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

2018 Final Crab SAFE

Compiled by

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of the Bering Sea and Aleutian Islands

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

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Introduction

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

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

The Crab Plan Team (CPT) annually assembles the SAFE report with contributions from ADF&G and the NMFS. This SAFE report is presented to the North Pacific Fishery Management Council (NPFMC) and is available to the public on the NPFMC web page at: http://fakr.noaa.gov/npfmc/membership/plan_teams/CRAB_team.htm. 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	2019
Aleutian Is. golden king crab (AIGKC)	May	June	Annual	2019
Pribilof Is. blue king crab (PIBKC)	May	June	Biennial	2019
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	2019
Bristol Bay red king crab (BBRKC)	September	October	Annual	2019
EBS Tanner crab	September	October	Annual	2019
Pribilof Is. red king crab (PIRKC)	September	October	Biennial	2019
Saint Matthew blue king crab (SMBKC)	September	October	Annual	2019

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 10-13, 2018 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 2018 Crab SAFE report contains all recommendations for all 10 stocks including those whose OFL and ABC were previously determined in February and June 2018. This SAFE report will be presented to the NPFMC in October for their annual review of the status of BSAI Crab stocks.

Members of the team who participated in this review include the following:

Bob Foy (Chair), Ben Daly (Vice-Chair), Katie Palof, Miranda Westphal, Brian Garber-Yonts, Ginny Eckert, Krista Milani, André Punt, Buck Stockhausen, Cody Szuwalski, Martin Dorn, Shareef Siddeek, Bill Bechtol and Diana Stram.

Stock Status Definitions

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

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

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

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

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

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

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

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

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

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

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

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

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

Status Determination Criteria

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

Status determination criteria for crab stocks are 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.

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

Stock assessment documents shall:

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

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

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

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

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

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

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

Tiers 1 through 3

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

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

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

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

Tier 4

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

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

If the information necessary to determine total catch OFLs and ACLs is available for a Tier 4 stock, then the OFL and ACL will be total catch limits comprised of three catch components: (1) non-directed fishery discard losses; (2) directed fishery discard losses; and (3) directed fishery retained catch. If the information necessary to determine total catch OFLs and ACLs is not available for a Tier 4 stock, then the OFL and ACL are determined for retained catch. In the future, as information improves, data would be available for some stocks to allow the formulation and use of selectivity curves for the discard fisheries (directed and non-directed losses) as well as the directed fishery (retained catch) in the models. The resulting OFL and ACL from this approach, therefore, would be the total catch OFL and ACL.

Tier 5

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

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

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

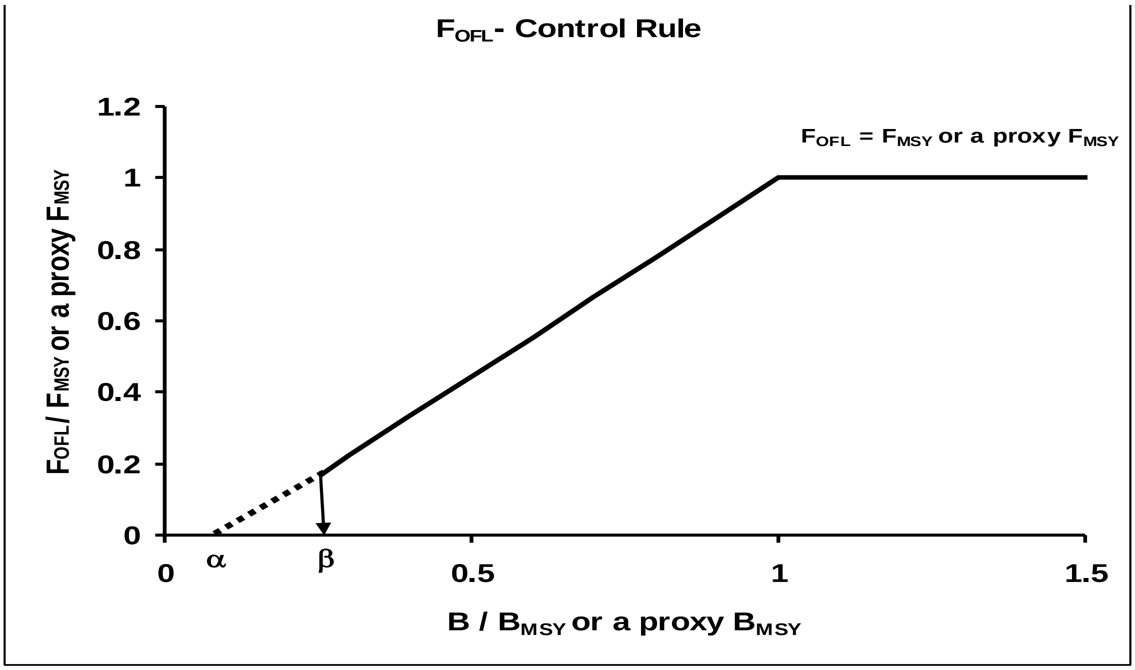

Table 2 Five-Tier System for setting overfishing limits (OFLs) and Acceptable Biological Catches (ABCs) for crab stocks. The tiers are listed in descending order of information availability. Table 2 contains a guide for understanding the five-tier system.

Information available	Tier	Stock status level	F_{OFL}	ABC control rule
B, B_{MSY}, F_{MSY}, and pdf of F_{MSY}	**1**	a. $\frac{B}{B_{msy}} > 1$	$F_{OFL} = \mu_A$ =arithmetic mean of the pdf	
		b. $\beta < \frac{B}{B_{msy}} \le 1$	$F_{OFL} = \mu_A \frac{B/B_{msy} - \alpha}{1-\alpha}$	ABC≤(1-b_y) * OFL
		c. $\frac{B}{B_{msy}} \le \beta$	*Directed fishery F = 0* $F_{OFL} \le F_{MSY}$†	
B, B_{MSY}, F_{MSY}	**2**	a. $\frac{B}{B_{msy}} > 1$	$F_{OFL} = F_{msy}$	
		b. $\beta < \frac{B}{B_{msy}} \le 1$	$F_{OFL} = F_{msy} \frac{B/B_{msy} - \alpha}{1-\alpha}$	ABC≤(1-b_y) * OFL
		c. $\frac{B}{B_{msy}} \le \beta$	*Directed fishery F = 0* $F_{OFL} \le F_{MSY}$†	
B, $F_{35\%}^{*}$, $B_{35\%}^{*}$	**3**	a. $\frac{B}{B_{35\%*}} > 1$	$F_{OFL} = F_{35\%}*$	
		b. $\beta < \frac{B}{B_{35\%}*} \le 1$	$F_{OFL} = F^{*}_{35\%} \frac{\frac{B}{B^{*}_{35\%}} - \alpha}{1-\alpha}$	ABC≤(1-b_y) * OFL
		c. $\frac{B}{B_{35\%}*} \le \beta$	*Directed fishery F = 0* $F_{OFL} \le F_{MSY}$†	
B, M, $B_{msy^{prox}}$	**4**	a. $\frac{B}{B_{msy^{prox}}} > 1$	$F_{OFL} = \gamma M$	
		b. $\beta < \frac{B}{B_{msy^{prox}}} \le 1$	$F_{OFL} = \gamma M \frac{B/B_{msy^{prox}} - \alpha}{1-\alpha}$	ABC≤(1-b_y) * OFL
		c. $\frac{B}{B_{msy^{prox}}} \le \beta$	*Directed fishery F = 0* $F_{OFL} \le F_{MSY}$†	
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 $F_{OFL} \le F_{MSY}$ 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 2018/2019 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 Adak red king crab). Table 4 lists those stocks for which the team recommends an ABC less than the maximum permissible ABC for 2018/19. Stock status in relation to status determination criteria are evaluated in this report (Table 5). Status of stocks in relation to status determination criteria for stocks in Tiers 3 and 4 are shown in Figure 2. EBS Tanner crab and Aleutian Islands golden king crab are estimated to be above B_{MSY} for 2018/19 while EBS snow crab, Bristol Bay red king crab, Pribilof Island red king crab and Norton Sound red king crab are estimated below B_{MSY}. Saint Matthew blue king crab is estimated to be below MSST while Pribilof Islands blue king crab stock remains overfished and estimated to be well below its MSST.

The CPT has general recommendations for all assessments and specific comments related to individual assessments. All recommendations are for consideration for the 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 2018 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 lb and 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 2017/18 was 10,500 t (with discard mortality rates applied), while the retained catch in the directed fishery was 8,600 t. This was below the 2017/18 OFL of 28,400 t. Snow crab bycatch occurs in the directed fishery and to a lesser extent in the groundfish trawl fisheries. Estimates of trawl bycatch in recent years are less than 1% of the total snow crab catch. Estimates of stock status were above the B_{MSY} proxy for this stock ($B_{35\%}$) in 2010/11-2012/13, but below the B_{MSY} proxy more recently. For 2018/19, the ratio of projected MMB (123.1 t) fishing at the F_{OFL} to B_{MSY} (142,800 t) remains less than 1 but above 0.5.

Data and assessment methodology

The stock assessment is based on a size- and sex-structured model in which crabs are categorized into immature or mature and new or old shell. The model is fitted to abundance and size frequency data from the NMFS trawl survey, total catch data from the directed fishery, bycatch data from the trawl fishery, size frequency data for male retained catch in the directed fishery, and male and female bycatch in the directed and trawl fisheries. The model is also fitted to biomass estimates and size frequency data from the 2009 and 2010 BSFRF surveys. Updated data in the model include biomass and length frequency data from the 2018 NMFS Eastern Bering Sea trawl survey, retained and discard catch and length frequencies from the 2017/18 directed fishery, and discard catch and length frequencies from the 2017/18 groundfish fisheries.

The model estimation structure is essentially identical to the 2017 assessment. A jittering approach within a maximum likelihood framework was used to evaluate model stability, and retrospective analysis was used as an additional model diagnostic. All model configurations exhibit some degree of model instability and retrospective patterns, but some model configurations were better than others.

The assessment author examined eight model runs. Model "New Data" was the 2017 final model with the new data. Model "Fix fem M" fixed mature female *M* at $0.23yr^{-1}$ as in 2016 assessment rather than estimating it with an informative prior. Model "Loose prior M" estimated all natural mortalities with a looser prior on *M*. Model "Looser prior M" estimated all natural mortalities with an even looser prior on *M*. Model "Sep devs" was similar to "New Data:, except separate recruitment deviations were estimated for females and males Model "Sep devs + Loose prior *M*" estimated separate recruitment deviations for females and males with a loose prior on *M*. Model "Sep devs + Looser prior *M*": estimated separate recruitment deviations for females and males with a looser prior on *M*. The final model was "Sep devs + Loose prior *M* + Growth", which estimated separate recruitment deviations for females and males with a loose prior on *M* and assumed a linear relationship between growth increment and pre-molt size.

The CPT selected model "Sep devs" because estimating separate recruitment deviations for males and females led to better fits to the survey biomass estimates and improved retrospective patterns. The CPT did not support the models based on loose and looser *M* priors owing to a lack of basis for the assumed priors.

Stock biomass and recruitment trends

Survey mature male biomass based on a maturity ogive decreased from 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, and increased to 84,000 t in 2017 and

198,400t in 2018. The 2018 survey mature male biomass is the largest since 1998. The 2018 model estimates of mature male biomass showed trends similar to survey biomass during 2011–2018, except that the model failed to match the 1-year spike in survey biomass observed in 2014 and was unable to match the high 2018 estimate. Observed survey mature female biomass rose quickly from 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 165,900t in 2018. Compared to the 2016 assessment, the model fits the abundance estimates quite closely from 2010. The increase in biomass is driven by high estimates of recruitment for 2014/15.

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 (142.8 thousand t) based on average recruitment over 1982 to 2017. Consequently, the minimum stock size threshold (MSST) is 71.4 thousand t. The CPT recommends that the ABC be less than maximum permissible ABC. The CPT recommends continuing the buffer of 20% adopted during 2017 for setting the 2018/19 ABC. This level of buffer is justified given the continuing concerns about model misspecification and parameter confounding, the ongoing evidence for retrospective patterns, and model instability even for the CPT-preferred model.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2014/15	78.9	168.0	30.8	30.8	34.3	69.0	62.1
2015/16	75.8	91.6	18.4	18.4	21.4	83.1	62.3
2016/17	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		123.1				29.7	23.8

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
2014/15	173.9	370.4	67.9	67.9	75.4	152.1	137.0
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		271.4				65.5	52.5

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

The current SOA harvest strategy allows a maximum harvest rate of 15% of mature-sized (≥120 mm CL) males, but also incorporates a maximum harvest rate of 50% of legal males and a threshold of 8.4 million mature-sized (≥90 mm CL) females and 14.5 million lb (6.6 thousand t) of effective spawning biomass (ESB), to prosecute a fishery. Annual non-retained catch of female and sublegal male RKC during the fishery averaged less than 3.9 million lb (8.6 thousand t) since data collection began in 1990. Total catch (retained and bycatch mortality) increased from 16.9 million lb (7.6 thousand t) in 2004/05 to 23.4 million lb (10.6 thousand t) in 2007/08 but has decreased since then; retained catch in 2017/18 was 6.82 million lb (3.09 thousand t) and total catch mortality was 7.67 million lb (3.48 thousand t).

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 carapace length from 1975 to the time of the 2018 survey and mature male (males ≥120 mm CL) biomass was projected to 15 February 2019. 2017/18 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 1975-2017 NMFS trawl survey dataset was updated with data from the 2018 survey, including sex-specific area-swept estimates of abundance, biomass, and size composition. The 2018 survey biomass estimate for mature males was the lowest since 1982.

Changes to the basic model methods included: (1) correcting to two minor coding errors that over-weighted size compositions in the NMFS surveys at small sizes and under-weighted BSFRF survey biomass when minimizing the model's objective function during parameter optimization, (2) dropping the terminal year recruitment estimate from the time period determining average recruitment in the calculation for B_{MSY} (as agreed at the May 2018 CPT meeting), and (3) fitting to observer-estimated total catch biomass and size compositions in the directed fishery instead of discarded male biomass and size compositions. For all scenarios, the BSFRF survey was assumed to capture all crab in the path of the net (i.e., the "capture probability" was 1 for all length groups). As a consequence, the BSFRF survey sex- and size-specific selectivities were identical to the availability of crab by sex and length bin and NMFS survey selectivities were simply the product of the estimated BSFRF survey selectivities (crab availabilities) and the NMFS survey capture probabilities. Additionally, bycatch in the groundfish fisheries in this scenario was separated into trawl and fixed gear fisheries.

Six model scenarios were evaluated for the 2018 assessment. Scenario “2b-old” was identical to Scenario 2b from the 2017 assessment and included the two coding errors noted above. The purpose of this scenario was to provide a basis for assessing the impact of the coding corrections on the model going forward, as well as to the 2017 assessment. Scenario “2b” in the 2018 assessment included the corrections to the two coding errors but was otherwise identical to Scenario 2b-old. Scenario “18.0” was similar to Scenario 2b, except that: (1) it fit observer-estimated total male catch biomass and size compositions in the directed fishery (replacing fits to discarded male biomass and size compositions), (2) estimated size-dependent curves reflecting male total catch selectivity and proportion retained (replacing curves reflecting retained selectivity and discarded male selectivity), and (3) estimated different logistic curves reflecting the proportion retained in the period before, and in the period after, rationalization in 2005 to account for potential differences in the degree of high-grading in the two periods, under the assumption that all fully-selected animals were retained. Scenario “18.0a” represented a minor variation on 18.0 in which the same annual effective sample sizes were the same for male and female length compositions (whereas they could be different in 18.0). Scenario “18.0b” was similar to 18.0, except that only one logistic curve was estimated to characterize retained proportions but annual factors for the maximum proportion retained were estimated for the post-rationalization period 2005-current to capture changes in high-grading. Finally, Scenario “18.0c” was similar to 18.0b, except that one logistic curve was estimated for male total selectivity in the directed fishery but with annual deviations in the length-at-50% selected while another was estimated for retained proportions, but with annual deviations for the length-at-50% retained after 2004.

The CPT selected model scenario 18.0a 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 NMFS survey biomass. The CPT noted that similar lacks of fit have 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). The effect of the coding errors on model results was small, but the former problematic estimate of Q = 1 for the NMFS survey was eliminated (estimated Q’s were ~ 0.92). Scenario 2b-old fit the NMFS survey data slightly better than the other scenarios but this was a result of it mistakenly overweighting the NMFS survey length compositions at small sizes and underweighting the BSFRF survey biomass. Scenario 2b, fitting to discard catch biomass and size compositions, can not be carried forward because at-sea crab observers will no longer predict which crab will be discarded. While all scenarios fit the retained catch and total catch biomass data similarly well, the estimated total male catch biomass in the directed fishery showed some odd variability in Scenario 18.0c when it extrapolated the available data, which starts in 1990/91, into the past back to 1975. The CPT rejected Scenario 18.0 on a technical issue because it incorrectly assigned different effective annual sample sizes to male and female size compositions when calculating the model likelihood. The CPT thus selected Scenario 18.0a for status determination and OFL setting on the basis that it was technically correctly on the issue of sample sizes for size compositions and exhibited similar fits to the data while being more parsimonious than Scenario 18.0b (i.e., having fewer parameters).

Stock biomass and recruitment trends

Based on the CPT-recommended scenario, 18.0a, the MMB at the time of mating is estimated to have been highest early in the late 1970s (approximately 111 thousand t), with secondary peaks in 1989 (28 thousand t) and 2002-3 and 2010-11 (~31 thousand t). The estimated MMB at time of mating in 2017/8 was 24.86 thousand t, the lowest in 1998 (23.41 thousand t). The projection for the 2018/19 time of mating, which assumes the fishing mortality in 2018/19 matches that corresponding to the OFL, is 20.80 thousand t. 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 (56, 53, and 43 million crab, respectively). The relatively low recruitment estimate of 14.6 million crab for 2018 was, however, the largest since 2011 (16.0 million crab).

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 (corresponding to fertilization in 1977) to the penultimate year of the assessment. Following discussions on the topic 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 25.5 thousand t. MMB projected for 2018/19 is 20.80 thousand t, 82% of $B_{35\%}$. Consequently, the BBRKC stock is in Tier 3b in 2018/19.

The CPT recommends that the OFL for 2018/19 be set according to model scenario 18.0a, for which the calculated OFL is 5.34 thousand t (11.76 million lb). Given the inability of the model to adequately fit the 2018 survey biomass, the team recommends that the ABC for 2018/19 be set below the maximum permissible ABC. The team recommends that a 20% buffer from the OFL be used to set the ABC at 4.27 thousand t (9.41 million lb). In previous assessments, a 10% buffer has been applied to the OFL to set ABC, but the CPT feels that the rather unusual environmental conditions in the EBS this year (e.g., elevated bottom temperatures, lack of a cold pool) and the model's poor fit to the 2018 survey data increase the uncertainty associated with this stock and warrant additional precaution.

MMB for 2017/18 was estimated to be 24.86 thousand t and above MSST (12.74 thousand t); hence the stock was not overfished in 2017/18. The total catch in 2017/18 (3.48 thousand t) was less than the 2017/18 OFL (5.60 thousand t); hence overfishing did not occur in 2017/18. The stock at 2018/19 time of mating is projected to be above the MSST and 82% of $B_{35\%}$ (see above); hence the stock is not approaching an overfished condition in 2018/19.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2014/15	13.03	27.25	4.49	4.54	5.44	6.82	6.14
2015/16	12.89	27.68	4.52	4.61	5.34	6.73	6.06
2016/17	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		20.80				5.34	4.27

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
2014/15	28.7	60.1	9.99	10.01	11.99	15.04	13.53
2015/16	28.4	61.0	9.97	10.17	11.77	14.84	13.36
2016/17	27.6	56.9	8.47	8.65	9.45	14.63	13.17
2017/18	28.1	54.8	6.60	6.82	7.67	12.35	11.11
2018/19		45.9				11.76	9.41

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 fisheries, 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 not overfished 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 1,130 t, 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 a new modeling framework, TCSAM02, which was endorsed by the SSC in June 2017. TCSAM02 is similar to previous Tanner crab assessment models but includes improvements to the modeling of fishery and population processes. 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 2018; bycatch, and size composition data from the 2017/18 crab fisheries; and data on Tanner crab bycatch in the groundfish fisheries in 2017/18.

The model recommended by the CPT to set the OFL and the ABC is a model with last year's configuration that was fully updated with recent survey and fishery data. The CPT identified several concerns with new models presented in the assessment. The most important of these concerns was that all of the new models used a revised catch estimates in the directed fishery and the bycatch in snow crab fish. 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). Inclusion of these revised catch estimates had a large impact on estimated Tanner crab biomass for the entire time series, shifting it upwards by approximately 70%. CPT was concerned that there was no opportunity to review the methodology to produce the new estimates, and it was unclear to the CPT whether observer coverage (the basis for the revised catch estimates) was adequate to support earlier estimates. Second, the revised catch time series was only used for Tanner crab and not for the other crab assessments in this cycle. The CPT would have preferred that revisions to catch estimates be done consistently for all crab stocks, rather than in a piecemeal way. Finally, it was not clear to the CPT what was driving the extreme sensitivity of the model to the revised catch estimates.

Stock biomass and recruitment trends

The MMB at the time of mating is estimated to have been highest early in the early 1970s (approximately 300 thousand t), with secondary peaks in 1989 (75 thousand t), 2008 – 2009 (76 thousand t), and in 2014 (83 thousand t). The estimated MMB at time of mating in 2017/18 was 64.09 thousand t and the projection for the 2018/19 time of mating is 35.95 thousand t. 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 and 2018, 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 R_{MSY}, the mean recruitment corresponding to B_{MSY} under prevailing environmental conditions. The recommended time period for defining average recruitment for determining the BMSY is 1982 – 2018; 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 2018, the stock is at Tier 3 level a. The F_{MSY} proxy ($F_{35\%}$) is 0.74 yr^{-1}, and the 2018/19 F_{OFL} is 0.74 yr^{-1} under the Tier 3 level a OFL Control Rule, which results in a total male and female OFL of 20.87 thousand t. The CPT recommends a 20% buffer to account for model uncertainty and stock productivity uncertainty be applied to the OFL, to set ABC = 16.70 thousand t. The 20% buffer is the same that the SSC recommended for determination of the 2017/18 ABC.

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

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2014/15	13.40	71.57	6.85	6.16	9.16	31.48	25.18
2015/16	12.82	73.93	8.92	8.91	11.38	27.19	21.75
2016/17	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		35.95				20.87	16.70

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
2014/15	29.53	157.78	15.10	13.58	20.19	69.40	55.51
2015/16	28.27	162.99	19.67	19.64	25.09	59.94	47.95
2016/17	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		79.26				46.01	36.82

4 Pribilof Islands red king crab [from the 2017 assessment]

In accordance with the approved schedule, no assessment was conducted for Pribilof Islands red king crab this year, however, a full stock assessment will be conducted in 2019. 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 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 0.32 to 13.1 t (<0.001 to 0.029 million pounds; 2012/13–2016/17).

Data and assessment methodology

The 2017 assessment is based on trends in male mature biomass (MMB) at the time of mating inferred from NMFS bottom trawl survey from 1975-2017 and commercial catch and observer data from 1973/74 to 2016/17. Two 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, and the second was a random effects model. The random effects model was presented with three variations: 1) λ fixed, 2) a prior on λ estimated from bootstrap (with CV=2.24) and 2) a prior on λ with CV 4.0.

Stock biomass and recruitment trends

Male and female abundance varies widely over the history of the survey time series and uncertainty around area-swept estimates of abundance are large due to relatively low sample sizes. Recruitment for this stock is generally low and episodic. Numbers at length vary dramatically from year to year; however, two (possibly three) cohorts can be seen moving through the length frequencies over time. MMB_{mating} increased over 2012 to 2016. Estimates for the 3-year moving average for MMB_{mating} in recent years approached those estimated during the early 1990s, peaking in 2014/15 at 9,963 t (21.96 million pounds).

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

The CPT recommended the Tier 4 stock status determination and selected the random effects model with a prior on λ estimated from a simple exponential model. A bootstrap analysis was used to obtain a prior CV=2.24. This model was selected because it is a better smoother of extreme survey values. For 2017/18 the B_{MSY} = 4,604 t (10.15 million pounds) derived as the mean MMB_{mating} from 1991/92 to 2016/17 from the random effects model. Male mature biomass at the time of mating for 2017/18 was estimated at 3,364 t (7.416 million pounds). The B/B_{MSY} = 0.73 and F_{OFL}= 0.13. $B/B_{MSY\ Proxy}$ is < 1, therefore the stock status level is Tier 4*b*. For the 2017/17 fishery, the OFL is 482 t (1.063 million lb). 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
2014/15	2,871	8,894	0	0	1.76	1,359	1,019
2015/16	2,756	9,062	0	0	0.32	2,119	1,467
2016/17	2,302	4,788	0	0	0.49	1,492	1,096
2017/18	2,302	3,364*	0	0	0.28	482	362
2018/19		Not estimated				482*	362*

*Value estimated from the most recent assessment

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
2014/15	6.33	19.61	0	0	0.002	3.00	2.25
2015/16	6.23	19.98	0	0	<0.001	4.67	3.23
2016/17	5.07	10.56	0	0	0.001	3.22	2.42
2017/18		7.42*	0	0	<0.001	1.06	0.80
2018/19						1.06*	0.80*

*Value estimated from the most recent assessment

The stock was above MSST in 2016/17 and was not overfished at the time of the last assessment. Overfishing did not occur during the 2017/18 fishing year.

5 Pribilof Islands blue king crab

In accordance with the approved schedule, no assessment was conducted for Pribilof Islands blue king crab this year, however, a full stock assessment will be conducted in 2019. 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 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 was rebuilt. In 2009, NMFS determined the stock would not meet its 10-year rebuilding horizon. Subsequently, Amendment 43 to the King and Tanner Crab FMP and Amendment 103 to the BSAI Groundfish FMP were approved by the Secretary of Commerce in 2014. This action, a revised rebuilding plan, closed the Pribilof Island Habitat Conservation Zone to Pacific cod pot fishing, which accounts for the highest recent rates of bycatch of this stock. This area was already closed to groundfish trawl fishing. To prevent overfishing in the future, ADF&G will implement closure areas for the commercial crab fisheries to reduce the blue king crab bycatch. NMFS recently implemented a procedure to account for blue king crab bycatch in the groundfish fisheries inseason and will take inseason action to prevent overfishing.

Data and assessment methodology

The calculation of the 2017/18 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 for the current year was estimated from the NMFS EBS bottom trawl survey using a three-year running average weighted by the inverse of the variance of the area-swept estimate. The new methodology to calculate MMB and B_{MSY} was recommended by the CPT and uses a random effects model to smooth the survey time series. This model smooths the MMB estimates without low abundance estimates having undue influence. Differences in abundance estimates from the two methods were largest during periods of high inter-annual variability. Differences between the methods were small in recent years. Results from this method are shown starting with the 2015/16 MMB and 2016/2017 projected MMB.

Stock biomass and recruitment trends

The 2017/18 MMB at mating is projected to be 230 t, which is approximately 6% of the proxy for B_{MSY}. The Pribilof blue king crab stock biomass continues to be low with no indication of recruitment.

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

This stock is recommended for placement into Tier 4. B_{MSY} was estimated using the time periods 1980/81 -1984/85 and 1990/91-1997/98. This range was chosen because it eliminates periods of extremely low abundance that may not be representative of the production potential of the stock. B_{MSY} is estimated at 4,108 t (9.06 million pounds) for 2017/18.

Because the projected 2017/18 estimate of MMB is less than 25% B_{MSY}, the stock is in stock status c and the directed fishery F is 0. However, an F_{OFL} must be determined for the non-directed catch. Ideally this should be based on the rebuilding strategy. For this stock the F_{OFL} is based on average groundfish bycatch between 1999/00 and 2005/06. The recommended OFL for 2017/18 is 1.16 t (0.0026 million lb).

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

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2014/15	2,055	344	Closed	0	0.07	1.16	0.87
2015/16	2,058	361	Closed	0	1.18	1.16	0.87
2016/17	2,054	232	Closed	0	0.38	1.16	0.87
2017/18		230*	Closed		0.33	1.16	0.87
2018/19		Not estimated				1.16*	0.87*

*Value estimated from the most recent assessment

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
2014/15	4.531	0.758	Closed	0	0.0002	0.0026	0.002
2015/16	4.537	0.796	Closed	0	0.0026	0.0026	0.002
2016/17	4.528	0.511	Closed	0	0.0008	0.0026	0.002
2017/18		0.507*	Closed	0	0.0007	0.0026	0.002
2018/19		Not estimated				0.0026*	0.002*

*Value estimated from the most recent assessment

The total catch for 2016/17 (0.38 t, 0.0008 million lb) was less than the 2016/17 OFL (1.16 t, 0.0026 million lb) so overfishing did not occur during 2016/17. The 2017/18 projected MMB estimate of 230 t (0.507 million lb) is below the proxy for MSST (MMB/B_{MSY} = 0.06) so the stock is projected to continue to be in an overfished condition.

6 St. Matthew blue king crab

Fishery information relative to OFL setting

The fishery was prosecuted as a directed fishery from 1977 to 1998. Harvests peaked in 1983/84 when 4,288 t (9.453 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 with a TAC of 529 t (1.166 million lb) and 209 t (0.461 million lb) of retained catch were harvested. The 2010/11 TAC was 726 t (1.601 million lb) and the fishery reported a retained catch of 573 t (1.263 million lb). The 2011/12 harvest of 853 t (1.881 million lb) represented 80% of the 1,152 t (2.540 million lb) TAC. In 2012/13, by contrast, harvesters landed 99% (733 t, 1.616 million lb) of a reduced TAC of 740 t (1.630 million lb), though fishery efficiency, at about 10 crab per pot, was little changed from what it had been in each of the previous three years. The directed fishery was closed in 2013/14 due to declining trawl survey estimates of abundance and concerns about the health of the stock. The directed fishery resumed again in 2014/15 with a TAC of 300 t (0.655 million pounds), but the fishery performance was relatively poor with the retained catch of 140 t (0.309 million pounds). The TAC in 2015/16 was 190 t (0.410 million pounds) with a retained catch of 47 t (0.105 million pounds). The fishery 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. Based on limited observer data, bycatch of sublegal male and female crabs in the directed blue king crab fishery off St. Matthew Island was relatively high when the fishery was prosecuted in the 1990s, and total bycatch (in terms of number of crabs captured) was often twice as high or higher than total catch of legal crabs.

Data and assessment methodology

This assessment is conducted in the General Model for Alaska Crab Stocks (GMACS) framework, which was accepted for use by the SSC in June 2016. This assessment differs from the original GMACS model in that natural and fishing mortality are continuous within 5 discrete seasons. In addition, the model estimates a dynamic B_0 computed as spawning biomass relative to spawning biomass if no fishing harvests had occurred. Season length in GMACS is controlled by changing the proportion of natural mortality that is applied during each season.

The GMACS assesses male crab ≥90 mm CL. The three length categories are: 90–104 mm CL; 105–119 mm CL; and ≥120 mm CL. Males ≥ 105 mm CL are used as a proxy for mature males, and males ≥120 mm CL are used as a proxy for legal males (≥5.5 inch carapace width). The model incorporates the following data: (1) commercial catch data from 1978/79 -1998/99, 2009/10–2012/13, 2015/16; (2) annual trawl survey data from 1978 to 2018; (3) triennial pot survey data from 1995 to 2013 and annually from 2015 to 2018; (4) bycatch data in the groundfish trawl and groundfish fixed-gear fisheries from 1991 to 2017; and (5) ADF&G crab-observer composition data for the years 1990/91–1998/99, 2009/10–2012/13, 2014/15, and 2015/16.

The NMFS summer trawl survey data are from 56 stations within the St. Matthew Island Section whereas the ADF&G pot survey included 96 stations in 2018. The pot surveys occur during July and August in areas of high-relief habitat important to blue king crab (particularly females) in areas missed by the NMFS trawl survey. Groundfish discard information for trawl and fixed gear is derived from NMFS observer data for the stock reporting area for SMBKC.

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 (7.7 million lb with a CV of 39%), followed by continued declines to the 2018 survey estimate of 1,731 t (3.816 million lb, with a CV of 28%). This value represents 31% of the long term mean (mean of 5,664 t during 1978–2018) with the most recent 3-year average surveys at 41% of the historical mean, again indicating a general decline in biomass since 2010.

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 2018 trawl-survey area-swept estimate of 0.154 million males in this size class is the third lowest in the 41-year time series since 1978 and only 15% of the long-term average recruitment. The 2018 abundance of this size group was also the lowest in the pot survey time series and 10% of the time series average.

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

The stock assessment examines five model configurations: (1) 2017 Model - the 2017 recommended model without any new data added; (2) BTS – Model 1 with 2018 bottom trawl survey (BTS) data; (3) BTS and pot, “reference model” – Model 2 with 2018 ADFG pot survey data; (4) VAST - a geo-spatial delta-GLMM model to the BTS data; and not run in GMACS; and (5) Fit survey - an exploratory scenario that revises the reference model by reweighting the NMFS trawl and ADF&G pot surveys by 2.0.

The CPT concurs with the author’s recommendation to use the reference case model for the 2018/19 crab year. This stock is in Tier 4. The CPT recommended model uses the full assessment period (1978/79–2017/18) to define the proxy for B_{MSY} in terms of average estimated MMB_{mating}. The projected MMB estimated for 2018/19 under the recommended model is 1,310 t (2.890 million lb) and the F_{MSY} proxy is the natural mortality rate (0.18^{-1} year) and $\mathrm{F_{OFL}}$ is 0.09, resulting in a mature male biomass OFL of 04 t (0.80 million lb). The MMB/$\mathrm{B_{MSY}}$ ratio is 0.35. 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 30 t (0.07 million lb).

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

Year	MSST	Biomass ($\mathrm{MMB_{mating}}$)	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	0.05	0.28	0.22
2016/17	1.97	2.23	0.00	0.00	0.05	0.14	0.11
2017/18	1.85	1.29	0.00	0.00	0.01	0.12	0.10
2018/19		1.31				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
2014/15	4.1	5.47	0.655	0.309	0.329	0.94	0.75
2015/16	4.0	4.65	0.41	0.105	0.105	0.62	0.49
2016/17	4.30	4.91	0.00	0.000	0.000	0.31	0.25
2017/18	4.1	2.85	0.00	0.000	0.000	0.27	0.22
2018/19		2.89				0.08	0.07

The stock was below MSST in 2017/18. Total catch was less than the OFL in 2017/18 and hence overfishing did not occur. The CPT discussed information that will be needed to develop a rebuilding plan if the stock is declared overfished.

7 Norton Sound red king crab

Fishery information relative to OFL setting

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

Data and assessment methodology

Four types of surveys have occurred periodically during the last three decades: summer trawl, summer pot, winter pot, and preseason summer pot, but none of these surveys have been conducted every year. 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 2017 summer commercial fishery, and 2016/17 winter commercial and subsistence catch. New trend data in the assessment included 2017 ADFG and NMFS surveys in Norton Sound. In addition, the standardized commercial catch CPUE indices were updated to include data for 1977-2017. The current model assumes a constant M=0.18 yr^{-1} for all length classes except the 124-133mm and the > 134mm CL length-classes, which had an estimated value of 0.579 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 summarized five model run alternatives, a base model (model 0) identical to last year's assessment model, and several models that changed fisheries selectivity and added in estimation of natural mortality for the largest size classes in various ways (models 3, 4, and 5). A final model, model 6, included summer pot survey data. The CPT selected the base model (model 0) as the recommended model. This is also the author's recommended model. This model is also the same configuration as last year's assessment model. Several other models presented in the assessment improved model fits, but the model outputs such as fishery selectivity and estimated natural mortality were considered implausible and thus these models were not regarded as improvements by the CPT.

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 current 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 1980-2018 was 4.818 million lb. The estimated 2018 mature male biomass on February 1 using Model 0 is 4.079 million lb., which is below the $B_{MSY\ \mathrm{proxy}}$ for this stock, placing Norton Sound red king crab in status category 4b.

The $F_{MSY\ \mathrm{proxy}}$ is M =0.18 yr^{-1} and the F_{OFL}=0.15yr^{-1}, because the 2018 mature male biomass is less than $B_{MSY\ \mathrm{proxy}}$, with the CPT choosing the default of gamma =1.0.

The CPT recommends that the OFL for 2018 be set according to model 0, for which the calculated OFL is 0.43 million lb. (0.20 thousand t). The team recommends that the ABC for 2018 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 0.35 million lb. (0.16 thousand t). The OFL is 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 due to concerns with model specification and unresolved competing hypotheses about whether the lack of large animals in catches and surveys is due to higher mortality or migration from the area.

Status and catch specifications (1000 t) for Norton Sound red king crab. Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

Year	MSST	Biomass (MMB)	GHL	Retained Catch[1]	Total Catch[2]	Retained Catch OFL	Retained catch ABC
2014/15	0.96	1.68	0.17	0.18	0.18	0.21	0.19
2015	1.09	2.33	0.18	0.18	0.24	0.33	0.26
2016	1.03	2.66	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	TBD	TBD	TBD	0.20	0.16

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

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

Year	MSST	Biomass (MMB)	GHL	Retained Catch[1]	Total Catch[2]	Retained Catch OFL	Retained catch ABC
2014/15	2.11	3.71	0.38	0.39	0.39	0.46	0.42
2015	2.41	5.13	0.39	0.40	0.52	0.72	0.58
2016	2.26	5.87	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	TBD	TBD	TBD	0.43	0.35

Total retained catch during 2017 did not exceed the OFL for this stock, thus overfishing is not occurring. Stock biomass is above MSST; thus, the stock is not overfished.

Additional Plan Team recommendations

The CPT has the following recommendations for the next assessment:

- Evaluate methods to improve ADFG bottom trawl survey biomass estimation, including model-based approaches.

- Quantitatively evaluate the representativeness of observer sampling.
- Estimate a fishery retention curve. Consider alternative (2-parameter and 1-parameter) curves for both retention and selectivity.
- Provide Tier 3 calculations for Norton Sound red king crab and evaluate its suitability for tier 3 status.

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. 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 (2005/06-2016/17) has ranged from 5.245 million lb in 2006/07 to 6.378 million lb in 2013/14. Total mortality ranged from 5.426 to 6.803 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 for AI golden king crab was under development for a number of years, with model assumptions and data inputs refined by reviews by the SSC and CPT. The modeling framework was recommended by the CPT in September 2016 and approved by the SSC in October 2016 for use in the 2017/18 specifications cycle.

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 CPUE data, length-frequency data for the directed fishery (landing and total catch), and mark-recapture data. These data are available through the 2016/17 season.

The assessment author examined seven model scenarios for EAG and six model scenarios for WAG in this assessment. Model 17_0 is the base model, which is the model for last year updated with new data. Model 17_0a used an abundance index from a VAST analysis of CPUE data rather than the standard GLM approach. Model 17_0b used an abundance index from a GLM analysis that uses AIC rather than r^2 for model selection. Model 17_0c used an abundance index from a GLM analysis that includes year-area interaction terms in the CPUE analysis. Model 17_0d added a third catchability and selectivity period for 2013-2016. Model 17_0e used the McAllister and Ianelli method for tuning the length composition data rather than the Francis method. Model 17_0f included an abundance index from a GLM analysis of the three years of collaborative pot survey data. This index was only evaluated in the EAG model because the survey is conducted only in EAG.

The CPT identified technical issues with each of the new model scenarios that would prevent them from being used for management advice. It is important to note that several of the model scenarios show promise and could potentially be used after additional development and review. The CPT recommends adopting the base model 17_0 for harvest projections.

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 2015-2017. A preliminary model using an index from this survey was evaluated in the assessment, however additional index development is needed before this model 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 in the last several years. Recruitment for the EAG is variable with a generally increasing trend while recruitment for WAG is lower in recent years than during the 1980s. However, recruitment in 2015 for WAG appears to be relatively strong. Stock trends reflected the fishery standardized CPUE trends in both areas.

Summary of major changes

The assessment model recommended by CPT is the same as the model used in the previous assessment. There were minor changes in the CPUE standardization and maturity breakpoint analysis that had negligible 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 2018/19. 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 $\mathrm{B_{MSY}}$ in both areas therefore no adjustment is needed to the F_{OFL} to determine the combined for both areas.

The CPT recommends that the $B_{MSY\mathrm{proxy}}$ for the Tier 3 harvest control rule be based on the average recruitment from 1987-2012, years for which recruitment is relatively precisely estimated.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch [a]	Total Catch[a]	OFL	ABC
2014/15	N/A	N/A	2.853	2.771	2.967	5.69	4.26
2015/16	N/A	N/A	2.853	2.729	2.964	5.69	4.26
2016/17	N/A	N/A	2.515	2.593	2.829	5.69	4.26
2017/18	6.044	14.205	2.515	2.585	2.942	6.048	4.536
2018/19		17.952				5.514	4.136

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

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC
2014/15	N/A	N/A	6.290	6.11	6.54	12.53	9.40
2015/16	N/A	N/A	6.290	6.016	6.54	12.53	9.40
2016/17	N/A	N/A	5.545	5.716	6.24	12.53	9.40
2017/18	13.325	31.315	5.545	5.699	6.49	13.33	10.00
2018/19		39.577				12.16	9.12

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

The MMB is above MSST in 2017/18 therefore the stock is not overfished. Catch was below the OFL in 2017/18 therefore overfishing did not occur.

Additional Plan Team recommendations

The CPT recommended additional assessment work in a number of areas. Additional development is needed for CPUE standardization, including consideration of year-area interactions, and continued development of the VAST spatial modeling approach. The chela measurement data should be reanalyzed to better estimate the maturity of AI golden king crab. Improvements are needed in the method used to project the OFL and ABC for the upcoming fishing year. 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 District 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 0.856 million lb (388 t) by 50 vessels during the 1983/84 season; fishery participation has since been sporadic and retained catches vary from 0 to 0.342 million lb (155 t). A guideline harvest level (GHL) was first established in 1999 at 0.200 million lb (91 t) and the fishery has been managed with a GHL of 0.150 million lb (68 t) since 2000. No directed fishery occurred during 2006–2009, but one vessel landed catch in 2010, two vessels landed catch in 2011, one vessel landed catch each year from 2012 to 2014, and two vessels landed catch in 2017. No vessels participated in the directed fishery during 2015 or 2016. 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 2001–2017 due to crab fisheries range from 0 0.160 million lb (73 t). Estimates of annual fishery mortality during 1991/92–2017 due to groundfish fisheries range from <0.001 to 0.019 million lb (8.84 t). Total fishery mortality in groundfish fisheries during the 2017 crab fishing year was 1.28 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:

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

where,

- $R_{2001–2010}$ is the average of the estimated annual ratio of lb of bycatch mortality to lb of retained in the directed fishery during 2001–2010.
- $RET_{1993-1998}$ is the average annual retained catch in the directed crab fishery during 1993–1998.

- $BM_{NC,1994\text{-}1998}$ is the estimated average annual bycatch mortality in non-directed crab fisheries during 1994–1998.
- $BM_{GF,1992/93\text{–}1998/99}$ is the estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99.

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

Calendar Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2014	N/A	N/A	68	Conf.	Conf.	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	Conf.	Conf.	93	70
2018	N/A	N/A				93	70
2019	N/A	N/A				93	70
2020	N/A	N/A				93	70

N/A = not available
Conf. = confidential
TBA = to be announced

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

Calendar Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2014	N/A	N/A	150,000	Conf.	Conf.	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	Conf.	Conf.	0.20	0.15
2018	N/A	N/A				0.20	0.15
2019	N/A	N/A				0.20	0.15
2020	N/A	N/A				0.20	0.15

N/A = not available
Conf. = confidential
TBA = to be announced

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 21.19 million lb. 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 0.5 million lb 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 0.94 million lb, but the retained catch during the 1995/96 season dropped to 0.04 million lb. Most of the catch since the 1990/91 season was harvested in the Petrel Bank area (between 179° W longitude and 179° E longitude) and the last two commercial fishery seasons were opened only in the Petrel Bank area with 0.51 million lb in 2002/03 and 0.48 million lb 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 2017/18 seasons averaged 0.002 million lb in crab fisheries and 0.015 million lb in groundfish fisheries. Estimated annual total fishing mortality from 1995/96 to 2017/18 averaged 0.072 million lb. The average retained catch during that period was 0.054 million lb. This fishery is rationalized under the Crab Rationalization Program only for the area west of 179° W longitude.

Data and assessment methodology

The 1960/61 to 2007/08 time series of retained catch (number and pounds of crabs), effort (vessels, landings and pot lifts), average weight and average carapace length of landed crabs, and catch-per-unit effort (number of crabs per pot lift) are available. Bycatch from crab fisheries from 1995/96 to 2017/18 and from groundfish fisheries from 1993/94 to 2017/18 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 0.123867 million lb.

The CPT continues to have concerns regarding the depleted condition of this stock. Groundfish bycatch in recent years has accounted for the majority of the total catch. The CPT recommends an ABC of 0.030967 million lb 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
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	<1	56	34
2017/18	N/A	N/A	Closed	0	<1	56	14
2018/19	N/A	N/A				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
2014/15	N/A	N/A	Closed	0	0.00047	0.12387	0.07432
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				0.12387	0.03097
2019/20	N/A	N/A				0.12387	0.03097

Figures and Tables

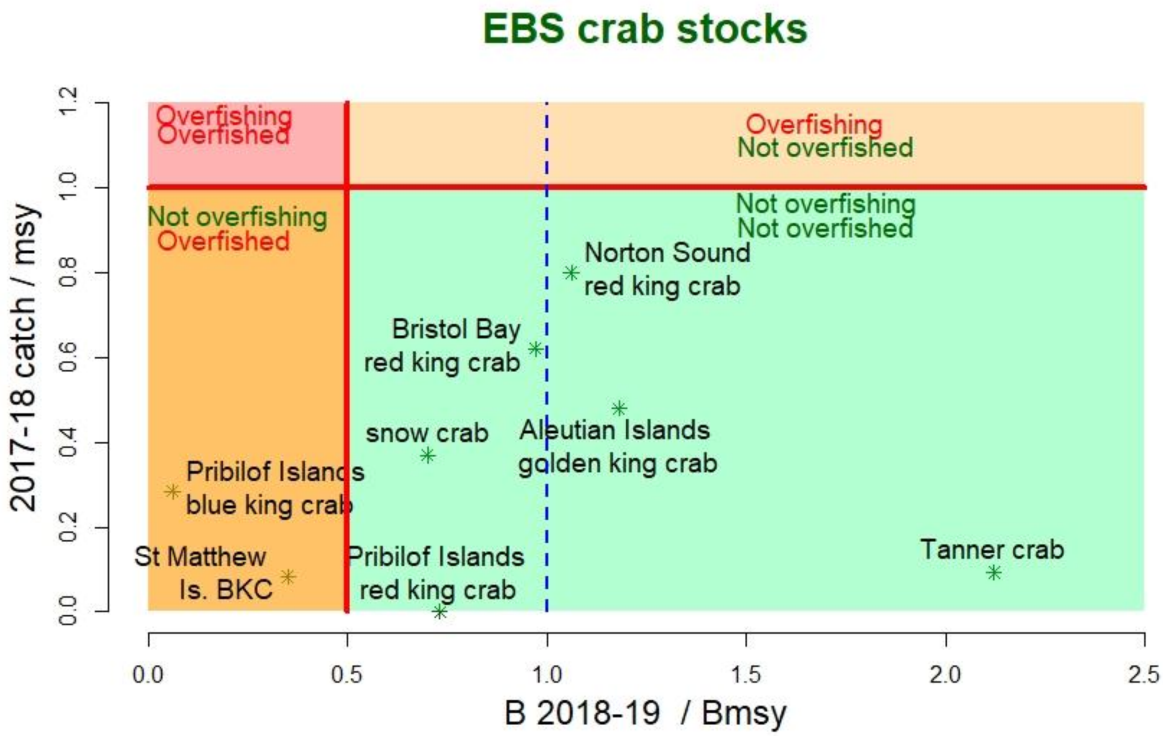

Figure 1. Status of 6 Bering Sea crab stocks in relation to status determination criteria (BMSY, MSST, overfishing) for 2018. Status of PIBKC, PIRKC is based upon the 2017 assessment. Note that information is insufficient to assess Tier 5 stocks according to these criteria (WAIRKC, PIGKC).

Table 4. Crab Plan Team recommendations for September 2018. Note that recommendations for stocks 7, 8 represent those final values from the SSC in February and June 2018 while 4,5,9,10 represent the most recent assessment in 2017. 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 $B_{MSYproxy}$	Years[1] (biomass or catch)	2018/19[2] MMB	2018/19 MMB / MMB_{MSY}	γ	Mortality (M)	2018/19[3] OFL	2018/19 ABC	ABC Buffer
1	EBS snow crab	3	b	1.04	142.80	1982-2017 [recruitment]	123.1	0.86		0.36 (females) 0.27 (imm) 0.26 (mat males)	29.70	23.80	20%
2	BB red king crab	3	b	0.25	25.50	1984-2017 [recruitment]	20.80	0.82		0.18	5.34	4.27	20%
3	EBS Tanner crab	3	a	0.74	30.29	1982-current [recruitment]	35.95	1.19		0.32 (females) 0.23 (imm) 0.27 (mat males)	20.87	16.70	20%
4	Pribilof Islands red king crab	4	b	0.18	4.60	1991/92-2016/17	3.36	0.73	1	0.18	0.48	0.36	25%
5	Pribilof Islands blue king crab	4	c	0.18	4.11	1980/81-1984/85 & 1990/91-1997/98	0.23	0.06	1	0.18	0.00116	0.00087	25%
6	St. Matthew Island blue king crab	4	b	0.04	3.70	1978-2018	1.31	0.35	1	0.18	0.04	0.03	20%
7	Norton Sound red king crab	4	b	0.15	2.19	1980-2017	1.85	0.84	1	0.18	0.20	0.16	20%
8	AI golden king crab	3	a	EAG (0.64) WAG (0.60)	12.09	1987/88-2012/13	17.95	1.48		0.21	5.51	4.14	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 for 2/1/2018 for Norton Sound red king crab, 2/15/2018 for AIGKC, and 2/15/2019 for other stocks.

[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 2018/19 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	2018/19 *Max* ABC[2]	2018/19 ABC
EBS Snow Crab	3	29.7	23.80
Bristol Bay RKC	3	5.13	4.27
Tanner Crab	3	20.87	16.7
Pribilof Islands RKC	4	0.48	0.36
Pribilof Islands BKC	4	0.00116	0.00087
Saint Matthew BKC	4	0.04	0.03
Norton Sound RKC	4	0.20	0.16
Aleutian Islands GKC	3	5.49	4.14
Pribilof Islands GKC[1]	5	0.09	0.07
Western Aleutian Islands RKC	5	0.06	0.01

[1] For Pribilof Islands golden king crab, this is for the 2018 calendar year instead of the 2017-2018 crab fishing year.

[2] For Tier 5 stocks this is 0.90 while all other stocks P*.

Table 6. Stock status in relation to status determination criteria for 2017/18 as estimated in May and September 2018. Hatched areas indicate parameters not applicable for that tier. Values are in thousand metric tons (kt).

Chapter	Stock	Tier	MSST[1]	B_{MSY} or $B_{MSYproxy}$	2017/18[2] MMB	2017/18 MMB / MMB_{MSY}	2017/18 OFL	2017/18 Total catch	Rebuilding Status
1	EBS snow crab	3	71.40	142.80	99.60	0.70	28.40	10.50	
2	BB red king crab	3	12.74	25.50	24.86	0.97	5.60	3.48	
3	EBS Tanner crab	3	15.15	30.29	64.09	2.12	25.42	2.37	
4	Pribilof Islands red king crab	4	2.30	4.60	3.36	0.73	0.48	0.00028	
5	Pribilof Islands blue king crab	4	2.05	4.11	0.23	**0.06**	0.00116	0.00033	**overfished**
6	St. Matthew Island blue king crab	4	1.85	3.70	1.29	**0.35**	0.12	0.01	**below MSST**
7	Norton Sound red king crab	4	1.09	2.19	2.33	1.06	0.30	0.24	
8	AI golden king crab	5	6.04	12.09	14.21	1.18	6.05	2.94	
9	Pribilof Islands golden king crab	5					0.091	Conf.	
10	Western AI red king crab	5					0.056	< 0.001	

[1] As estimated in the 2018 assessment.

[2] For stocks 1-6 MMB on 2/15/2017 is estimated using the current assessment in September 2018. For Norton Sound red king crab MMB on 2/1/2017 is estimated using the current assessment in January 2017.

A stock assessment for eastern Bering Sea snow crab

Cody Szuwalski

September 12, 2018

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 2017 was low (8.6 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 1.93 kt which was 22% 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-nineties (observed MMB during 1990, 1991, and 1997 were 443.79, 466.61, and 326.75 kt, respectively). The stock was declared overfished in 1999 in response to the total mature biomass dropping below the minimum stock size threshold. MMB in that year decreased to 95.85 kt. Observed MMB slowly increased after 1999, and the stock was declared rebuilt in 2011 when estimated MMB at mating was above $B_{35\%}$. However, since 2011, the stock has declined again and the observed MMB at the time of survey dropped to an all time low in 2017 of 83.96 kt. This year's MMB (2018) marks the highest observed at the time of the survey since 1998.

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, appears to have persisted to the present, and 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		123.1				29.7	23.8

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		271.39				65.48	52.47

6. Basis for the OFL

The OFL for 2018 from the chosen model (Sep devs) was 29.74 kt fishing at $F_{OFL} = 1.04$ (85 % of the calculated $F_{35\%}$, 1.22). The calculated OFL was a 5% change from the 2017 OFL of 28.4 kt. The projected ratio of MMB at the time of mating in 2019 to $B_{35\%}$ is 0.86.

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

Year	Tier	BMSY	MMB	Status	FOFL	Years	M
2017/2018	3	142.8	99.6	0.7	1.04	1982-2017	0.27, 0.26, 0.36

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 male crab, and mature female crab, respectively.

Year	Tier	BMSY	MMB	Status	FOFL	Years	M
2017/2018	3	314.8	219.6	0.7	1.04	1982-2017	0.27, 0.26, 0.36

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. PDFs of the OFL for selected models were characterized using a Markov Chain Monte Carlo algorithm to sample from its posterior distribution. Reported OFLs are maximum likelihood estimates because of pathologies in the MCMC output.

8. Basis for ABC

The ABC for the chosen model was 23.79 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: 2018 Bering Sea survey biomass and length frequency data, 2017 directed fishery retained and discard catch and length frequencies for retained and discard catch, and groundfish discard length frequency and discard from 2017. Growth data were updated with 70 observations of pre- and post-molt lengths (45 for females; 25 for males).

3. Assessment methodology:

The recommended OFL was calculated using Bayesian methodologies in 2016 and 2017, which was a departure from the previous projection framework (but provided similar management advice). Both a maximum likelihood approach (including 'jittering') and a Bayesian treatment of the data were completed for selected models this year. Management quantities from the author chosen model are reported as the maximum likelihood estimates because of convergence issues with MCMC.

4. Assessment results

The updated estimate of MMB (February 15, 2017) was 85.84 which placed the stock at 60% of $B_{35\%}$. Projected MMB on February 15, 2018 from this assessment's chosen model was 123.07 kt after fishing at the OFL , which will place the stock at 86% 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 2018 comments, SSC comments, and author response:

CPT and SSC comments

The CPT made three recommendations for scenarios to be presented in September based on analyses presented during the May 2018 CPT meeting:

- 2017 accepted model–Estimate M for females, males, and immature crab.
- Fix female M–The same model as above, but fix natural mortality for mature females at 0.23, to match the 2016 accepted model.
- Fit the model to total and retained size composition data, rather than the total and discarded size comps.

The CPT also recommended resolving problems with any parameters hitting bounds. The SSC agreed with these suggestions and proposed additional runs to explore the impact of priors on natural mortality. The SSC suggested exploring the potential that catchability for the BSFRF data was not 1 by locating information (e.g. underwater video of surveys) to inform this assumption. The SSC also noted potential issues with the mixing of several parameters when implementing an MCMC algorithm and suggested that the model 'may now be getting too complicated'. The SSC supported an increase of the buffer for the ABC from 10% to 20%.

The author presents 7 runs based on these recommendations:

- "2017 Accepted" – Last year's accepted model fit to last year's data.
- "New Data" – Last year's accepted model fit to this year's data.
- "Fix fem M" – Last year's accepted model fit to this year's data, but turning off estimation of mature female natural mortality to more closely match the 2016 accepted model.
- "Loose prior M" – Estimate mature female natural mortality (and mature male and immature female and male), but use a less informative prior.
- "Looser prior M" – Estimate mature female natural mortality (and mature male and immature female and male), but use an even less informative prior.
- "Sep devs" – Estimate recruitment deviations for males and females instead of using a common recruitment between sexes. This is an addition of the author's, given the runs in the residuals of the fits to the survey mature biomass and observed retrospective patterns. Female mature biomass is underestimated in recent years, whereas male biomass is overestimated. Potential rationale for fitting different recruitment deviations by sex include different growth rates between sexes (resulting in different ages of crab by sex in the first length bins) and different observed spatial distribution of immature females and males.
- "Sep devs + loose prior M" – Combine "Sep devs" and "Loose prior M"
- "Sep devs + looser prior M" – Combine "Sep devs" and "Looser prior M"
- "Sep devs + loose + growth" – Combine "Sep devs" and "Loose prior M", but replace the the 'kinked' growth curves for males and females with linear growth.

Authors response

Most of the SSC and CPT's suggestions are addressed in this assessment and changes within were undertaken in a step-wise fashion. Model scenarios include all CPT recommended models.

'Jittering' was performed for all models, but did not perform as well last year's implementation in identifying a mode of likelihood to which many runs of the same model configuration converged. Jittering the models with all new data for 2018 produced less stable estimates of management quantities than in 2017, so two additional model runs were performed in which the newest catch and survey data and new growth data were added separately to explore their relative impact on the stability of the model. Bimodality was a problem in some models. Given what appears to be instability in convergence in the maximum likelihood estimation, Bayesian posteriors of management quantities were also calculated for selected models. However, the Bayesian methods also had difficulties converging. Retrospective analyses for selected models were also performed.

Tentatively, "Sep devs" is the author preferred model based on fit to the data, the number of assumptions placed on the data, and the magnitude of retrospective patterns (see discussion below). However, the author looks forward to discussion and guidance from the CPT on this issue.

It should be noted that fitting the model to total and retained size composition is already done in previous assessments, but the data input as discards and retained composition data, then summed in the code. Also, the author has been in contact with the BSFRF and hopes to procure video to explore the assumption of q = 1 for the BSFRF gear in the future.

C. Introduction

Distribution

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

Life history characteristics

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

Natural Mortality

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

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

The mean for the prior for natural mortality used in this assessment is based on the assumption (informed by the studies above) that longevity would be at least 20 years in a virgin population of snow crab. Under negative exponential depletion, the 99th percentile corresponding to age 20 of an unexploited population corresponds to a natural mortality rate of 0.23. Using Hoenig's (1983) method a natural mortality equal to 0.23 corresponds to a maximum age of 18 years. Given this background, the mean of the prior on natural mortality for immature males and females, mature males, and mature females was set to 0.23 yr^{-1}.

In one model "Fix fem M", mature female was not estimated. In all others, natural mortality was estimated with varying standard errors for the prior distribution around the mean. Natural mortality was estimated in

2017 with a standard error equal to 0.054. Models down-weighting the prior on natural mortality (e.g. "Loose prior M", "Looser prior M", and their derivatives), used standard errors of 0.154 and 2.154, respectively, to reduce the impact of the prior in model fitting (Figure 6). The standard error of 0.054 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).

Weight at length

Weight at length is calculated by a power function, the parameters for which were recalculated by the Kodiak lab in August 2016 and resulted in very small changes in weight at length for males, but rather large changes for females. 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. Morphometric maturity for males was determined by chela height measurements, which were available starting from the 1989 survey (Otto 1998). Mature male biomass referenced throughout this document refers to a morphometrically mature male. A maturity curve for males was estimated using the average fraction mature based on chela height data and applied to all years of survey data to estimate mature survey numbers. The separation of mature and immature males by chela height may not be adequately refined given the current measurement to the nearest millimeter. Chela height measured to the nearest tenth of a millimeter (by Canadian researchers on North Atlantic snow crab) shows a clear break in chela height at small and large widths and shows fewer mature animals at small widths than the Bering Sea data measured to the nearest millimeter. Measurements taken in 2004-2005 on Bering Sea snow crab chela to the nearest tenth of a millimeter show a similar break in chela height to the Canadian data (Rugolo et al. 2005). The probability of maturing (which is different from the fraction mature at length) is estimated within the model for both sexes as a freely estimated (but smoothed) function of length.

Molting probability

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

Male snow crabs that do not molt (old shell) may be important in reproduction. Paul et al. (1995) found that old shell mature male Tanner crab out-competed new shell crab of the same size in breeding in a laboratory study. Recently molted males did not breed even with no competition and may not breed until after ~100 days from molting (Paul et al. 1995). Sainte-Marie et al. (2002) stated that only old shell males take part in mating for North Atlantic snow crab. If molting precludes males from breeding for a three month period, then males that are new shell at the time of the survey (June to July), would have molted during the preceding spring (March to April), and would not have participated in mating. The fishery targets new shell males, resulting in those animals that molted to maturity and to a size acceptable to the fishery of being removed from the population before the chance to mate. However, new shell males will be a mixture of crab less than 1 year from terminal molt and 1+ years from terminal molt due to the inaccuracy of shell condition as a measure of shell age. Crabs in their first few years of life may molt more than once per year, however, the smallest crabs included in the model are approximately 4 years old and would be expected to molt annually. Further research on the relationship between shell condition and time from last molt is needed.

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

Further complicating the process of quantifying reproductive capacity, clutch fullness and fraction of unmated females may not account for the fraction of females that may have unfertilized eggs, since these cannot be detected by the naked eye at the time of the survey. The fraction of barren females observed in the survey may not be an accurate measure of fertilization success because females may retain unfertilized eggs for months after extrusion. To examine this hypothesis, RACE personnel sampled mature females from the Bering Sea in winter and held them in tanks until their eggs hatched in March of the same year (Rugolo et al. 2005). All females then extruded a new clutch of eggs in the absence of males. All eggs were retained until the crabs were 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, this year's addition of 70 pre- and post-molt lengths brings the total to 110 data points derived from 6 studies used to estimate grow increments for females and males (Table 6). These studies include:

1. Transit study (Rugolo unpublished data, 2003); 14 crab
2. Cooperative seasonality study (Rugolo); 6 crab
3. Dutch harbor holding study; 9 crab
4. NMFS Kodiak holding study held less than 30 days; 6 crab
5. NMFS Kodiak holding study 2016; 5 crab
6. NMFS Kodiak holding study 2017; 70 crab.

Data from the NMFS Kodiak study 2017 are new for this year's assessment. 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 (Rugolo, pers. com.). The holding studies include only data for crab held less than 30 days because growth of crabs held until the next spring's molting was much lower. Females molting to maturity were excluded from all data sets, since the molt increment is usually smaller. Crab missing more than two limbs were excluded due to other studies showing lower growth. Crab from Rugolo's seasonal study were excluded that were measured less than 3 days after molting due to difficulty in measuring soft crab accurately. In general, growth of snow crab in the Bering Sea appears to be greater than growth of some North Atlantic snow crab stocks (Sainte-Marie 1995).

Management history

ADFG harvest strategy

Before the year 2000, the Guideline Harvest Level (GHL) for retained crab only was a harvest rate 58% of the number of male crab over 101 mm CW estimated from the survey. The minimum legal size limit for snow crab is 78 mm, however, the snow crab market generally 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 (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 54% for the chosen model in this assessment (Figure 7).

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

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

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

History of BMSY

Prior to adoption of Amendment 24, B$_{MSY}$ was defined as the average total mature biomass (males and females) estimated from the survey for the years 1983 to 1997 (921.6 million lbs; NPFMC 1998) and MSST was defined as 50% of B$_{MSY}$. Definitions of biological reference points based on the biomass over a range of years make a host of assumptions that may or may not be fulfilled. Currently, the biological reference point for biomass is calculated using a spawning biomass per recruit proxy, B$_{35\%}$ (Clark, 1993). B$_{35\%}$ is the biomass at which spawning biomass per recruit is 35% of 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.

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-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 2017 was low (8.6 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 1.93 kt which was 22% of the retained catch.

Discard from the directed pot fishery has been estimated from observer data since 1992 and ranged from 11% to 64% (average 33%) of the retained catch of male crab biomass (Table 7). 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 8). Bycatch in fisheries other than the groundfish trawl fishery has historically been relatively low, but in 2015 bycatch from sources other than the groundfish trawl fishery reached almost ~25% of the reported bycatch. Size frequency data and catch per pot have been collected by observers on snow crab fishery vessels since 1992. Observer coverage has been 10% on catcher vessels larger than 125 ft (since 2001), and 100% coverage on catcher processors (since 1992).

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

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

Catch data

Catch data and size composition of retained crab from the directed snow crab pot fishery from survey year 1978 to the 2017 were used in this analysis (Table 7). Size composition data on the total catch (retained plus discarded) in the directed crab fishery were available from survey year 1992 to 2017. Total discarded catch was estimated from observer data from 1992 to 2017 (Table 1). The discarded male catch was estimated for survey year 1978 to 1991 in the model using the estimated fishery selectivities based on the observer data for the period of survey year 1992 to 2017. 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 currently used strategy (since 2001) to the present by ADFG to set the TAC, which assumes a discard mortality of 25% (Zheng, et al. 2002). The discards prior to 1992 may be underestimated due to the lack of escape mechanisms for undersized crab in the pots before 1997. See Table 5 for a summary of catch data.

Table 5: Data included in the assessment. Dates indicate survey year.

Data component	Years
Retained male crab pot fishery size frequency by shell condition	1982 - 2017
Discarded Males and female crab pot fishery size frequencey	1992 - 2017
Trawl fishery bycatch size frequencies by sex	1991 - 2017
Survey size frequencies by sex and shell condition	1982 - 2018
Retained catch estimates	1982 - 2017
Discard catch estimates from crab pot fishery	1992 - 2017
Trawl bycatch estimates	1993 - 2017
Total survey biomass estimates and coefficients of variation	1982 - 2018
2009 study area biomass estimates, CVs, and size frequencey for BSFRF and NMFS tows	2009
2010 study area biomass estimates, CVs, and size frequencey for BSFRF and NMFS tows	2010

Survey biomass and size composition data

Abundance was estimated from the annual eastern Bering Sea (EBS) bottom trawl survey conducted by NMFS (see Rugolo et al. 2003 for design and methods). 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 three 'eras' in the assessment (1978-1981, 1982-1988, 1989-present). Currently only data from 1982 onward are used in the assessment–a change adopted in the 2017 assessment (Figure 9). 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 10 & Figure 11) 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 8). 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 south west portion of the shelf (Figure 4) while smaller males have been more prevalent on the north west portion of the shelf (Figure 1). Females have exhibited a similar pattern (compare Figure 2 to Figure 5). In addition to changing spatially over the size and shelf, distributions of crab by size and maturity have also changed temporally. The centroids of abundance in the summer survey have moved over time (Figure 12 & Figure 13). Centroids of mature female abundance early in the history of the survey were the farther south, but moved north during the 1990s. Since the late 1990s and early 2000s, the centroids moved south again, but not to the extent seen in the early 1980s. This phenomenon was mirrored in centroids of abundance for large males (Figure 13).

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

The distribution of large males during the summer survey and the fishery catch are different. 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 did 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) conducted a survey of 108 tows in 27 survey stations (hereafter referred to as the 'study area') in the Bering Sea in summer 2009 (Figure 14). The BSFRF performed a similar study during 2010 in which the study area covered a larger portion of the distribution of snow crab than the 2009 study area. The mature biomass and size composition data gleaned from each of these experiments (and their complimentary NMFS survey observations; Figure 15 & Figure 16) are incorporated into the model by fitting them as an extra survey that is linked to the NMFS survey through a shared selectivity (see appendix A for a description of the way in which the surveys are related in the assessment model). Abundances estimated by the industry surveys were generally higher than the NMFS estimates, which provides evidence that the catchability of the NMFS survey gear is less than 1. Larger females are an exceptions to this observation, but this difference may be due to different towing locations for the two nets within the study area, or to variable catchability of females due to aggregation behavior.

E. Analytic approach

History of modeling approaches for the stock

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

Model description

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

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

The snow crab population dynamics model tracked the number of crab of sex s, shell condition v, maturity state m, during year y at length l, $N_{s,v,m,y,l}$. A terminal molt was modeled in which crab move from an immature to a mature state, after which no further molting occurred. The mid-points of the size bins tracked in the model spanned from 27.5 to 132.5mm carapace width, with 5 mm size classes. For the base assessment (2017 model_new data), 323 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 (also sometimes subject to a prior; see Table 9 & Table 10). 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 explored in order 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 70 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.

Samples were also drawn from the posterior distributions of estimated parameters and derived quantities used in management (e.g. MMB and OFL) via MCMC for select models. This involved conducting 10,000,000 cycles of the MCMC algorithm, implementing a 5% burn-in period, and saving every 2000th draw. Chains were then thinned until diagnostic statistics (e.g. Geweke statistics and autocorrelation) demonstrated a lack of evidence of non-convergence (if possible).

Retrospective analyses were performed in which the terminal year of data was removed sequentially and a given model was refit to each subset of the data. 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.

Model selection and evaluation

Models were evaluated based on their fit to the data (Table 11), the credibility of the estimated population processes, stability of the model (Figure 17, Figure 18, Figure 19), 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 10 and their posterior distributions can be seen for selected models in Figure 20, Figure 21, Figure 22, and Figure 23 (these posterior distributions are for illustrative purposes only in this assessment given poor convergence).

Results

Several of the models exhibited unstable behavior when jittered (Figure 18). The new survey and catch data appear to be a bigger driver of the instability than the additional growth data (Figure 17). Models appeared to 'converge' (i.e. small gradients) over a wide range of likelihood values and derived management quantities exhibited bimodality to some degree for several models. This bimodality can still be linked to the change point growth model (Figure 24).

In addition to jittering, MCMC was performed for selected models ("2017 model_new data" & "Loose prior M"). Both models appeared to converge acceptably on first glance (Figure 19). However, MCMC for "2017 model_new data" failed–ten millions draws (~65 hours) produced posteriors with very little variability (in spite of what appeared to be plausible var/covar matrices; see Figure 20).

All models for which retrospective analyses were performed displayed retrospective patterns (Figure 25). However, models in which separate recruitment deviations for males and females were estimated had smaller retrospective patterns.

Below, the fits to the data and estimated population processes for eight models are described. The data for all eight models were the same, however, the priors on natural mortality changed. Consequently, only the total likelihood of those models with the same prior on natural mortality can be directly compared. Individual likelihood components can be compared among models with the understanding that changing the weighting or data for one likelihood component influences others.

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 26); models in which separate recruitment deviations for males and females were estimated fit the data significantly better than those that did not. (Table 11). Estimates of survey MMB in the final year ranged from 85.84 to 141.6 kt. All models underestimated the final year of observed survey MMB (198.384 kt).

Fits to the survey mature female biomass (MFB) changed markedly when separate recruitment deviations were estimated for males and females (Figure 26). Models in which priors on natural mortality were less informative also improved the fit. All models overestimated the final year of observed survey MFB (165.895 kt).

Growth data

A range of shapes of growth curve were estimated to fit the female growth increment data (Figure 27). Models in which the prior on natural mortality for mature females was less informative, but separate recruitment deviations were not estimated, fit the female growth data the best (Table 11). These models estimate a linear relationship between growth increment and pre-molt length. The shapes of the growth curves for males were generally similar, save the linear growth curve imposed by "Sep devs + loose + linear growth". Improved fits to the male growth data resulted from less informative priors on natural mortality, but, in contrast to females, so did estimating separate recruitment deviations (Table 11). The model in which a linear growth curve was fit ("Sep devs + loose + growth") was very unstable– only 2 of 70 jittered models had gradients less than 0.005 (and most were >>1).

Catch data

Retained catch data were fit by all models well, with no visually discernible differences among models (Figure 28). Female discard data were fit adequately given the specified uncertainty (Figure 28 & Table 11). 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 28). Models in which separate recruitment deviations were estimated returned significantly lower likelihoods for male discard data (Table 11). Fits to the trawl data were adequate for all models given the uncertainty in the data (Figure 28).

Size composition data

Retained catch size composition data were fit well by all models (Figure 29); total catch size composition data were similarly well fit (Figure 30). Trawl size composition data were generally well fit, with several exceptions in certain years. All models performed similarly in fitting the trawl size composition data (Figure 31 & Table 11).

Models that estimated separate recruitment deviations for males and females fit the BSFRF size composition data better than those that did not (Figure 32 & Table 11). 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. Models that estimated separate recruitment deviations for males and females fit the survey composition data better than those that did not (Figure 33, Figure 34, & Table 11). The distribution of residuals for male and female survey composition data for the chosen model varied by sex. Female and male size composition data from the survey sum to 1 in a given year. Size composition data for females tended to be overestimated (Figure 35), whereas males tended to be underestimated (Figure 36).

Estimated population processes and derived quantities

Population processes and derived quantities varied among models, sometimes widely. Projected MMB for 2018 ranged from 101.38 to 135.01 kt (Figure 37). In general, estimated fishing mortality in the recent past has been well below $F_{35\%}$, save the years 2012-2014, which were close to $F_{35\%}$ (Figure 38). Estimated MMB has been less than $B_{35\%}$ since 2010, and estimates from "Sep devs" suggest that the population may have been overfished in 2015 (Figure 38). Still, the estimated MMB is currently above MSST and is projected to exceed $B_{35\%}$ in the coming year.

Estimates of selectivity and catchability varied among models (Figure 39). Estimated catchability in both eras was lower for males than for females. In era 1 (1982-1988), catchability ranged from 0.31 - 0.52 for males; for females, it ranged from 0.35 - 0.75. In era 2 (1989-present), catchability ranged from 0.48 - 0.78 for males; for females, it ranged from 0.74 - 1. Estimated size at 50% selection in the survey gear for era 1 ranged from ~38 mm to ~45 mm for both females and males. Size at 50% selection in the survey gear during era 2 ranged from 34 mm to 42 mm for females and 34 mm to 41 mm for males. BSFRF 'availability' curves varied widely from 2009 to 2010 and among models, with the availability of crab to the experimental survey generally increasing in 2010 (Figure 40).

The probability of maturing by size was dependent upon the strength of the prior on natural mortality. The probability of maturing at length for males when the prior was informative was less than scenarios in which the prior was less informative (Figure 41). In general, the shape of the curve representing the probability of maturing for both sexes was consistent, but the magnitude of the probabilities varied. 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 41). 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, models that estimated separate recruitment deviations for males and females estimated higher fishing mortalities (Figure 42). 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 42). Estimated size at 50% selection in the trawl fishery varied more than selectivity in the directed fishery, ranging from 108 - 113 mm (Figure 42). Size at 50% selection for discarded females was similar for all models (Figure 42).

Patterns in recruitment were similar for all models that estimated recruitment similarly (i.e. models that estimated a single vector of recruitment deviations vs. models that estimated a vector each for males and females). A period of high recruitment was observed in which 3 large 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 in the last few years (Figure 43). Recruitment entering the model was placed primarily in the first three size bins (Figure 43). Stock recruitment relationships were not apparent between the estimates of MMB and recruitment for any model (Figure 43). Relationships were not apparent between mature female biomass and recruitment either (not shown).

Estimated natural mortality ranged from 0.27 to 0.35 for immature crab, 0.26 to 0.61 for mature male crab, and 0.345 to 1.04 for mature females (Table 10). Some of these estimates are markedly higher than previous estimates of M from the assessment and literature.

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 control rule to adjust the proportion of $F_{35\%}$ that is applied based on the status of the population relative to $B_{35\%}$ (Amendment 24, NMFS).

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

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

Calculated OFLs and interpretation

Maximum likelihood estimates of OFLs calculated for the suite presented models ranged from 29.74 to 79.54kt (Figure 44 & Table 12). Differences in OFLs were a result of differences in estimated MMB (see above), calculated $B_{35\%}$ (which ranged from 108.89 to 142.77kt), Table 12), $F_{35\%}$ (which ranged from 1.19 to 9.42 yr^{-1}, Table 12), and F_{OFL} (which ranged from 0.88 to 9.42 yr^{-1}, Table 12).

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, which was recommended by the SSC.

Author recommendations

Selecting an author preferred model was challenging. Models without separate recruitment deviations for males and females displayed large retrospective patterns in estimated MMB, a key determinant of the OFL. Models in which the prior for natural mortality was less informative fit the data best and not all of this improvement was derived from the decreased contribution of the prior to the likelihood. However, estimates of natural mortality from models with the least informative priors were unrealistic and the mid-range prior has little rationale for selection (though Murphy et al., (2018) suggest that natural mortality may be higher than currently assumed in the assessment). Still, given the confounding between natural mortality and recruitment (and other parameters) freeing recruitment up by estimating separate recruitment deviations by sex, but placing a strong prior on M are not very satisfying model assumptions. Estimates of female catchability equaling 1 in the survey are also likely unreasonable. Several models also still estimate a kink in the growth curve, in spite of what appears to be very linear data, however the linear growth model had convergence issues.

The model construction in which male and female recruitment deviations are separate and the prior on natural mortality is relatively uninformative ("Sep devs + loose M") is the most attractive of the presented models because it imposes fewer assumptions on the data without allowing most key parameters to stray into unbelievable territory. Further, the model that imposes linear growth in this model is even more attractive because the growth data are best fit by a linear model, but that model had serious convergence problems. Only 2% of models converged after jittering and there was a 40kt difference in the OFLs from the 2 converged models.

H. Data gaps and research priorities

Data sources

As many raw data sources as possible should be included in the assessment. Estimating parameters outside of the model and inputting them as 'known' artificially decreases the uncertainty represented in the standard errors and posteriors of management quantities. Weight at length data, data used to develop priors for natural mortality and maturity, and the selectivities calculated from the BSFRF data should be considered for inclusion in the model to comprehensively represent the uncertainty in management quantities. In addition to pulling as much data into the model as possible, 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.

Additional growth data for males would be useful because there are regions of pre-molt length for which we have no data. This is particularly important if the 'kinked' growth model is retained–if not, these data become less important.

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 Kodiak lab. In spite of these data, just 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.

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 (as shown above), but is poorly known. Tagging studies targeted at estimating natural mortality could be useful and could also shed light on the migration patterns, which could help us understand the impact of the fishery (e.g. centroids of large male abundance in the survey and catch do not match–is this because the crab are moving or because the fishery operates in a specific place? The answer to this question could influence priors on catchability.)

Similarly, establishing measures of reproductive capacity that include females, the spatial overlap of mature individuals, the role water temperature plays in biennial spawning, and the effectiveness of mating by size for males may allow for relationships between recruitment and mature biomass to be found (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 suggest that retrospective patterns may be a problem for the snow crab assessment (Szuwalski and Turnock, 2016), 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 an large estimate of survey MMB in 2014 and the assumption of shared recruitment deviations between male and females. The large survey MMB may have caused by a change in catchability for that year and focused research on time-variation in important population processes for snow crab should be pursued to confront retrospective biases.

Additionally, moving to a designation of the ABC based on the standard errors or posterior distributions (similar to the p-star methods) rather than a flat percentage buffer may represent the uncertainty in the data better, but would require including more data sources into the estimation procedure.

Style

Although the code has been trimmed considerably recently, legacy code and unused variables still exist within the assessment. Streamlining the code makes it more readable and reduces the probability of bugs. Most constants were migrated from the .TPL to the .CTL file, but parameter bounds have not yet been moved. Adjusting the manner in which output files are opened when evaluating MCMC output should also be implemented to avoid overwriting output files. A move to GMACs would obviate the need for these corrections, but the GMACs code still needs to be adapted to accommodate snow crab life history.

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 (from Szuwalski and Punt, 2013) showed that the relationship has broken down with the addition of new data (which is a common phenomenon; Myers 2001). However, the PDO is highly correlated with the Arctic Oscillation (AO) and the AO is significantly correlated with estimated snow crab recruitment (Figure 45). 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. 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.

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Appendix A: Model structure

Population dynamics

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

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

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

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

The dynamics after the initial year were described by:

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

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

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

Where $N_{s,v,m,y,l}$ represented the numbers, N, of sex s during year y of shell condition v and maturity state m at length l. $Z_{x,v,m,y,l}$ represented the total mortality experienced by the population and consisted of the sum of instantaneous rates of natural mortality by sex and maturity state, $M_{s,m}$, and fishing mortality, $F_{s,f,y,l}$ from each fishery. Each fishing mortality was subject to 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 9; 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_{avg}^{log}) with yearly deviations around that mean ($F_{dev,y}^{log}$).

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

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 13). 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 13 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 13 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 13 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 6: 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 7: Observed retained catches, discarded catch, and bycatch

Survey year	Retained catch (kt)	Discarded females (kt)	Discarded males (kt)	Trawl bycatch (kt)
1982	11.85	0.02	1.22	0.38
1983	12.16	0.01	1.2	0.49
1984	29.94	0.01	2.67	0.52
1985	44.45	0.01	3.88	0.45
1986	46.22	0.02	4.1	1.91
1987	61.4	0.03	5.34	0.01
1988	67.79	0.04	5.62	0.69
1989	73.4	0.05	6.46	0.8
1990	149.1	0.05	14.71	0.61
1991	143	0.06	11.6	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

Table 8: 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	0.11	20.52	35.02
2018	165.9	0.21	198.4	0.17	26.75	48.08

Table 9: 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	$\Omega_{m,l}$
matestfe	-6	-1e-10	$\Omega_{f,l}$
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 10: Estimated parameter values by scenario (these are maximum likelihood estimates)

Parameter	2017 model_old data	2017 model_new data	Fix fem M	Loose prior M	Looser prior M	Sep devs	Sep devs + loose prior	Sep devs + looser prior	Sep devs + loose + growth
af	-5.26	2.61	2.63	2.61	2.61	-1.46	-0.91	-1.01	-0.46
am	-5.34	-0.95	-1.02	-1.02	-1.01	-0.78	-0.72	1.04	3.4
bf	1.53	1.18	1.18	1.18	1.18	1.35	1.33	1.33	1.31
bm	1.52	1.37	1.37	1.37	1.37	1.36	1.36	1.28	1.2
b1	1.15	1.16	1.16	1.16	1.17	1.17	1.17	1.17	
bf1	1.04	1.34	1.34	1.35	1.35	1.04	1	1	
deltam	32.13	32.55	32.56	32.62	32.63	32.53	32.57	41.75	
deltaf	34.13	26.22	26.23	26.22	26.22	41.1	44.38	44.37	
mateste	vector	vector	vector	vector	vector	vector	vector	vector	vector
matestfe	vector	vector	vector	vector	vector	vector	vector	vector	vector
rec_devf	vector	vector	vector	vector	vector	vector	vector	vector	vector
mnatlen_styr	vector	vector	vector	vector	vector	vector	vector	vector	vector
fnatlen_styr	vector	vector	vector	vector	vector	vector	vector	vector	vector
log_avg_fmort	-0.29	-0.29	-0.26	-0.36	-0.44	-0.17	-0.22	-0.24	-0.18
fmort_dev	vector	vector	vector	vector	vector	vector	vector	vector	vector
log_avg_fmortdf	-5.66	-5.93	-6.16	-5.99	-6.11	-5.62	-5.53	-5.42	-5.91
fmortdf_dev	vector	vector	vector	vector	vector	vector	vector	vector	vector
log_avg_fmortt	-4.61	-4.64	-4.73	-4.77	-4.75	-4.62	-4.69	-4.7	-4.62
fmortt_dev_era1	vector	vector	vector	vector	vector	vector	vector	vector	vector
fmortt_dev_era2	vector	vector	vector	vector	vector	vector	vector	vector	vector
log_avg_sel50_mn	4.67	4.66	4.66	4.66	4.66	4.66	4.66	4.67	4.67
fish_slope_mn	0.19	0.19	0.19	0.19	0.2	0.19	0.2	0.2	0.19
fish_fit_slope_mn	0.43	0.44	0.44	0.44	0.44	0.43	0.43	0.43	0.44
fish_fit_sel50_mn	96.07	96.09	96.08	96.15	96.25	96.14	96.2	96.23	96.11
fish_disc_slope_f	0.25	0.26	0.25	0.27	0.28	0.26	0.27	0.28	0.27
fish_disc_sel50_f	4.25	4.23	4.25	4.22	4.22	4.25	4.25	4.25	4.22
fish_disc_slope_tf	0.07	0.08	0.09	0.08	0.08	0.08	0.08	0.09	0.08
fish_disc_sel50_tf	112.95	111.88	108.82	110.43	111.85	110.18	109.96	110.2	111.13
srv2_q	0.43	0.44	0.44	0.36	0.31	0.52	0.43	0.36	0.43
srv2_q_f	0.51	0.52	0.52	0.41	0.35	0.75	0.65	0.55	0.67
srv2_sel95	54.52	55.78	55.43	59.73	64.24	58.85	62.83	66.06	65.52
srv2_sel50	38.26	39.05	38.96	41.39	43.3	39.99	42.9	45.2	44.14
srv3_q	0.71	0.73	0.77	0.64	0.48	0.78	0.68	0.55	0.67
srv3_sel95	48.02	49.08	50.26	55.9	60.37	49.04	56.18	61.35	59.44
srv3_sel50	34.38	34.84	35.46	38.16	40	34.94	38.42	41.14	39.73
srv3_q_f	1	1	0.74	1	0.83	1	1	0.82	1
srv3_sel95_f	45.58	46.79	43.82	50.52	52.47	47.2	51.58	54.94	51.26
srv3_sel50_f	35.22	36.05	33.72	38.98	40.51	36.1	39.48	42.3	39.23
srvind_q	1	1	1	1	1	1	1	1	1
srvind_q_f	0.17	0.17	0.13	0.16	0.14	0.16	0.17	0.17	0.15
srvind_sel95_f	55	55	55	52.74	53.39	54.56	56.22	57.13	49.54
srvind_sel50_f	49.39	49.46	49.28	48.85	49.15	49.79	50.86	51.51	49.5
srv10ind_q_f	1	1	1	1	1	1	0.94	0.75	0.97
selsmo10ind	vector	vector	vector	vector	vector	vector	vector	vector	vector
selsmo09ind	vector	vector	vector	vector	vector	vector	vector	vector	vector

Parameter	2017 model_old data	2017 model_new data	Fix fem M	Loose prior M	Looser prior M	Sep devs	Sep devs + loose prior	Sep devs + looser prior	Sep devs + loose + growth
Mmult_imat	1.22	1.21	1.28	1.56	1.33	1.18	1.49	1.38	1.48
Mmult	1.16	1.17	1.14	1.54	2.7	1.14	1.51	2.48	1.55
Mmultf	1.55	1.51		2.19	3.08	1.57	2.48	4.48	2.38
cpueq	0	0	0	0	0	0	0	0	0

Table 11: 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	2017 model_old data	2017 model_new data	Fix fem M	Loose prior M	Looser prior M	Sep devs	Sep devs + loose prior	Sep devs + looser prior	Sep devs + loose + growth
Recruitment deviations	38.81	40.06	42.5	34.61	27.79	70.18	62.23	53.01	63.23
Initial numbers old shell males small length bins	4.73	4.66	4.71	4.51	4.09	4.62	4.47	4.1	4.61
ret fishery length	305.31	322.53	321.01	323.98	326.97	320.96	320.32	325.14	329.39
total fish length (ret + disc)	866.83	924.56	921.06	925.59	929.29	920.93	919.63	922.26	925.17
female fish length	233.89	238.86	238.41	237.26	235.43	241.32	239.74	237.81	237.09
survey length	4266.95	4482.15	4598.46	4379.56	4352.86	4293.05	4210.37	4190.75	4228.96
trawl length	265.69	279.01	315.53	271.09	271.59	300.15	289.07	292.49	289.09
2009 BSFRF length	-93.56	-93.63	-89.83	-93.89	-94.44	-92.24	-93.54	-93.24	-81.4
2009 NMFS study area length	-74.83	-73.93	-70.65	-75.45	-75.95	-75.15	-75.89	-76.05	-40.61
M multiplier prior	81.53	73.63	20.21	60.92	1.42	77.61	72.88	2.04	68.84
maturity smooth	36.73	45.47	47.67	40.09	34.42	43.65	38.44	31.12	42.19
growth males	36.46	142.25	142.28	141	139.27	140.07	138.18	128.83	136.57
growth females	117.57	335.98	342.93	332.09	331.39	394.96	359.65	355.02	384.94
2009 BSFRF biomass	0.38	0.39	0.52	0.22	0.03	0.47	0.26	0.07	0.22

Likelihood component	2017 model_old data	2017 model_new data	Fix fem M	Loose prior M	Looser prior M	Sep devs	Sep devs + loose prior	Sep devs + looser prior	Sep devs + loose + growth
2009 NMFS study area biomass	0.12	0.14	0.19	0.06	0	0.22	0.1	0.02	0.11
cpue q	0.18	0.2	0.21	0.2	0.18	0.21	0.22	0.22	0.23
retained catch	3.88	4.59	4.48	4.54	4.43	3.65	3.66	3.94	3.98
discard catch	157.39	170.33	157.17	182.94	198.96	116.77	121.99	134.52	133.47
trawl catch	7.08	7.86	8.4	7.65	6.51	6.95	6.55	6.01	6.5
female discard catch	5.36	6.03	5.94	6.16	6.35	4.17	4.13	4.22	4.09
survey biomass	281.73	287.32	306.48	274.77	269.54	207.32	183.12	160.24	186.12
F penalty	24.64	25.58	25.49	25.89	25.74	23.51	23.35	23.77	24.86
2010 BSFRF Biomass	20.78	22.33	11.38	17.59	9.18	9.58	6.63	3.72	6.15
2010 NMFS Biomass	1.45	1.14	1.81	0.76	0.09	3.44	2.83	1.19	2.9
Extra weight survey lengths first year	553.32	551.54	558.89	547.77	544.01	547.47	541.06	531.03	773.64
2010 BSFRF length	-49.58	-48.28	-47.31	-49.79	-49.27	-51.66	-50.52	-45.11	-49.44
2010 NMFS length	-58.37	-59.94	-55.2	-65.77	-68.77	-64.14	-69.05	-71.81	-67.74
smooth selectivity	2.99	3.95	3.61	3.97	3.94	2.44	2.38	2.42	2.31
smooth female selectivity	0	0	0	0	0	0	0	0	0
init nos smooth constraint	45.81	45.4	46.55	45.2	45.12	43.32	43.24	42.2	37.19
Total	7083.27	7740.18	7862.9	7583.52	7480.17	7493.83	7305.5	7169.93	7652.66

Table 12: Changes in management quantities for each scenario considered. Reported management quantities are median posterior values.

Model	MMB	B35	F35	FOFL	OFL
2017 model_old data	96.97	140.5	1.28	0.88	29.92
2017 model_new data	107.2	137.8	1.32	1.2	40.37
Fix fem M	103.5	141.9	1.19	1.12	39.19
Loose prior M	116.2	121.3	2.3	2.28	54.67
Looser prior M	144.4	108.9	9.42	9.42	79.54
Sep devs	85.84	142.8	1.22	1.04	29.74
Sep devs + loose prior	93.74	125.4	2.29	2.24	42.15
Sep devs + looser prior	109.3	109.5	8.13	8.13	59.21
Sep devs + loose + growth	94.89	124.4	2.57	2.52	43.28

Table 13: Likelihoods form and weighting for each likelihood component for models in the analysis (continued below)

Likelihood component	Form	2017 model_old data
Recruitment deviations	normal	0.71
Initial numbers old shell males small length bins	normal	707.1
ret fishery length	multinomial	200
total fish length (ret + disc)	multinomial	200
female fish length	multinomial	200
survey length	multinomial	200
trawl length	multinomial	200
2009 BSFRF length	multinomial	200
2009 NMFS study area length	multinomial	200
M multiplier prior	normal	0.23
maturity smooth	normal	3.16
growth males	normal	0.71
growth females	normal	0.32
2009 BSFRF biomass	lognormal	NA
2009 NMFS study area biomass	lognormal	NA
cpue q	normal	0.32
retained catch	normal	0.22
discard catch	normal	3
trawl catch	normal	0.22
female discard catch	normal	17
survey biomass	lognormal	NA
F penalty	normal	0.5
2010 BSFRF Biomass	lognormal	NA
2010 NMFS Biomass	lognormal	NA
Extra weight survey lengths first year	multinomial	200
2010 BSFRF length	multinomial	200
2010 NMFS length	multinomial	200
smooth selectivity	norm2(firstdiff(firstDiff))	2
smooth female selectivity	norm2(firstdiff(firstDiff))	3
init nos smooth constraint	norm2(firstdifference)	1

2017 model_new data	Fix fem M	Loose prior M	Looser prior M	Sep devs	Sep devs + loose prior	Sep devs + looser prior	Sep devs + loose + growth
0.71	0.71	0.71	0.71	0.71	0.71	0.71	200
707.1	707.1	707.1	707.1	707.1	707.1	707.1	NA
200	200	200	200	200	200	200	NA
200	200	200	200	200	200	200	NA
200	200	200	200	200	200	200	NA
NA	NA	NA	NA	NA	NA	NA	NA
200	200	200	200	200	200	200	NA
200	200	200	200	200	200	200	NA
200	200	200	200	200	200	200	NA
0.23	0.23	0.39	1.47	0.23	0.39	1.47	NA
3.16	3.16	3.16	3.16	3.16	3.16	3.16	NA
0.71	0.71	0.71	0.71	0.71	0.71	0.71	NA
0.32	0.32	0.32	0.32	0.32	0.32	0.32	NA
NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA
0.32	0.32	0.32	0.32	0.32	0.32	0.32	NA
0.22	0.22	0.22	0.22	0.22	0.22	0.22	NA
3	3	3	3	3	3	3	NA
0.22	0.22	0.22	0.22	0.22	0.22	0.22	NA
17	17	17	17	17	17	17	NA
NA	NA	NA	NA	NA	NA	NA	NA
0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA
NA	NA	NA	NA	NA	NA	NA	NA
NA	NA	NA	NA	NA	NA	NA	NA
200	200	200	200	200	200	200	NA
200	200	200	200	200	200	200	NA
200	200	200	200	200	200	200	200
2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3
1	1	1	1	1	1	1	1

Table 15: 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 that will differ slightly from the median posterior values.

