00	0.15	4.89	4.67
2009/10	0.00	0.39	0.14	6.40
2010/11	0.00	2.07	0.04	1.99
2011/12	0.00	0.49	1.19	0.82
2012/13	0.00	0.44	0.01	0.24
2013/14	0.00	1.46	0.01	0.04
2014/15	0.00	0.28	0.00	0.11
2015/16	0.00	0.00	0.03	1.46

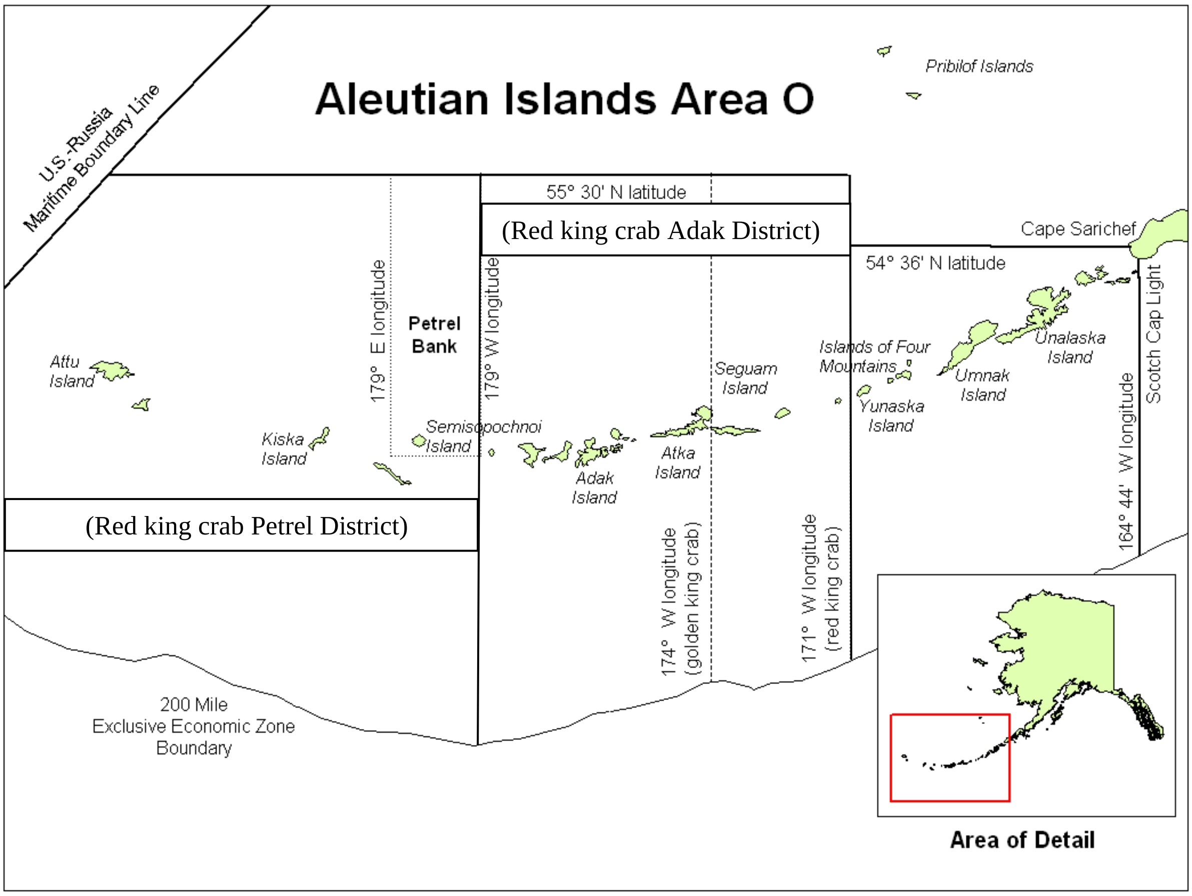

Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Baechler and Cook 2014, updated to show boundaries of the Adak and Petrel Districts for red king crab as established by the Alaska Board of Fisheries in March 2014).

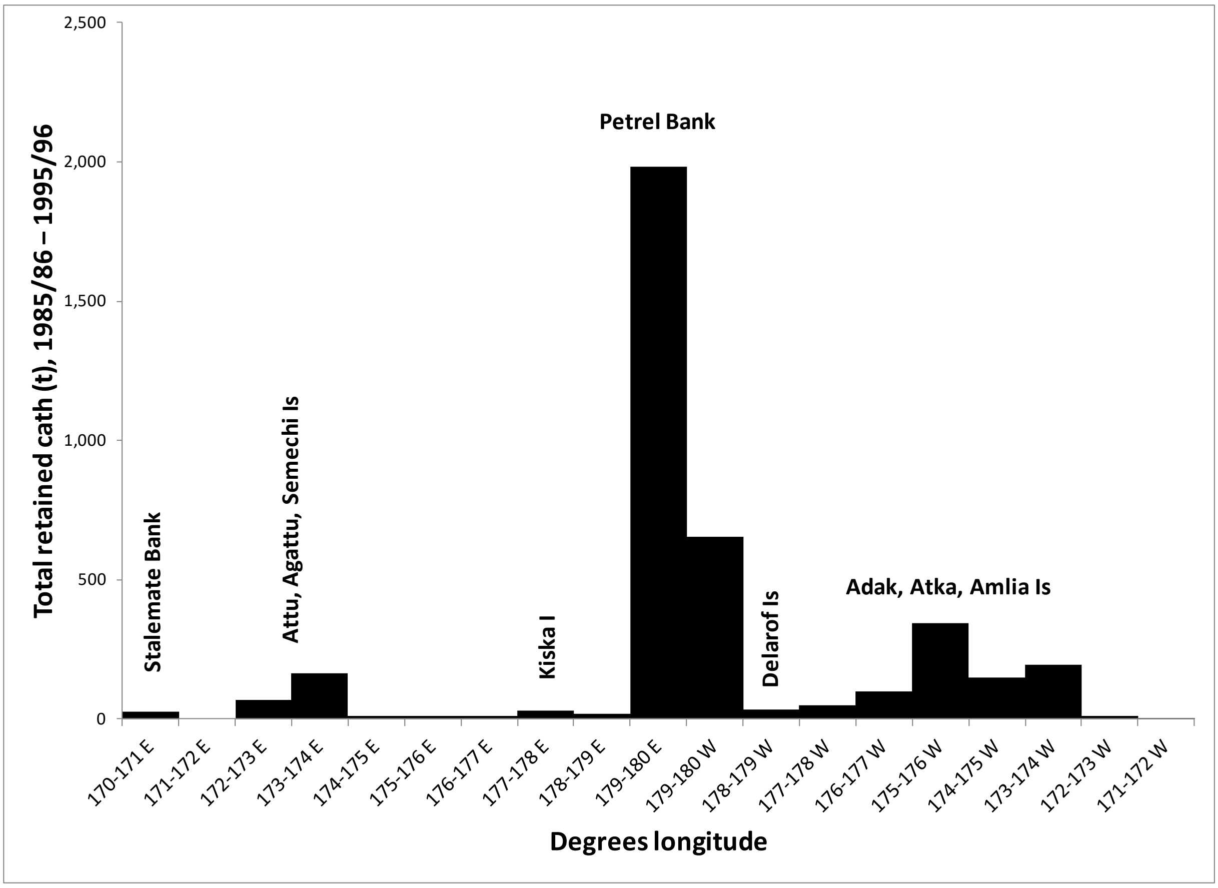

Figure 2. Retained catch (**t**) in the Western Aleutian Islands red king crab fishery, 1985/86–1995/96 by 1-degree longitude grouping, summarized from fish ticket catch by state statistical area landing data.

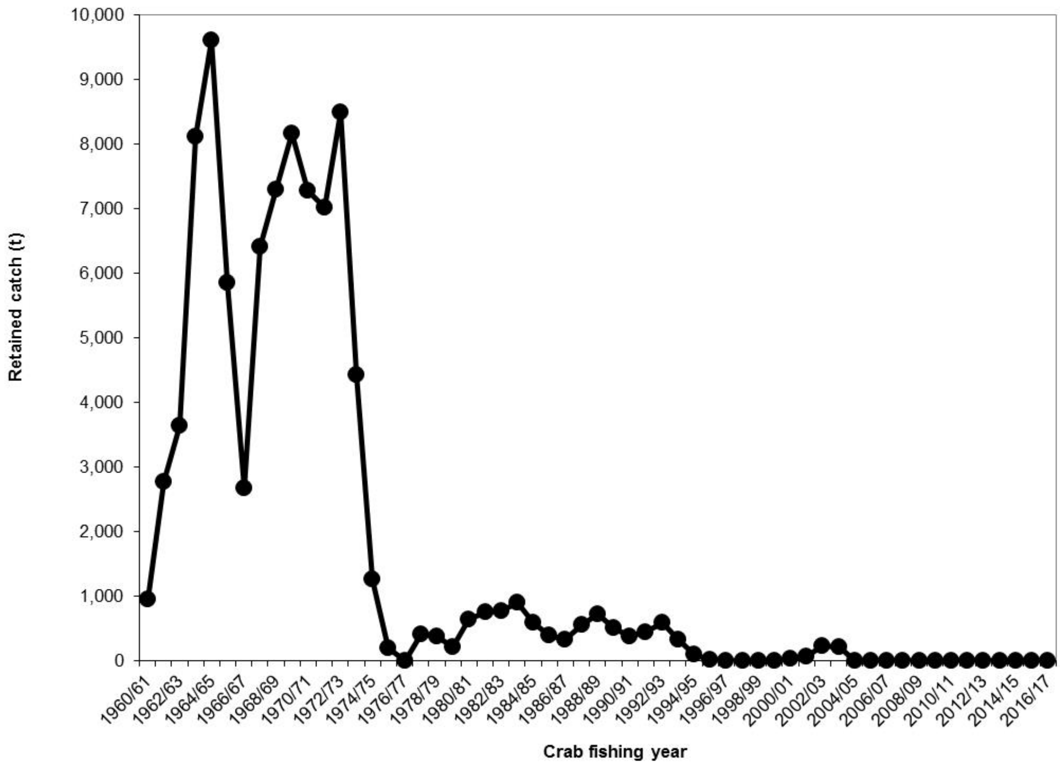

Figure 3. Retained catch (**t**) in the Western Aleutian Islands red king crab fishery, 1960/61–2016/17 (catch is for the area west of 172° W longitude during 1960/61–1983/84 and for the area west of 171° W longitude during 1984/85–2016/17; see Table 1a).