Survey year	FMB	MMB	Male >101 biomass	Male >101 (millions)	FMB	MMB	Male >101 biomass	Male >101 (millions)
1982	65.22	121.3	28.61	54.27	97.17	233.3	47.68	90.46
1983	53.85	129.7	49.22	87.75	79.3	249.4	82.03	146.3
1984	40.52	137.9	67.47	115.7	59.72	265.5	112.5	192.8
1985	35.97	132.3	68.73	116.1	53.31	255.2	114.6	193.5
1986	44.37	117.1	46.27	78.04	66.26	226.5	88.72	149.6
1987	102.1	117.3	39.84	69.39	154.1	228	76.38	133
1988	208.7	200.6	44.35	77.37	212.5	257.3	85.02	148.3
1989	206.5	241	54.94	95.78	209.8	309.1	105.3	183.6
1990	173.4	305.6	84.45	146.3	176	391.7	161.9	280.5
1991	149.2	287.4	77.77	134.5	151.6	368.2	149.1	257.9
1992	137.4	240.6	62.78	109.2	139.7	308.2	120.4	209.3
1993	141.3	205.5	80.92	136.7	143.8	263.7	103.5	174.9
1994	153.3	173.9	48.61	80.82	156	223.2	62.16	103.3
1995	158.9	189.8	45	79.3	161.6	243.5	57.55	101.4
1996	141.5	269.2	110.5	193.8	143.7	344.9	141.3	247.9
1997	112.9	326	180.2	302	114.6	417.4	230.5	386.2
1998	88.28	241.7	125.4	207.2	89.62	309.5	160.4	265
1999	72.15	148.8	60.42	101.2	73.27	190.7	77.26	129.4
2000	64.82	119.2	45.48	75.83	65.88	152.8	58.15	96.97
2001	58.26	100.6	34.35	58.05	59.19	128.9	43.92	74.24
2002	50.27	94.79	33.17	57.46	51.06	121.5	42.42	73.47
2003	42.78	100.9	44.33	75.4	43.46	129.3	56.69	96.42
2004	43.96	102.2	49.31	81.88	44.74	130.9	63.06	104.7
2005	65.11	98.39	43.69	72.36	66.39	126.2	55.87	92.53
2006	78.43	102.9	40.37	68.68	79.8	131.9	51.63	87.83
2007	79.32	127.1	55.28	94.8	80.64	162.9	70.69	121.2
2008	70.46	148.3	72.96	124	71.57	189.9	93.3	158.5
2009	59.91	159.2	86.96	145.4	60.84	203.8	111.2	185.9
2010	90.23	153.8	88.53	146.3	92.06	196.9	113.2	187.1
2011	113.2	131.2	72.91	119.8	115.2	168	93.24	153.2
2012	109.2	94.29	40.92	68.91	110.9	120.8	52.33	88.12
2013	97.49	80.31	30.53	53.32	99.06	102.9	39.04	68.18
2014	90.7	77.83	32.68	55.97	92.2	99.75	41.79	71.57
2015	84.1	63.68	22.77	38.76	85.47	81.67	29.12	49.57
2016	91.97	62.65	19.14	32.81	93.61	80.46	24.48	41.95
2017	137.8	86.73	27.04	46.46	140.5	111.6	34.58	59.41
2018	198.3	139.4	45.7	78.1	202.1	179.1	58.44	99.87

Table 16: 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 that will differ slightly from the median posterior values.

Survey year	Mature male biomass	Mature female biomass	Recruits	Fishing mortality
1982	184.6	77.48	162.5	0.42
1983	198.6	63.23	463.6	0.24
1984	194.1	47.61	1087	0.46
1985	170.6	42.5	4557	0.74
1986	143.3	52.81	1517	1.12
1987	131.1	122.9	842.9	2.28
1988	150.9	169.4	373.6	2.26
1989	190.4	167.3	942.3	1.72
1990	187	140.3	891.8	3.32
1991	171.3	120.8	1444	3.86
1992	158.4	111.3	1484	2.83
1993	154.8	114.6	1179	1.65
1994	152	124.2	267.8	1.23
1995	176.6	128.8	208.4	1.04
1996	239.7	114.5	240.2	0.73
1997	239.8	91.36	308.9	1.06
1998	172.2	71.45	454	1.24
1999	145.8	58.41	243.1	0.32
2000	117.3	52.52	194.5	0.33
2001	93.65	47.19	180.1	0.63
2002	89.93	40.7	545.8	0.54
2003	98.38	34.64	1326	0.32
2004	99.05	35.66	536.7	0.3
2005	89.72	52.94	527.1	0.54
2006	94.97	63.61	206.8	0.58
2007	109.8	64.29	257.8	0.78
2008	134.7	57.06	2277	0.5
2009	150.8	48.51	749.4	0.33
2010	142.2	73.41	432.3	0.37
2011	101.3	91.71	532.4	0.87
2012	71.49	88.42	643	1.32
2013	62.54	78.96	446.3	1.48
2014	53.47	73.41	1225	2.04
2015	50.22	68.13	2765	1.55
2016	58.33	74.64	2847	0.76
2017	85.84	112	600	0.44

Table 17: Maximum likelihood estimates of predicted total numbers (billions), not subject to survey selectivity at the time of the survey. These are maximum likelihood estimates that will differ slightly from the median posterior values.

Survey year	Total numbers
1982	3.994
1983	4.322
1984	4.829
1985	6.057
1986	12.26
1987	11.9
1988	12.29
1989	9.464
1990	8.136
1991	6.922
1992	10.36
1993	9.797
1994	8.803
1995	6.856
1996	5.271
1997	4.108
1998	3.709
1999	3.546
2000	3.008
2001	2.549
2002	2.502
2003	3.277
2004	4.705
2005	4.701
2006	4.466
2007	3.599
2008	3
2009	5.112
2010	4.852
2011	4.221
2012	3.747
2013	3.83
2014	3.731
2015	5.34
2016	10.17
2017	12.96
2018	10.65

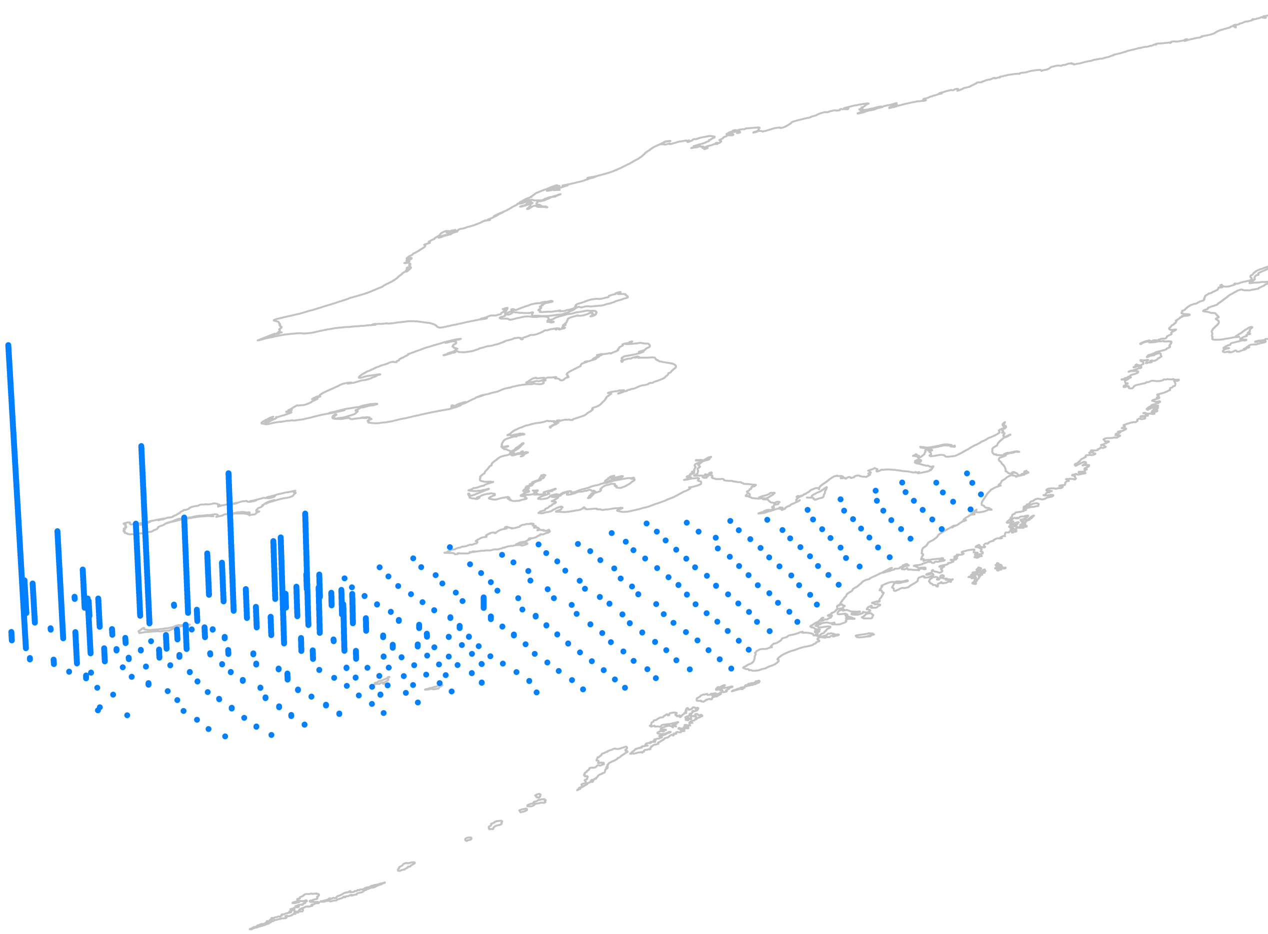

Figure 1: Observed relative density of all males at the time of the 2018 NMFS summer survey

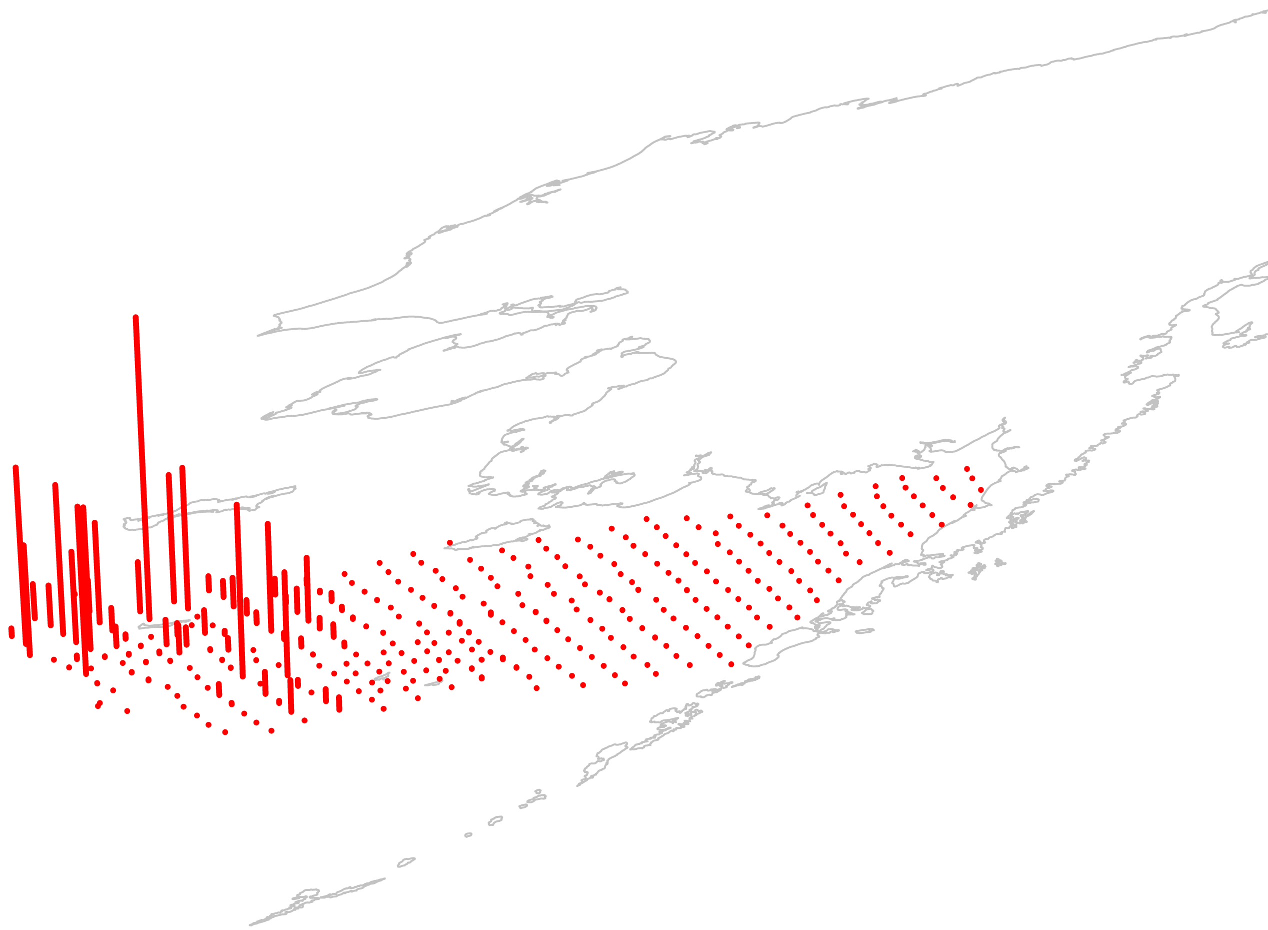

Figure 2: Observed relative density of all females at the time of the 2018 NMFS summer survey

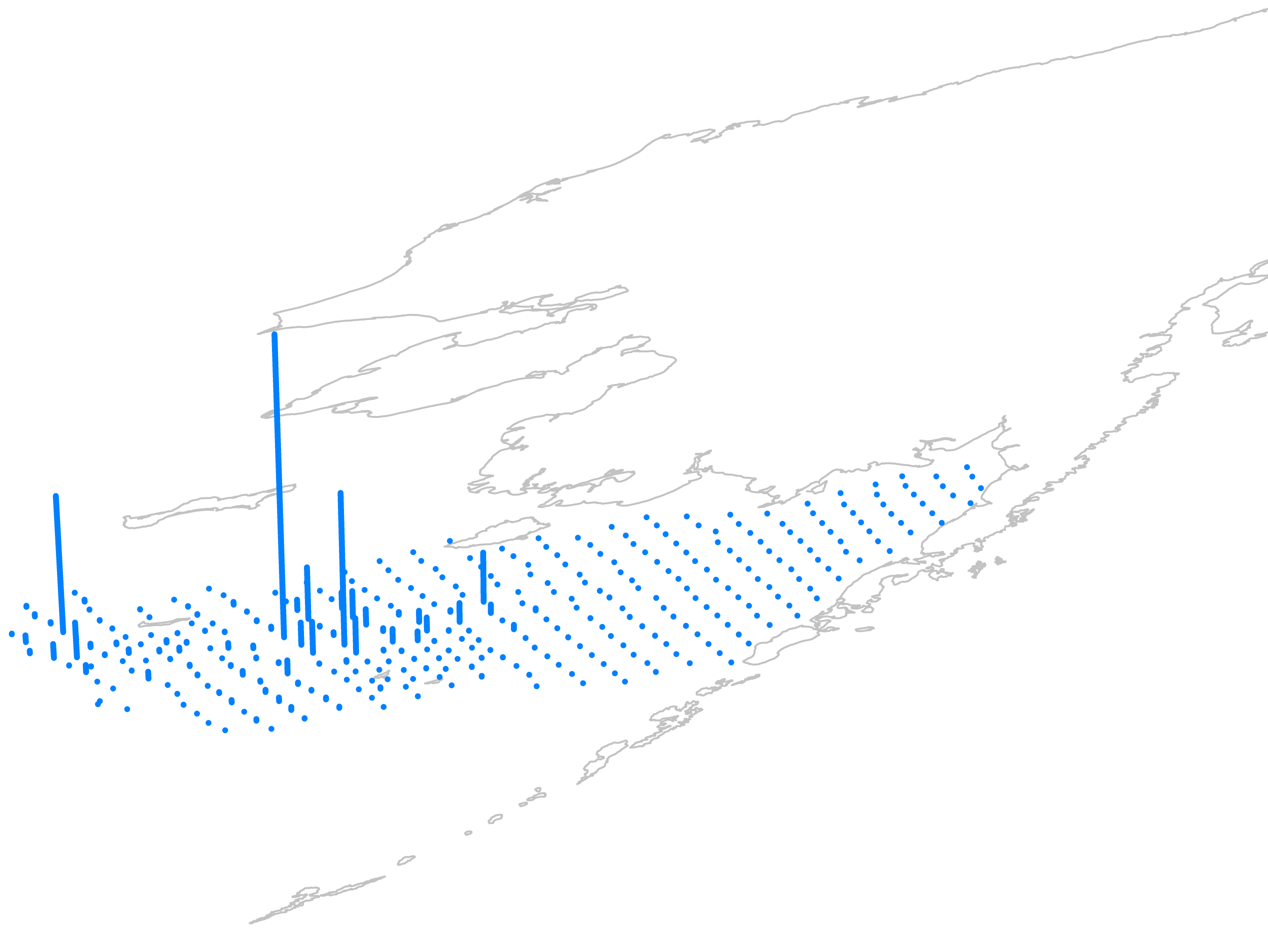

Figure 3: Observed relative density of males >77mm carapace width at the time of the 2018 NMFS summer survey

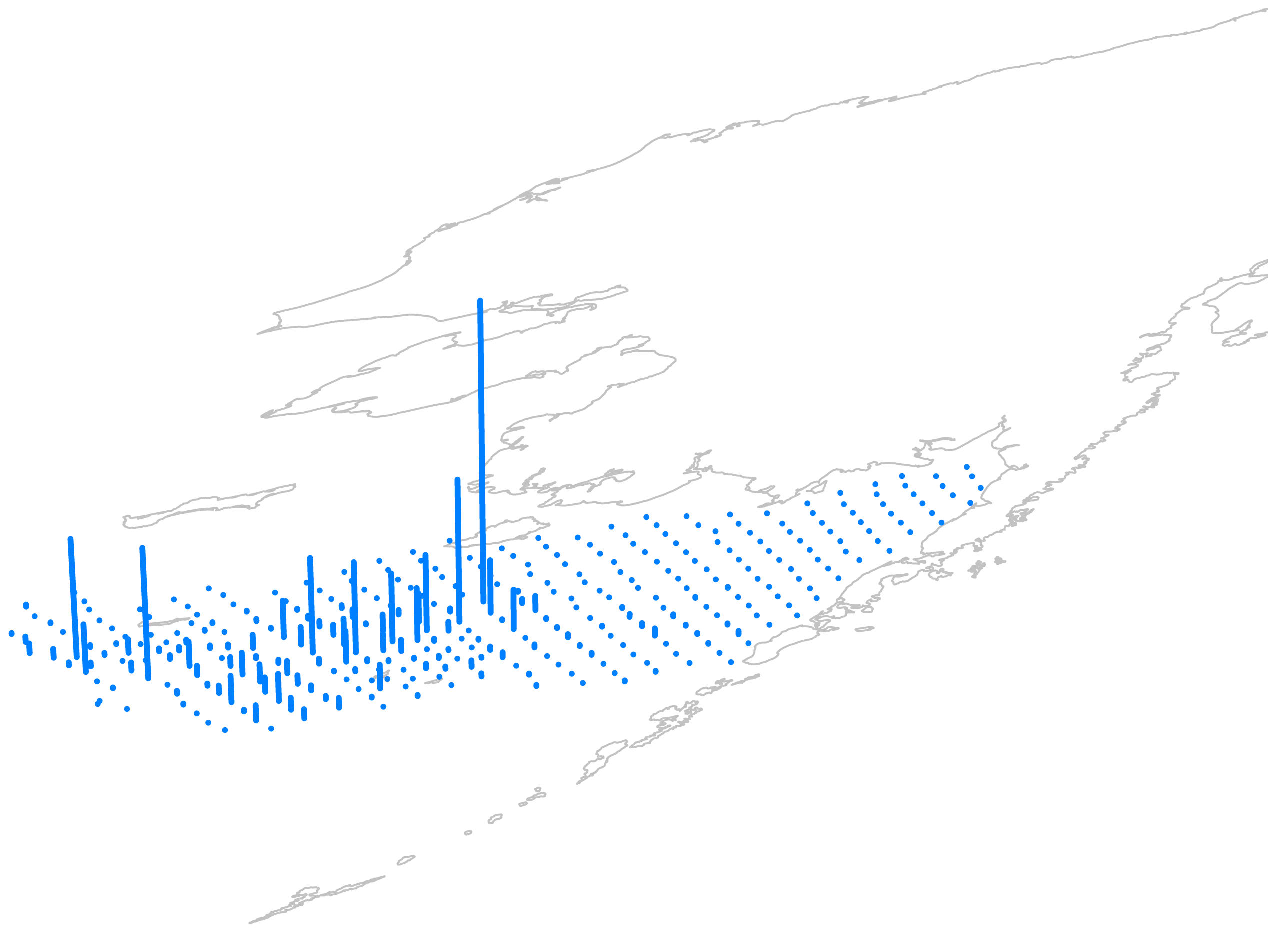

Figure 4: Observed relative density of males >101mm carapace width at the time of the 2018 NMFS summer survey

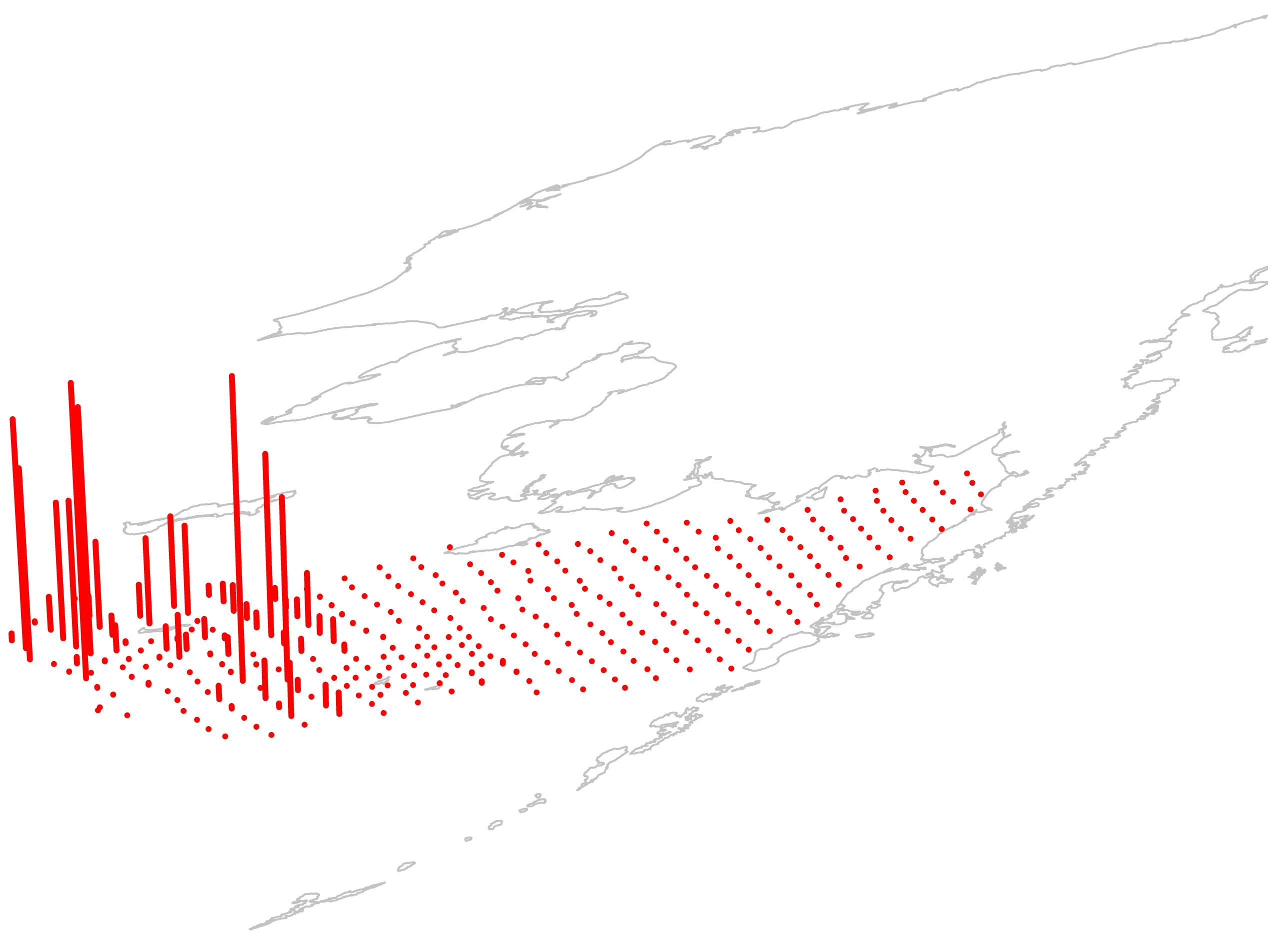

Figure 5: Observed relative density of mature females at the time of the 2018 NMFS summer survey

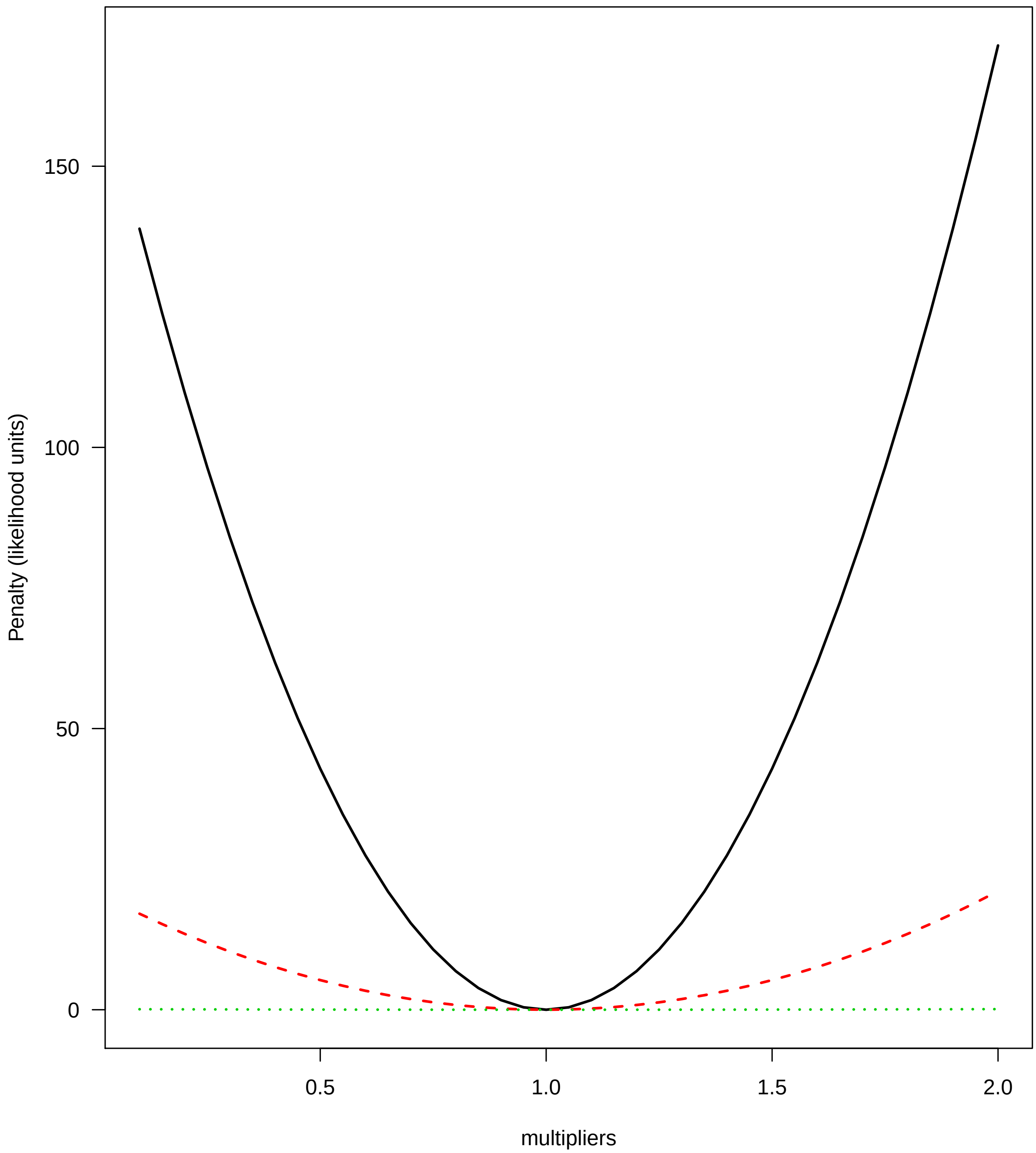

Figure 6: Prior on multiplier for mature natural mortality. Black is 0.054. Red is 0.154. Green is 2.154

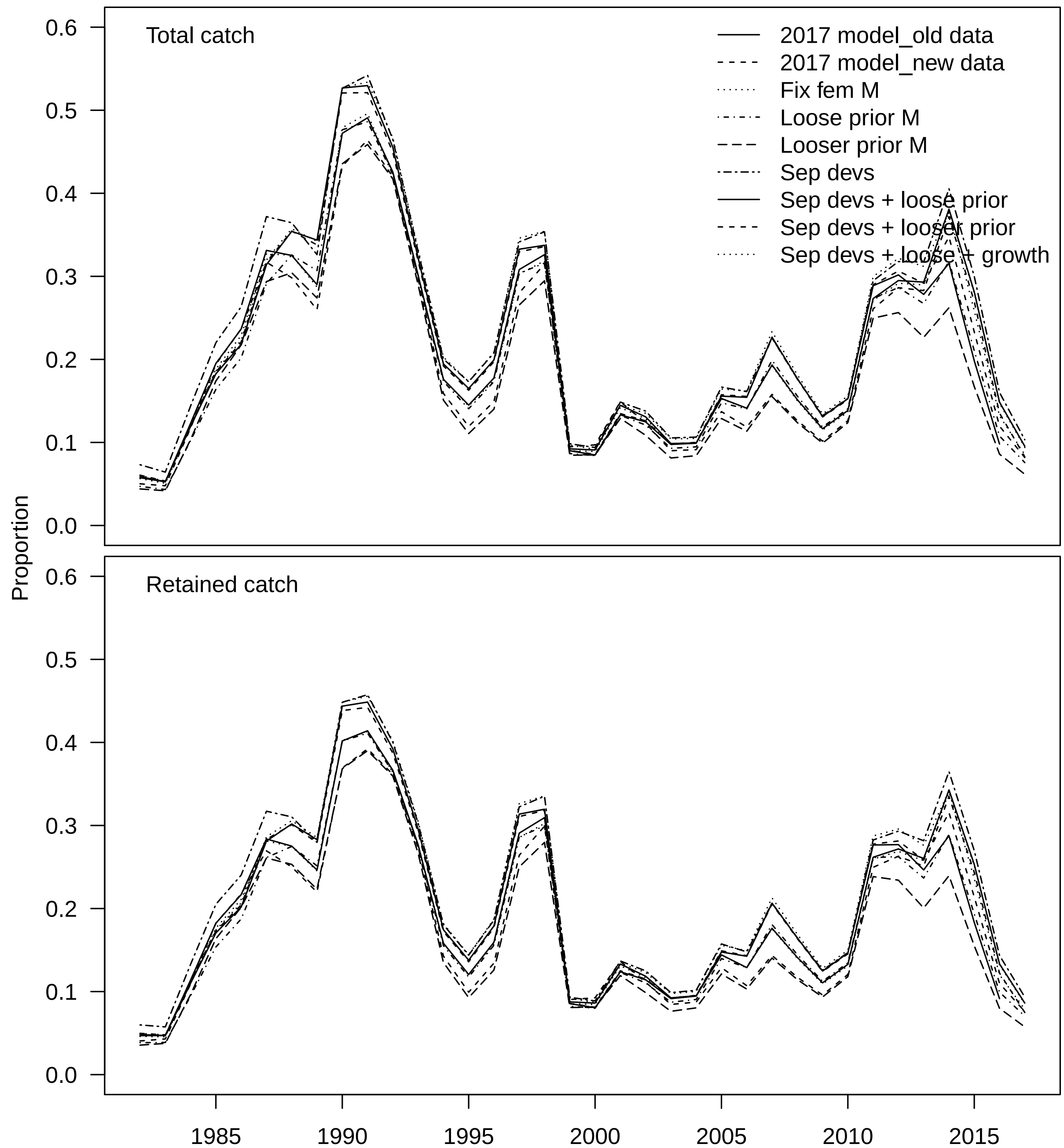

Figure 7: Model predicted ratio of catch to mature male biomass

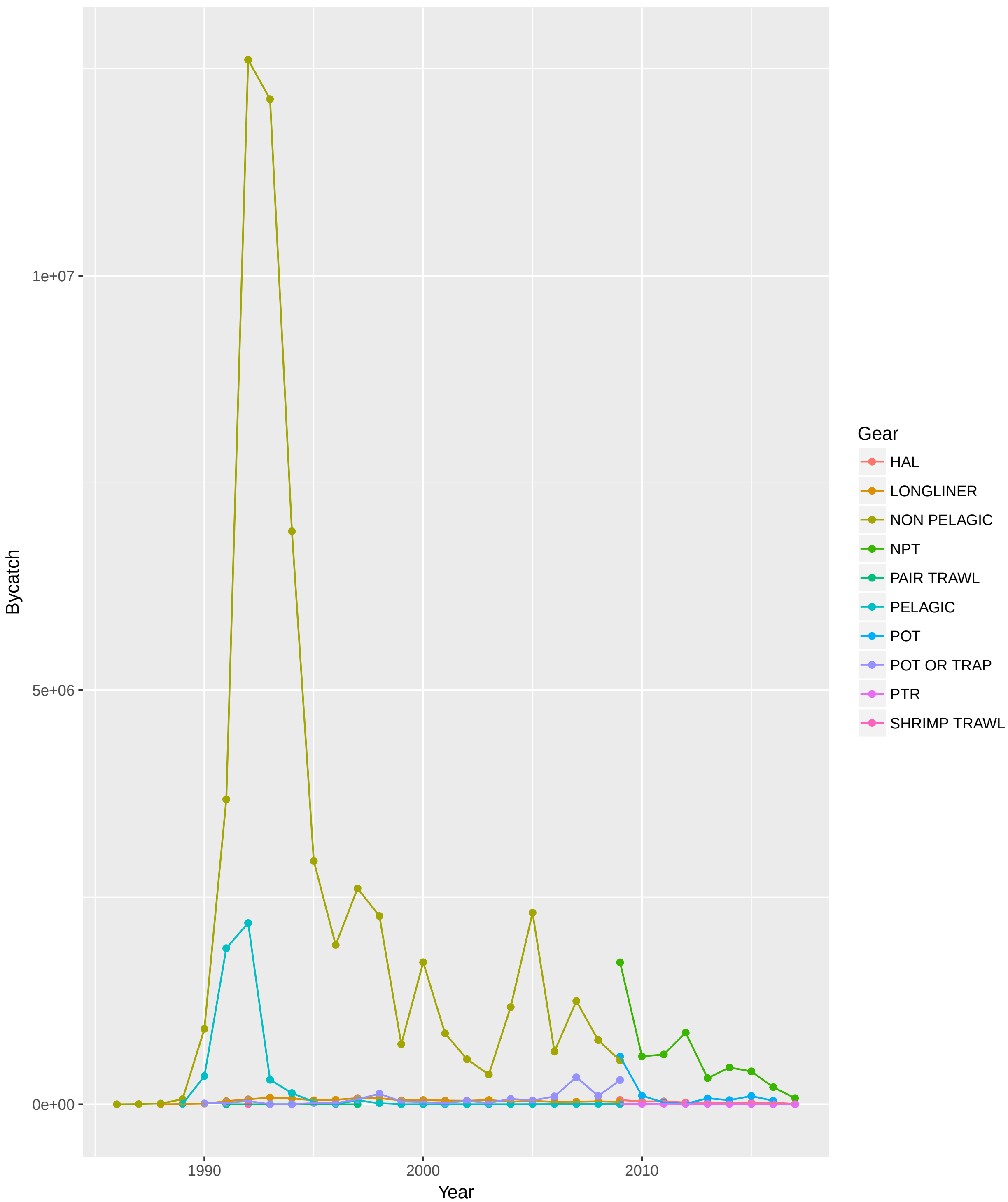

Figure 8: Bycatches in other fishing fleets.

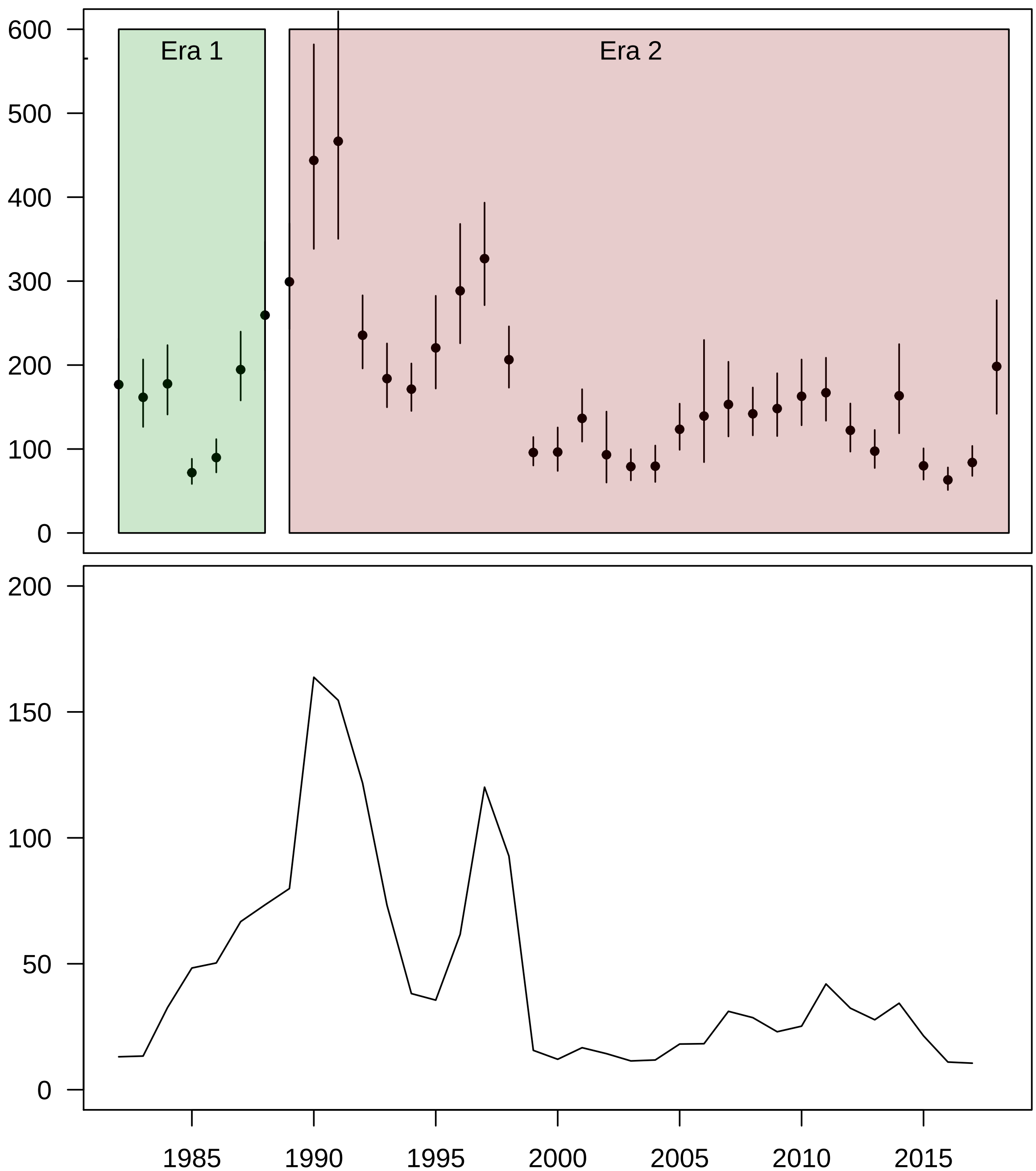

Figure 9: Divisions of survey data for estimation of q (MMB shown for reference; top) and total catches (bottom)

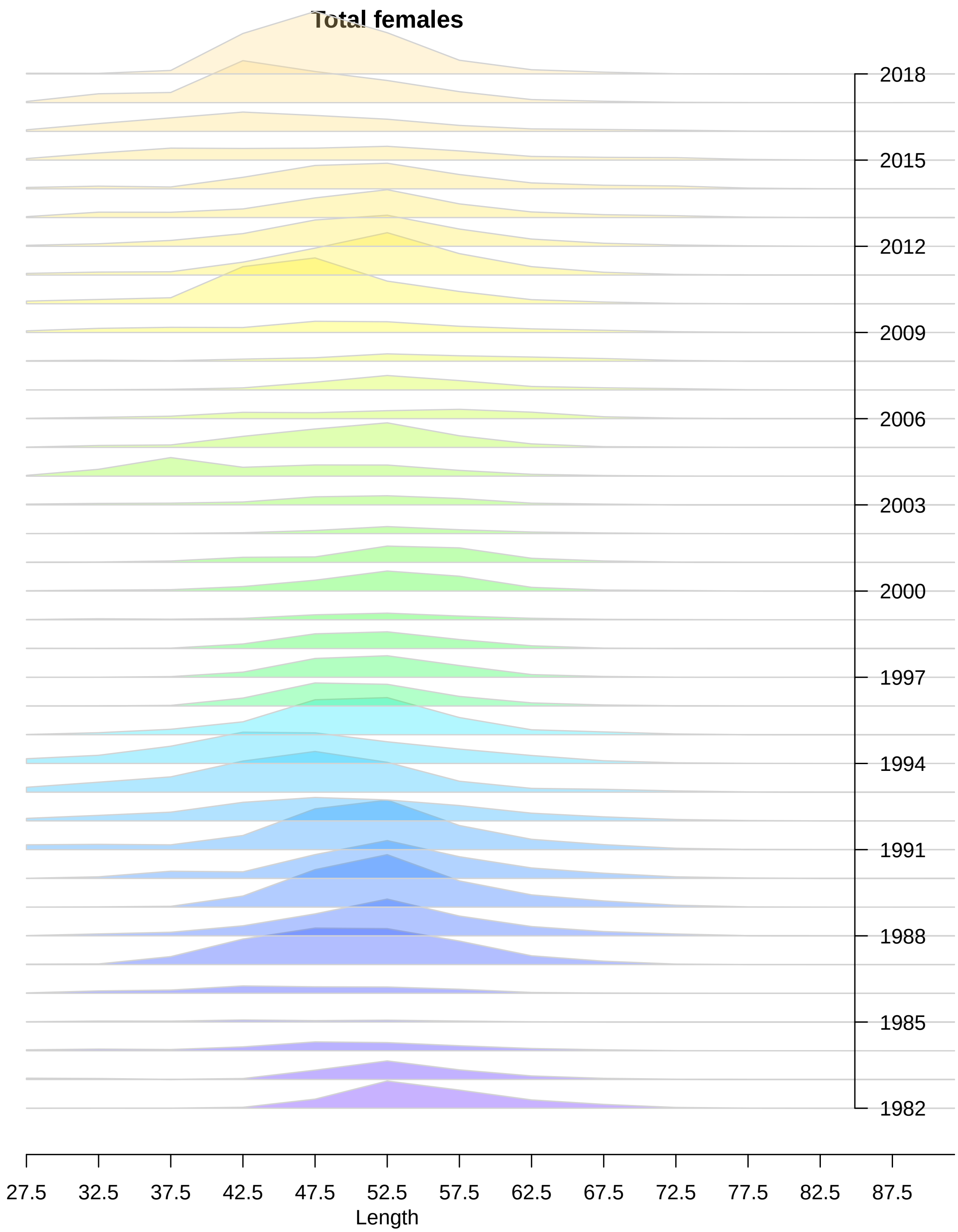

Figure 10: Observed relative numbers at length at the time of the survey

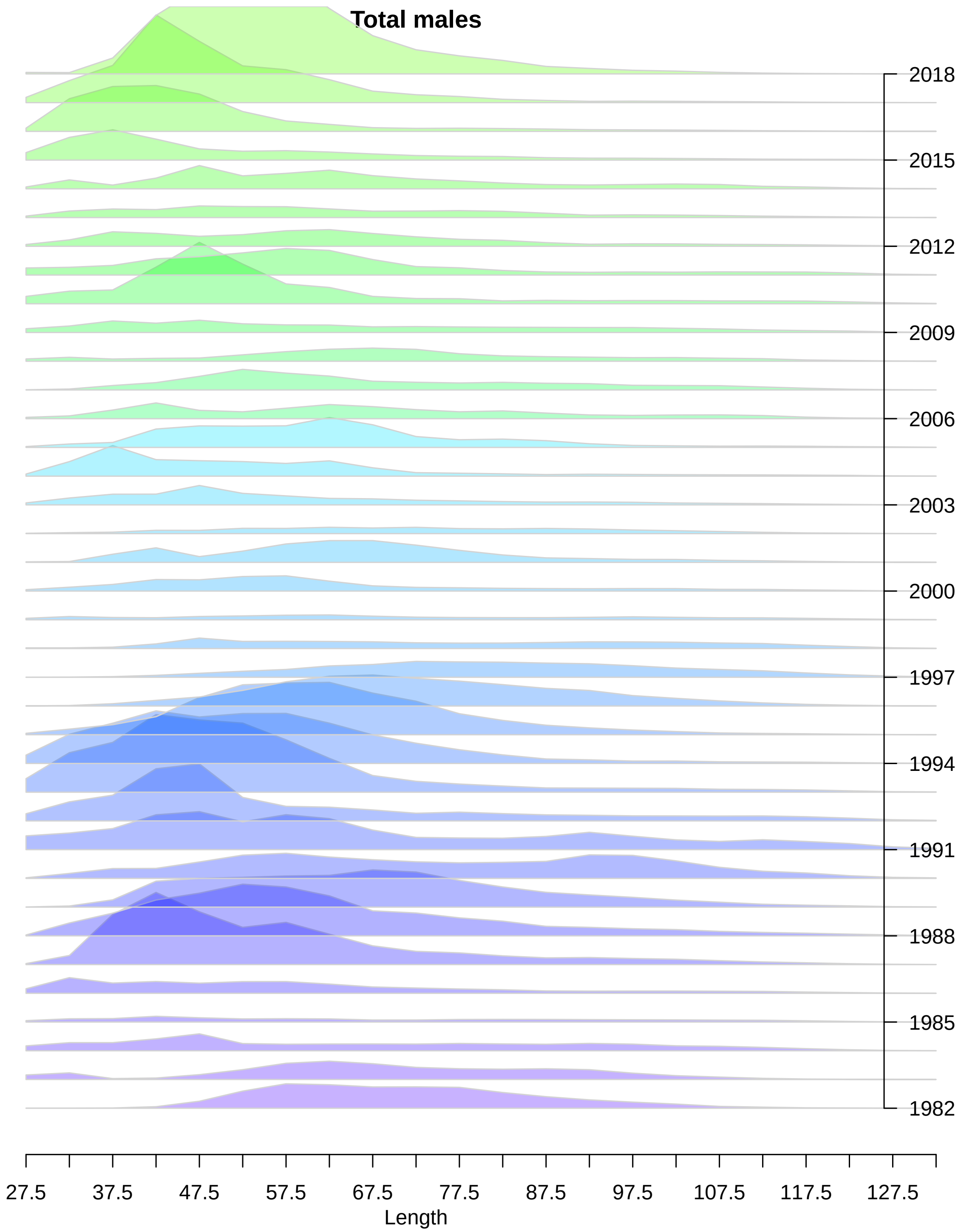

Figure 11: Observed relative numbers at length at the time of the survey

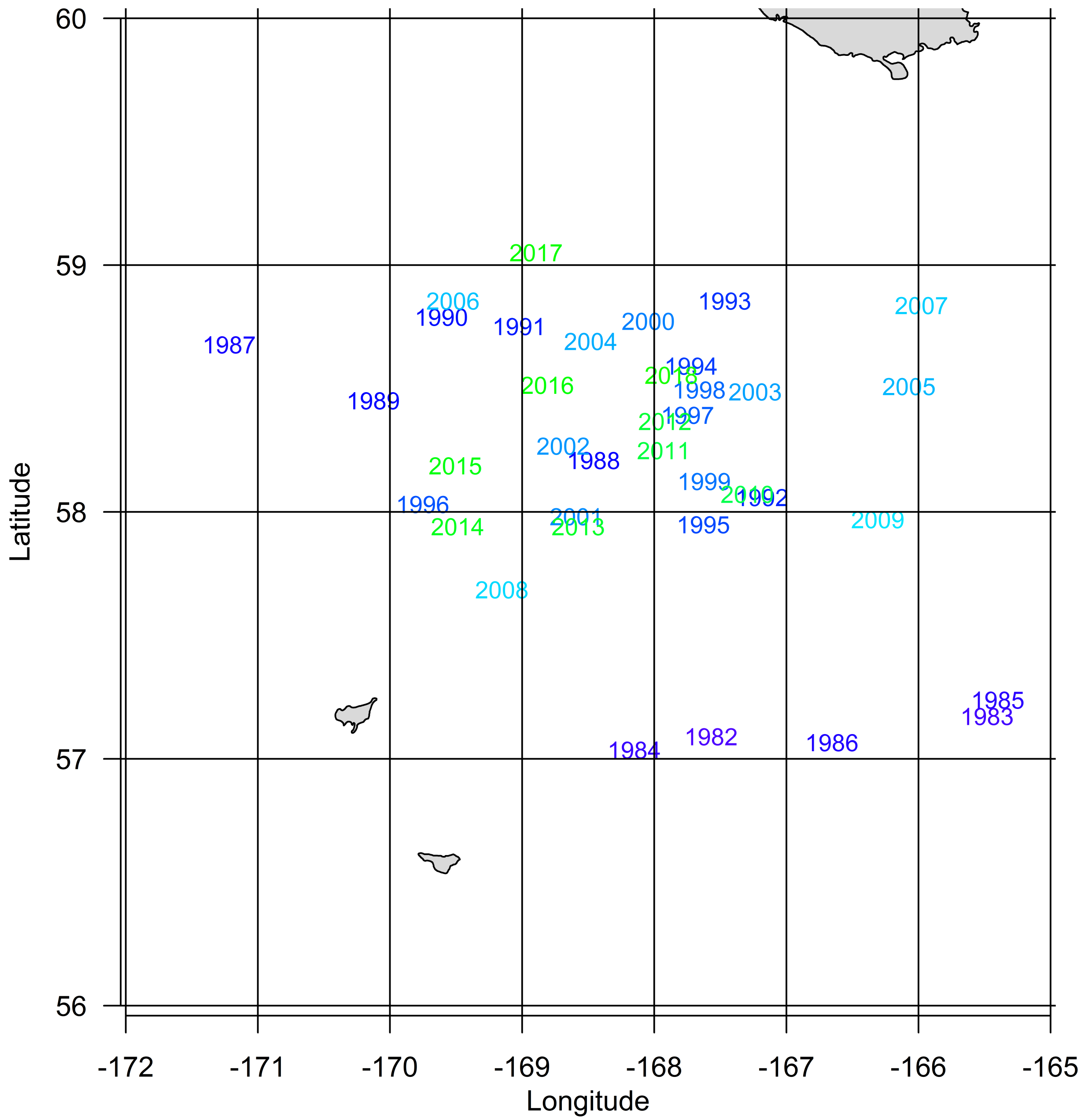

Figure 12: Centroid of mature females observed in the survey over time. Dark blue indicates years early in the time series; green are the most recent years in the time series.

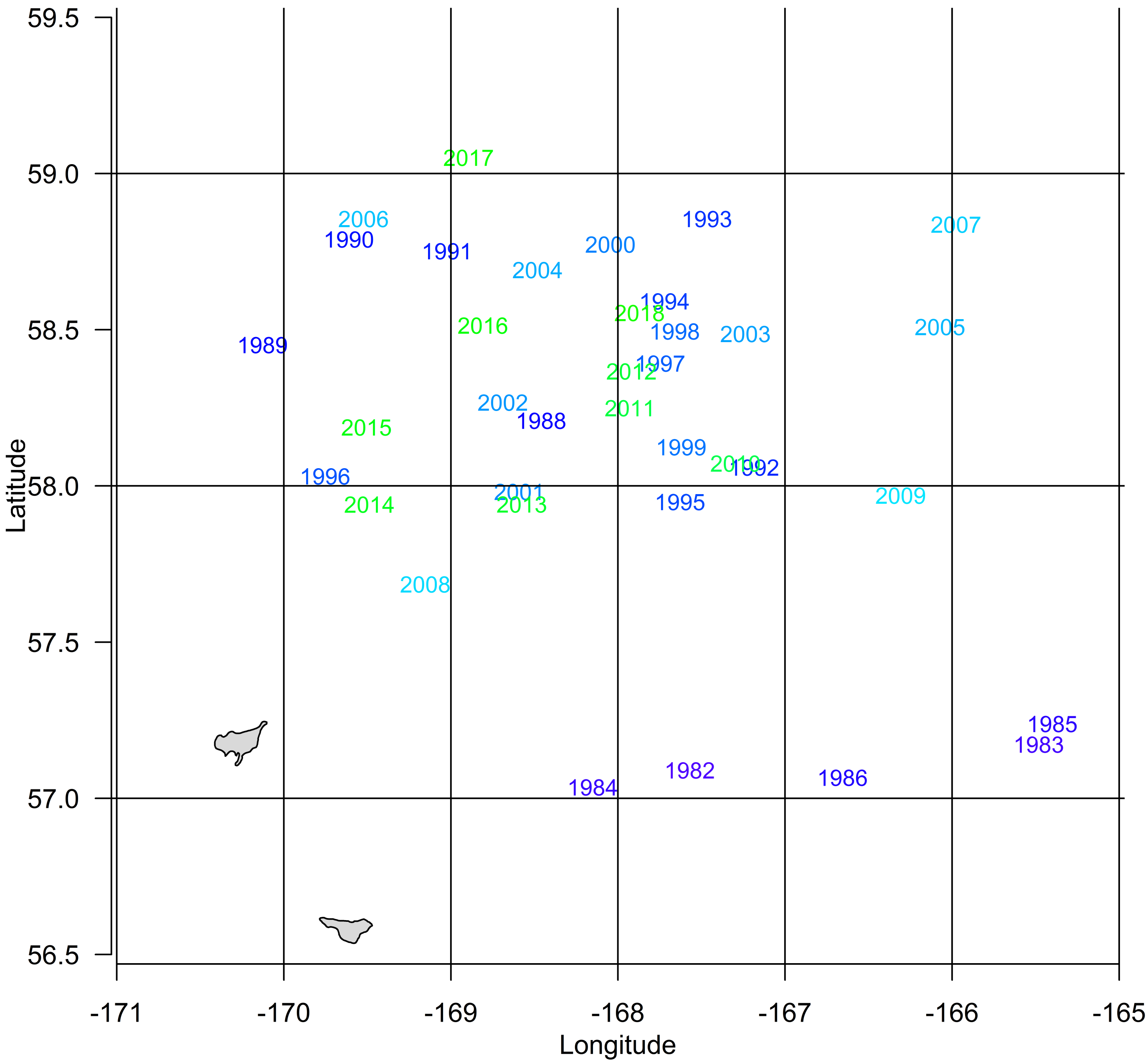

Figure 13: Centroid of large males observed in the survey over time. Dark blue indicates years early in the time series; green are the most recent years in the time series.

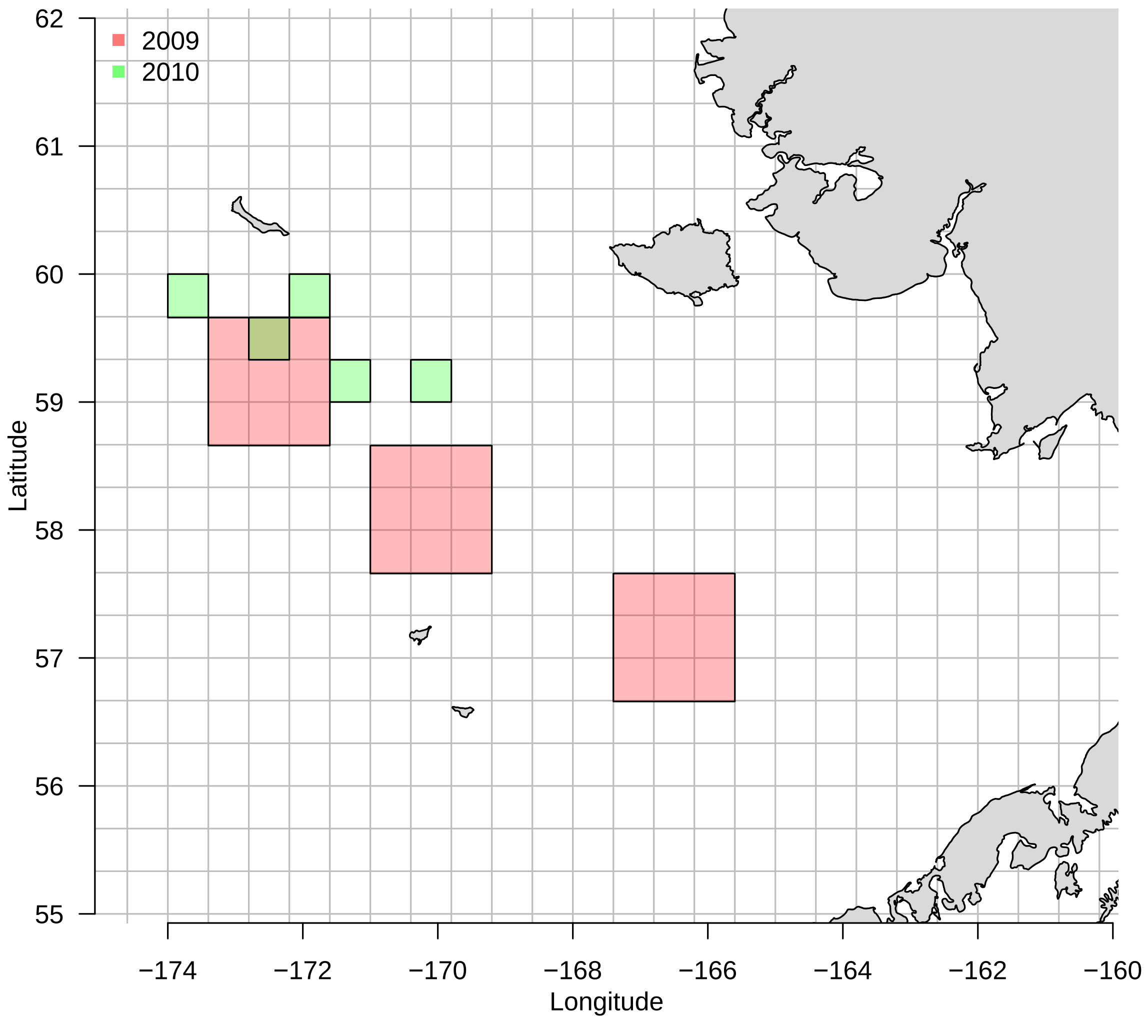

Figure 14: Location of survey selectivity experiments (2009 & 2010; this was reproduced from the 2015 SAFE; revise this figure with BSFRF data)

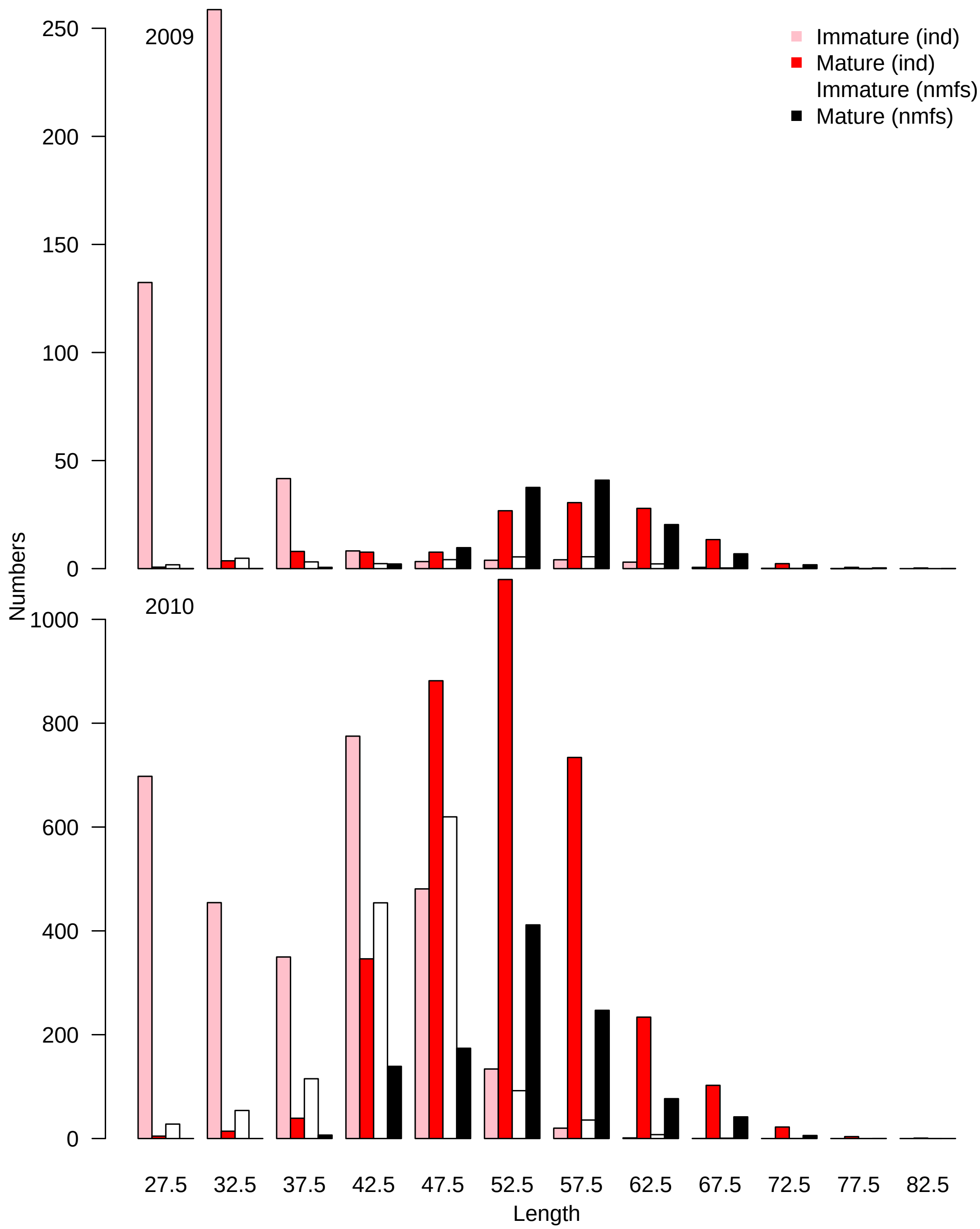

Figure 15: Raw female numbers from BSFRF survey selectivity experiments (2009 & 2010). Note a change in scale on the y-axis from 2009 to 2010

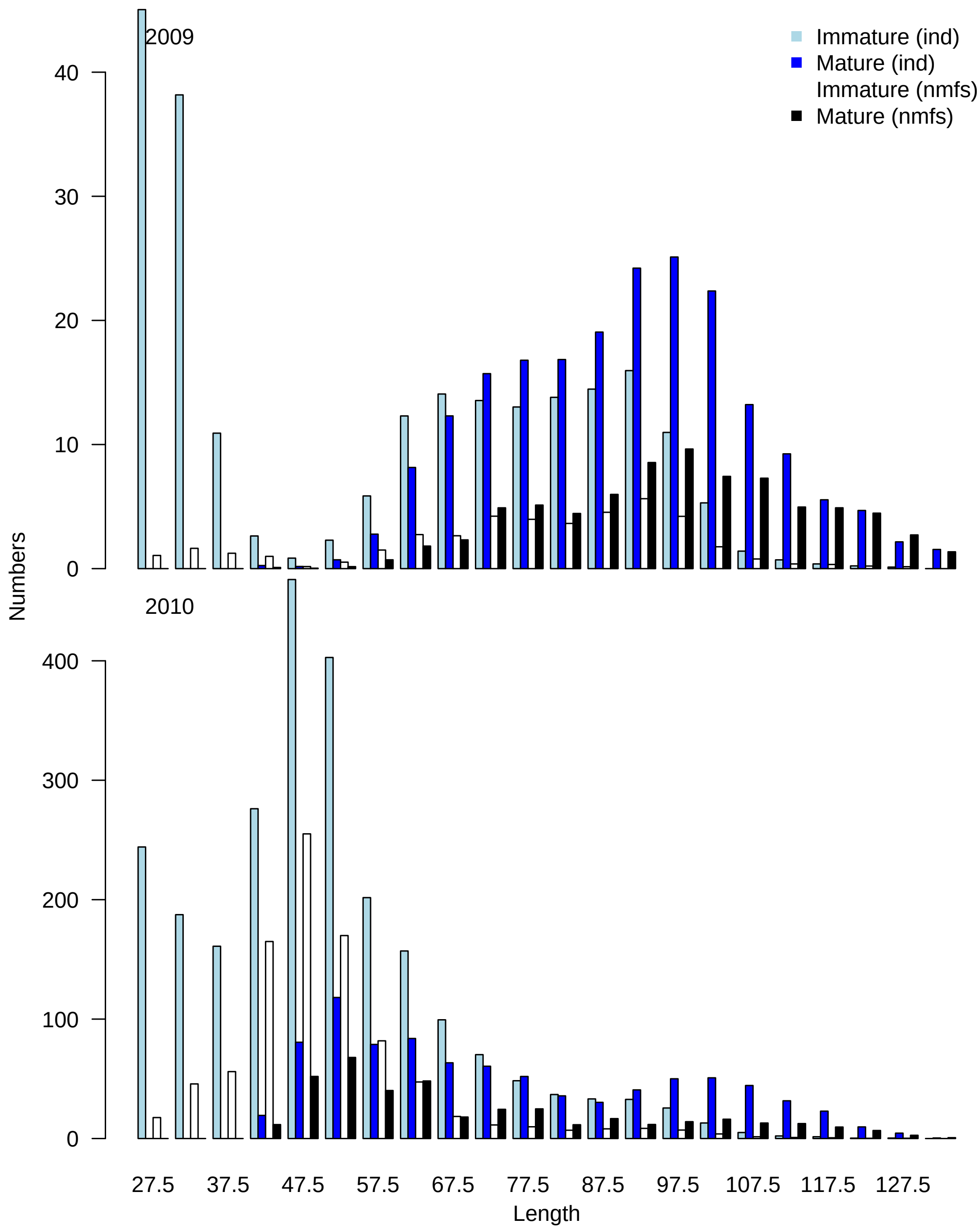

Figure 16: Raw male numbers from BSFRF survey selectivity experiments (2009 & 2010). Note a change in scale from 2009 to 2010 on the y-axis.

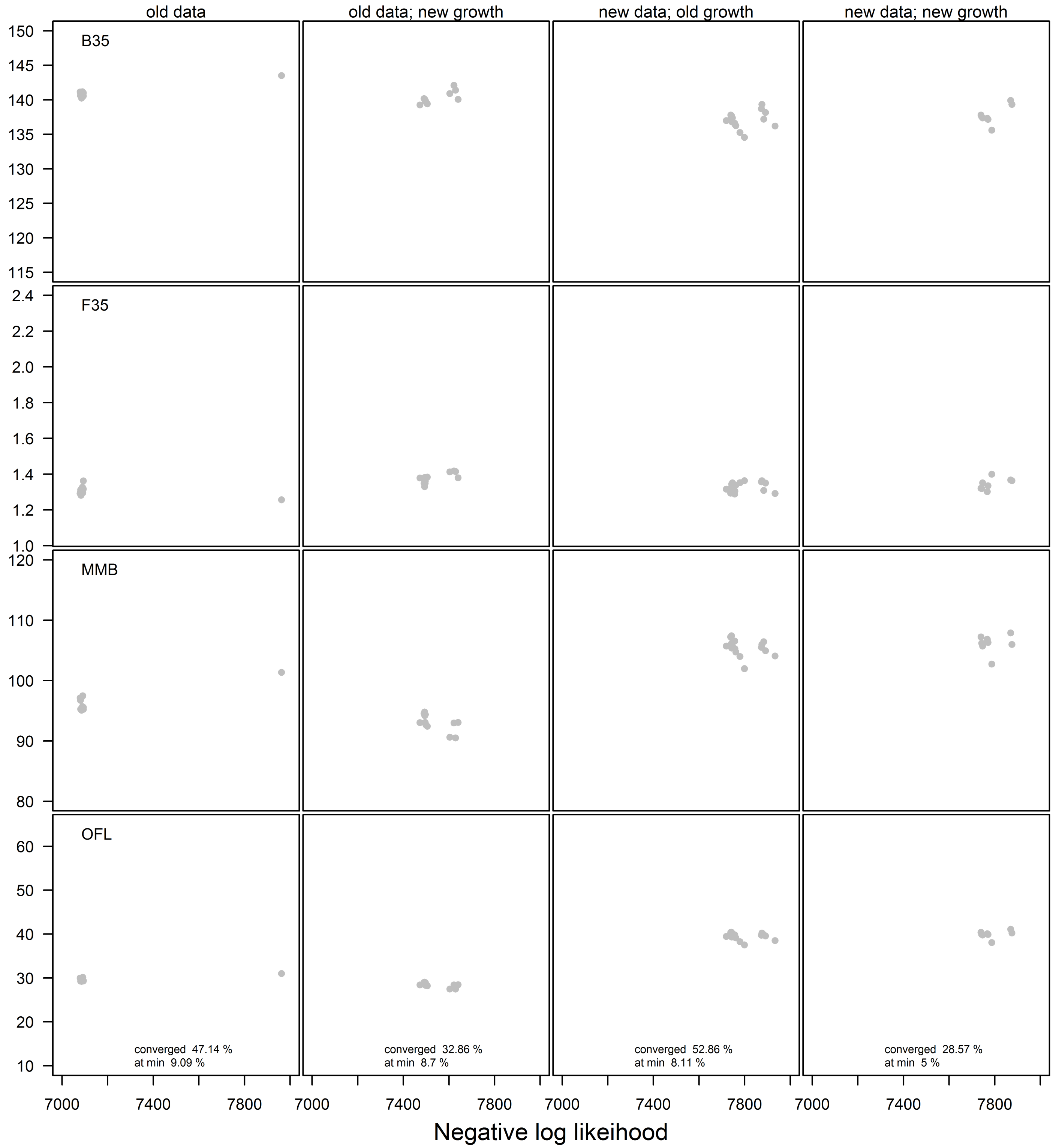

Figure 17: Management quantities after jittering the base model with different configurations of new data sources. X-axis is the negative log likelihood

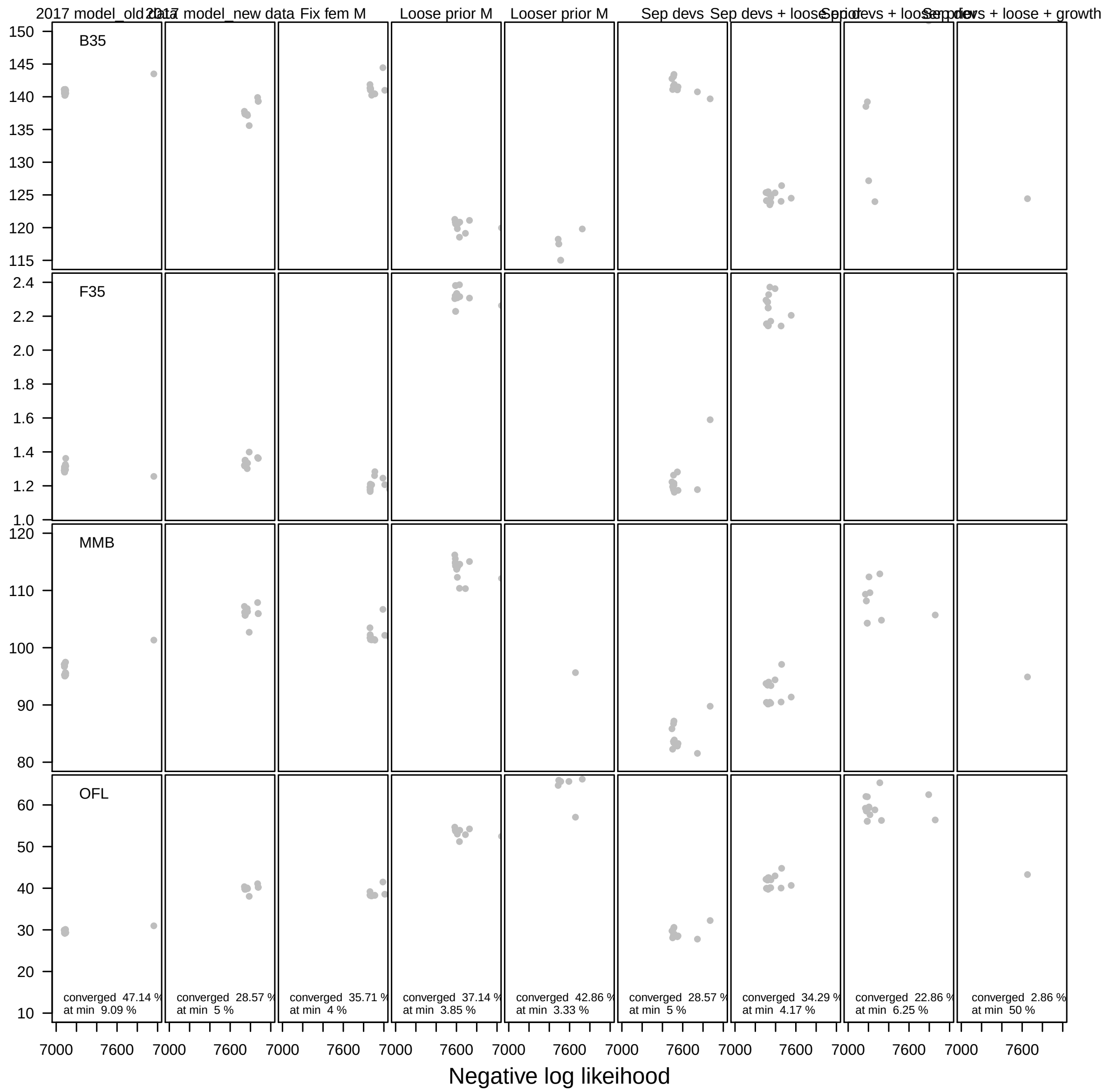

Figure 18: Management quantities after jittering selected models. Converged % indicates the % of jittered models that had a maximum gradient component < 0.005. at min % indicates the number of runs that converged to the minimum observed negative log likelihood

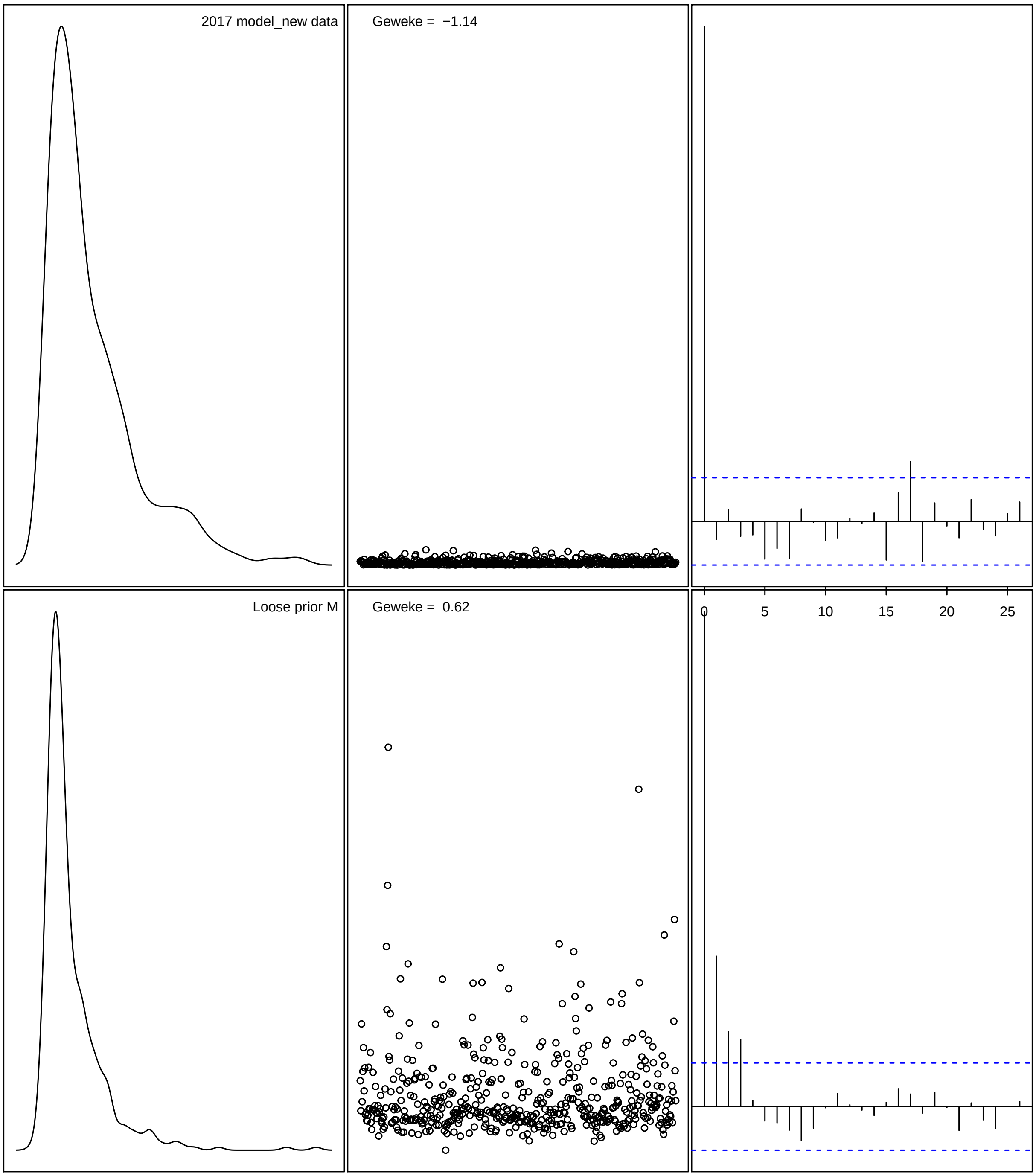

Figure 19: Basic MCMC diagnostics. Left colum is the density of the value of the objective function. Middle column is the trace of the objective function. Number in the upper left of each panel is the z-score of the Geweke diagnostic. Right is the autocorrelation in the objective function value.

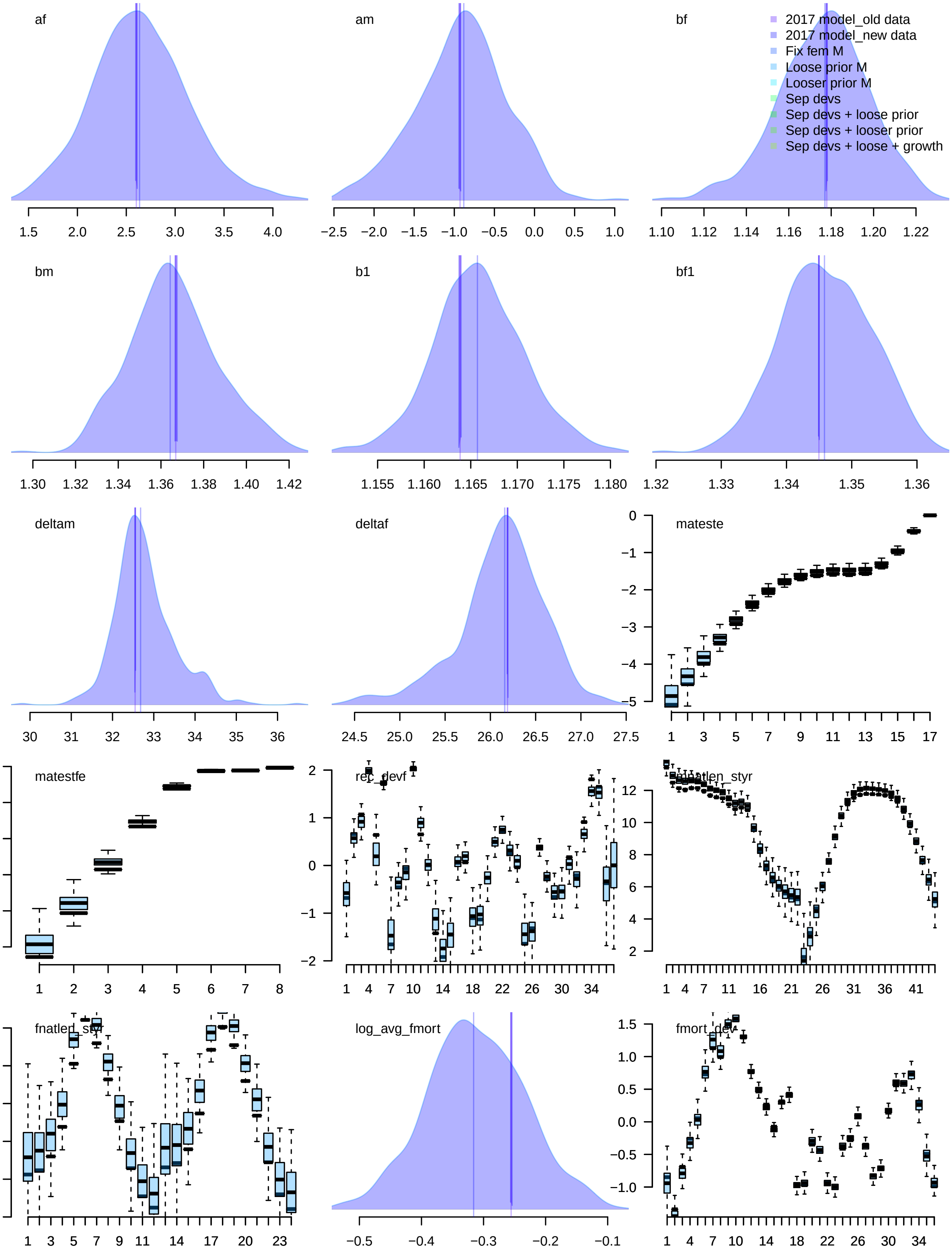

Figure 20: Posterior densities for estimated parameters by scenario

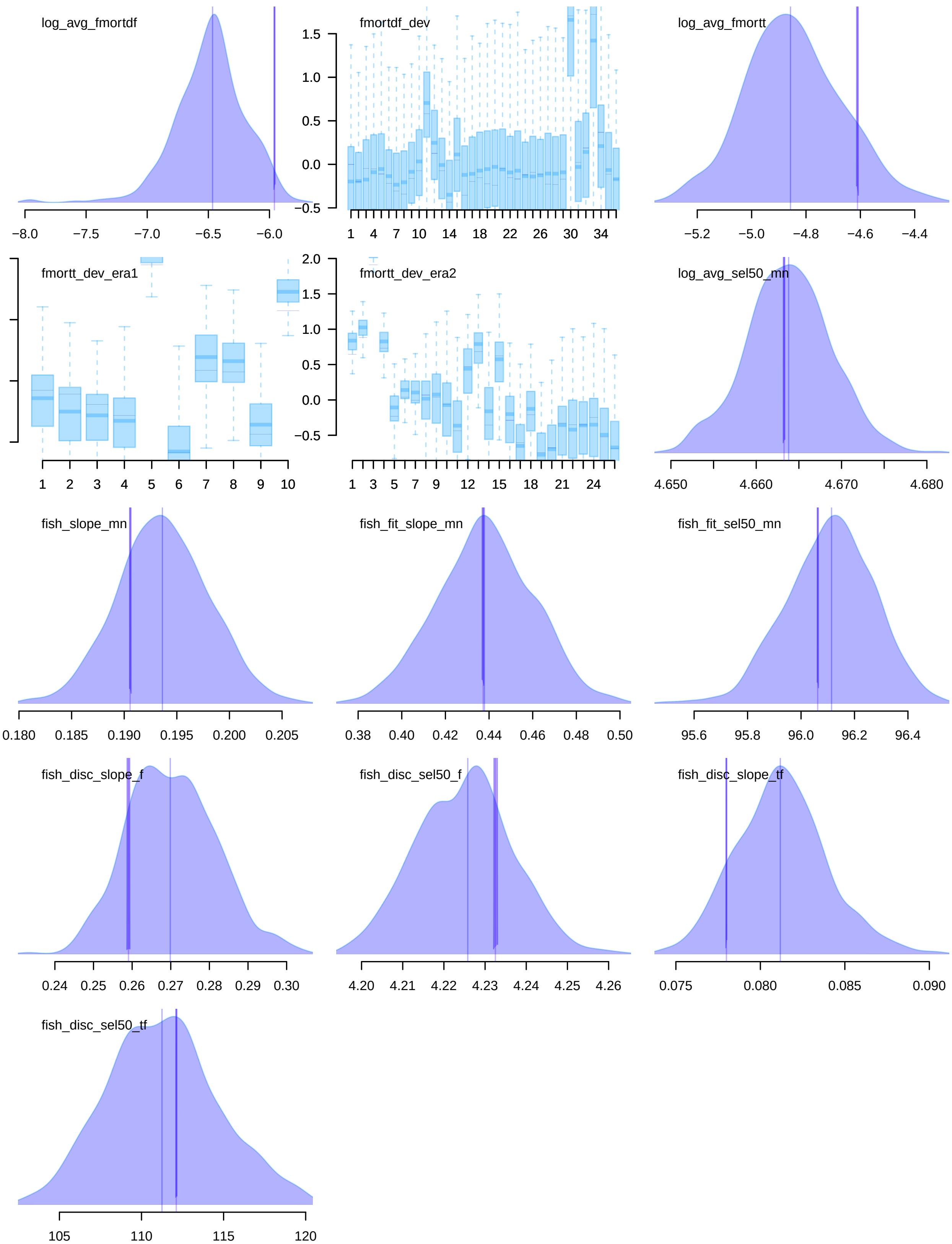

Figure 21: Posterior densities for estimated parameters by scenario

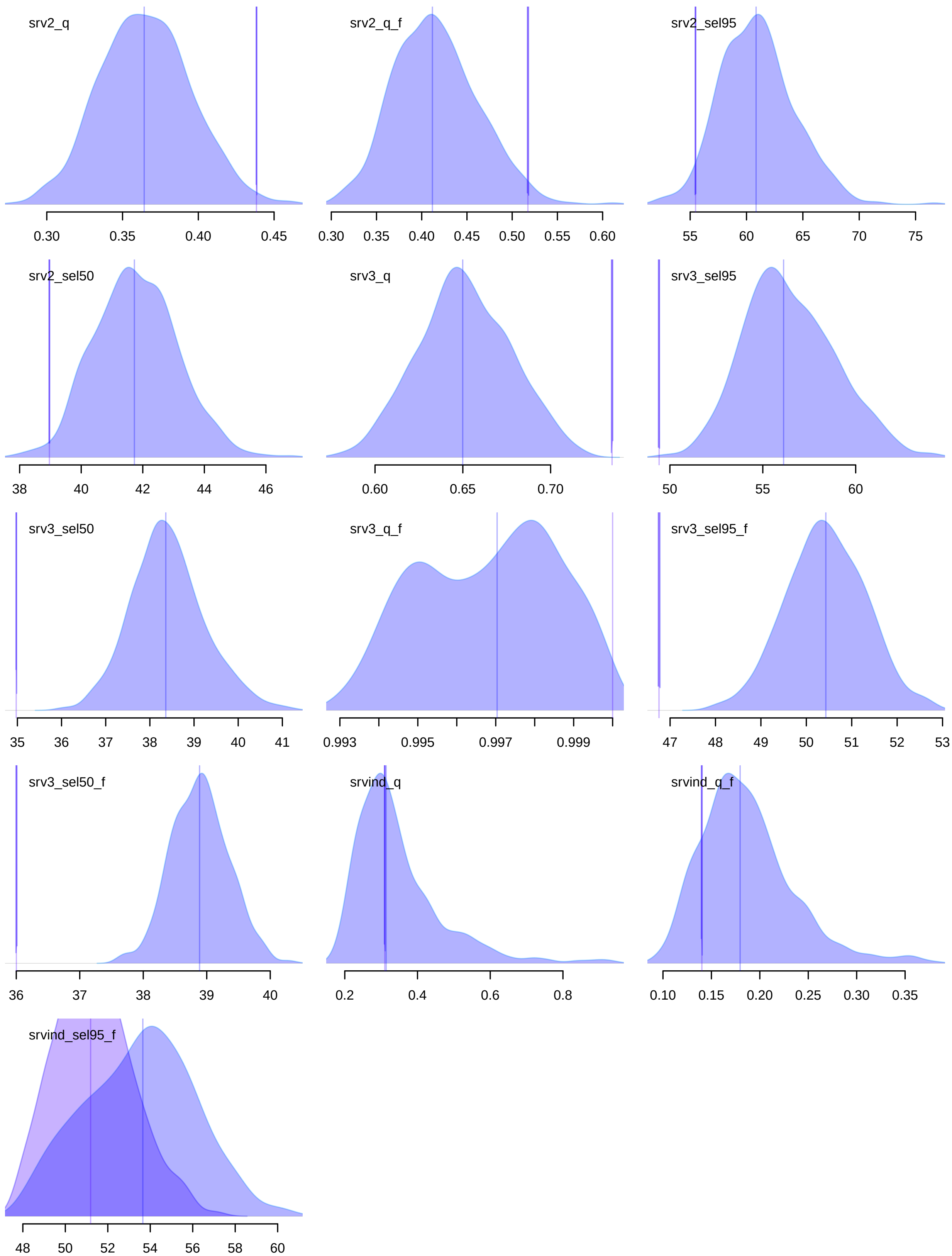

Figure 22: Posterior densities for estimated parameters by scenario

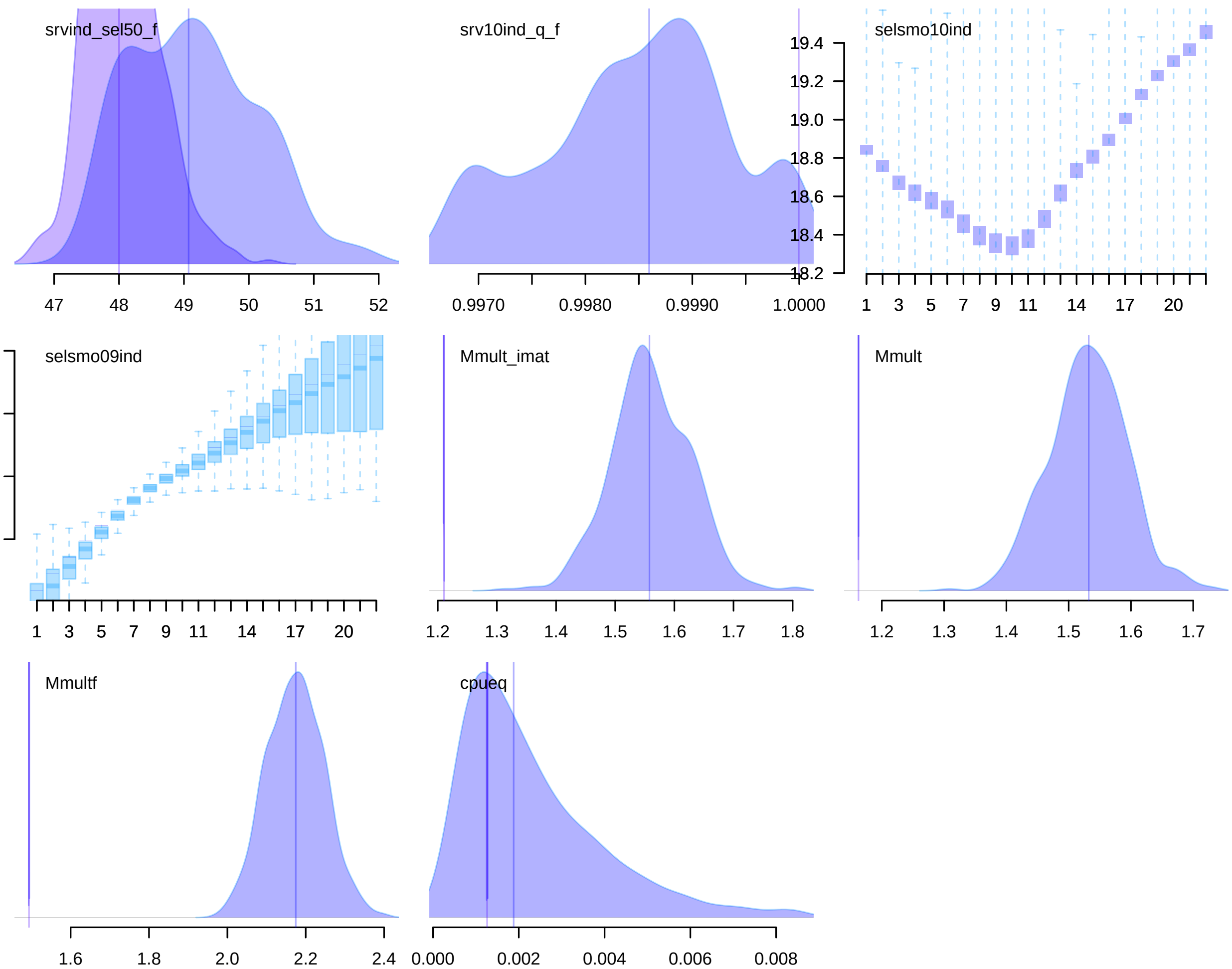

Figure 23: Posterior densities for estimated parameters by scenario

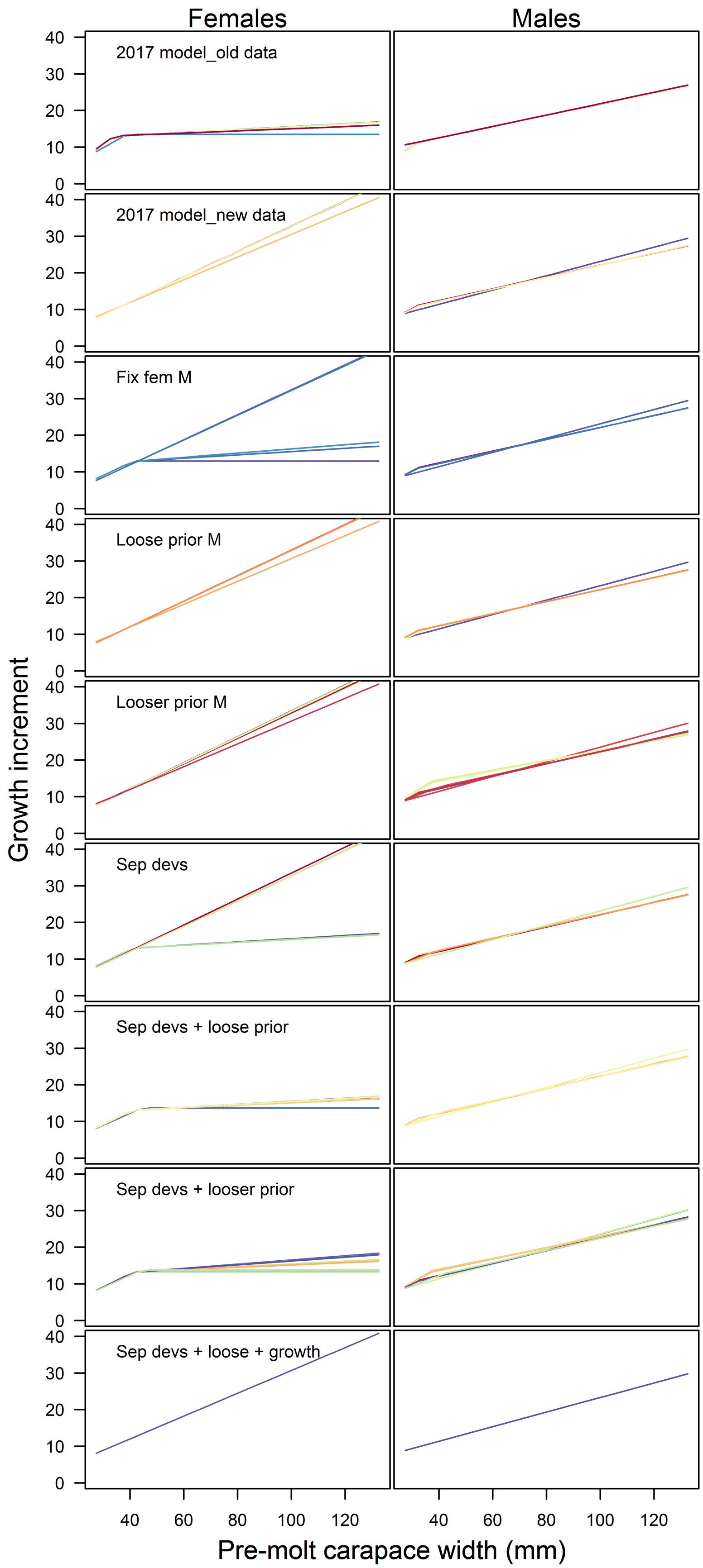

Figure 24: Estimated growth curves from jittered runs for all models. Colors represent the relative magnitude of the estimated OFL resulting from a given growth curve. Actual magnitude is not important–this figure is meant to show that the bimodality in the OFL is related to the growth curve (in particular, the female growth curve).

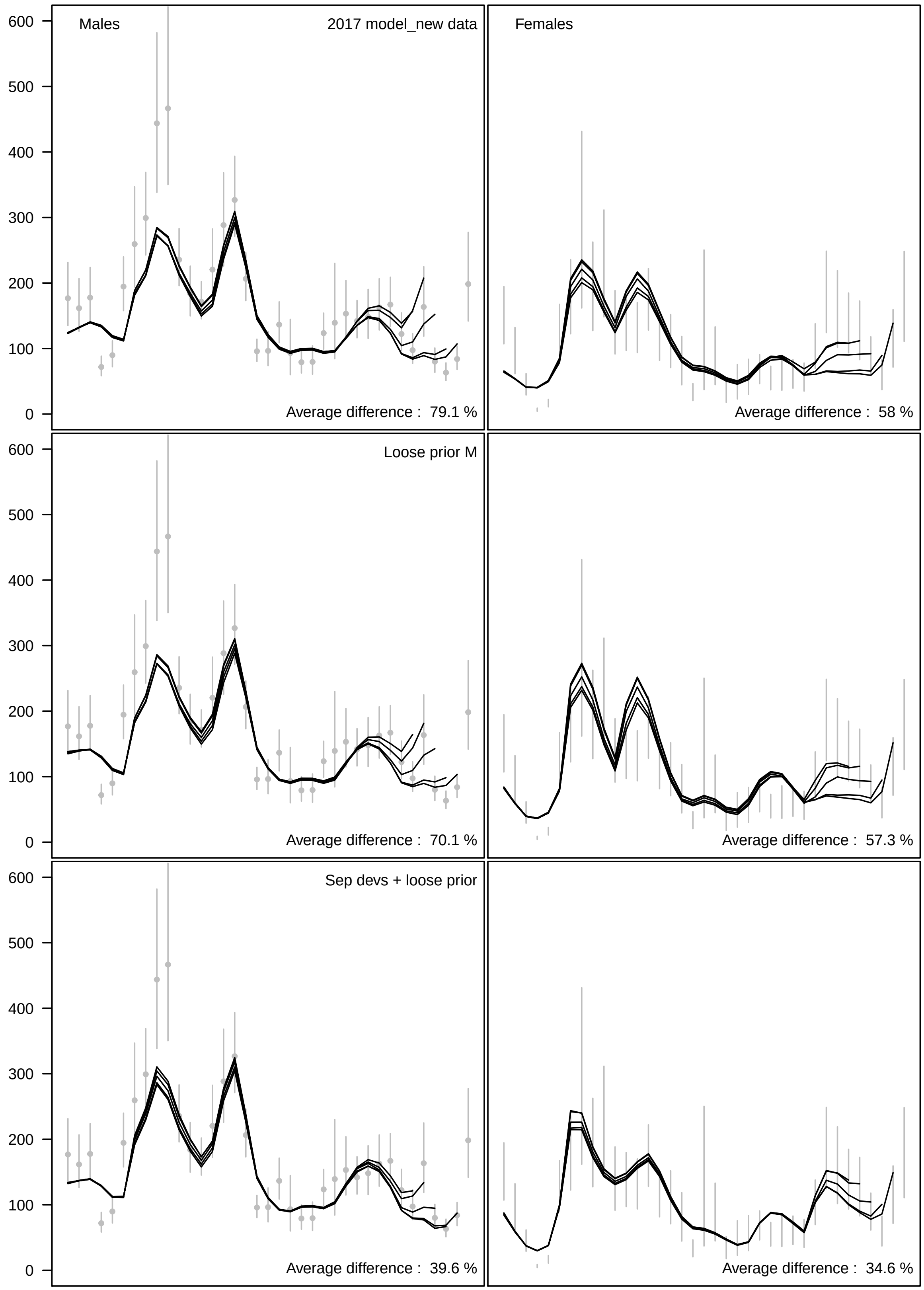

Figure 25: Retrospective analysis for selected models. Each line represents the model predictions for survey mature biomass when successively more years of data are removed from the analysis. Average difference is calculated as the mean relative error over the retrospective period (i.e. (Peeled MMB - 2017 MMB)/ 2017 MMB)

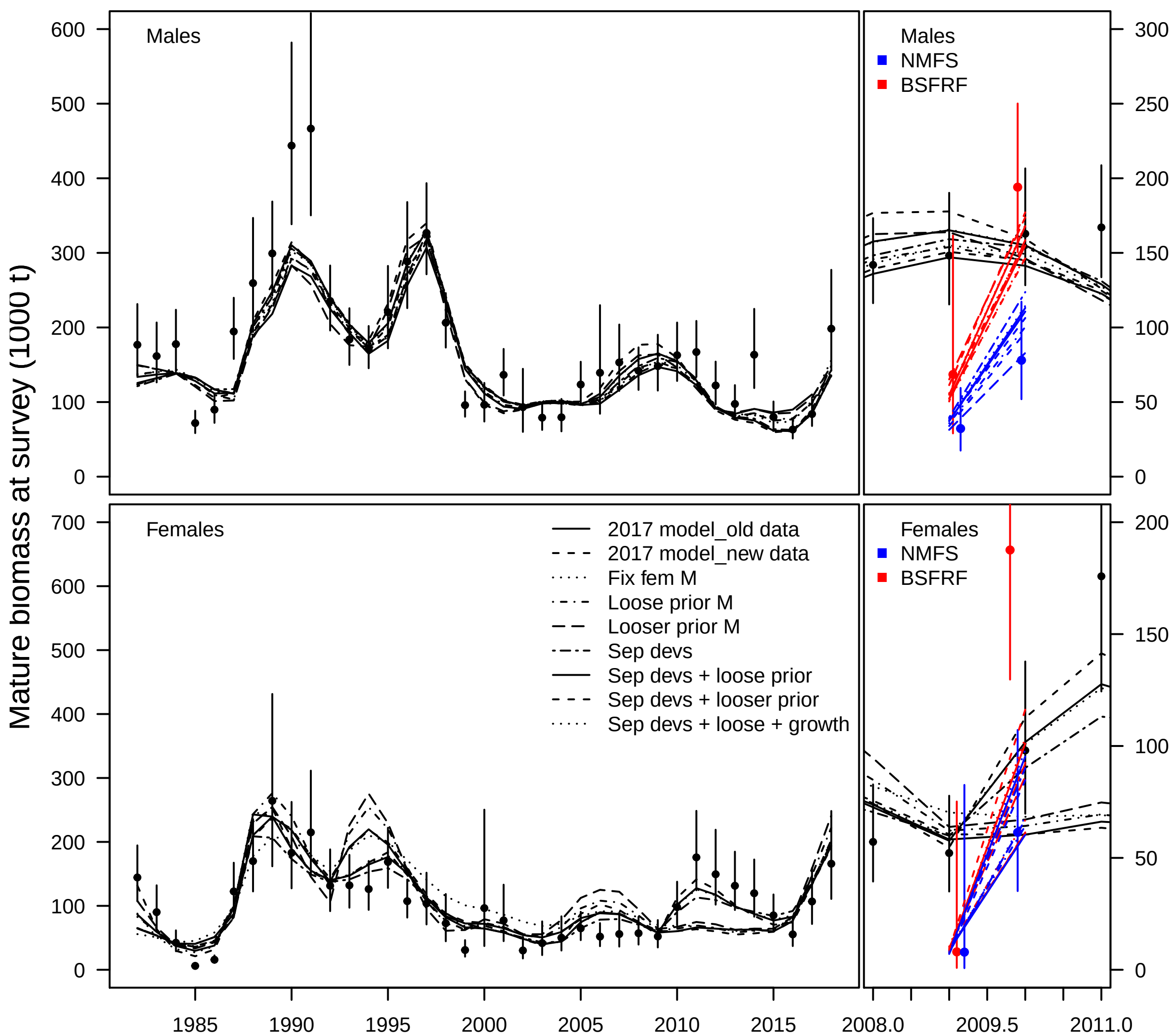

Figure 26: Model fits to the observed mature biomass at survey

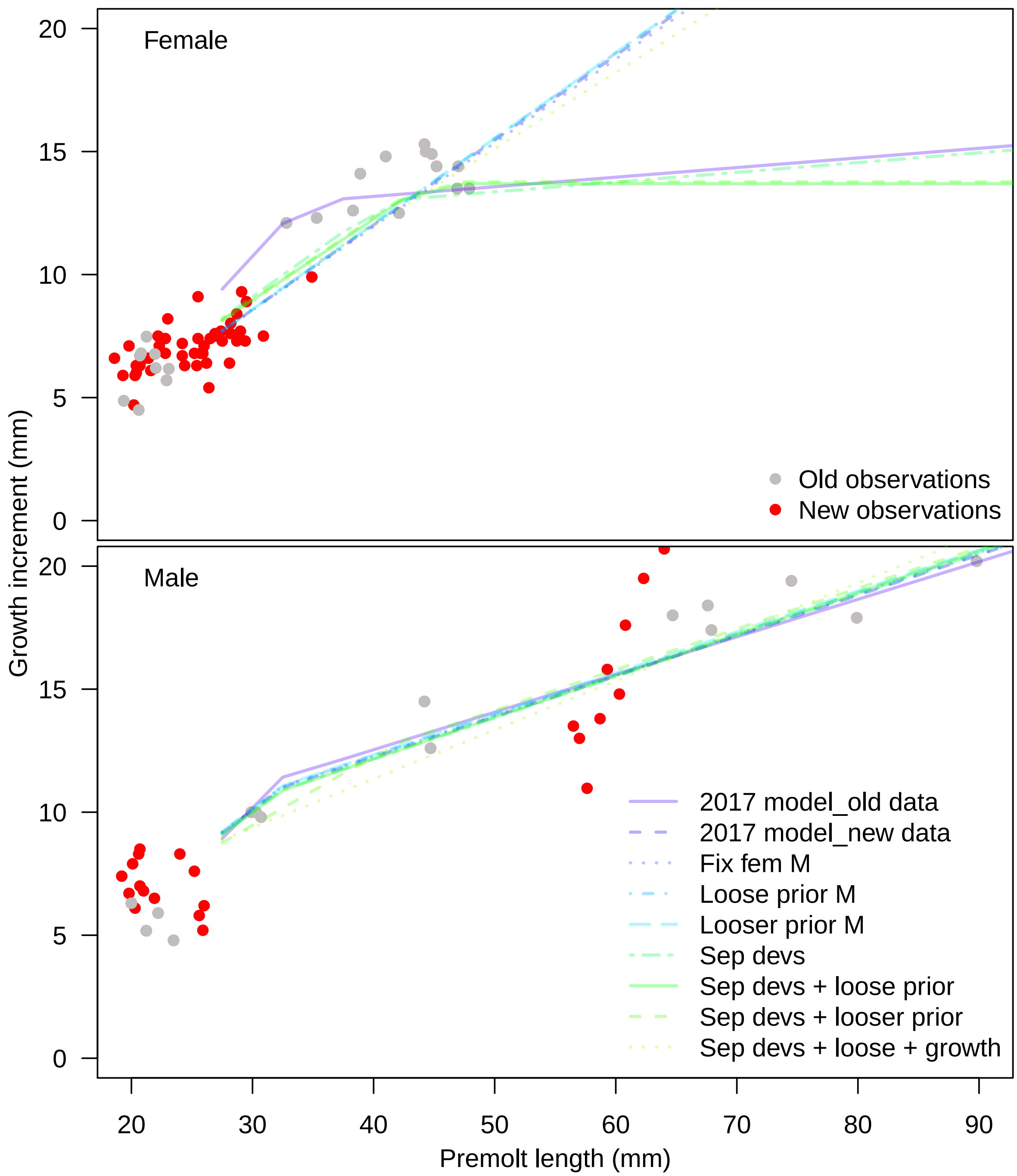

Figure 27: Model fits to the growth data

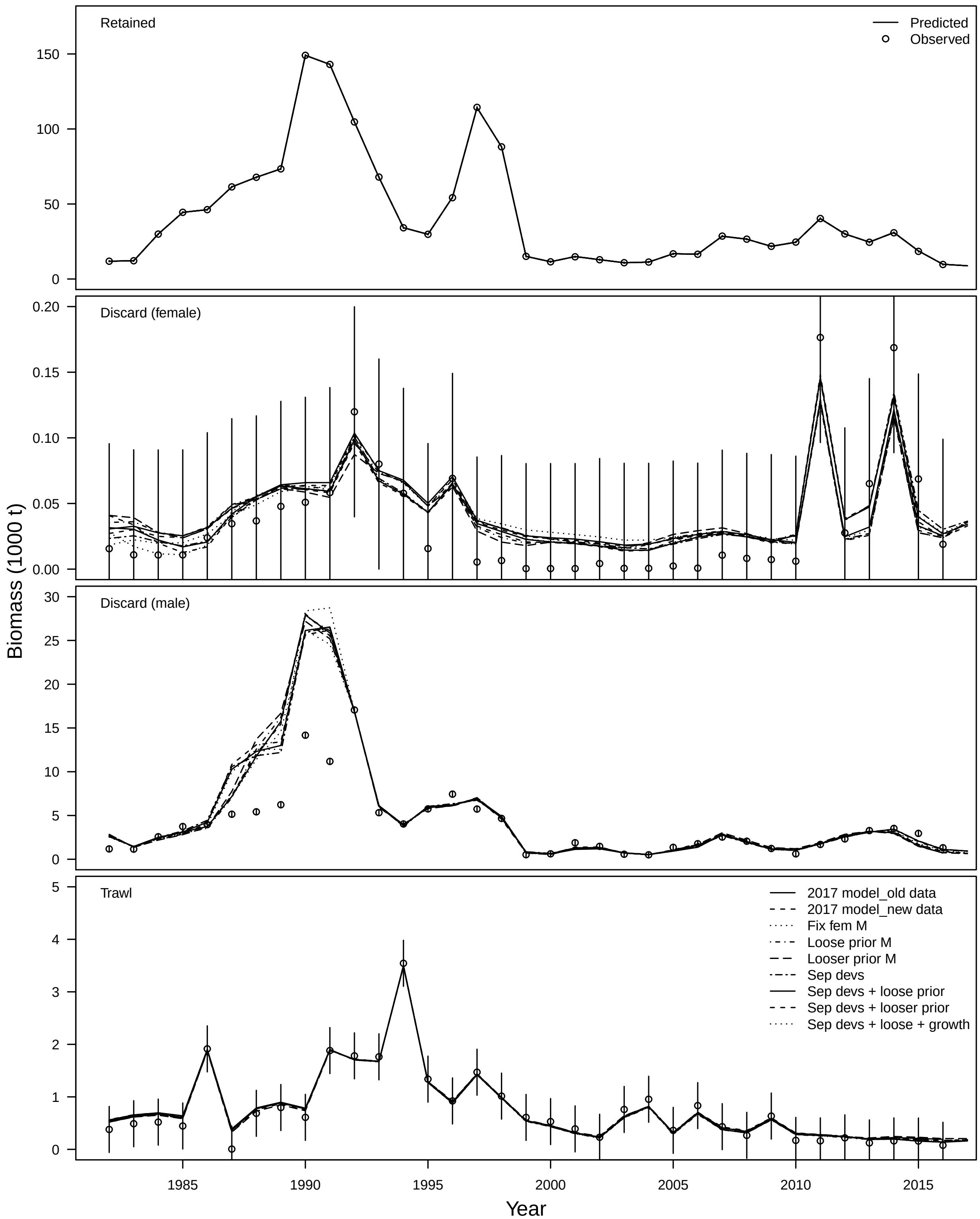

Figure 28: Model fits to catch data

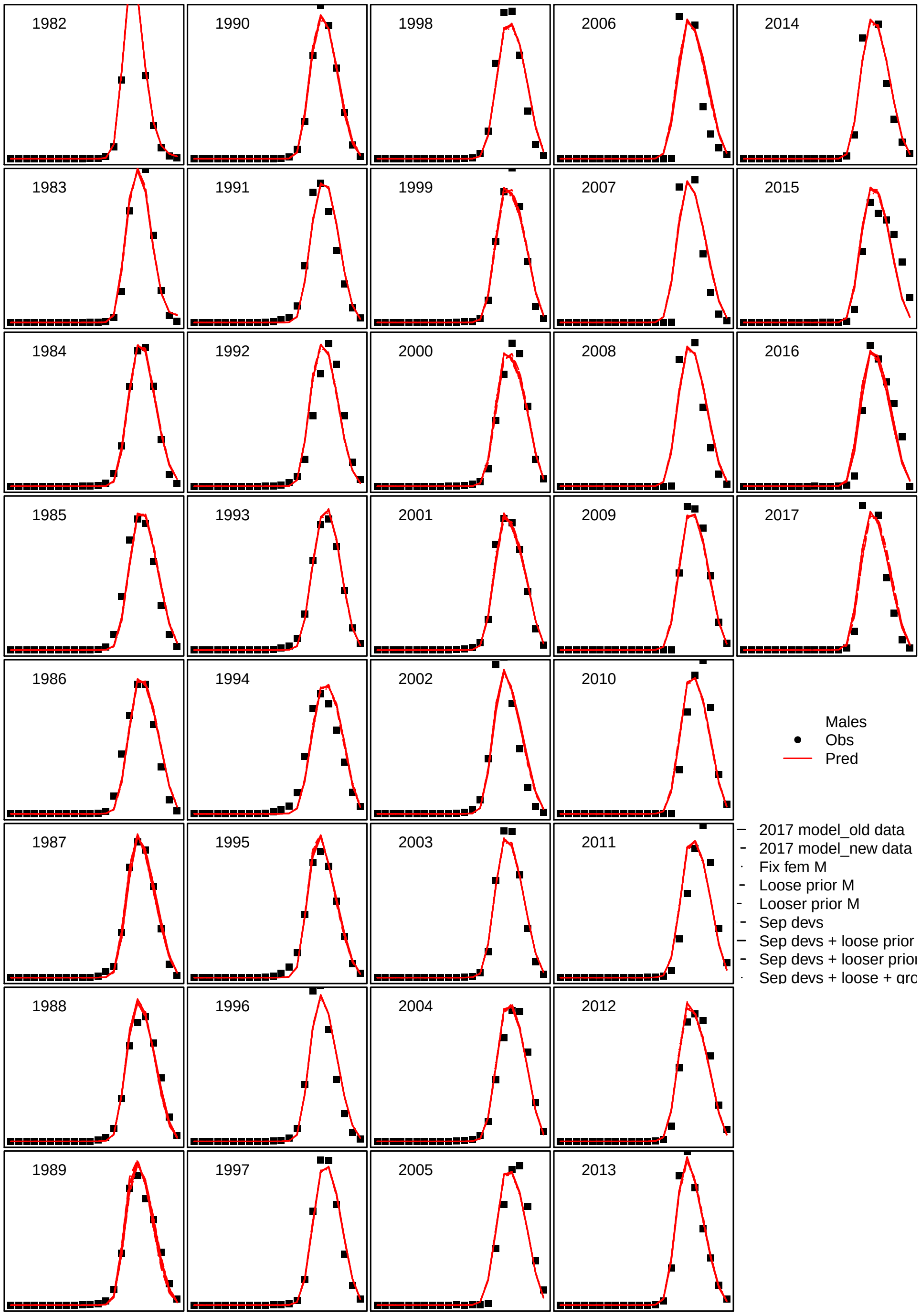

Figure 29: Model fits to retained catch size composition data

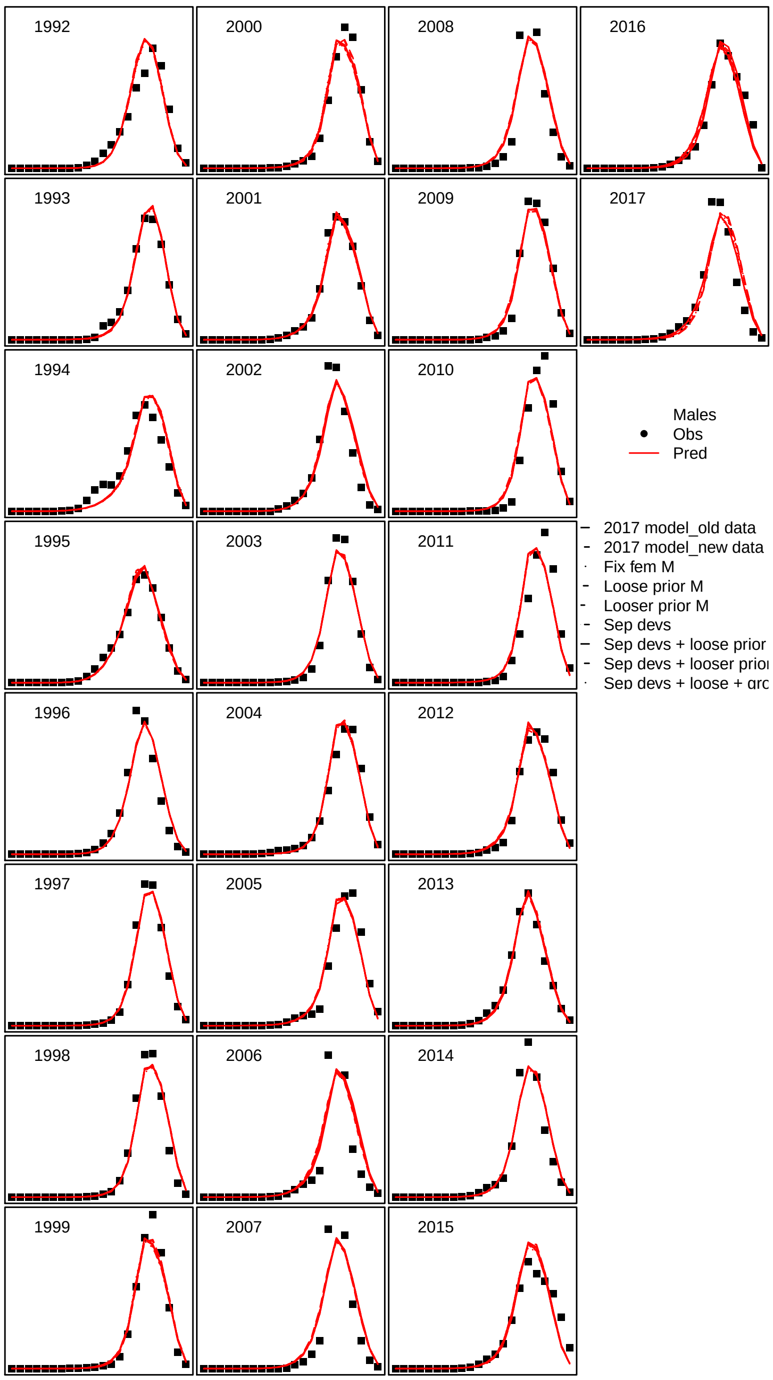

Figure 30: Model fits to total catch size composition data

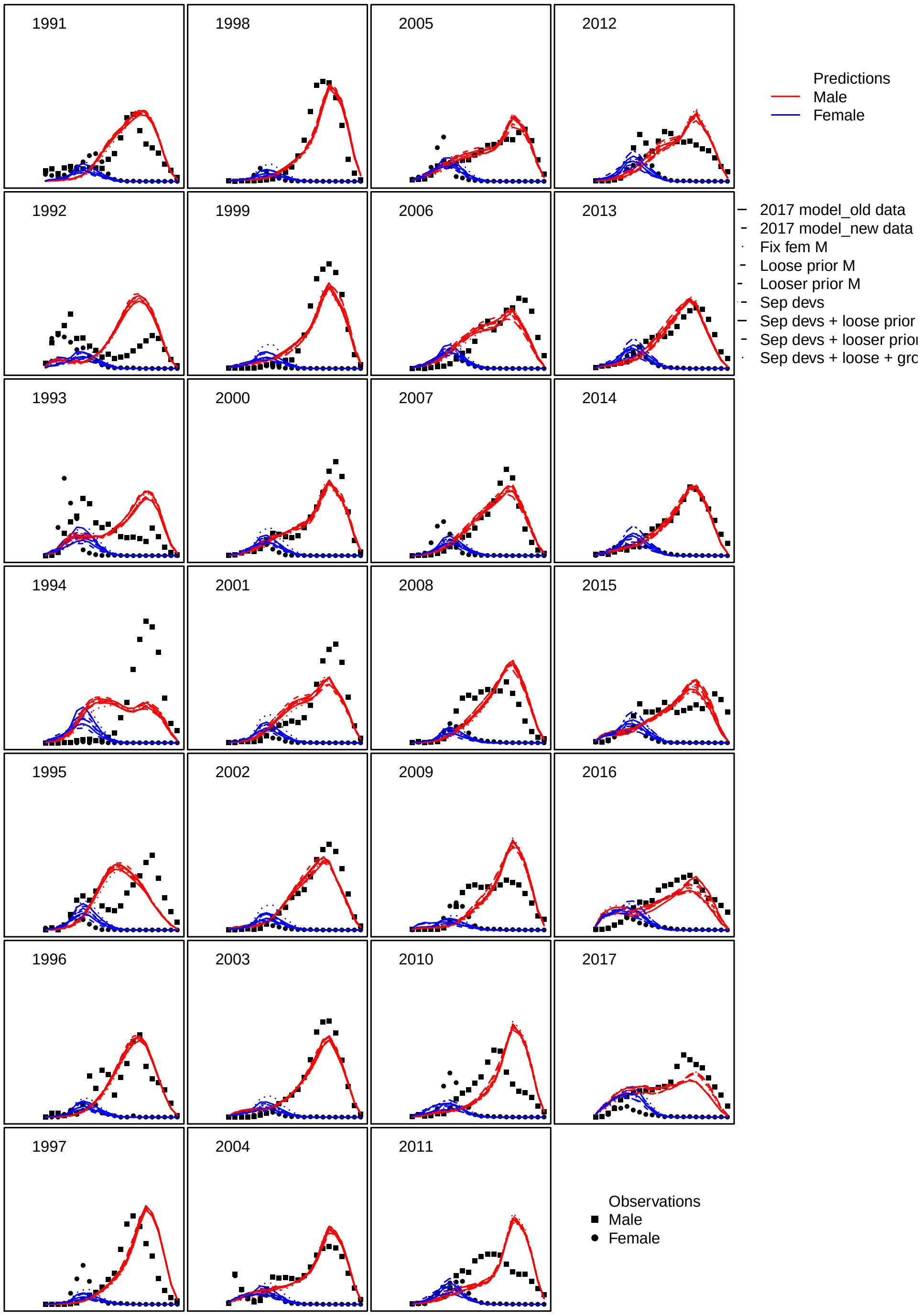

Figure 31: Model fits to trawl catch size composition data

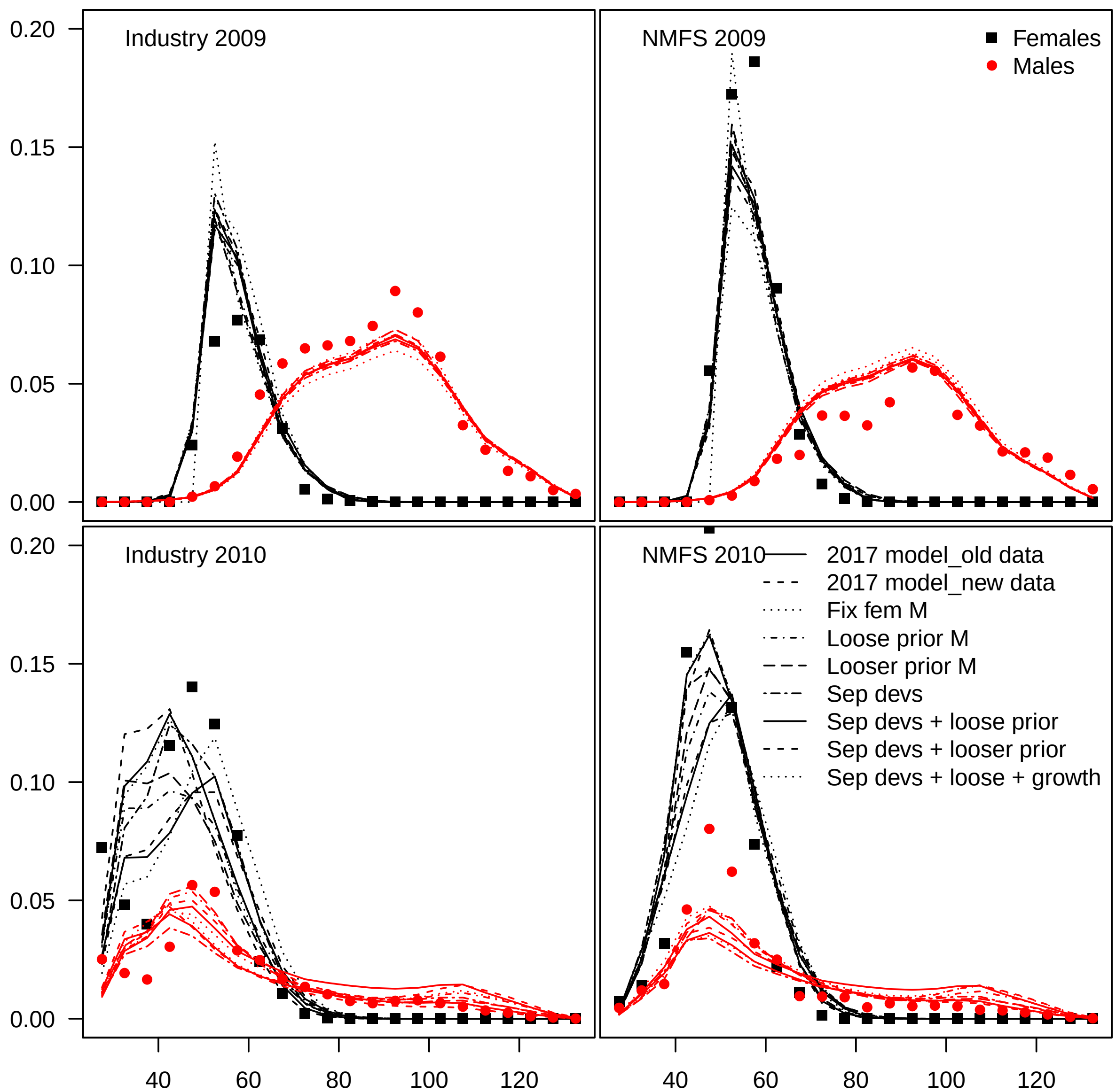

Figure 32: Model fits to size composition data from summer survey experiments (2009 & 2010)

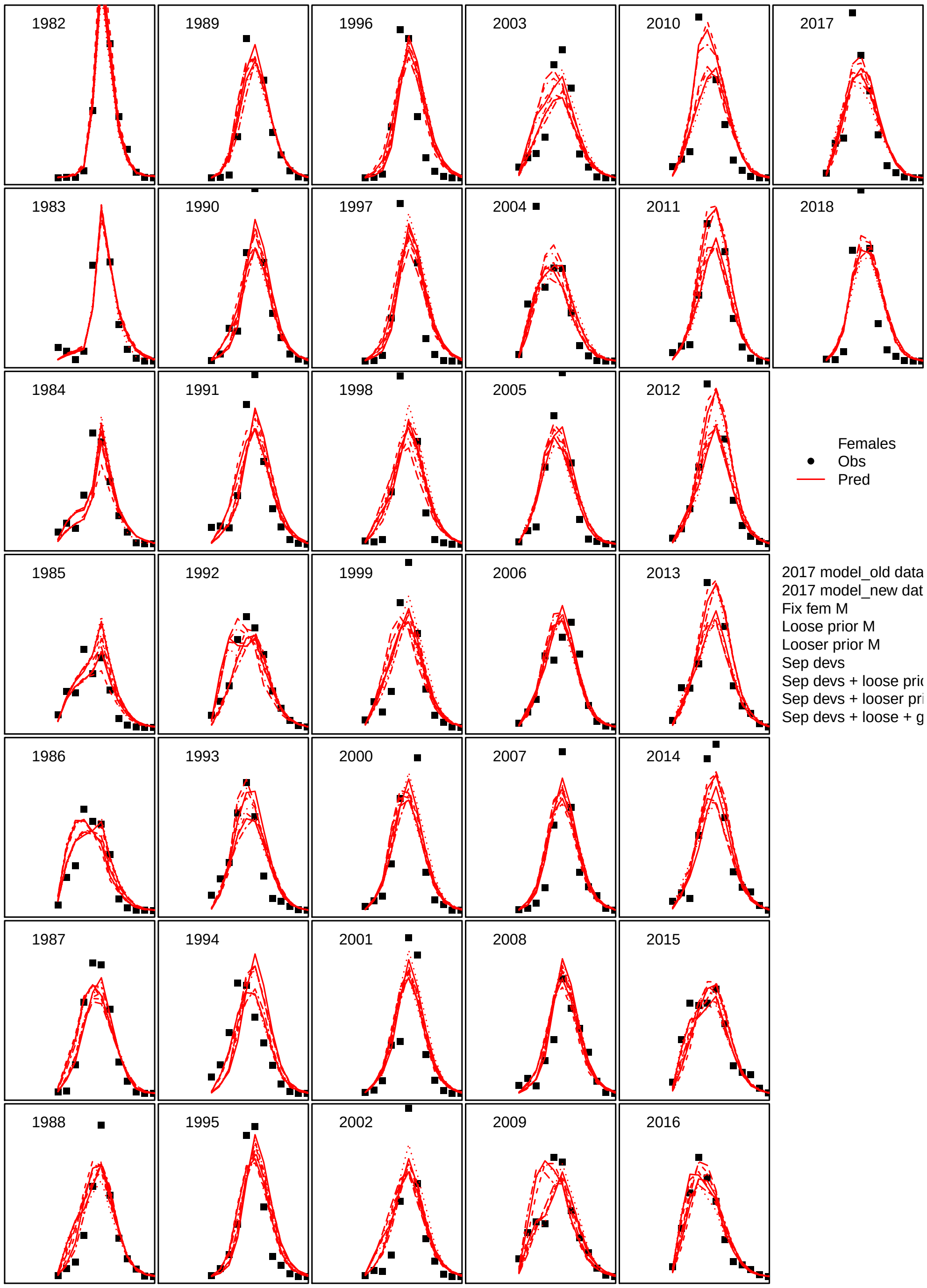

Figure 33: Model fits to female survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

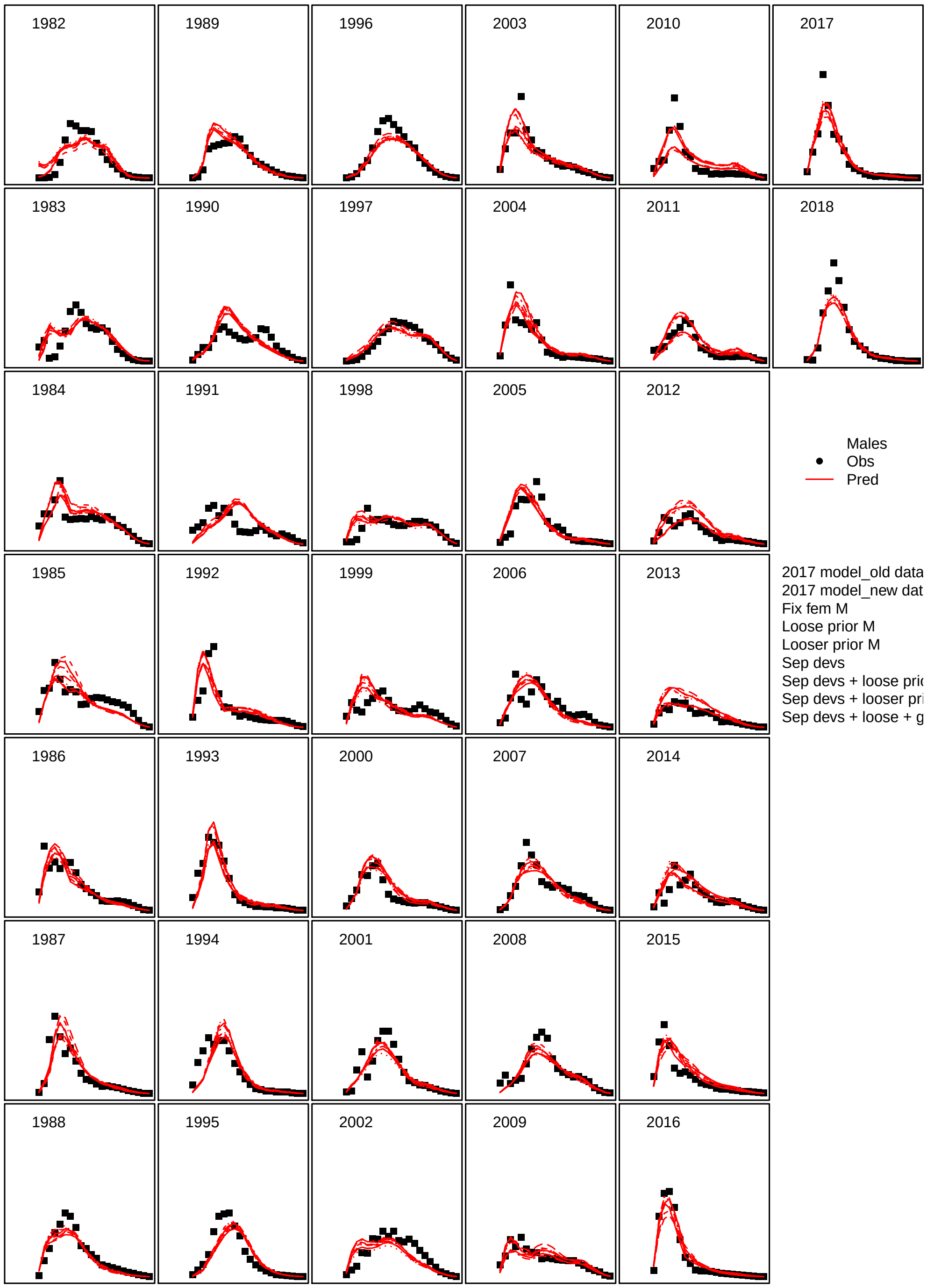

Figure 34: Model fits to male survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.

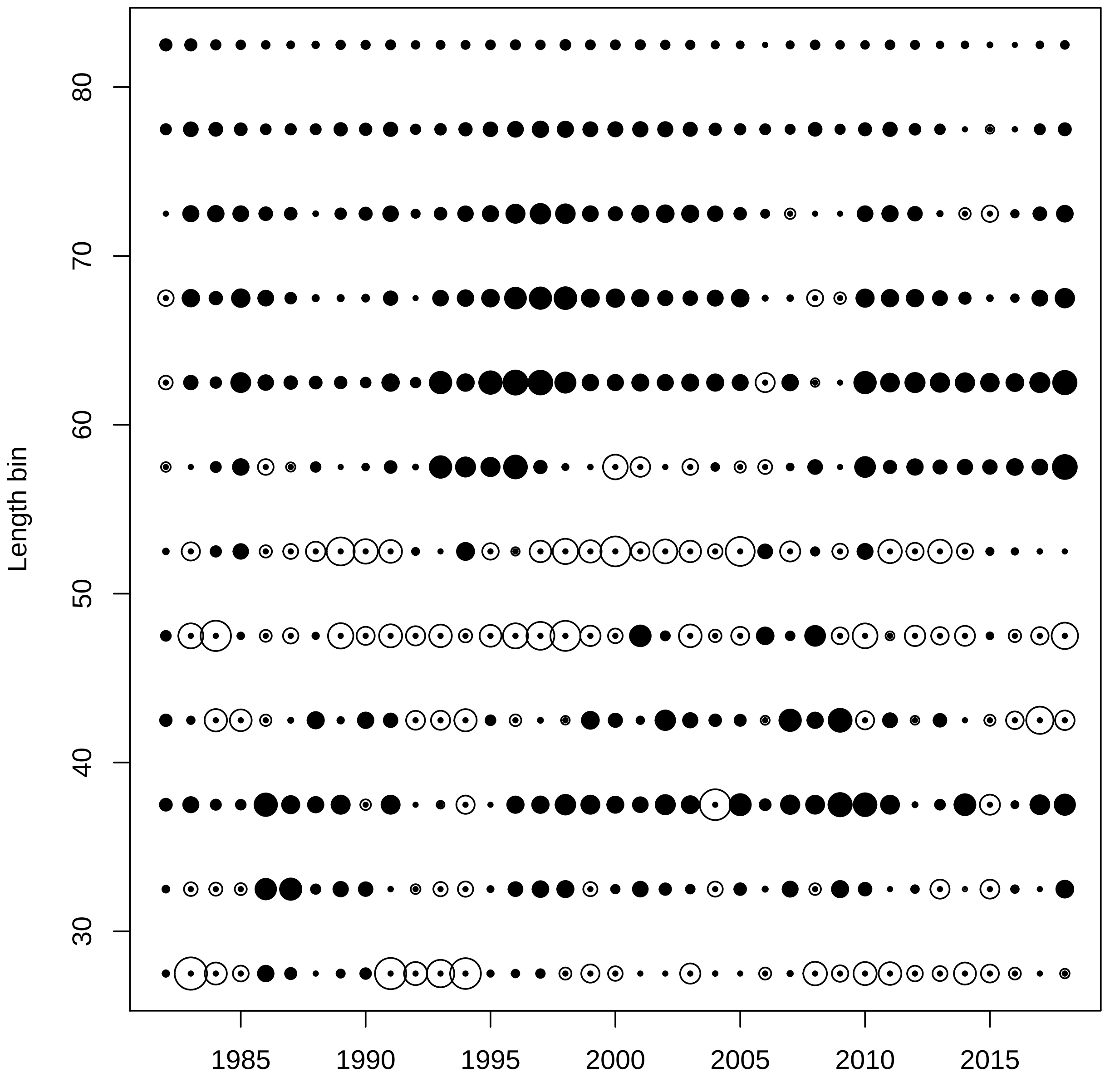

Figure 35: Residuals for female survey length proportion data for the author's preferred model (3b). Open circles are positive residuals, filled are negative, and the size of the circle is proportional to the magnitude of the residual. Stars are residuals > 5.

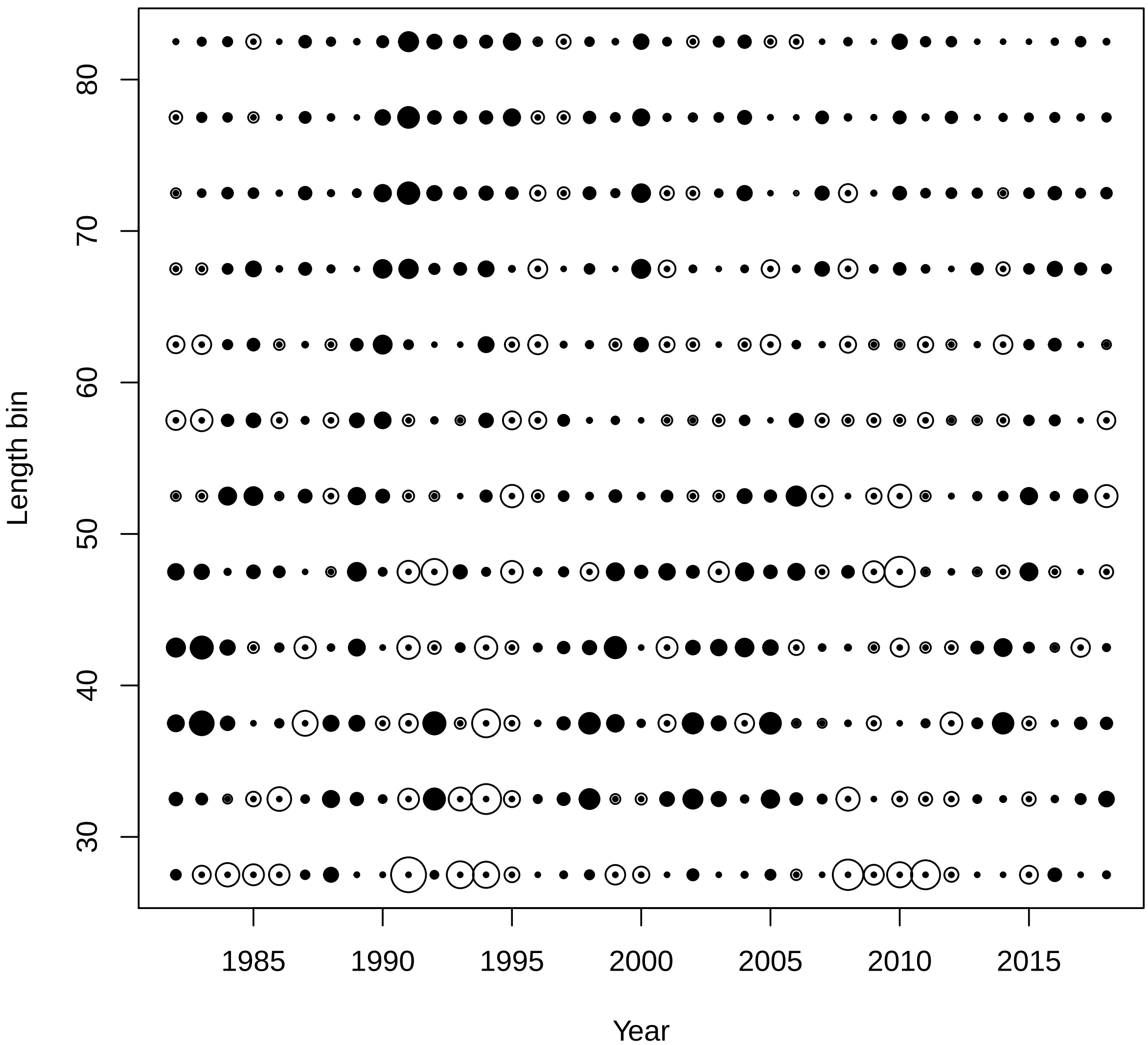

Figure 36: Residuals for male survey length proportion data for the author's preferred model (3b). Open circles are positive residuals, filled are negative, and the size of the circle is proportional to the magnitude of the residual. Stars are residuals > 5.

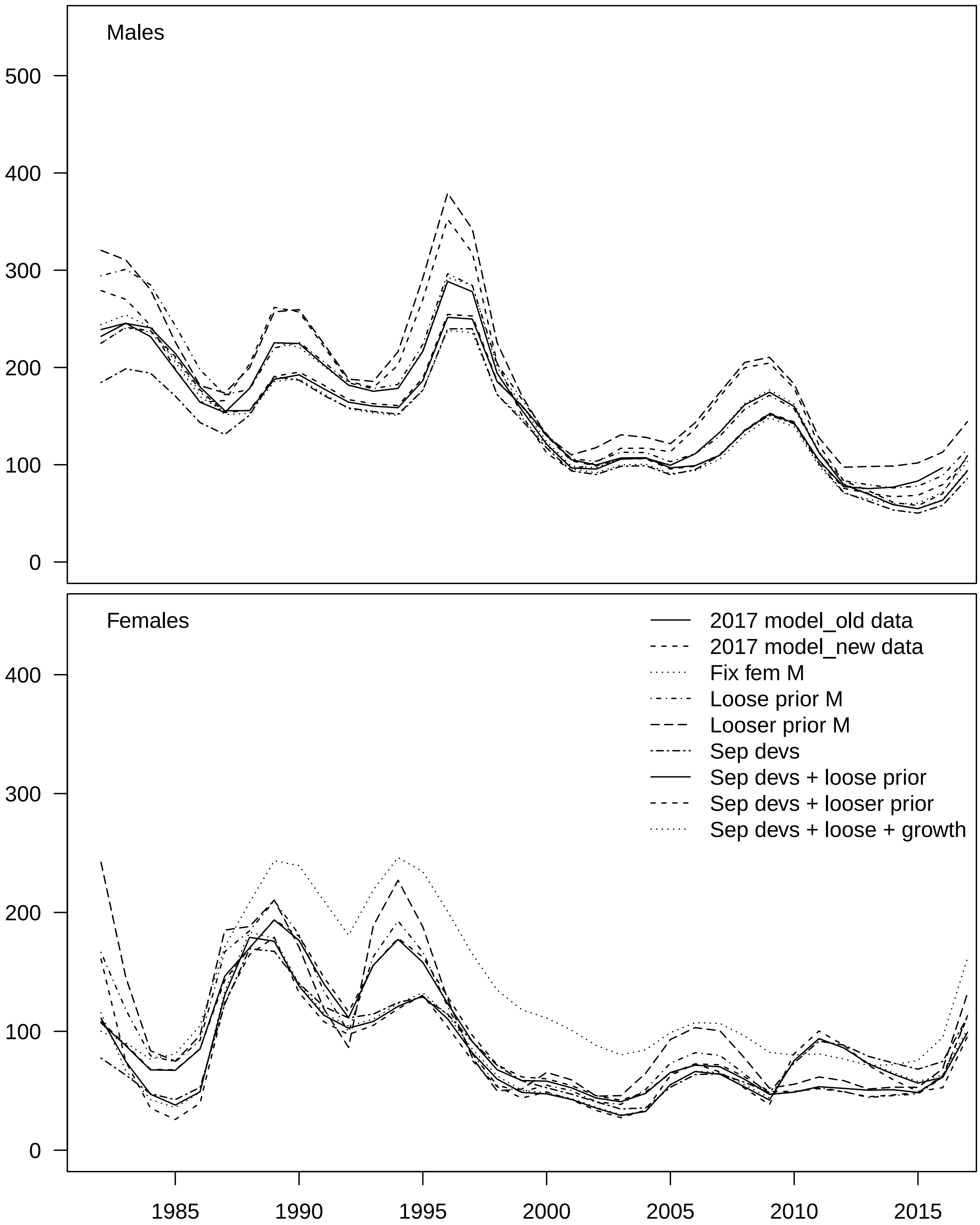

Figure 37: Model predicted mature male biomass at mating time

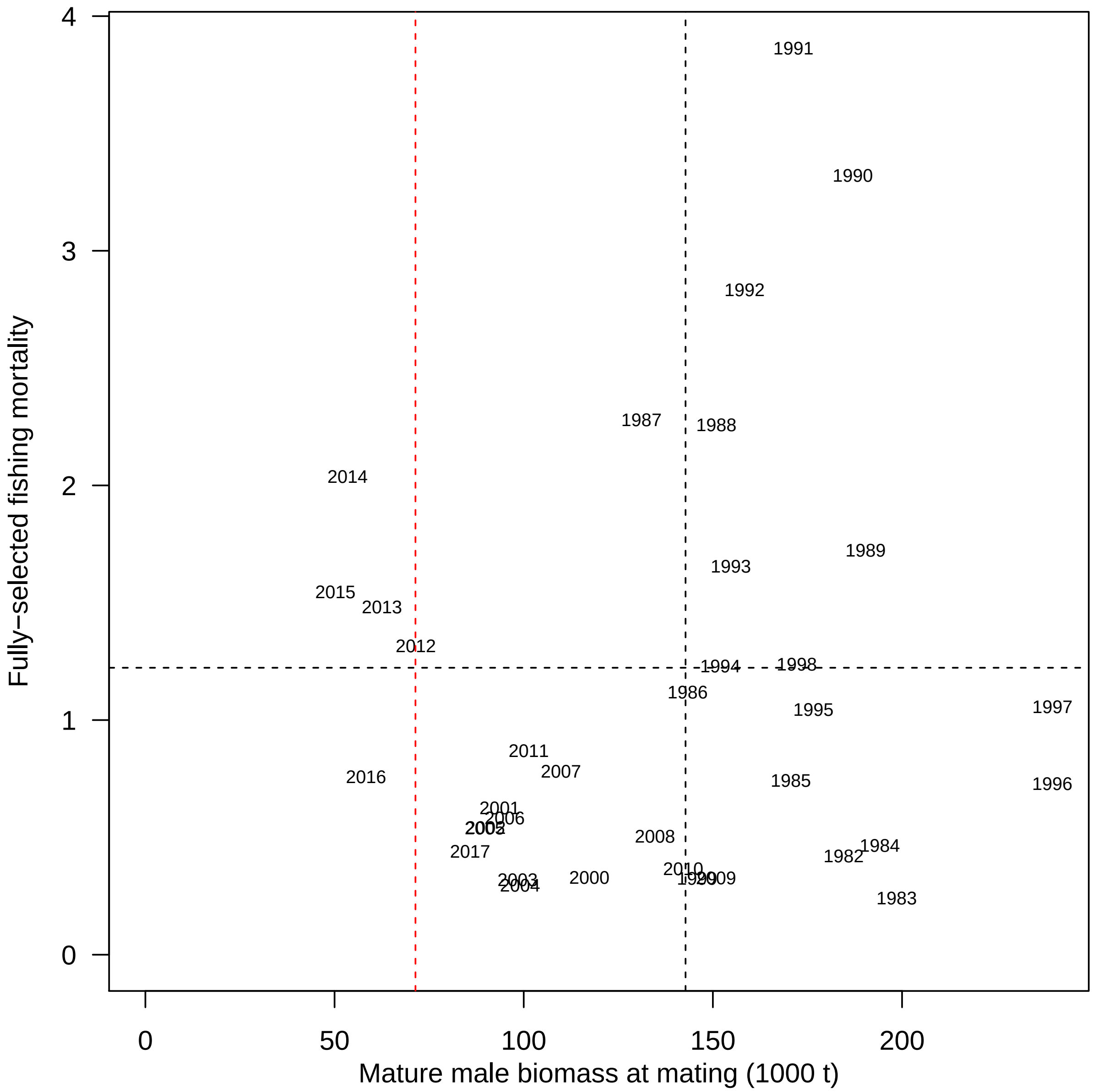

Figure 38: Kobe plot for the chosen model. Vertical dashed black line represents the median posterior value for B35; Vertical dashed red line represents the overfished level, horizontal dashed black line represents F35

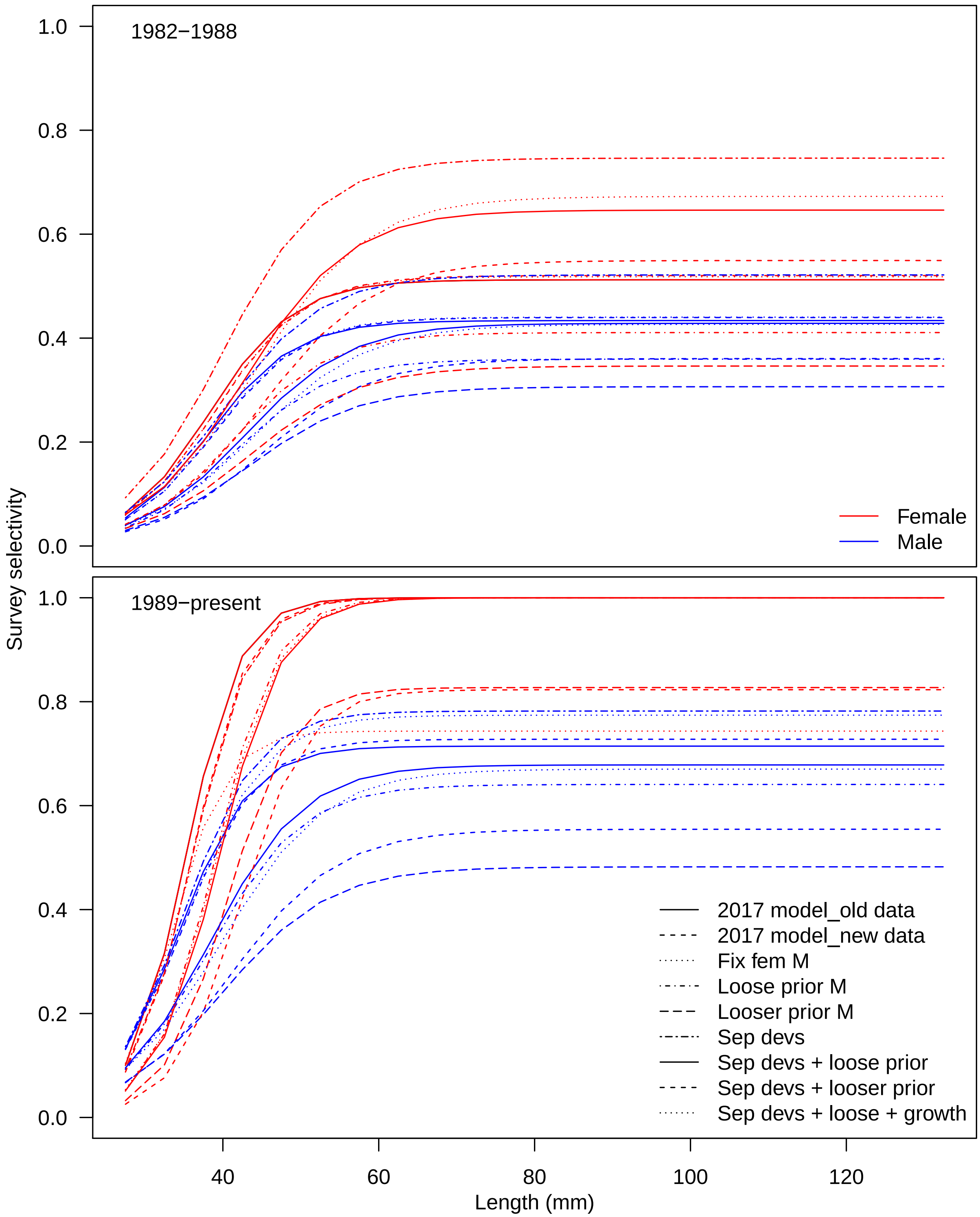

Figure 39: Estimated survey selectivity

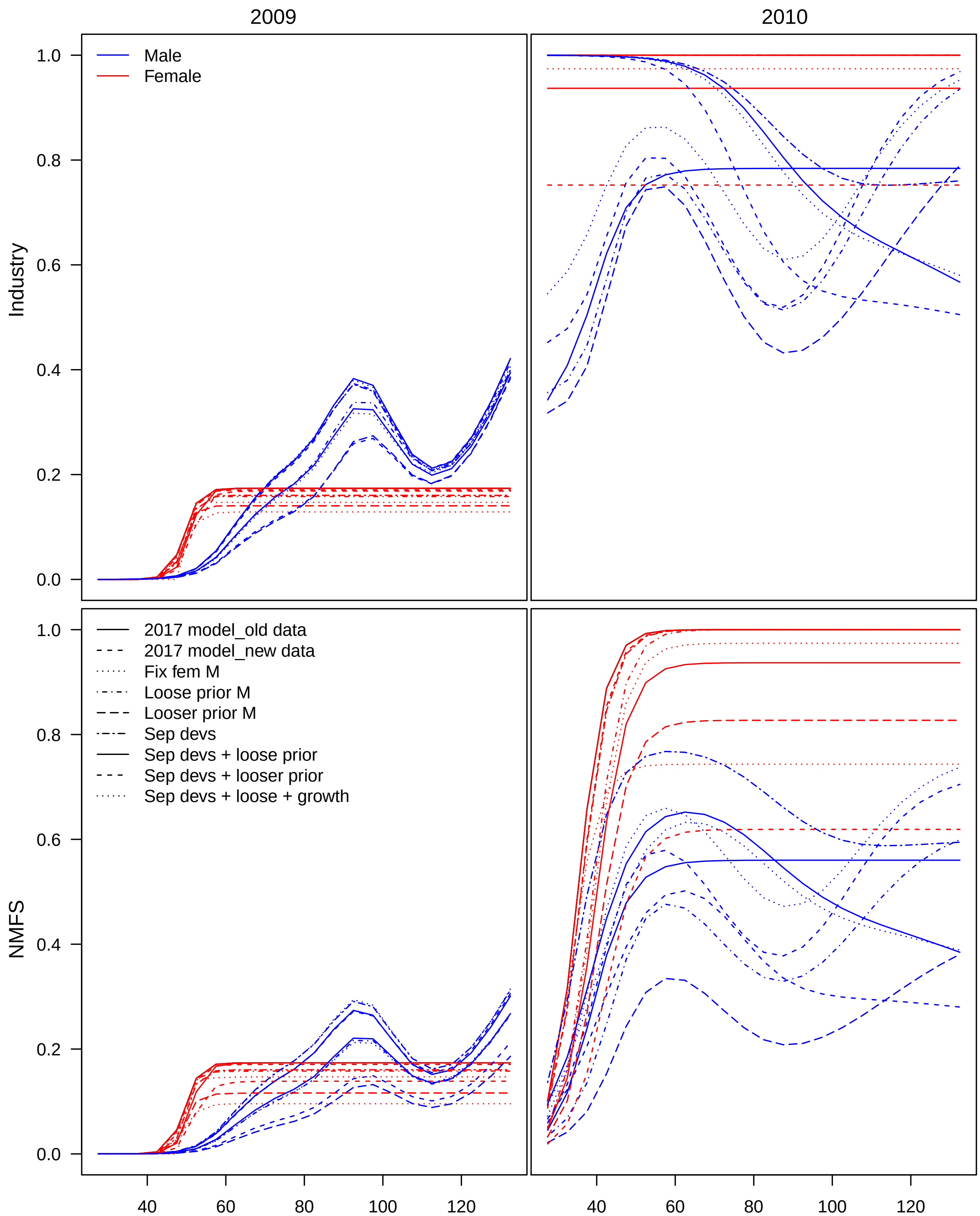

Figure 40: Estimated experimental survey selectivity (availability * survey selectivity)

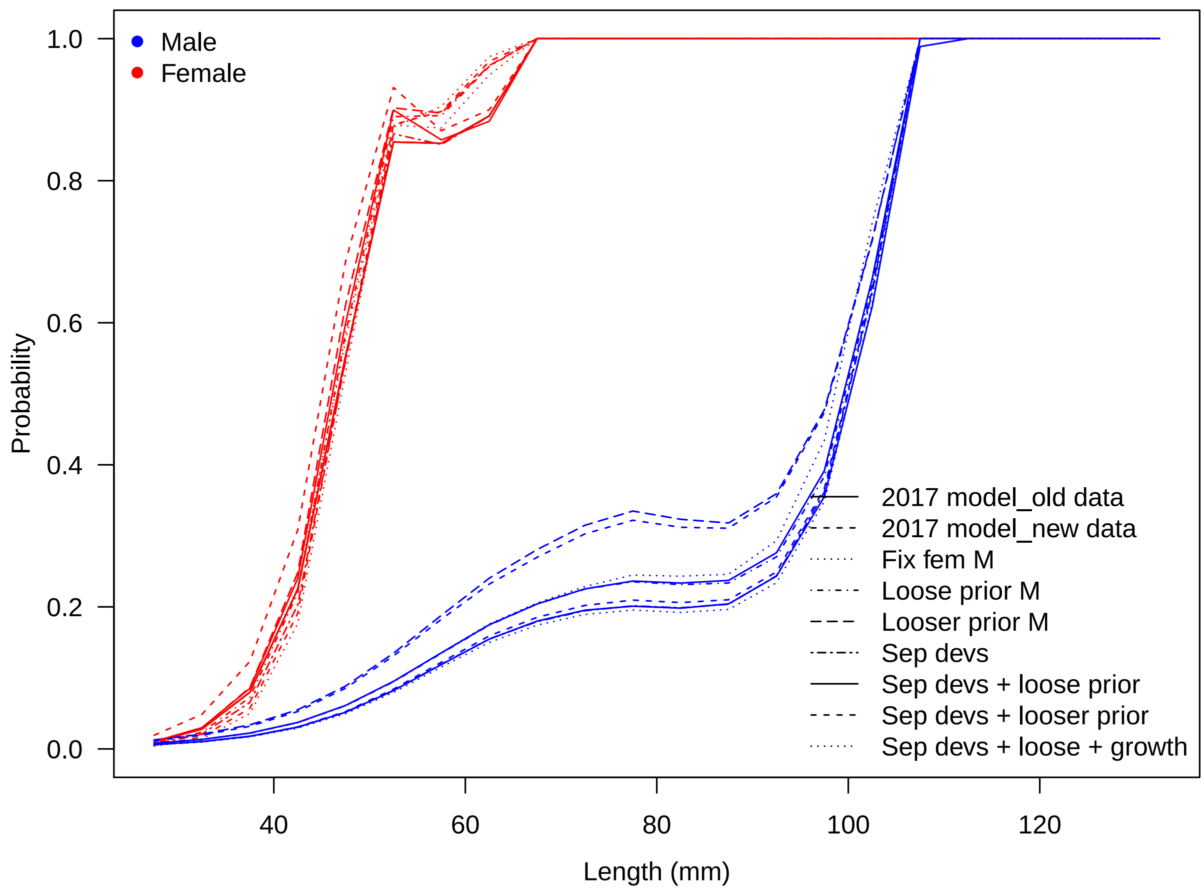

Figure 41: Estimated probability of maturing

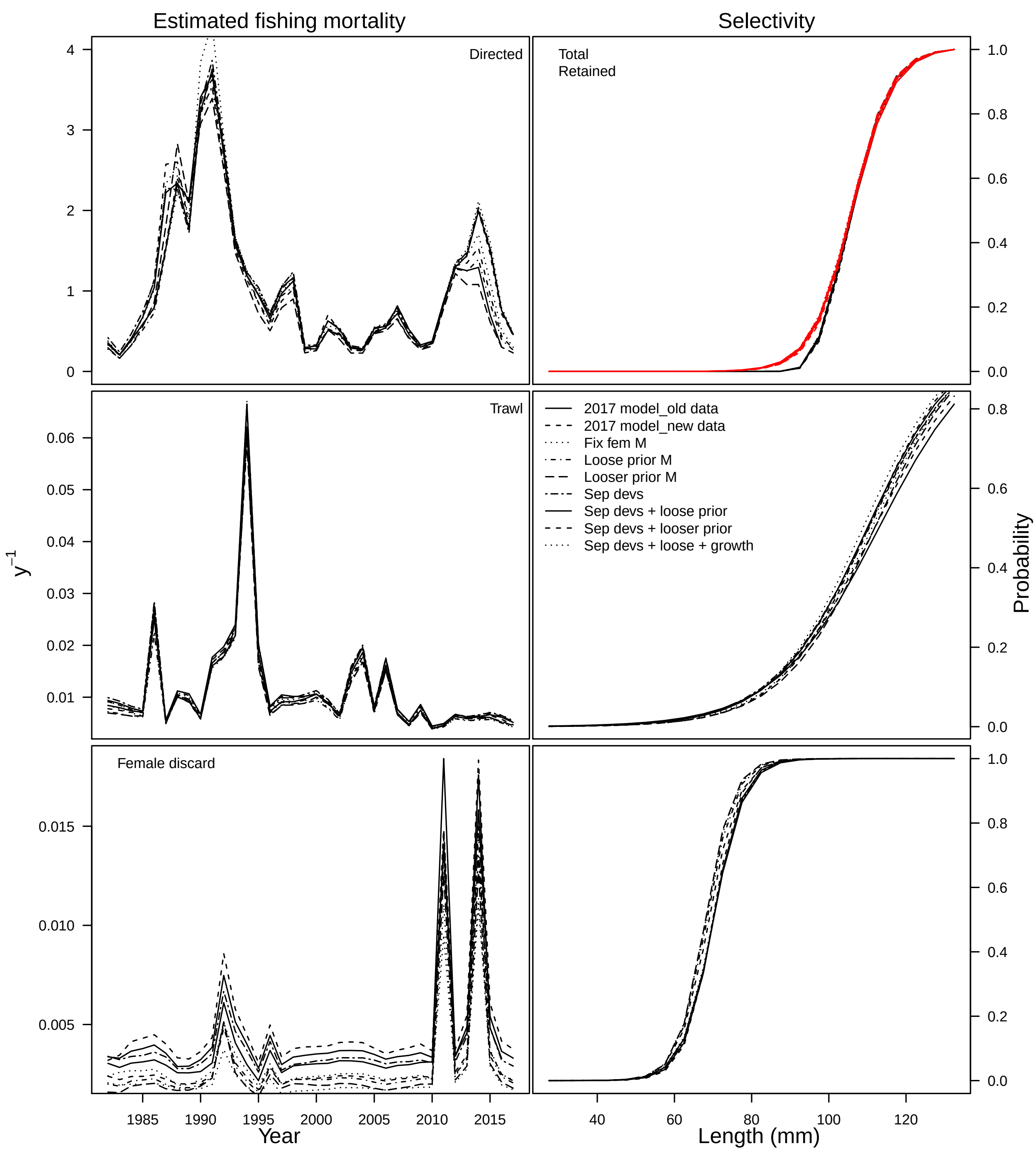

Figure 42: Model predicted fishing mortalities and selectivities for all sources of mortality

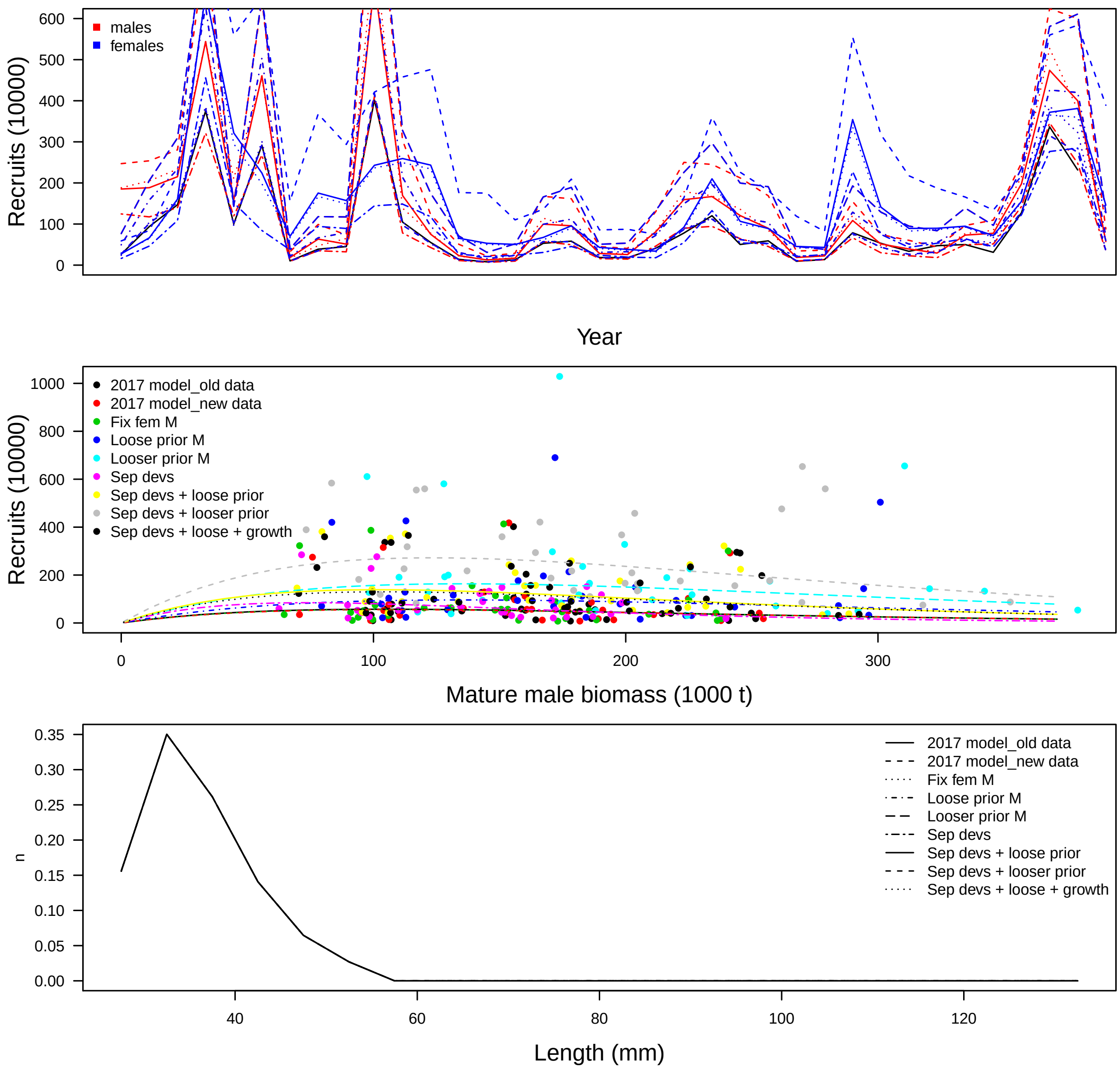

Figure 43: Estimated recruitment, fits to stock recruit curve (MMB lagged 5 years), and proportions recruiting to length bin

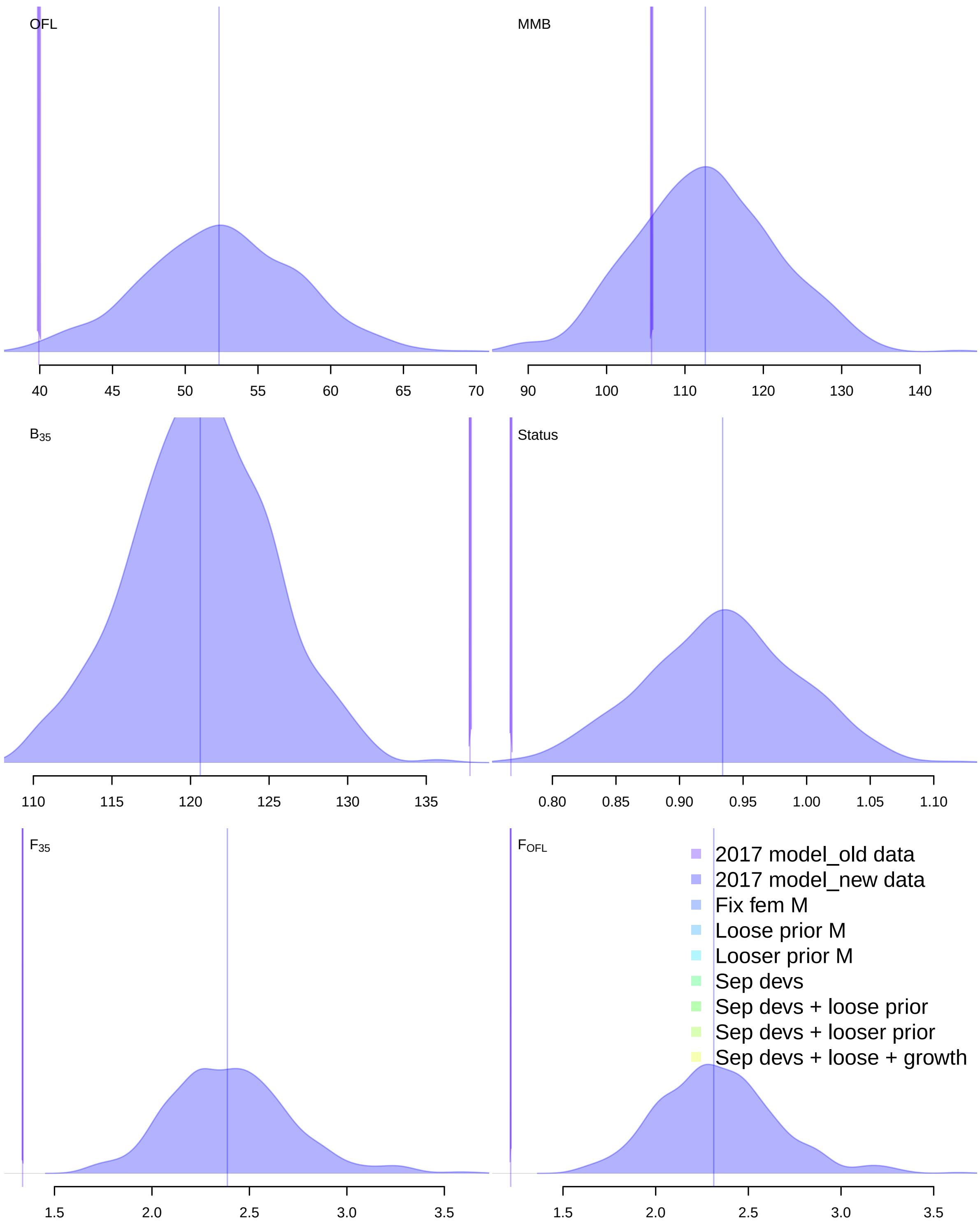

Figure 44: Posterior densities for management quantities by scenario

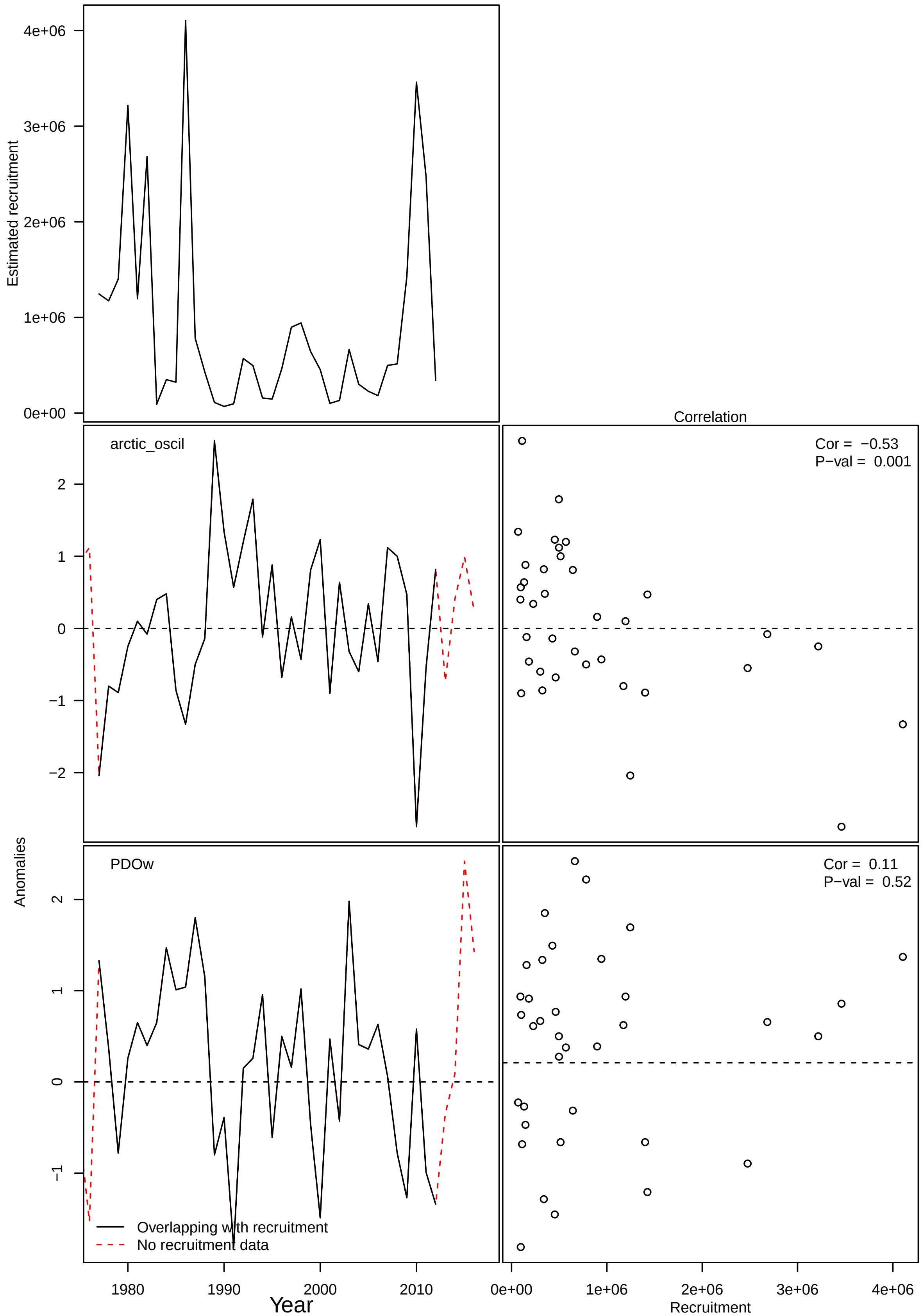

Figure 45: Comparison of estimated recruitment from the chosen model with the Pacific Decadal Oscillation and the Arctic Oscillation

BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN FALL 2018

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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 2017/18 was approximately 6.8 million lbs (3,094 t), below the catch in 2016/17 (8.5 million lbs). 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 1984-2018, only in 1984, 1986, 1995, 1999, 2002 and 2005 were estimated recruitments above the historical average for 1976-2018. Estimated recruitment was extremely low during the last ten years.
5. Management performance:

Status and catch specifications (1,000 t) (scenario 18.0a):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2014/15	13.03[A]	27.25[A]	4.49	4.54	5.41	6.82	6.14
2015/16	12.89[B]	27.68[B]	4.52	4.61	5.31	6.73	6.06
2016/17	12.53[C]	25.81[C]	3.84	3.92	4.35	6.64	5.97
2017/18	12.74[D]	24.86[D]	2.99	3.09	3.48	5.60	5.04
2018/19		20.80[D]				5.34	4.27

The stock was above MSST in 2017/18 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
2014/15	28.7[A]	60.1[A]	9.99	10.01	11.92	15.04	13.53
2015/16	28.4[B]	61.0[B]	9.97	10.17	11.71	14.84	13.36
2016/17	27.6[C]	56.9[C]	8.47	8.65	9.59	14.63	13.17
2017/18	28.1[D]	54.8[D]	6.60	6.82	7.67	12.35	11.11
2018/19		45.9[D]				11.76	9.41

Notes:
A – Calculated from the assessment reviewed by the Crab Plan Team in September 2015
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2016
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2017
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2018

6. Basis for the OFL: All table values are in 1000 t (Scenario 18.0a):

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

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

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

A. Summary of Major Changes

1. Change to management of the fishery: None.

2. Changes to the input data:

a. Updated summer trawl survey data and directed pot fisheries catch and bycatch data through 2018.

b. Updated groundfish fisheries bycatch data during 2013-2017.

3. Changes to the assessment methodology:

a. Correcting two coding errors that result in overweighting small size length composition data of NMFS surveys and underweighting BSFRF survey biomass. These two errors were discovered recently by Dr. Andre Punt while working on GMACS. Combinations of these two errors make the model fit the NMFS survey data a little better and fit the BSFRF data a little worse. Comparison of the model results with the errors and without the errors are showed in survey biomass fits and absolute mature male biomass. The two errors do not affect past TACs and fishery.

b. Estimated recruitment in the terminal year is not used for estimating $B_{35\%}$. That is, the mean recruitment from 1984-2017 is used for estimating $B_{35\%}$.

c. For the directed pot fishery, the model fits total observer male biomass and length compositions, instead of discarded male biomass and length compositions. Observers will not separate retained and discarded legal males in the directed pot fishery from now on.

d. Analyses of terminal year of recruitment and dynamic B_0 (see Appendix C).

e. Six model scenarios are compared in this report (See Section E.3.a for details):

Scenario 2b: the scenario 2b in the SAFE report in September 2017 with correction of the two errors mentioned in (a) above. This scenario 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. Also, groundfish fisheries bycatch is separated into trawl fisheries and fixed gear fisheries.

Scenario 2b-old: the scenario 2b in the SAFE report in September 2017 without two error corrections. The purpose to include this scenario is to compare it with scenario 2b to examine the impacts of the two errors on the results.

Scenario 18.0: renamed from scenario 2bn1 in May 2018 with some changes based on the requests of CPT and SSC and the same as scenario 2b except with differences: (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, and (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.

Scenario 18.0a: the same as scenario 18.0 except with equal annual effective sample sizes of male and female length compositions. Annual effective sample sizes with scenario 18.0 may be different between male and female length composition data.

Scenario 18.0b: renamed from scenario 2bn2 in May 2018 with some changes based on the requests of CPT and SSC and the same as scenario 18.0 except that only one logistic curve is estimated for all years for retained proportions and annual retention adjusted factors are estimated to modify retained proportions for years after 2004.

Scenario 18.0c: the same as scenario 18.0 except with the differences of total male selectivity and retained proportions in the directed pot fishery: (1) one logistic curve for total male selectivity is estimated with annual deviations of length at 50% selectivity parameter ($L_{50}^{dir,tot}$) and (2) another logistic curve is estimated for all years for retained proportions and for years after 2004 with annual deviations of length at 50% retained proportion parameter (L_{50}^{ret}). Similar to scenario 18.0b, after 2004, annual deviations are used to deal with annual high gradings

4. Changes to assessment results:

The population biomass estimates in 2018 are lower than those in 2017. Among the six scenarios, model estimated relative survey biomasses are very similar. The absolute mature male biomass estimates are higher for scenarios 18.0, 18.0a, 18.0b and 18.0c than for scenarios 2b and 2b-old during recent years. The model fits to BSFRF survey biomass are similar among six scenarios. The absolute mature male biomass estimates between scenarios 2b and 2b-old are very close: average relative error of -1.6% and average absolute relative error of 7.5%, and during the period covering the BSFRF survey data (2006-2017), relative errors ranging from -10.4% to 6.4%. Because of overweighting NMFS survey small length composition data and underweighting BSFRF survey biomass, scenario 2b-old fits the NMFS survey data better than other scenarios. We recommend scenario 18.0 or scenario 18.0a for overfishing definition for September 2018 because the results are hardly different among scenarios 18.0, 18.0a, 18.0b and 18.0c and these two scenarios have the least number of estimated parameters. Scenario 2b will be discontinued next year due to changes in data collection.

The recruitment breakpoint analysis (Appendix B) estimates 1986 as the breakpoint brood year, or 1992 recruitment year in May 2017. Terminal year recruitment analysis suggests the estimated recruitment in the last terminal year should not be used for estimating $B_{35\%}$.

B. Responses to SSC and CPT Comments

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

CPT and SSC Comments (from January and February 2018)
Conduct a dynamic B0 analysis and a retrospective analysis of terminal years of recruitment for the CPT meeting of May 2018.

Response: These two analyses are presented in this draft report (see retrospective results and Appendix C).

CPT comments (from January 2018)

"The CPT requested for the May 2018 meeting that assessment authors evaluate the impacts associated with discontinuing the collecting of information on legal retention status by crab observers. In addition, authors were encouraged to evaluate alternative discard calculations and/or suggest alternative methods for the determination of legal male retention status. It was also suggested that stock assessment authors outline for the CPT how legal not retained information is used or addressed in stock assessments."

Response: Four approaches (scenarios 18.0, 18.0a, 18.0b, and 18.0c) to deal with this issue are presented in this draft report.

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

Response to CPT Comments (from September 2017):

"Look at the weighting again for this assessment: it is still based on multiplicative lambda's."

Response: Corresponding CV values are provided for the lambda values in this SAFE report.

"The difficulties achieving convergence need to be explored: they are unexpected and concerning."

Response: Yes, it is a concern. At the September 2017 CPT meeting, Jack Turnock mentioned that he had similar problems with the snow crab model. This could be parameter confounding or initial value problems.

"Jittering initial parameter values was not used in this assessment, but may be useful in evaluating convergence issues."

Response: Agreed. We used jittering before and may use it in the future.

"The tensions in the assessment data leading to estimates of NMFS survey Q at 1 need to be identified and approaches to deal with them need to be developed."

Response: Correcting the error of underweighting BSFRF survey biomass help reducing estimated Q values somewhat. There may be several causes to explain this: (1) M and Q are confounded, (2) the sharp decline of abundance in the early 1980s may make estimated Q higher, and (3) few small crab were caught in the survey during the most recent 10 or more years, causing small estimated survey logistic curve values for the small size classes; for a given length, the overall selectivity value (combined catchability and logistic curve value) is Q times logistic curve value, not just Q.

In May 2018, we did several runs to explore Q values: (1) for scenario 2b, estimated Qs are 0.97, 0.95, and 0.93 with base M of 0.18, 0.22 and 0.3; (2) starting the model in 1985 for scenario 2b, resulting in scenario 2b85, Q is estimated as 0.91, which fits the BSFRF survey biomass very well (see the results for scenario 2b85 in this draft SAFE report); (3) starting the model in 1985 for scenario 2c with a fixed M of 0.18, resulting in scenario 2c85, Q is estimated as 0.92. These runs were with the error of underweighting BSFRF survey biomass. After correcting the error, estimated Q values would be smaller than the values here; for example, estimated Q value is 0.91 with scenario 2b in this report.

"The assessment document needs to be updated to reflect changes in the 2016 BSFRF estimate in the main section of text, not just in the Executive Summary."

Response: This was done in 2017 SAFE report.

"Provide an explanation of why Equation A4 (catch in the directed fishery) is correct (or correct it if it is wrong)."

Response: The equation A4 (below) is correct. It is a simple equation under the assumption of pulse fishing. Total abundance is reduced by natural mortality to the mid-point of the directed pot fishing and then total fishing mortality is applied to the remaining abundance to get catch. For females, it is female bycatch. For males, the retained catch and bycatch are then separated by their selectivity proportions. The Tanner crab fishery and groundfish fisheries are assumed to be pulse fishing and occur after the directed fishery.

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

Response to CPT Comments (from May 2018):

"1) fitting the total catch estimated from at-sea observer data and total retained catch without incorporating the "subtraction" method for estimating legal discards,"

Response: Done for scenarios 18.0, 18.0a, 18.0b and 18.0c.

"2) incorporating time varying fishery selectivity and annual retained proportions,"

Response: Scenarios 18.0, 18.0b and 18.0c address this.

"3) the recruitment in terminal year should not be used for estimating B35% (i.e., mean recruitment is estimated from recruitments from 1984 to endyear – 1)."

Response: Done for all scenarios.

Response to SSC Comments specific to this assessment (from October 2017):

"The SSC reiterates its request from June 2017 for the BBRKC author and CPT to objectively define the terminal year of recruitment to include in reference point calculations in this and other crab assessments, and again requests that the author use the breakpoint analysis applied for Tanner crab to BBRKC to evaluate whether there was a detectable break in production in 2006. The SSC looks forward to the outcomes of a more comprehensive discussion on this topic at the January 2018 CPT meeting."

Response: Analysis of terminal year of recruitment is included in this draft SAFE report. Based on the results, we recommend not including the recruitment in the most recent year. Breakpoint analysis was done in May 2017, which includes brood years only up to 2005. We will repeat the breakpoint analysis in May 2019 to detect brood year 2006 when we get one more data point.

"This assessment uses the number of lengths measured as a starting point for input sample sizes. The SSC recommends following the approach of other crab and groundfish stocks in using the number of stations or pots sampled as a better proxy for statistical sample size given the frequently very high correlation among individuals within a single sample."

Response: Right now for crab stocks, only the Aleutian Islands golden king crab model does not use the number of lengths measured as a starting point for input sample sizes. The golden king crab model uses only directed fishery length composition data, so it is easy for the model to use boat-days for a starting point for effective sample sizes. The Bristol Bay red king crab model includes length composition data from the trawl survey, directed pot fishery, Tanner crab fishery bycatch, groundfish trawl bycatch, and groundfish fixed gear bycatch. It is difficult to find measurement units of sample sizes that are comparable. The number of survey hauls will be almost constant over time, which is difficult to compare with number of pots, or boat-days, or trips. Snow and Tanner crab models have the same problem. Hopefully we can learn from the groundfish stock model approaches and find a better way to deal with sample sizes in the future.

"More research on catchability is needed, including review of existing camera work from BSFRF surveys that may shed light on crab behavior in response to trawl gear. The SSC provided some comments on new research using modifications of the BSFRF Model under the subsection "Crab Bycatch" earlier in this report."

Response: We agree with these suggestions for needed research. Analysis of camera work from BSFRF surveys will be helpful, especially on the herding effects of BSFRF surveys.

"The CPT suggested that large catches that drove the stock down in the early 1980s could drive the fits, resulting in an estimate of q near 1.0. On this basis, other evaluation of q could include investigating the effect of the period of historical decline (perhaps by down-weighting it) on more

recent estimates of catchability, or fitting a research model fit to BBRKC with only data after the stock collapse in the early 1980s."

"The SSC noted that historical modelling was conducted using relatively simple catch-survey analysis (Collie and Kruse 1998; Can. Spec. Publ. Fish. Aquat. Sci. 125: 73-83). This might provide another tool for exploring why current estimates of catchability are so close to 1.0."

Response: There may be several causes to explain Q value close to or higher than 1.0: (1) M and Q are confounded, (2) the sharp decline of abundance in the early 1980s may make estimated Q higher and (3) few small crab were caught in the survey during the most recent 10 or more years, causing small estimated survey logistic curve values for the small size classes; for a given length, the overall selectivity value (combined catchability and logistic curve value) is Q times logistic curve value, not just Q.

We did several runs to explore Q values in May 2018: (1) for scenario 2b, estimated Qs are 0.97, 0.95, and 0.93 with base M of 0.18, 0.22 and 0.3; (2) starting the model in 1985 for scenario 2b, resulting in scenario 2b85, Q is estimated as 0.91, which fits the BSFRF survey biomass very well (see the results for scenario 2b85 in this draft SAFE report); (3) starting the model in 1985 for scenario 2c with a fixed M of 0.18, resulting in scenario 2c85, Q is estimated as 0.92. After correcting the error that underweights BSFRF survey biomass, estimated Q values would be smaller than the values here; for example, estimated Q value is 0.91 with scenario 2b in this report.

The catch-survey analysis (Collie and Kruse 1998; Can. Spec. Publ. Fish. Aquat. Sci. 125: 73-83) is a simple way to explore Q and M relationships. With similar M values as our model, Q is estimated to be 0.95 by Collie and Kruse (1998); however, with a constant M of 0.36, Q is estimated to be 1.01.