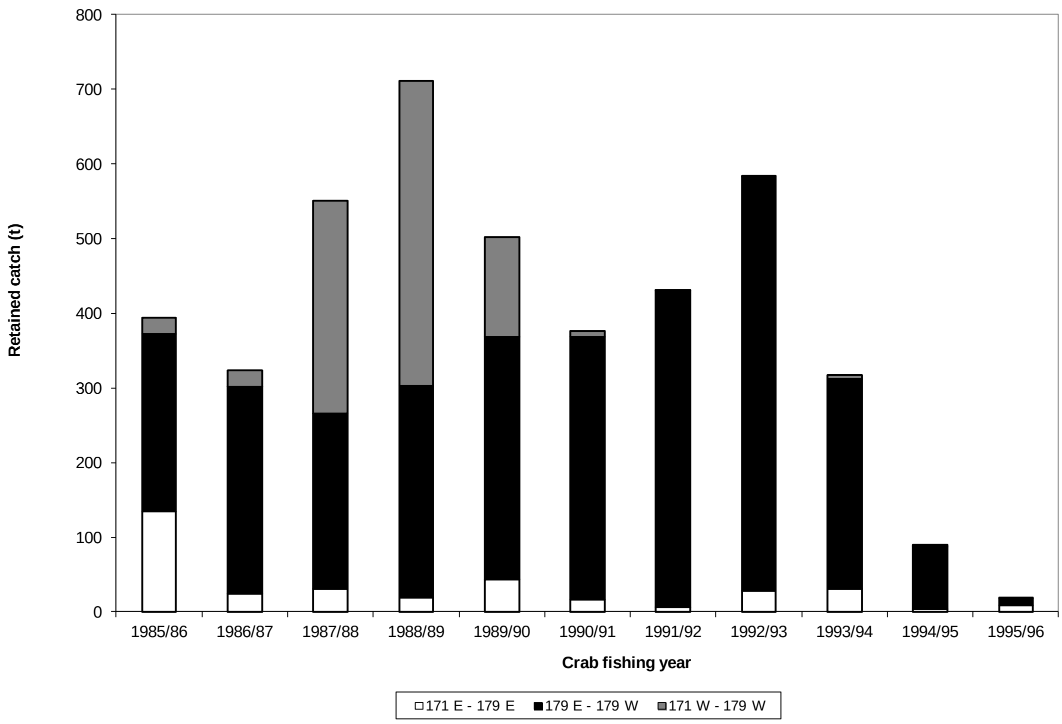

Figure 4. Annual retained catch (**t**) in the Western Aleutian Islands red king crab fishery during 1985/86–1995/96, partitioned into three longitudinal zones: 171º W longitude to 179º W longitude (white bars); 179º W longitude to 179º E longitude (black bars); and 179º E longitude to 171º E longitude.

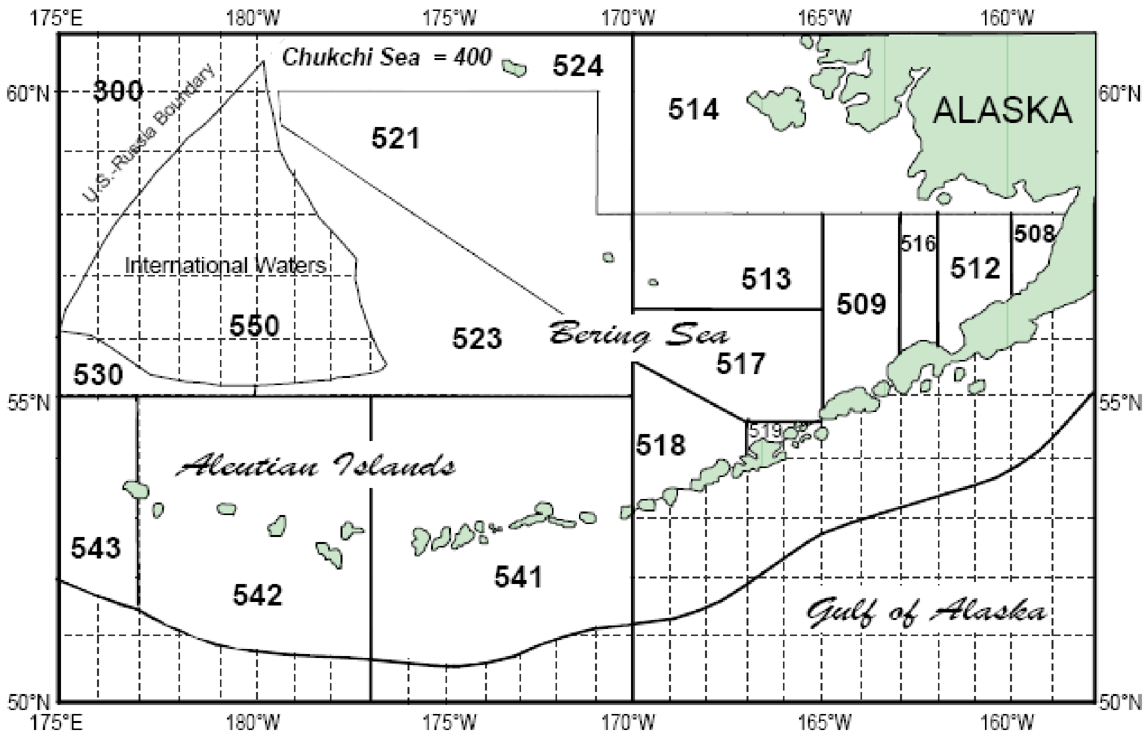

Figure 5. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands showing reporting areas 541, 542, and 543 that are used to obtain data on discarded catch of Western Aleutian Islands red king crab during groundfish fisheries (from http://www.alaskafisheries.noaa.gov/rr/figures/fig1.pdf).