"The SSC is also looking forward to continued development of the Gmacs model for BBRKC during 2018."

Response: We are looking forward to the day of moving over to GMACS too.

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

"to not use the subtraction method moving forward."

Response: Agree and no subtraction method from now on.

"The SSC also requests that the authors investigate whether groundfish discard information is available for fixed gear prior to 2010. In addition, the document uses inconsistent terminology for pot gear and fixed gear (particularly on figure and table headings), as well as groundfish gear versus crab gear, and the associated mortality rates. The SSC requests that the authors check the document for consistent use of these terms."

Response: We did some preliminary search on groundfish bycatch data and found that the data from 1991 to 2009 have been added to the NMFS database. During these years, fixed gear bycatch is an average of 22.6% of total groundfish bycatch. Due to time constraint, we will not separate groundfish bycatch into trawl and fixed gear bycatch before 2009 for this CPT meeting (September 2018) and will sort out these data and use them in the CPT meeting in May 2019.

We went through our SAFE report to check for consistent use of gear terms and corrected them as necessary.

C. Introduction

1. Species

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

2. General distribution

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

3. Stock Structure

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

4. Life History

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

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

5. Fishery

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

6. Fisheries Management

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

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

D. Data

1. Summary of New Information

The NMFS and BSFRF trawl survey data were updated to include the 2018 survey data.

Catch and biomass data were updated to 2017/18. Groundfish fisheries bycatch data during 2013-2017 were updated.

Data types and ranges are illustrated in Figure 2.

2. Catch Data

Data on landings of Bristol Bay RKC by length and year and catch per unit effort from 1960 to 1973 were obtained from annual reports of the International North Pacific Fisheries Commission (Hoopes et al. 1972; Jackson 1974; Phinney 1975) and from the ADF&G from 1974 to 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 1 and illustrated in Figure 2. Retained catch and estimated bycatch from the directed fishery include the general, open-access fishery (prior to rationalization), or the individual fishery quota (IFQ) fishery (after rationalization), as well as the Community Development Quota (CDQ) fishery and the ADF&G cost-recovery harvest. Starting in 1973, the fishery generally occurred during the late summer and fall. Before 1973, a small portion of retained catch in some years was caught from April to June. Because most crab bycatch from the groundfish trawl fisheries occurred during the spring, the years in Table 1 are one year less than those from the NMFS trawl bycatch database to approximate the annual bycatch for reporting years defined as July 1 to June 30; e.g., year 2002 in Table 1 for trawl bycatch corresponds to what is reported for year 2003 in the NMFS database. Catch biomass is shown in Figure 3. Bycatch data for the cost-recovery fishery before 2006 were not available. In this report, pot fisheries include both the directed fishery and RKC bycatch in the Tanner crab pot fishery and trawl fisheries are groundfish trawl fisheries.

(ii). Catch Size Composition

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

Japanese and U.S. fisheries. After 1969, foreign catch declined sharply and only length compositions from the U.S. fishery were used to distribute catch by length.

(iii). Catch per Unit Effort

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

3. NMFS Survey Data

The NMFS has performed annual trawl surveys of the eastern Bering Sea since 1968. Two vessels, each towing an eastern otter trawl with an 83 ft headrope and a 112 ft footrope, conducted this multispecies, crab-groundfish survey during the summer. Stations were sampled in the center of a systematic 20 X 20 nm grid overlaid in an area of ≈140,000 nm^2. Since 1972, the trawl survey has covered the full stock distribution except in nearshore waters. The survey in Bristol Bay occurs primarily during late May and June. Tow-by-tow trawl survey data for Bristol Bay RKC during 1975-2017 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). Spatial distributions of crab from the standard trawl surveys during recent years are shown in Appendix B. Until the late 1980s, NMFS used a post-stratification approach, but subsequently treated Bristol Bay as a single stratum; the estimates shown for Bristol Bay in Figures 4 and 5 were made without post-stratification. If multiple tows were made for a single station in a given year, the average of the abundances from all tows within that station was used as the estimate of abundance for that station. The new time series since 2015 discards all "hot spot" tows. We used the new area-swept estimates provided by NMFS in 2018.

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 density. The resurveys were necessary because a high proportion of mature females had not yet molted or mated when sampled by the standard survey. Differences in area-swept estimates of abundance between the standard surveys and resurveys of these same stations are attributed to survey measurement errors or to seasonal changes in distribution between survey and resurvey. More large females were observed in the resurveys than during the standard surveys in 1999 and 2000 because most mature females had not molted prior to the standard surveys. As in 2006, area-swept estimates of males >89 mm CL, mature males, and legal males within the 32 resurvey stations in 2007 were not significantly different (P=0.74, 0.74 and 0.95; paired t-test of sample means) between the standard survey and resurvey tows. However, similar to 2006, area-swept estimates of mature females within the 32 resurvey stations in 2007 were significantly different (P=0.03; paired t-test) between the standard survey and resurvey tows. Resurvey stations were close to shore during 2010-2012, and mature and legal male abundance estimates were lower for the re-tow than the standard survey. Following the CPT recommendation, we used the standard survey data for male abundance estimates and only the resurvey data, plus the standard survey data outside the resurveyed stations, to assess female abundances during these resurvey years.

4. Bering Sea Fisheries Research Foundation Survey Data

The BSFRF conducted trawl surveys for Bristol Bay RKC in 2007 and 2008 with a small-mesh trawl net and 5-minute tows. The surveys occurred at similar times as the NMFS standard surveys and covered about 97% of the Bristol Bay area. Few Bristol Bay RKC were found outside of the BSFRF survey area. Because of the small mesh size, the BSFRF surveys were expected to catch more of RKC within the swept area. Crab abundances of different size groups were estimated by the kriging method. Mature male abundances were estimated to be 22.331 in 2007 and 19.747 million in 2008 with respective CVs of 0.0634 and 0.0765. BSFRF also conducted 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. Total survey biomass decreased from 87,725.1 t initially estimated in September 2016 to 77,815.7 t in the final estimate in May 2017, about 11.3% reduction. The initial estimate mistakenly included the tows conducted in the recruitment study.

E. Analytic Approach

1. History of Modeling Approaches

To reduce annual measurement errors associated with abundance estimates derived from the area-swept method, ADF&G developed a length-based analysis (LBA) in 1994 that incorporates multiple years of data and multiple data sources in the estimation procedure (Zheng et al. 1995a). Annual abundance estimates of the Bristol Bay RKC stock from the LBA have been used to manage the directed crab fishery and to set crab bycatch limits in the groundfish fisheries since 1995 (Figure 1). An alternative LBA (research model) was developed in 2004 to include small size groups for federal overfishing limits. The crab abundance declined sharply during the early 1980s. The LBA estimated natural mortality for different periods of years, whereas the research model estimated additional mortality beyond a basic constant natural mortality during 1976-1993. In this report, we present only the research model that was fit to the data from 1975 to 2018.

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. Francis' approaches for re-weighting the effective sample sizes for size composition data are detailed in Appendix C.

a-f. See appendix A.

g. Critical assumptions of the model:

   i. The base natural mortality is constant 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 trawl bycatch selectivities, which are the same for both sexes. Two different survey selectivities were estimated: (1) 1975-1981 and (2) 1982-2018, based on modifications to the trawl gear used in the assessment survey.

   iii. Growth is a function of length and is assumed to not change over time for males. For females, growth-per-molt increments as a function of length were estimated for three periods (1975-1982, 1983-1993, and 1994-2018) based on sizes at maturity. Once mature, female red king crab grow with a much smaller growth increment per molt.

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

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

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

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

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

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

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

3. Model Selection and Evaluation

a. Alternative model configurations (scenarios):

2b: Scenario 2b is the same as scenario 2b in the SAFE draft report in September 2017 with correction of the two errors that result in overweighting small size length composition data of NMFS surveys and underweighting BSFRF survey biomass. This scenario 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. Also, groundfish fisheries bycatch is separated into trawl fisheries and fixed gear fisheries.

Scenario 2b includes:

(1) Base M = 0.18, with an additional mortality level during 1980-1984 for males and two additional mortality levels (one for 1980-1984 and the other for 1976-1979 and 1985-1993) for females. Additional mortalities are estimated in the model.

(2) Including BSFRF survey data during 2007-2008 and 2013-2016. The BSFRF survey is treated as an independent survey, and no assumption is made about the capture probabilities of the BSFRF survey. In effect, survey selectivities for both surveys are estimated separately in the model.

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

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

(5) Estimating effective sample size from observed sample sizes. Stage-1 effective sample sizes are estimated as min(0.5*n1, N) for trawl surveys and min(0.1* n1, N) for catch and bycatch, where n1 is an observed sample size for a sex, 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 a justification for enforcing a maximum limit to effective sample sizes because the number of length measurements is large (Fournier at al. 1998). The effective sample sizes are plotted against the implied effective sample sizes in Figures 6 and 7, where the implied effective sample sizes are estimated as follows:

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

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 retow data (during cold years) for females.

(7) Estimating initial year length compositions.

For scenario 2b, 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:

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

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

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

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.

Scenario 2b 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):

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

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

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

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

Since fishing times for both Tanner crab fishery and groundfish fishery are assumed to occur 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 $F_i = F_{tot}$.

2b-old: the scenario 2b in the SAFE report in September 2017 without two error corrections. The purpose to include this scenario is to compare it with scenario 2b to examine the impacts of the two errors on the results.

18.0: renamed from scenario 2bn1 in May 2018 with some changes based on the requests of CPT and SSC and the same as scenario 2b except with differences: (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, and (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.

18.0a: the same as scenario 18.0 except with equal annual effective sample sizes of male and female length compositions. Annual effective sample sizes with scenario 18.0 may be different between male and female length composition data. To maintain the same level of effective sample sizes with scenario 18.0, stage-1 effective sample sizes for scenario 18.0a 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, 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.

18.0b: renamed from scenario 2bn2 in May 2018 with some changes based on the requests of CPT and SSC and the same as scenario 18.0 except that only one logistic curve is estimated for all years for retained proportions and to deal with annual high gradings, annual adjusted factor parameter, x_t, is estimated for each year after 2004 and a logit transformation is used to make sure the adjusted factor, u_t, be <1.0:

$$u_t = \frac{e^{x_t}}{1+e^{x_t}} \tag{6}$$

Annual retained proportions after 2004 are estimated as:

$$S_{l,t}^{ret} = u_t \, S_l^{ret} \tag{7}$$

To avoid overfitting the data, a negative likelihood value is computed as:

$$\sum_t (u_t - 1.0)^2/(2\sigma^2) \tag{8}$$

where σ is the standard deviation of u_t and is assumed to be 0.1. The model results hardly change with either 0.1 or 0.2.

18.0c: the same as scenario 18.0 except with the differences of total male selectivity and retained proportions in the directed pot fishery: (1) one logistic curve for total male selectivity is estimated with annual deviations of length at 50% selectivity parameter ($devL_{50,t}^{dir,tot}$) and (2) another logistic curve is estimated for all years for retained proportions and for years after 2004 with annual deviations of length at 50% retained proportion parameter ($devL_{50,t}^{ret}$). Similar to scenario 18.0b, after 2004, annual deviations are used to deal with annual high gradings.

To avoid overfitting the data, a negative likelihood value is computed as:

$$0.1[first\ difference(devL_{50,t}^{dir,tot})]^2 + 0.1[first\ difference(devL_{50,t}^{ret})]^2 \tag{9}$$

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

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

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

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

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

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

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

i. Model evaluation is provided under Results, below.

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

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

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

with the final jittered starting parameter value backtransformed as:

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

where P_{max} and P_{min} are upper and lower bounds of parameters and P_{val} is the estimated parameter value before the jittering. Due to time constraints, the jittering approach is not used in this report.

4. Results

a. Effective sample sizes and weighting factors. Effective sample sizes and weighting factors.

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

ii. CVs are assumed to be 0.03 for retained catch biomass, and 0.07 for all bycatch biomasses, 0.53 for recruitment variation, and 0.23 for recruitment sex ratio.

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

b. Tables of estimates.

i. Parameter estimates for scenarios 18.0 and 18.0a are summarized in Tables 3-5.

ii. Abundance and biomass time series are provided in Table 6 for scenarios 18.0 and 18.0a.

iii. Recruitment time series for scenarios 18.0 and 18.0a 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 were very low due to low bycatch as well as handling mortality rates less than 1.0. Estimated recruits varied greatly from year to year (Table 6). Estimated selectivities for female pot bycatch were close to 1.0 for all mature females, and the estimated full fishing mortalities for female pot bycatch were lower than for male retained catch and bycatch (Table 5).

c. Graphs of estimates.

i. Selectivities and molting probabilities by length are provided in Figures 8 and 9 for scenarios 18.0, 18.0a, and 18.0c.

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

For all scenarios, estimated molting probabilities during 1975-2018 (Figure 9) were generally lower than those estimated from the 1954-1961 and 1966-1969 tagging data (Balsiger 1974). Lower molting probabilities mean more oldshell crab, possibly due to changes in molting probabilities over time or shell aging errors. Overestimates or underestimates of oldshell crab will result in lower or higher estimates of male molting probabilities.

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

Model estimated relative survey biomasses are very similar among the six scenarios and fit the survey data quite well. The absolute mature male biomass estimates are higher for scenarios 18.0, 18.0a, 18.0b and 18.0c than for scenarios 2b and 2b-old in recent years. The model fits to BSFRF survey biomass are similar among six scenarios. The absolute mature male biomass estimates between scenarios 2b and 2b-old are very close: average relative error of -1.6% and average absolute relative error of 7.5%, and during the period covering the BSFRF survey data (2006-2017), relative errors ranging from -10.4% to 6.4%. Because of overweighting NMFS survey small length composition data and underweighting BSFRF survey biomass, scenario 2b-old fits the NMFS survey data better than other scenarios. The two errors with scenario 2b-old do not affect past TACs and fishery.

Although the model did not fit the mature crab abundances directly, trends in the mature abundance estimates agree well with observed survey values except in 2014 and 2018 (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 scenarios have a similar trend over time (Figure 11).

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

iii. Estimated recruitment time series are plotted in Figure 12 for scenarios 18.0 and 18.0a.

iv. Estimated fishing mortality rates are plotted against mature male biomass in Figure 13 for scenarios 18.0 and 18.0a.

The average of estimated male recruits from 1984 to 2017 (Figure 12) and mature male biomass per recruit were used to estimate $B_{35\%}$. Alternative periods of 1976-present and 1976-1983 were compared in our report. The full fishing mortalities for the directed pot fishery at the time of fishing were plotted against mature male biomass on Feb. 15 (Figure 13). Estimated fishing mortalities in most years before the current harvest strategy was adopted in 1996 were above $F_{35\%}$ (Figure 13). Under the current harvest strategy, estimated fishing mortalities were at or above the $F_{35\%}$ limits in 1998-1999, 2005-2009 for scenarios 18.0 and 18.0a but below the $F_{35\%}$ limits in the other post-1995 years.

For scenario 18.0, estimated full pot fishing mortalities ranged from 0.00 to 2.41 during 1975-2017. Estimated values were greater than 0.40 during 1975-1982, 1984-1987, 1990-1991, 1993, 1998 and 2007-2008 (Table 5, Figure 13). For scenario 18.0a, estimated full pot fishing mortalities ranged from 0.00 to 2.36 during 1975-2017, with estimated values over 0.40 during 1975-1982, 1984-1987, 1990-1991, 1993, 1998, and 2007-2008 (Figure 13). Estimated fishing mortalities for pot female and groundfish fisheries bycatches were generally less than 0.06.

v. Estimated mature male biomass and recruitment are plotted to illustrate their relationships with scenario 18.0 (Figure 14a). Annual stock productivities are illustrated in Figure 14b.

Stock productivity (recruitment/mature male biomass) was generally lower during the last 20 years (Figure 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 were high in some years before 1990, but have been low since 1990 (Figure 15). The highest proportion of empty clutches (0.2) was in 1986, and primarily involved soft shell females (shell condition 1). Clutch fullness fluctuated annually around average levels during two periods: before 1991 and after 1990 (Figure 15). The average clutch fullness was similar for these two periods (Figure 15). 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 model (six scenarios) fit the fishery biomass data well and the survey biomass reasonably well (Figures 10 and 16). Because the model estimates annual fishing mortality for directed pot male catch, undirected pot male bycatch, pot female bycatch, 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). The model also fit the length proportions of the total pot males well with different approaches (Figure 21).

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

Standardized residuals of total survey biomass and proportions of length are plotted to examine their patterns. Residuals were calculated as observed minus predicted and standardized by the estimated standard deviation. Standardized residuals of total survey biomass did not show any consistent patterns (Figure 17). Standardized residuals of proportions of survey males appear to be random over length and year (Figure 25). There is an interesting pattern for residuals of proportions of survey females. Residuals were generally negative for large-sized mature females during 1975-1987 for scenarios 18.0 and 18.0a (Figure 26). Changes in growth over time or increased mortality may cause this pattern. The inadequacy of the model can be corrected by adding parameters to address these factors or with improved growth data.

e. Retrospective and historic analyses.

Two kinds of retrospective analyses were conducted for this report: (1) the 2018 model (scenario 18.0) hindcast results and (2) historical results. The 2018 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 2018 estimates as the baseline values, we can also evaluate how well the model had done in the past.

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

The performance of the 2018 model includes sequentially excluding one-year of data. The model with scenario 18.0 performed reasonably well during 2011-2017 with a lower terminal year estimates of mature male biomass in 2011-2013 and higher estimates in 2014-2016 (Figures 27-28).

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

The model first fit the data from 1985 to 2004 in the terminal year of 2004. Thus, sequentially incrementing the terminal year provided 10 historical assessments for comparison with the 2018 assessment model results (Figure 29). The main differences of the 2004 model were weighting factors and effective sample sizes for the likelihood functions. In 2004, the weighting factors were 1,000 for survey biomass, 2,000 for retained catch biomass and 200 for bycatch biomasses. The effective sample sizes were set to be 200 for all proportion data but weighting factors of 5, 2, and 1 were also respectively applied to retained catch proportions, survey proportions and bycatch proportions. Estimates of time series of abundance in 2004 were generally higher than those estimated after 2004 (Figure 29).

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

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

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

Overall, both historical results (historic analysis) and the 2018 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 2018 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 scenarios 18.0 and 18.0a. Estimated standard deviations of mature male biomass are listed in Table 6.

ii. Probabilities for trawl survey catchability *Q* are illustrated in Figure 30 for scenarios 18.0 and 18.0a using the mcmc approach; estimated *Q*s are less than 1.0. Probabilities for mature male biomass and OFL in 2018 are illustrated in Figure 31 for scenarios 18.0 and 18.0a 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 model scenarios

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

In this report (September 2018), six scenarios are compared. Model estimated relative survey biomasses are very similar among the scenarios. The absolute mature male biomass estimates are higher for scenarios 18.0, 18.0a, 18.0b and 18.0c than for scenarios 2b and 2b-old during recent years. The model fits to BSFRF survey biomass are similar among six scenarios. The absolute mature male biomass estimates between scenarios 2b and 2b-old are very close: average relative error of -1.6% and average absolute relative error of 7.5%, and during the period covering the BSFRF survey data (2006-2017), relative errors ranging from -10.4% to 6.4%. Because of overweighting NMFS survey small length composition data and underweighting BSFRF survey biomass, scenario 2b-old fits the NMFS survey data better than other scenarios. The two errors with scenario 2b-old do not affect past TACs and fishery.

We recommend scenario 18.0 or scenario 18.0a for overfishing determination for September 2018 because the results are hardly different among scenarios 18.0, 18.0a, 18.0b and 18.0c and these two scenarios have the least number of estimated parameters. Scenario 2b will be discontinued next year due to changes in data collection.

F. Calculation of the OFL and ABC

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

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

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

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

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

Where

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

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

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

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

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

Because trawl bycatch fishing mortality is not related to pot fishing mortality, average trawl bycatch fishing mortality during 2008 to 2017 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 1990-2017. Some discards of legal males occurred since the IFQ fishery started in 2005, but the discard rates were much lower during 2007-2013 than in 2005 after the fishing industry minimized discards of legal males. However, due to the high proportion of large oldshell males, the discard rate increased greatly in 2014. The average of retained selectivities and discard male selectivities during 2016-2017 are used to represent current trends for per recruit analysis and projections. Average molting probabilities during 2008-2017 are used for per recruit analysis and projections.

Average recruitments during three periods are used to estimate $B_{35\%}$: 1976-2017, 1984-2017, and 1991-2017 (Figure 12). Estimated $B_{35\%}$ is compared with historical mature male biomass in Figure 13a. We recommend using the average recruitment during 1984-present, corresponding to the 1976/77 regime shift. Note that recruitment period 1984-present has been used since 2011 to set the overfishing limits. Several factors support our recommendation. First, estimated recruitment was lower after 1983 than before 1984, which corresponded to brood years 1978 and later, after the 1976/77 regime shift. Second, high recruitments during the late 1960s and 1970s generally occurred when the spawning stock was primarily located in the southern Bristol Bay, whereas the current spawning stock is mainly in the middle of Bristol Bay. The current flows favor larvae hatched in the southern Bristol Bay (see the section on Ecosystem Considerations for SAFE reports in 2008 and 2009). Finally, stock productivity (recruitment/mature male biomass) was higher before the 1976/1977 regime shift.

If we believe that differences in productivity and other population characteristics before 1978 were caused by fishing, not by the regime shift, then we should use the recruitment from 1976-1983 (corresponding to brood years before 1978) as the baseline to estimate B35%. If we believe that the regime shift during 1976/77 caused the productivity differences, then we should select the recruitments from period 1984-2018 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 2018 is illustrated in Figure 30. Based SSC suggestion in 2011, ABC = 0.9*OFL. However, the CPT recommended ABC = 0.8*OFL in May 2018, which is used to estimate ABC in this report.

Status and catch specifications (1,000 t) (scenario 18.0a):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2014/15	13.03[A]	27.25[A]	4.49	4.54	5.41	6.82	6.14
2015/16	12.89[B]	27.68[B]	4.52	4.61	5.31	6.73	6.06
2016/17	12.53[C]	25.81[C]	3.84	3.92	4.35	6.64	5.97
2017/18	12.74[D]	24.86[D]	2.99	3.09	3.48	5.60	5.04
2018/19		20.80[D]				5.34	4.27

The stock was above MSST in 2017/18 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
2014/15	28.7[A]	60.1[A]	9.99	10.01	11.92	15.04	13.53
2015/16	28.4[B]	61.0[B]	9.97	10.17	11.71	14.84	13.36
2016/17	27.6[C]	56.9[C]	8.47	8.65	9.59	14.63	13.17
2017/18	28.1[D]	54.8[D]	6.60	6.82	7.67	12.35	11.11
2018/19		45.9[D]				11.76	9.41

Notes:

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2015
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2016
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2017
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2018

4. Based on the $B_{35\%}$ estimated from the average male recruitment during 1984-2017, the biological reference points and OFL are illustrated in Table 4.

5. Based on the CPT recommendation of 20% buffer rule in May 2018, ABC = 0.8*OFL (Table 4). If P*=49% is used, the ABC will be higher.

G. Rebuilding Analyses

NA.

H. Data Gaps and Research Priorities

1. The following data gaps exist for this stock:
    a. Information about changes in natural mortality in the early 1980s;
    b. Un-observed trawl bycatch in the early 1980s;
    c. Natural mortality;
    d. Crab availability to the trawl surveys;
    e. Juvenile crab abundance;
    f. Female growth per molt as a function of size and maturity;
    g. Changes in male molting probability over time.
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 1984-2018. Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2018. The 2018 abundance is randomly selected from the estimated normal distribution of the assessment model output for each replicate. Three scenarios of fishing mortality for the directed pot fishery 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 scenario is replicated 1,000 times and projections made over 10 years beginning in 2018 (Table 7).

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

2. Near Future Outlook

The near future outlook for the Bristol Bay RKC stock is a declining trend. The three recent above-average year classes (hatching years 1990, 1994, and 1997) had entered the legal population by 2006 (Figure 34). Most individuals from the 1997 year class will continue to gain weight to offset loss of the legal biomass to fishing and natural mortalities. The above-average year class (hatching year 2000) with lengths centered around 87.5 mm CL for both males and females in 2006 and with lengths centered around 112.5-117.5 mm CL for males and around 107.5 mm CL for females in 2008 has largely entered the mature male population in 2009 and the legal population by 2014 (Figure 34). No strong cohorts have been observed in the survey data after this cohort through 2010 (Figure 34). There was a huge tow of juvenile crab of size 45-55 mm in 2011, but these juveniles were not tracked during 2012-2018 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 2015-2018 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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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			597.8			3948.9
1989	4656.0		0	4656.0			174.1			4830.1
1990	9236.2	36.6	0	9272.8	526.9	651.5	247.6			10698.7
1991	7791.8	93.4	0	7885.1	407.8	75.0	316.0		1401.8	10085.7
1992	3648.2	33.6	0	3681.8	552.0	418.5	335.4		244.4	5232.2
1993	6635.4	24.1	0	6659.6	763.2	637.1	426.6		54.6	8541.0
1994	0.0	42.3	0	42.3	3.8	1.9	88.9		10.8	147.8
1995	0.0	36.4	0	36.4	3.3	1.6	194.2		0.0	235.5
1996	3812.7	49.0	0	3861.7	164.6	1.0	106.5		0.0	4133.9
1997	3971.9	70.2	0	4042.1	244.7	19.6	73.4		0.0	4379.8
1998	6693.8	85.4	0	6779.2	959.7	864.9	159.8		0.0	8763.7
1999	5293.5	84.3	0	5377.9	314.2	8.8	201.6		0.0	5902.4
2000	3698.8	39.1	0	3737.9	360.8	40.5	100.4		0.0	4239.5
2001	3811.5	54.6	0	3866.2	417.9	173.5	164.6		0.0	4622.1
2002	4340.9	43.6	0	4384.5	442.7	7.3	155.1		0.0	4989.6
2003	7120.0	15.3	0	7135.3	918.9	430.4	172.3		0.0	8656.9
2004	6915.2	91.4	0	7006.7	345.5	187.0	119.6		0.0	7658.8

2005	8305.0	94.7	0	8399.7	1359.5	498.3	155.2		0.0	10412.8
2006	7005.3	137.9	0	7143.2	563.8	37.0	116.7		3.8	7864.4
2007	9237.9	66.1	0	9303.9	1001.3	186.1	138.5		1.8	10631.6
2008	9216.1	0.0	0	9216.1	1165.5	148.4	159.5		4.0	10693.5
2009	7226.9	45.5	0	7272.5	888.1	85.2	94.8	5.8	1.6	8348.1
2010	6728.5	33.0	0	6761.5	797.5	122.6	83.3	2.4	0.0	7767.3
2011	3553.3	53.8	0	3607.1	395.0	24.0	56.3	10.9	0.0	4093.2
2012	3560.6	61.1	0	3621.7	205.2	12.3	34.2	18.4	0.0	3891.9
2013	3901.1	89.9	0	3991.0	310.6	99.8	66.8	55.5	28.5	4552.1
2014	4530.0	8.6	0	4538.6	584.7	86.2	34.7	118.8	42.0	5405.0
2015	4522.3	91.4	0	4613.7	266.1	222.9	46.3	77.3	84.2	5310.6
2016	3840.4	83.4	0	3923.9	237.4	87.1	71.0	29.3	0.0	4348.6
2017	2994.1	99.6	0	3093.7	225.2	53.3	97.4	11.0	0.0	3480.6

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	

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 Bycatch		Trawl & Fixed Gear Bycatch		Tanner Fishery Bycatch	
	Males	Females		Males	Females	Males	Females	Males	Females
1975	2,943	2,139	29,570						
1976	4,724	2,956	26,450			2,327	676		
1977	3,636	4,178	32,596			14,014	689		
1978	4,132	3,948	27,529			8,983	1,456		
1979	5,807	4,663	27,900			7,228	2,821		
1980	2,412	1,387	34,747			47,463	39,689		
1981	3,478	4,097	18,029			42,172	49,634		
1982	2,063	2,051	11,466			84,240	47,229		
1983	1,524	944	0			204,464	104,910		
1984	2,679	1,942	4,404			357,981	147,134		
1985	792	415	4,582			169,767	30,693		
1986	1,962	367	5,773			1,199	284		
1987	1,168	1,018	4,230			723	927		
1988	1,834	546	9,833			437	275		
1989	1,257	550	32,858			3,147	194		
1990	858	603	7,218	873	699	761	1,570		
1991	1,378	491	36,820	1,801	375	208	396	885	2,198
1992	513	360	23,552	3,248	2,389	214	107	280	685
1993	1,009	534	32,777	5,803	5,942			232	265
1994	443	266	0	0	0	330	247		
1995	2,154	1,718	0	0	0	103	35		
1996	835	816	8,896	230	11	1,025	968		
1997	1,282	707	15,747	4,102	906	1,202	483		
1998	1,097	1,150	16,131	11,079	9,130	1,627	915		
1999	764	540	17,666	1,048	36	2,154	858		
2000	731	1,225	14,091	8,970	1,486	994	671		
2001	611	743	12,854	9,102	4,567	4,393	2,521		
2002	1,032	896	15,932	9,943	302	3,372	1,464		
2003	1,669	1,311	16,212	17,998	10,327	1,568	1,057		
2004	2,871	1,599	20,038	8,258	4,112	1,689	1,506		
2005	1,283	1,682	21,938	55,019	26,775	1,815	1,872		
2006	1,171	2,672	18,027	32,252	3,980	1,481	1,983		
2007	1,219	2,499	22,387	59,769	12,661	1,011	1,097		
2008	1,221	3,352	14,567	49,315	8,488	1,867	1,039		
2009	830	1,857	16,708	52,359	6,041	1,431	848		
2010	705	1,633	20,137	36,654	6,868	612	837		
2011	525	994	10,706	20,629	1,920	563	1,068		
2012	580	707	8,956	7,206	561	1,507	1,751		
2013	633	560	10,197	13,828	6,048	4,806	4,198	218	596
2014	1,106	1,255	9,618	13,040	1,950	2,027	2,602	256	381
2015	600	677	11,746	8,037	5,889	1,267	3,753	726	2163
2016	374	803	10,811	9,497	4,216	1,977	3,035		
2017	470	558	9,867	12,511	3,725	1,001	1,145		
2018	384	420							

Table 3. Number of parameters and the list of likelihood components for the model (Scenarios 2b,18.0, 18.0a, 18.0b, and 18.0c).

Parameter counts	**Sce. 2b**	**Sce. 18.0 & 18.0a**	**Sce. 18.0b**	**Sce. 18.0c**
Fixed growth parameters	9	9	9	9
Fixed recruitment parameters	2	2	2	2
Fixed length-weight relationship parameters	6	6	6	6
Fixed mortality parameters	4	4	4	4
Fixed survey catchability parameter	1	1	1	1
Fixed high grading parameters	13	0	0	0
Total number of fixed parameters	35	22	22	22
Free survey catchability parameter	1	1	1	1
Free growth parameters	6	6	6	6
Initial abundance (1975)	1	1	1	1
Recruitment-distribution parameters	2	2	2	2
Mean recruitment parameters	1	1	1	1
Male recruitment deviations	43	43	43	43
Female recruitment deviations	43	43	43	43
Natural and fishing mortality parameters	4	4	4	4
Pot male fishing mortality deviations	44	44	44	44
Bycatch mortality from the Tanner crab fishery	11	11	11	11
Pot female bycatch fishing mortality deviations	29	29	29	29
Trawl bycatch fishing mortality deviations	43	43	43	43
Fixed gear bycatch fishing mortality deviations	10	10	10	10
Initial (1975) length compositions	35	35	35	35
BSFRF survey extra CV	1	1	1	1
Free selectivity parameters	24	25	37	81
Total number of free parameters	298	299	311	355
Total number of fixed and free parameters	333	321	333	377

Table 4. Negative log likelihood components for scenarios 2b, 18.0, 18.0a, 18.0b, and 18.0c and some management quantities.

Scenario

Negative log likelihood	18.0	18.0a	18.0b	18.0c	2b	18.0-18.0b	18.0-18.0c	18.0-2b	18.0b-18.0c
R-variation	65.0	64.7	65.6	65.8	65.6	-0.54	-0.77	-0.55	-0.23
Length-like-retained	-1109.7	-1109.7	-1104.3	-1124.5	-1102.6	-5.43	14.77	-7.15	20.20
Length-like-tot/dis male	-1273.8	-1274.2	-1274.9	-1296.9	-1133.1	1.11	23.07	-140.71	21.96
Length-like-discfemale	-859.4	-859.4	-854.9	-854.7	-845.0	-4.49	-4.70	-14.41	-0.22
Length-like-survey	-5096.2	-5097.4	-5096.7	-5098.4	-5070.7	0.54	2.23	-25.48	1.69
Length-like-disctrawl	-3918.1	-3935.9	-3922.1	-3926.5	-3913.2	3.98	8.37	-4.89	4.39
Length-like-discfix	-880.6	-887.4	-881.2	-879.6	-878.2	0.63	-1.01	-2.34	-1.63
Length-like-discTanner	-480.5	-491.8	-480.4	-480.4	-477.4	-0.18	-0.10	-3.13	0.07
Length-like-bsfrfsurvey	-649.7	-650.7	-649.8	-650.2	-644.9	0.15	0.52	-4.76	0.37
Catchbio_retained	16.7	16.7	14.6	9.2	27.5	2.11	7.55	-10.83	5.44
Catchbio_tot/discmale	58.2	58.4	48.1	21.7	135.8	10.11	36.44	-77.67	26.33
Catchbio-discfemale	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
Catchbio-disctrawl	0.0	0.0	0.0	0.0	0.0	0.00	0.00	-0.01	0.00
Catchbio-discfix	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
Catchbio-discTanner	0.0	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00
Biomass-trawl survey	115.3	115.9	115.2	116.9	112.4	0.10	-1.59	2.84	-1.69
Biomass-bsfrfsurvey	-10.8	-10.9	-10.9	-11.1	-10.0	0.18	0.38	-0.81	0.20
Q-trawl survey	0.7	0.7	0.6	0.9	0.2	0.07	-0.20	0.48	-0.26
Others	18.1	18.1	22.1	19.6	18.0	-4.03	-1.45	0.13	2.58
Total	-14005	-14043	-14009	-14088	-13715	4.30	83.50	-289.30	79.20
Free parameters	299	299	311	368	298	-12	-69	1	-57
B35%(t)	25540	25479	25514	25920	24910	26.30	-380.10	630.40	-406.40
F35%	0.31	0.31	0.32	0.30	0.30	-0.01	0.01	0.01	0.02
MMB2018(t)	20617	20804	20581	20940	19820	35.60	-323.70	797.00	-359.30
OFL2018	5207	5336	5137	5236	4789	69.88	-28.77	417.78	-98.65
ABC2018(t)	4166	4269	4110	4189	3831	55.90	-23.02	334.22	-78.92
Fofl2018	0.244	0.247	0.251	0.236	0.232	-0.01	0.01	0.01	0.02
Q	0.925	0.925	0.923	0.929	0.911	0.00	0.00	0.01	-0.01

Table 5(18.0). Summary of estimated model parameter values and standard deviations and limits for scenario 18.0 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	15.965	0.034	15.965	0.034	-1.570	0.042	0.012	0.001	-4.484	0.078

Limits↑	13,18		13,18		-3.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-10,2.43		-6.0,3.5		-10,10	
1975					0.780	0.135				
1976	0.083	0.597	0.480	0.393	0.737	0.096			0.165	0.128
1977	0.550	0.438	0.510	0.260	0.656	0.075			0.629	0.118
1978	0.519	0.396	0.765	0.217	0.805	0.062			0.663	0.112
1979	0.746	0.297	1.135	0.199	1.093	0.056			0.821	0.110
1980	0.248	0.306	1.609	0.174	2.005	0.056			1.610	0.110
1981	0.012	0.370	0.992	0.243	2.425	0.013			1.295	0.110
1982	0.012	0.155	2.335	0.109	0.780	0.089			2.481	0.114
1983	0.041	0.238	1.436	0.139	-9.995	0.029			2.120	0.111
1984	0.655	0.177	1.065	0.123	0.885	0.090			3.219	0.114
1985	-0.268	0.428	-0.304	0.208	0.927	0.098			1.998	0.114
1986	0.742	0.177	0.334	0.124	1.237	0.077			0.988	0.113
1987	-0.039	0.392	-0.422	0.183	0.826	0.068			0.578	0.111
1988	-0.065	0.448	-0.932	0.212	-0.069	0.056			1.388	0.106
1989	-0.094	0.341	-0.580	0.166	0.060	0.050			-0.030	0.105
1990	0.307	0.183	0.073	0.118	0.753	0.045	1.988	0.089	0.396	0.105
1991	0.138	0.239	-0.239	0.137	0.749	0.047	-0.618	0.089	0.768	0.106
1992	-0.536	0.478	-1.243	0.234	0.174	0.052	2.141	0.091	0.838	0.107
1993	-0.192	0.287	-0.513	0.151	0.920	0.059	1.920	0.095	1.315	0.111
1994	-0.113	0.478	-1.227	0.242	-4.201	0.056	1.254	0.122	-0.500	0.107
1995	0.053	0.095	1.164	0.072	-4.622	0.046	1.408	0.123	0.058	0.105
1996	-0.999	0.455	-0.604	0.245	-0.076	0.045	-3.702	0.140	-0.574	0.105
1997	-0.894	0.453	-0.887	0.234	0.017	0.047	-0.389	0.088	-0.954	0.105
1998	-0.577	0.327	-0.104	0.151	0.823	0.052	1.495	0.088	-0.067	0.106
1999	0.065	0.158	0.625	0.100	0.421	0.049	-2.778	0.095	0.083	0.105
2000	-0.126	0.366	-0.307	0.193	-0.178	0.047	1.133	0.084	-0.778	0.105
2001	0.116	0.368	-0.352	0.205	-0.232	0.046	0.817	0.084	-0.387	0.104
2002	0.419	0.132	0.906	0.096	-0.110	0.046	-1.972	0.089	-0.505	0.104
2003	-0.415	0.472	-0.410	0.242	0.354	0.044	1.122	0.083	-0.390	0.104
2004	-0.248	0.387	-0.141	0.197	0.336	0.045	0.328	0.084	-0.760	0.104
2005	0.076	0.160	0.874	0.095	0.636	0.048	0.820	0.085	-0.457	0.104
2006	-0.189	0.289	0.237	0.138	0.411	0.047	-1.404	0.085	-0.782	0.104
2007	-0.492	0.334	-0.096	0.151	0.698	0.047	-0.272	0.084	-0.594	0.104
2008	-0.059	0.372	-0.693	0.201	0.820	0.051	-0.517	0.086	-0.417	0.104
2009	0.366	0.304	-0.491	0.181	0.555	0.051	-0.695	0.086	-0.983	0.105
2010	0.390	0.227	0.092	0.122	0.355	0.050	-0.225	0.086	-1.178	0.105
2011	0.368	0.286	-0.252	0.157	-0.350	0.049	-1.117	0.087	-1.672	0.106
2012	-0.032	0.354	-0.511	0.169	-0.417	0.049	-1.775	0.089	-2.222	0.108
2013	-0.325	0.342	-0.596	0.159	-0.285	0.051	0.253	0.085	-1.560	0.107
2014	-0.224	0.446	-1.233	0.220	-0.072	0.053	-0.277	0.087	-2.185	0.110
2015	0.132	0.333	-0.900	0.203	-0.059	0.058	0.852	0.089	-1.863	0.111
2016	0.120	0.314	-0.585	0.205	-0.183	0.064	0.317	0.092	-1.406	0.112
2017	-0.174	0.452	-0.892	0.261	-0.383	0.069	-0.106	0.095	-1.149	0.114
2018	-0.095	0.421	-0.120	0.295						

Table 5(18.0) (continued). Summary of estimated model parameter values and standard deviations and limits for scenario 18.0 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	0.512	0.031	0.184, 1.0	68	1.015	0.421	-5, 5
Mf80-84	0.815	0.041	0.276, 1.5	73	0.662	0.602	-5, 5
Mf76-79,85-93	0.088	0.012	0.0, 0.108	78	0.465	0.456	-5, 5

log_betal, females	0.552	0.133	-0.67, 1.32	83	0.688	0.299	-5, 5
log_betal, males	-0.146	0.240	-0.67, 1.32	88	0.554	0.277	-5, 5
log_betar, females	-0.396	0.219	-1.14, 0.5	93	0.439	0.275	-5, 5
log_betar, males	-0.574	0.167	-1.14, 0.5	98	0.454	0.260	-5, 5
Bsfrf_CV	0.088	0.055	0.00, 0.40	103	0.322	0.275	-5, 5
moltp_slope, 75-78	0.110	0.018	0.01, 0.259	108	0.404	0.259	-5, 5
moltp_slope, 79-18	0.093	0.006	0.01, 0.259	113	0.457	0.253	-5, 5
log_moltp_L50, 75-78	4.954	0.013	4.445, 5.52	118	0.239	0.293	-5, 5
log_moltp_L50, 79-18	4.940	0.005	4.445, 5.52	123	0.243	0.287	-5, 5
log_N75	19.919	0.052	15.0, 22.0	128	0.097	0.315	-5, 5
log_avg_L50_tot	4.767	0.011	4.38, 5.45	133	0.239	0.266	-5, 5
tot_fish_slope	0.101	0.006	0.05, 0.57	138	0.034	0.199	-5, 5
Log_ret_L50, 75-04	4.921	0.002	4.6, 5.1	143	-0.228	0.195	-5, 5
Ret_fish_slope, 75-04	0.496	0.034	0.05, 0.87	148	-0.408	0.201	-5, 5
Log_ret_L50, 05-18	4.930	0.003	4.6, 5.1	153	-0.777	0.228	-5, 5
Ret_fish_slope, 05-18	0.494	0.065	0.05, 0.7	158	-1.307	0.287	-5, 5
pot disc.fema., slope	0.085	0.014	0.05, 0.43	163	-1.355	0.290	-5, 5
log_pot disc.fema., L50	4.556	0.040	4.20, 4.666	68	1.686	0.391	-5, 5
trawl disc slope	0.057	0.003	0.01, 0.20	73	1.461	0.431	-5, 5
log_trawl disc L50	5.195	0.077	4.50, 5.40	78	1.367	0.363	-5, 5
log_srv_L50, m, bsfrf	4.345	0.039	3.359, 5.48	83	1.165	0.331	-5, 5
srv_slope, f, bsfrf	0.041	0.009	0.01, 0.134	88	1.108	0.279	-5, 5
log_srv_L50, f, bsfrf	4.491	0.061	3.471, 5.539	93	0.716	0.311	-5, 5
log_srv_L50, m, 75-81	4.349	0.027	3.551, 5.864	98	0.350	0.372	-5, 5
srv_slope, f, 75-81	0.102	0.013	0.01, 0.303	103	0.131	0.411	-5, 5
log_srv_L50, f, 75-81	4.434	0.026	3.709, 4.80	108	-0.024	0.413	-5, 5
log_srv_L50, m, 82-18	4.092	0.283	3.709, 5.10	113	-0.217	0.443	-5, 5
srv_slope, f, 82-18	0.073	0.021	0.01, 0.43	118	-0.805	0.657	-5, 5
log_srv_L50, f, 82-18	4.170	0.083	3.709, 4.90	123	-0.992	0.732	-5, 5
TC_slope, females	0.344	0.103	0.02, 0.40	128	-1.296	0.871	-5, 5
log_TC_L50, females	4.530	0.014	4.24, 4.90	133	-2.346	1.906	-5, 5
TC_slope, males	0.211	0.079	0.05, 0.90	138	-2.640	2.281	-5, 5
log_TC_L50, males	4.569	0.022	4.25, 5.14	143	NA	NA	
Q	0.925	0.022	0.59, 1.2	Fixed gear bycatch parameters:			
log_TC_F, males, 91	-3.949	0.092	-10.0, 1.00	log_avg_f	-8.146	0.079	-8.5, -0.5
log_TC_F, males, 92	-5.915	0.094	-10.0, 1.00	fmortf_09	-1.276	0.112	-10, 10
log_TC_F, males, 93	-6.613	0.099	-10.0, 1.00	fmortf_10	-2.157	0.132	-10, 10
log_TC_F, males, 13	-8.314	0.093	-10.0, 1.00	fmortf_11	-0.643	0.104	-10, 10
log_TC_F, males, 14	-7.460	0.091	-10.0, 1.00	fmortf_12	-0.117	0.101	-10, 10
log_TC_F, males, 15	-7.049	0.093	-10.0, 1.00	fmortf_13	0.991	0.097	-10, 10
log_TC_F, females, 91	-2.897	0.098	-10.0, 1.00	fmortf_14	1.788	0.097	-10, 10
log_TC_F, females, 92	-4.540	0.101	-10.0, 1.00	fmortf_15	1.413	0.098	-10, 10
log_TC_F, females, 93	-6.441	0.104	-10.0, 1.00	fmortf_16	0.504	0.100	-10, 10
log_TC_F, females, 13	-7.761	0.092	-10.0, 1.00	fmortf_17	-0.503	0.106	-10, 10
log_TC_F, females, 14	-7.624	0.092	-10.0, 1.00	Fix_slo	0.093	0.020	0, 0.2
log_TC_F, females, 15	-6.602	0.090	-10.0, 1.00	log_l50	4.656	0.035	4.5, 5.4

Table 5(18.0a). Summary of estimated model parameter values and standard deviations and limits for scenario 18.0a 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	15.968	0.034	15.968	0.034	-1.570	0.042	0.012	0.001	-4.465	0.079
Limits↑	13,18		13,18		-3.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-15,2.43		-6.0,3.5		-10,10	
1975					0.779	0.135				
1976	0.094	0.593	0.483	0.390	0.738	0.096			0.166	0.129
1977	0.554	0.434	0.508	0.260	0.657	0.075			0.629	0.118

1978	0.520	0.392	0.764	0.217	0.806	0.062			0.662	0.112
1979	0.744	0.296	1.133	0.199	1.094	0.056			0.820	0.110
1980	0.245	0.304	1.608	0.173	2.006	0.056			1.611	0.110
1981	0.019	0.367	0.990	0.242	2.425	0.013			1.296	0.110
1982	0.007	0.154	2.332	0.108	0.780	0.089			2.482	0.114
1983	0.045	0.236	1.433	0.139	-9.995	0.030			2.121	0.111
1984	0.638	0.177	1.056	0.123	0.885	0.090			3.221	0.114
1985	-0.270	0.425	-0.314	0.208	0.929	0.098			2.004	0.114
1986	0.725	0.175	0.324	0.124	1.238	0.077			0.995	0.113
1987	-0.027	0.386	-0.434	0.183	0.828	0.068			0.585	0.111
1988	-0.067	0.446	-0.941	0.212	-0.065	0.056			1.394	0.106
1989	-0.112	0.337	-0.566	0.162	0.065	0.050			-0.026	0.105
1990	0.325	0.180	0.069	0.117	0.761	0.045	1.980	0.089	0.402	0.105
1991	0.068	0.243	-0.226	0.135	0.760	0.047	-0.628	0.089	0.777	0.106
1992	-0.540	0.475	-1.250	0.235	0.188	0.052	2.127	0.090	0.847	0.107
1993	-0.213	0.282	-0.508	0.151	0.935	0.060	1.906	0.095	1.328	0.111
1994	-0.162	0.463	-1.212	0.244	-4.190	0.056	1.244	0.122	-0.492	0.108
1995	0.061	0.093	1.157	0.072	-4.616	0.047	1.409	0.123	0.062	0.105
1996	-0.998	0.454	-0.605	0.245	-0.073	0.045	-3.701	0.140	-0.574	0.105
1997	-0.876	0.452	-0.887	0.234	0.019	0.047	-0.392	0.088	-0.956	0.105
1998	-0.545	0.324	-0.104	0.150	0.824	0.052	1.491	0.088	-0.066	0.106
1999	0.082	0.157	0.623	0.100	0.422	0.049	-2.782	0.095	0.085	0.105
2000	-0.108	0.364	-0.307	0.193	-0.176	0.047	1.126	0.084	-0.777	0.105
2001	0.091	0.373	-0.354	0.206	-0.230	0.046	0.807	0.084	-0.388	0.104
2002	0.392	0.132	0.905	0.096	-0.109	0.046	-1.978	0.090	-0.507	0.104
2003	-0.370	0.466	-0.402	0.240	0.355	0.044	1.117	0.083	-0.391	0.104
2004	-0.253	0.388	-0.140	0.197	0.337	0.045	0.324	0.084	-0.761	0.104
2005	0.076	0.159	0.876	0.095	0.636	0.048	0.819	0.085	-0.459	0.104
2006	-0.219	0.291	0.239	0.137	0.410	0.047	-1.404	0.085	-0.784	0.104
2007	-0.489	0.330	-0.097	0.150	0.696	0.047	-0.271	0.084	-0.596	0.104
2008	-0.052	0.370	-0.704	0.201	0.815	0.051	-0.514	0.086	-0.419	0.104
2009	0.365	0.303	-0.488	0.179	0.548	0.051	-0.690	0.086	-0.985	0.105
2010	0.377	0.227	0.109	0.120	0.347	0.050	-0.217	0.086	-1.182	0.105
2011	0.315	0.293	-0.241	0.154	-0.358	0.049	-1.108	0.087	-1.677	0.106
2012	0.010	0.342	-0.509	0.168	-0.424	0.049	-1.766	0.089	-2.229	0.108
2013	-0.323	0.339	-0.596	0.159	-0.293	0.050	0.262	0.085	-1.569	0.107
2014	-0.204	0.442	-1.239	0.219	-0.082	0.053	-0.266	0.087	-2.194	0.110
2015	0.183	0.326	-0.898	0.199	-0.072	0.058	0.866	0.089	-1.874	0.111
2016	0.160	0.308	-0.581	0.200	-0.198	0.063	0.332	0.092	-1.419	0.112
2017	-0.179	0.452	-0.888	0.261	-0.399	0.068	-0.092	0.095	-1.163	0.114
2018	-0.087	0.420	-0.119	0.293						

Table 5(18.0a) (continued). Summary of estimated model parameter values and standard deviations and limits for scenario 18.0a 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	0.512	0.031	0.184, 1.0	68	1.016	0.420	-5, 5
Mf80-84	0.811	0.041	0.276, 1.5	73	0.662	0.600	-5, 5
Mf76-79,85-93	0.087	0.012	0.0, 0.108	78	0.467	0.454	-5, 5
log_betal, females	0.542	0.129	-0.67, 1.32	83	0.688	0.298	-5, 5
log_betal, males	-0.154	0.239	-0.67, 1.32	88	0.553	0.277	-5, 5
log_betar, females	-0.430	0.216	-1.14, 0.5	93	0.439	0.275	-5, 5
log_betar, males	-0.575	0.166	-1.14, 0.5	98	0.454	0.260	-5, 5
Bsfrf_CV	0.084	0.054	0.00, 0.40	103	0.323	0.275	-5, 5

moltp_slope, 75-78	0.110	0.018	0.01, 0.259	108	0.405	0.259	-5, 5
moltp_slope, 79-18	0.093	0.006	0.01, 0.259	113	0.459	0.253	-5, 5
log_moltp_L50, 75-78	4.954	0.013	4.445, 5.52	118	0.241	0.293	-5, 5
log_moltp_L50, 79-18	4.940	0.005	4.445, 5.52	123	0.244	0.287	-5, 5
log_N75	19.918	0.052	15.0, 22.0	128	0.098	0.315	-5, 5
log_avg_L50_tot	4.767	0.011	4.38, 5.45	133	0.239	0.265	-5, 5
tot_fish_slope	0.101	0.006	0.05, 0.57	138	0.035	0.199	-5, 5
Log_ret_L50, 75-04	4.921	0.002	4.6, 5.1	143	-0.227	0.194	-5, 5
Ret_fish_slope, 75-04	0.496	0.034	0.05, 0.87	148	-0.408	0.201	-5, 5
Log_ret_L50, 05-18	4.930	0.003	4.6, 5.1	153	-0.777	0.228	-5, 5
Ret_fish_slope, 05-18	0.495	0.065	0.05, 0.7	158	-1.307	0.287	-5, 5
pot disc.fema., slope	0.091	0.015	0.05, 0.43	163	-1.355	0.290	-5, 5
log_pot disc.fema., L50	4.551	0.037	4.20, 4.666	68	1.678	0.395	-5, 5
trawl disc slope	0.056	0.003	0.01, 0.20	73	1.456	0.434	-5, 5
log_trawl disc L50	5.222	0.091	4.50, 5.40	78	1.365	0.364	-5, 5
log_srv_L50, m, bsfrf	4.340	0.040	3.359, 5.48	83	1.163	0.332	-5, 5
srv_slope, f, bsfrf	0.041	0.009	0.01, 0.134	88	1.108	0.279	-5, 5
log_srv_L50, f, bsfrf	4.484	0.063	3.471, 5.539	93	0.716	0.310	-5, 5
log_srv_L50, m, 75-81	4.348	0.027	3.551, 5.864	98	0.351	0.371	-5, 5
srv_slope, f, 75-81	0.103	0.013	0.01, 0.303	103	0.132	0.410	-5, 5
log_srv_L50, f, 75-81	4.434	0.026	3.709, 4.80	108	-0.022	0.411	-5, 5
log_srv_L50, m, 82-18	4.127	0.251	3.709, 5.10	113	-0.218	0.442	-5, 5
srv_slope, f, 82-18	0.071	0.020	0.01, 0.43	118	-0.804	0.656	-5, 5
log_srv_L50, f, 82-18	4.180	0.082	3.709, 4.90	123	-0.993	0.733	-5, 5
TC_slope, females	0.338	0.104	0.02, 0.40	128	-1.296	0.872	-5, 5
log_TC_L50, females	4.531	0.014	4.24, 4.90	133	-2.348	1.913	-5, 5
TC_slope, males	0.213	0.068	0.05, 0.90	138	-2.638	2.278	-5, 5
log_TC_L50, males	4.566	0.020	4.25, 5.14	143	NA	NA	
Q	0.925	0.022	0.59, 1.2	Fixed gear bycatch parameters:			
log_TC_F, males, 91	-3.942	0.092	-10.0, 1.00	log_avg_f	-8.134	0.081	-8.5, -0.5
log_TC_F, males, 92	-5.909	0.093	-10.0, 1.00	fmortf_09	-1.270	0.112	-10, 10
log_TC_F, males, 93	-6.609	0.099	-10.0, 1.00	fmortf_10	-2.154	0.132	-10, 10
log_TC_F, males, 13	-8.325	0.093	-10.0, 1.00	fmortf_11	-0.642	0.104	-10, 10
log_TC_F, males, 14	-7.472	0.091	-10.0, 1.00	fmortf_12	-0.117	0.101	-10, 10
log_TC_F, males, 15	-7.062	0.093	-10.0, 1.00	fmortf_13	0.992	0.097	-10, 10
log_TC_F, females, 91	-2.889	0.097	-10.0, 1.00	fmortf_14	1.787	0.097	-10, 10
log_TC_F, females, 92	-4.534	0.100	-10.0, 1.00	fmortf_15	1.411	0.098	-10, 10
log_TC_F, females, 93	-6.433	0.103	-10.0, 1.00	fmortf_16	0.501	0.100	-10, 10
log_TC_F, females, 13	-7.756	0.091	-10.0, 1.00	fmortf_17	-0.508	0.106	-10, 10
log_TC_F, females, 14	-7.620	0.091	-10.0, 1.00	Fix_slo	0.087	0.019	0, 0.2
log_TC_F, females, 15	-6.599	0.090	-10.0, 1.00	log_l50	4.664	0.037	4.5, 5.4

Table 6(18.0). 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 (scenario 18.0) from 1975-2018. 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	59.461	29.052	86.150	9.149	65.001		257.439	202.731
1976	69.210	36.783	101.903	8.271	96.044	28.949	293.778	331.868
1977	73.151	42.454	110.539	6.673	119.542	39.074	300.230	375.661
1978	75.042	45.067	110.395	4.916	115.822	49.458	287.312	349.545
1979	65.294	44.165	88.041	3.227	102.734	83.039	261.876	167.627
1980	45.133	33.828	22.711	0.918	97.168	97.908	229.005	249.322
1981	13.075	7.488	5.410	0.493	47.113	46.566	96.719	132.669
1982	6.026	2.068	5.642	0.555	23.308	178.326	52.657	143.740
1983	6.060	2.181	7.055	0.556	17.542	73.647	48.574	49.320

1984	6.266	2.600	5.546	0.530	17.861	72.873	47.194	155.311
1985	8.271	2.212	10.872	0.804	15.248	11.178	36.671	34.535
1986	13.073	5.016	16.350	1.146	20.472	37.168	47.084	48.158
1987	15.160	7.094	21.244	1.316	24.238	11.041	52.113	70.263
1988	15.270	8.803	25.685	1.367	27.765	6.549	54.405	55.372
1989	16.240	10.078	28.168	1.306	25.148	9.181	56.177	55.941
1990	15.880	10.703	24.389	1.230	21.306	21.804	55.689	60.321
1991	12.368	8.982	19.048	1.167	19.953	14.519	49.800	85.055
1992	9.754	6.863	17.660	1.127	20.405	3.926	44.268	37.687
1993	10.430	6.361	15.167	1.140	18.764	9.382	43.009	53.703
1994	10.022	5.735	20.294	1.205	15.795	4.764	37.973	32.335
1995	10.720	7.497	23.272	1.208	15.474	56.490	45.109	38.396
1996	11.078	8.246	21.747	1.172	21.860	6.420	53.672	44.649
1997	10.560	7.534	20.442	1.173	29.903	4.984	58.720	85.277
1998	15.797	7.340	23.438	1.362	28.126	12.082	62.542	85.176
1999	17.137	9.311	27.610	1.555	24.944	33.140	62.591	65.604
2000	14.909	10.518	27.973	1.563	27.168	11.887	64.845	68.102
2001	14.485	10.228	28.106	1.525	30.874	12.809	68.492	53.188
2002	16.902	10.171	31.302	1.529	30.884	53.541	74.265	69.786
2003	17.802	11.483	30.815	1.525	37.502	9.457	80.089	116.794
2004	16.238	11.164	28.596	1.477	44.803	13.280	82.045	131.910
2005	18.419	10.455	29.410	1.472	42.654	42.769	85.104	107.341
2006	18.368	11.190	30.894	1.503	43.847	19.881	87.019	95.676
2007	17.107	11.493	27.277	1.476	47.858	12.560	90.249	104.841
2008	18.456	10.253	27.749	1.567	46.175	8.342	88.979	114.430
2009	19.219	10.832	30.704	1.693	42.055	12.834	85.559	91.673
2010	18.134	11.780	30.922	1.706	38.997	23.310	83.293	81.642
2011	15.849	11.494	31.319	1.666	39.408	16.318	81.125	67.053
2012	14.756	11.139	30.493	1.615	41.333	10.140	81.403	61.248
2013	15.082	10.572	30.458	1.603	40.560	8.151	80.608	62.410
2014	15.264	10.572	29.854	1.635	37.335	4.499	77.862	114.103
2015	14.301	10.345	28.221	1.672	33.313	7.476	73.217	64.240
2016	12.992	9.698	26.491	1.704	29.720	10.177	68.049	61.231
2017	11.452	8.968	24.529	1.705	27.862	6.477	63.528	52.922
2018	10.315	8.123	20.617	1.385	26.366	14.547	60.436	28.932

Table 6(18.0a). 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 (scenario 18.0a) from 1975-2018. 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	59.480	29.058	86.181	9.146	65.006		257.619	202.731
1976	69.257	36.777	101.950	8.268	95.921	29.262	293.907	331.868
1977	73.181	42.456	110.550	6.672	119.395	39.150	300.394	375.661
1978	75.065	45.057	110.380	4.917	115.754	49.524	287.515	349.545
1979	65.334	44.154	88.037	3.226	102.775	82.878	262.099	167.627
1980	45.164	33.829	22.701	0.917	97.215	97.773	229.229	249.322
1981	13.080	7.490	5.420	0.493	47.276	46.752	96.976	132.669
1982	6.027	2.069	5.647	0.554	23.482	177.879	52.667	143.740
1983	6.059	2.181	7.056	0.554	17.579	73.717	48.556	49.320
1984	6.259	2.599	5.540	0.528	17.958	71.531	47.055	155.311
1985	8.264	2.209	10.860	0.800	15.211	11.080	36.548	34.535

1986	13.057	5.013	16.324	1.140	20.342	36.453	46.853	48.158
1987	15.114	7.084	21.171	1.309	23.936	10.996	51.802	70.263
1988	15.196	8.773	25.556	1.358	27.405	6.494	54.044	55.372
1989	16.139	10.027	27.980	1.294	24.856	9.248	55.797	55.941
1990	15.760	10.631	24.149	1.216	21.087	21.983	55.328	60.321
1991	12.250	8.895	18.790	1.153	19.827	14.215	49.459	85.055
1992	9.668	6.774	17.431	1.116	20.308	3.902	43.964	37.687
1993	10.367	6.290	14.977	1.134	18.602	9.360	42.756	53.703
1994	9.990	5.680	20.163	1.201	15.635	4.737	37.773	32.335
1995	10.710	7.468	23.195	1.205	15.302	56.446	44.923	38.396
1996	11.081	8.234	21.711	1.169	21.648	6.430	53.507	44.649
1997	10.572	7.534	20.438	1.171	29.816	5.019	58.576	85.277
1998	15.784	7.344	23.411	1.362	28.063	12.246	62.426	85.176
1999	17.106	9.303	27.554	1.555	24.933	33.439	62.517	65.604
2000	14.880	10.500	27.914	1.563	27.267	12.009	64.837	68.102
2001	14.465	10.207	28.056	1.525	31.135	12.649	68.538	53.188
2002	16.892	10.155	31.269	1.529	31.116	52.714	74.263	69.786
2003	17.798	11.476	30.795	1.526	37.359	9.731	80.050	116.794
2004	16.234	11.162	28.585	1.477	44.473	13.282	81.990	131.910
2005	18.425	10.453	29.415	1.473	42.383	42.963	85.064	107.341
2006	18.393	11.197	30.935	1.504	43.616	19.697	87.005	95.676
2007	17.144	11.513	27.348	1.477	47.674	12.595	90.272	104.841
2008	18.520	10.283	27.874	1.567	45.952	8.296	89.036	114.430
2009	19.307	10.884	30.885	1.691	41.857	12.886	85.651	91.673
2010	18.223	11.851	31.128	1.704	38.827	23.574	83.425	81.642
2011	15.920	11.568	31.511	1.663	39.285	16.020	81.281	67.053
2012	14.821	11.201	30.677	1.612	41.171	10.393	81.601	61.248
2013	15.193	10.630	30.706	1.602	40.353	8.170	80.857	62.410
2014	15.417	10.660	30.184	1.634	37.228	4.526	78.166	114.103
2015	14.457	10.463	28.586	1.671	33.255	7.715	73.570	64.240
2016	13.133	9.821	26.852	1.701	29.741	10.465	68.451	61.231
2017	11.572	9.083	24.864	1.701	28.033	6.497	63.970	52.922
2018	10.420	8.224	20.804	1.378	26.629	14.641	60.900	28.932

Table 7(18.0). 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 scenario 18.0 are used for the projection.

			No Directed Fishery			
Year	MMB	95% LCI	95% UCI	Catch	95% LCI	95% UCI
2018	25.347	20.810	29.632	0.000	0.000	0.000
2019	26.515	21.768	30.997	0.000	0.000	0.000
2020	27.673	22.719	32.351	0.000	0.000	0.000
2021	30.070	24.722	35.429	0.000	0.000	0.000
2022	34.151	27.308	45.596	0.000	0.000	0.000
2023	38.829	29.136	59.221	0.000	0.000	0.000
2024	43.524	31.093	67.482	0.000	0.000	0.000
2025	47.937	32.665	75.040	0.000	0.000	0.000
2026	51.887	34.423	81.460	0.000	0.000	0.000
2027	55.497	35.681	87.154	0.000	0.000	0.000
			$F_{40\%}$			
2018	21.373	18.091	24.357	4.119	2.819	5.466

2019	19.729	17.018	22.143	3.290	2.367	4.204
2020	18.821	16.413	20.945	2.860	2.121	3.573
2021	19.417	16.990	21.634	2.815	2.128	3.513
2022	21.507	17.878	31.030	3.141	2.332	4.137
2023	23.850	18.105	39.611	3.650	2.476	5.713
2024	25.874	17.967	42.028	4.217	2.519	7.492
2025	27.432	18.200	46.223	4.702	2.542	8.167
2026	28.509	18.636	49.131	5.075	2.619	8.880
2027	29.372	18.630	50.436	5.328	2.684	9.478

			$F_{35\%}$			
2018	20.692	17.601	23.485	4.824	3.326	6.367
2019	18.748	16.279	20.932	3.660	2.669	4.629
2020	17.709	15.547	19.606	3.089	2.326	3.818
2021	18.223	16.037	20.225	3.004	2.301	3.708
2022	20.185	16.854	29.140	3.366	2.503	4.673
2023	22.316	16.996	37.107	3.951	2.650	6.494
2024	24.058	16.799	39.108	4.591	2.661	8.439
2025	25.321	16.937	42.935	5.105	2.694	9.036
2026	26.134	17.370	44.698	5.473	2.753	9.809
2027	26.778	17.315	45.949	5.704	2.799	10.426

Table 7(18.0a). 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 scenario 18.0a are used for the projection.

			No Directed Fishery			
Year	MMB	95% LCI	95% UCI	Catch	95% LCI	95% UCI
2018	25.653	21.105	29.949	0.000	0.000	0.000
2019	26.802	22.050	31.290	0.000	0.000	0.000
2020	27.944	22.989	32.623	0.000	0.000	0.000
2021	30.326	24.984	35.681	0.000	0.000	0.000
2022	34.390	27.555	45.820	0.000	0.000	0.000
2023	39.049	29.367	59.326	0.000	0.000	0.000
2024	43.726	31.292	67.578	0.000	0.000	0.000
2025	48.122	32.932	75.147	0.000	0.000	0.000
2026	52.058	34.550	81.402	0.000	0.000	0.000
2027	55.656	35.820	87.205	0.000	0.000	0.000

			$F_{40\%}$			
2018	21.576	18.301	24.552	4.228	2.908	5.595
2019	19.863	17.168	22.262	3.354	2.425	4.273
2020	18.916	16.528	21.024	2.902	2.162	3.616

2021	19.487	17.082	21.684	2.848	2.162	3.544
2022	21.559	17.956	31.048	3.167	2.361	4.148
2023	23.888	18.157	39.692	3.671	2.500	5.717
2024	25.903	18.001	42.041	4.234	2.539	7.511
2025	27.455	18.219	46.191	4.716	2.560	8.175
2026	28.530	18.688	49.074	5.088	2.639	8.879
2027	29.390	18.632	50.407	5.340	2.696	9.484

			$F_{35\%}$			
2018	20.879	17.798	23.664	4.949	3.429	6.513
2019	18.865	16.413	21.034	3.727	2.731	4.701
2020	17.790	15.647	19.671	3.132	2.368	3.860
2021	18.282	16.116	20.266	3.036	2.335	3.737
2022	20.227	16.912	29.121	3.392	2.529	4.684
2023	22.345	17.038	37.146	3.972	2.667	6.507
2024	24.078	16.805	39.112	4.608	2.680	8.459
2025	25.335	16.946	42.972	5.120	2.709	9.051
2026	26.146	17.369	44.638	5.486	2.780	9.823
2027	26.788	17.309	45.966	5.716	2.805	10.418

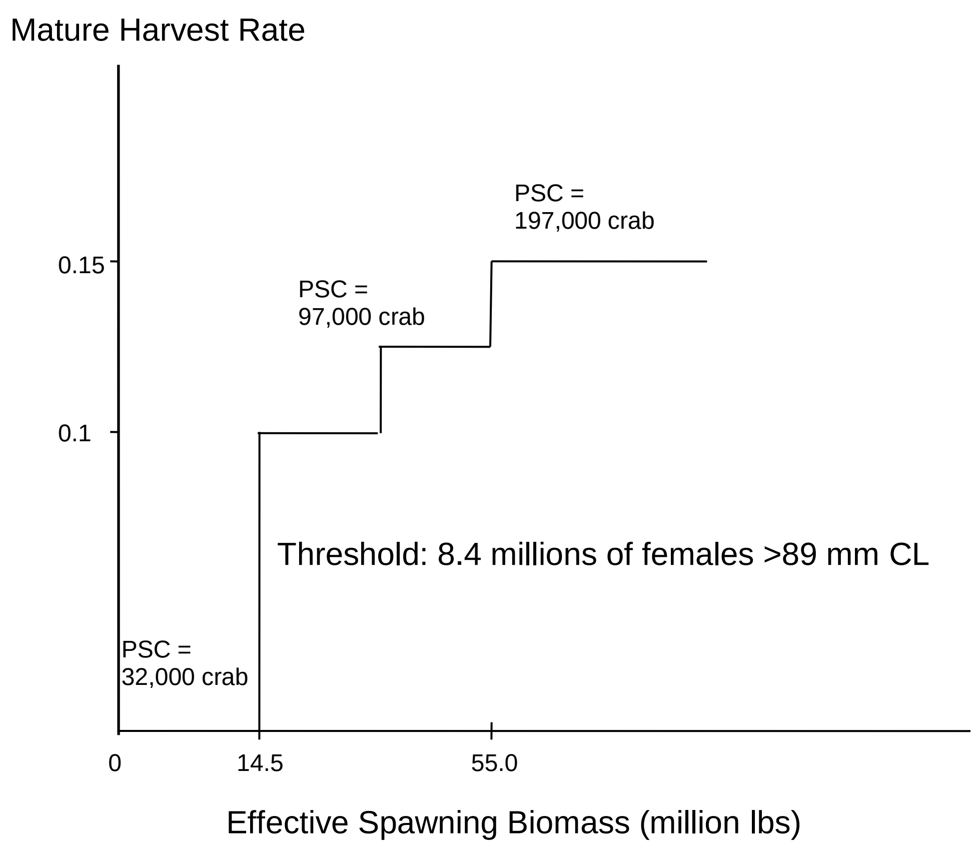


Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crab) of Bristol Bay red king crab in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates of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

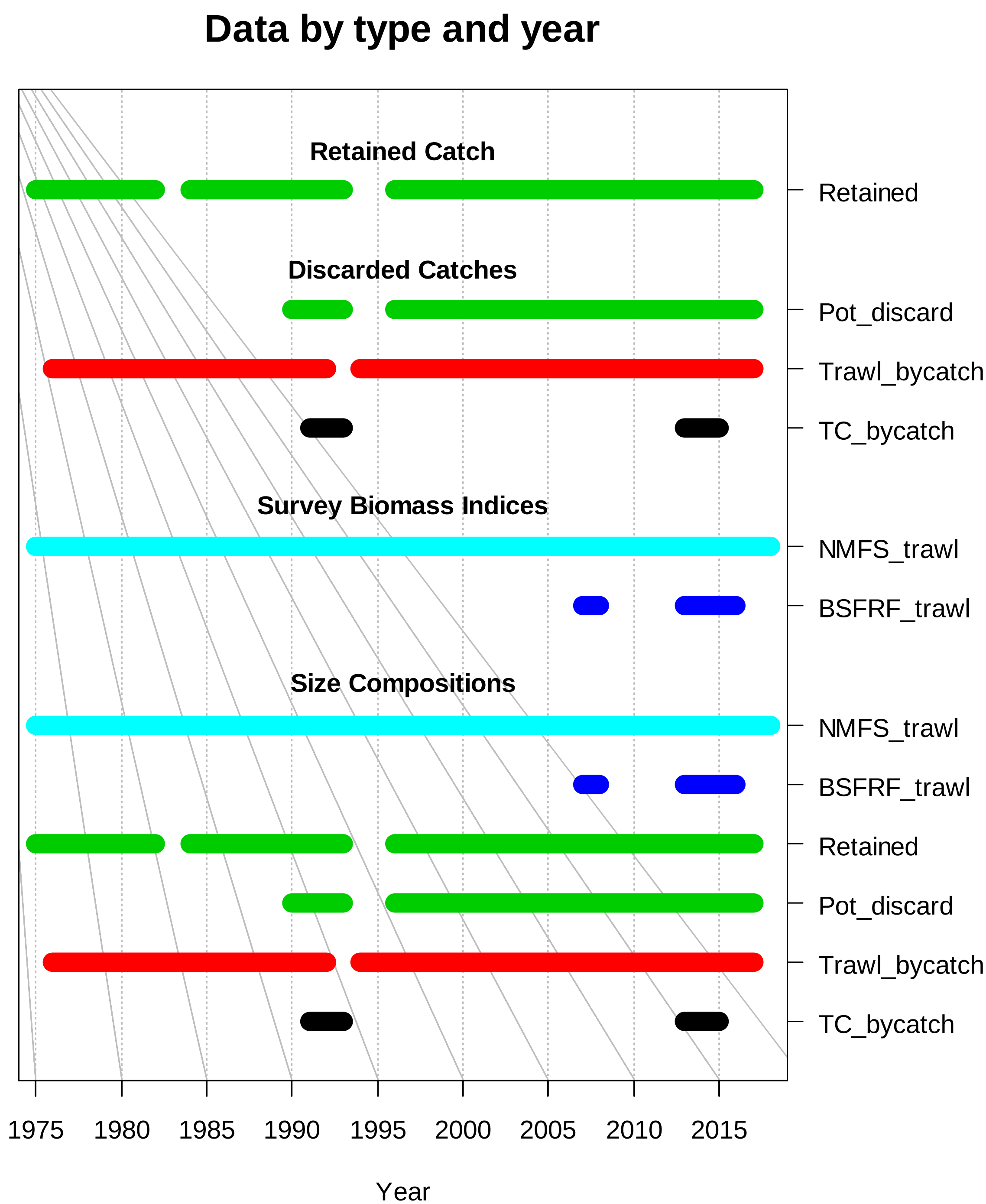


Figure 2. Data types and ranges used for the stock assessment.

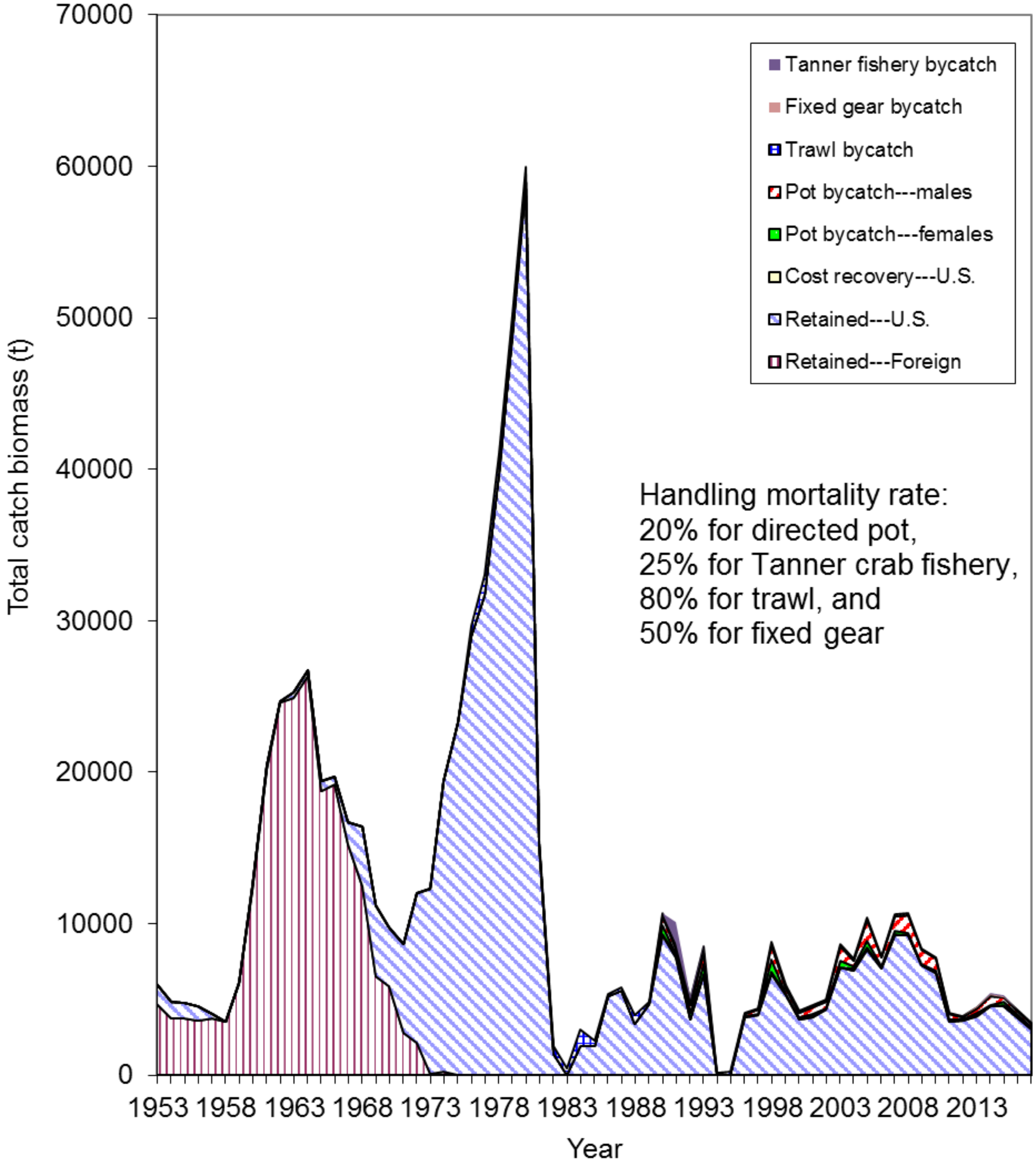


Figure 3. Retained catch biomass and bycatch mortality biomass (t) for Bristol Bay red king crab from 1953 to 2017. Handling mortality rates were assumed to be 0.2 for the directed pot fishery, 0.25 for the Tanner crab fishery, 0.8 for the trawl fisheries, and 50% for the fixed gear fisheries.

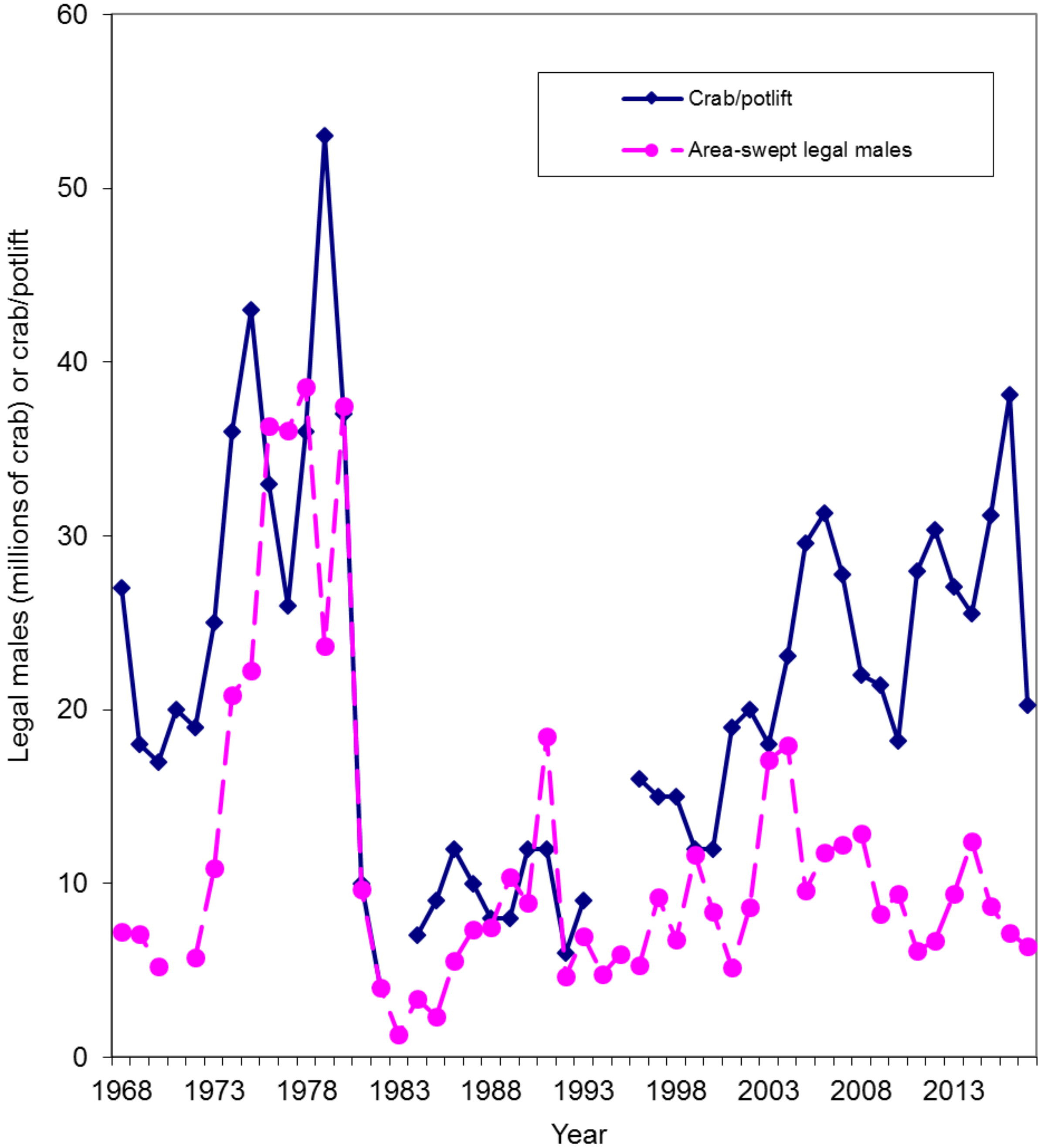


Figure 4. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2017.

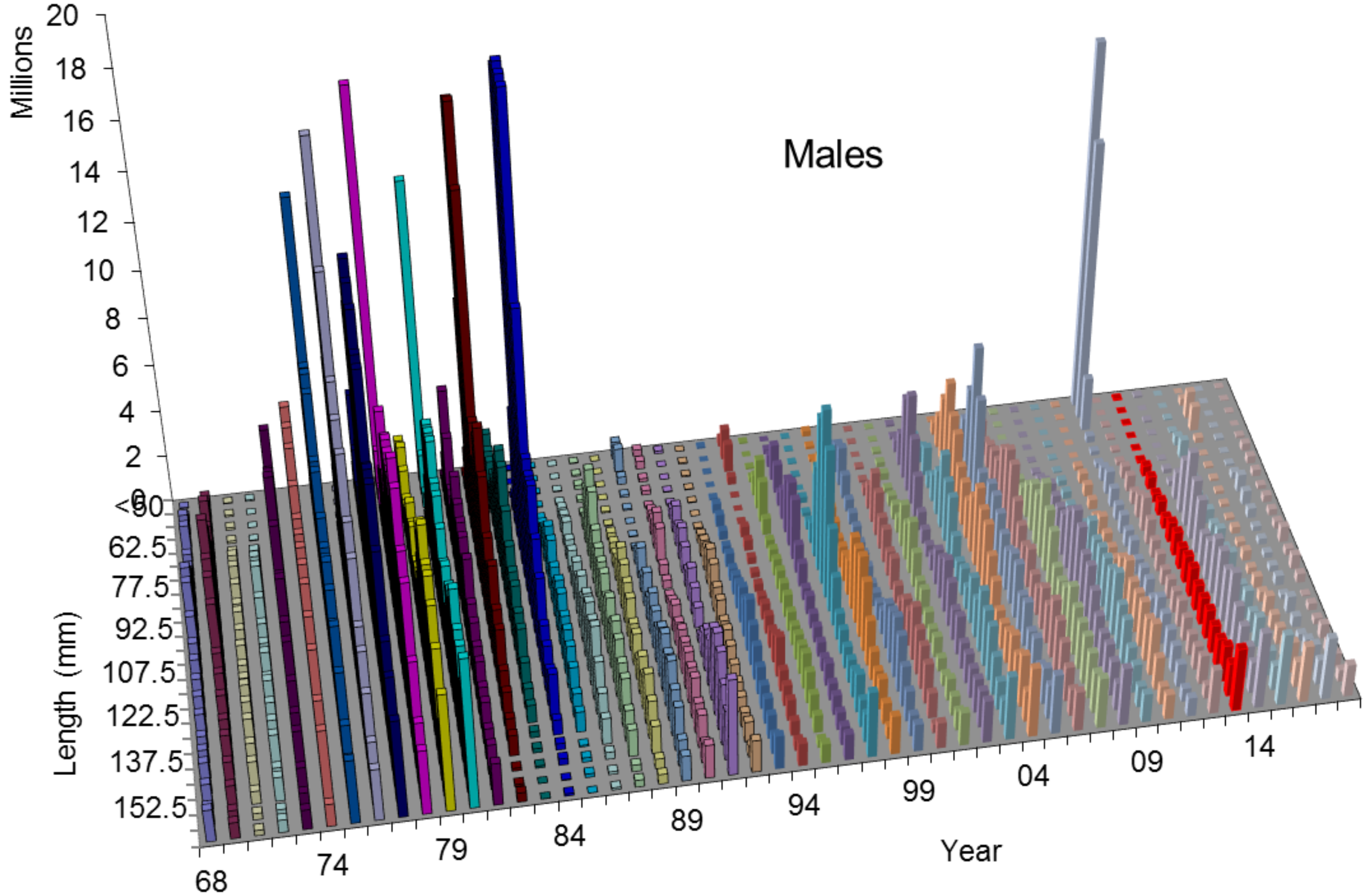


Figure 5a. Survey abundances by 5-mm carapace length bin for male Bristol Bay red king crab from 1968 to 2018.

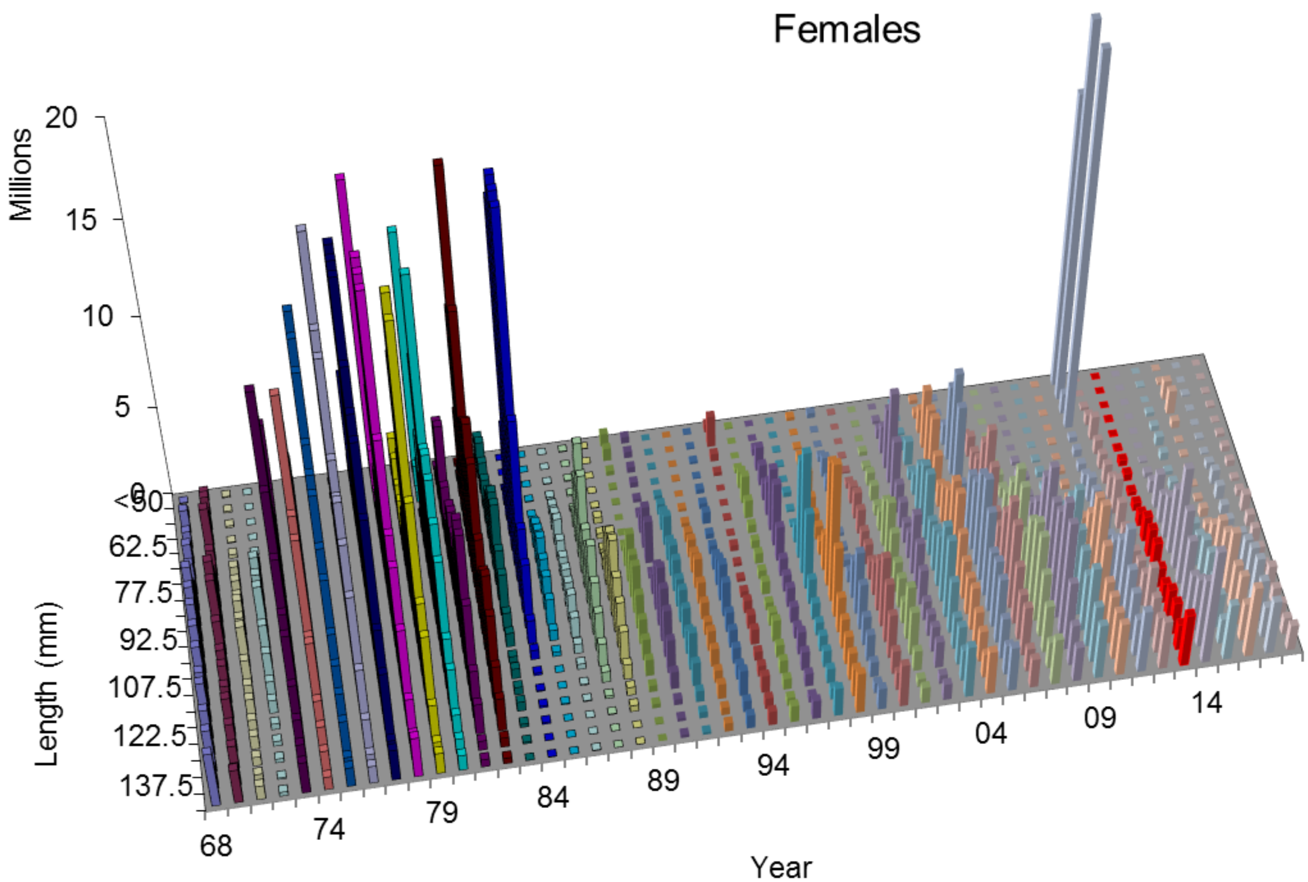
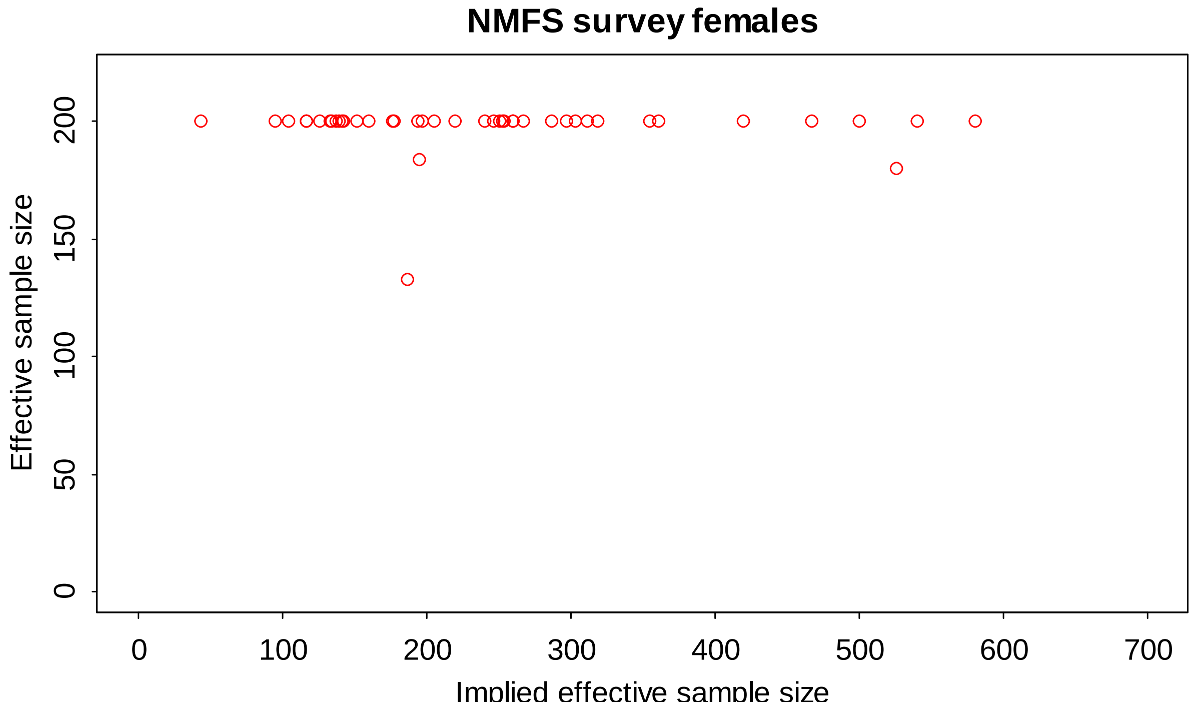


Figure 5b. Survey abundances by 5 mm carapace length bin for female Bristol Bay red king crab from 1968 to 2018.



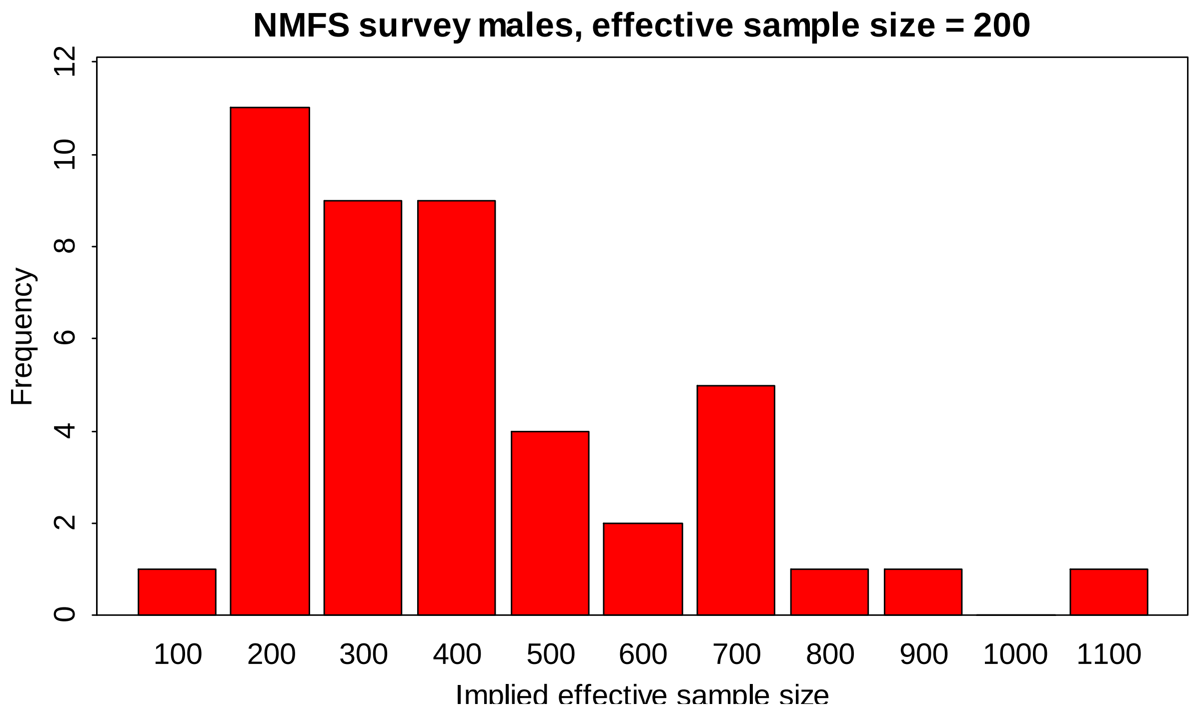


Figure 6. Relationship between implied effective sample sizes (section 3(a)(5)(i)) and effective sample sizes (see effective sample sizes for scenario 18.0) for length/sex composition data with scenario 18.0: trawl survey data.

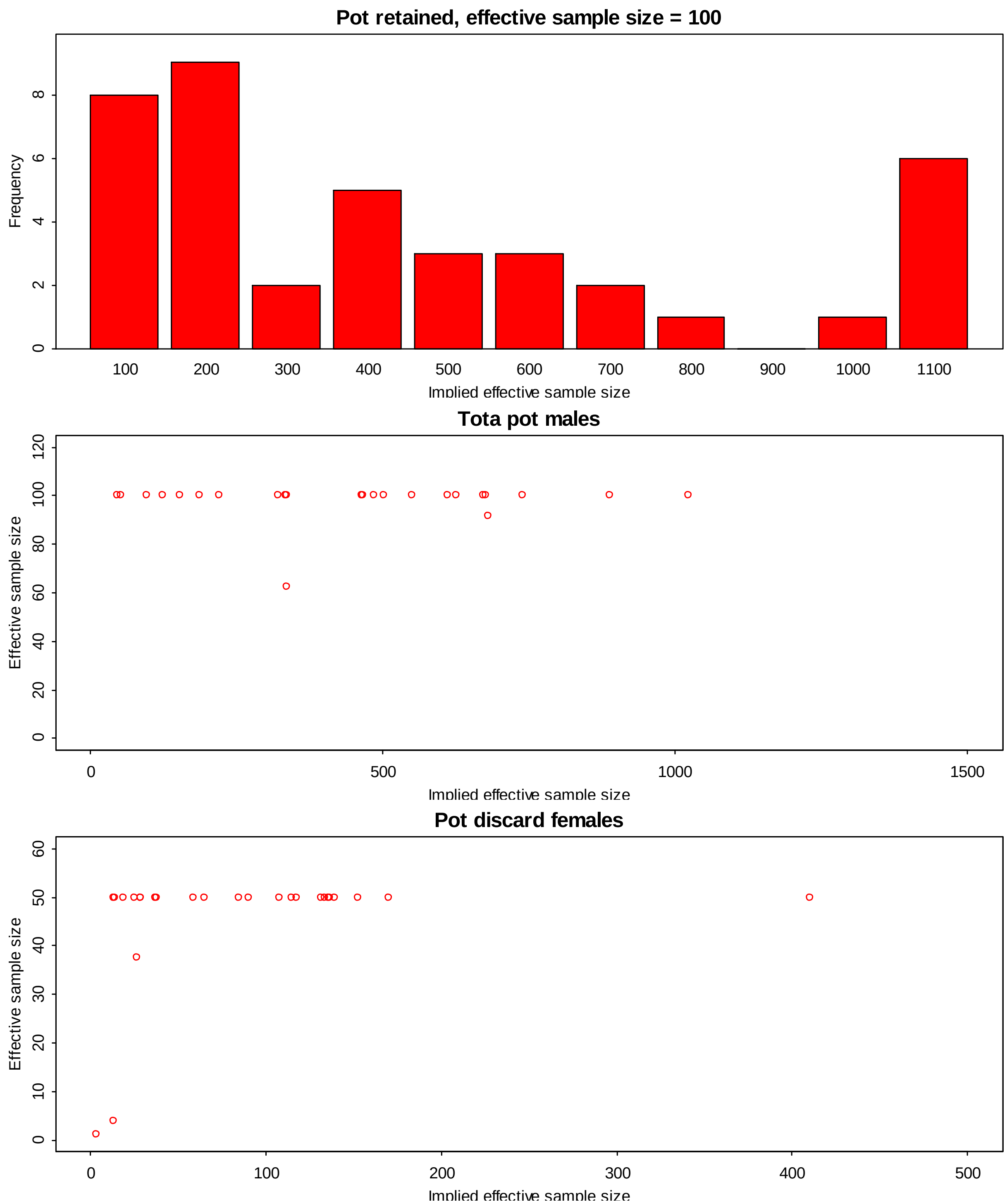


Figure 7. Relationship between implied effective sample sizes (section 3(a)(5)(i)) and effective sample sizes (see effective sample sizes for scenario 18.0) for length/sex composition data with scenario 18.0: directed pot fishery data.

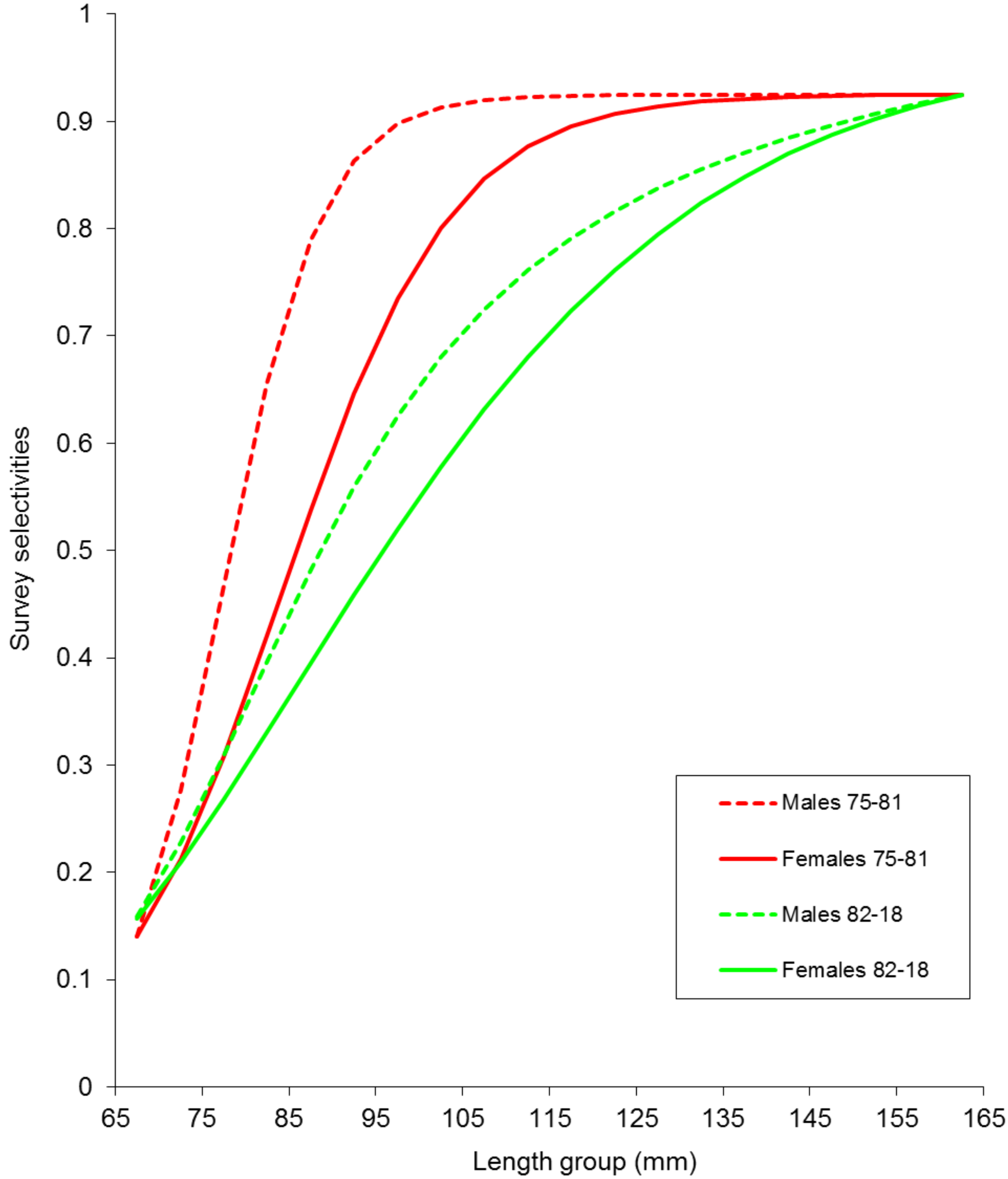


Figure 8a(18.0). Estimated trawl survey selectivities under scenario 18.0. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

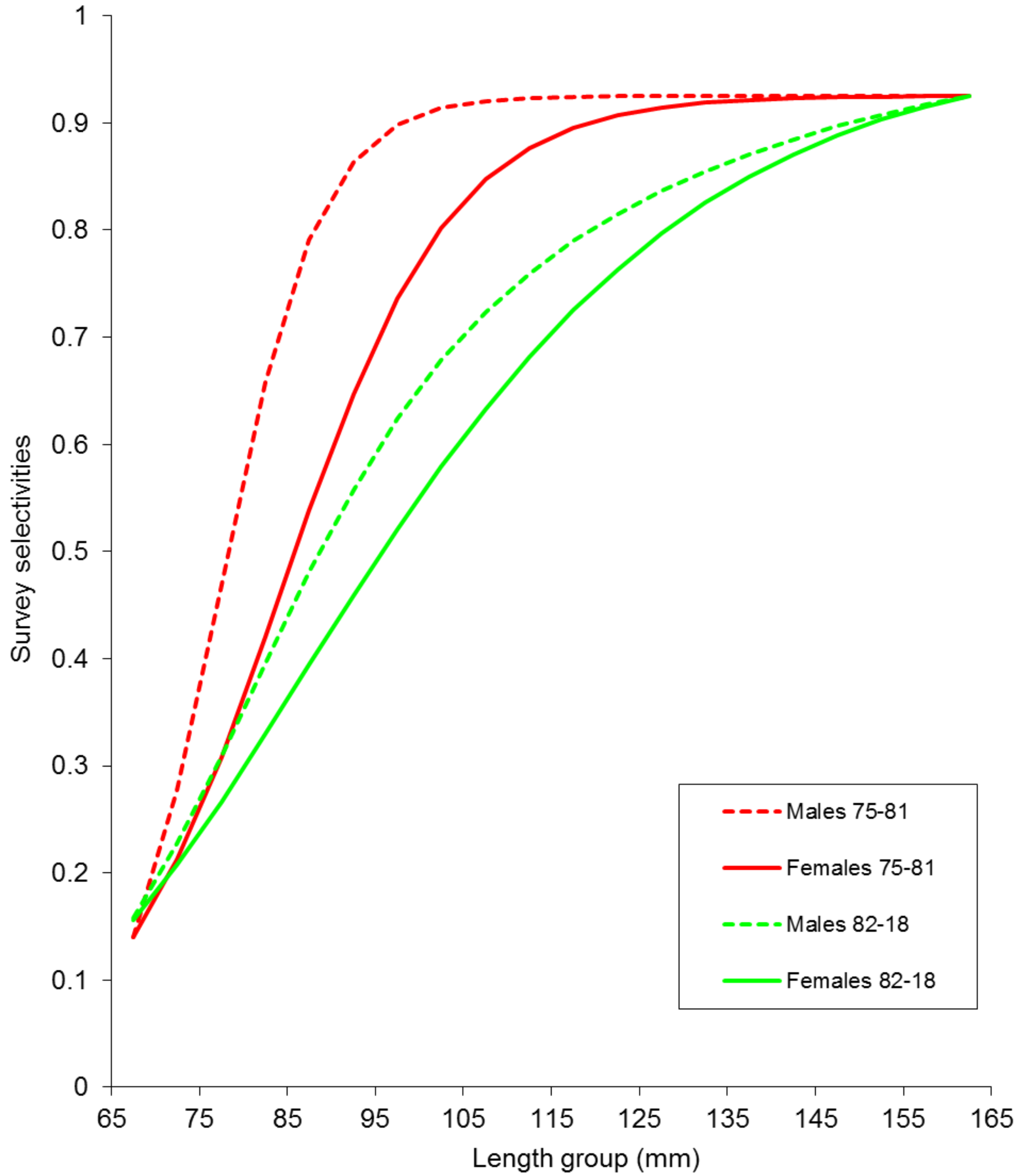


Figure 8a(18.0a). Estimated trawl survey selectivities under scenario 18.0a. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

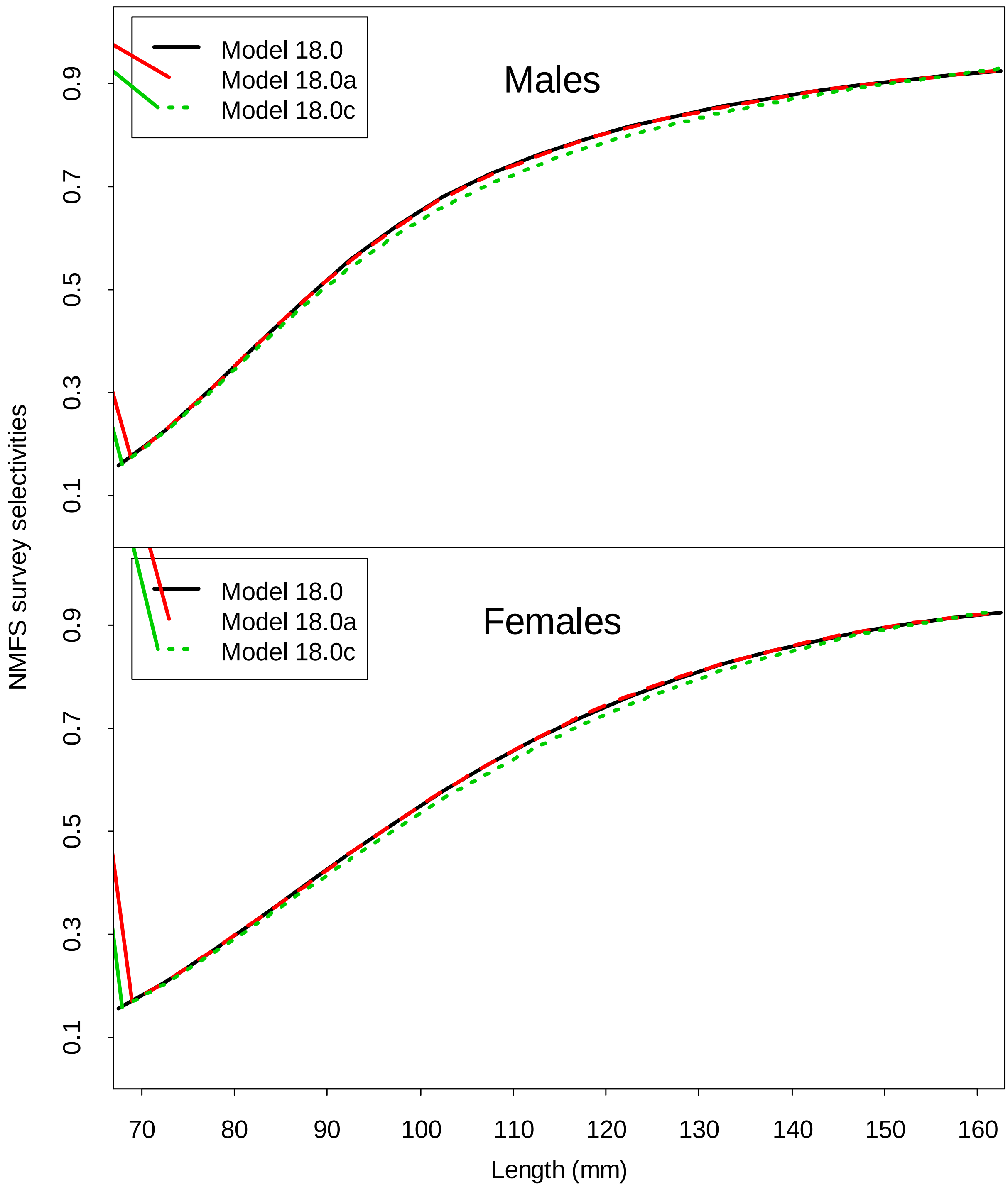


Figure 8b. Comparisons of estimated NMFS trawl survey selectivities for period 1982-2018 under scenarios 18.0, 18.0a, and 18.0c. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

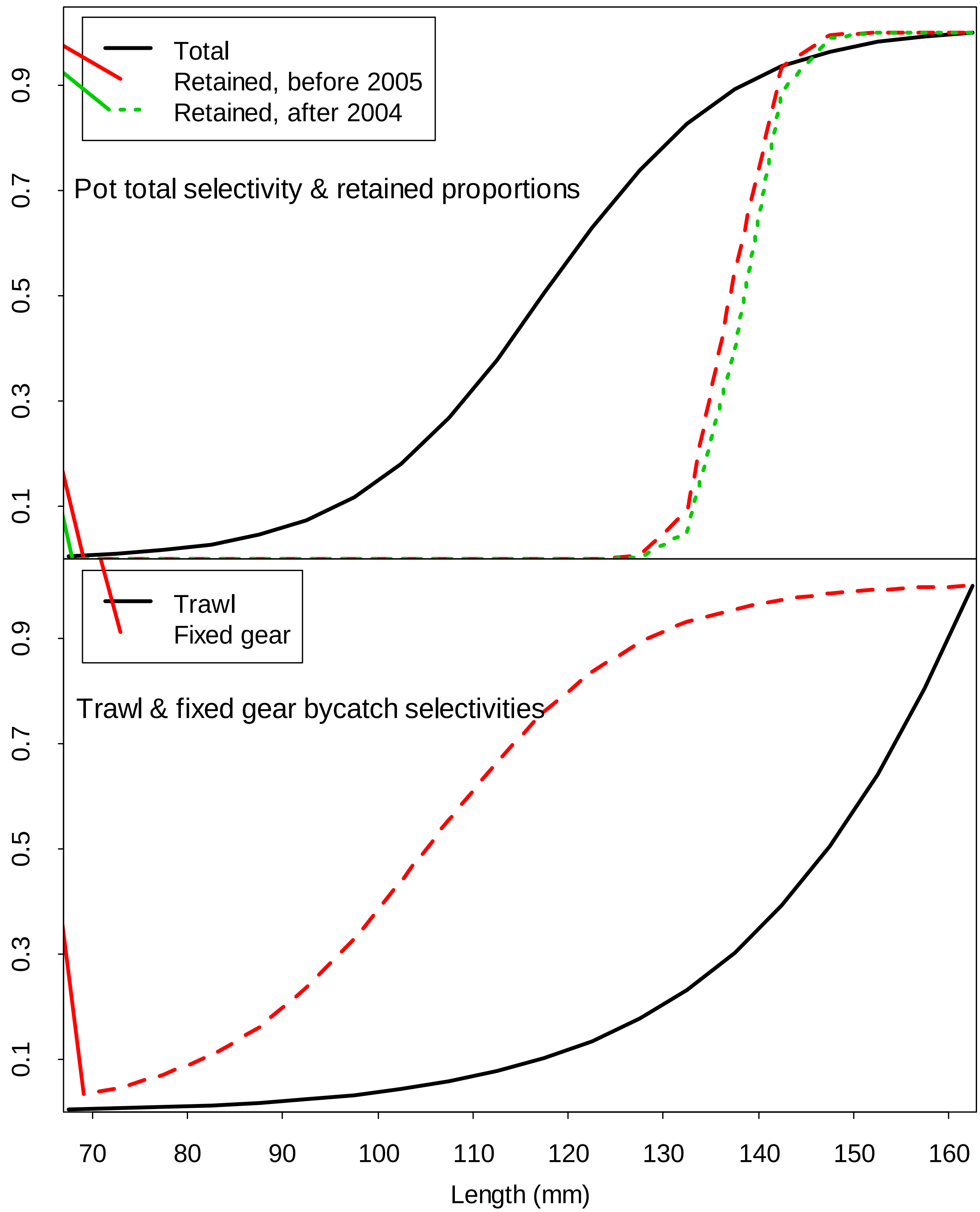


Figure 8c. Estimated pot fishery selectivities and groundfish trawl bycatch selectivities under scenario 18.0. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

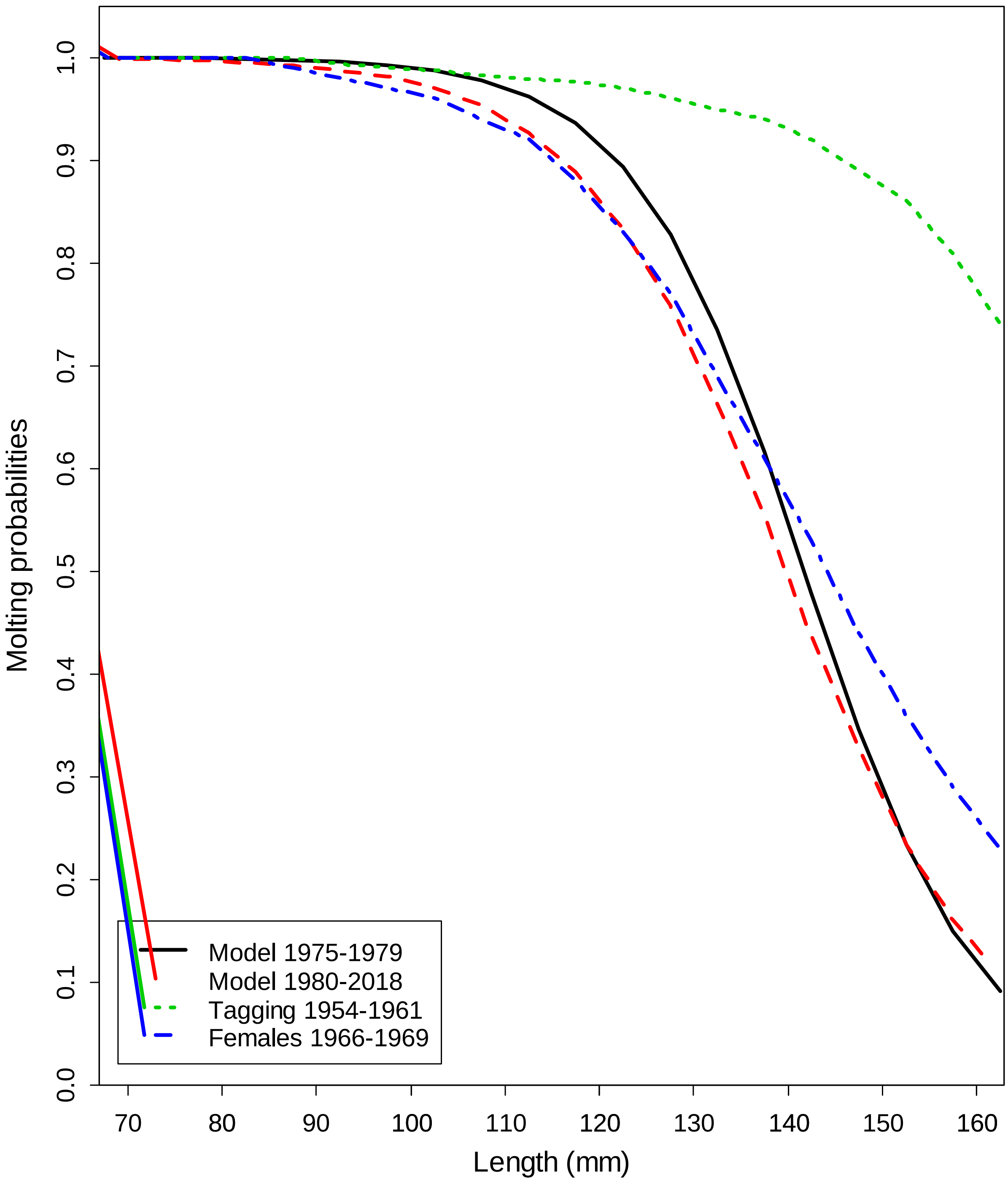


Figure 9(18.0). Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-2018 were estimated with a length-based model.

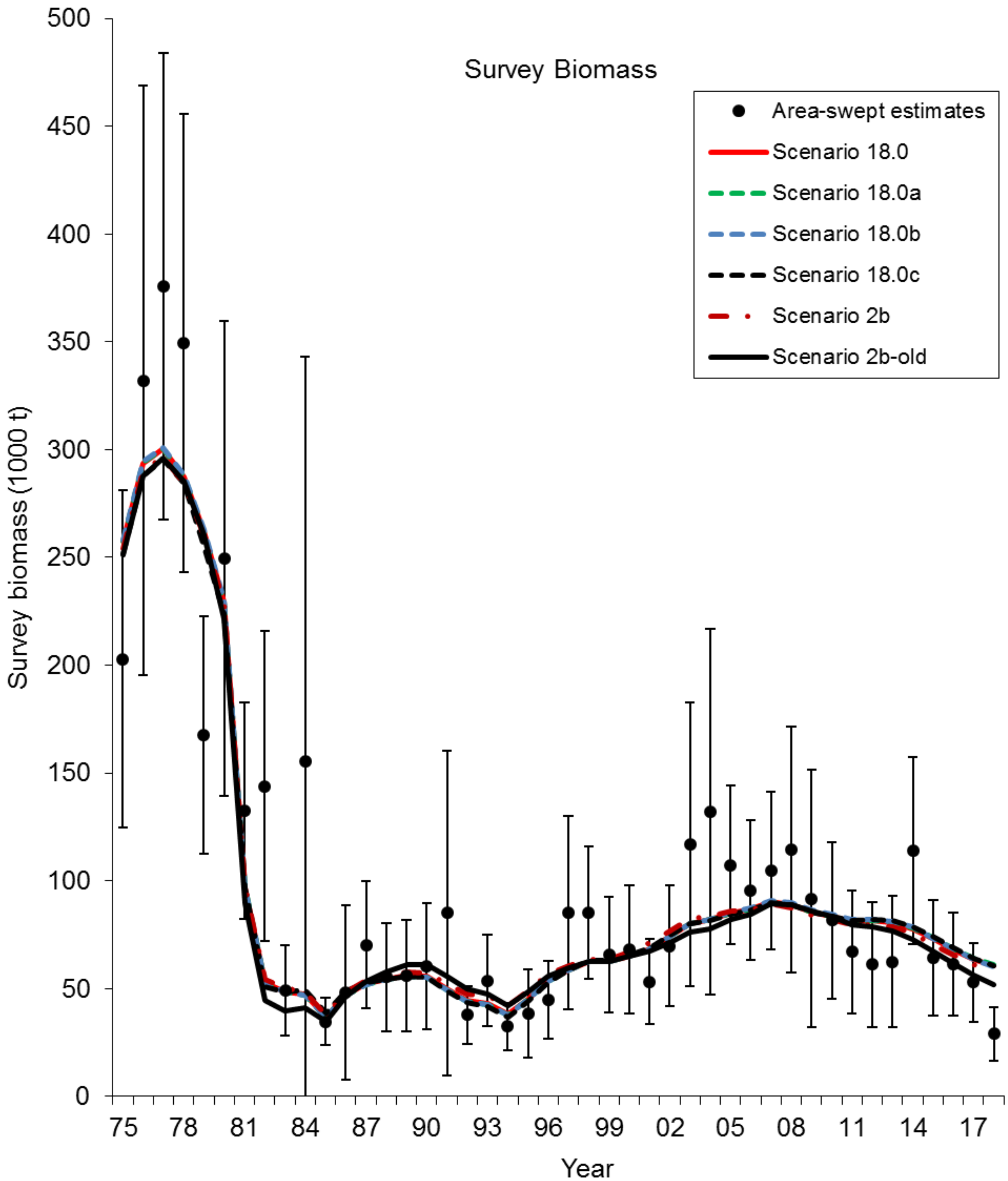


Figure 10a. Comparisons of area-swept estimates of total survey biomass and model prediction for model estimates in 2018 under scenarios 18.0, 18.0a, 8.0b, 18.0c, 2b and 2b-old. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively. The error bars are plus and minus 2 standard deviations.

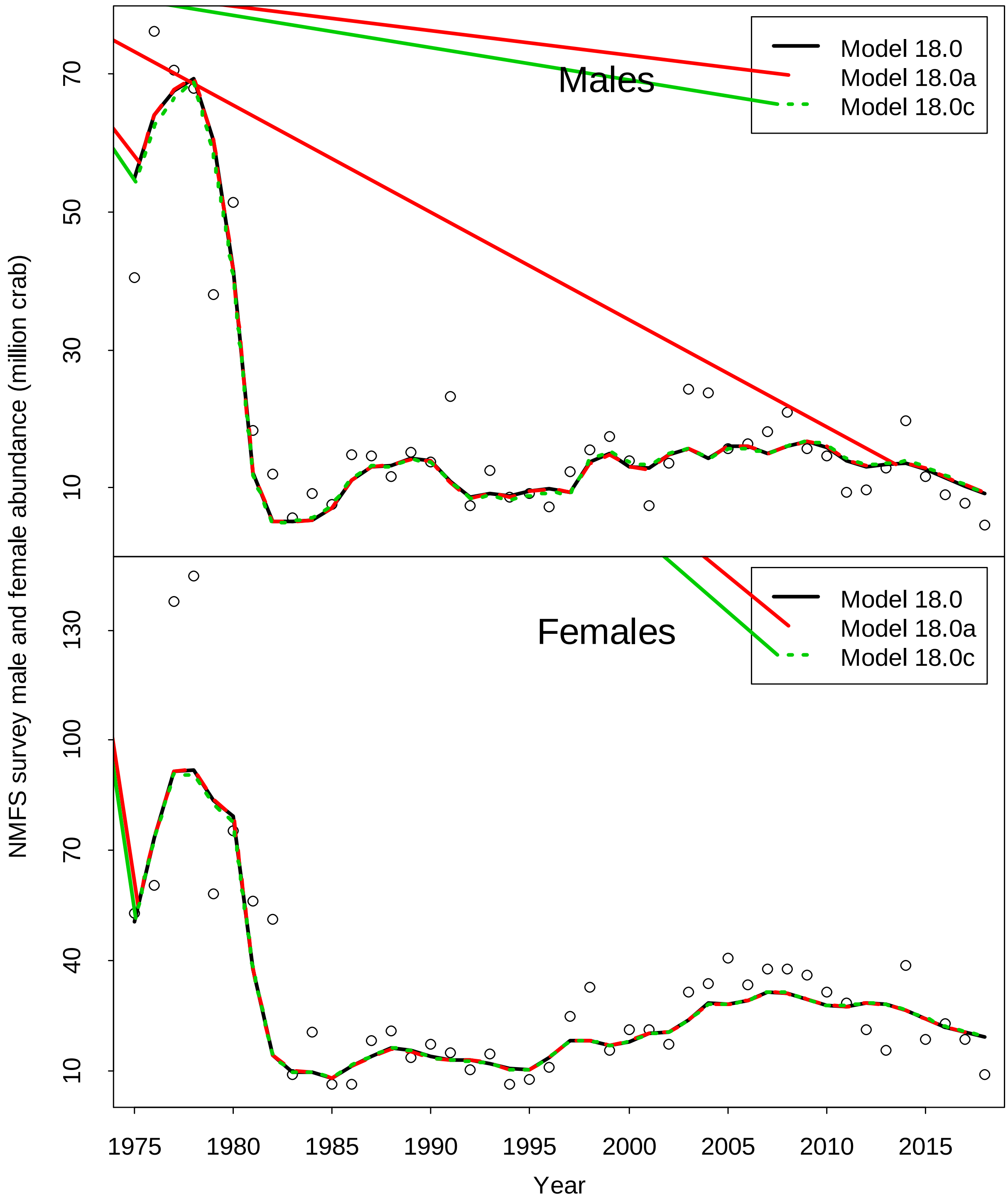


Figure 10b. Comparisons of area-swept estimates of male (>119 mm) and female (>89 mm) abundance and model prediction for model estimates in 2018 under scenarios 18.0, 18.0a, and 18.0c. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

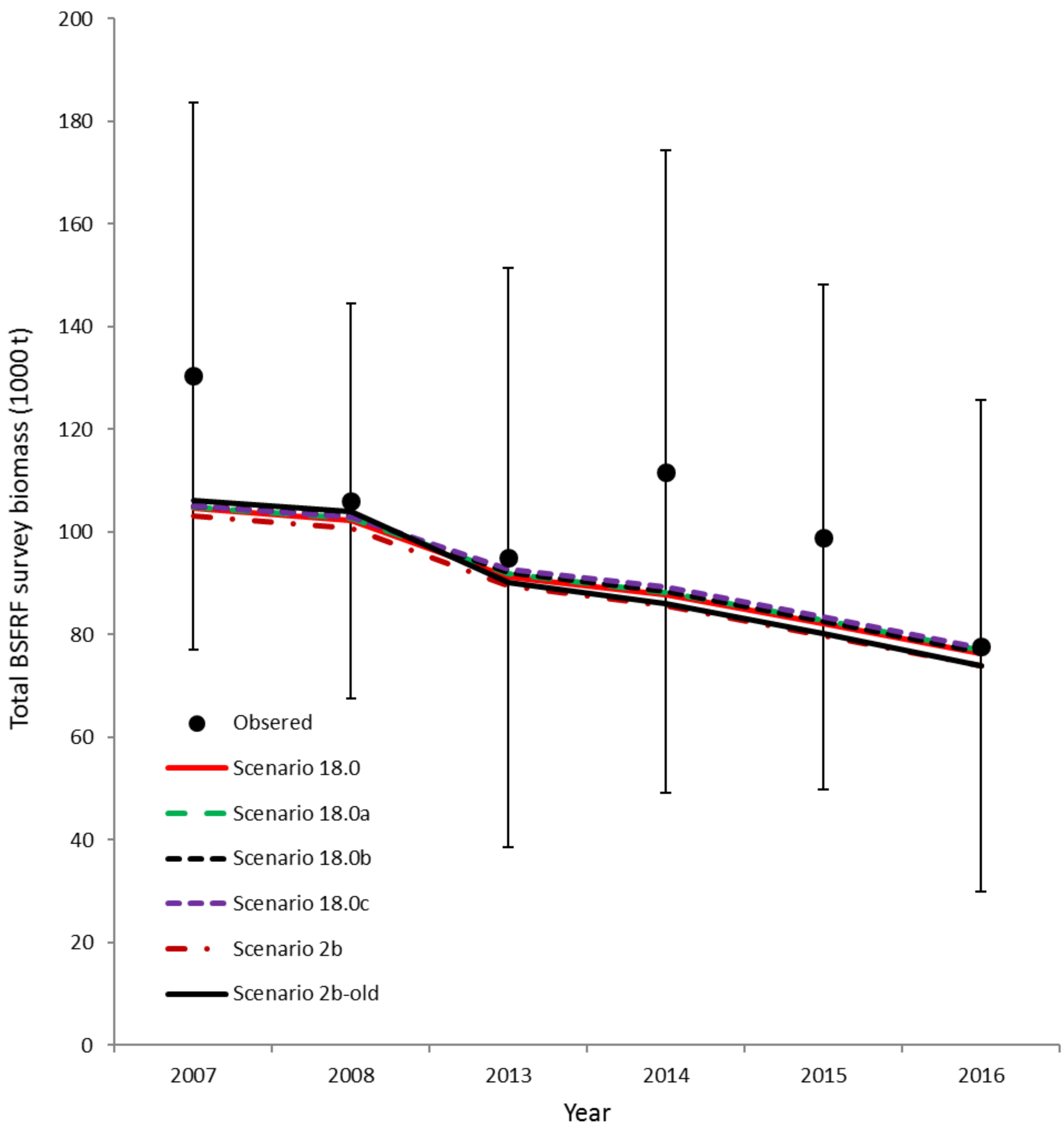


Figure 10c. Comparisons of total survey biomass estimates by the BSFRF survey and the model for model estimates in 2018 (scenarios 18.0, 18.0a, 8.0b, 18.0c, 2b and 2b-old). The error bars are plus and minus 2 standard deviations of scenario 18.0.

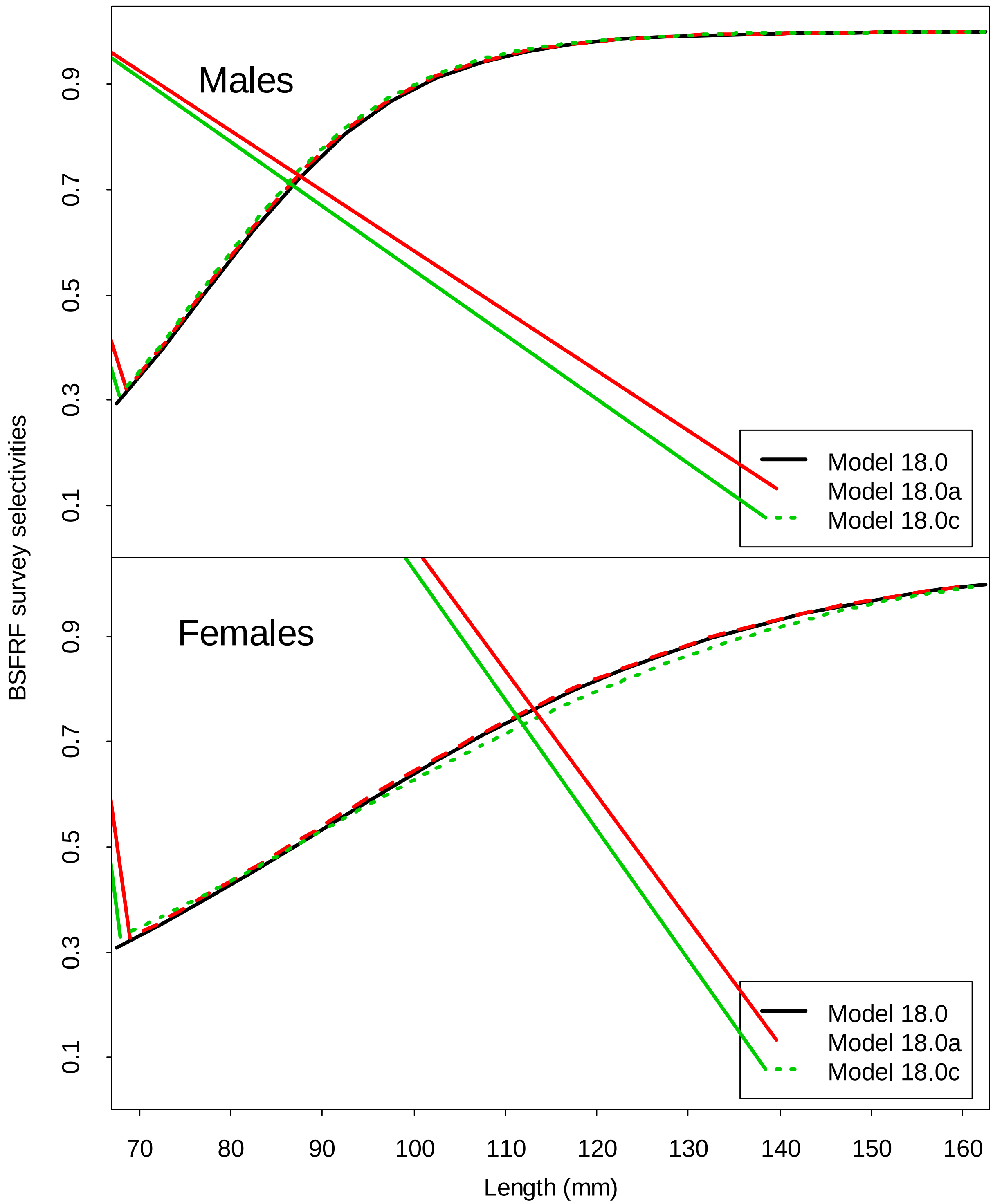


Figure 10d. Comparisons of estimated BSFRF survey selectivities with scenarios 18.0, 18.0a, and 18.0c. The catchability is assumed to be 1.0.

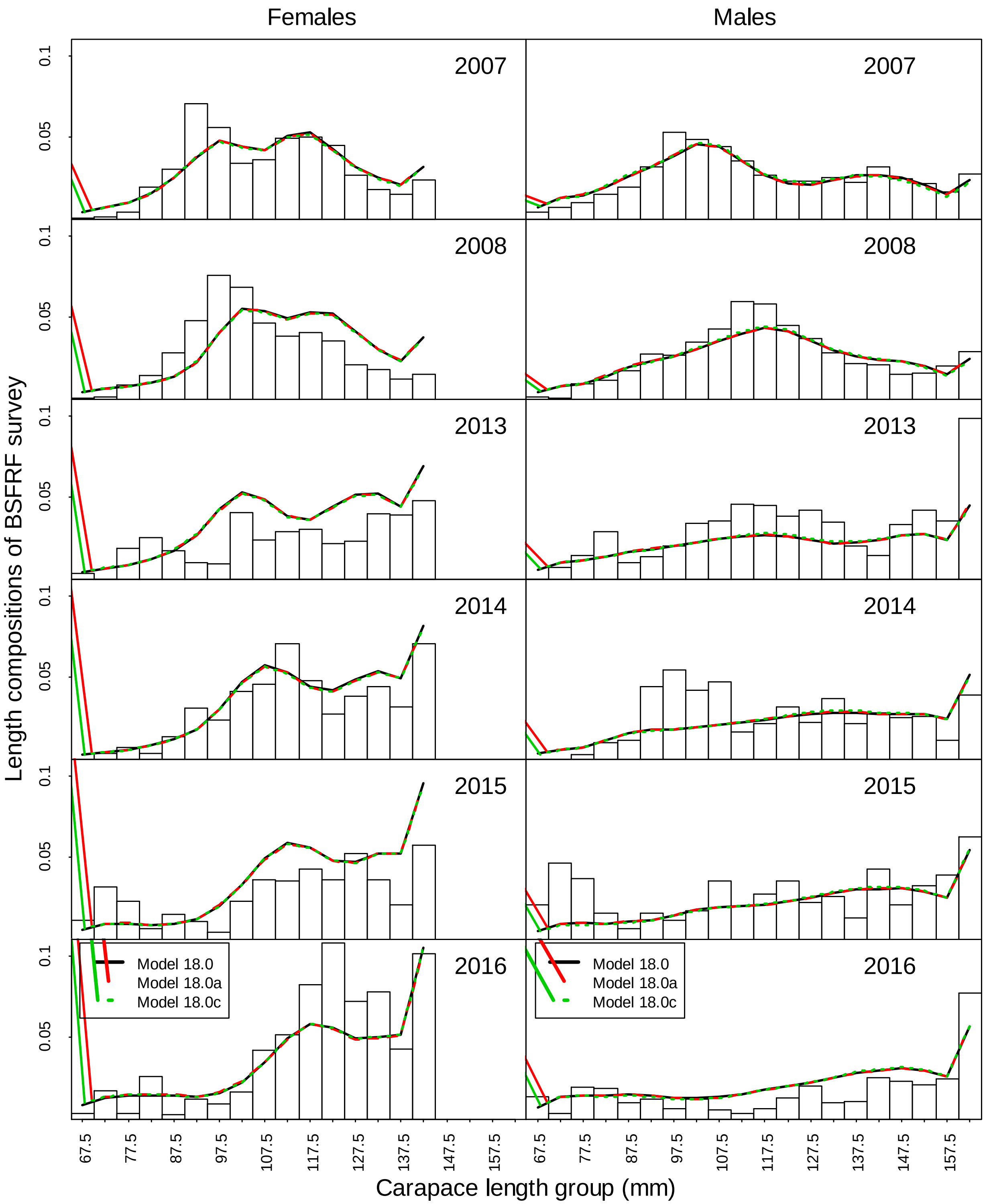


Figure 10e(18.0, 18.0a, & 18.0c). Comparisons of length compositions by the BSFRF survey and the model estimates during 2007-2008 and 2013-2016 with scenarios 18.0 (solid black), 18.0a (dashed red), and 18.0c (green lines).

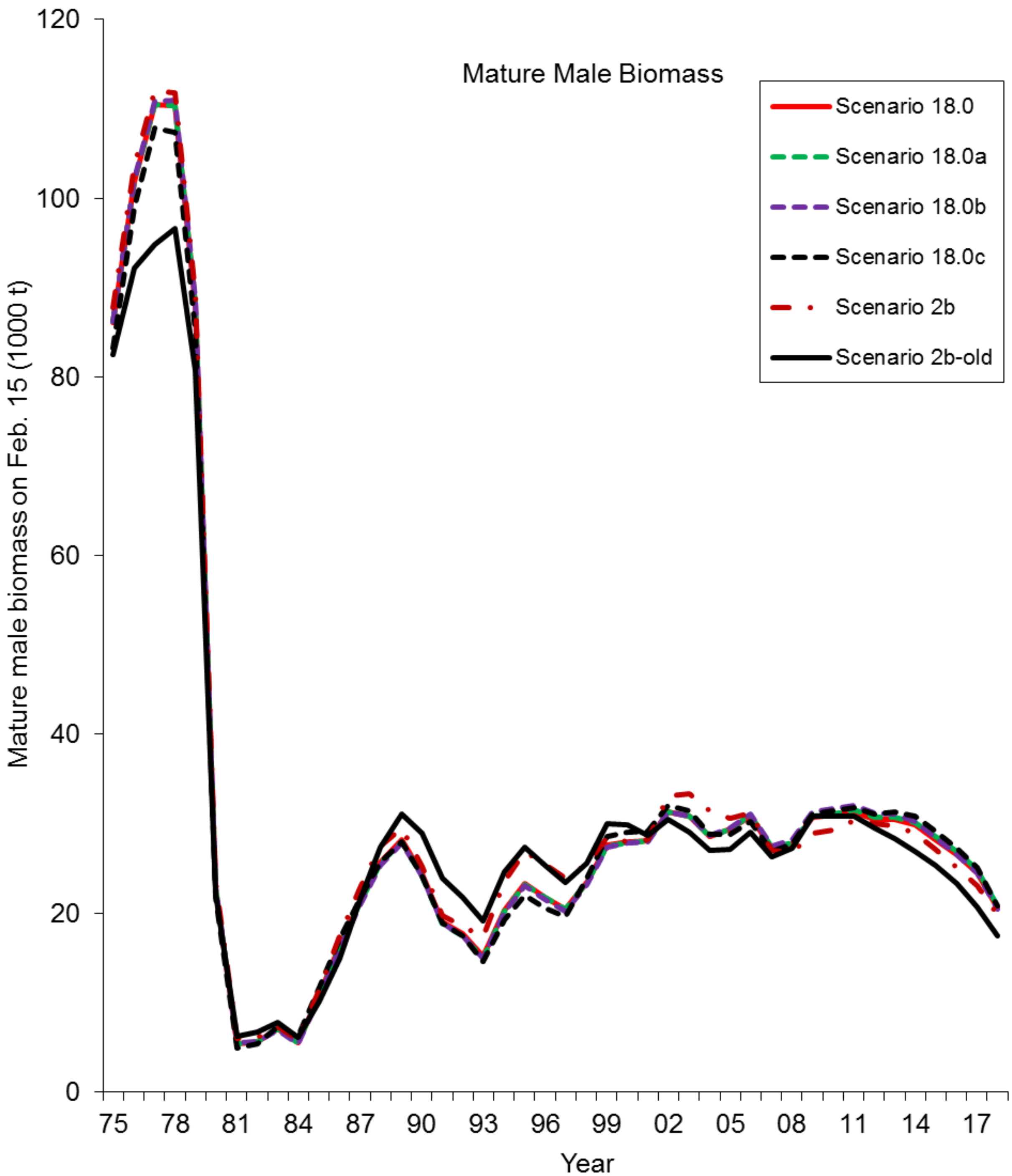


Figure 11. Estimated absolute mature male biomasses during 1975-2018 for scenarios 18.0, 18.0a, 18.0b, 18.0c, 2b, and 2b-old.

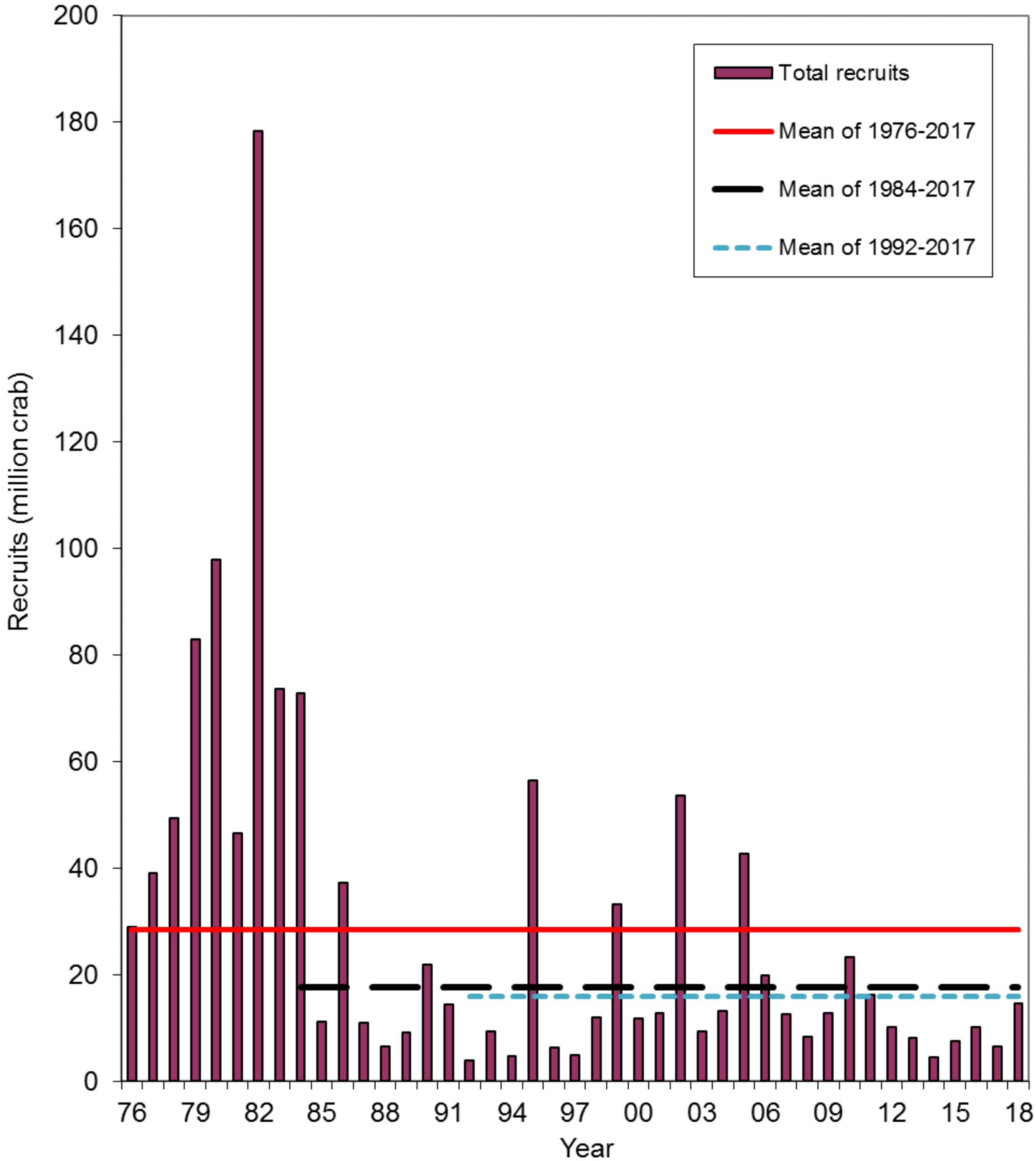


Figure 12(18.0). Estimated recruitment time series during 1976-2018 with scenario 18.0. Mean male recruits during 1984-2017 was used to estimate $B_{35\%}$.

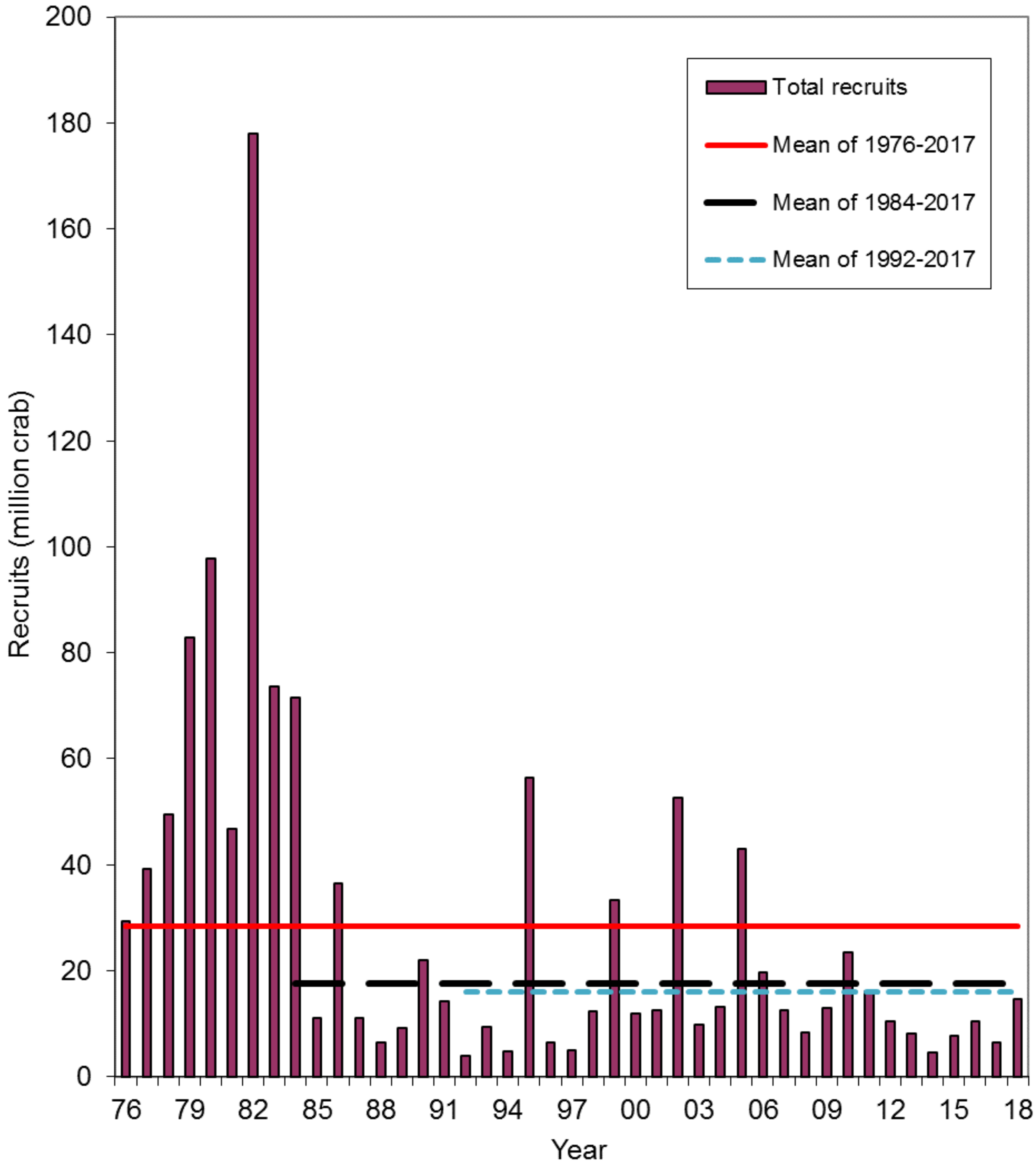


Figure 12(18.0a). Estimated recruitment time series during 1976-2018 with scenario 18.0a. Mean male recruits during 1984-2017 was used to estimate B35%.

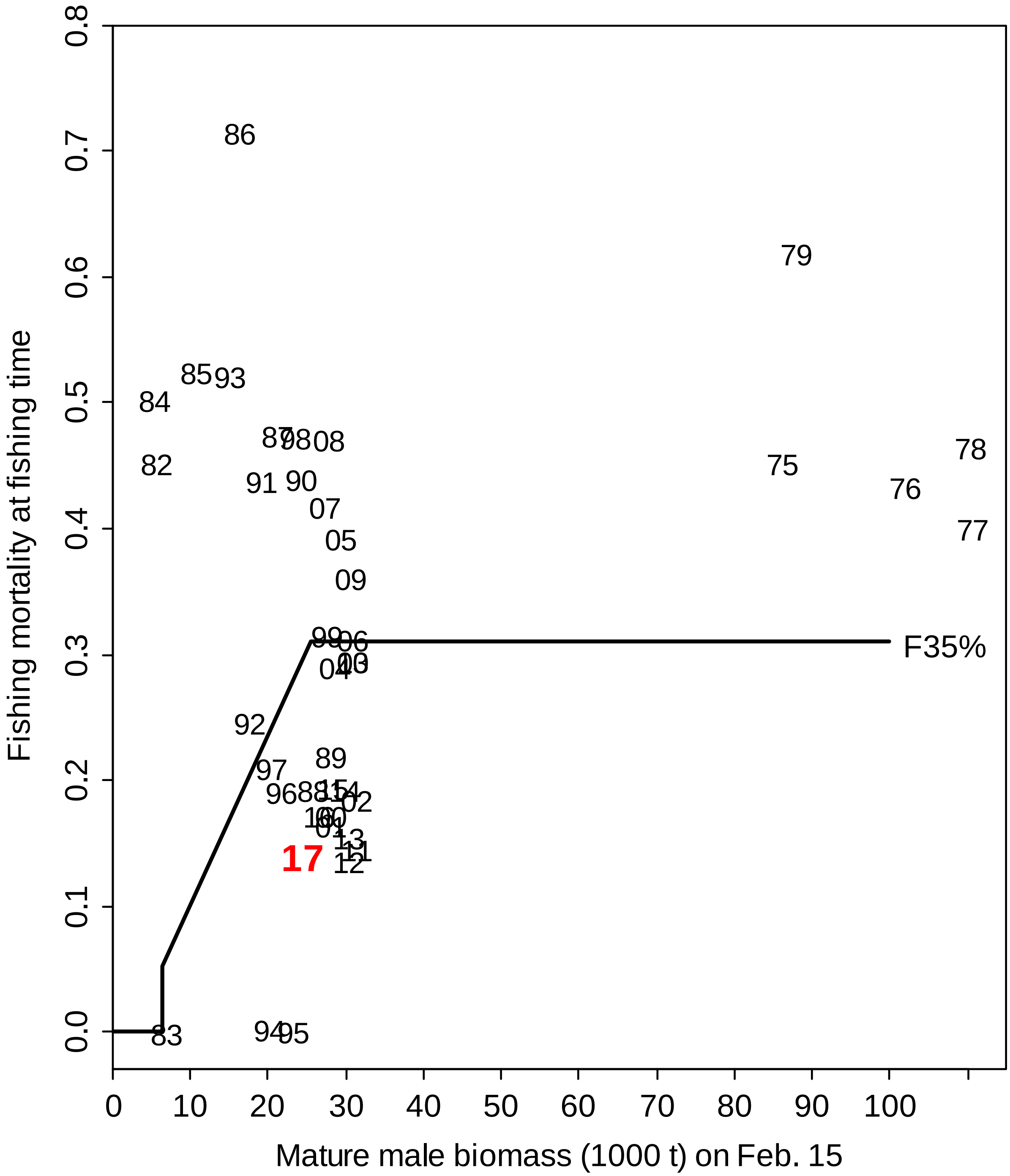


Figure 13(18.0). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2018 under scenario 18.0. Average of recruitment from 1984 to 2017 was used to estimate B_{MSY}. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

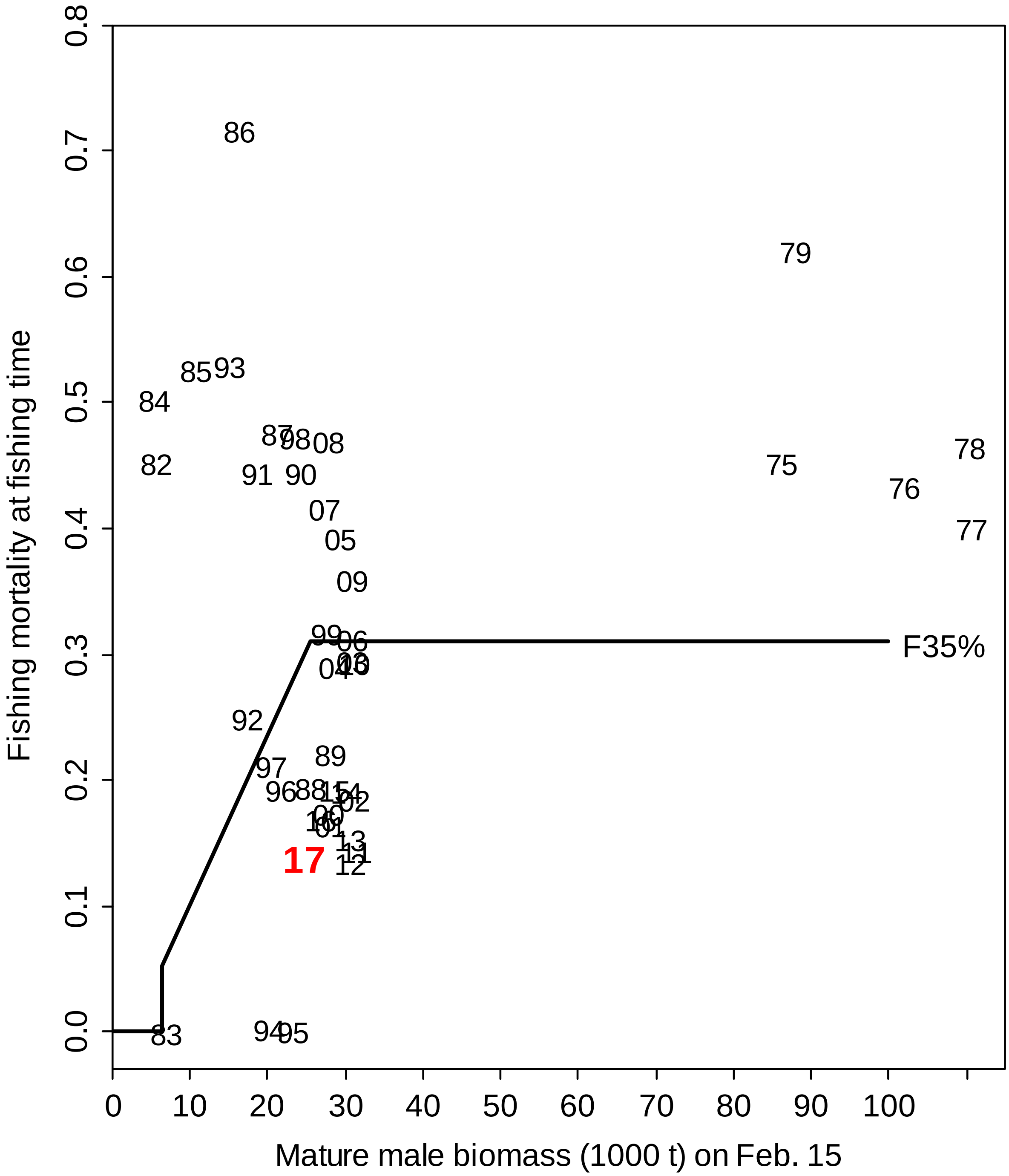


Figure 13(18.0a). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2018 under scenario 18.0a. Average of recruitment from 1984 to 2017 was used to estimate BMSY. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

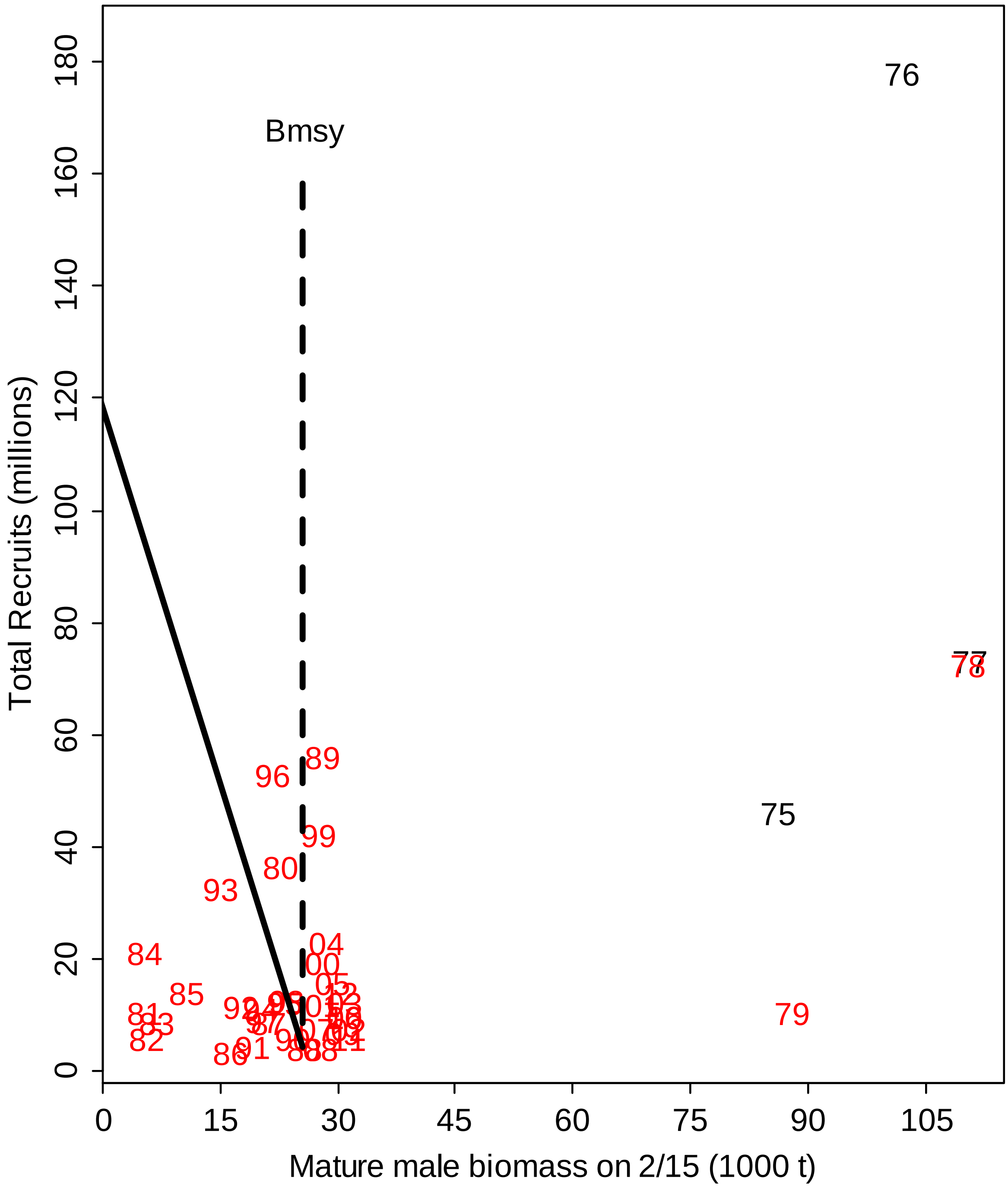


Figure 14a. Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab with pot handling mortality rate of 0.2 under scenario 18.0. Numerical labels are years of mating, and the vertical dotted line is the estimated $B_{35\%}$ based on the mean recruitment level during 1984 to 2017.

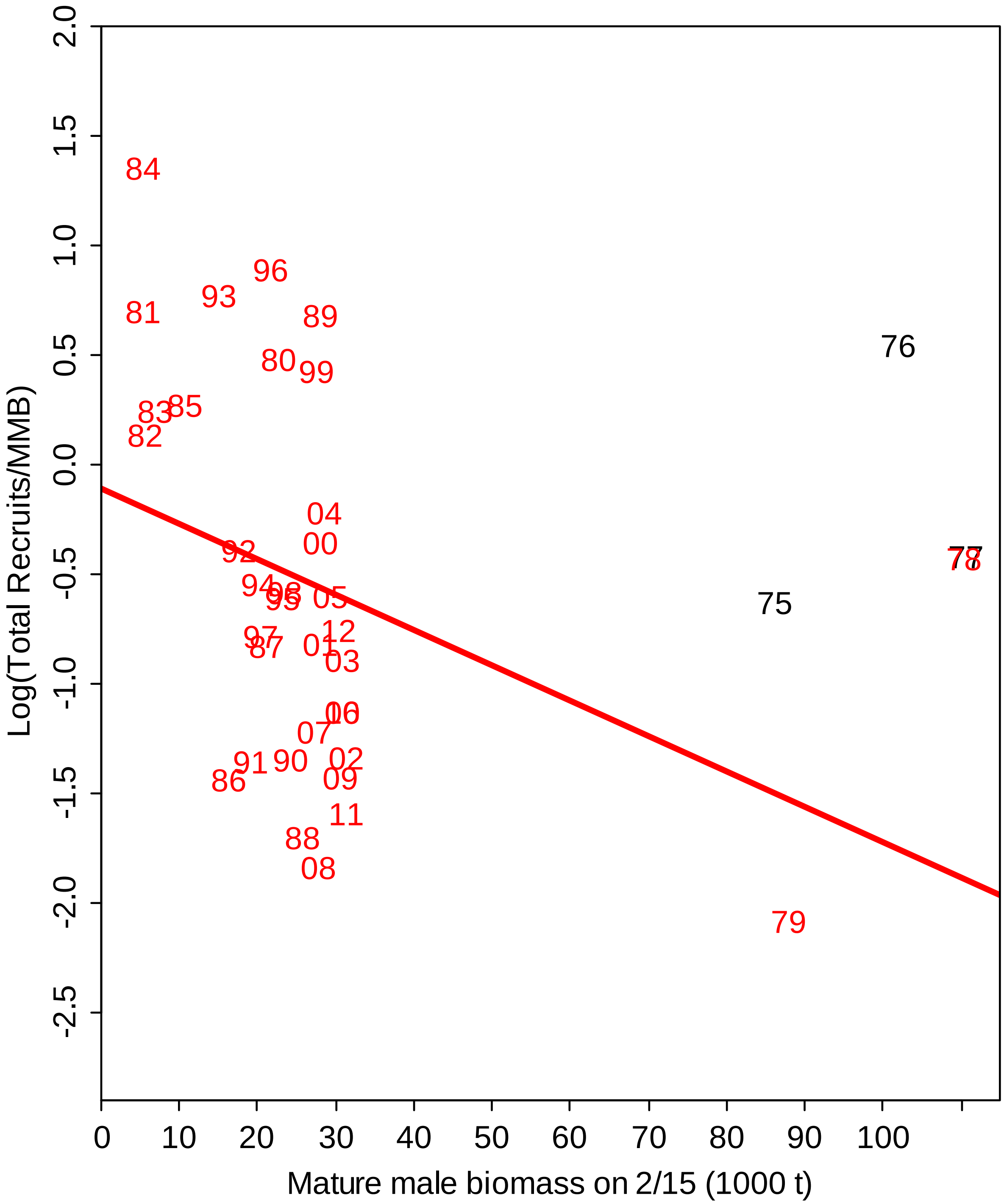


Figure 14b. Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate of 0.2 under scenario 18.0. Numerical labels are years of mating, and the line is the regression line for data of 1978-2012.

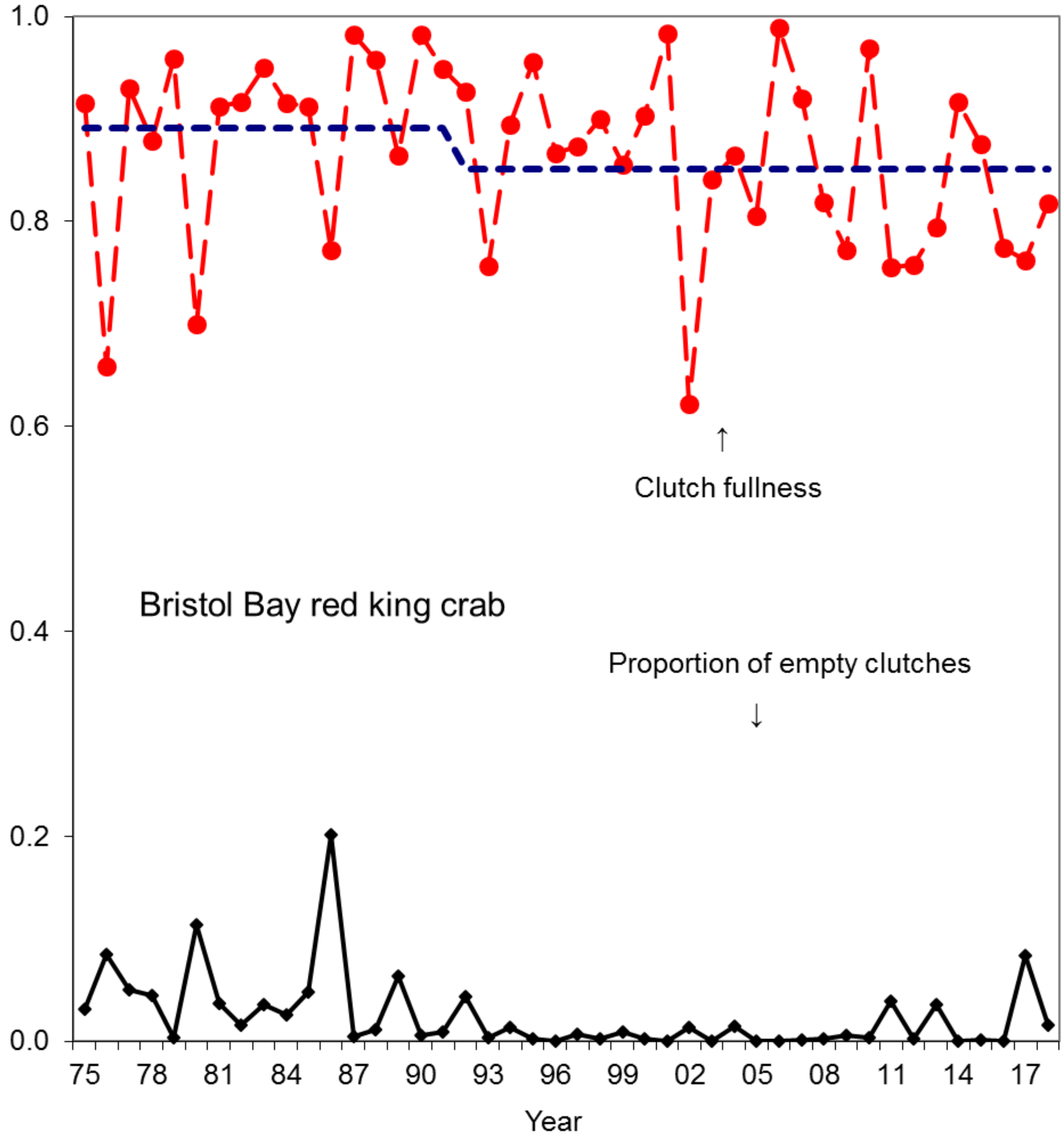


Figure 15. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crab >89 mm CL from 1975 to 2018 from survey data. Oldshell females were excluded. The blue dashed line is the mean clutch fullness during two periods before 1992 and after 1991.

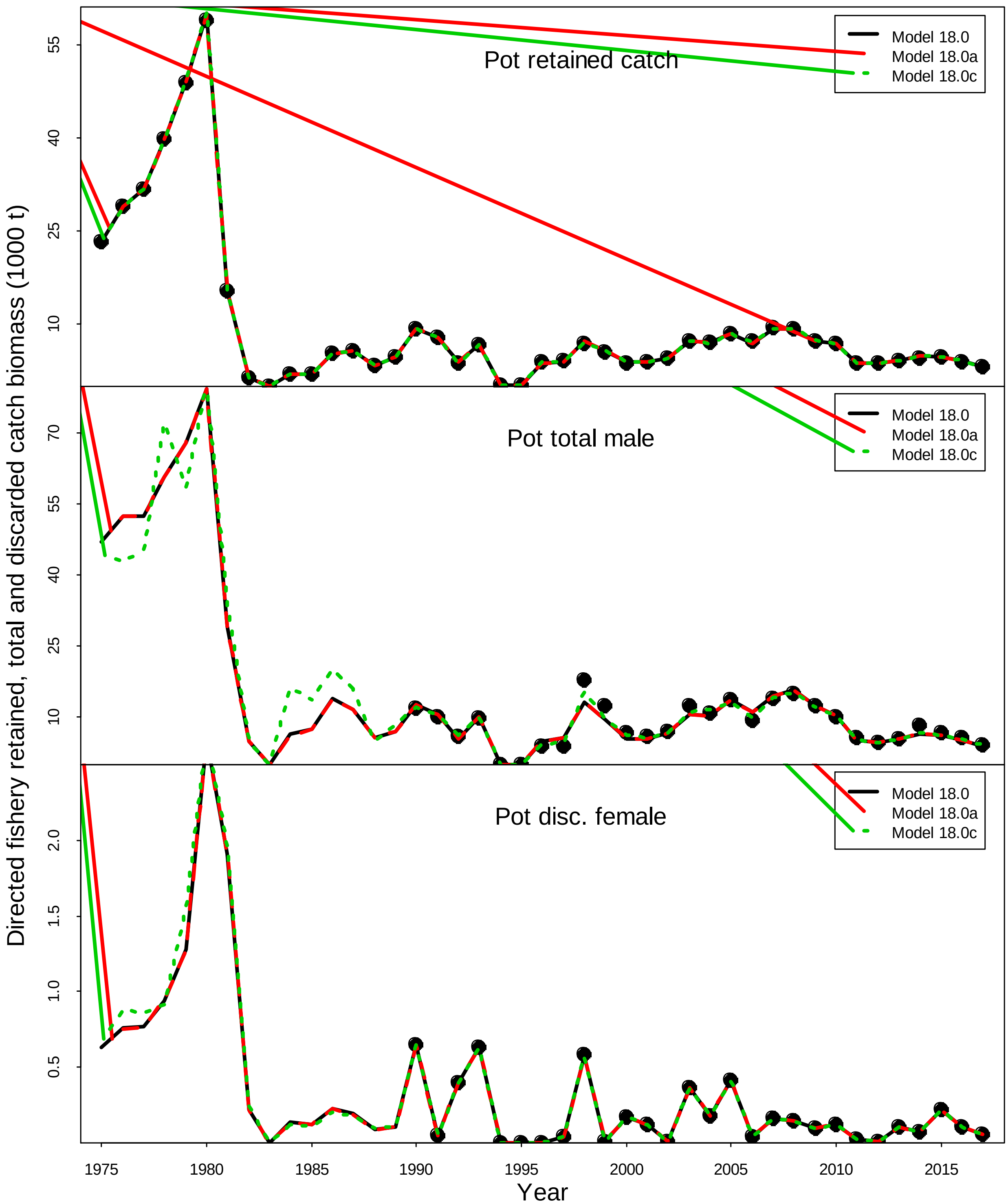


Figure 16a. Observed and predicted catch mortality biomass under scenarios 18.0(solid black), 18.0a (dashed red), and 18.0c (green lines). Mortality biomass is equal to caught biomass times a handling mortality rate.

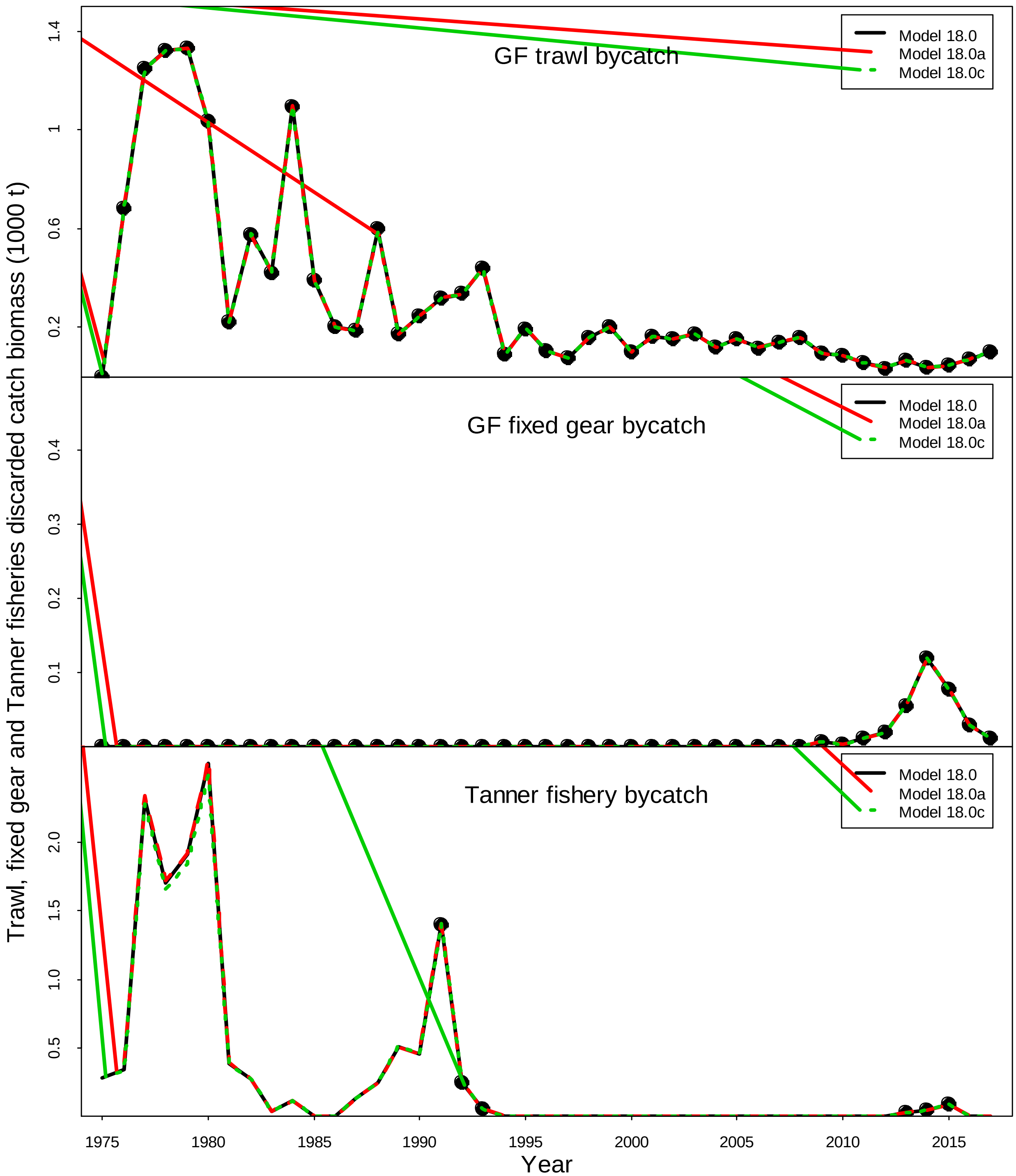


Figure 16b. Observed and predicted bycatch mortality biomass from groundfish fisheries and the Tanner crab fishery under scenarios 18.0(solid black), 18.0a (dashed red), and 18.0c (green lines). Mortality biomass is equal to caught biomass times a handling mortality rate. Pot, Tanner crab, fixed gear 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.