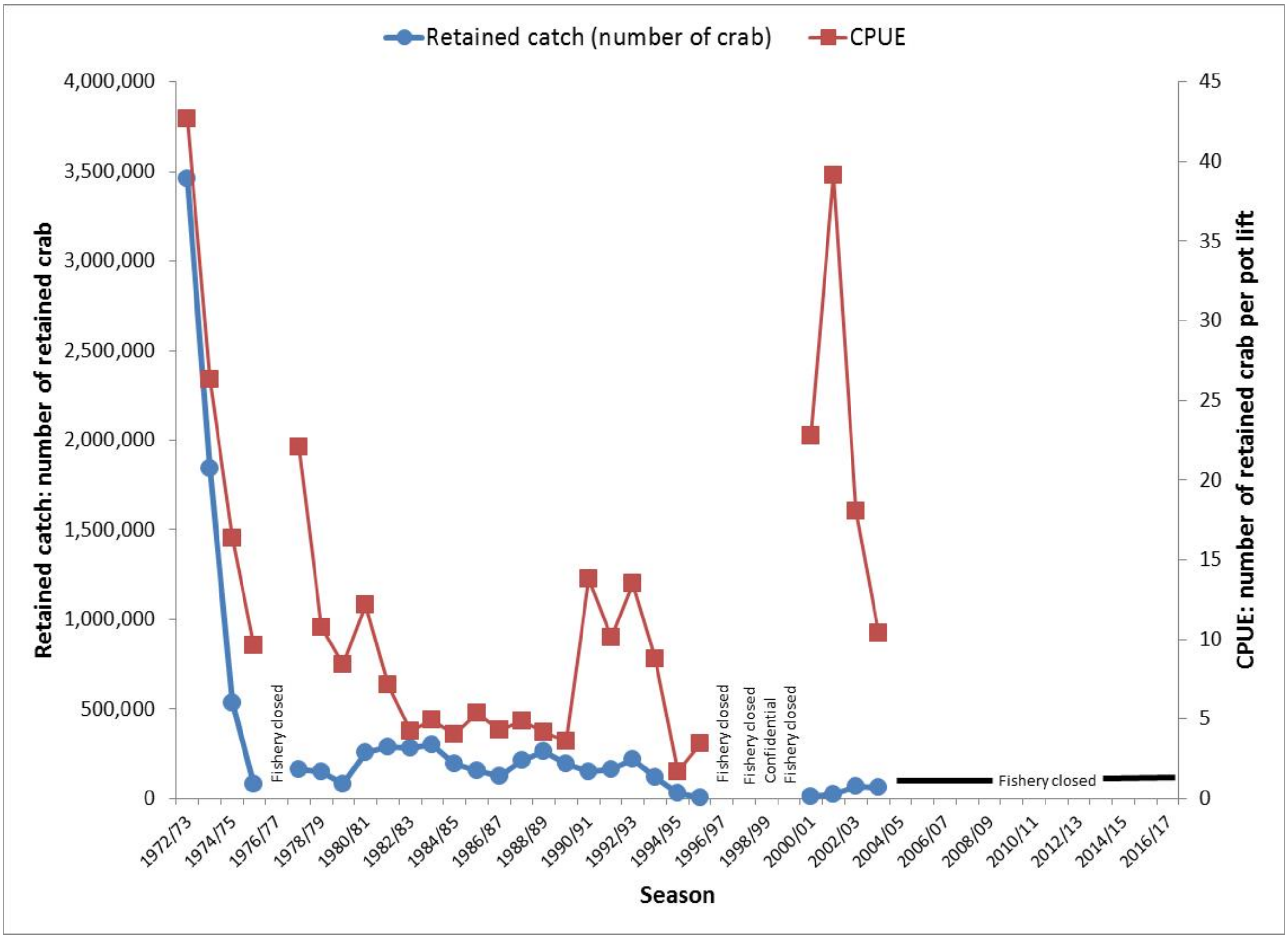

Figure 6. Retained catch (number of crab) and CPUE (number of retained crab per pot lift) in the western Aleutian Islands red king crab fishery, 1972/73–2016/17 (from Table 1a). Data for 1972/73–1983/84 are for the area west of 172° W longitude; data for 1984/85–1997/98, 1999/00, and 2004/05–2016/17 are for the area west of 171° W longitude; data for 1998/99 are for the area west of 174° W longitude; and data for 2000/01–2003/04 are for the area between 179° W longitude and 179° E longitude.