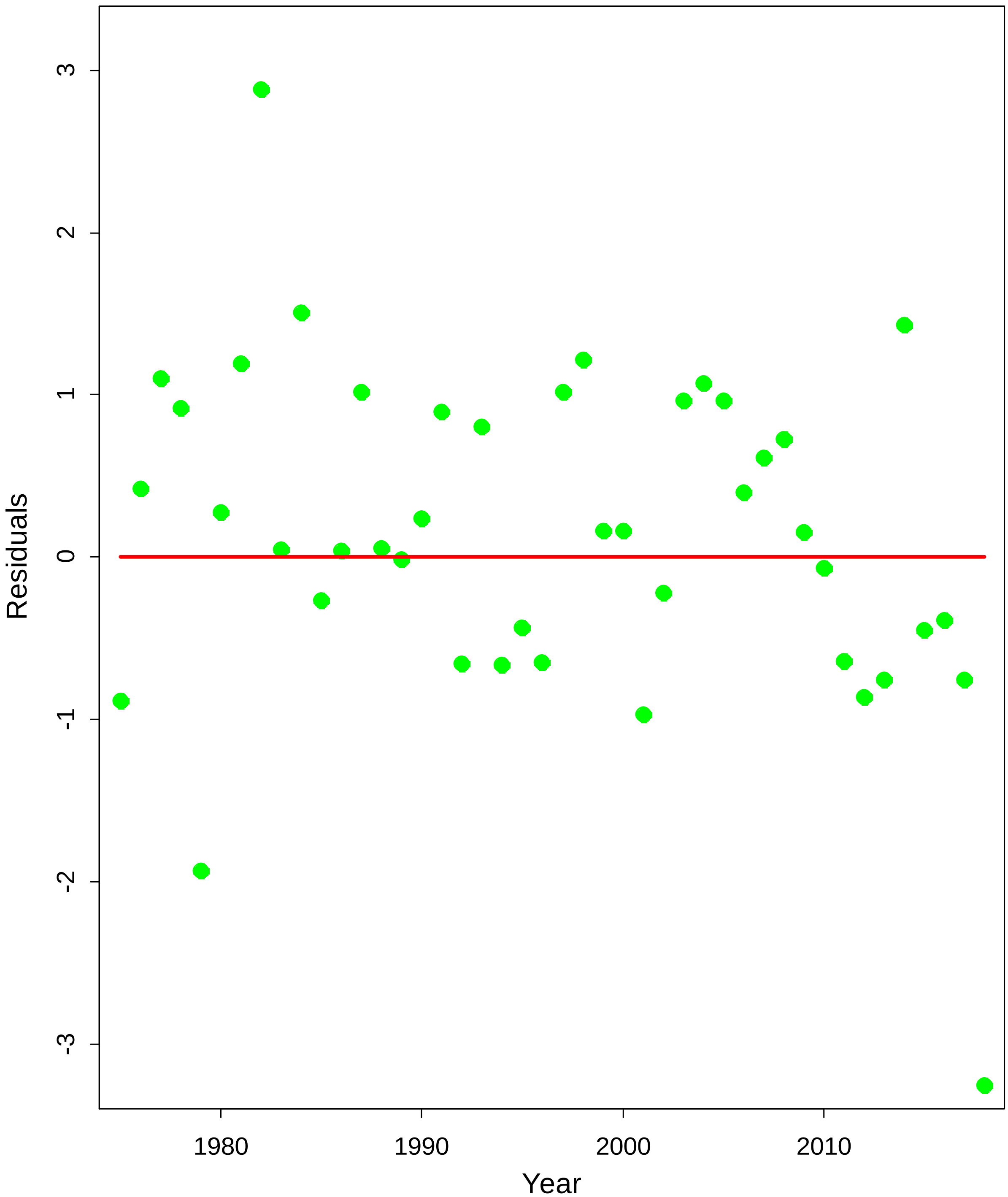


Figure 17(18.0). Standardized residuals of total survey biomass under scenario 18.0. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

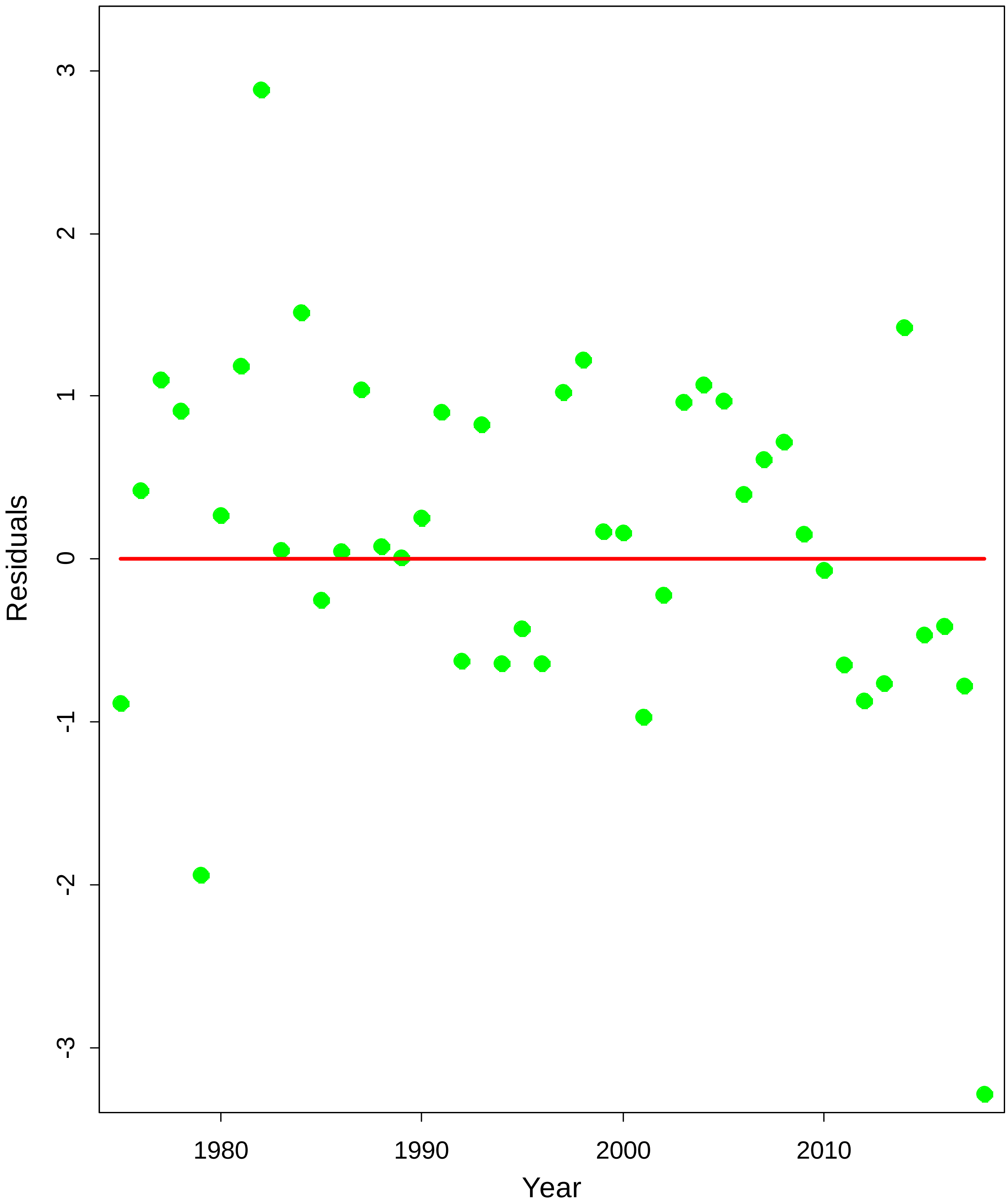


Figure 17(18.0a). Standardized residuals of total survey biomass under scenario 18.0a. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

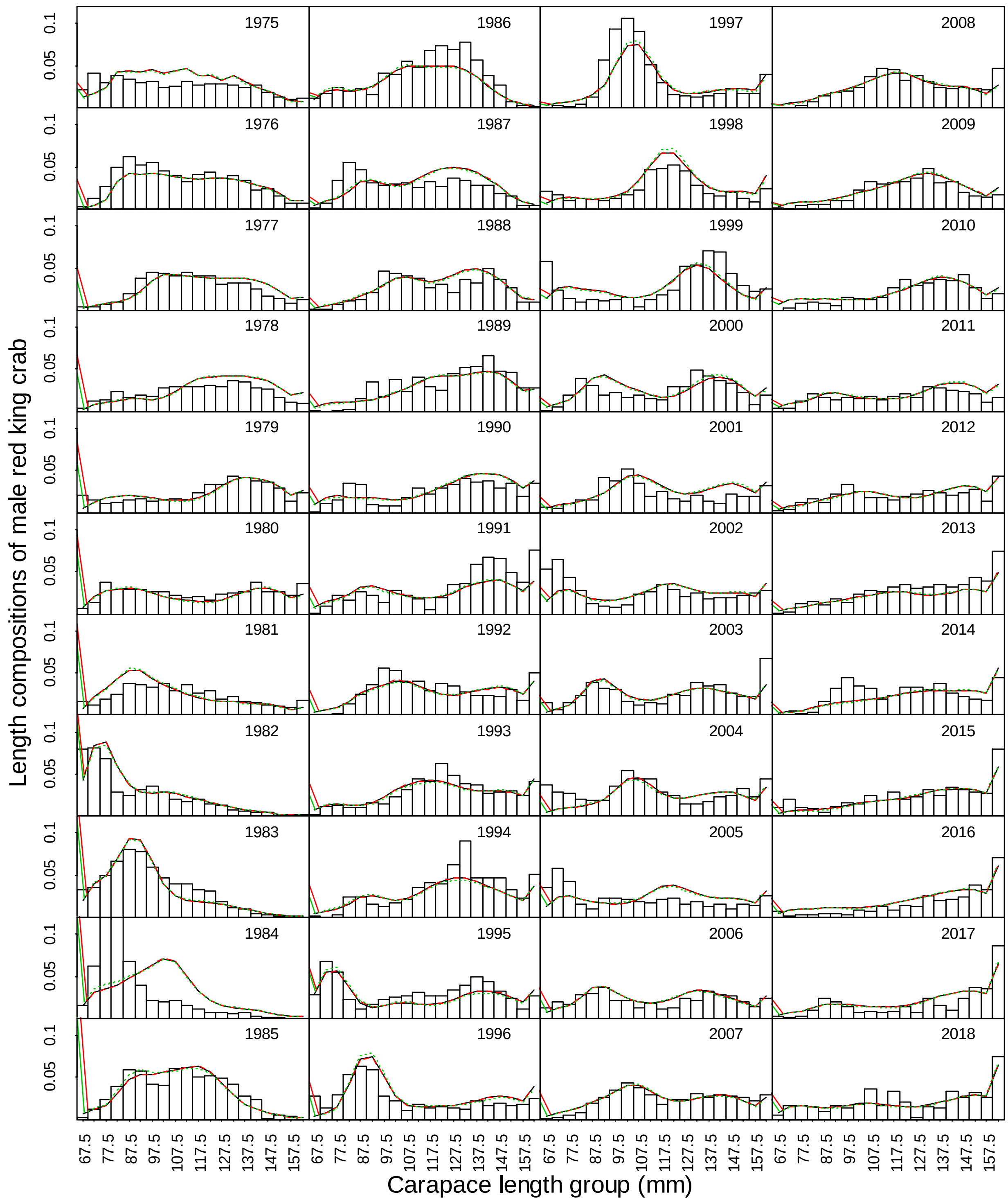


Figure 18(18.0, 18.0a & 18.0c). Comparison of area-swept and model estimated NMFS survey length frequencies of Bristol Bay male red king crab by year under scenarios 18.0(solid black), 18.0a (dashed red), and 18.0c (green lines). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

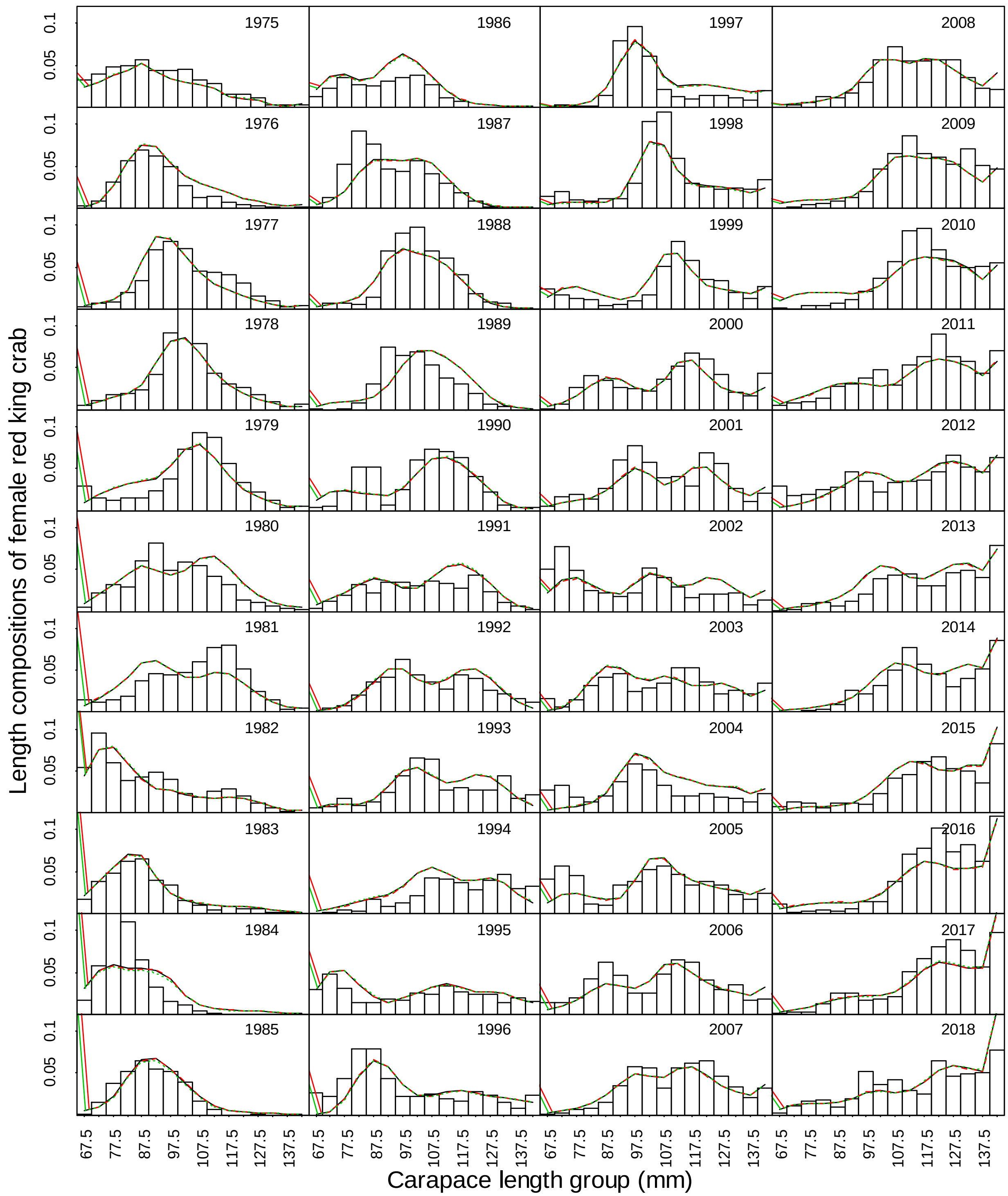


Figure 19(18.0, 18.0a & 18.0c). Comparison of area-swept and model estimated NMFS survey length frequencies of Bristol Bay female red king crab by year under scenarios 18.0(solid black), 18.0a (dashed red), and 18.0c (green lines). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

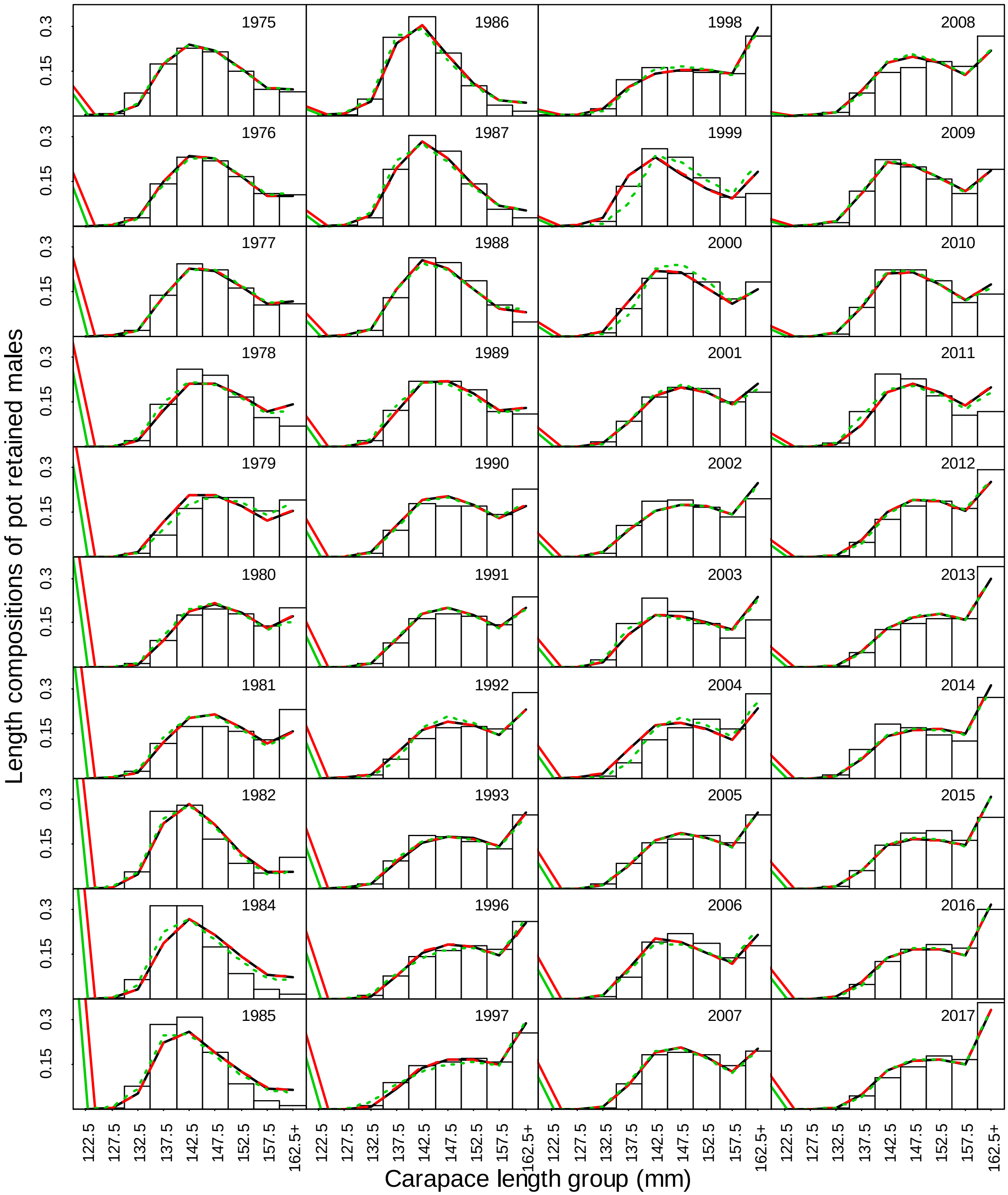


Figure 20(18.0, 18.0a & 18.0c). Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under scenarios 18.0(solid black), 18.0a (dashed red), and 18.0c (green lines). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

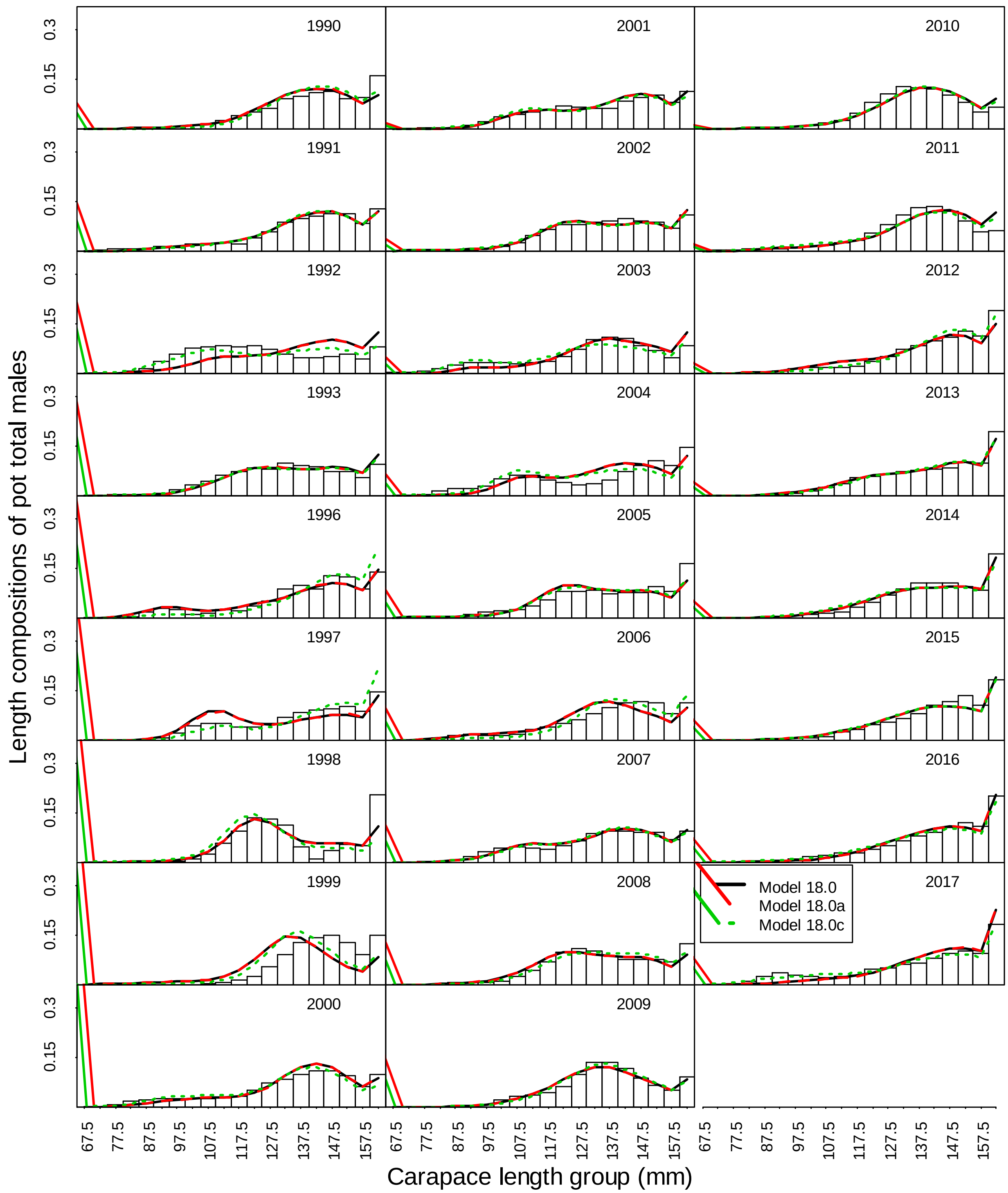


Figure 21(18.0, 18.0a & 18.0c). Comparison of observer and model estimated total observer length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under scenarios 18.0(solid black), 18.0a (dashed red), and 18.0c (green lines). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

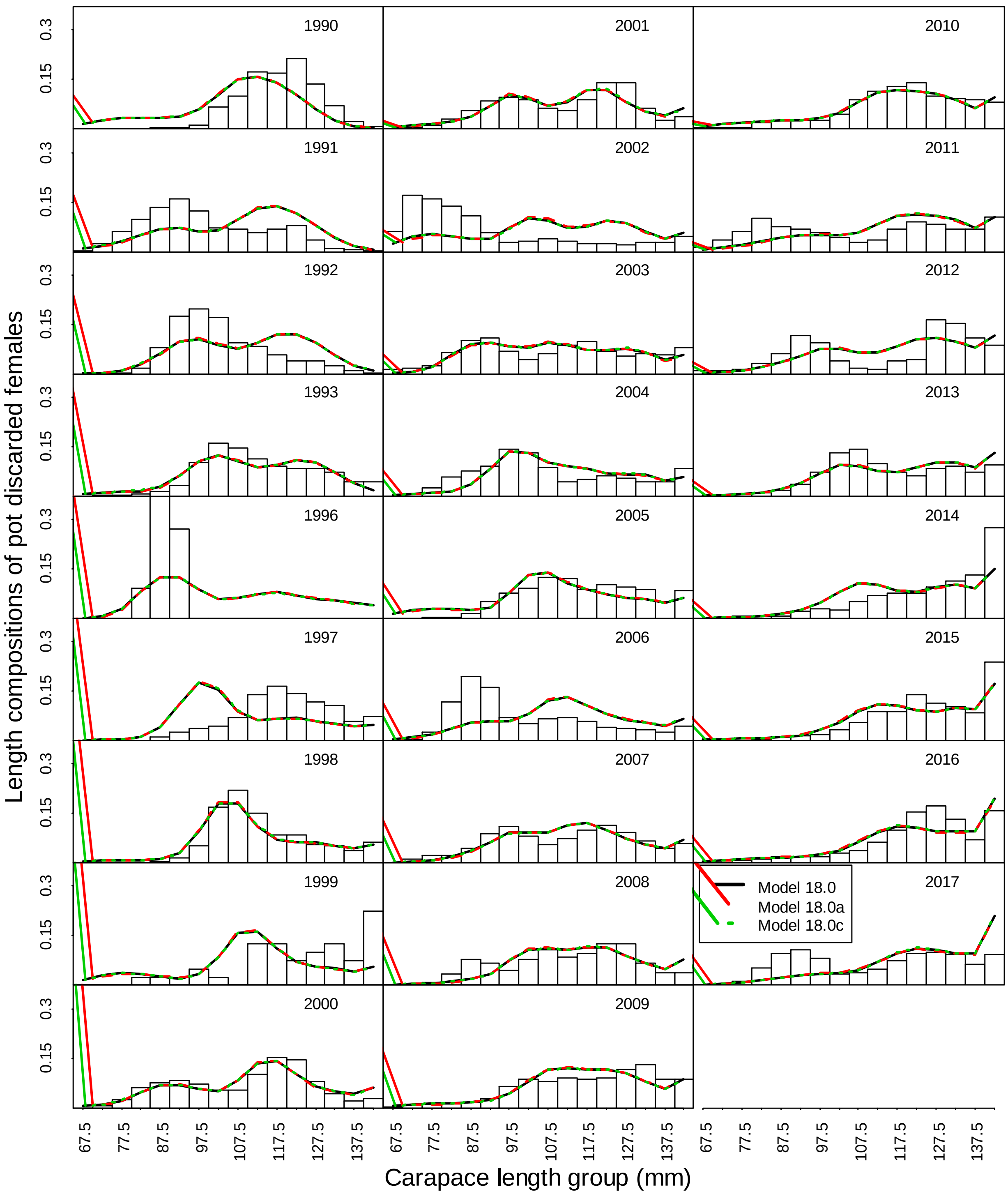


Figure 22(18.0, 18.0a & 18.0c). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the directed pot fishery under scenarios 18.0(solid black), 18.0a (dashed red), and 18.0c (green lines). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

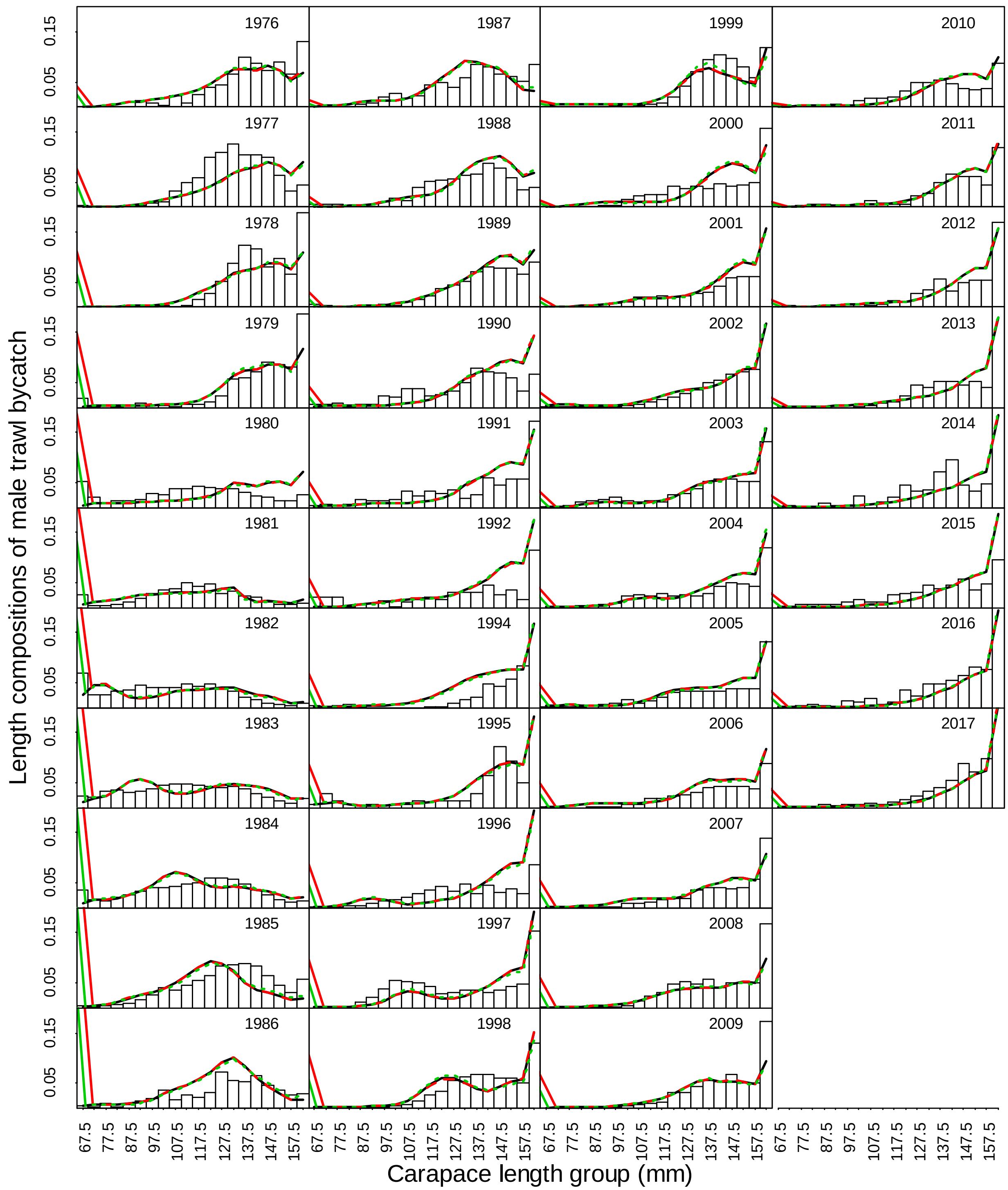


Figure 23(18.0, 18.0a & 18.0c). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish trawl fisheries under scenarios 18.0(solid black), 18.0a (dashed red), and 18.0c (green lines). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

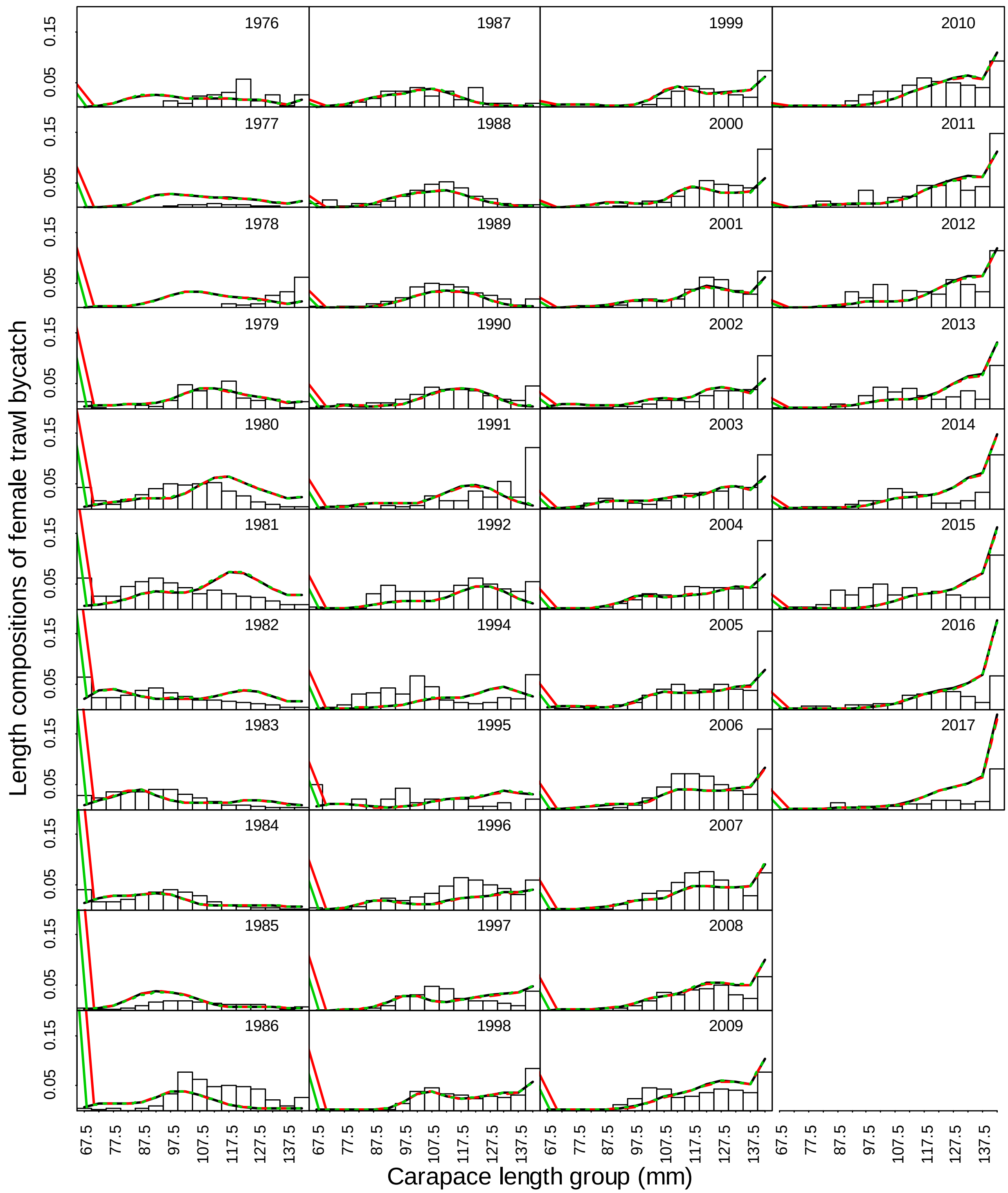


Figure 23(18.0, 18.0a & 18.0c). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish trawl fisheries under scenarios 18.0(solid black), 18.0a (dashed red), and 18.0c (green lines). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

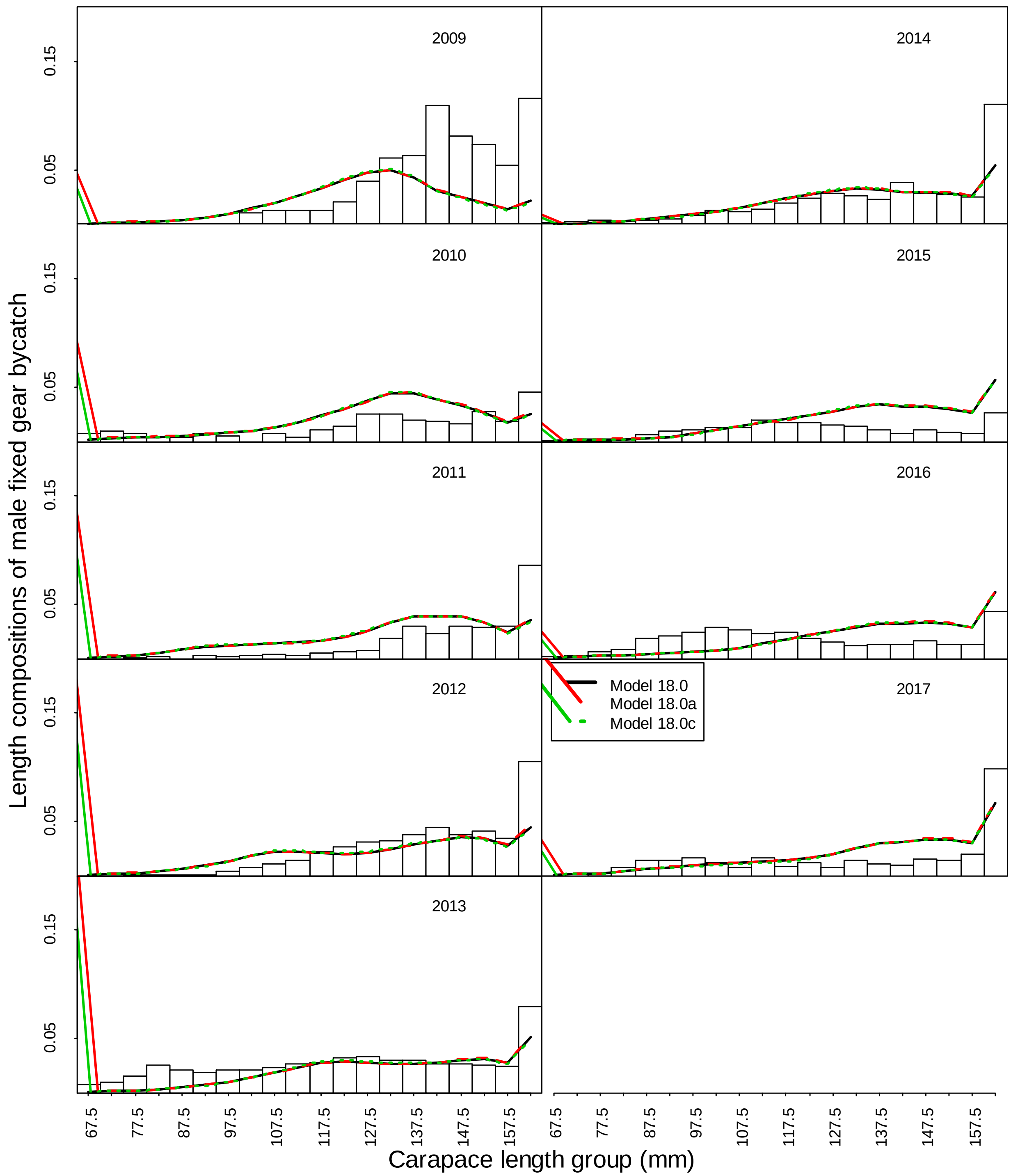


Figure 24(18.0, 18.0a & 18.0c). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish fixed gear fisheries under scenarios 18.0(solid black), 18.0a (dashed red), and 18.0c (green lines). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

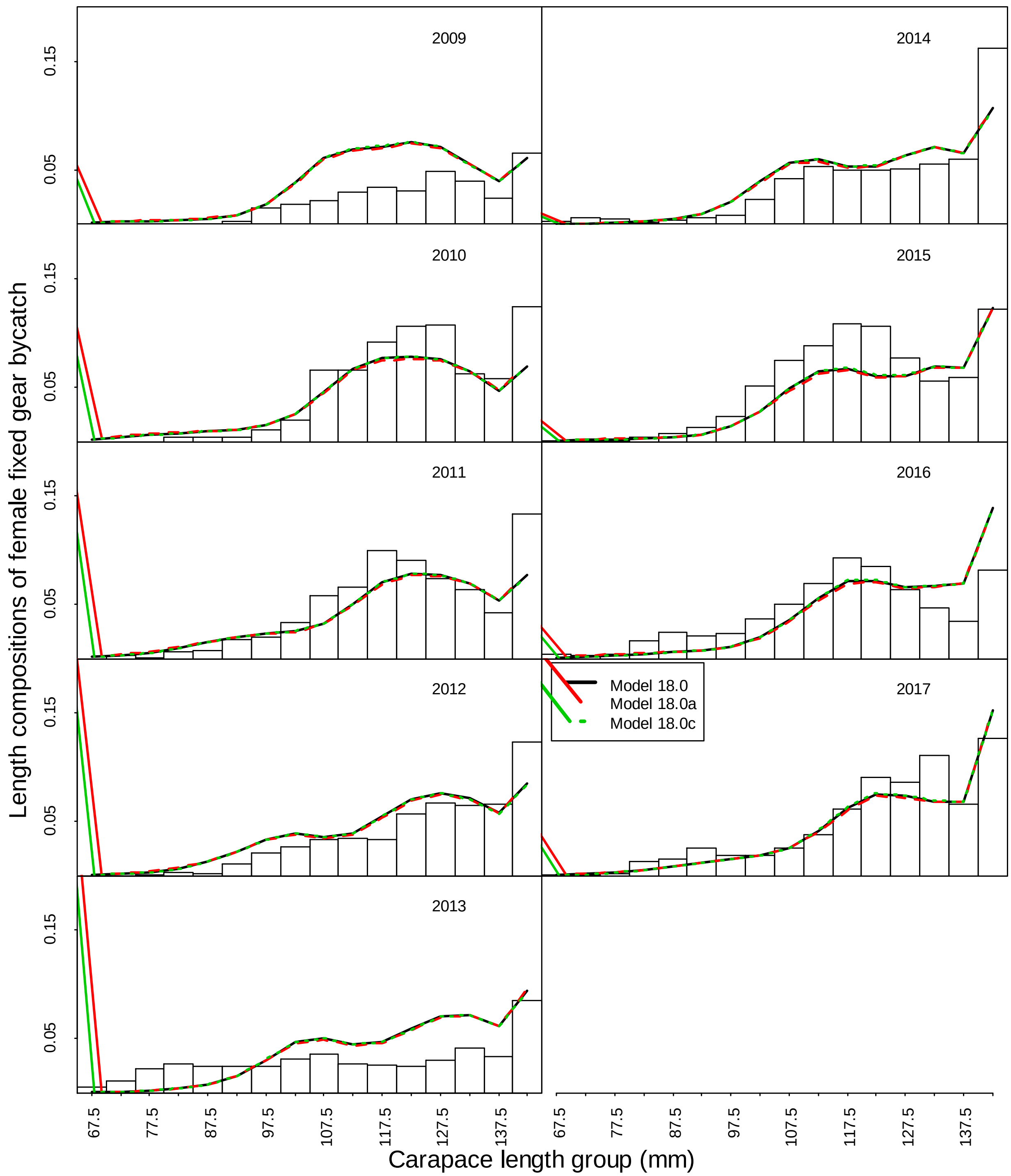


Figure 24(18.0, 18.0a & 18.0c). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish fixed gear fisheries under scenarios 18.0 (solid black), 18.0a (dashed red), and 18.0c (green lines). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

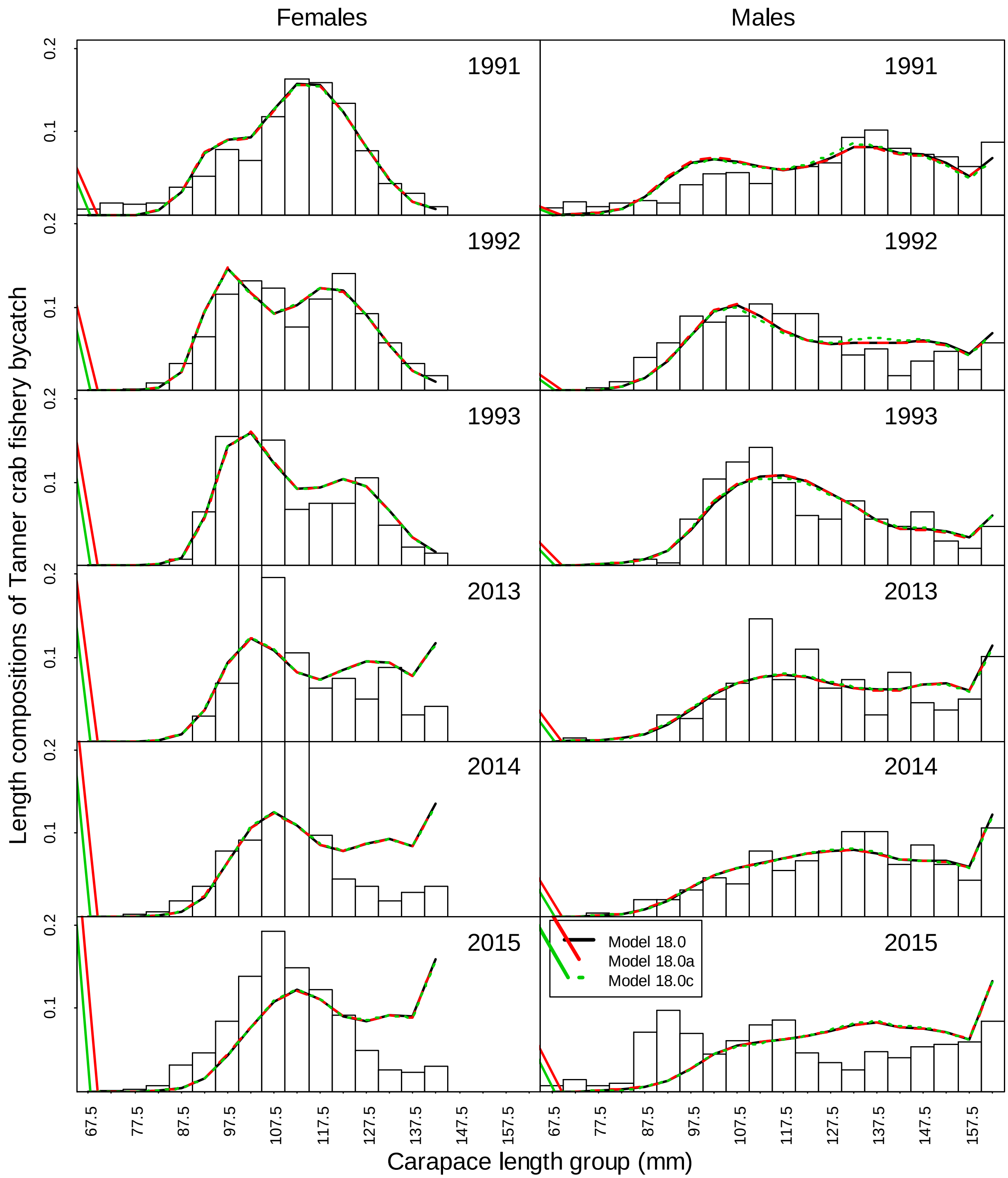


Figure 24(18.0, 18.0a & 18.0c). Comparison of observer and model estimated discarded length frequencies of Bristol Bay red king crab by year in the Tanner crab fishery under scenarios 18.0(solid black), 18.0a (dashed red), and 18.0c (green lines). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

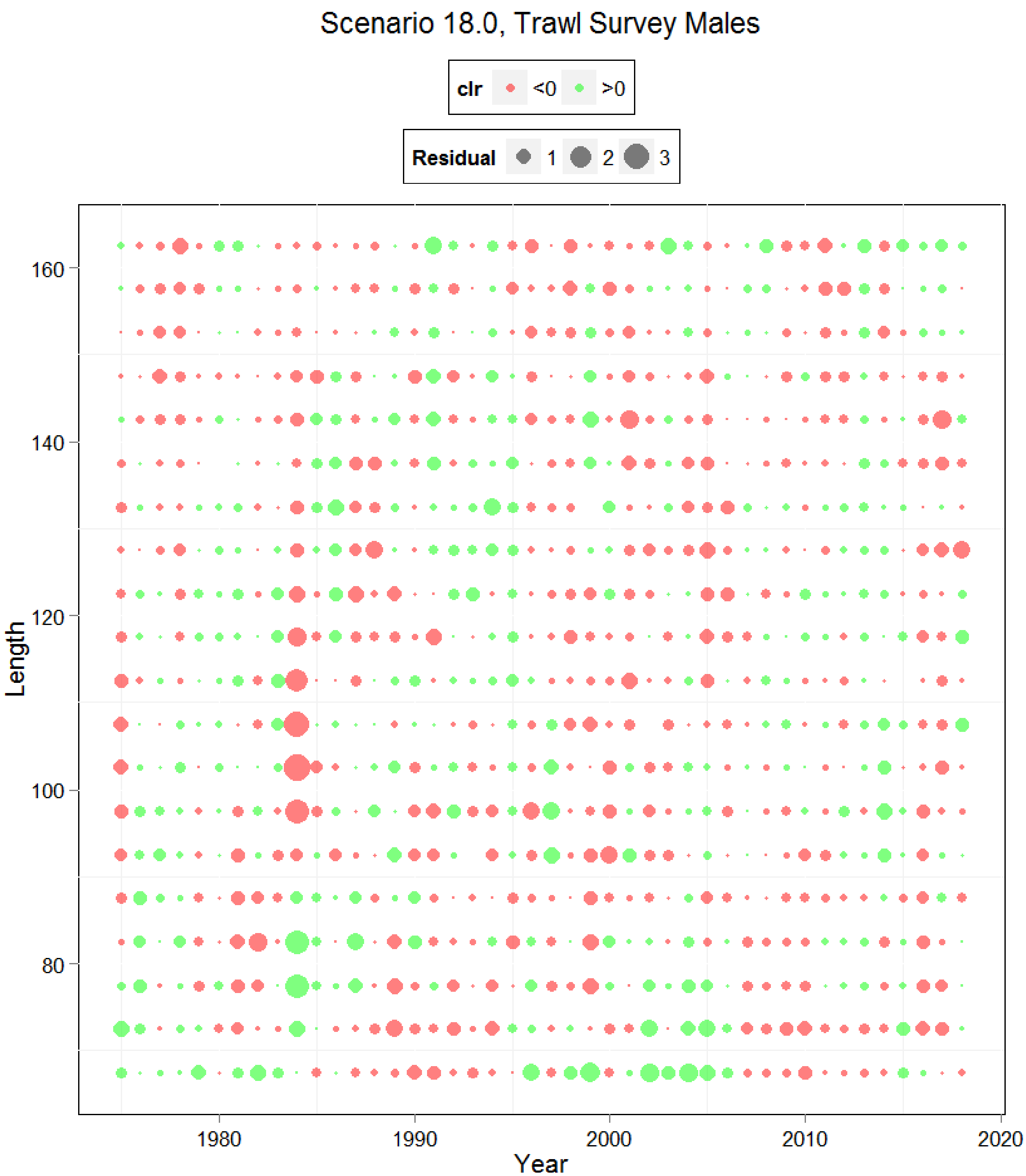


Figure 25(18.0). Standardized residuals of proportions of survey male red king crab by year and carapace length (mm) under scenario 18.0. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2,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

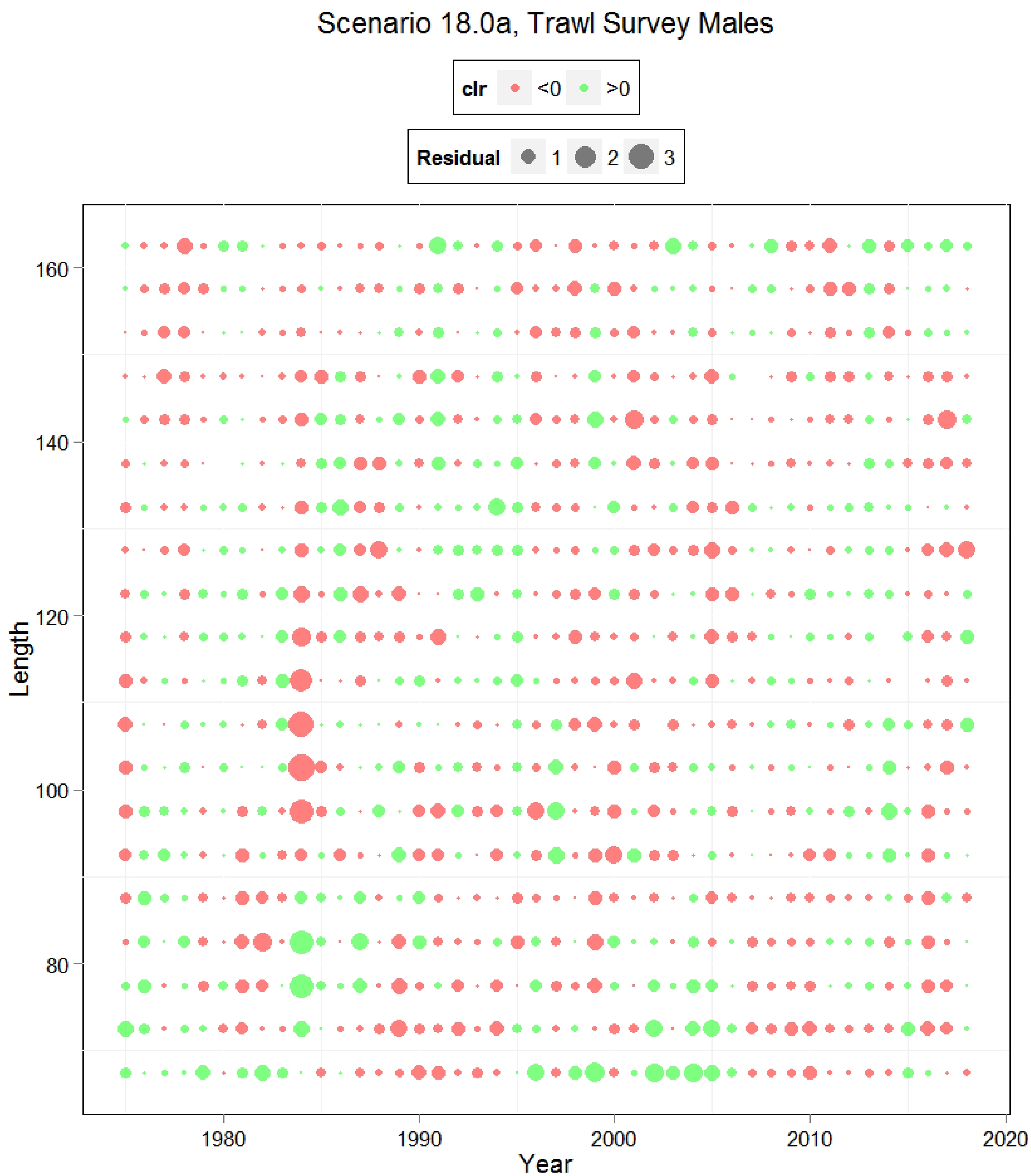


Figure 25(18.0a). Standardized residuals of proportions of survey male red king crab by year and carapace length (mm) under scenario 18.0a. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be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

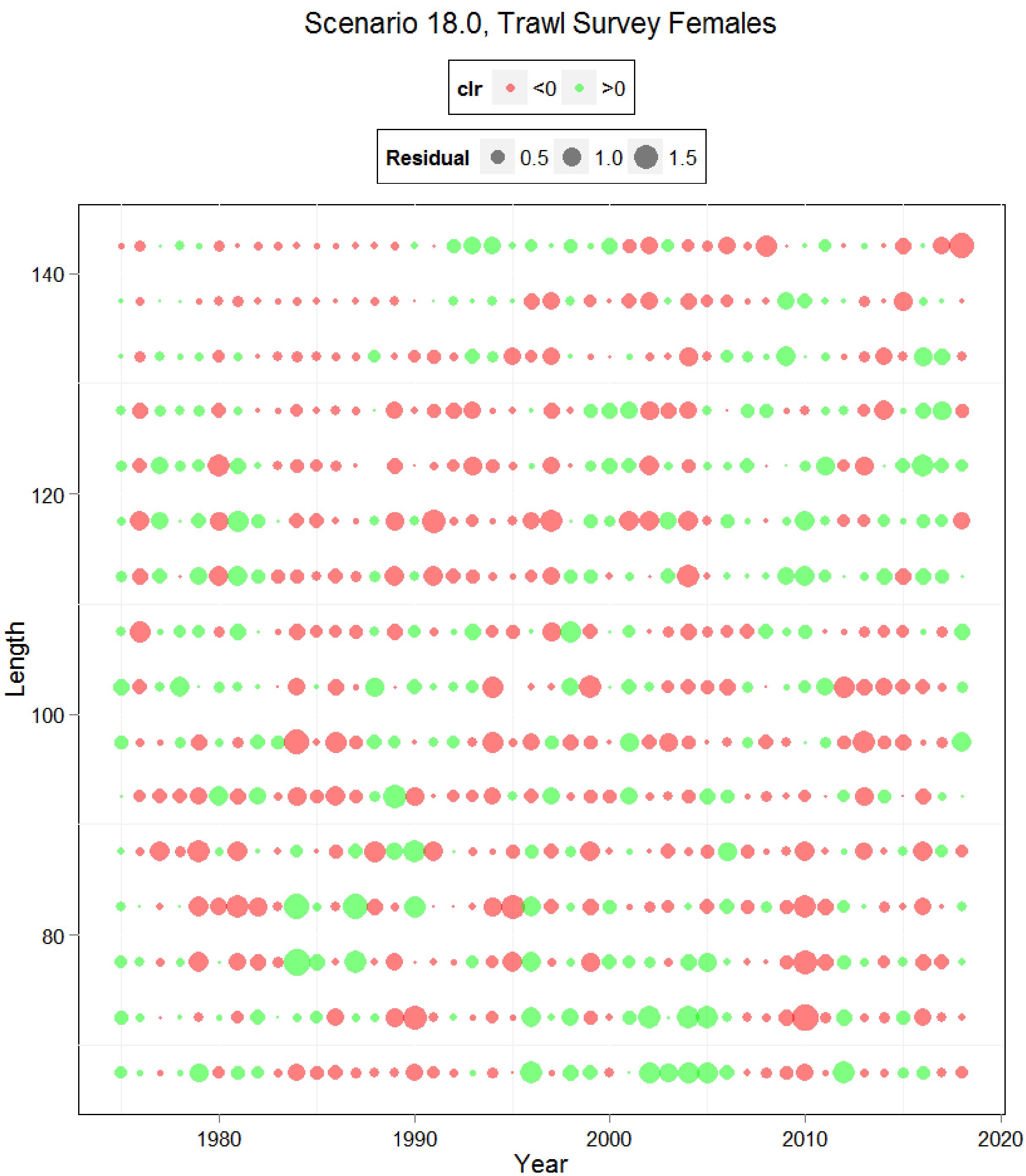


Figure 25(18.0). Standardized residuals of proportions of survey female red king crab by year and carapace length (mm) under scenario 18.0. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be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

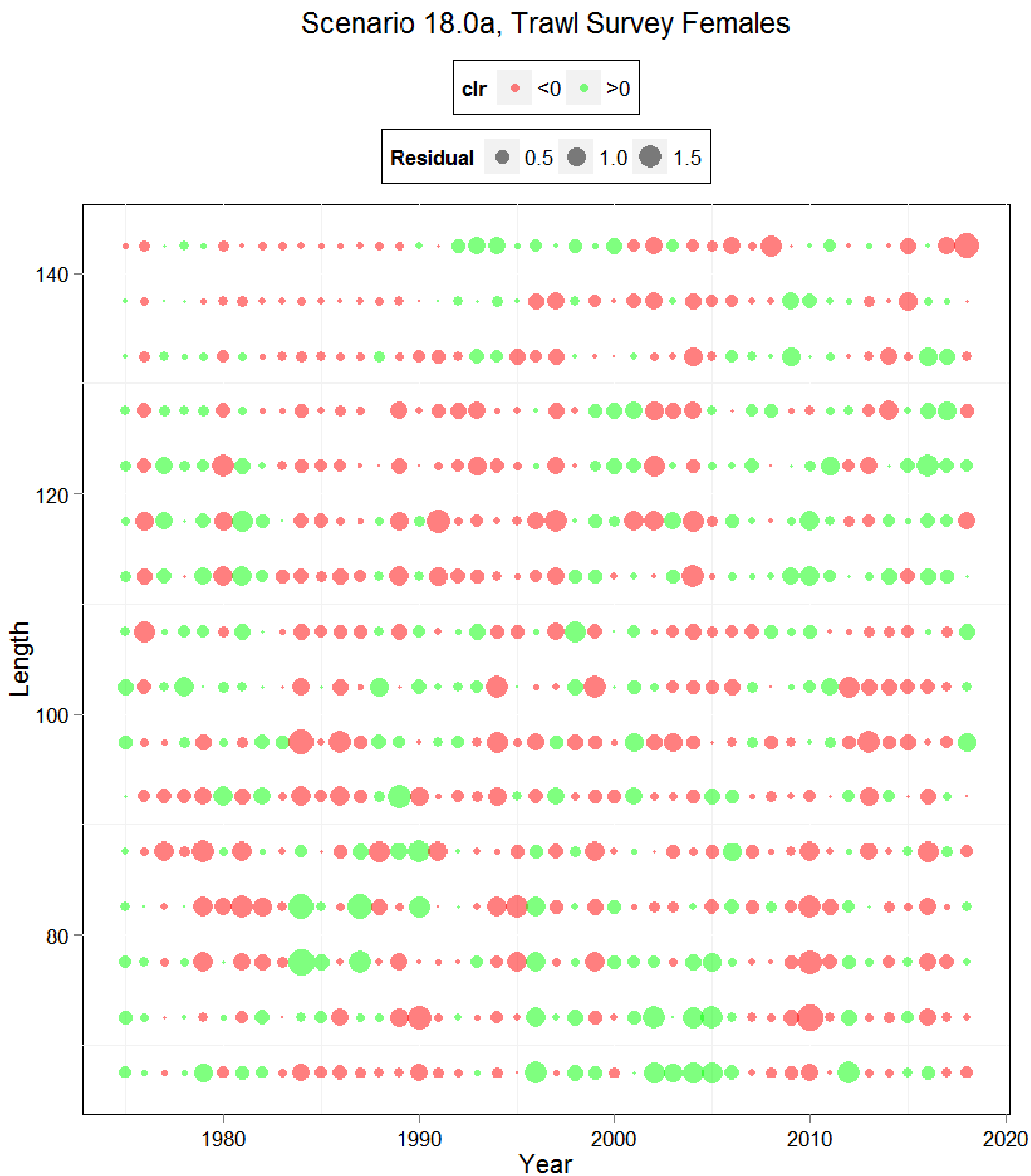
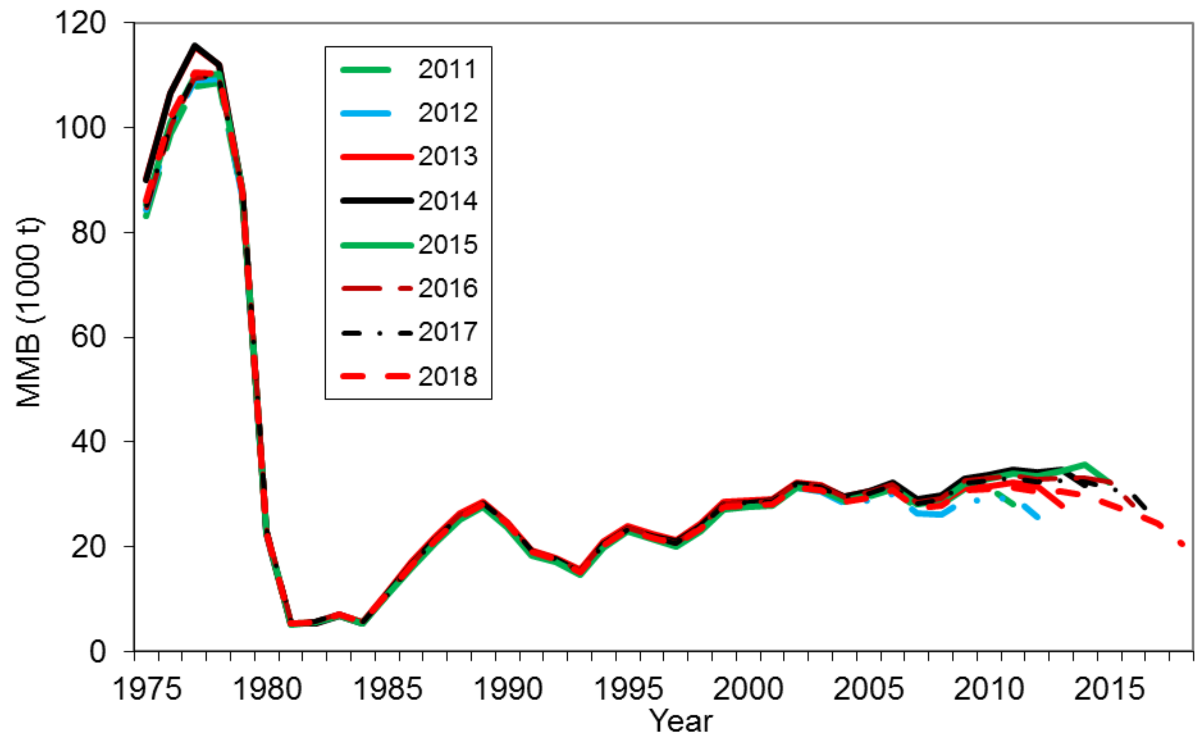


Figure 25(18.0a). Standardized residuals of proportions of survey female red king crab by year and carapace length (mm) under scenario 18.0a. Green circles are positive residuals, and red circles are negative residuals. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be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



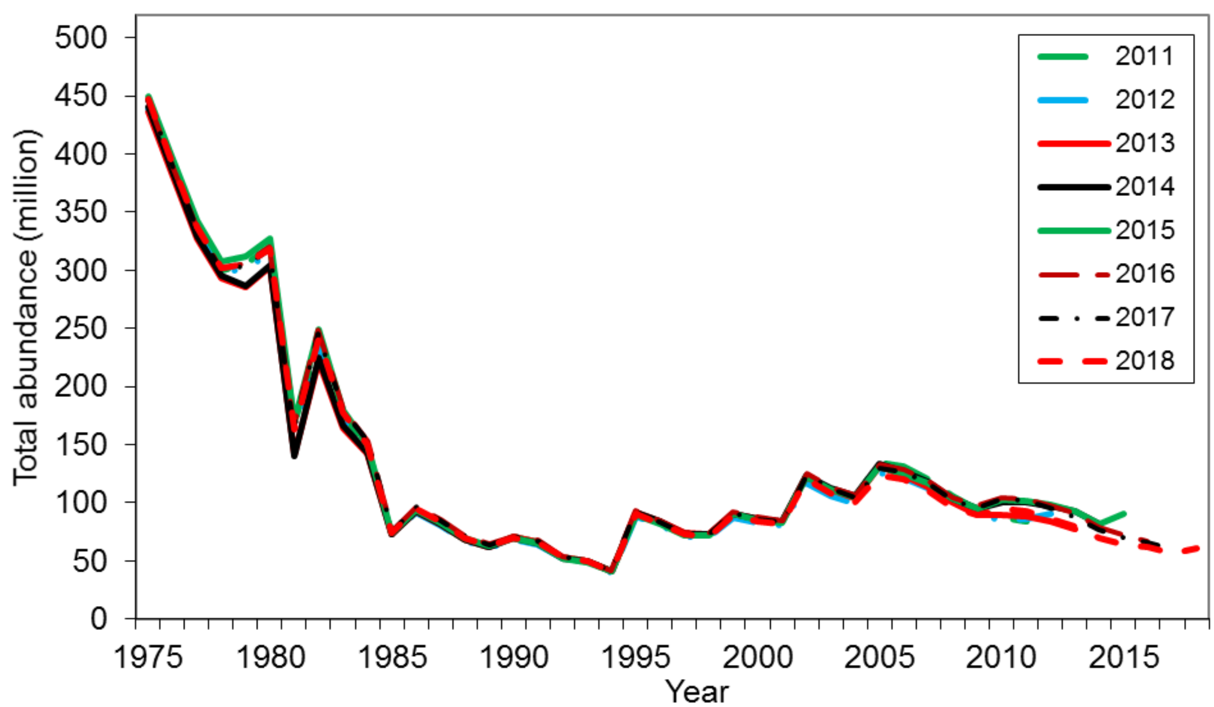


Figure 27. Comparison of hindcast estimates of mature male biomass on Feb. 15 (top) and total abundance (bottom) of Bristol Bay red king crab from 1975 to 2018 made with terminal years 2012-2018 with scenario 18.0. These are results of the 2018 model. Legend shows the terminal year. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

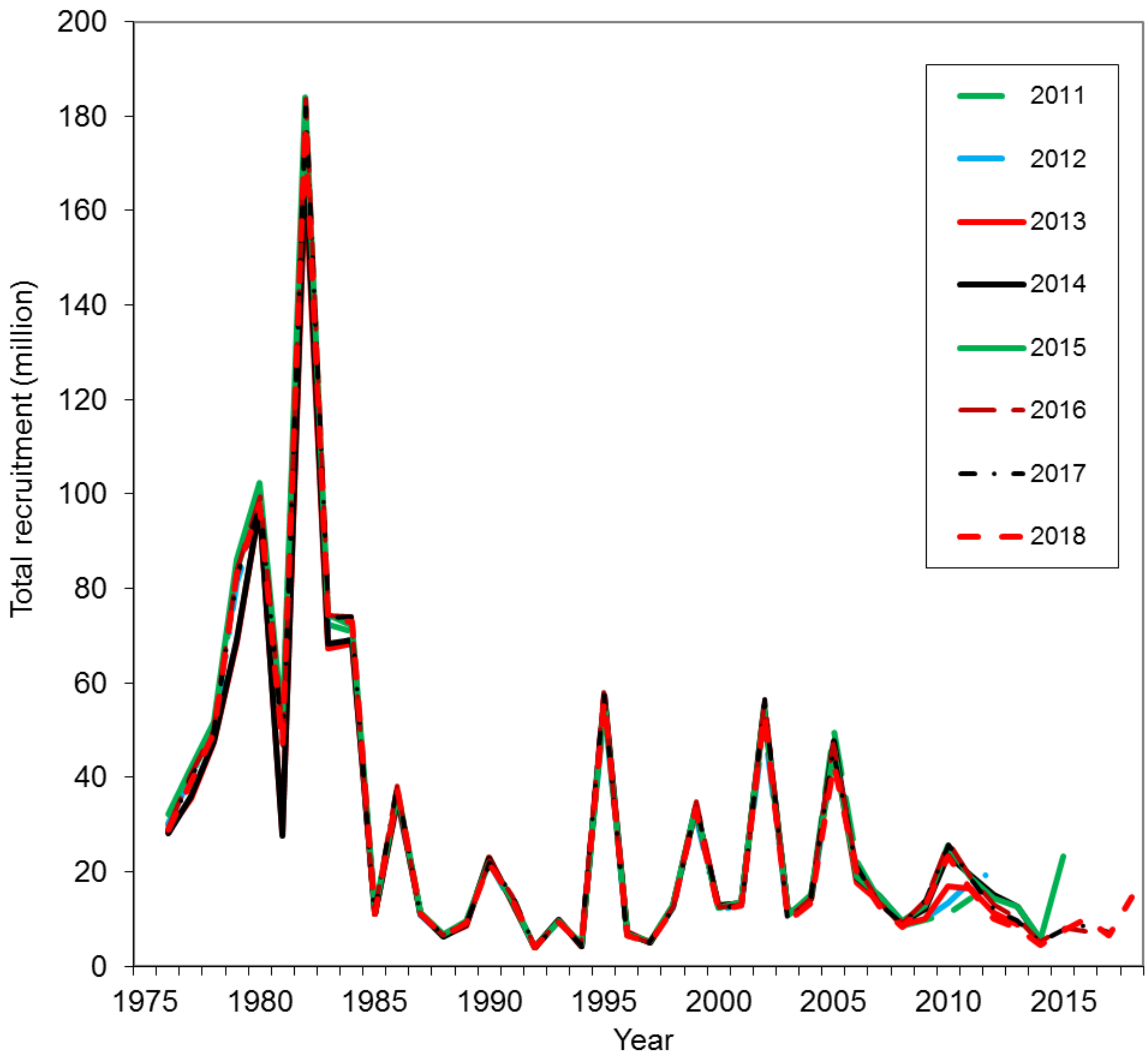


Figure 28a. Comparison of hindcast estimates of total recruitment for scenario 18.0 of Bristol Bay red king crab from 1976 to 2018 made with terminal years 2012-2018. These are results of the 2018 model. Legend shows the terminal year. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

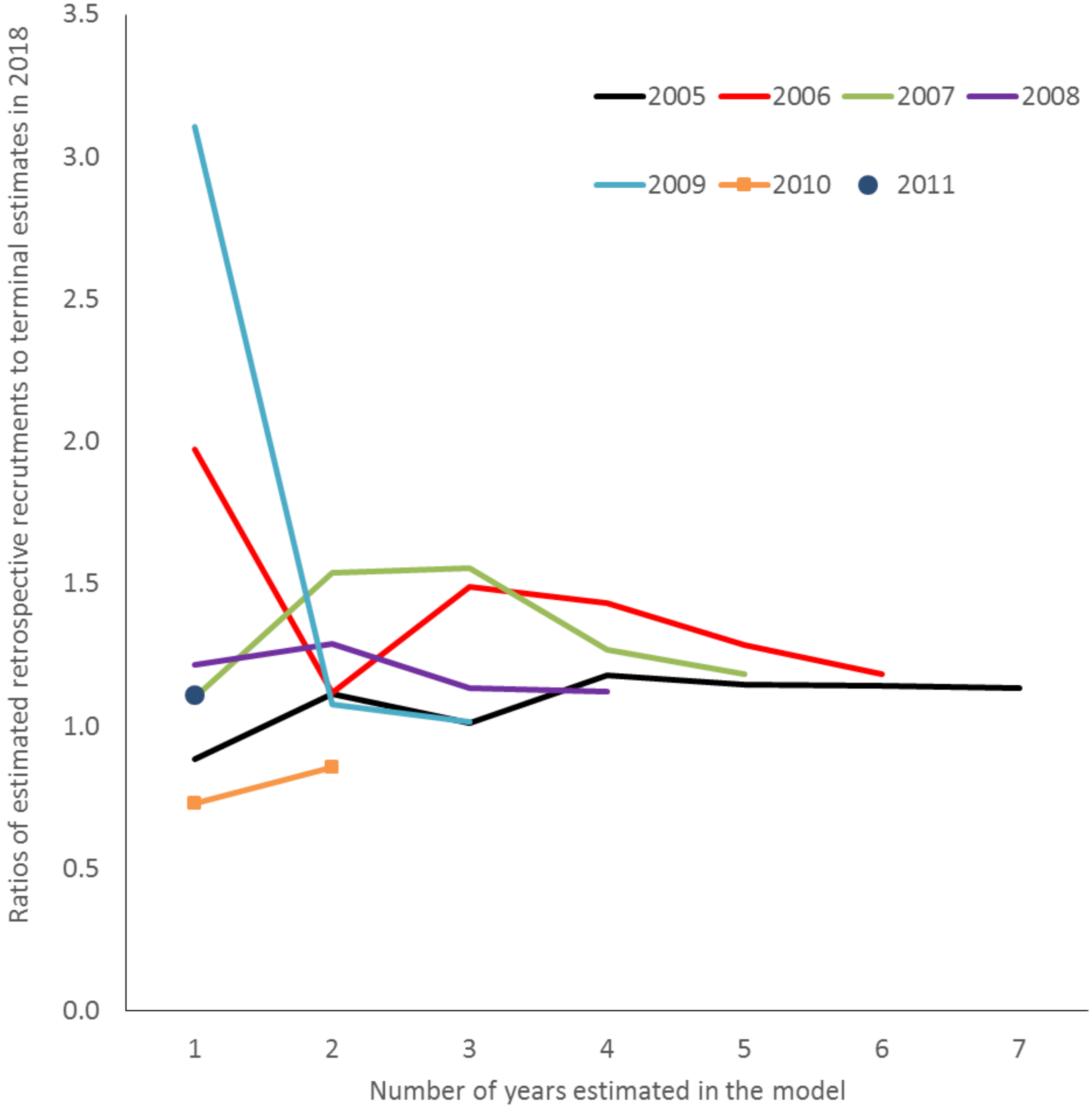


Figure 28b. Evaluation of Bristol Bay red king crab retrospective errors on recruitment estimates as a function of the number of years in the model for scenario 18.0.

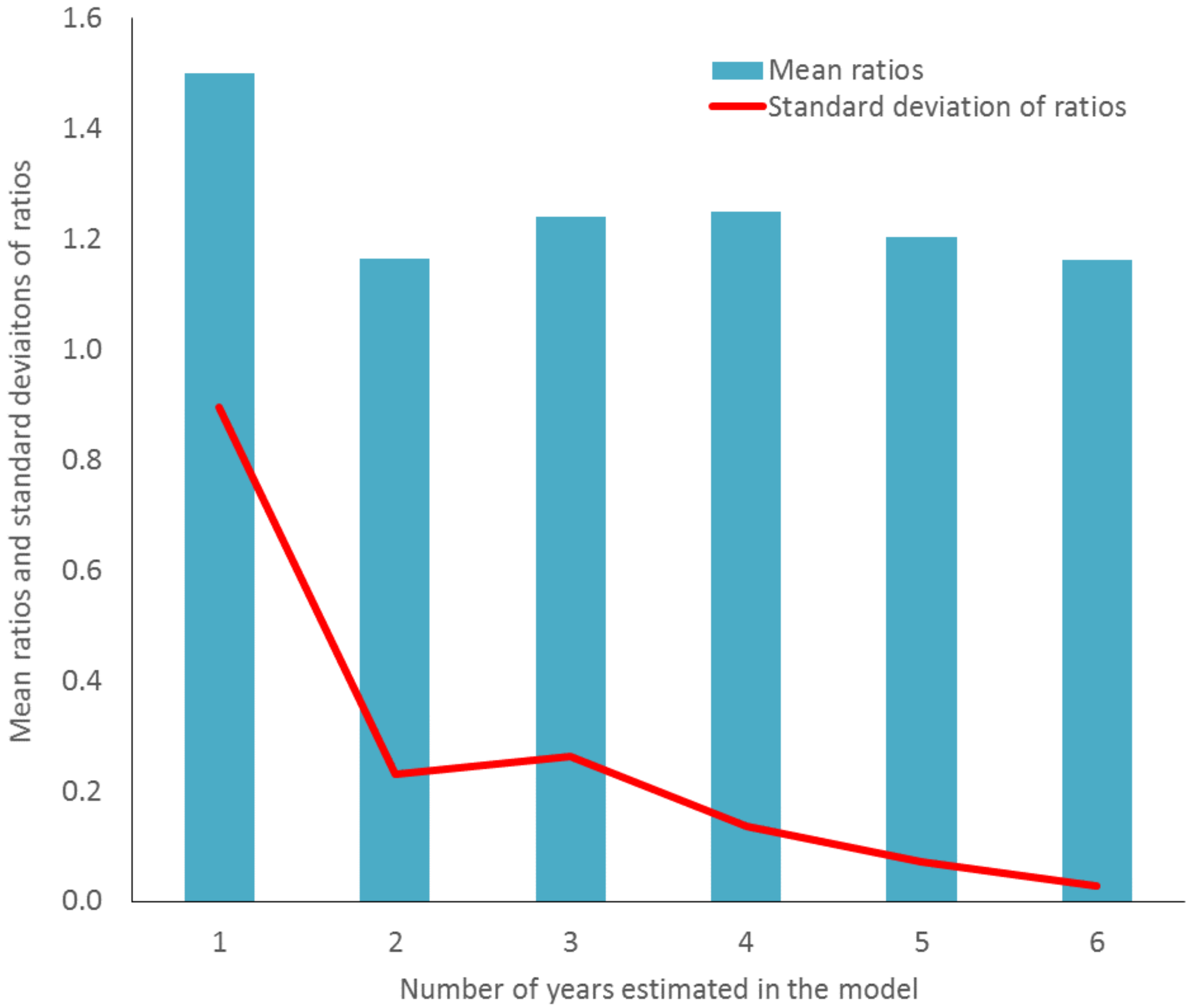


Figure 28c. Mean ratios of retrospective estimates of recruitments to those estimated in the most recent year (2018) and standard deviations of the ratios as a function of the number of years in the model for scenario 18.0.

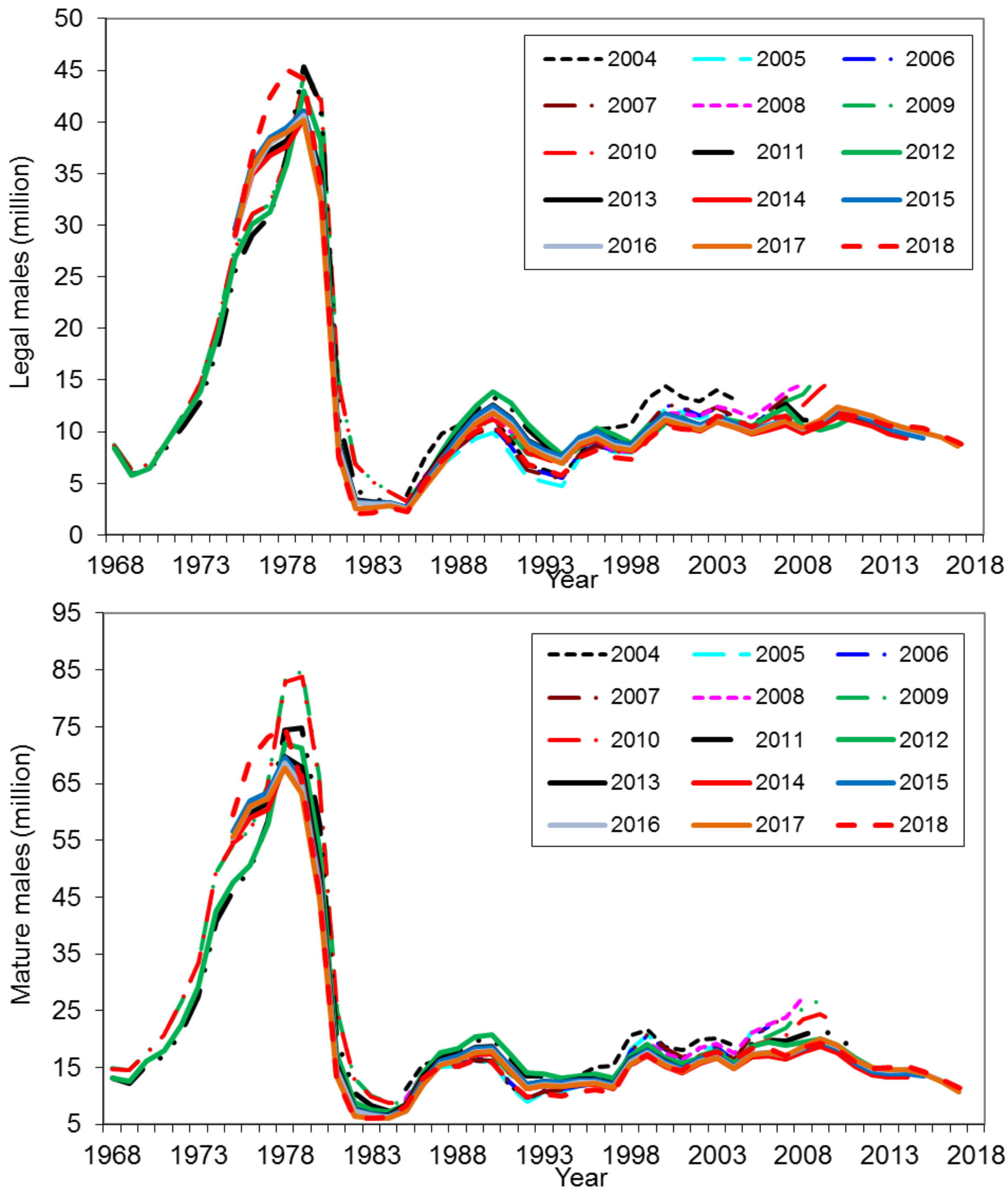


Figure 29. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1968 to 2018 made with terminal years 2004-2018 with the base scenarios. Scenario 18.0 is used for 2018. These are results of historical assessments. Legend shows the year in which 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.

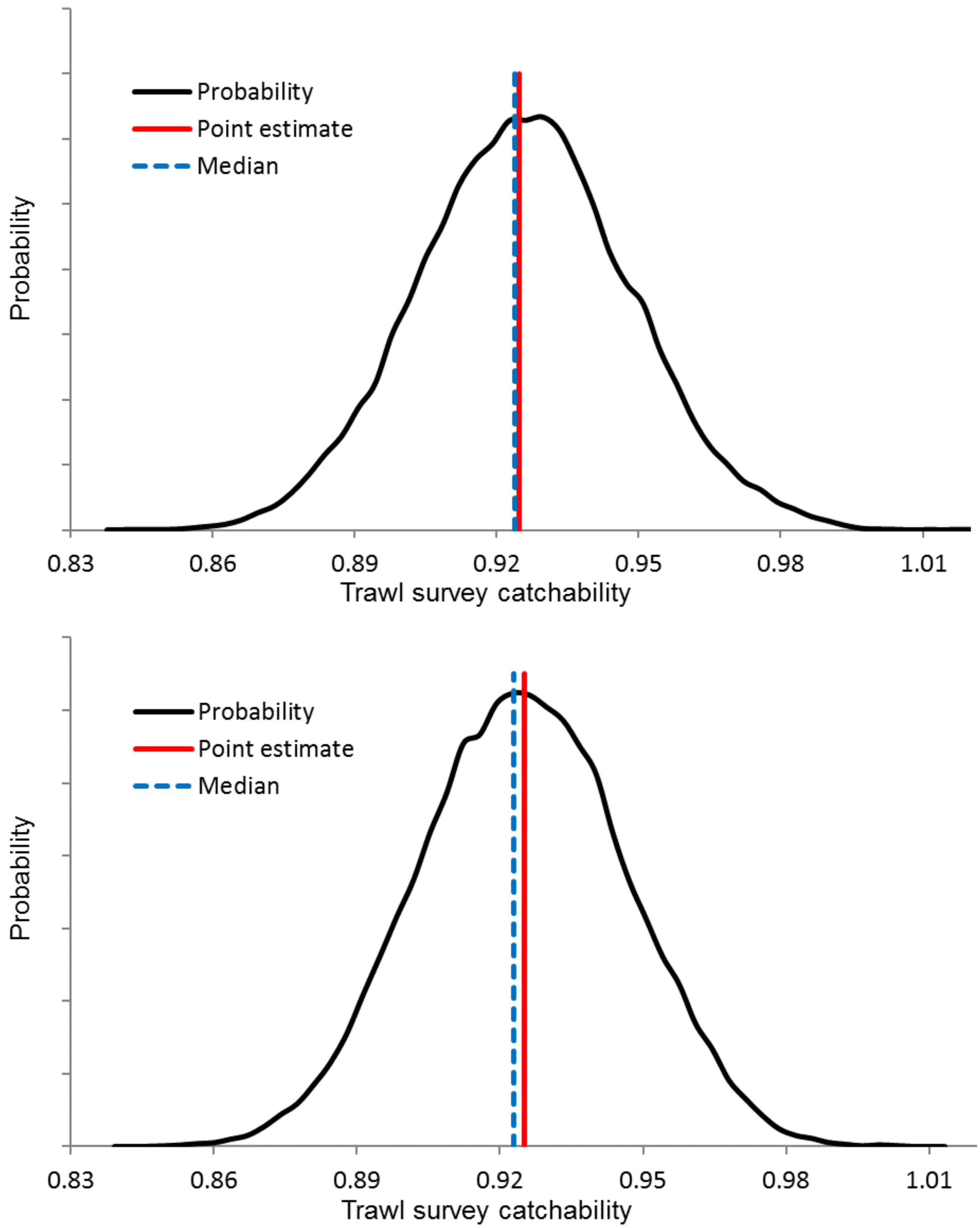
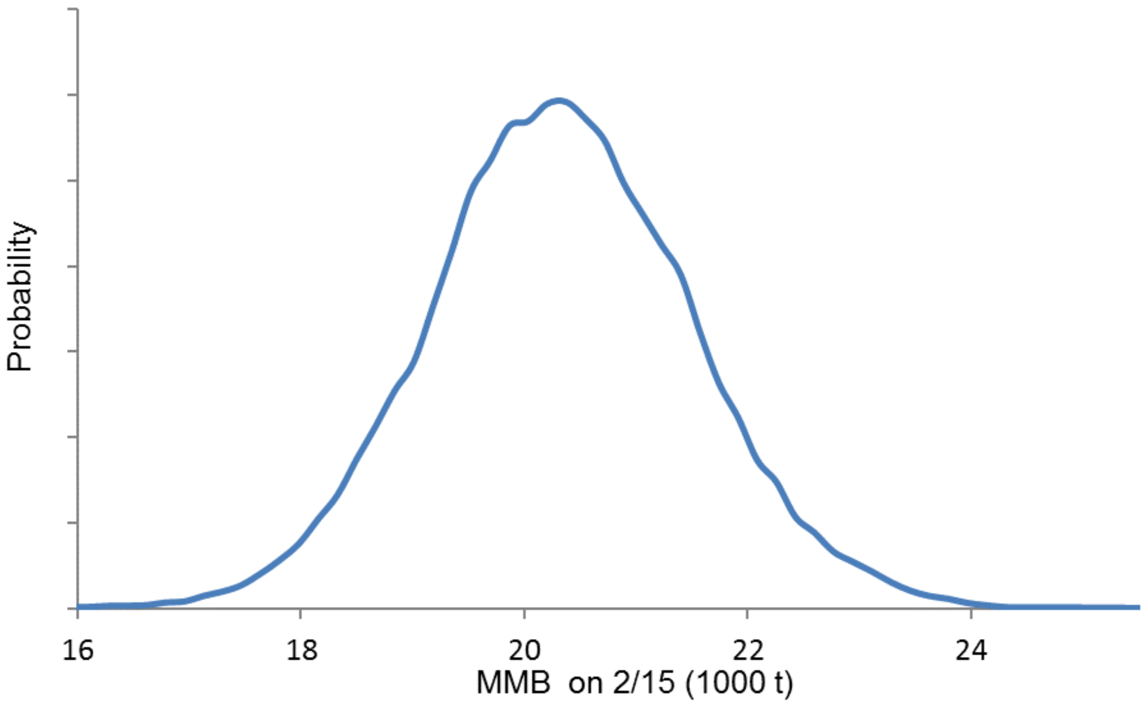


Figure 30. Probability distributions of estimated trawl survey catchability (*Q*) under scenario 18.0 (upper panel) and 18.0a (lower panel) with the mcmc approach. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.



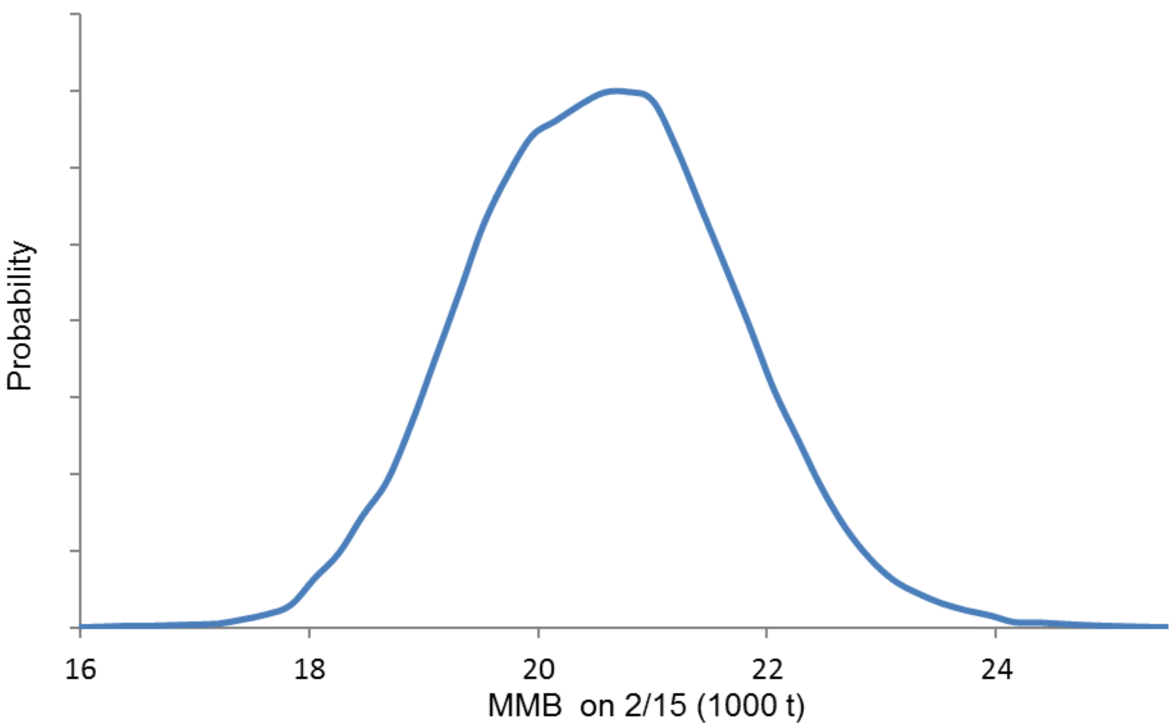


Figure 31a(18.0 & 18.0a). Probability distributions of estimated mature male biomass on Feb. 15, 2018 with $F_{35\%}$ under scenarios 18.0 (upper panel) and 18.0a (lower panel) with the mcmc approach. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

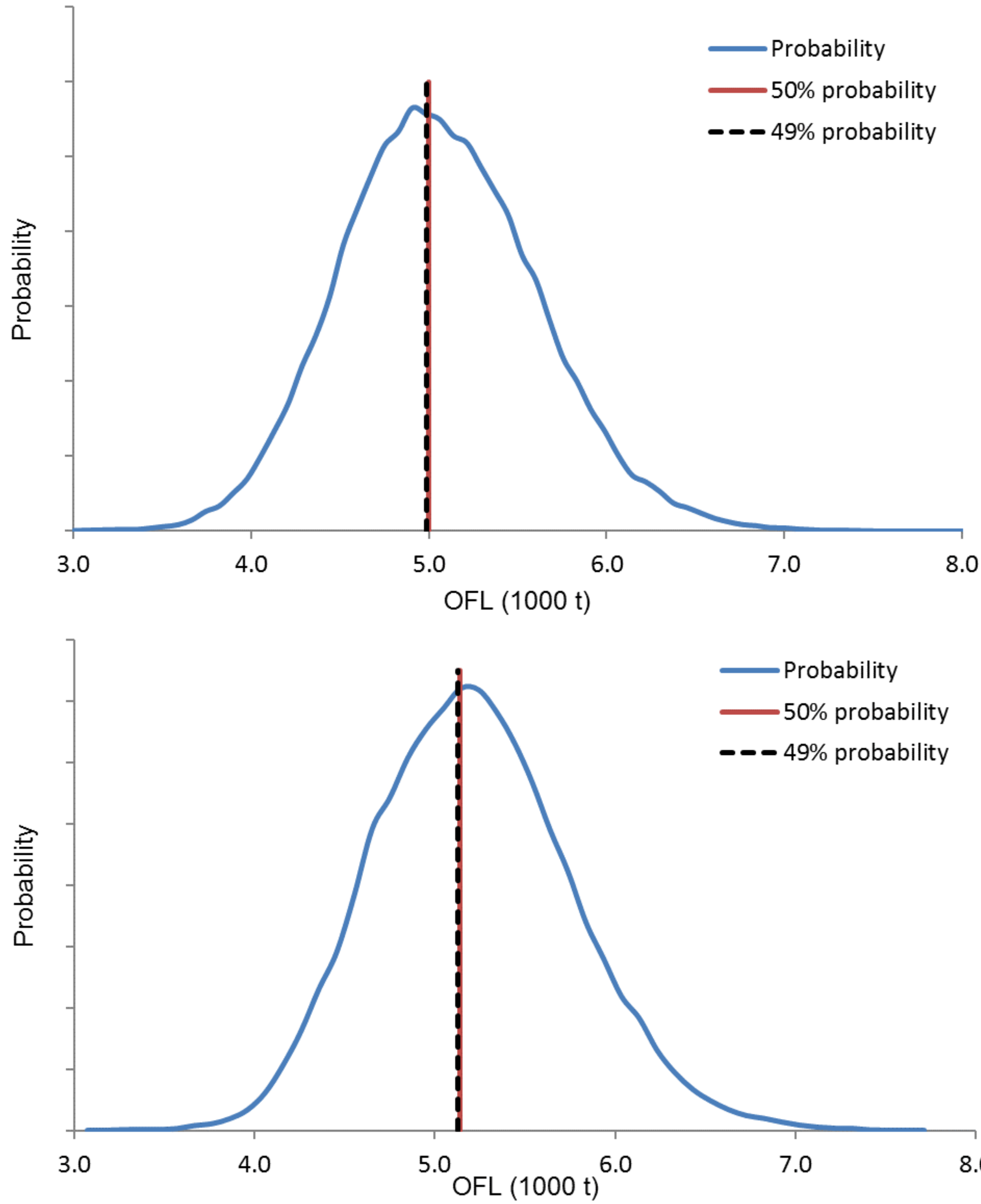


Figure 31b(18.0 & 18.0a). Probability distributions of the 2018 estimated OFL with scenarios 18.0 (upper panel) and 18.0a (lower panel) with the mcmc approach. Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively.

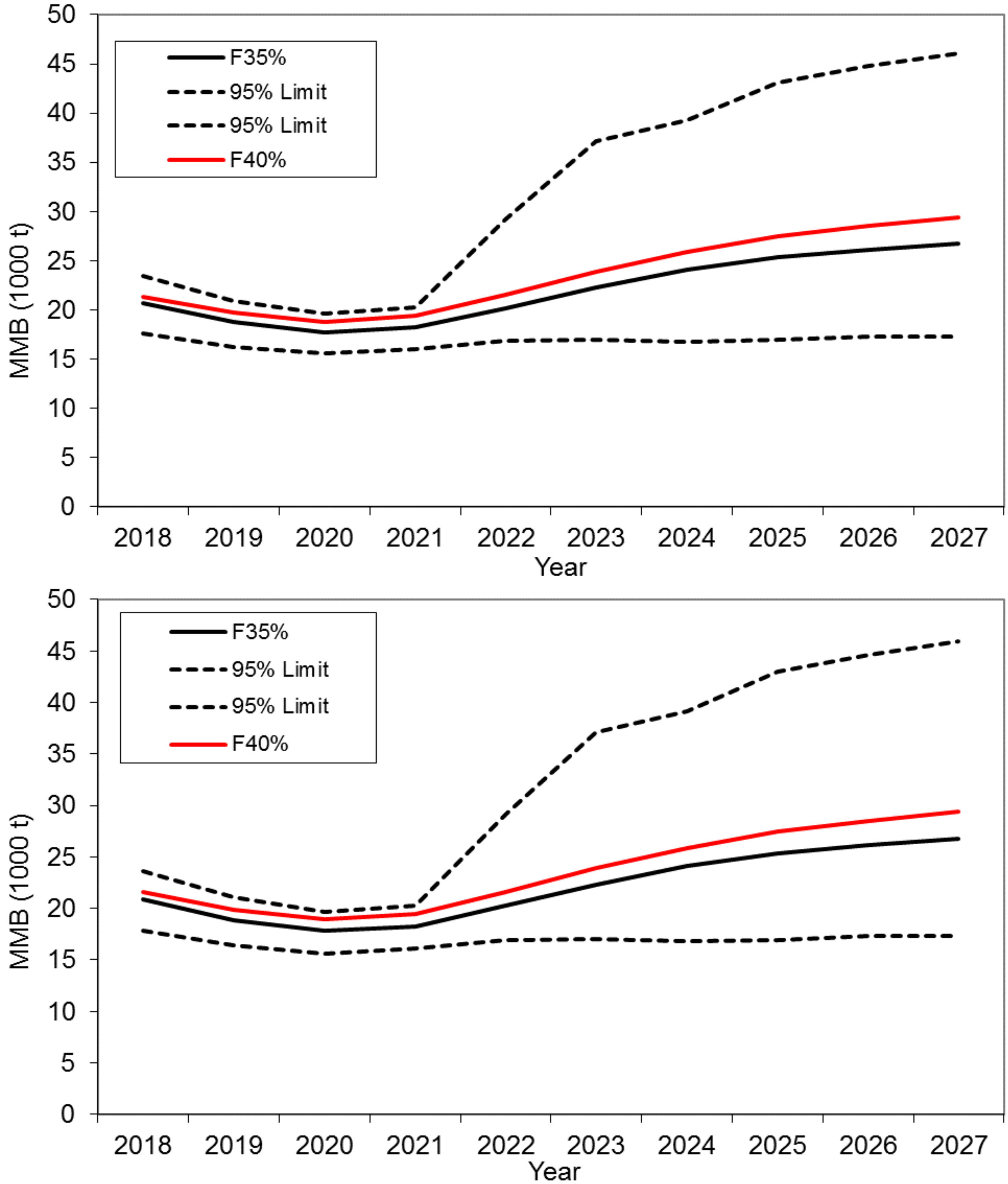
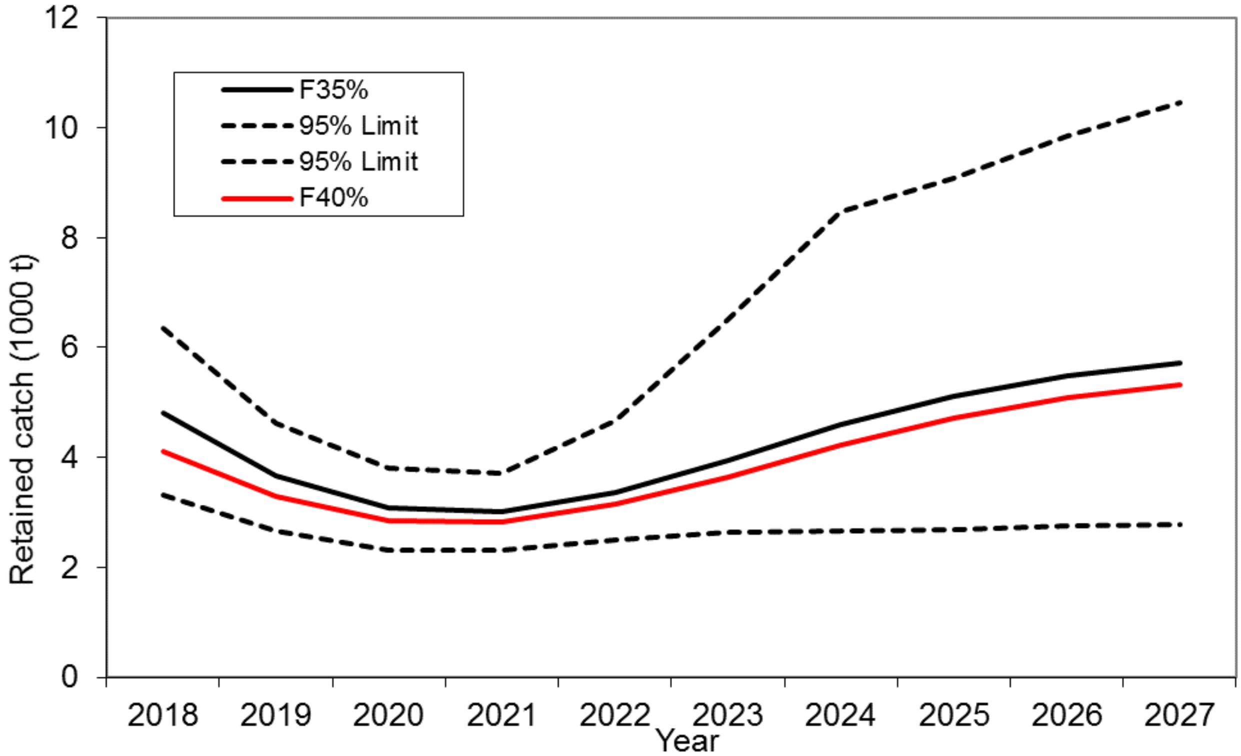


Figure 32(18.0 & 18.0a). Projected mature male biomass on Feb. 15 with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2018-2027. Input parameter estimates are based on scenarios 18.0 (upper panel) and 18.0a (lower panel). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.



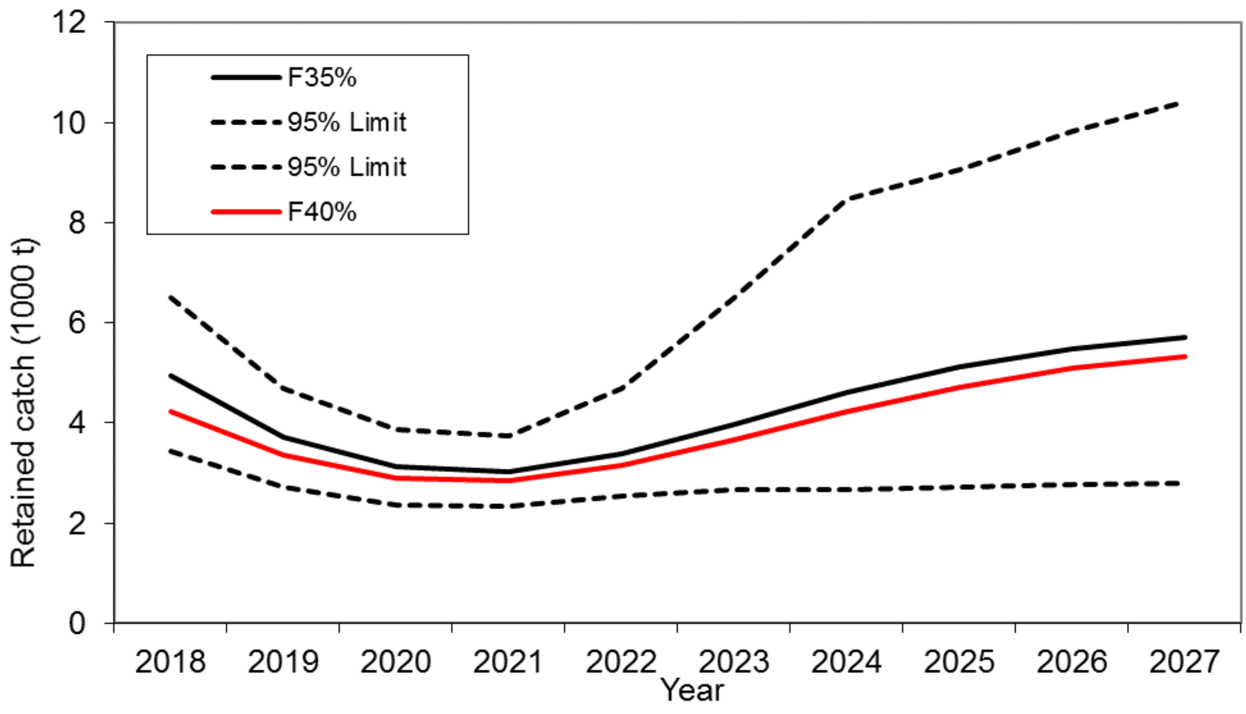


Figure 33(18.0 & 18.0a). Projected retained catch biomass with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2018-2127. Input parameter estimates are based on scenarios 18.0 (upper panel) and 18.0a (lower panel). Pot, Tanner crab, fixed gear and trawl handling mortality rates were assumed to be 0.2, 0.25, 0.5 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

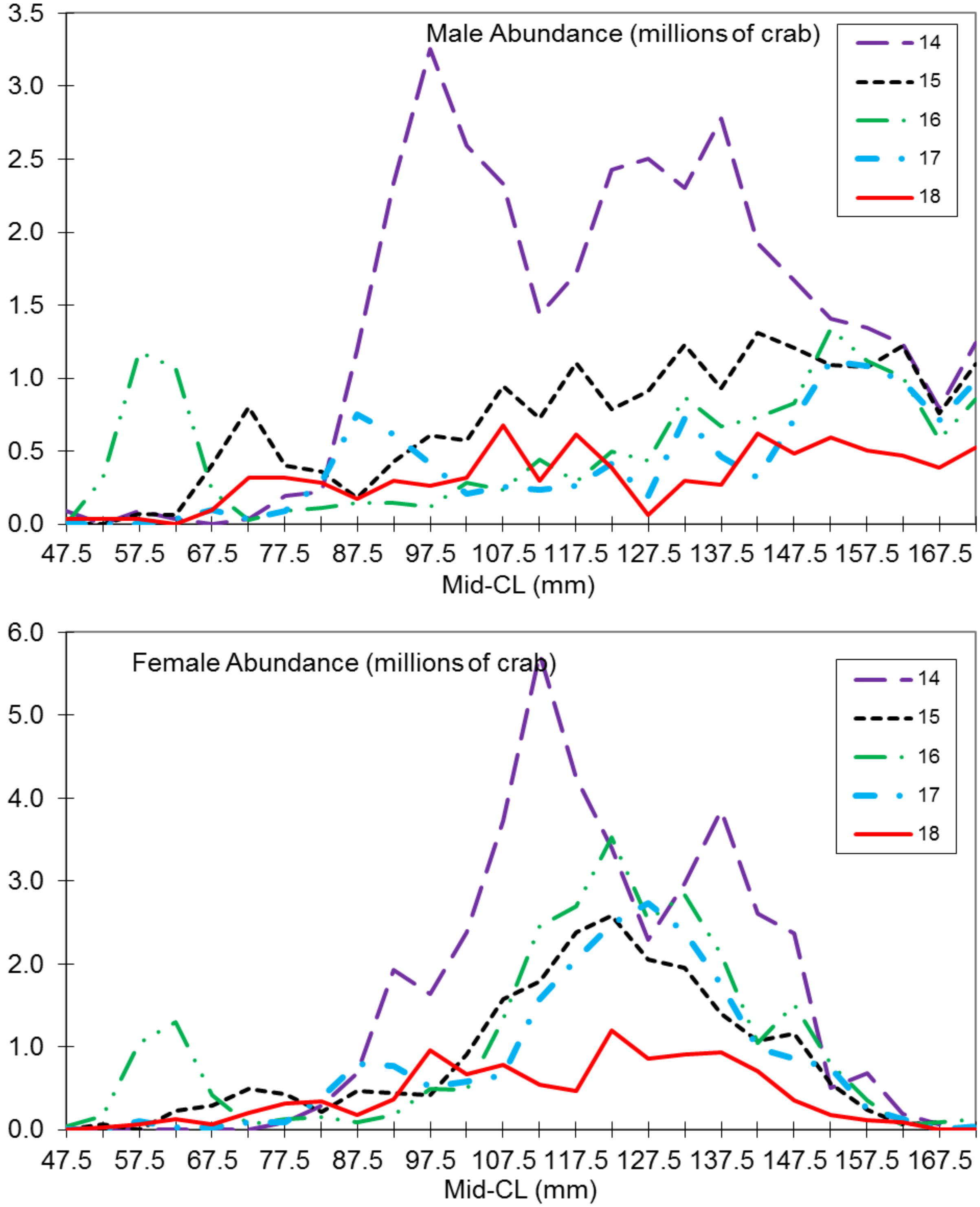


Figure 34. Length frequency distributions of male (top panel) and female (bottom panel) red king crab in Bristol Bay from NMFS trawl surveys during 2014-2018. For purposes of these graphs, abundance estimates are based on area-swept methods.