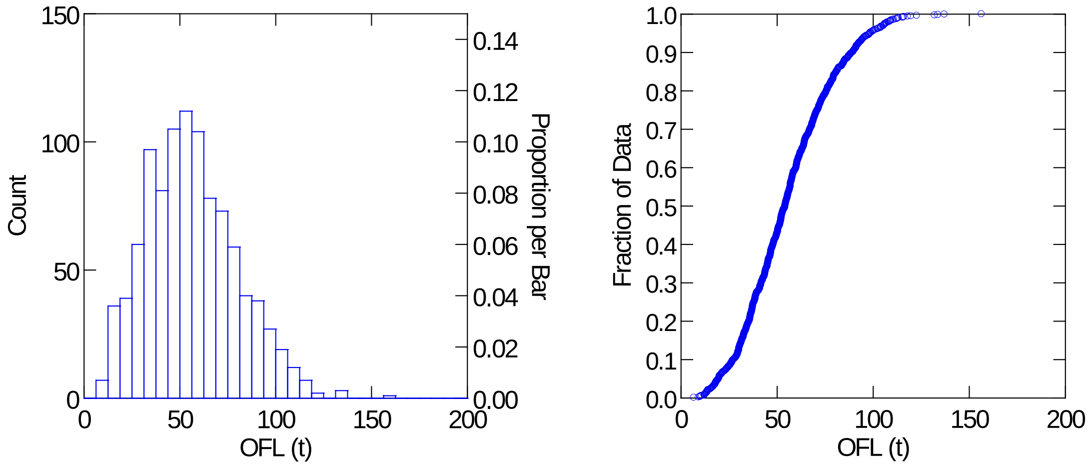

Figure 7. Bootstrapped estimate of the sampling distribution of the recommended 2016/2017 Tier 5 OFL (total-catch, t) for the Western Aleutian Islands red king crab stock; histogram in left column, cumulative distribution in right column.

Appendix A1. Summary of retained catch size frequency data available from Western Aleutian Islands directed red king crab fishery, 1960/61–2015/16.

Crab fishing year	N
1960/61	0
1961/62	386
1962/63	661
1963/64	0
1964/65	1,285
1965/66	423
1966/67	0
1967/68	0
1968/69	0
1969/70	0
1970/71	0
1971/72	0
1972/73	10,043
1973/74	9,789
1974/75	2,609
1975/76	680
1976/77	0
1977/78	666
1978/79	1,485
1979/80	963
1980/81	2,537
1981/82	2,175
1982/83	6,287
1983/84	3,806
1984/85	1,805
1985/86	1,217
1986/87	422
1987/88	441
1988/89	4,860
1989/90	12,405
1990/91	9,406
1991/92	8,306
1992/93	5,195
1993/94	4,426
1994/95	1,037
1995/96	978
1996/97−1997/98	Closed
1998/99	0
1999/00	Closed
2000/01	460
2001/02	589
2002/03	2,056
2003/04	2,381
2004/05−2015/16	Closed

Appendix A2. Available retained catch size frequency sample data 1961/62–1979/80 western Aleutian Islands directed red king crab fishery. Page 1 of 3.

CL (mm)	1961/62	1962/63	1964/65	1965/66	1972/73	1973/74	1974/75	1975/76	1977/78	1978/79	1979/80
98	0	0	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0
101	0	0	0	0	0	0	0	0	0	0	0
102	0	0	0	0	0	0	0	0	0	0	0
103	0	0	0	0	0	0	0	0	0	0	0
104	0	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0
106	0	0	0	0	0	0	0	0	0	0	0
107	0	0	0	0	0	0	0	0	0	0	0
108	0	0	0	0	0	0	0	0	0	0	0
109	0	0	0	0	0	0	0	0	0	0	0
110	0	0	0	0	0	0	0	0	0	0	0
111	0	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	0	0	0	0	0
114	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0
116	0	0	0	0	0	0	0	0	0	0	0
117	0	0	0	0	0	0	0	0	0	0	0
118	0	0	0	0	0	0	0	0	0	0	0
119	0	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0	0
121	0	0	0	0	0	0	0	0	0	0	0
122	0	0	0	0	0	0	0	0	0	0	0
123	0	0	0	0	0	0	0	0	0	0	0
124	0	2	0	0	0	0	0	0	0	0	0
125	0	1	0	0	0	0	0	0	0	0	0
126	0	2	0	0	0	0	0	0	0	0	0
127	0	3	0	0	0	0	0	0	0	0	0
128	0	2	0	0	0	0	0	0	0	0	0
129	0	1	0	0	0	0	0	0	0	1	0
130	0	7	0	0	3	1	0	0	0	3	0
131	0	2	0	0	1	0	0	0	0	1	0
132	0	1	0	0	1	7	6	1	0	1	1
133	0	3	0	0	13	15	9	1	0	7	4
134	0	3	2	0	22	24	15	0	1	4	1
135	0	5	0	0	52	58	31	7	0	12	9
136	0	4	0	1	91	107	30	7	5	13	3
137	0	3	2	0	179	174	52	17	11	37	8

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CL (mm)	1961/62	1962/63	1964/65	1965/66	1972/73	1973/74	1974/75	1975/76	1977/78	1978/79	1979/80
138	0	3	4	0	313	281	114	20	16	40	9
139	0	6	3	1	267	295	103	22	15	38	15
140	0	9	1	2	434	362	119	37	19	45	28
141	0	11	2	1	384	403	102	31	17	53	15
142	0	9	3	0	476	445	150	46	29	65	33
143	0	8	3	2	532	462	136	44	35	71	32
144	0	6	7	1	473	497	112	49	35	52	32
145	2	7	14	1	547	549	109	37	30	82	49
146	2	15	10	4	508	514	119	31	16	63	39
147	0	5	9	7	552	488	114	25	35	80	43
148	2	3	11	4	589	478	101	46	41	101	36
149	2	10	17	4	477	488	79	29	15	64	50
150	8	9	23	5	524	490	84	28	24	59	38
151	4	12	10	1	393	432	65	21	17	58	46
152	10	16	20	7	436	409	93	21	21	69	40
153	0	13	29	9	439	367	69	13	12	45	32
154	10	11	33	6	324	318	76	17	17	53	37
155	2	13	42	8	330	337	67	14	27	56	49
156	2	19	32	9	272	285	60	10	24	37	35
157	4	22	28	6	203	229	63	11	12	43	36
158	12	10	39	16	226	234	62	17	17	31	36
159	10	17	34	14	147	174	51	6	11	24	22
160	18	13	38	15	180	146	53	5	20	25	30
161	18	12	30	10	127	129	40	7	6	23	21
162	8	16	32	17	120	145	45	8	17	14	21
163	8	7	44	15	99	93	39	10	15	17	12
164	4	13	34	9	74	70	33	5	11	13	15
165	6	16	54	17	46	56	31	5	6	15	16
166	16	18	39	13	51	43	25	6	6	12	14
167	10	13	55	24	40	37	21	4	7	16	5
168	24	13	47	19	24	30	19	5	15	7	8
169	10	20	36	12	14	29	10	3	12	9	13
170	22	20	28	23	16	18	16	2	7	2	10
171	18	14	43	16	9	15	6	2	8	6	3
172	16	15	36	18	10	9	13	2	5	5	4
173	8	9	42	12	6	7	7	0	8	4	1
174	8	12	25	8	5	7	5	2	3	0	1
175	22	27	30	14	4	6	7	3	7	1	3
176	14	19	30	11	1	3	3	0	1	3	3
177	12	10	22	9	4	5	1	0	1	0	1
178	14	17	23	12	2	6	4	1	4	1	0

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CL (mm)	1961/62	1962/63	1964/65	1965/66	1972/73	1973/74	1974/75	1975/76	1977/78	1978/79	1979/80
179	0	11	21	10	2	2	4	1	2	0	0
180	10	13	20	9	0	3	4	1	0	2	1
181	2	14	13	3	0	1	1	0	0	0	2
182	4	11	23	6	0	2	2	0	1	0	0
183	8	8	13	3	0	1	2	0	1	1	0
184	4	7	16	1	1	0	3	0	0	1	1
185	6	2	10	3	0	1	1	0	1	0	0
186	2	4	15	1	0	0	5	0	0	0	0
187	8	8	11	1	0	0	4	0	0	0	0
188	6	4	10	2	0	0	2	0	0	0	0
189	0	5	11	1	0	0	0	0	0	0	0
190	2	4	12	0	0	0	2	0	0	0	0
191	0	3	8	0	0	0	1	0	0	0	0
192	0	2	8	0	0	1	3	0	0	0	0
193	0	1	5	0	0	0	1	0	0	0	0
194	0	1	5	0	0	1	1	0	0	0	0
195	0	0	2	0	0	0	0	0	0	0	0
196	0	1	3	0	0	0	0	0	0	0	0
197	0	1	5	0	0	0	0	0	0	0	0
198	0	0	3	0	0	0	2	0	0	0	0
199	2	1	3	0	0	0	2	0	0	0	0
200	2	3	0	0	0	0	0	0	0	0	0
201	0	0	0	0	0	0	0	0	0	0	0
202	0	0	1	0	0	0	0	0	0	0	0
203	4	0	0	0	0	0	0	0	0	0	0
204	0	0	1	0	0	0	0	0	0	0	0
205	0	0	0	0	0	0	0	0	0	0	0
206	0	0	0	0	0	0	0	0	0	0	0
207	0	0	0	0	0	0	0	0	0	0	0
208	0	0	0	0	0	0	0	0	0	0	0
209	0	0	0	0	0	0	0	0	0	0	0
210	0	0	0	0	0	0	0	0	0	0	0
Total	386	661	1,285	423	10,043	9,789	2,609	680	666	1,485	963

Appendix A3. Available retained catch size frequency sample data 1980/81–1989/90 Western Aleutian Islands directed red king crab fishery. Page 1 of 3.

CL (mm)	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90
98	0	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0
101	0	0	0	0	0	0	0	0	0	0
102	0	0	0	0	0	0	0	0	0	0
103	0	0	0	0	0	0	0	0	0	0
104	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0
106	0	0	0	0	0	0	0	0	0	0
107	0	0	0	0	0	0	0	0	0	0
108	0	0	0	0	0	0	0	0	0	0
109	0	0	0	0	0	0	0	0	0	1
110	0	0	0	0	0	0	0	0	0	0
111	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	0	0	0	0
114	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0
116	0	0	0	0	0	0	0	0	0	0
117	0	0	0	0	0	0	0	0	0	0
118	0	0	0	0	0	0	0	0	0	0
119	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0
121	0	0	0	0	0	0	0	0	0	0
122	0	0	0	1	0	0	1	0	0	1
123	0	0	0	0	0	0	0	0	0	0
124	0	0	0	0	1	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	1
126	0	0	0	0	0	1	0	0	0	0
127	1	1	1	0	0	3	0	0	0	2
128	0	0	1	0	1	0	0	0	1	0
129	2	1	0	0	0	1	0	0	3	1
130	3	4	2	3	1	2	1	1	5	8
131	4	3	8	2	3	7	0	3	7	29
132	6	6	23	8	6	9	2	2	5	51
133	15	11	34	10	6	19	2	5	18	88
134	25	11	55	17	9	10	5	8	19	161
135	34	25	70	25	19	27	3	10	38	280
136	53	51	92	27	21	18	8	8	55	276
137	72	45	145	32	33	23	12	11	92	370