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:

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

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.:

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

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; 1994-2017) 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 fishery:

$$F^s_{l,t} = \begin{cases} [(S^{dir,land}_l(1+h_t\phi) + S^{dir,disc,mal}_l]\, F^{dir}_t & \text{if } s = \text{mal} \\ S^{dir,disc,\,fem}_l \; F^{disc,fem}_t & \text{if } s = \text{fem} \end{cases} \tag{A5}$$

$$F^s_{l,t} = \begin{cases} \left[S^{dir,land}_l(1+h_t\emptyset) + S^{dir,disc,mal}_l\right]F^{dir}_t & if\ s = mal\ and\ scen.2b \\ \left[S^{tot,mal}_l S^{ret}_{l,t} + S^{tot,mal}_l\left(1-S^{ret}_{l,t}\right)\emptyset\right]F^{dir}_t & if\ s\ is\ male\ and\ other\ scen. \\ S^{dir,disc,fem}_l F^{disc,fem}_t & if\ s = fem \end{cases} \tag{A5}$$

where $S_l^{\text{dir,land}}$ is the selectivity pattern for the landings by the directed fishery, $S_l^{\text{dir,disc},s}$ the selectivity pattern for the discards in the directed fishery by sex, $S_l^{tot,mal}$ the total male selectivity in the directed fishery, $S_{l,t}^{ret}$ the retained proportions of males in the directed fishery, F_t^{dir} the fully-selected fishing mortality during year t (on males), $F_t^{disc,fem}$ the fully-selected fishing mortality on female animals during year t related to discards in the directed fishery, ϕ the handling mortality (the proportion of animals which die due to being returned to the water following capture), and h_t the rate of high-grading during year t , i.e. discards of animals which can be legally-retained by the directed pot fishery (non-zero only for 2005-2016).

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:

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

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

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

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

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

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

$$\begin{aligned} TC_{l,t}^s &= (N_{l,t}^s + O_{l,t}^s) e^{-j_t M_t^s} \; e^{-F_{l,t}^s} (1 - e^{-\tilde{F}_{l,t}^s}) \, S_l^{Tanner,s} F_t^{Tanner,s} / \tilde{F}_{l,t}^s \\ GT_{l,t}^s &= (N_{l,t}^s + O_{l,t}^s) e^{-j_t M_t^s} \; e^{-F_{l,t}^s} (1 - e^{-\tilde{F}_{l,t}^s}) \, S_l^{trawl} F_t^{trawl} / \tilde{F}_{l,t}^s \\ GF_{l,t}^s &= (N_{l,t}^s + O_{l,t}^s) e^{-j_t M_t^s} \; e^{-F_{l,t}^s} (1 - e^{-\tilde{F}_{l,t}^s}) \, S_l^{fixed} F_t^{fixed} / \tilde{F}_{l,t}^s \end{aligned} \tag{A9}$$

For scenarios 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:

$$D^{i}_{l,t} = N^{i}_{l,t}\, e^{-y_t M^{fem}_t} (1 - e^{-F^{fem}_{l,t}})$$
$$D^{m}_{l,t} = N^{m}_{l,t}\, e^{-y_t M^{fem}_t} (1 - e^{-F^{fem}_{l,t}}) \qquad (A10)$$

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:

$$T^{i}_{l,t} = N^{i}_{l,t}\, e^{-j_t M^{fem}_t} e^{-F^{fem}_{l,t}} (1 - e^{-\tilde{F}^{fem}_{l,t}})$$
$$T^{m}_{l,t} = N^{m}_{l,t}\, e^{-j_t M^{fem}_t} e^{-F^{fem}_{l,t}} (1 - e^{-\tilde{F}^{fem}_{l,t}}) \qquad (A11)$$

Retained selectivity, $S^{\text{dir,land}}$, selectivity for females in the directed fishery, $S^{\text{dir,disc,fem}}$, total male selectivity, $S^{tot,mal}_{l}$, retained proportions, $S^{ret}_{l,t}$, 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, $S^{\text{Tanner},s}$, are all assumed to be logistic functions of length:

$$S^{type}_{l} = \frac{1}{1 + e^{-\beta^{type}\,(\iota - L^{type}_{50})}} \qquad (A12)$$

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.

For scenario 2b, male pot bycatch selectivity in the directed fishery is modeled by two linear functions:

$$s_l = \varphi + \kappa\,\iota, \quad if \;\; \iota < 135 \text{ mm CL},$$
$$s_l = s_{l-1} + 5\gamma, \quad if \;\; \iota > 134 \text{ mm CL} \qquad (A13)$$

where φ, κ, γ are parameters.

iii. Trawl Survey Selectivities

Trawl survey selectivities are estimated as

$$S^{s}_{l,t} = \frac{Q}{1 + e^{-\beta^{s}_{t}\,(\iota - L^{s}_{50,t})}} \qquad (A14)$$

with different sets of parameters (β, L_{50}) estimated for males and females as well as two different periods (1975-81 and 1982-17). 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 during 1994 and 2006-2009. Bycatch fishing mortalities for male and females during 1975-1989 in the directed pot fishery were estimated as

$$F_t^{disc,s} = r^s \; F_t^{dir} \qquad \text{(A15)}$$

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^o 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):

$$F_t^{Tanner,s} = a^s \; E_t \qquad \text{(A16)}$$

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^o 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 :

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

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

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

The weighted negative log likelihood functions are:

$$\begin{aligned}
&\textit{Length compositions}: \quad -\sum \ln(Rf_i) \\
&\textit{Biomasses other than survey}: \quad \lambda_j \sum \left[\ln(C_t / \hat{C}_t)^2\right] \\
&\textit{NMFS survey biomass}: \quad \sum \left[\ln(B_t / \hat{B}_t)^2 / (2\ln(CV_t^2 + 1))\right] \\
&\textit{BSFRF mature males}: \quad \sum [\ln(\ln(CV_t^2 + 1))^{0.5} + \ln(B_t / \hat{B}_t)^2 / (2\ln(CV_t^2 + 1))] \\
&\textit{R variation}: \quad \lambda_R \sum [\ln(R_t / \overline{R})^2] \\
&\textit{R sex ratio}: \quad \lambda_s [\ln(\overline{R}_M / \overline{R}_F)^2] \qquad\qquad \text{(A18)} \\
&\textit{Trawl bycatch fishing mortalities}: \lambda_t [\ln(F_{t,t} / \overline{F}_t)^2] \\
&\textit{Pot female bycatch fishing mortalities}: \lambda_p [\ln(F_{t,f} / \overline{F}_f)^2] \\
&\textit{Trawl survey catchability}: (Q - \hat{Q})^2 / (2\sigma^2)
\end{aligned}$$

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

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

Weights λ_j are assumed to be 500 for retained catch biomass, and 100 for all bycatch biomasses, 2 for recruitment variation, 10 for recruitment sex ratio, 0.2 for pot female bycatch fishing mortality, and 0.1 for trawl bycatch fishing mortality. These λ_j values correspond to CV values of 0.03, 0.07, 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. High grading parameters h_t were estimated to be 0.2785 in 2005, 0.0440 in 2006, 0.0197 in 2007, 0.0198 in 2008, 0.0337 in 2009, 0.0153 in 2010, 0.0113 in 2011, 0.0240 in 2012, 0.0632 in 2013, 0.1605 in 2014, 0.07 in 2015, 0.0826 in 2016, and 0.0749 in 2017, based on the proportions of discarded legal males to total caught legal males. Handling mortality rates were set to 0.2 for the directed pot fishery, 0.25 for the Tanner crab fishery, 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 scenarios.

(2). Length-weight Relationship

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

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

Ovigerous Females: $W = 0.003593\ L^{2.666076}$ (A19)

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 1994-2017, 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 1994-2017, 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 1994-2017).

(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 0.18yr^{-1}, all directed fishing mortality, and non-directed fishing mortality. These three mortality parameters could be attributed to natural mortality as well as undocumented non-directed fishing mortality. The model fit the data much better with these three parameters than without them.

ii. Parameters estimated conditionally

The following model parameters were estimated for male and female crab: total recruits for each year (year class strength R_t for t = 1976 to 2018), total abundance in the first year (1975), growth parameter β, and recruitment parameter β_r for males and females separately. Molting probability parameters β and L_{50} were also estimated for male crab. Estimated parameters also include β and L_{50} for retained selectivity, β and L_{50} for pot-discarded female selectivity, β and L_{50} for pot-discarded male and female selectivities from the eastern Bering Sea Tanner crab fishery, β and L_{50} for groundfish trawl discarded selectivity, φ, κ and γ for pot-discarded male selectivity, and β for trawl survey selectivity and L_{50} for trawl survey male and females separately. The NMFS survey catchabilities Q for some scenarios were also estimated. Three selectivity parameters were estimated for the survey data from the Bering Fisheries Research Foundation. Annual fishing mortalities were also estimated for the directed pot fishery for males (1975-2017), pot-discarded females from the directed fishery (1990-2017), pot-discarded males and females from the eastern Bering Sea Tanner crab fishery (1991-93, 2013-15), and groundfish trawl discarded males and females (1976-2017). Three additional mortality parameters for Mm_t and Mf_t were also estimated. Some estimated parameters were constrained in the model. For example, male and female recruitment estimates were forced to be close to each other for a given year.

f. Definition of model outputs.

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

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

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

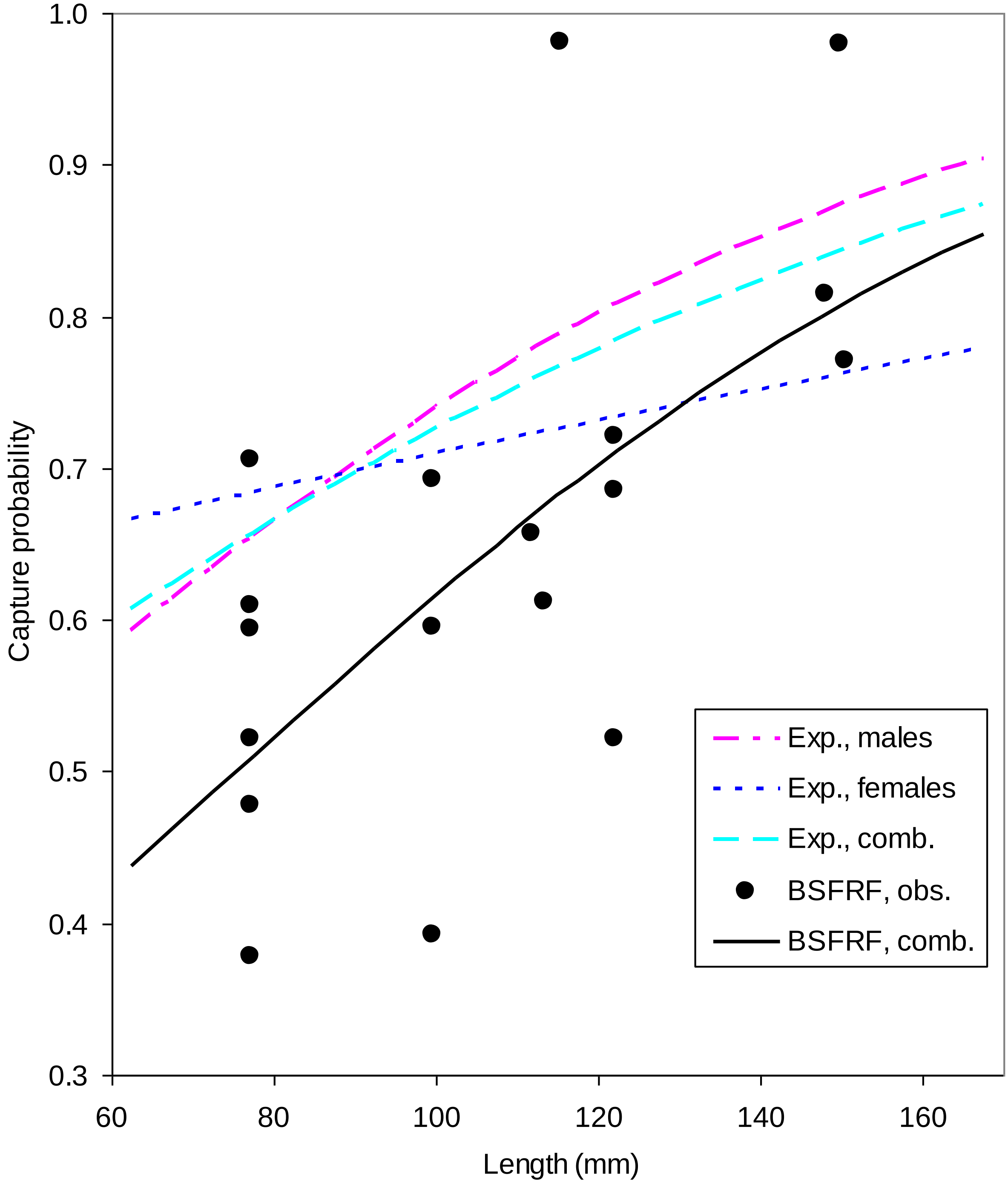
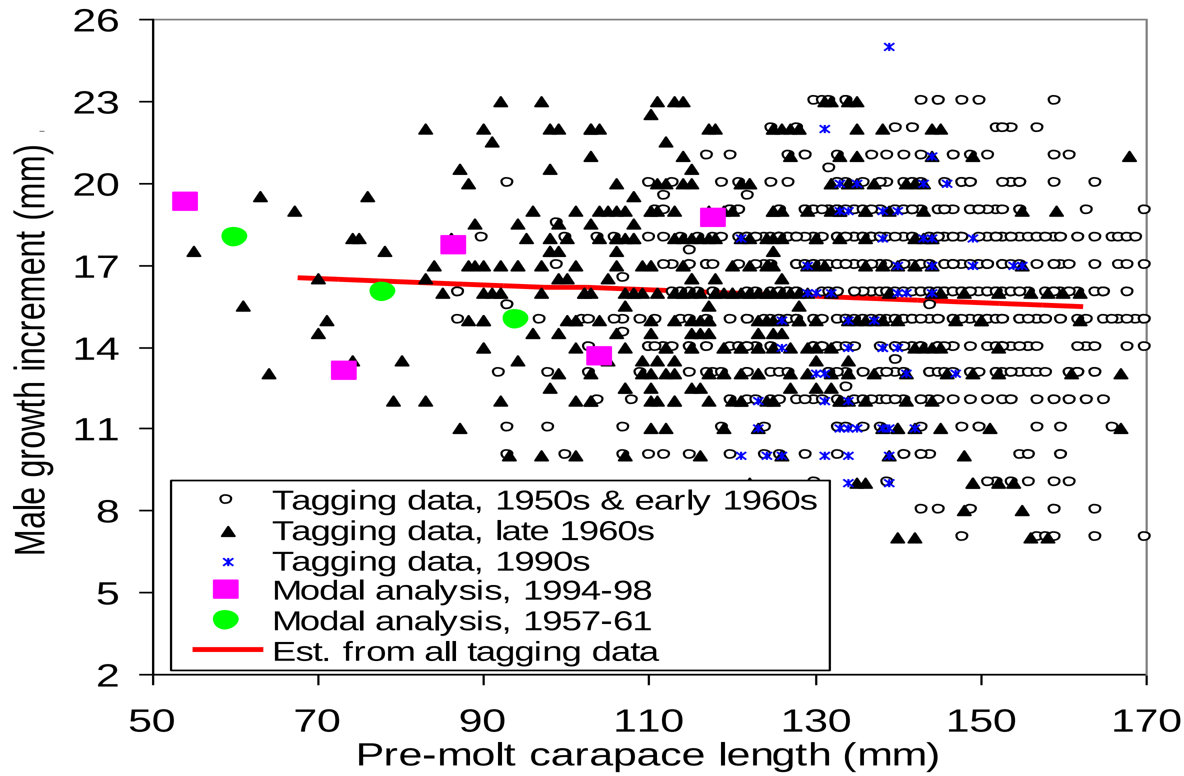


Figure A1. Estimated capture probabilities for NMFS Bristol Bay red king crab trawl surveys by Weinberg et al. (2004) and the Bering Sea Fisheries Research Foundation surveys.



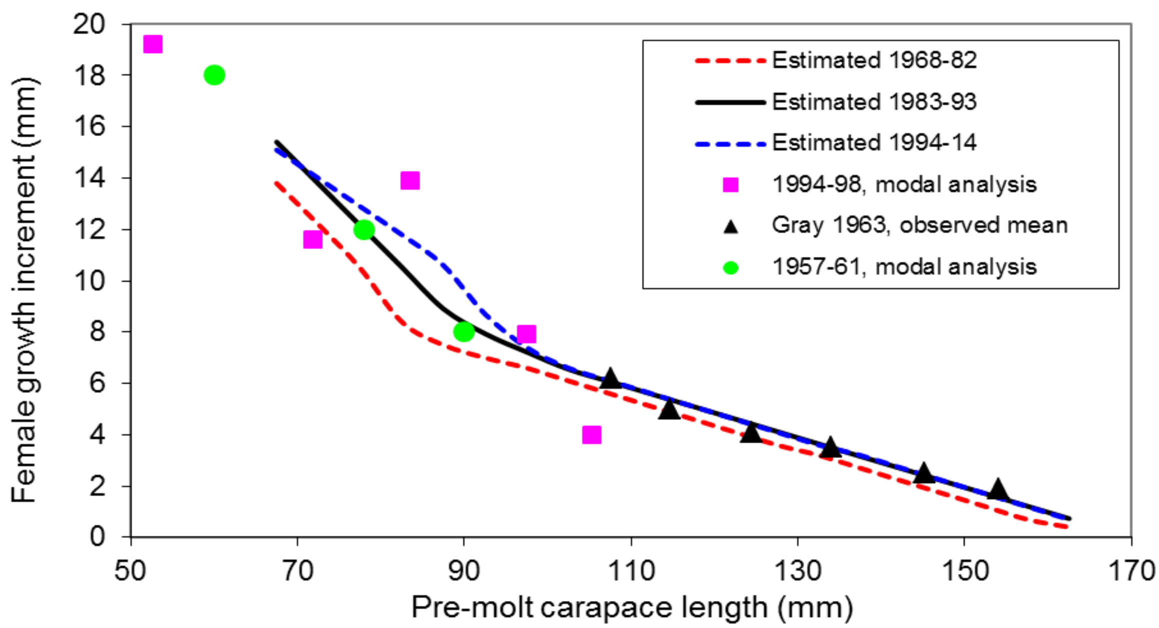


Figure A2. Mean growth increments per molt for Bristol Bay red king crab. Note: “tagging”---based on tagging data; “mode”---based on modal analysis. The female growth increments per molt are for scenarios 1, 1n and 2.

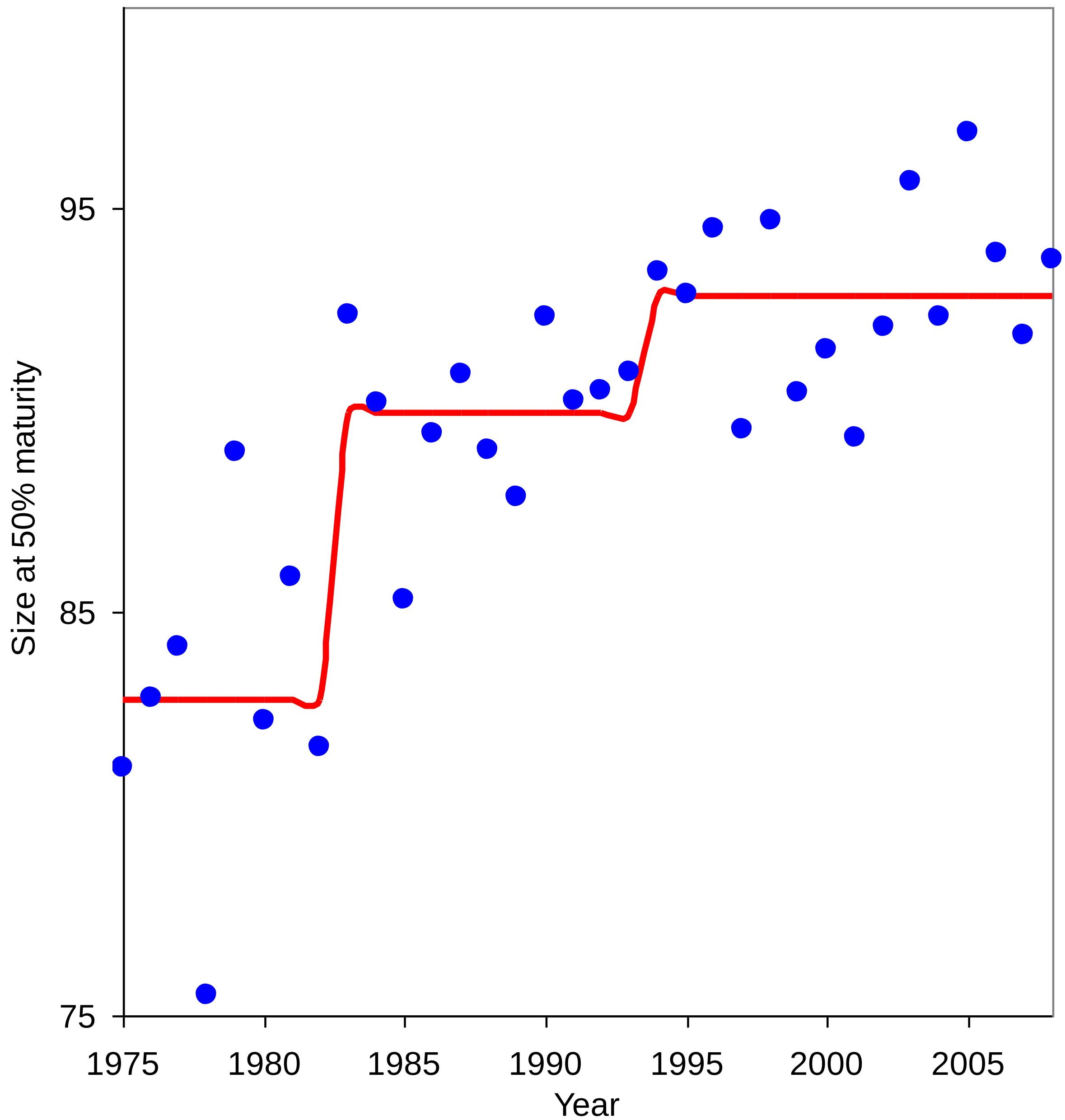


Figure A3. Estimated sizes at 50% maturity for Bristol Bay female red king crab from 1975 to 2008. Averages for three periods (1975-82, 1983-93, and 1994-08) are plotted with a line.

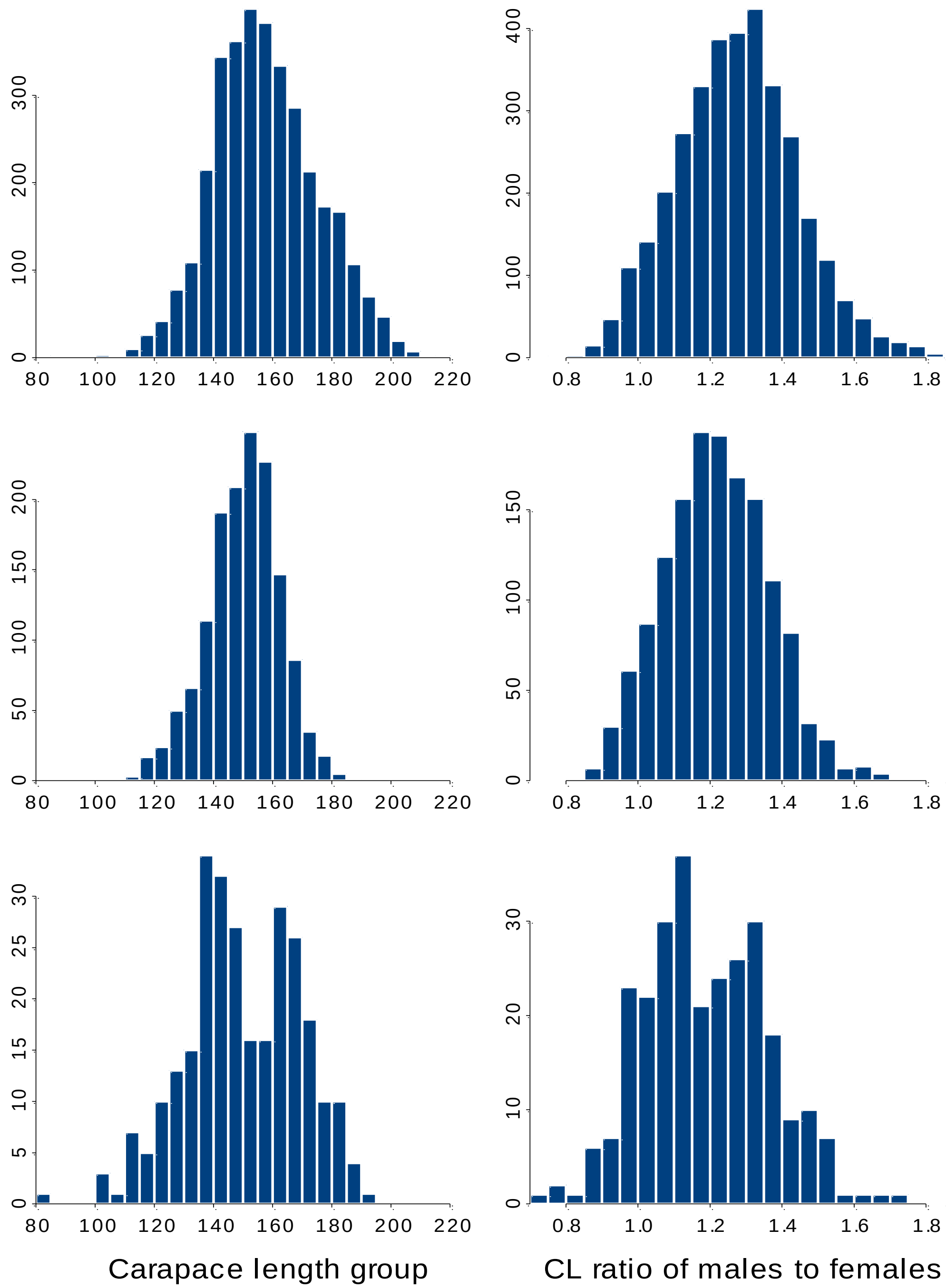
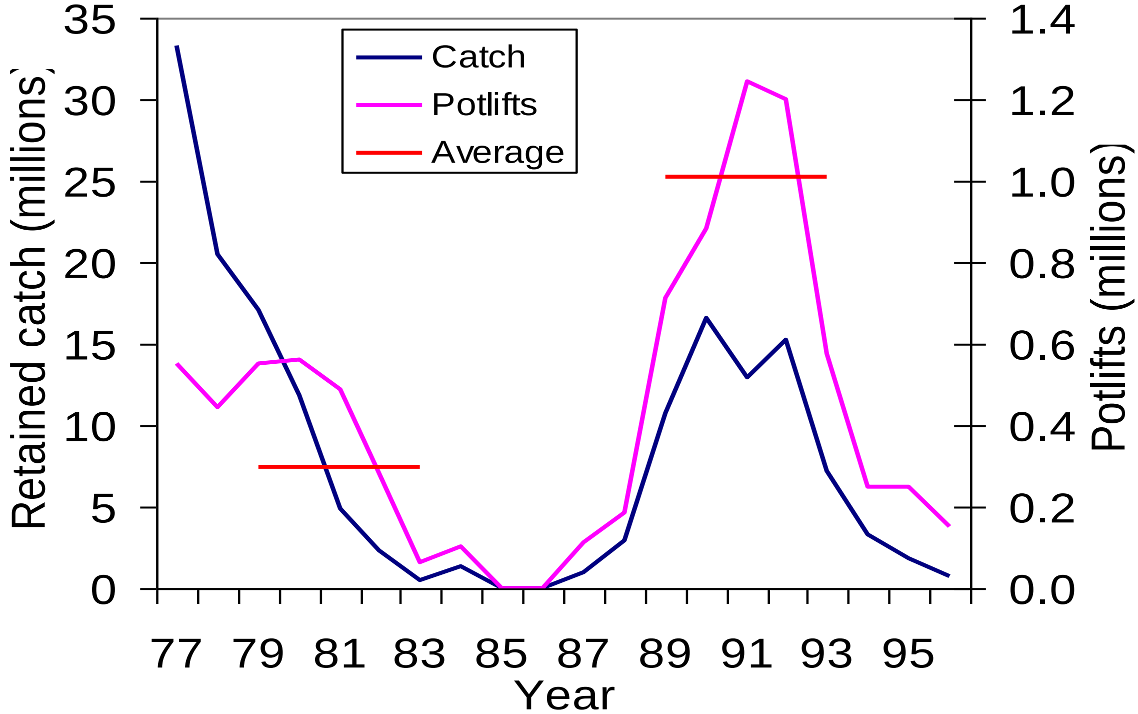


Figure A4. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages ≤13 months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak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



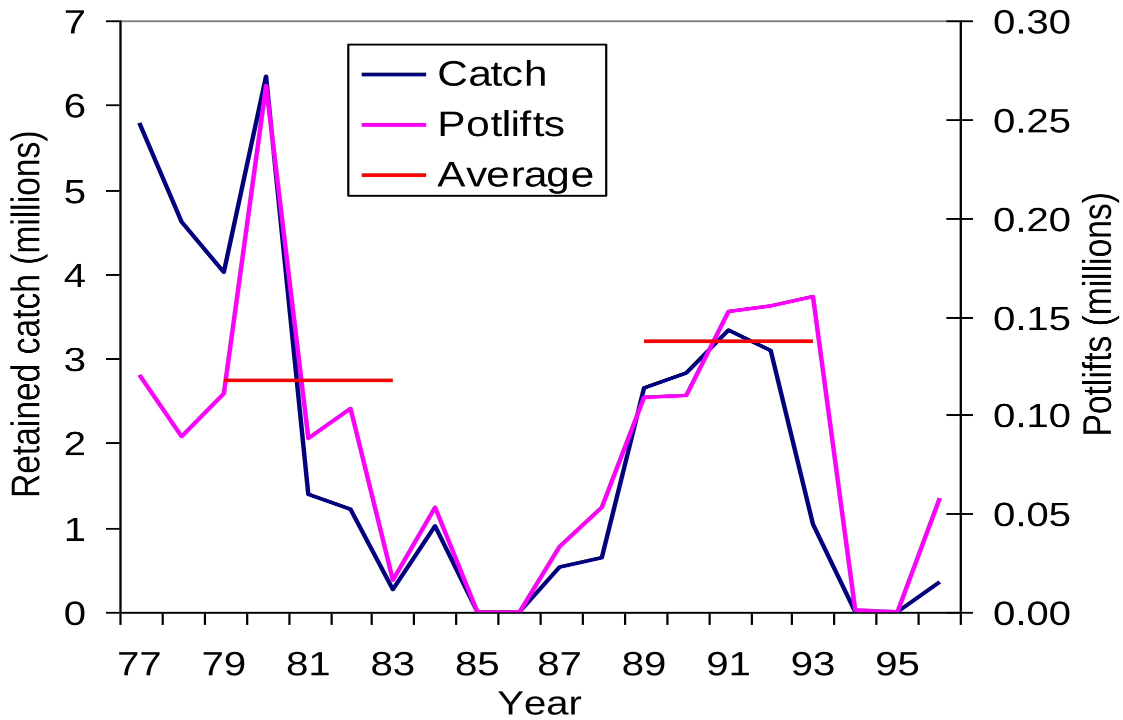


Figure A5. Retained catch and potlifts for total eastern Bering Sea Tanner crab fishery (upper plot) and the Tanner crab fishery east of 163° W (bottom).

Appendix B. Recruitment Breakpoint Analysis in May 2017

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 scenario 2d 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 2005 is evaluated as a potential breakpoint *b* using time series of ln(R/MMB) and MMB for brood years 1975-2010. 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, both Ricker model and Beverton-Holt model result in the same breakpoint brood year of 1986, which corresponds to recruitment year of 1992. The model with no breakpoint (i.e., a single time period) is about 5 times less probable than the 1986 breakpoint model for Beverton-Holt stock-recruitment models and about eight 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 1980-1985 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 two years earlier than our estimate, even though our results show that brood year of 1984 is also a likely breakpoint. The different time series of data may explain the different results. 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 scenario 2d during 1984-present is 17.77 million of crab, compared to the mean recruitment of 15.45 million of crab during 1992-present, about 13.0% reduction (Figure 12(2d)). 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	46.4933	15.0232

1980	41.0741	1.0000
1981	43.5372	3.4266
1982	43.4335	3.2535
1983	43.5460	3.4417
1984	43.5839	3.5075
1985	43.0025	2.6227
1986	42.4169	1.9570
1987	45.4294	8.8255
1988	46.1588	12.7097
1989	49.4106	64.6036
1990	46.6891	16.5684
1991	47.9850	31.6723
1992	48.2826	36.7550
1993	48.0169	32.1822
1994	48.9392	51.0375
1995	48.9373	50.9899
1996	49.2335	59.1297
1997	48.8284	48.2862
1998	48.8394	48.5532
1999	48.8440	48.6658
2000	46.3349	13.8795
2001	45.4607	8.9648
2002	45.5360	9.3088
2003	45.9752	11.5951
2004	46.2300	13.1701
2005	45.8085	10.6673

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.
			-0.523	0.319			0.005	0.008	0.001	0.122	0.191	0.285
1980	-7.356	5.342	0.708	0.505	-0.077	0.061	0.061	0.021	-0.117	0.122	-0.052	0.286
1981	0.428	1.239	0.688	0.494	0.012	0.016	0.062	0.021	-0.111	0.122	-0.102	0.279
1982	0.517	0.750	0.615	0.540	0.013	0.010	0.060	0.022	-0.112	0.122	-0.100	0.275
1983	0.337	0.582	0.675	0.602	0.011	0.008	0.062	0.024	-0.111	0.122	-0.107	0.273

1984	0.265	0.493	0.747	0.694	0.010	0.008	0.065	0.028	-0.111	0.122	-0.108	0.274
1985	0.512	0.431	0.035	0.872	0.013	0.007	0.037	0.034	-0.118	0.122	-0.116	0.275
1986	0.500	0.397	-0.677	1.148	0.013	0.007	0.011	0.044	-0.132	0.122	-0.083	0.281
1987	0.179	0.380	0.578	1.468	0.009	0.007	0.057	0.056	-0.088	0.122	-0.102	0.273
1988	0.089	0.392	0.706	1.693	0.009	0.007	0.062	0.064	-0.081	0.121	0.002	0.279
1989	-0.174	0.384	0.819	1.738	0.007	0.007	0.063	0.066	-0.038	0.121	-0.029	0.281
1990	-0.069	0.389	1.505	1.759	0.008	0.007	0.093	0.067	-0.076	0.122	0.080	0.274
1991	-0.173	0.385	1.457	1.805	0.007	0.008	0.090	0.069	-0.057	0.122	0.088	0.272
1992	-0.342	0.374	2.270	1.875	0.005	0.008	0.118	0.071	-0.051	0.122	0.090	0.271
1993	-0.354	0.358	2.646	2.036	0.005	0.007	0.131	0.076	-0.054	0.121	0.068	0.270
1994	-0.259	0.357	1.700	2.961	0.006	0.008	0.097	0.109	-0.042	0.121	0.079	0.283
1995	-0.290	0.344	2.037	3.181	0.006	0.007	0.109	0.116	-0.041	0.121	0.064	0.276
1996	-0.336	0.333	2.213	3.163	0.006	0.007	0.114	0.116	-0.036	0.121	-0.036	0.121
1997	-0.236	0.342	-0.002	3.514	0.007	0.008	0.038	0.127	-0.048	0.122	0.111	0.292
1998	-0.293	0.322	1.265	4.351	0.006	0.007	0.082	0.156	-0.044	0.121	0.060	0.272
1999	-0.298	0.312	0.359	5.150	0.006	0.007	0.051	0.183	-0.045	0.121	0.041	0.270
2000	-0.249	0.294	2.030	5.027	0.006	0.007	0.116	0.179	-0.082	0.122	0.013	0.268
2001	-0.260	0.275	2.972	4.984	0.006	0.006	0.153	0.178	-0.096	0.122	-0.060	0.268
2002	-0.281	0.269	2.991	5.003	0.005	0.006	0.155	0.179	-0.095	0.122	-0.076	0.269
2003	-0.312	0.268	3.717	5.370	0.005	0.006	0.183	0.193	-0.089	0.122	-0.079	0.270
2004	-0.336	0.266	4.122	5.359	0.005	0.006	0.200	0.193	-0.086	0.122	-0.078	0.267
2005	-0.338	0.261	2.435	5.684	0.005	0.006	0.143	0.203	-0.093	0.122	-0.082	0.267

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	45.3981	5.0697
1980	43.8995	2.3964
1981	42.3954	1.1297
1982	42.3742	1.1177
1983	42.5415	1.2153
1984	42.6196	1.2637
1985	42.6775	1.3008

1986	42.1516	1.0000
1987	45.3144	4.8618
1988	45.9970	6.8395
1989	49.1365	32.8664
1990	47.0869	11.7947
1991	48.2198	20.7824
1992	49.4103	37.6892
1993	49.4378	38.2106
1994	49.0962	32.2110
1995	49.2897	35.4830
1996	49.7282	44.1816
1997	48.3534	22.2179
1998	48.8959	29.1420
1999	48.7480	27.0641
2000	46.5764	9.1378
2001	45.9210	6.5844
2002	45.8966	6.5046
2003	46.4147	8.4280
2004	46.6195	9.3366
2005	45.6408	5.7238

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.
			-0.159	0.894			-3.713	2.225	-0.005	0.123	0.215	0.295
1980	-0.625	0.391	7.820	66.239	-11.19	60.247	5.471	66.254	-0.101	0.123	-0.164	0.282
1981	1.500	4.577	7.493	50.669	-2.440	5.381	5.185	50.685	-0.129	0.122	-0.078	0.287
1982	0.796	1.109	6.982	47.358	-3.321	1.661	4.681	47.381	-0.129	0.122	-0.097	0.276
1983	0.460	0.724	7.357	43.960	-3.817	1.354	5.044	43.974	-0.126	0.122	-0.108	0.275
1984	0.349	0.586	8.411	65.301	-3.999	1.241	6.091	65.308	-0.126	0.122	-0.111	0.274
1985	0.666	0.573	0.959	3.804	-3.492	1.065	-1.508	4.519	-0.123	0.122	-0.108	0.276
1986	0.647	0.530	-0.690	1.307	-3.514	1.031	-4.454	5.662	-0.135	0.122	-0.080	0.280
1987	0.292	0.483	5.501	41.505	-3.983	1.175	3.163	41.573	-0.092	0.122	-0.096	0.274

1988	0.227	0.528	6.910	83.603	-3.992	1.316	4.571	83.636	-0.084	0.121	0.031	0.276
1989	-0.005	0.560	5.507	42.863	-4.127	1.569	3.080	42.939	-0.042	0.121	0.007	0.280
1990	0.103	0.571	5.404	31.615	-4.034	1.491	3.066	31.672	-0.071	0.122	0.107	0.279
1991	0.016	0.593	5.997	43.869	-4.059	1.603	3.631	43.913	-0.054	0.122	0.107	0.276
1992	-0.179	0.584	6.277	42.024	-4.316	1.863	3.830	42.059	-0.037	0.122	0.115	0.277
1993	-0.194	0.571	6.265	41.986	-4.334	1.867	3.820	42.021	-0.037	0.122	0.121	0.277
1994	-0.049	0.608	4.133	30.922	-4.054	1.719	1.753	31.120	-0.040	0.122	0.135	0.282
1995	-0.090	0.592	4.862	43.254	-4.112	1.752	2.481	43.386	-0.038	0.122	0.118	0.279
1996	-0.143	0.583	4.980	43.179	-4.170	1.810	2.577	43.299	-0.033	0.121	-0.033	0.121
1997	-0.027	0.598	0.689	17.930	-4.018	1.685	-1.771	21.766	-0.052	0.122	0.129	0.297
1998	-0.112	0.548	3.575	39.931	-4.175	1.718	1.269	40.335	-0.047	0.122	0.078	0.275
1999	-0.124	0.528	1.114	24.395	-4.213	1.703	-1.266	27.474	-0.050	0.121	0.051	0.273
2000	-0.096	0.481	3.838	44.284	-4.274	1.592	1.729	44.563	-0.084	0.122	0.030	0.272
2001	-0.117	0.449	5.966	109.07	-4.344	1.556	3.936	109.14	-0.094	0.122	-0.033	0.270
2002	-0.133	0.450	4.710	58.628	-4.345	1.571	2.726	58.765	-0.094	0.122	-0.038	0.269
2003	-0.150	0.470	4.518	51.104	-4.308	1.611	2.561	51.245	-0.086	0.122	-0.031	0.269
2004	-0.169	0.476	4.207	43.439	-4.307	1.638	2.300	43.595	-0.082	0.121	-0.036	0.269
2005	-0.176	0.459	2.668	27.512	-4.331	1.609	0.892	27.915	-0.096	0.122	-0.058	0.268

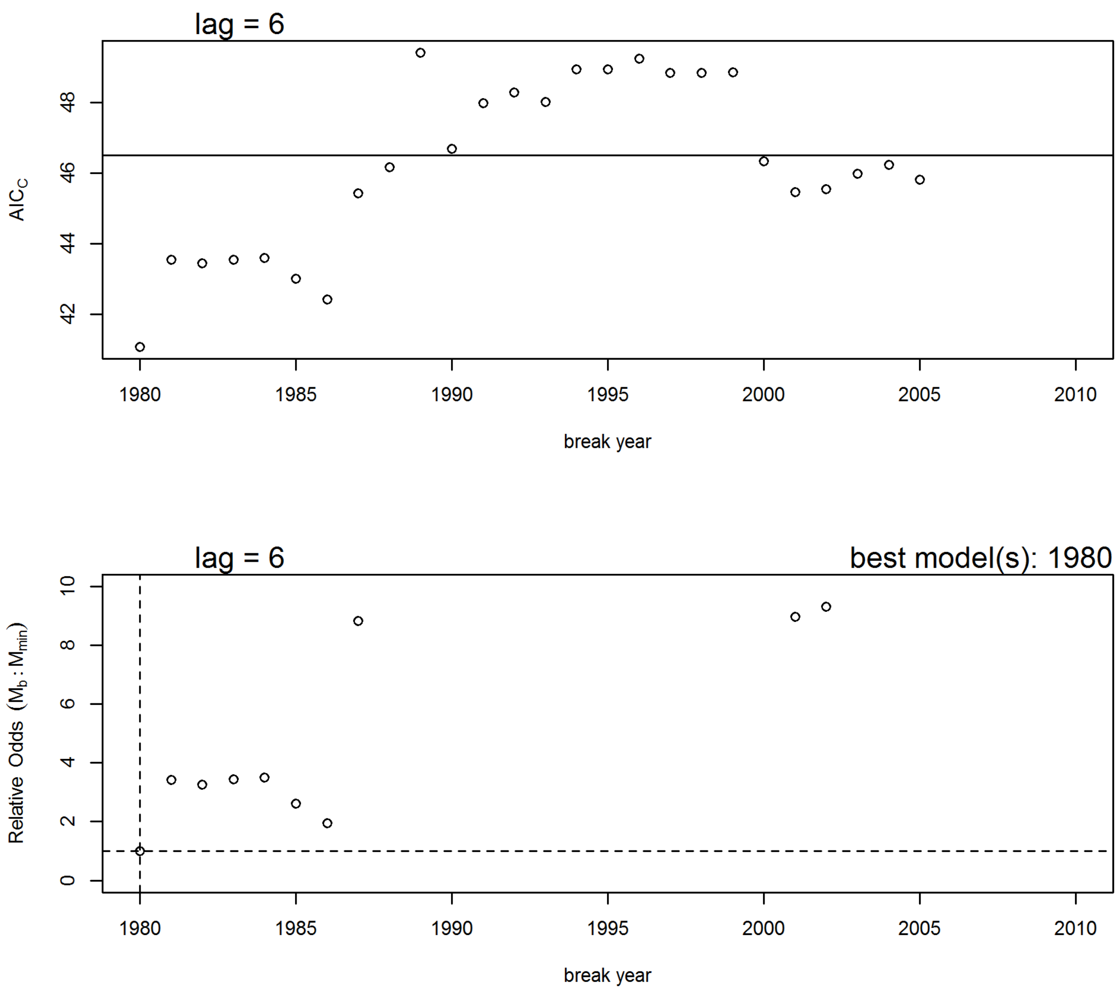


Figure B1. Results from the Ricker stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint 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.

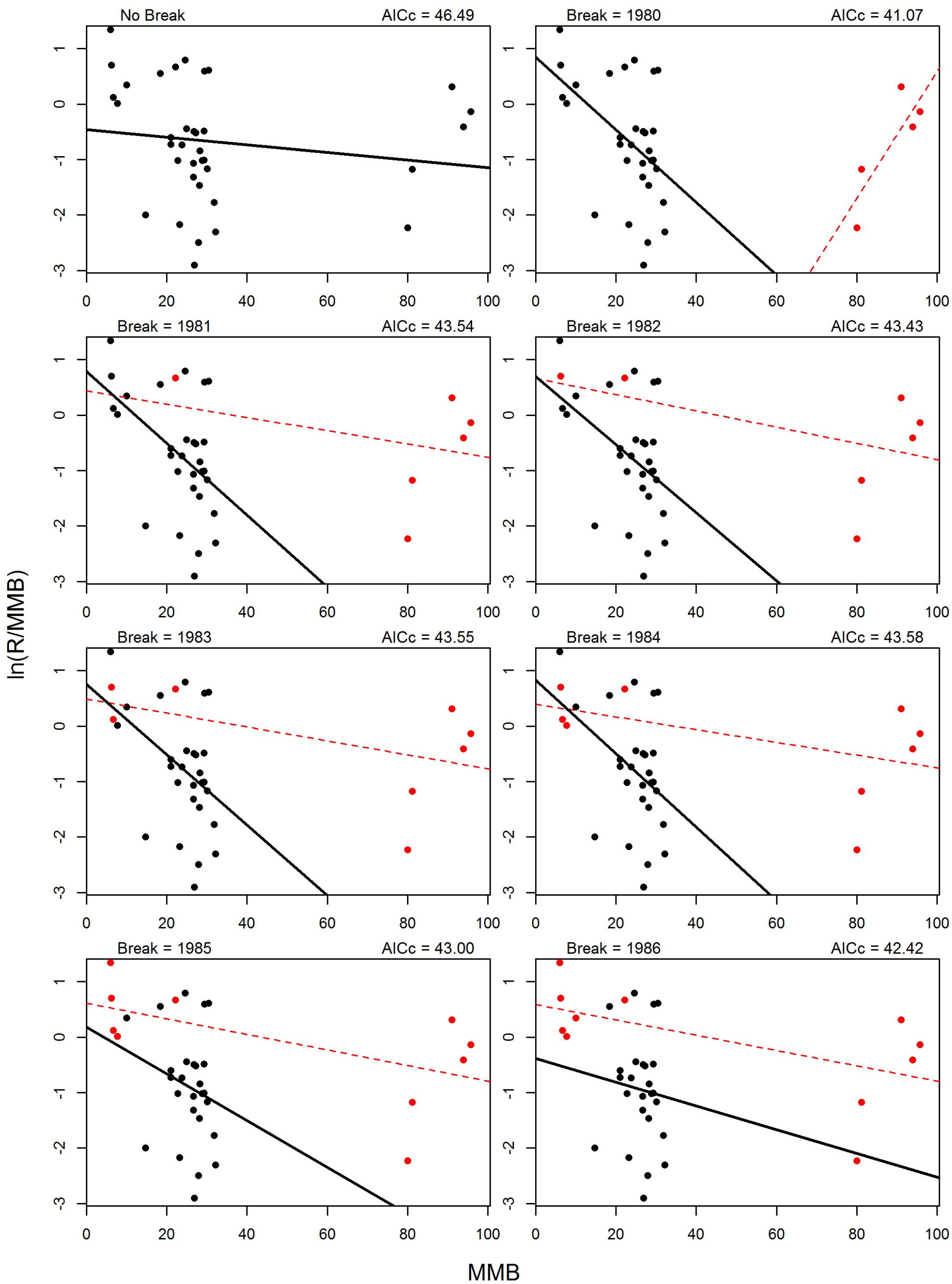
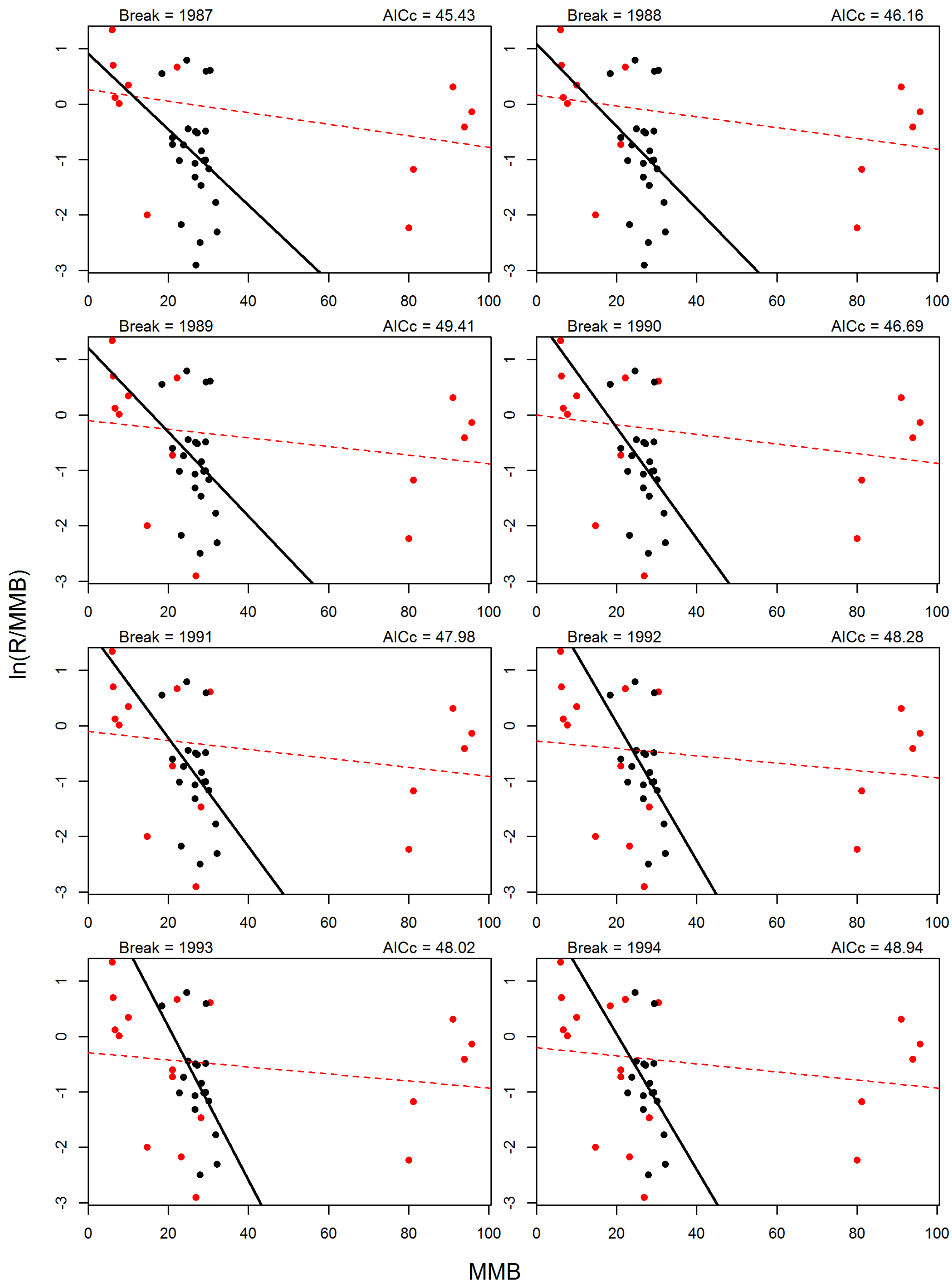


Figure B2. Fits for Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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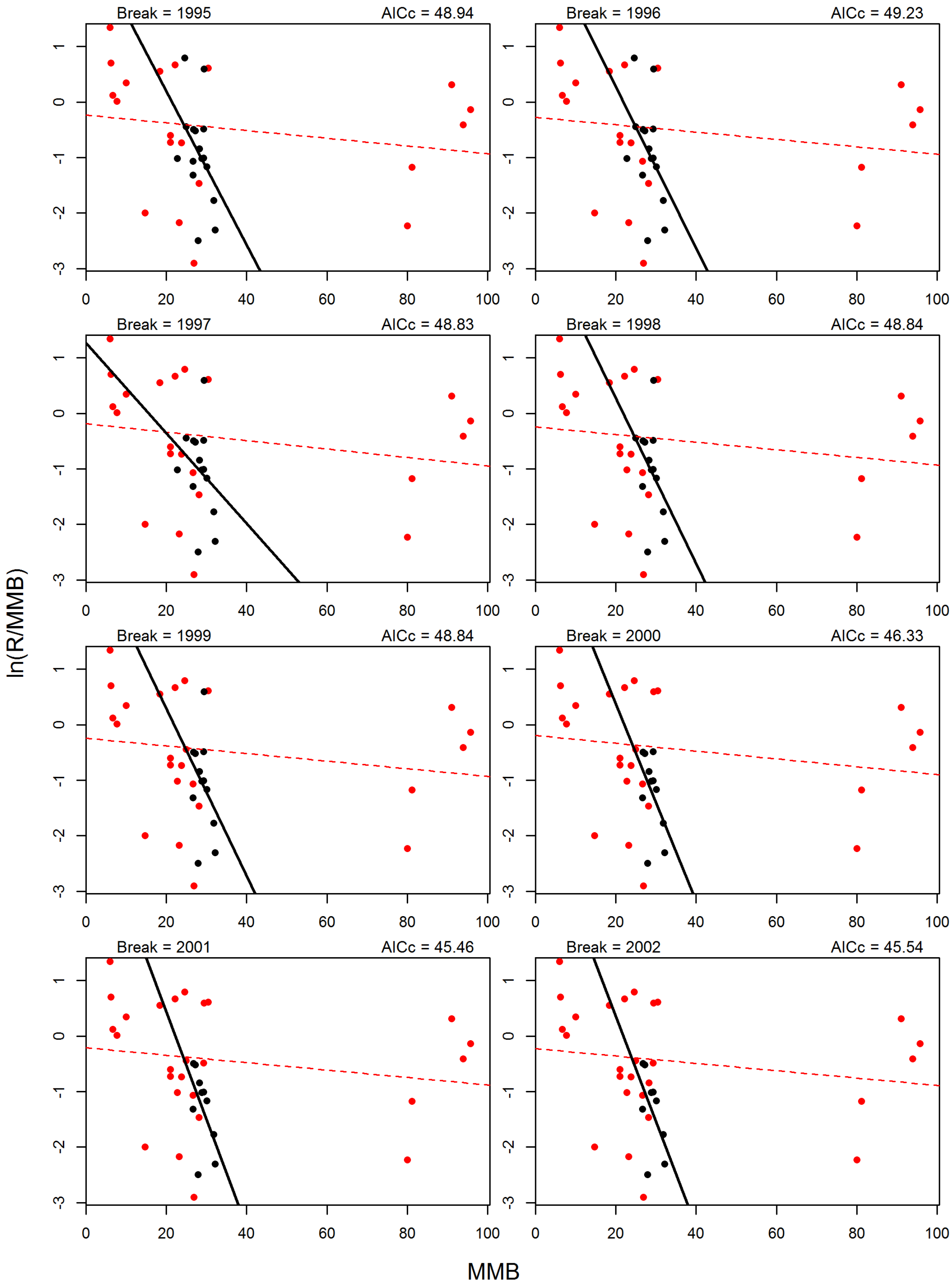

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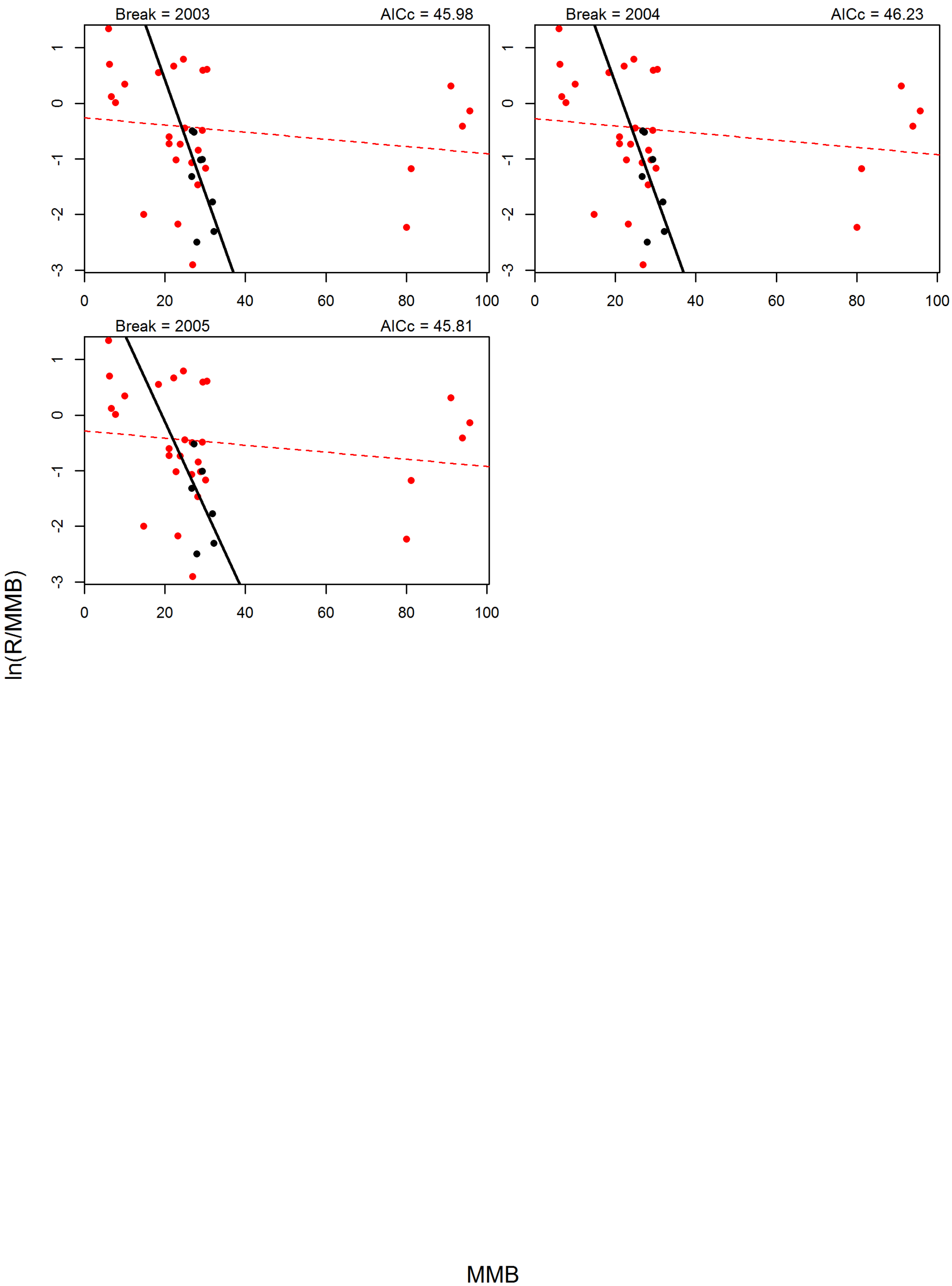

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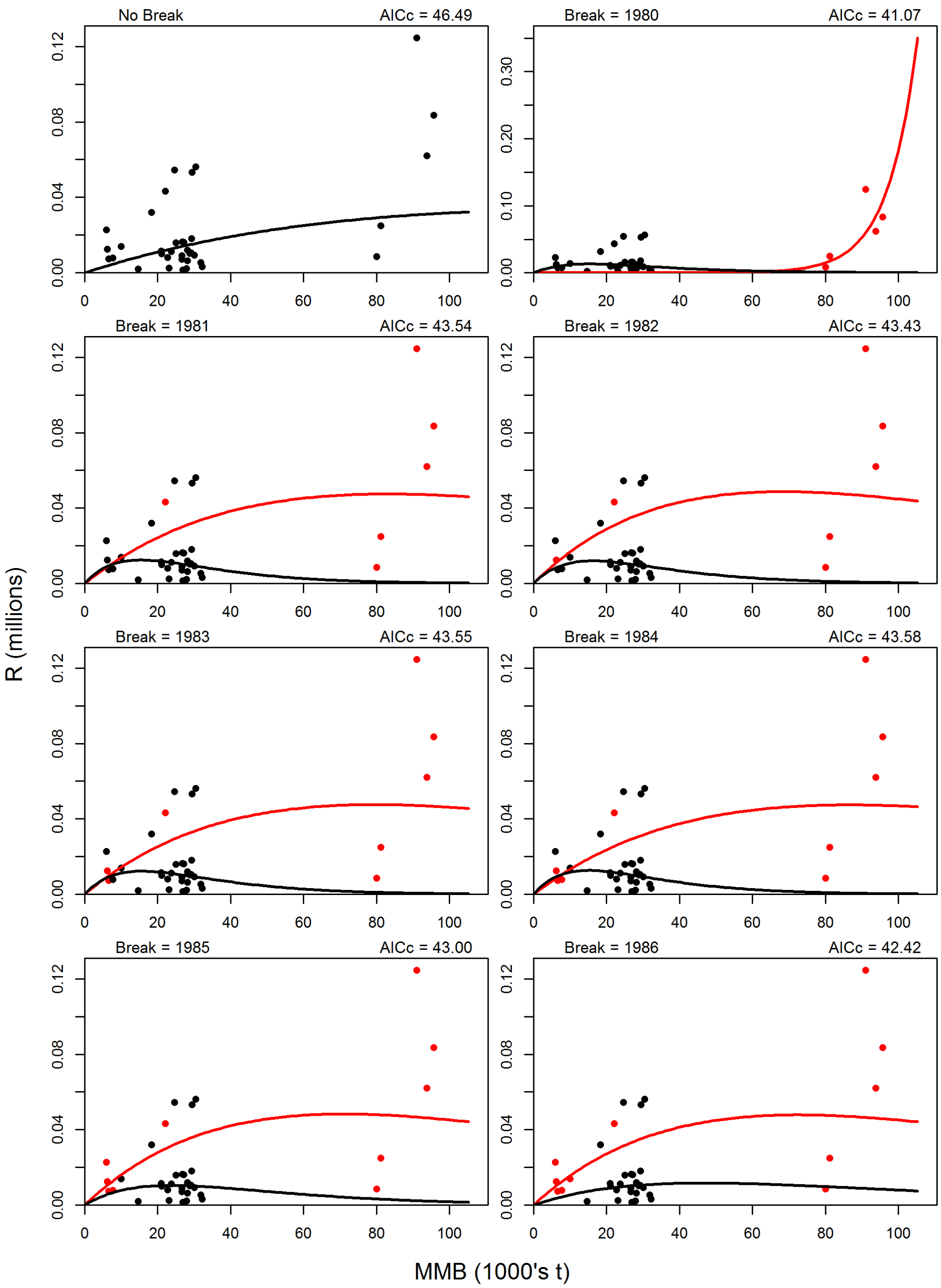
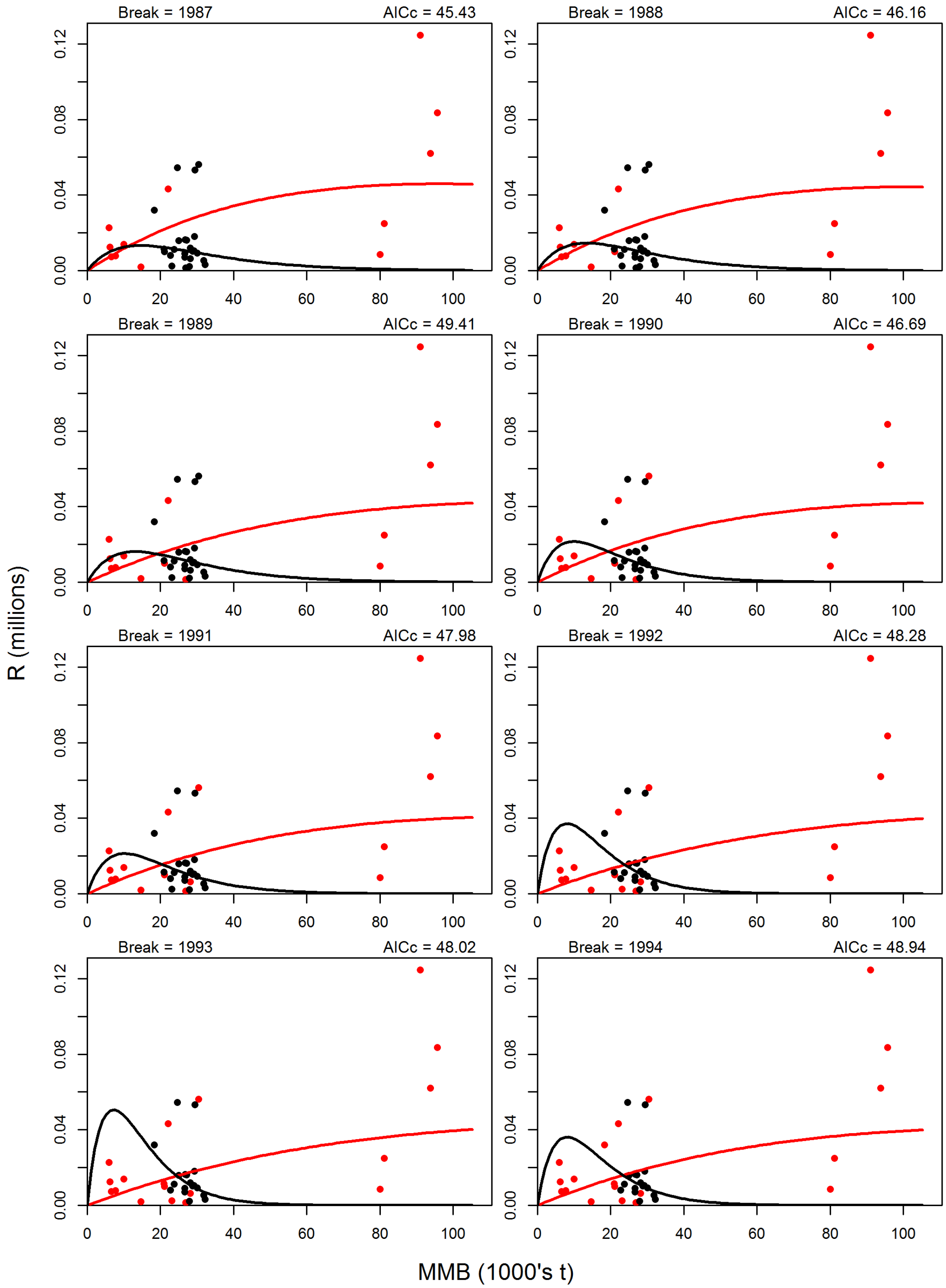


Figure B3. Fits on the arithmetic scale for Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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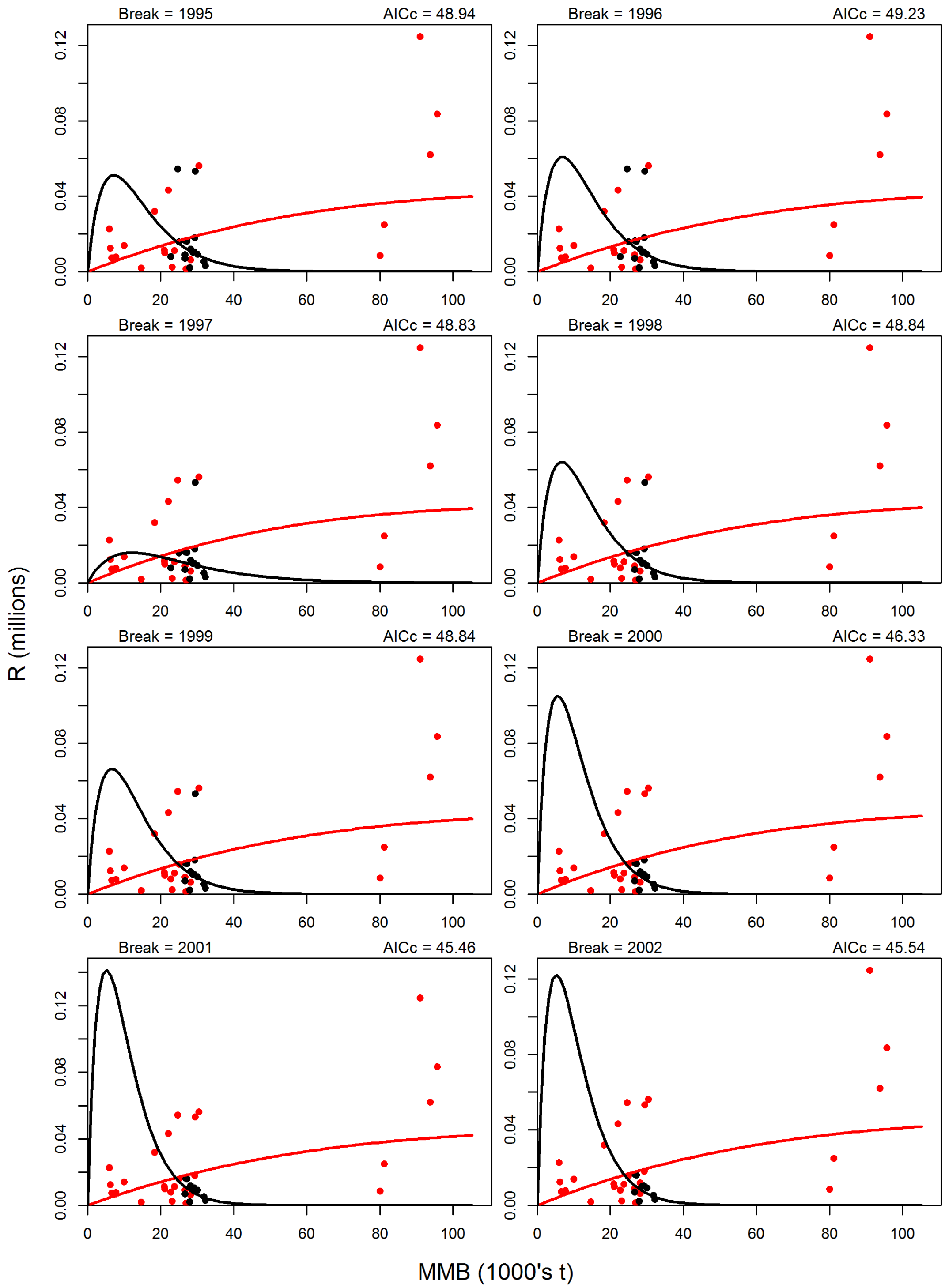

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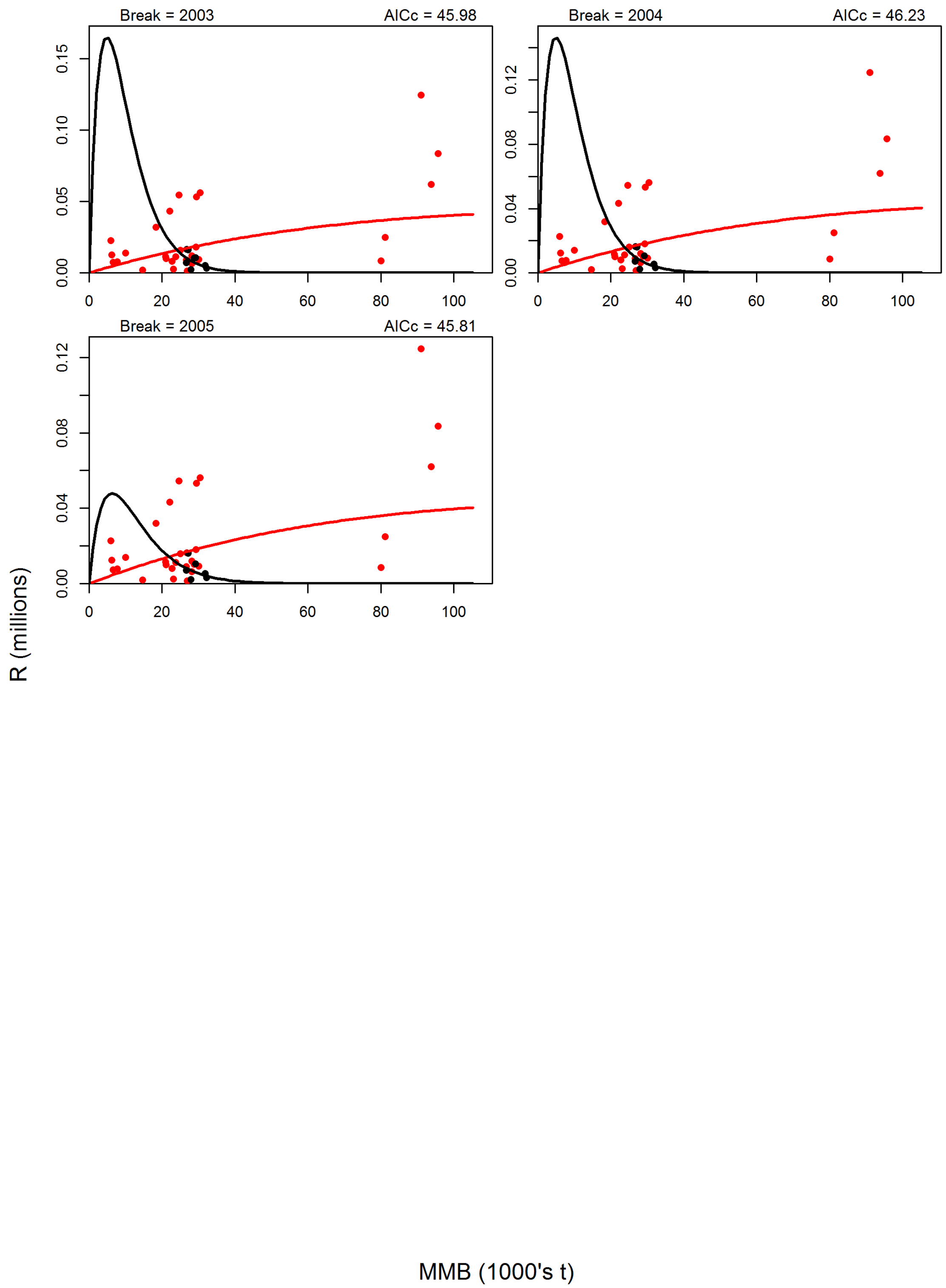

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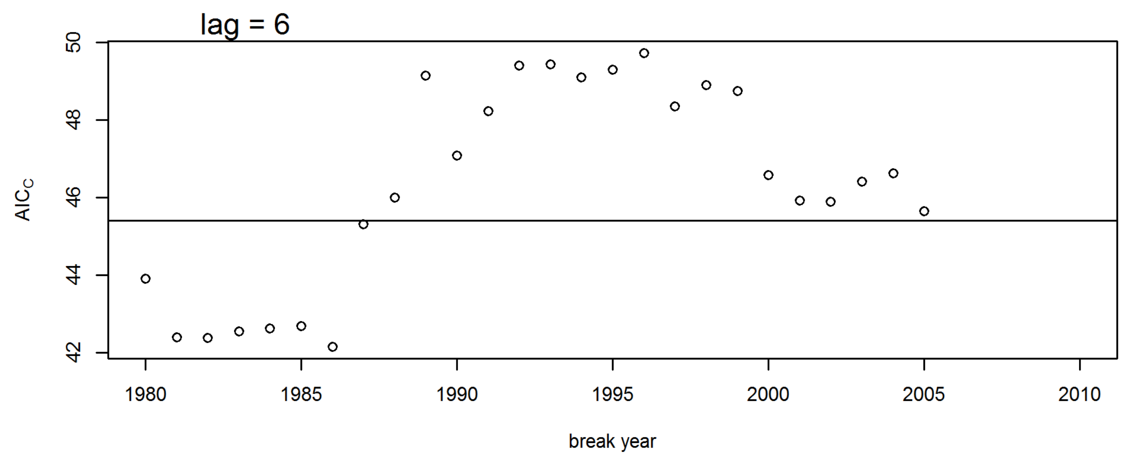


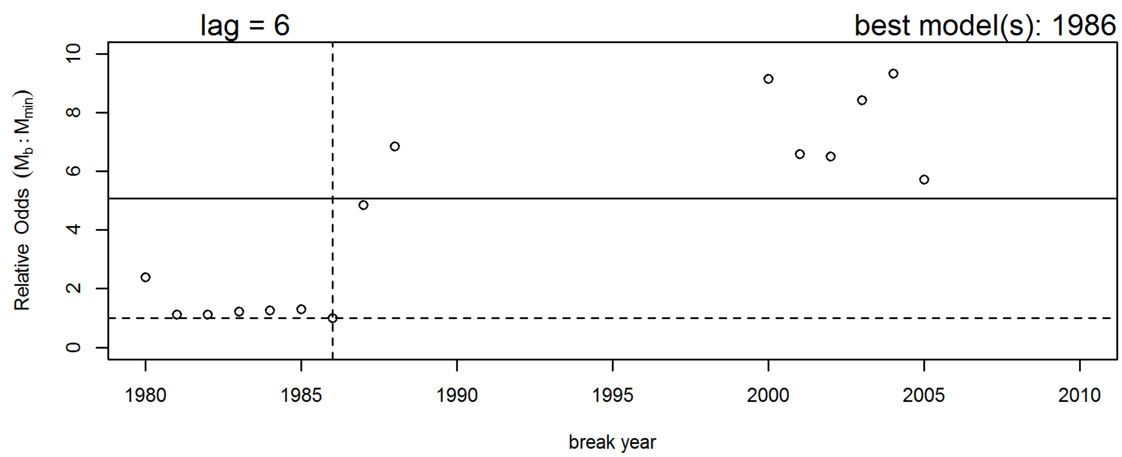


Figure B4. Results from the B-H stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint model (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 1986). Not shown are 1-breakpoint models with high odds (>10) of being incorrect.

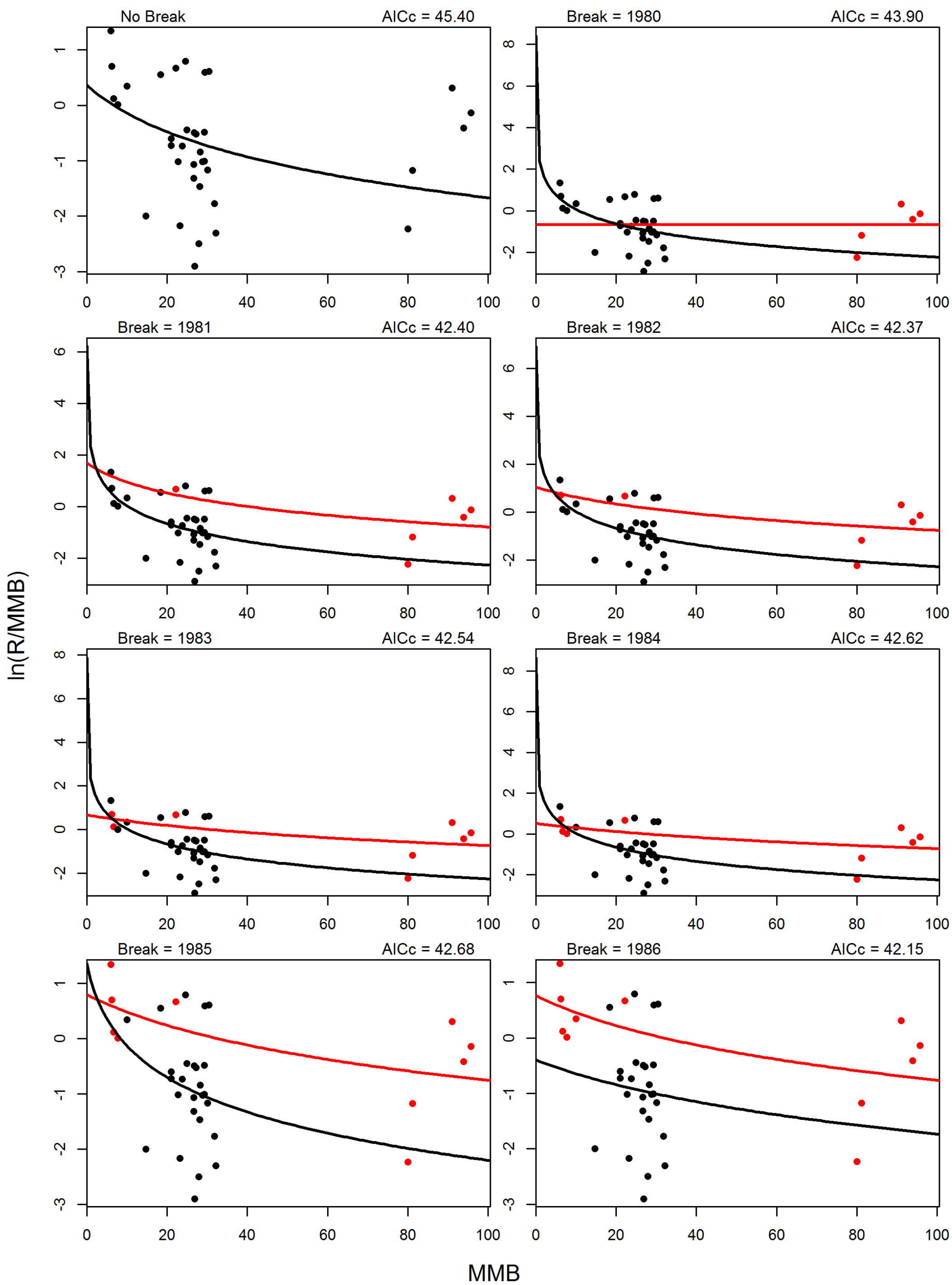
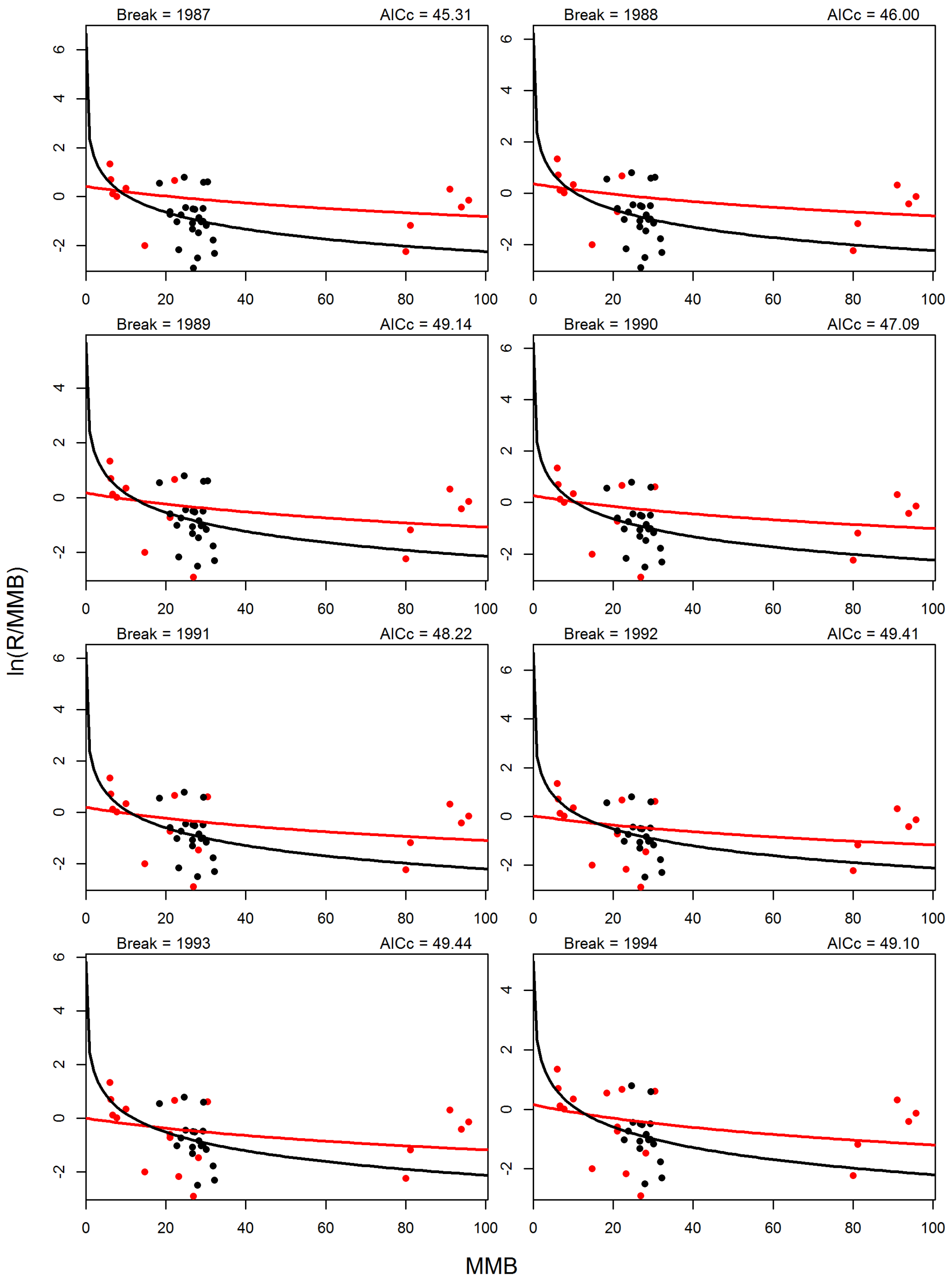


Figure B5. Fits for B-H models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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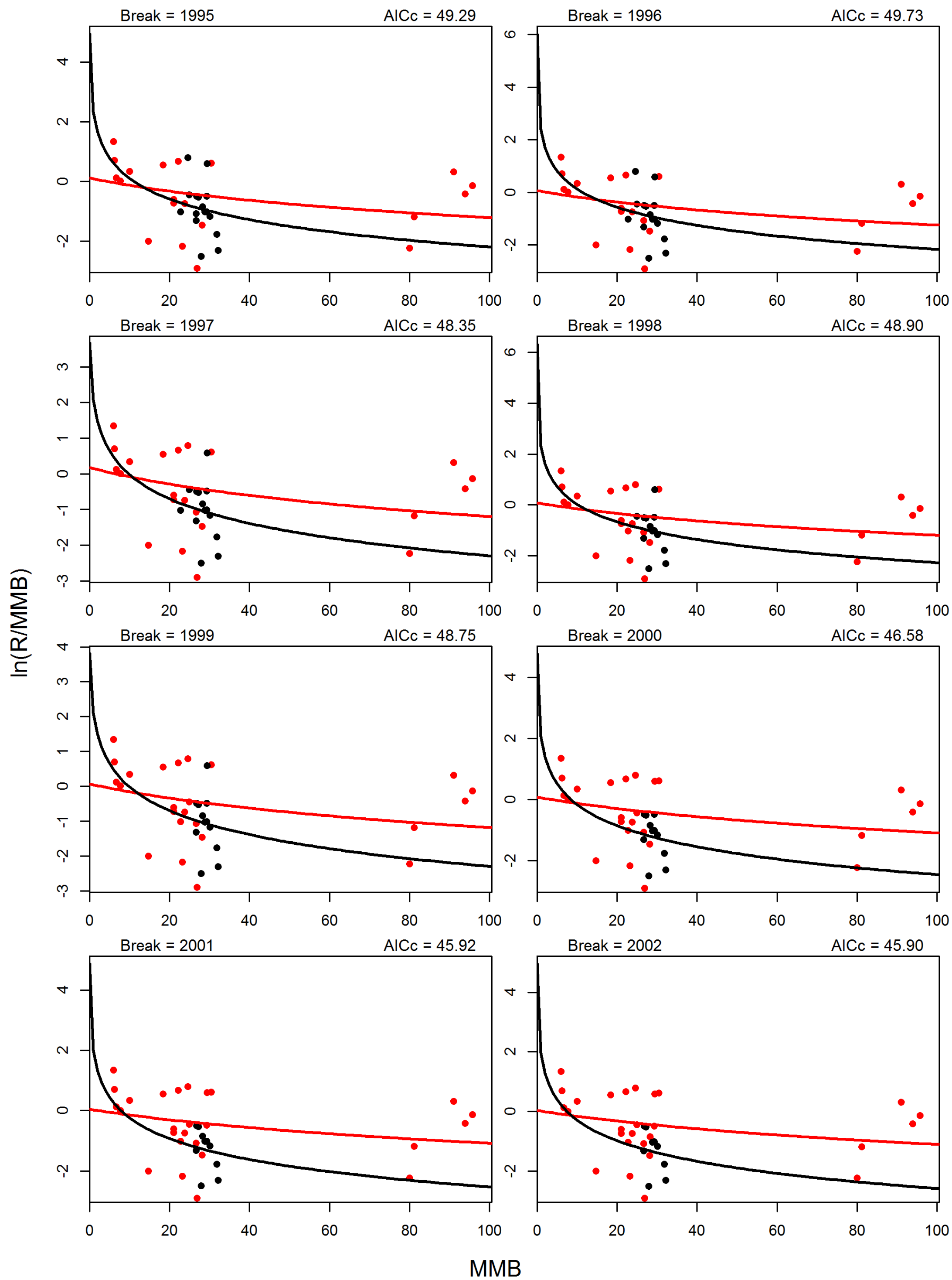

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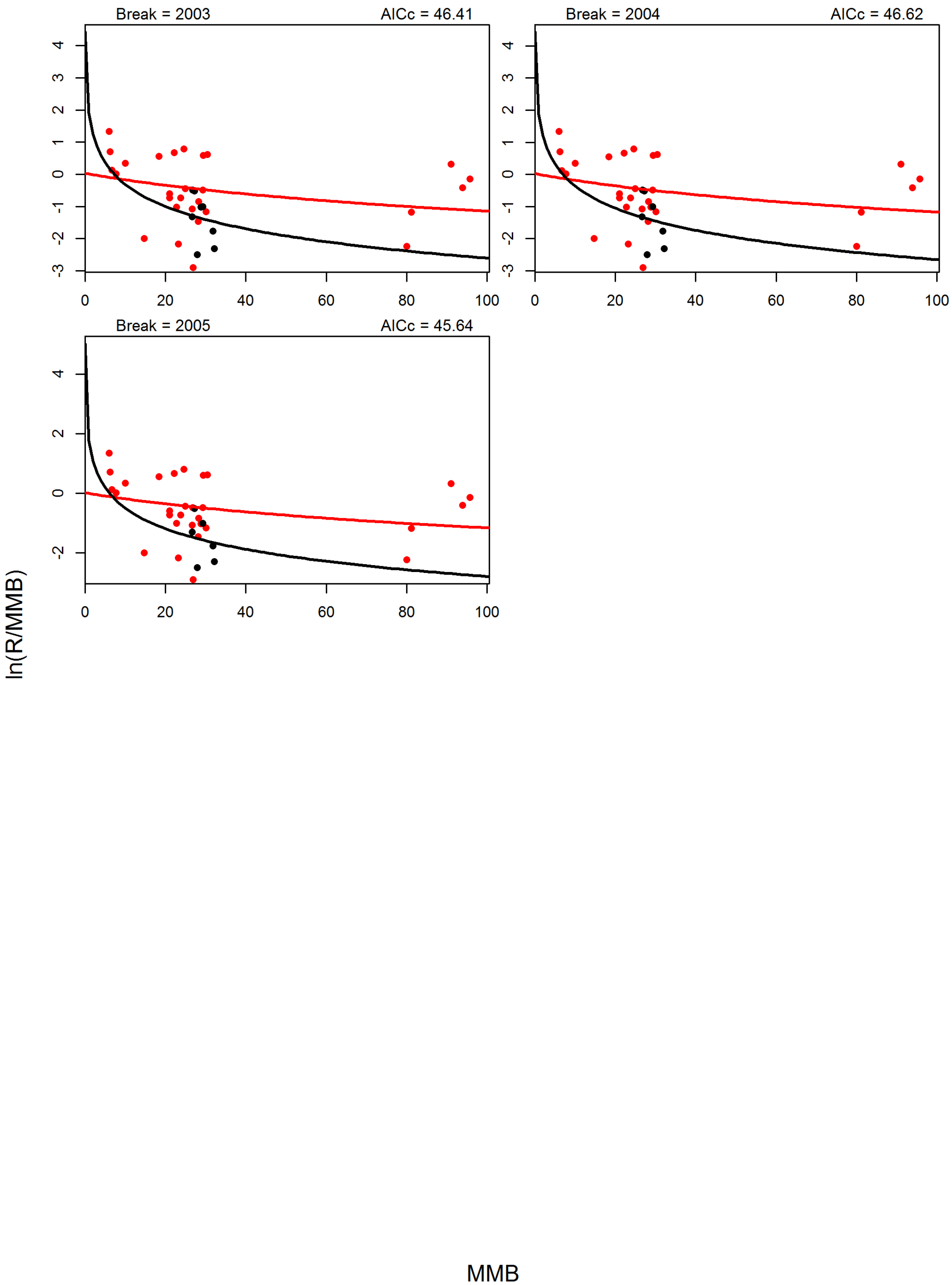

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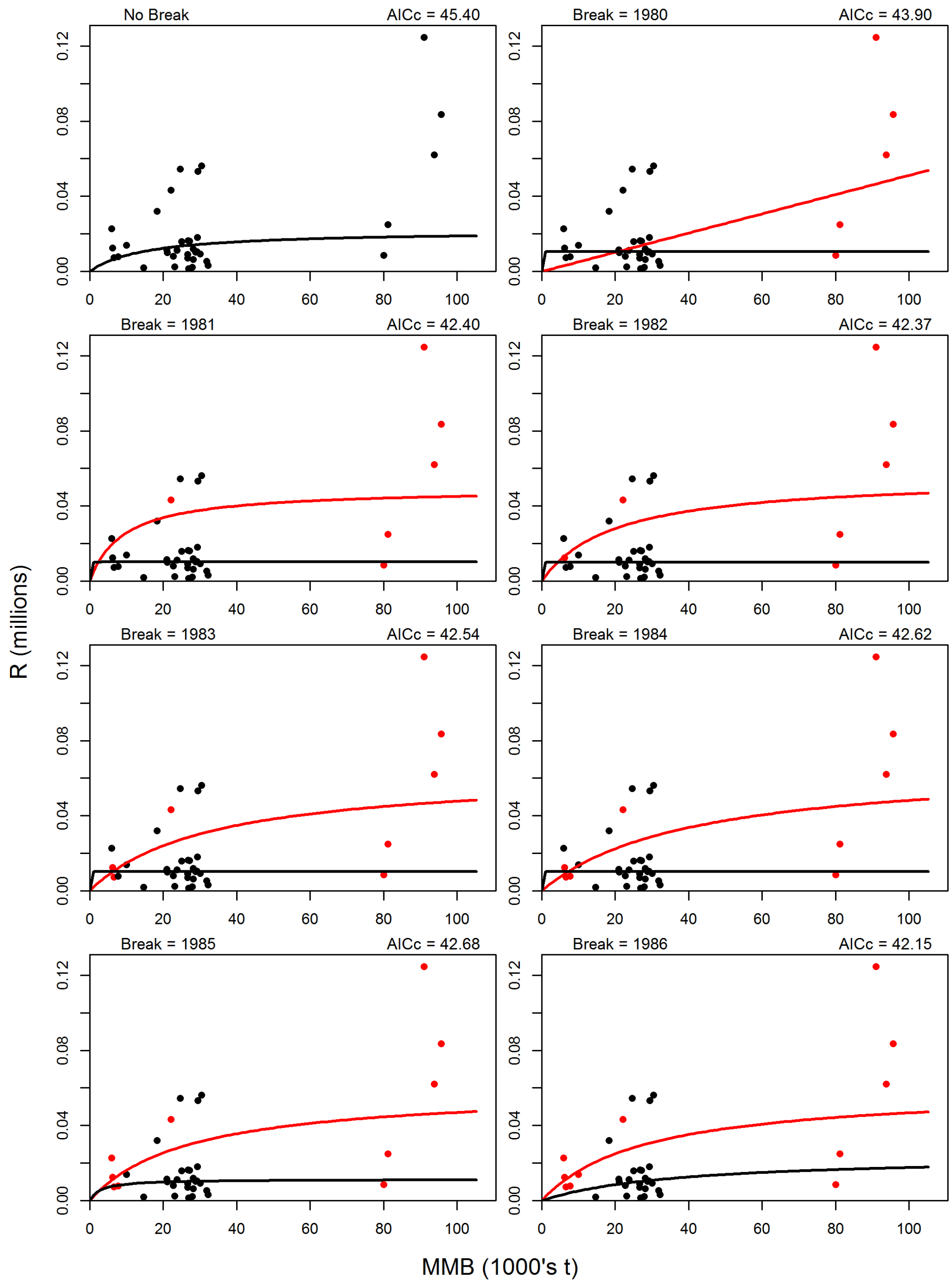
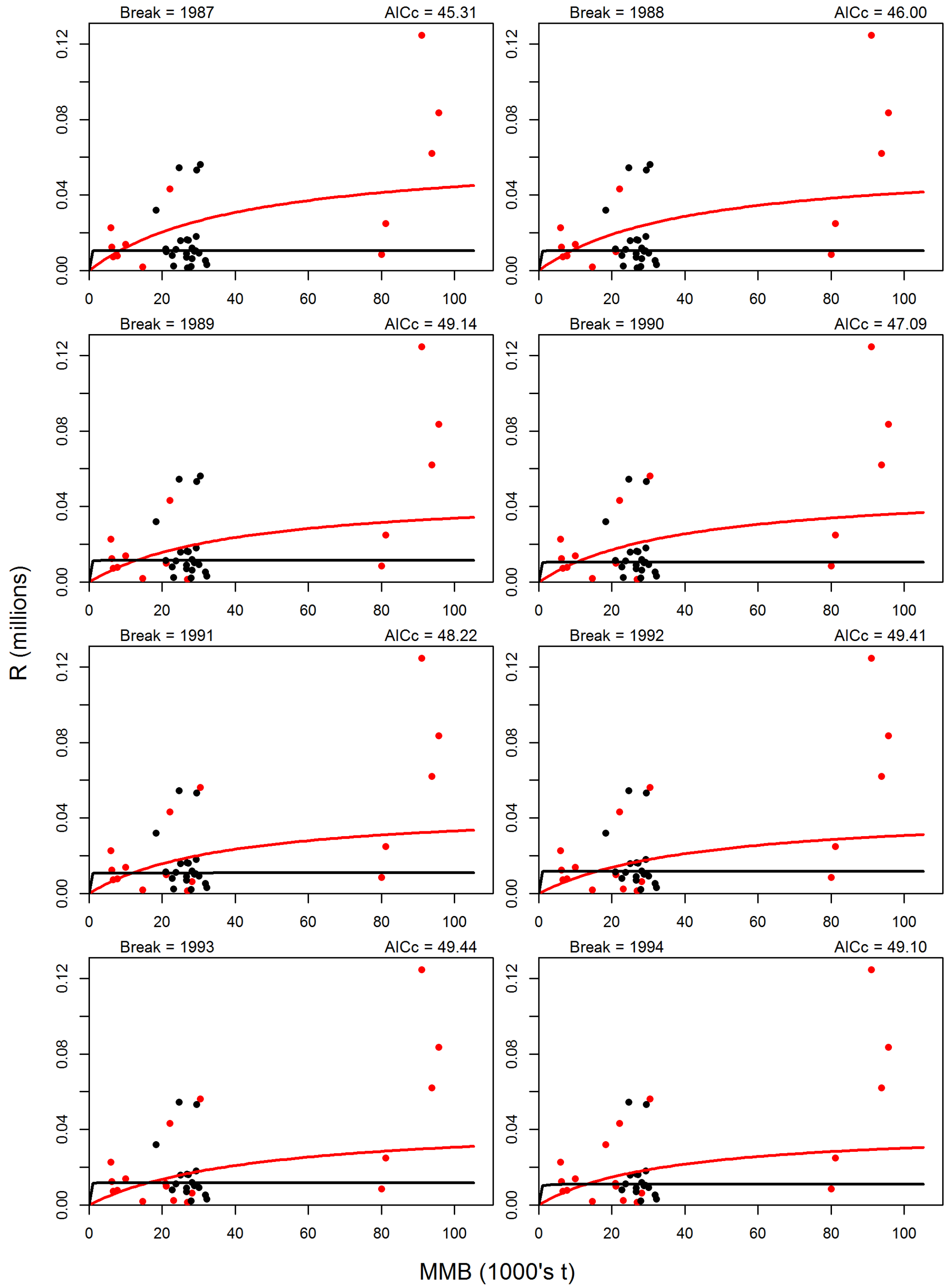


Figure B6. Fits on the arithmetic scale for B-H models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.