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CL (mm)	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90
138	89	76	187	49	39	29	10	10	108	497
139	106	55	184	49	30	39	10	11	121	532
140	119	76	221	74	30	48	16	17	134	631
141	99	78	224	58	46	48	16	13	118	529
142	128	104	256	97	41	59	16	20	157	562
143	127	110	323	94	57	38	13	18	161	514
144	96	100	226	73	39	33	14	21	139	494
145	115	105	224	94	56	28	25	21	179	559
146	95	112	208	107	49	21	14	25	164	460
147	103	97	250	99	47	36	14	17	186	460
148	98	93	269	128	55	36	11	10	158	483
149	94	79	186	94	36	28	14	17	170	399
150	85	100	249	122	61	42	16	21	177	451
151	76	82	172	87	47	27	13	18	146	283
152	59	98	215	121	48	24	13	5	191	371
153	66	75	234	134	58	27	8	17	170	361
154	59	72	184	104	40	30	14	16	152	292
155	45	73	176	104	58	39	12	13	147	370
156	53	63	152	99	44	24	15	12	129	265
157	59	59	164	111	41	31	6	7	132	244
158	32	54	162	117	42	35	10	17	132	256
159	41	27	131	70	30	36	14	6	105	232
160	40	34	126	100	62	31	7	5	128	233
161	30	33	99	93	30	17	6	9	105	190
162	42	37	89	83	53	34	6	7	98	178
163	31	21	106	94	52	23	6	4	97	185
164	40	24	87	77	26	34	7	9	108	134
165	43	18	86	88	50	24	5	8	92	153
166	27	7	69	161	38	18	5	5	72	92
167	32	11	90	80	41	17	3	2	71	92
168	29	5	86	73	45	19	2	3	70	76
169	21	1	46	51	32	18	5	2	57	85
170	20	11	45	69	39	12	5	2	65	85
171	18	3	37	47	22	3	3	1	45	65
172	19	9	42	59	30	12	1	1	50	51
173	15	1	45	57	24	7	2	1	32	48
174	13	3	41	44	30	10	3	0	48	32
175	12	3	28	36	24	5	1	0	48	35
176	7	1	20	40	17	7	3	0	28	23
177	9	2	20	39	17	2	0	0	19	26
178	6	0	19	34	18	7	1	0	21	18

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CL (mm)	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88	1988/89	1989/90
179	8	1	13	33	12	1	6	0	14	19
180	2	2	14	28	8	4	2	0	13	16
181	3	0	10	15	7	1	0	0	15	9
182	2	0	12	23	4	5	1	1	5	4
183	2	0	4	22	6	2	2	0	7	12
184	1	0	8	27	3	5	3	0	6	4
185	1	0	6	21	5	1	2	0	5	5
186	2	1	2	14	3	0	0	0	5	2
187	0	0	1	14	1	2	2	1	4	2
188	0	1	4	10	2	2	1	0	7	3
189	1	0	2	11	2	3	0	0	2	4
190	1	0	0	13	4	1	0	0	1	4
191	0	0	1	10	1	1	0	0	1	2
192	0	0	0	2	0	3	0	0	1	0
193	1	0	0	10	0	2	1	0	0	2
194	0	0	1	4	0	2	1	0	1	0
195	0	0	0	6	2	0	1	0	0	1
196	0	0	0	4	0	0	0	0	0	0
197	0	0	0	1	0	0	0	0	0	0
198	0	0	0	1	1	2	0	0	0	1
199	0	0	0	0	0	0	0	0	0	0
200	0	0	0	1	0	0	0	0	0	0
201	0	0	0	0	0	0	0	0	0	0
202	0	0	0	0	0	0	1	0	0	0
203	0	0	0	0	0	1	0	0	0	0
204	0	0	0	0	0	1	0	0	0	0
205	0	0	0	0	0	0	0	0	0	0
206	0	0	0	0	0	0	0	0	0	0
207	0	0	0	0	0	0	0	0	0	0
208	0	0	0	0	0	0	0	0	0	0
209	0	0	0	0	0	0	0	0	0	0
210	0	0	0	1	0	0	0	0	0	0
Total	2,537	2,175	6,287	3,806	1,805	1,217	422	441	4,860	12,405

Appendix A4. Available retained catch size frequency sample data 1990/91–2003/04 Western Aleutian Islands directed red king crab fishery. Page 1 of 3.

CL (mm)	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	2000/01	2001/02	2002/03	2003/04
98	1	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0
101	0	0	0	0	0	0	0	0	0	0
102	0	0	0	0	0	0	0	0	0	0
103	1	0	0	0	0	0	0	0	0	0
104	0	0	0	0	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0
106	0	0	0	0	0	0	0	0	0	0
107	0	0	0	0	0	0	0	0	0	0
108	0	0	0	0	0	0	0	0	0	0
109	0	0	0	0	0	0	0	0	0	0
110	0	0	0	0	0	0	0	0	0	0
111	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	0	0	0	0
114	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0
116	0	0	0	0	0	0	0	0	0	0
117	1	0	0	0	0	0	0	0	0	0
118	0	0	0	0	0	0	0	0	0	0
119	0	0	0	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0	0	0	0
121	0	0	0	0	0	0	0	0	0	0
122	0	0	0	1	0	0	0	0	0	0
123	0	0	0	0	0	0	0	0	0	0
124	0	0	0	0	0	0	0	0	0	0
125	0	0	0	0	0	0	0	0	0	0
126	0	0	0	0	0	0	0	0	0	0
127	2	0	0	0	0	0	0	0	0	0
128	0	0	0	0	0	0	0	0	0	0
129	2	0	0	0	0	0	0	0	0	1
130	4	0	1	1	0	1	0	0	0	0
131	9	0	1	2	0	0	0	0	0	0
132	12	3	6	1	2	4	0	0	0	0
133	22	13	6	4	1	3	0	0	0	0
134	46	47	19	9	5	8	0	0	0	0
135	108	65	47	15	8	9	0	0	1	0
136	152	115	59	15	10	11	0	3	1	1
137	223	173	76	32	15	17	0	2	5	1

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CL (mm)	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	2000/01	2001/02	2002/03	2003/04
138	310	211	118	35	11	27	0	3	6	1
139	381	255	101	41	18	24	1	2	2	0
140	391	289	186	63	12	24	0	4	7	3
141	455	315	156	89	16	31	1	5	14	4
142	467	341	184	92	24	32	1	9	10	3
143	449	392	216	102	20	23	2	8	13	6
144	521	342	206	114	23	32	2	11	15	5
145	483	359	220	148	16	32	3	7	18	11
146	456	356	229	162	27	38	4	7	30	8
147	469	390	244	155	29	24	3	7	18	12
148	408	304	221	183	31	27	6	16	18	9
149	428	319	160	136	20	30	7	10	30	8
150	386	364	251	177	39	24	12	13	26	19
151	315	288	145	186	29	25	15	16	35	22
152	333	344	233	169	31	29	19	25	43	17
153	292	369	170	180	38	18	20	22	41	27
154	288	320	145	180	19	33	12	28	63	36
155	311	295	164	174	28	34	14	18	58	39
156	223	280	165	182	30	18	22	14	74	46
157	203	294	148	154	25	30	17	24	74	33
158	169	211	158	167	30	37	12	23	81	52
159	167	199	86	154	25	23	20	20	97	56
160	136	149	142	154	43	23	26	19	81	78
161	106	121	88	149	28	21	16	15	69	64
162	103	115	92	114	33	27	22	25	84	72
163	77	118	96	115	34	16	15	30	78	57
164	78	80	76	117	30	23	26	25	100	98
165	78	66	79	95	21	22	20	13	75	115
166	48	51	52	85	33	17	22	17	91	95
167	59	56	74	77	24	29	21	24	82	105
168	34	47	69	68	24	33	13	18	80	99
169	33	43	29	70	16	13	20	13	53	99
170	25	33	52	39	22	15	9	13	71	126
171	29	33	33	47	13	10	16	6	58	87
172	24	20	37	30	14	16	12	13	60	119
173	14	19	23	19	17	10	4	18	41	99
174	17	15	20	27	13	6	7	5	44	86
175	18	12	19	23	8	11	6	9	49	92
176	11	11	19	12	13	4	3	4	35	62
177	4	5	12	19	13	2	5	4	27	68
178	6	3	12	7	4	5	0	2	20	50

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CL (mm)	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	2000/01	2001/02	2002/03	2003/04
179	7	7	11	9	3	1	1	6	20	53
180	1	8	9	5	6	1	2	2	20	45
181	1	13	6	5	7	1	0	2	9	44
182	2	5	5	6	3	1	0	3	12	37
183	0	8	3	2	3	1	0	2	3	22
184	2	2	2	4	4	0	1	1	2	26
185	1	1	3	0	6	0	0	0	0	11
186	2	0	3	2	2	0	0	0	7	14
187	1	2	0	1	4	1	0	1	1	13
188	0	3	1	0	0	1	0	1	1	1
189	1	1	1	1	5	0	0	0	0	6
190	0	1	1	1	3	0	0	0	3	6
191	0	1	1	0	1	0	0	1	0	2
192	0	1	1	0	2	0	0	0	0	4
193	0	0	1	0	0	0	0	0	0	3
194	0	1	1	0	2	0	0	0	0	3
195	0	0	1	0	1	0	0	0	0	0
196	0	2	0	0	0	0	0	0	0	0
197	0	0	0	0	0	0	0	0	0	0
198	0	0	0	0	0	0	0	0	0	0
199	0	0	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0	0	0
201	0	0	0	0	0	0	0	0	0	0
202	0	0	0	0	0	0	0	0	0	0
203	0	0	0	0	0	0	0	0	0	0
204	0	0	0	0	0	0	0	0	0	0
205	0	0	0	0	0	0	0	0	0	0
206	0	0	0	0	0	0	0	0	0	0
207	0	0	0	0	0	0	0	0	0	0
208	0	0	0	0	0	0	0	0	0	0
209	0	0	0	0	0	0	0	0	0	0
210	0	0	0	0	0	0	0	0	0	0
Total	9,406	8,306	5,195	4,426	1,037	978	460	589	2,056	2,381

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).