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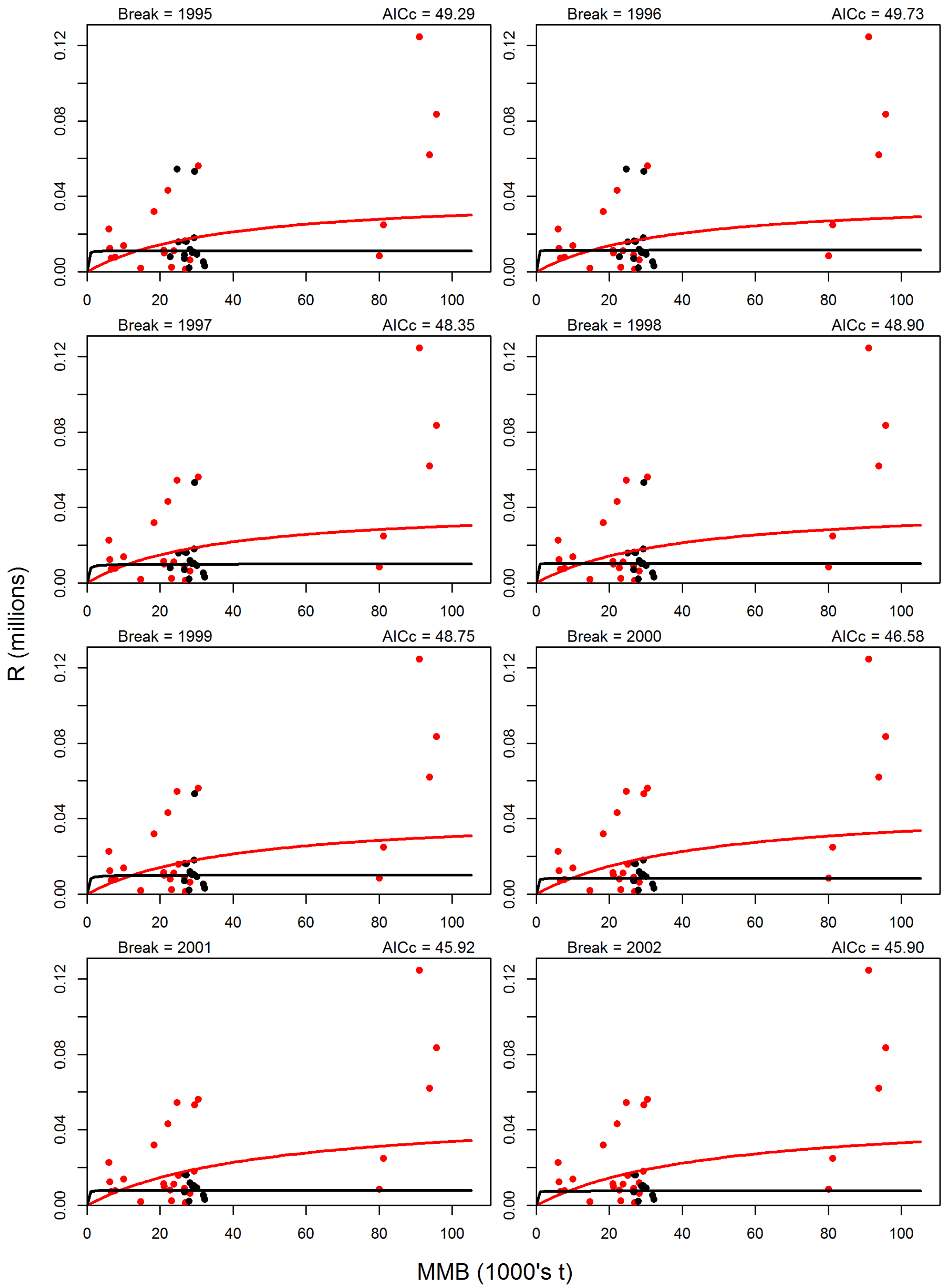


Figure B6. Continue.

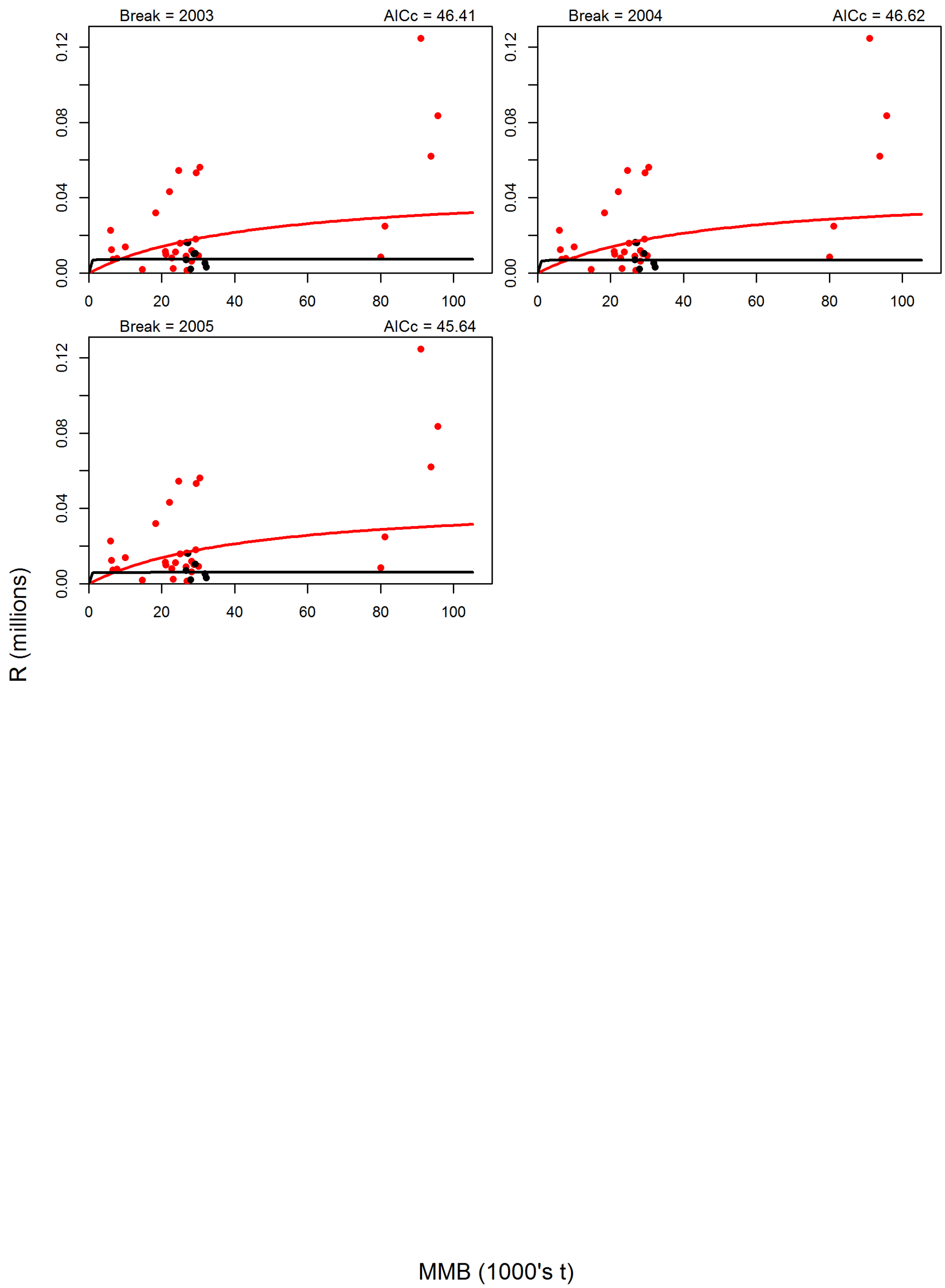


Figure B6. Continue.

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 scenario 18.0. As expected, estimated B0 values change greatly over time.

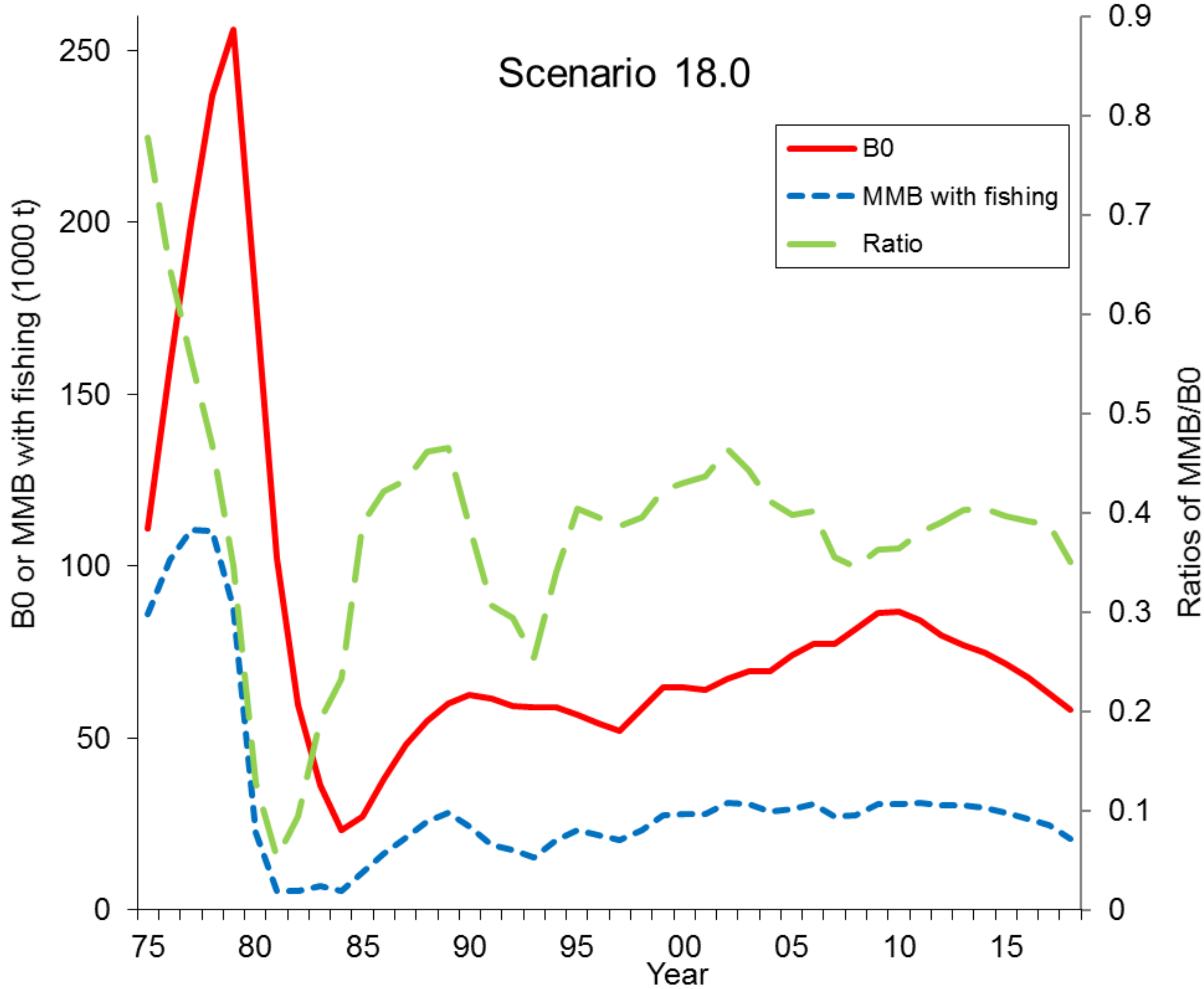


Figure D1. Estimated B0, MMB with fishing, and ratios of MMB/B0 from 1975 to 2018 for scenario 18.0 for Bristol Bay red king crab.

2018 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
2 September 2018

Executive Summary

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

2. Catches: trends and current levels.
Legal-sized male Tanner crab are caught and retained in the directed (male-only) Tanner crab fishery in the EBS. The NPFMC annually determines the overfishing limit (OFL) and acceptable biological catch (ABC) levels for Tanner crab in the EBS, while the Alaska Department of Fish and Game (ADFG) determines the total allowable catch (TAC) separately for areas east and west of 166ºW longitude in the Eastern Subdistrict of the Bering Sea District Tanner crab Registration Area J. Following rationalization of the Bering Sea and Aleutian Islands (BSAI) crab fisheries in 2005/06, the directed fishery for Tanner crab was open through 2009/10, after which time it was determined that the stock was overfished in the EBS and directed fishing was closed. Prior to the closure, the retained catch averaged 770 t per year between 2005/06-2009/10. The directed fishery was re-opened in 2013/14 following determinations by NMFS in 2012 that the stock was rebuilt and no longer overfished and by ADFG that the stock met state harvest guidelines for opening the fishery. ADFG set the TAC at 1,645,000 lbs (746 t) for the area west of 166º W and at 1,463,000 lbs (664 t) for the area east of 166º W. On closing, 79.6% (594 t) of the TAC was taken in the western area while 98.6% (654 t) was taken in the eastern area.

TACs were steadily increased for the next two years, with concomitant increasing harvests. In 2014/15, TAC was set at 6,625,000 lbs (2,329 t) for the area west of 166º W and at 8,480,000 lbs (3,829 t) for the area east of 166º W. On closing, 77.5% (2,329 t) of the TAC was taken in the western area while 99.6% (3,829 t) were taken in the eastern area. In 2015/16, TAC was set at 11,272,000 lbs (5,113 t) for the eastern area and 8,396,000 lbs (3,808 t) for the western area. On closing, essentially 100% of the TAC was taken in both areas (11,268,885 lbs [5,111 t] in the eastern area, 8,373,493 lbs [3,798 t] in the western area based on the 5/20/2016 in-season catch report).

Although the NPFMC determined an OFL of almost 60,000,000 lbs (~25,000 t) based on the 2016 assessment (Stockhausen, 2016), mature female Tanner crab biomass fell below the threshold set in the State of Alaska's harvest strategy for opening the fishery; consequently, the fishery was closed and the TAC was set to 0. Thus, no directed harvest occurred in 2016/17. In 2017/18, ADFG determined that a directed fishery could occur in the area west of 166oW longitude. The TAC was set at 2,500,200 lbs (1,130 t), of which 100% was taken.

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 are 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 1,500 t for the 5-year period 2012/13-2016/17. Bycatch in the snow crab fishery in 2017/18 was 1,120 t. The groundfish fisheries have been the next major source of Tanner crab bycatch over the same five year time period, averaging 360 t. Bycatch in the groundfish fisheries in 2017/18 was 143 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 85 t over the 5-year time period. In 2017/18, this fishery accounted for 182 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 (Model 18C2a), estimated MMB for 2017/18 was 47.0 thousand t (Table 33; Appendix I7, Figure 3). This was smaller than those for the past three years (58.7, 61.0, and 57.7 thousand t, respectively), but it remains above the very low levels seen in the mid-1990s to early 2000s (1990 to 2005 average: 16.8 thousand t). However, it is considerably below model-estimated historic levels in the late 1970s (1975-1980 average: 72.2 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 (Model 18C2a), the estimated total recruitment for 2017/18 (the number of crab entering the population on July 1) is 662.47 million crab (Table 36; Appendix I7, Figure 1). Although this value is highly uncertain, it follows a similarly high estimate for 2016/17 (354.6 million crab). The average 5-year recruitment prior to 2016/17 was only 68.3 million crab while the longterm (1982+) mean is 202.6 million crab.

5. Management performance

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

(a) in 1000's t. FROM 18C2a, THE AUTHOR"S PREFERRED SCENARIO. See Appendix L for table based on CPT-recommended scenario.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2014/15	13.40	71.57 [A]	6.85	6.16	9.16	31.48	25.18
2015/16	12.82	73.93 [A]	8.92	8.91	11.38	27.19	21.75
2016/17	14.58	77.96 [A]	0.00	0.00	1.14	25.61	20.49
2017/18	10.93[C]	43.31[A]	1.13	1.13	2.39[C]	25.42	20.33
2018/19		23.53[B,C]				16.76[C]	13.41[C]

(b) in millions lbs. FROM 18C2a, THE AUTHOR"S PREFERRED SCENARIO. See Appendix L for table based on CPT-recommended scenario.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2014/15	29.53	157.78 [A]	15.10	13.58	20.19	69.40	55.51
2015/16	28.27	162.99 [A]	19.67	19.64	25.09	59.94	47.95
2016/17	32.15	171.87 [A]	0.00	0.00	2.52	56.46	45.17
2017/18	24.10 [C]	95.49 [A]	2.50	2.50	5.27 [C]	56.03	44.83
2018/19		51.87 [B,C]				36.95 [C]	29.56 [C]

A—Estimated at time of mating for the year concerned. This is a revised estimate, based on the subsequent assessment.
B—Projected biomass from the current stock assessment. This value will be updated next year.
C—Based on the author's preferred model (Model 18C2a).

6. Basis for the OFL

a) in 1000's t. FROM 18C2a, THE AUTHOR"S PREFERRED SCENARIO. See Appendix L for table based on CPT-recommended scenario.

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})
2014/15	3a	29.82	63.80	2.14	0.61	1982-2014	0.23
2015/16	3a	26.79	53.70	2.00	0.58	1982-2015	0.23
2016/17	3a	25.65	45.34	1.77	0.79	1982-2016	0.23
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

b) in millions lbs. FROM 18C2a, THE AUTHOR"S PREFERRED SCENARIO. See Appendix L for table based on CPT-recommended scenario.

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})
2014/15	3a	65.74	140.66	2.14	0.61	1982-2014	0.23
2015/16	3a	59.06	118.38	2.00	0.58	1982-2015	0.23
2016/17	3a	56.54	99.95	1.77	0.79	1982-2016	0.23
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

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 2018/19.
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 2018/19, is estimated at 23.53 thousand t. B_{MSY} for this stock is calculated to be 21.87 thousand t, so MSST is 10.93 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 2017/18 was 2.39 thousand t, which was less than the OFL for 2016/17 (25.42 thousand t); consequently **overfishing did not occur**. The OFL for 2018/19 based on the author's preferred model (Model 18C2a) is 16.76 thousand t. The ABC_{max} for 2018/19, based on the p^* ABC, is 16.44 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 13.41 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 was closed in 2017/18, as in 2016/17, because mature female Tanner crab biomass failed to meet the criteria defined in the SOA's harvest strategy to open the fisheries. However, a directed fishery was conducted in the area west of 166ºW longitude.

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.

Data source	Data types	Time frame	Notes	Agency
NMFS EBS Bottom Trawl Survey	area-swept abundance, biomass	1975-2018	recalculated, new	NMFS
	size compositions	1975-2018	recalculated, new	
	molt-increment data	1990+	new	
NMFS/BSFRF	molt-increment data	2014-16	same as 2017	NMFS, BSFRF
Directed fishery	retained catch (numbers, biomass)	2005/06-2017/18	updated, new	ADFG
	retained catch size compositions	2013/14-2017/18	updated	ADFG
	effort	2015/16, 2016/17	updated, new	ADFG
	total catch (abundance, biomass)	1991/92-2017/18	updated, new	ADFG
	total catch size compositions	1991/92-2017/18	updated, new	ADFG
Snow Crab Fishery	effort	1990/91-2017/18	revised, new	ADFG
	total bycatch (abundance, biomass)	1990/91-2017/18	revised, new	ADFG
	total bycatch size compositions	1990/91-2017/18	revised, new	ADFG
Bristol Bay	effort	1990/91-2017/18	revised, new	ADFG
Red King Crab Fishery	total bycatch (abundance, biomass)	1990/91-2017/18	revised, new	ADFG
	total bycatch size compositions	1990/91-2017/18	revised, new	ADFG
Groundfish Fisheries	total bycatch (abundance, biomass)	1991/92-2017/18	revised, new	NMFS/AKFIN
(all gear types)	total bycatch size compositions	1991/92-2017/18	updated, new	

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 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).

The author-recommended model scenario proposed here, 18C2a, differs rather substantially from the 2017 assessment model by: 1) fixing NMFS EBS bottom trawl survey catchability and selectivity parameters in the 1982+ time period to ones equivalent to those from Somerton and Otto (1999)'s so-called "underbag" experiment; 2) adding a likelihood component to fit annual male maturity ogives determined from chela height-to-carapace width ratios in the NMFS survey; and 3) 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 instead fitting to time series of aggregated male survey biomass and abundance, as well as to male size compositions classified by shell condition. In addition, revised time series data for retained and total catch abundance and biomass since 1990/91 were provided by ADFG for the directed Tanner crab, snow crab and Bristol Bay red king crab fisheries and incorporated into model parameter estimation.

4. Changes to the assessment results
Given the fairly substantial changes in model configuration and input data, the results from the author's preferred model this year (Model 18C2a) are surprisingly similar to those of the previous assessment (see Appendix J for a visual comparison of population trajectories from the two models). Average recruitment (1982-present) was estimated at 214 million in last year's model, whereas it is estimated at 199 million in the author's preferred model this year. F_{MSY} is larger this year (0.93 yr^{-1} this year vs. 0.75 yr^{-1} last year), while B_{MSY} was estimated somewhat smaller than last year (21.87 thousand t vs. 29.17 thousand t).

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 2018 SSC Meeting
No general comments.

May 2018 Crab Plan Team Meeting
No general comments.

October 2017 SSC Meeting
No general comments.

September 2017 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 2018 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: See response above to general comments from the June 2017 SSC Meeting.

May2018 Crab Plan Team Meeting
The CPT outlined a number of alternative models built on the 2017 assessment model (2017AM) as the base model to be evaluated.
Response: The CPT referred to these models as 2018B0, 2018B1, 2018B2, 2018B3, 2018B4 and 2018B5. These models were all run for this assessment, but renamed as 18A, 18B, 18C0, 18C1, 18D0, and 18D1, where "18" refers to the assessment year, A/B/C/D refers to different datasets included in the likelihood, and 0/1 refers to whether (1) or not (0) survey abundance time series were included in the fitting process in addition to survey biomass time series. 2017AM is subsequently referred to herein as 17AM. In addition to the alternative model scenarios requested by the CPT, several additional scenarios were also run: 17AMu, 18C0a, 18C1a, 18C2a, and 18C3a. Scenario 17AMu represents the 2017 assessment model re-run with revised (i.e., "u"pdated) data for the crab fisheries. The "a" in the remaining scenarios refers to ones in which the likelihood component for male maturity ogive data was down-weighted, whereas "2" and "3" refer to fixing the survey catchability and selectivity parameters to match ones from Somerton and Otto (1999)'s underbag experiment.

October 2017 SSC Meeting

Comment: "The SSC endorses all of the CPT recommendations with respect to the poor fits to some of the retained catch time series, poor fits to the size composition data for retained catch and survey data, and issues with the total directed fishery selectivity curve for males (in particular the 1996 'outlier')."
Response: With respect to the 1996 'outlier', this was a result of the combination of a very small sample size for the 1996 size compositions and the using the mean size-st-50%-selected for 1991-1996 as the value for the size-at-50%-selected prior to 1991. Because the sample size for 1996 was small, the 1996 size-at-50%-selected essentially became a free parameter uninformed by the 1996 data but sensitive to changes in the overall likelihood through changes in the mean value. Regarding the other issues, see the responses to CPT comments below.

September 2017 CPT Meeting

Comment: "The model fits total catch well, but does a poorer job in fitting retained catch, catch of females, and catch in the bycatch fisheries."
Response: Catch of females was improved by estimating a female-specific offset to fully-selected male capture rates in the fisheries. There appears to be a conflict in the model between fitting total (male) catch and retained catch in the directed fishery. In this assessment, I've explored the use of varying the estimated retention function annually and within time blocks, as well as the possibility that retention is not 100% for the largest male crab (i.e., the retention function asymptotes at less than 1). These options seem to reduce the conflict, but not eliminate it.

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 166ºW, 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.

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, and 2017 in cooperative research between NMFS and the Bering Sea Research Foundation (R. Foy, NMFS, pers. comm.). Previous analysis of the data suggests it is not substantially different from that obtained near Kodiak Island (Stockhausen, 2017). This 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, for the first time, several model scenarios are considered in which size-specific annual proportions of immature to mature male crab in the NMFS EBS bottom trawl survey, based on classification using CH:CW ratios, are fit to inform size-specific probabilities of terminal molt.

Although observations are lacking in the EBS, seasonal differences have been observed between mating periods for pubescent and multiparous females in the Gulf of Alaska and Prince William Sound. There, pubescent molting and mating takes place over a protracted period from winter through early summer, whereas multiparous mating occurs over a relatively short period during mid April to early June (Hilsinger 1976, Munk et al. 1996, and Stevens 2000). In the EBS, egg condition for multiparous Tanner crabs assessed between April and July 1976 also suggested that hatching and extrusion of new clutches for this maturity state began in April and ended sometime in mid-June (Somerton 1981a).

e. Fecundity

A variety of factors affect female fecundity, including somatic size, maturity status (primiparous vs. multiparous), age post terminal molt, and egg loss (NMFS 2004). Of these factors, somatic size is the most important, with estimates of 89 to 424 thousand eggs for females 75 to 124 mm CW, respectively

(Haynes et al. 1976). Maturity status is another important factor affecting fecundity, with primiparous females being only ~70% as fecund as equal size multiparous females (Somerton and Meyers 1983). The number of years post maturity molt, and whether or not, a female has had to use stored sperm from that first mating can also affect egg counts (Paul 1984, Paul and Paul 1992). Additionally, older senescent females often carry small clutches or no eggs (i.e., are barren) suggesting that female crab reproductive output is a concave function of age (NMFS 2004).

f. Size at Maturity

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

g. Mortality

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

Rugolo and Turnock (2011a) examined empirical evidence for reliable estimates of oldest observed age for male Tanner crab. Unlike its congener the snow crab, information on longevity of the Tanner crab is lacking. They reasoned that longevity in a virgin population of Tanner crab would be analogous to that of the snow crab, where longevity would be at least 20 years, given the close analogues in population dynamic and life-history characteristics (Turnock and Rugolo 2011a). Employing 20 years as a proxy for longevity and assuming that this age represented the upper 98.5th percentile of the distribution of ages in an unexploited population, M was estimated to be 0.23 based on Hoenig's (1983) method. 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, with federal oversight (Bowers et al. 2008). The State of Alaska manages Tanner crab based on registration areas divided into districts. Under the FMP, the state can adjust districts as needed to avoid overharvest in a particular area, change size limits from other stocks in the registration area, change fishing seasons, or encourage exploration (NPFMC 2011).

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

In March 2011, the Alaska Board of Fisheries (BOF) approved a new minimum size limit harvest strategy for Tanner crab effective for the 2011/12 fishery. Prior to this change, the minimum legal size limit was 5.5" (138 mm CW) throughout the Bering Sea District. The new regulations established different minimum size limits east and west of 166º W. The minimum size limit for the fishery to the east of 166ºW is now 4.8" (122 mm CW) and that to the west is 4.4" (112 mm CW), where the size measurement includes the lateral spines. For economic reasons, fishers may adopt larger minimum sizes for retention of crab in both areas, and the SOA's harvest strategy and total allowable catch (TAC) calculations are based on assumed minimum preferred sizes that are larger than the legal minimums. In 2011, these minimum preferred sizes were set at 5.5" (140 mm CW) in the east and 5" (127 mm CW) in the west, including the lateral spines. In 2015, following a petition by the crab industry, the BOF revised the minimum preferred size for TAC calculations in the area east of 166º W longitude to 5" (127 mm CW), the same as that in the western area. These new "preferred" sizes were used to set the TAC for the 2015/16 fishery season.

In 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 this assessment, I use the term "legal males" to refer to crab 125 mm CW, the minimum "preferred" size used in both eastern and western areas the SOA's harvest strategy, and larger.

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

The domestic Tanner crab pot fishery developed rapidly in the mid-1970s (Tables 1 and 2; 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 18.19 thousand t, and then fell sharply through the mid-1990s. The domestic Tanner crab fishery was closed between 1996/97 and 2004/05 as a result of conservation concerns regarding depressed stock status. It re-opened in 2005/06 and averaged 0.77 thousand t retained catch between 2005/06-2009/10 (Tables 1 and 2). For the 2010/11-2012/13 seasons, the State of Alaska closed directed commercial fishing for Tanner crab due to estimated female stock metrics being below thresholds adopted in the state harvest strategy. However, these thresholds were met in fall 2013 and the directed fishery was opened in 2013/14. TAC was set at 1,645,000 lbs (746 t) for the area west of 166º W and at

1,463,000 lbs (664 t) for the area east of 166° W in the State of Alaska's Eastern Subdistrict of Tanner crab Registration Area J. The fisheries opened on October 15 and closed on March 31. On closing, 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.

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 first available) to 2004/05, the groundfish fisheries accounted for the largest proportion of discard mortality. Since 2005/06, however, the crab fisheries have accounted for the largest proportion.

D. Data

1. Summary of new information

ADFG provided revised values for retained catch abundance and biomass by shell condition from fish ticket data for 2005/06-2016/17, with new values for 2017/18 (Appendix A). This included a breakout of incidental retained Tanner crab catch in the snow crab and BBRKC fisheries; previously, 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. Retained catch size composition data from "dockside" observer sampling in the directed fishery were updated by ADFG for 2013/14-2015/16 and new data for 2017/18 were provided (Appendix A).

Revised estimates of total catch (retained + discards) abundance and biomass in all three crab fisheries, based on "at-sea" crab observer sampling, were provided by sex and shell condition by ADFG for 1990/91-2016/17, with new estimates provided for 2017/18 (Appendix B). ADFG also provided size composition data from "at-sea" crab observer sampling by sex and shell condition for 1990/91-2017/18 (Appendix B). Revised estimates of total effort (potlifts) in the three crab fisheries were also provided for 1990/91-2016/17, with new estimates for 2017/18 (Appendix C).

Tanner crab bycatch data in the groundfish fisheries (abundance, biomass, size compositions) were extracted for 1991/92-2017/18 from the groundfish observer and AKRO databases on AKFIN (Appendix D). Results for 1991/92-2016/17 were slightly different than last year, reflecting small changes in the algorithms used to expand observed bycatch to total bycatch, as well as data editing. Although the bycatch data in the groundfish fisheries available by gear type, all model scenarios examined here fit the data aggregated over gear types (see below).

Swept-area abundance, biomass and size composition data from the 2018 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. More details are provided in Appendices E and F.

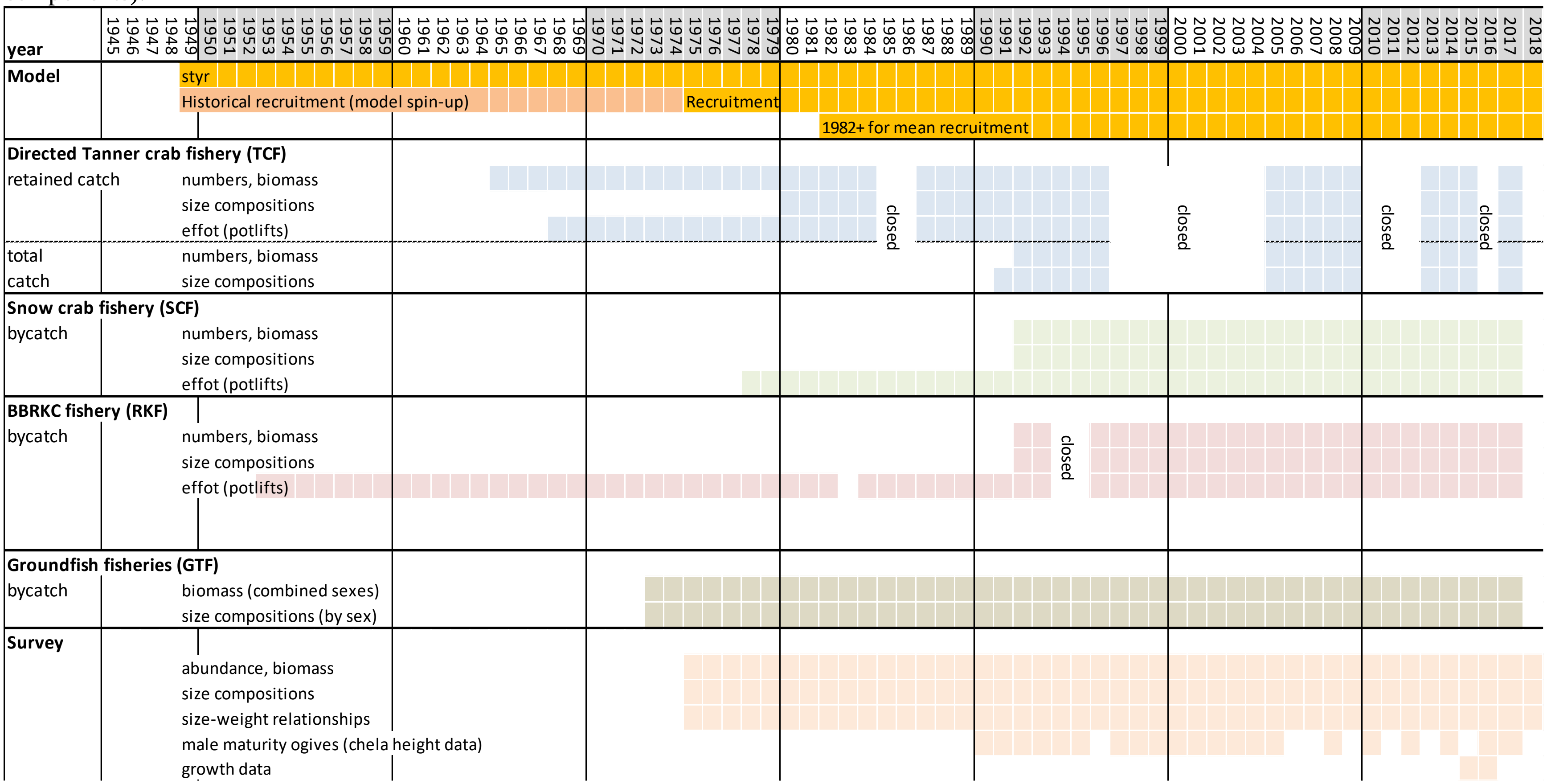
Molt increment data from growth studies conducted in the EBS as cooperative research by NMFS and BSFRF are fit in the model scenarios included in this assessment. These data are described in more detail in Appendix G.

Finally, annual maturity ogives based on classification of male crab in the NMFS EBS bottom trawl survey using CH:CW ratios are fit for the first time in a number of the model scenarios considered in this assessment. These data are described in more detail in Appendix H.

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

Data source	Data types	Time frame	Notes	Agency
NMFS EBS Bottom Trawl Survey	area-swept abundance, biomass	1975-2018	recalculated, new	NMFS
	size compositions	1975-2018	recalculated, new	
	molt-increment data	1990+	new	
NMFS/BSFRF	molt-increment data	2014-16	same as 2017	NMFS, BSFRF
Directed fishery	retained catch (numbers, biomass)	2005/06-2017/18	updated, new	ADFG
	retained catch size compositions	2013/14-2017/18	updated	ADFG
	effort	2015/16, 2016/17	updated, new	ADFG
	total catch (abundance, biomass)	1991/92-2017/18	updated, new	ADFG
	total catch size compositions	1991/92-2017/18	updated, new	ADFG
Snow Crab Fishery	effort	1990/91-2017/18	revised, new	ADFG
	total bycatch (abundance, biomass)	1990/91-2017/18	revised, new	ADFG
	total bycatch size compositions	1990/91-2017/18	revised, new	ADFG
Bristol Bay	effort	1990/91-2017/18	revised, new	ADFG
Red King Crab Fishery	total bycatch (abundance, biomass)	1990/91-2017/18	revised, new	ADFG
	total bycatch size compositions	1990/91-2017/18	revised, new	ADFG
Groundfish Fisheries	total bycatch (abundance, biomass)	1991/92-2017/18	revised, new	NMFS/AKFIN
(all gear types)	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
Information on retained catch is also discussed in Appendix A. 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 Figure 2 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 6). 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.

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 3 based on ADFG "at-sea" crab observer sampling starting in 1992/93. 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 slow but rather steady decline to the present (255 t in 2016/17). Since reliable at-sea ADFG crab observer data has been available (1992), the snow crab fishery has consistently accounted for the highest fraction of bycatch mortality among the crab fisheries, followed by the directed fishery and the BBRKC fishery. Estimated bycatch mortality was highest for all crab fisheries in the early 1990s (~12,000 t total) but subsequently declined as (presumably) the stock declined and the directed fishery was curtailed. Since the directed fishery re-opened in 2013/14, bycatch mortality has averaged 325 t in the directed fishery, 554 t in the snow crab fishery, 32 t in the BBRKC fishery, and 309 t in the groundfish fisheries (Stockhausen, 2017).

In the crab fisheries, the largest component of bycatch occurs on males (Stockhausen, 1991). 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 crab observer sampling is presented in Appendix A, Figures 7-8, by fishery region (and total) 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.

Size compositions expanded to total catch (retained + discards) from at-sea crab fishery observer sampling in the directed fishery are presented by shell condition and fishery region in Appendix B, Figures 3-4 and 13-14, by sex. The male size compositions suggest that about half the males caught in the directed fishery in 2015/16 were less than the minimum preferred size of 125 mm CW. If old shell males really are males at least one year past their terminal molt (as assumed in the assessment model), the size compositions for these crab suggest that 30-50% of these crab (which will not grow) are less than the preferred size.

Size compositions expanded to total bycatch of Tanner crab in the snow crab fishery, based on at-sea crab fishery observer sampling, are presented by sex and shell condition in Appendix B, Figures 5-8 and 15-18. Because this fishery is prosecuted further north and west, on average, than the directed fishery, its bycatch composition consists of somewhat smaller males than in the directed fishery. Conversely, the expanded bycatch size compositions for the BBRKC fishery tend to be shifted toward somewhat larger males than the directed fisheries because the BBRKC fishery is prosecuted further to the south and east on average than the directed fishery (Appendix B, Figures 9-12 and 19-22). Size compositions expanded to total bycatch based on observer sampling in the groundfish fisheries for 1991/92 to the present are shown in Appendix D, Figures 15-18. Size compositions prior to 1991/92 have not been expanded to total bycatch; thus, the scales are incompatible with those after 1990/91. Male bycatch size compositions in the snow crab fishery clearly reflect some sort of "dome-shaped" selectivity pattern (as assumed in the assessment model), with selectivity small for small and large males and highest for intermediate-sized males. In contrast, the BBRKC fishery appears to catch mostly larger Tanner crab males (consistent with asymptotic selection), while the groundfish fisheries take a wide range of sizes as bycatch.

Raw and input sample sizes (number of individuals measured) for the various fisheries are presented in Tables 4-8.

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 9-10, Appendix E Figures 1-14). Estimated biomass of mature crab in the survey time series started at its maximum (277,000 t) in 1975, decreased rapidly to a low (17,000 t) in 1986, and rebounded quickly to a smaller peak (157,000 t) in 1991 (Appendix E, Figure 5). After 1991, mature survey biomass decreased again, reaching a minimum of 13,100 t in 1998. Recovery following this decline was slow and mature survey biomass did not peak again until 2008 (82,900 t), after which it has fluctuated more rapidly—decreasing within two years by almost 50% and reaching a minimum in 2010 (44,600 t), followed by an increase of almost 50% to reach a peak in 2014 (97,300 t). The most recent trend in mature biomass (2014-2018) has been a declining one (Appendix E, Figure 6). Trends in the male and female components of mature survey biomass and abundance have primarily been in synchrony with one another, as have changes in the eastern and western fishery regions (east and west of 166ºW longitude), although the magnitudes differ (Appendix E, Figures 5-8). Preferred-size male survey biomass and abundance 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 and remains essentially unchanged in 2018 (Appendix E, Figures 9-12).

e. Survey catch-at-length

Plots of survey size compositions for Tanner crab by sex and fishery region, expanded to total abundance by shell condition for males and maturity state for females, in Appendix E, Figures 13-15. The absence of small (new shell) male crab in the eastern region since 2009 is notable, as is the progression of a possible cohort through both regions starting in 2009. Similar to males, a cohort progression of immature females starting in 2009 is evident in both regions, although it is much clearer in the western region. It can also be tracked into the mature female size comps starting in 2013. A potential new cohort is also evident in the size comps for both sexes in the western region, but not the eastern region, in 2017 and 2018.

Observed sample sizes for the size compositions, aggregated to the EBS regional level used in the assessment, are presented in Table 11. 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 2012-2018 NMFS bottom trawl surveys are mapped in Appendix F for immature males, mature males, immature females, mature females and legal males. There has been some suggestion 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 but absent during the 2018 survey, but the distribution of mature males did not change remarkably (Appendix F, Figures 7-8).

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

Maturity ogives for male crab, using chela height to carapace width ratios to classify male crab on which chela height measurements have been taken during the NMFS EBS bottom trawl survey, are available for a number of years since 1990 (Appendix G). These data are used in a number of the model scenarios considered for this assessment to inform the size–specific probability of terminal molt by immature male crab.

3. Data which may be aggregated over time:

a. Growth-per-molt

Molt increment data collected for Tanner crab in 2015 and 2016 in the EBS is now fit in the model (see Appendix H), but it 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 4.

c. Size distribution at recruitment

The assumed size distribution for recruits to the population in the assessment model is presented in Figure 5.

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. Data collected on Tanner crab abundance and size compositions collected in BSFRF surveys are not yet incorporated in 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

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

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 calculation directly within a model run, so a follow-on, stand-alone projection model does not need to be run, as 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. 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 K.

In brief, crab enter the modeled population as recruits following the size distribution in Figure 22. An equal (50:50) sex ratio is assumed at recruitment, and all recruits begin as immature, new shell crab. Within a model year, new shell, immature recruits are added to the population numbers-at-sex/shell condition/maturity state/size remaining on July 1 from the previous year. These are then projected forward to Feb. 15 ($\delta t = 0.625$ yr) and reduced for the interim effects of natural mortality. Subsequently, the various fisheries that either target Tanner crab or catch them as bycatch are prosecuted as pulse fisheries (i.e., instantaneously). Catch by sex/shell condition/maturity state/size in the directed Tanner crab, snow crab, BBRKC, and groundfish fisheries is calculated based on fishery-specific stage/size-based selectivity curves and fully-selected fishing mortalities and removed from the population. The numbers of surviving immature, new shell crab that will molt to maturity are then calculated based on sex/size-specific probabilities of maturing, and growth (via molt) is calculated for all surviving new shell crab. Crab that were new shell, mature crab become old shell, mature crab (i.e., they don't molt) and old shell crab remain old shell. Population numbers are then adjusted for the effects of maturation, growth, and change in shell condition. Finally, population numbers are reduced for the effects of natural mortality operating from Feb. 15 to July 1 ($\delta t = 0.375$ yr) to calculate the population numbers (prior to recruitment) on July 1.

Model parameters are estimated using a maximum likelihood approach, with Bayesian-like priors on some parameters and penalties for smoothness and regularity on others. Data components 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.

Since the 2017 assessment, two principal changes have been implemented in the TCSAM02 framework. The first is a change in the way so-called "devs" vectors are handled in the code. The second is the introduction of fits to annual maturity ogive data in the model likelihood and parameter optimization.

"Devs" vectors are vectors of model parameters that have the property that the elements of each vector sums to zero (hence "deviations"). Previously, this constraint was met by allowing n-1 elements of an n-element devs vector to be estimated, while the final element was fixed at the negative sum of the preceding elements. However, this presented difficulties when bounds were placed on the values the elements could take on. The new approach is to allow all elements of a devs vector to be freely-estimable,

[3] https://github.com/wStockhausen/wtsTCSAM02.git

but with a component in the likelihood that penalizes non-zero sums across the vector elements. This approach is similar in nature to that taken in ADMB to achieve similar behavior.

Fits to annual male maturity ogives can now be included in the model likelihood (modeled as a size-specific binomial) in order to better estimate size-specific probabilities for immature crab to undergo terminal molt. This obviates, in particular, the need to impose an immature/mature classification on male crab in the NMFS survey whose chela heights have not been measured, as was done previously (e.g., Stockhausen, 2017).

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.

3. Model Selection and Evaluation

a. Description of alternative model configurations

The model selected for the 2017 assessment (Model B2b from Stockhausen, 2017) provides the baseline model configuration for subsequent alternative model scenarios evaluated in this assessment. Here, the 2017 assessment model is designated "17AM". The following tables provide a summary of the baseline model configuration, 17AM, for this assessment.

Model 17AM: 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
	1975-2017	ln-scale mean + annual devs
Growth	1949-2016	sex-specific
		mean post-molt size: power function of pre-molt size
		post-molt size: gamma distribution conditioned on pre-molt size
Maturity	1949-2016	sex-specific
		size-specific probability of terminal molt
		logit-scale parameterization
Natural mortalty	1949-1979,	estimated sex/maturity state-specific multipliers on base rate
	1985-2016	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 17AM: Description of model fishery characteristics.

Fishery/process	time blocks	description
TCF	directed Tanner crab fishery	
capture rates	pre-1965	male nominal rate
	1965-2016	male ln-scale mean + annual devs
	1949-2016	ln-scale female offset
male selectivity	1949-1990	ascending logistic
	1991-1996	annually-varying ascending logistic
	2005-2016	annually-varying ascending logistic
female selectivity	1949-2016	ascending logistic
male retention	1949-1990, 1991-1996, 2005-2009, 2013-2015	ascending logistic
SCF	bycatch in snow crab fishery	
capture rates	pre-1978	nominal rate on males
	1979-1991	extrapolated from effort
	1992-2016	male ln-scale mean + annual devs
	1949-2016	ln-scale female offset
male selectivity	1949-1996	dome-shaped
	1997-2004	dome-shaped
	2005-2016	dome-shaped
female selectivity	1949-1996	ascending logistic
	1997-2004	ascending logistic
	2005-2016	ascending logistic
RKF	bycatch in BBRKC fishery	
capture rates	pre-1952	nominal rate on males
	1953-1991	extrapolated from effort
	1992-2016	male ln-scale mean + annual devs
	1949-2016	ln-scale female offset
male selectivity	1949-1996	ascending logistic
	1997-2004	ascending logistic
	2005-2016	ascending logistic
female selectivity	1949-1996	ascending logistic
	1997-2004	ascending logistic
	2005-2016	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 17AM: Description of model likelihood components.

Component	Type	Distribution	Likelihood
TCF: retained catch	abundance	--	--
	biomass	norm2	males only
	size comp.s	multinomial	males only
TCF: total catch	abundance	--	--
	biomass	norm2	by sex
	size comp.s	multinomial	by sex
SCF: total catch	abundance	--	--
	biomass	norm2	by sex
	size comp.s	multinomial	by sex
RKF: total catch	abundance	--	--
	biomass	norm2	by sex
	size comp.s	multinomial	by sex
GTF: total catch	abundance	--	--
	biomass	norm2	by sex
	size comp.s	multinomial	by sex
NMFS survey	abundance	--	--
	biomass	lognormal	by sex, for mature crab only
	size comp.s	multinomial	by sex/maturity
	chela height data	--	--
growth data	EBS only	gamma	by sex

The following alternative model scenarios were evaluated as part of this assessment (previous names applied to these scenarios in the 2017 assessment and May 2018 CPT report are given in parentheses):

model scenario	number of parameters	objective function value	max gradient	description
17AM (B2b)	344	2,905.84	0.0001	2017 assessment model
17AMu	344	3,014.71	0.0007	17AM with updated crab fishery data
18A (B0)	357	3,139.58	0.0010	17AMu with 2017/18 fishery data and 2018 NMFS survey data
18B (B1)	340	3,830.91	0.0000	18A with fits to male maturity ogives. Reduced number of molt-to-maturity parameters (17 fewer)
18C0 (B2)	340	4,310.76	0.0012	Fitting male maturity ogives, survey biomass by sex, size compositions for males by shell condition and by maturity state and shell condition for females
18C0a	340	3,557.00	0.0012	18C0, but reduced weight (/100) on fitting male maturity ogives
18C1 (B4)	340	4,651.98	0.0008	18C0, but also fitting survey abundanceby sex
18C1a	340	3,911.39	0.0015	18C1, but reduced weight (/100) on fitting male maturity ogives
18C2a	334	4,234.40	0.0088	18C1a, but fixing sex-specific survey Q's and selectivity functions for 1982+ based on Somerton and Otto (1999)'s underbag experiment
18C3a	334	4,352.58	0.0193	18C2a, but fixing survey Q's 1982+ based only on Somerton and Otto (1999)'s male catchability from the underbag experiment
18D0 (B3)	340	3,706.10	0.0019	Fits to male maturity ogives, survey biomass by sex, and size compositions for males aggregated over shell condition and by maturity state for females
18D1 (B5)	340	--	--	18D0, but also fitting survey abundance by sex

Scenarios 18A, 18B, 18C0, 18C1, 18D0 and 18D1 correspond to the scenarios B0, B1, B2, B3, B4 and B5 the CPT requested (at the May 2018 CPT meeting) be evaluated for this assessment. Several other scenarios (18C0a, 18C1a) were also run which considered changes to the weighting placed on fitting the male maturity ogive data in the likelihood, as well as scenarios (18C2a, 18C3a) which used fixed values to describe catchability and selectivity for the NMFS survey data after 1981 based on the Somerton and Otto underbag experiment (Somerton and Otto, 1999). These two latter scenarios were included because estimated values for survey catchability in the other scenarios were unrealistically small and led to what appear to be unrealistically high estimates of recruitment, population biomass and MMB, and population productivity for the Tanner crab stock. Using results from the underbag experiment at least provides an empirical basis for fixing the catchability and selectivity values in scenarios C2a and C3a.

The number of estimated parameters, the final value of the objective function for each converged scenario (each based on at least 1,200 jitter runs), and the maximum gradient of the objective function at the converged solution are also listed in the table above (18D1 did not converge). The total objective function values, however, cannot be directly compared between scenarios because each scenario fits different datasets.18C2a is the author’s preferred model, as explained below.

The alternative scenarios listed above primarily incorporate the same model structure but differ in the datasets used to perform the parameter optimization. As noted above, however, scenarios 18C2a and 18C3a differ from the remaining scenarios in fixing, rather than estimating, values for NMFS survey catchabilities and selectivities in the 1982-2018 time frame based on Somerton and Otto (1999)’s underbag experiment.

Scenario 17AMu fits the revised crab fishery data provided by ADFG and groundfish fishery data provided by AKFIN through 2016/17 (see Appendices A, B, C) using the same model configuration as 17AM, thus providing a means of evaluating the effects of the changes to the input data on model results. As discussed below, the effects are rather dramatic. 18A builds on 17AMu by including the new data for 2017/18. Additionally, as recommended by the CPT in May 2018, the probability of terminal molt for male crab was fixed at 0 for crab less than 60 mm CW and at 1 for crab > 150 in order to be more biologically realistic. Similarly, the probability of terminal molt for female crab less than 40 mm CW was fixed at 0. 18B builds on 18A and provides a bridging scenario by including fits to the male maturity ogive data from the NMFS EBS bottom trawl survey in the parameter optimization (even though Rugolo and Turnock's empirical maturity ogive is used to classify male abundance as immature/mature prior to input to the model).

Scenario 18C0 represents a distinct break with the previous scenarios because it removes the empirical maturity classification from the male survey data and fits total survey biomass by sex and size compositions by shell condition for males and maturity state and shell condition for females rather than fitting mature biomass by sex and size compositions by sex and maturity state. Scenario 18C0a reduces the weight placed on fits to the male maturity ogives in the model likelihood in 18C0 by a factor of 100. Scenario 18C1 includes fits to male survey abundance by shell condition and female survey abundance by maturity state and shell condition, in addition to similar components of survey biomass. Scenario 18C1a reduces the weight placed on fits to the male maturity ogives in the model likelihood in 18C1 by a factor of 100. Scenario 18C2a differs from 18C1a by fixing the survey catchability parameter values (Q's) and selectivities in the 1982-2018 time block to those estimated by Somerton in the "underbag" experiment for "males + immature females" and mature females, rather than estimating them as in prior scenarios. Scenario 18C3a is similar to 18C2a, but fixes the survey catchabilities in 1982-2018 for all crab to that estimated for "males + immature females" in the underbag experiment. Scenario 18D0 is similar to 18C0, except that the survey biomass and size composition components are aggregated over shell condition before being included in the model likelihood. Scenario 18D1 is similar that of 18D0, except that fits to survey abundance (aggregated across shell condition) are included by sex.

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

The following table summarizes basic model results from the 2017 assessment model (17AM) and the 11 scenarios considered here:

Model Scenario	average recruitment	Final MMB	B0	Bmsy	Fmsy	MSY	Fofl	OFL	projected MMB	projected MMB / Bmsy
	millions	1000's t	1000's t	1000's t		1000's t		1000's t	1000's t	
17AM (B2b)	213.96	80.58	83.34	29.17	0.75	12.26	0.75	25.42	43.32	1.49
17AMu	371.11	136.48	111.38	38.98	1.25	18.03	1.25	50.85	63.55	1.63
18A	391.22	114.10	120.00	42.00	1.22	19.24	1.22	42.01	53.87	1.28
18B	464.60	124.18	130.45	45.66	2.61	22.35	2.61	55.40	48.01	1.05
18C0	536.07	122.84	124.39	43.54	3.06	24.32	3.04	56.15	43.25	0.99
18C0a	366.37	99.63	100.92	35.32	1.07	18.13	1.07	35.44	46.25	1.31
18C1	540.64	128.64	129.28	45.25	2.79	25.90	2.78	58.26	45.12	1.00
18C1a	404.67	110.14	109.74	38.41	1.14	20.41	1.14	39.87	49.67	1.29
18C2a	199.49	50.12	63.01	22.05	0.91	11.54	0.91	16.76	24.06	1.09
18C3a	188.34	49.93	63.61	22.26	0.79	10.84	0.79	15.93	25.44	1.14
18D0	503.62	145.40	149.02	52.16	2.64	24.09	2.64	65.30	57.35	1.10

Scenario 18D1 is not included in the above table because, as mentioned above, the model failed to converge for this scenario. The author's preferred model, 18C2a, is highlighted for reference. All new model scenarios were evaluated using at least 1,200 runs with jittered initial parameter values to select the run with the smallest objective function value and smallest maximum gradient. The large number of runs for each scenario were required because randomly-selected growth parameters were frequently inconsistent with positive growth. For each converged scenario, the selected run was re-run to invert the hessian and obtain standard deviations for parameter estimates. All models except 18D1 resulted in hessians that were invertible and provided uncertainty estimates associated with the parameter estimates.

As noted previously, the substantial differences in results between scenarios 17AM and 17AMu in the above table illustrate the rather dramatic impact the revised crab fishery data provided by ADFG has on this assessment. Both scenarios fit the (same) survey biomass data equally well (Figure 6), and both scenarios fit the different input fishery data equally well (Figures 7 and 8, illustrating fits to retained catch biomass and total catch biomass for males in the directed and snow crab fisheries). The changes are substantially driven by large changes (~ *x* 0.5) in estimated survey catchability from 17AM to 17AMu (Figure 9) such that recruitment (Figure 10), mature biomass (Figure 11), and MSY-related quantities are higher using the revised data. Adding the 2017/18 data (scenario 18A) does not affect the previous fits to survey biomass (Figure 12), retained catch and total catch biomass for males in the directed and snow crab fisheries (Figures 13 and 14) or the BBRKC and groundfish fisheries (not shown). Estimated survey catchabilities in the 1982+ time frame are slightly smaller for 18A than 17AMu (Figure 15), but this has little to no effect on estimated trends in recruitment (Figure 16) and mature biomass (Figure 17). The small differences between the two scenarios in MSY-related quantities in the above table are primarily due to a slightly higher estimate of average recruitment from 18A driven by a very large estimate of recruitment (~1 billion crab) in 2018.

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 this was suggested by non-zero ratios of the abundance of mature, new shell male crab to all new shell males at sizes less than 60 mm CW based on chela height data collected in the NMFS EBS bottom trawl survey. 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 18B and subsequent).

d. Convergence status and convergence criteria

Convergence in all models was assessed by running each model at least 1,200 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 achieving a minimum threshold for the max gradient or exceeding the maximum number of iterations. Typically, 5-10 jittered runs converged to the same minimum value, but sets of runs also converged to larger values—emphasizing the need to jitter to evaluate convergence to the minimum objective function value in the first place.

e. Sample sizes assumed for the compositional data

Input sample sizes used for compositional data are listed in Tables 4-8 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 alternative scenarios in Tables 13 and 14 (values for all parameters other than annually-varying ln-scale fishery capture rate deviations are listed in Tables 15-23). 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 can be fixed in future models. Many of the scenarios estimated survey catchability parameters at the lower bounds placed on them (Table 13; pQ[1], pQ[3], and pQ[4]) and width of the selectivity function (pS2[2] and pS4[4] in Table 14), indicating that the data provides little information on absolute population size. These results provided the rationale for fixing the survey parameters to those from the Somerton and Otto (1999) underbag experiment.

A number of parameters related to fishery bycatch selectivity in the snow crab and BBRKC fisheries typically hit one of their bounds consistently across scenarios, as well (parameters for the size at 95% selected in the BBRKC fishery in different time blocks and parameters describing the slope of the descending limb of selectivity in the snow crab fishery). 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 22). These may reflect indeterminancy between the estimated capture rate for fully-selected crab and these parameters in determining the effective capture rates on large crab.

Finally, it may be worthwhile noting that the beta parameter (pGrBeta[1]) determining the spread of potential molt increments for a given pre-molt size was estimated at its lower bound in all of the scenarios that did not fit survey abundance (17AMu, 18A, 18B, 18C0, 18C0a and 18D0), but in none which did (18C1, 18C2a, 18C3a).

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 15-23). 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). Selectivity parameters for female bycatch in the BBRKC fishery in 1997-2004 also exhibited high uncertainty when the estimates were not hitting a bound.

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 datasets were fit, or different likelihood weights were used, in all scenarios. Consequently, the criteria used to evaluate the alternative models were based primarily on: 1) goodness of fit (assessed using RMSE for different datasets even when the datasets were not included in the likelihood), 2) parameter sensibility, and 3) biological realism.

The author's preferred model, 18C2a, fits all of the datasets reasonably well, incorporates empirical parameters for survey catchability and selectivity to determine absolute scale, and appear to yield more biologically-reasonable estimates of population size and stock productivity than other scenarios.

h. Residual analysis

Residuals for the author's preferred model, Model 18C2a, are discussed below under the Results section.

i. Evaluation of the model(s)

Results from the "18" scenarios (i.e., scenarios 18A, 18B, 18C0, 18C0a, 18C1, 18C1a, 18C2a, 18C3a, and 18D0) are compared amongst each other in Appendix I, which is broken into 9 sections (I1-I9) which organize different categories of results in the following manner:

Appendix	Description
I1	fits to survey and fishery biomass and abundance
I2	mean fits to survey size compositions; effective sample sizes
I3	mean fits to fishery size compositions; effective sample sizes
I4	fits to size compositions by year
I5	fits to growth and male maturity ogive data
I6	population processes (natural mortality rates, etc.)
I7	population quantities (recruitment, population abundance and biomass)
I8	survey characteristics (catchabilities, selectivities)
I9	fishery characteristics (capture rates, selectivities)

The models in all "18" scenarios matched the fishery retained catch and total catch biomass and abundance data time series nearly equally well (Figures I1.19-25; i.e., Appendix I1, Figures 19-25). Differences among the scenarios were more apparent in comparisons with survey abundance and biomass trends (Figures I1.1-18). The scenarios generally fit the data equally well after the early 1990's, with the largest differences occurring prior to that time. Scenarios 18C2a and 18C3a stood out from the others by following the large increase/decrease in abundance/biomass seen from 1987-1993.

All scenarios fit mean female survey size compositions reasonably well and in similar fashion (Appendix I2), but some differences existed for mean male survey size compositions, in particular for immature males (Figure I2.1) and for old shell males (Figure I2.5). 18A, which included fits to immature and mature male size compositions without fits to the male maturity ogives, had the best fit to the immature male size compositions whereas 18C2a and 18C3a tended to underpredict the proportion of immature males around 100 mm CW while the other scenarios overpredicted these proportions. All scenarios predicted mean proportions of new shell crab equally well, but 18C2a and 18C3a appeared to predict those mean proportions for old shell males somewhat more closely than the other scenarios (Figure I2.5). All scenarios predicted mean fishery size compositions equally well (Append I3). Comparison among the scenarios with annual size compositions (Appendix I4) generally reflects the observations regarding the fits to mean size compositions—and the scenarios generally either all do well, or all do poorly, at fitting a given annual size composition. That said, there are some "interesting"-ly poor fits to male survey size compositions by shell type at the start of the time series (late 1970s, early 1980s; see Figures I4.21 and I4.26) which may have to do with inconsistent classification of shell condition in the early years of the survey.

Scenario 18C3a exhibited the highest slope of mean post-molt size regarded as function of pre-molt size among all scenarios for both males and females, while the other scenarios were almost indistinguishable from one another (Figure I5.1). Scenarios 18C2a and 18C3a consistently estimated smaller probabilities of terminal molt for a given post-molt size than the other scenarios (Figures I5.4-8), indicating that male crab that survived were more likely to grow to larger sizes before undergoing terminal molt in scenarios 18C2a and 18C3a than in the others.

Estimated natural mortality rates are shown in Figure I6.1. Mortality rates are assumed equal by sex for immature crab but are allowed to differ by sex for mature crab. Mortality rates for mature crab were estimated by sex across two time periods: 1949-1979/80+1985/86-2016/17 and 1980/81-1984/85. The latter period has been identified as a period of high natural mortality in the BBRKC stock (Zheng et al., 2012) and was identified as a separate period for Tanner crab in the 2012 assessment. Natural mortality rates for immature crab were similar across all scenarios, while they differed somewhat (more so in the "high" period) from one another for mature crab. 18C3a exhibited the highest rates for mature females across both time blocks while 18C2a estimated the highest rate on mature crab during the "high mortality" period.

The scenarios all exhibited similar temporal trends in recruitment but differed as to level (Figure I7.1). 18D0 consistently exhibited the largest recruitments, while 18C2a and 18C3a exhibited the smallest. Population abundance and biomass trends among the scenarios were similar to those for recruitment (Figures I7.2-3).

Fully-selected catchability in the NMFS EBS bottom trawl survey is estimated on a sex-specific basis in two time periods: 1975-81 and 1982+. All scenarios that estimated survey catchability in the 1975-81 time period yielded identical results for males, ending at the lower bound of 0.5, as did most of the scenarios for female catchability in this time period (all except 18C2a and 18C3a; Figure I8.1). In the post-1981 time period, estimated survey catchability was lower than that in the earlier time period across all scenarios that estimated catchability (scenarios 18C2a and 18C3a fixed catchabilities in this time period). Male selectivities were similar across all scenarios in the post-1981 time period (and consequently estimated selectivities were similar to those from the underbag experiment), while female selectivity functions differed substantially at smaller sizes (Figure I8.2). When catchabilities and selectivity functions were combined as "capture probabilities" (Figure I8.3), the main factor for the differences between scenarios 18C2a and 18C3a and the other scenarios in characterizing the Tanner crab stock (i.e., recruitment and biomass trends) were apparent: the capture probabilities in the other scenarios were much smaller over all sizes, and with varied with size, than did those from 18C2a and 18C3a.

Given the previous results, it is unsurprising that, while temporal trends in fishery catchability were similar across all scenarios, scenarios 18C2a and 18C3a consistently exhibited the highest values across years for each fishery (Figures I9.1-4). Estimated selectivity functions estimated for the directed and bycatch fisheries were generally similar across scenarios (Figures I9.5-30), except for those for male bycatch in the snow crab fishery prior to 1997. Although these selectivity functions were all dome-shaped, the level at which the plateau occurred was substantially lower than 1 for 18C3a.

The model scenarios examined here are all in good agreement on the *relative* scale of fluctuations in Tanner crab stock abundance and biomass, but they are not in good agreement on the overall absolute scale. The combination of estimated (fully-selected) survey catchability and survey selectivity (i.e., survey capture probabilities), would appear to be the driver behind the absolute scale for the model's predictions of Tanner crab stock biomass under any of these scenarios. However, the estimates of this scale are highly uncertain given that the relevant parameters are frequently estimated either at one of the bounds placed on the parameter or are highly uncertain. Although the situation is not new to this assessment, what little information was formerly available in the data regarding absolute scale seems to have diminished with the revised fishery data from ADFG. Time constraints on the assessment have not allowed anywhere near a full exploration of this issue, but given the past apparent sensitivity of this stock to fishing pressure (given several cycles of a closure following a period of high catches), the rather high exploitation rates (F_{MSY}) and sustainable stock sizes (F_{OFL}) which many of the scenarios suggest for the

Tanner crab stock suggest it is necessary to impose tighter restrictions on survey capture probabilities. Scenarios 18C2a and 18C3a embody a simple, empirically-based approach to do so until further information (e.g., the BSFRF surveys) can be incorporated into the assessment that better defines absolute scale. Scenario 18C2a appears to fit the survey data somewhat better than 18C3a, and thus is the author's preferred model going forward.

4. Results (best model(s))

Model 18C2a was selected as the author's preferred model for the 2018 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 26-31 from the 2017 assessment model and scenario 18C2a. 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 15-23.

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

Estimates for mature survey biomass, by sex, are listed in Table 32 and for mature biomass at mating, by sex, in Table 33 for the 2017 assessment model and the author's preferred model, 18C2a. 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 18C2a are available online as zipped csv files (see Tables 34 and Table 35, respectively).

iii. Recruitment time series

The estimated recruitment time series from the 2017 assessment and Model 18C2a are listed in Table 36. The time series are compared graphically in Figure J1.

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 37.

c. Graphs of estimates

Graphs of estimates from the preferred scenario, 18C2a, are given in Appendix I. Most have been discussed above in the "Model Selection" section.

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

Estimated natural mortality rates are shown in Figure I6-1. Mortality rates are assumed equal by sex for immature crab but are allowed to differ by sex for mature crab. Mortality rates for mature crab were estimated by sex across two time periods: 1949-1979/80+1985/86-2016/17 and 1980/81-1984/85. The latter period has been identified as a period of high natural mortality in the BBRKC stock (Zheng et al., 2012) and was identified as a separate period for Tanner crab in the 2012 assessment. Natural mortality rates for immature crab were estimated at 0.21 yr^{-1} and, excluding the high mortality period, at 0.35 yr^{-1} for mature crab. Estimated sex- and size-specific probabilities of the terminal molt-to-maturity (Figure I1-2) were quite similar to the other models for females but were somewhat right-shifted for males—with the consequence that the average mature male would be somewhat larger than that predicted in the other scenarios. The mean growth curves estimated in scenario 18C2a were among those implying the fastest growth (Figure I1-3).

iii. Estimated full selection F over time

Estimated time series of fully-selected F (*capture rates*, not mortality) on males in the directed fishery and bycatch in the snow crab, BBRKC and groundfish fisheries are compared among the model scenarios in Figures I9.1-4.

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

Estimates of population biomass and abundance are shown in Figures I7.2-3. and J.5, J.9, and J.13.

iv. Estimated fishing mortality versus estimated spawning stock biomass

See Section F (Calculation of the OFL; Figure 21).

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

See Appendix I1.

ii. Graphs of model fits to survey numbers

See Appendix I1.

iii. Graphs of model fits to catch proportions by size class

See Appendix I4 for model fits to annual catch proportions by size class.

iv. Graphs of model fits to survey proportions by size class

See Appendix I4 for model fits to annual survey proportions by size class.

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

See Appendices I2 and I3 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 I2 and I3 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 24 and 25.

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 18C0a to explore model uncertainty. The model was run for a single chain, which was set to run 5 million iterations, keeping results for every 1,000th to reduce serial autocorrelation, with a burn-in period of 1,000,000 iterations, yielding 4000 samples. Mixing appeared to be sufficient, but this can be difficult to evaluate with only single chains. This run provides empirical posterior distributions for model parameters and selected derived quantities, including OFL-related quantities.

Time constraints did not allow a full exploration of the MCMC results. Summary results for the objective function and OFL-related quantities (Figure 18) 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). MCMC results for the time trends in recruitment and mature biomass-at-mating are shown in Figure 19.

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 2017/18 was 25.42 thousand t while the total catch mortality was 2.39 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 2017/18. 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 19):

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

and is based on an estimate of "current" spawning biomass at mating (*B* above, taken as 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 2018/19 require estimates of B = $MMB_{2018/19}$ (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 198.99 million. The estimates of average recruitment are reasonably similar between the 2017 assessment model (214 million) and the author's preferred model (Table 38). The value of $B_{MSY}=B_{35\%}$ for $\bar{R}$ is 21.87 thousand t, which is smaller than that from the 2017 assessment (29 thousand t).

Once F_{OFL} is determined using the control rule (Figure 19), 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, 2018 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 2018/19 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. In practice, a single (due to time constraints) chain of 5 million MCMC steps was 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 1,000,000 steps and subsequently thinned by a factor of 1,000 to reduce serial autocorrelation in the MCMC sampling. This resulted in about 4,000 MCMC samples with which to characterize the distribution of the OFL. **The median value of this distribution was taken as the OFL for 2018/19. Thus, the OFL for 2018/19 from the author's preferred model (Model 18C2a) is 16.46 thousand t** (Figure 20)**.**

The B_{MSY} proxy, $B_{35\%}$, from the author's preferred model is 21.87 thousand t, so MSST = 0.5 B_{MSY} = 10.93 thousand t. Because current projected B = 23.53 thousand t > MSST, **the stock is not overfished**. The population state (directed F vs. MMB) is plotted for each year from 1965/66-2017/18 in Figure 21 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, 18C2a, the P* ABC (ABC_{max}) is 16.44 thousand t while the 20% Buffer ABC is 13.17 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. 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 13.17 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. More data regarding temperature-dependent effects on molting frequency would be helpful to assess potential impacts of the EBS cold pool on the stock. Information on temperature-dependent changes in crab movement and survey catchability would also be of value. In addition, it would be extremely worthwhile to develop a "better" index of reproductive potential than MMB that can be calculated in the assessment model and to revisit the issue of MSY proxies for this stock.

The characterization of fisheries in the assessment model needs to be carefully reconsidered. How, and whether or not, the differences in the directed fishery in areas east and west 166ºW 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 explored.

With the implementation of TCSAM02, several research avenues can be explored much more efficiently: 1) time-varying growth; 2) decomposing the currently "lumped" directed fishery into its eastern and western components, and 3) incorporating the BSFRF surveys into the assessment. Development of a fully-Gmacs version of the Tanner crab model will also begin.

I. Ecosystem Considerations
Mature male biomass is currently used as the "currency" of Tanner crab spawning biomass for assessment purposes. However, its relationship to stock-level rates of egg production, perhaps an ideal measure of stock-level reproductive capacity, is unclear. Thus, use of MMB to reflect Tanner crab reproductive potential may be misleading as to stock health. Nor is it likely that mature female biomass has a clear relationship to annual egg production. For Tanner crab, the fraction of barren mature females by shell condition appears to vary on a decadal time scale (Rugolo and Turnock, 2012), suggesting a potential climatic driver.

1. Ecosystem Effects on Stock
Time series trends in prey availability or abundance are generally unknown for Tanner crab because typical survey gear is not quantitative for Tanner crab prey. On the other hand, Pacific cod (*Gadus macrocephalus*) is thought to account for a substantial fraction of annual mortality on Tanner crab (Aydin et al., 2007). Total P. cod biomass is estimated to have been slowly declining from 1990 to 2008, during

the time frame of a collapse in the Tanner crab stock, but has been increasing rather rapidly since 2008 (Thompson and Lauth, 2012). This suggests that the rates of "natural mortality" used in the stock assessment for the period post-1980 may be underestimates (and increasingly biased low if the trend in P. cod abundance continues). This trend is definitely one of potential concern.

2. Effects of Tanner crab fishery on ecosystem

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

Effects of Tanner crab fishery on ecosystem			
Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	salmon are unlikely to be trapped inside a pot when it is pulled, although halibut can be	unlikely to have substantial effects at the stock level	minimal to none
Forage (including herring, Atka mackerel, cod and pollock)	Forage fish are unlikely to be trapped inside a pot when it is pulled	unlikely to have substantial effects	minimal to none
HAPC biota	crab pots have a very small footprint on the bottom	unlikely to be having substantial effects post-rationalization	minimal to none
Marine mammals and birds	crab pots are unlikely to attract birds given the depths at which they are fished	unlikely to have substantial effects	minimal to none
Sensitive non-target species	Non-targets are unlikely to be trapped in crab pot gear in substantial numbers	unlikely to have substantial effects	minimal to none
Fishery concentration in space and time	substantially reduced in time following rationalization of the fishery	unlikely to be having substantial effects	probably of little concern
Fishery effects on amount of large size target fish	Fishery selectively removes large males	May impact stock reproductive potential as large males can mate with a wider range of females	possible concern
Fishery contribution to discards and offal production	discarded crab suffer some mortality	May impact female spawning biomass and numbers recruiting to the fishery	possible concern
Fishery effects on age-at-maturity and fecundity	none	unknown	possible concern

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Table captions

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Tables

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

Eastern Bering Sea *Chionoecetes bairdi* Retained Catch (1,000's t)				
Year	US Pot	Japan	Russia	Total
1965/66	--	1.17	0.75	1.92
1966/67	--	1.69	0.75	2.44
1967/68	--	9.75	3.84	13.60
1968/69	0.46	13.59	3.96	18.00
1969/70	0.46	19.95	7.08	27.49
1970/71	0.08	18.93	6.49	25.49
1971/72	0.05	15.90	4.77	20.71
1972/73	0.10	16.80	--	16.90
1973/74	2.29	10.74	--	13.03
1974/75	3.30	12.06	--	15.24
1975/76	10.12	7.54	--	17.65
1976/77	23.36	6.66	--	30.02
1977/78	30.21	5.32	--	35.52
1978/79	19.28	1.81	--	21.09
1979/80	16.60	2.40	--	19.01
1980/81	13.47	--	--	13.43
1981/82	4.99	--	--	4.99
1982/83	2.39	--	--	2.39
1983/84	0.55	--	--	0.55
1984/85	1.43	--	--	1.43
1985/86	0.00	--	--	0.00
1986/87	0.00	--	--	0.00
1987/88	1.00	--	--	1.00
1988/89	3.15	--	--	3.18
1989/90	11.11	--	--	11.11
1990/91	18.19	--	--	18.19
1991/92	14.42	--	--	14.42
1992/93	15.92	--	--	15.92
1993/94	7.67	--	--	7.67
1994/95	3.54	--	--	3.54
1995/96	1.92	--	--	1.92
1996/97	0.82	--	--	0.82
1997/98	0.00	--	--	0.00
1998/99	0.00	--	--	0.00
1999/00	0.00	--	--	0.00
2000/01	0.00	--	--	0.00
2001/02	0.00	--	--	0.00
2002/03	0.00	--	--	0.00
2003/04	0.00	--	--	0.00
2004/05	0.00	--	--	0.00
2005/06	0.43	--	--	0.43
2006/07	0.96	--	--	0.96
2007/08	0.96	--	--	0.96
2008/09	0.88	--	--	0.88
2009/10	0.60	--	--	0.60
2010/11	0.00	--	--	0.00
2011/12	0.00	--	--	0.00
2012/13	0.00	--	--	0.00
2013/14	1.26	--	--	1.26
2014/15	6.22	--	--	6.22
2015/16	8.91	--	--	8.91
2016/17	0.00	--	--	0.00
2017/18	1.13	--	--	1.13

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

Table 3. Total catch (1000's t) of Tanner crab in various fisheries, as estimated from observer data.

fishery	Directed Fishery				Snow Crab		BBRKC		Groundfish	Total
	West of 166W		East of 166W						fisheries	Catch
year	males	females	males	females	males	females	males	females		1000's t
1972/73	--	--	--	--	--	--	--	--	17.74	--
1973/74	--	--	--	--	--	--	--	--	24.45	--
1974/75	--	--	--	--	--	--	--	--	9.41	--
1975/76	--	--	--	--	--	--	--	--	4.70	--
1977/78	--	--	--	--	--	--	--	--	2.78	--
1977/78	--	--	--	--	--	--	--	--	1.87	--
1978/79	--	--	--	--	--	--	--	--	3.40	--
1979/80	--	--	--	--	--	--	--	--	2.11	--
1980/81	--	--	--	--	--	--	--	--	1.47	--
1981/82	--	--	--	--	--	--	--	--	0.45	--
1982/83	--	--	--	--	--	--	--	--	0.67	--
1983/84	--	--	--	--	--	--	--	--	0.64	--
1984/85	--	--	--	--	--	--	--	--	0.40	--
1985/86	--	--	--	--	--	--	--	--	0.65	--
1986/87	--	--	--	--	--	--	--	--	0.64	--
1987/88	--	--	--	--	--	--	--	--	0.46	--
1988/89	--	--	--	--	--	--	--	--	0.67	--
1989/90	--	--	--	--	--	--	--	--	0.94	--
1990/91	--	--	--	--	--	--	--	--	2.54	--
1992/93	7.35	0.60	29.66	1.10	2.49	0.16	1.32	0.02	2.76	45.46
1993/94	1.64	0.14	10.21	0.86	2.87	0.40	3.13	0.15	1.76	21.16
1994/95	0.36	0.11	6.96	0.73	1.35	0.19	0.00	0.00	2.10	11.79
1995/96	0.65	0.14	4.42	0.92	1.02	0.12	0.00	0.00	1.52	8.80
1996/97	0.07	0.00	0.23	0.06	1.96	0.12	0.27	0.00	1.59	4.30
1997/98	0.00	0.00	0.00	0.00	1.96	0.09	0.16	0.00	1.18	3.40
1998/99	0.00	0.00	0.00	0.00	0.66	0.08	0.12	0.00	0.94	1.79
1999/00	0.00	0.00	0.00	0.00	0.13	0.01	0.08	0.00	0.63	0.85
2000/01	0.00	0.00	0.00	0.00	0.31	0.01	0.07	0.00	0.74	1.13
2001/02	0.00	0.00	0.00	0.00	0.55	0.02	0.04	0.00	1.19	1.79
2002/03	0.00	0.00	0.00	0.00	0.17	0.01	0.06	0.00	0.72	0.96
2003/04	0.00	0.00	0.00	0.00	0.06	0.01	0.05	0.00	0.42	0.55
2004/05	0.00	0.00	0.00	0.00	0.13	0.04	0.05	0.00	0.68	0.90
2005/06	0.68	0.02	0.00	0.00	1.16	0.02	0.04	0.00	0.62	2.55
2006/07	0.58	0.07	1.13	0.05	1.53	0.09	0.03	0.00	0.72	4.19
2007/08	0.68	0.01	1.78	0.03	1.86	0.05	0.06	0.00	0.69	5.17
2008/09	0.12	0.00	1.18	0.01	1.10	0.02	0.28	0.00	0.53	3.25
2009/10	0.00	0.00	0.66	0.00	1.56	0.02	0.19	0.00	0.37	2.80
2010/11	0.00	0.00	0.00	0.00	1.45	0.01	0.03	0.00	0.23	1.73
2011/12	0.00	0.00	0.00	0.00	2.14	0.01	0.02	0.00	0.20	2.38
2012/13	0.00	0.00	0.00	0.00	1.56	0.01	0.04	0.00	0.15	1.77
2013/14	0.93	0.01	0.75	0.01	1.84	0.02	0.13	0.00	0.35	4.04
2014/15	3.06	0.03	5.31	0.01	5.33	0.05	0.31	0.00	0.44	14.53
2015/16	5.47	0.03	6.76	0.03	3.92	0.02	0.20	0.01	0.36	16.79
2016/17	0.00	0.00	0.00	0.00	2.58	0.02	0.18	0.00	0.31	3.08
2017/18	2.11	0.06	0.00	0.00	1.11	0.01	0.18	0.00	0.14	3.62

Table 4. 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	97.8
1981/82	11,311	83.1
1982/83	13,519	99.3
1983/84	1,675	12.3
1984/85	2,542	18.7
1988/89	12,380	91.0
1989/90	4,123	30.3
1990/91	120,676	200.0
1991/92	126,299	200.0
1992/93	125,193	200.0
1993/94	71,622	200.0
1994/95	27,658	200.0
1995/96	1,525	11.2
1996/97	4,430	32.6
2005/06	705	5.2
2006/07	2,940	21.6
2007/08	6,935	51.0
2008/09	3,490	25.6
2009/10	2,417	17.8
2013/14	4,760	35.0
2014/15	14,055	103.3
2015/16	24,420	200.0
2016/17	--	--
2017/18	3,470	25.5

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

	N		N'	
year	males	females	males	females
1991/92	31,252	5,605	200.0	40.2
1992/93	54,836	8,755	200.0	62.8
1993/94	40,388	10,471	200.0	75.1
1994/95	5,792	2,132	42.6	15.3
1995/96	5,589	3,119	41.1	22.4
1996/97	352	168	2.6	1.2
2005/06	19,715	1,107	144.9	7.9
2006/07	24,226	4,432	178.0	31.8
2007/08	61,546	3,318	200.0	23.8
2008/09	29,166	646	200.0	4.6
2009/10	17,289	147	127.0	1.1
2013/14	17,291	710	127.0	5.2
2014/15	85,116	1,191	200.0	8.8
2015/16	119,843	1,622	200.0	11.9
2016/17	--	--	--	--
2017/18	18,785	1,721	138.0	12.6

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

year	N		N'	
	males	females	males	females
1992/93	6,280	859	46.4	6.3
1993/94	6,969	1,542	51.5	11.4
1994/95	2,982	1,523	22.0	11.2
1995/96	1,898	428	14.0	3.2
1996/97	3,265	662	24.1	4.9
1997/98	3,970	657	29.3	4.9
1998/99	1,911	324	14.1	2.4
1999/00	976	82	7.2	0.6
2000/01	1,237	74	9.1	0.5
2001/02	3,113	160	23.0	1.2
2002/03	982	118	7.2	0.9
2003/04	688	152	5.1	1.1
2004/05	848	707	6.3	5.2
2005/06	9,792	368	72.3	2.7
2006/07	10,391	1,256	76.7	9.3
2007/08	13,797	728	101.9	5.4
2008/09	8,455	722	62.4	5.3
2009/10	11,057	474	81.6	3.5
2010/11	12,073	250	89.1	1.8
2011/12	9,453	189	69.8	1.4
2012/13	7,336	190	54.2	1.4
2013/14	12,932	356	95.5	2.6
2014/15	24,877	804	183.7	5.9
2015/16	19,838	230	146.5	1.7
2016/17	19,346	262	142.8	1.7
2017/18	5,598	109	41.1	0.8

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

year	N		N'	
	males	females	males	females
1992/93	2,056	105	15.1	0.8
1993/94	7,359	1,196	54.1	8.8
1996/97	114	5	0.8	0.0
1997/98	1,030	41	7.6	0.3
1998/99	457	20	3.4	0.1
1999/00	207	14	1.5	0.1
2000/01	845	44	6.2	0.3
2001/02	456	39	3.4	0.3
2002/03	750	50	5.5	0.4
2003/04	555	46	4.1	0.3
2004/05	487	44	3.6	0.3
2005/06	983	70	7.3	0.5
2006/07	798	76	5.9	0.6
2007/08	1,399	91	10.3	0.7
2008/09	3,797	121	28.0	0.9
2009/10	3,395	72	25.1	0.5
2010/11	595	30	4.4	0.2
2011/12	344	4	2.5	0.0
2012/13	618	48	4.6	0.4
2013/14	2,110	60	15.6	0.4
2014/15	3,110	32	23.0	0.2
2015/16	2,176	182	16.1	1.3
2016/17	3,048	245	22.5	1.8
2017/18	3,782	86	27.8	0.6

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

year	N		N'	
	males	females	males	females
1973/74	3,155	2,277	23.3	16.8
1974/75	2,492	1,600	18.4	11.8
1975/76	1,251	839	9.2	6.2
1976/77	6,950	6,683	51.3	49.3
1977/78	10,685	8,386	78.9	61.9
1978/79	18,596	13,665	137.3	100.9
1979/80	19,060	11,349	140.7	83.8
1980/81	12,806	5,917	94.5	43.7
1981/82	6,098	4,065	45.0	30.0
1982/83	13,439	8,006	99.2	59.1
1983/84	18,363	8,305	135.6	61.3
1984/85	27,403	13,771	200.0	101.7
1985/86	23,128	12,728	170.7	94.0
1986/87	14,860	7,626	109.7	56.3
1987/88	23,508	15,857	173.6	117.1
1988/89	10,586	7,126	78.2	52.6
1989/90	59,943	41,234	200.0	200.0
1990/91	23,545	11,212	173.8	82.8
1991/92	6,817	3,479	50.1	25.6
1992/93	3,128	1,175	23.0	8.6
1993/94	1,217	358	8.9	2.6
1994/95	3,628	1,820	26.7	13.4
1995/96	3,904	2,669	28.7	19.6
1996/97	8,306	3,400	61.0	25.0
1997/98	9,949	3,900	73.1	28.7
1998/99	12,105	4,440	89.0	32.6
1999/00	11,053	4,522	81.2	33.2
2000/01	12,895	3,087	94.8	22.7
2001/02	15,788	3,083	116.0	22.7
2002/03	15,401	3,249	113.2	23.9
2003/04	9,572	2,733	70.3	20.1
2004/05	13,844	4,460	101.7	32.8
2005/06	17,785	3,709	130.7	27.3
2006/07	15,903	3,047	116.9	22.4
2007/08	16,148	3,819	118.7	28.1
2008/09	26,171	4,235	192.3	31.1
2009/10	19,075	2,704	140.2	19.9
2010/11	15,131	2,275	111.2	16.7
2011/12	16,119	4,244	118.4	31.2
2012/13	12,987	3,083	95.4	22.7
2013/14	28,782	6,064	200.0	44.6
2014/15	39,119	4,212	200.0	31.0
2015/16	27,428	5,735	200.0	42.1
2016/17	18,313	4,299	134.6	31.6
2017/18	12,276	1,143	90.2	8.4

Table 9. Trends in Tanner crab biomass (1000's t) in the NMFS EBS summer bottom trawl survey.

Survey	Females (1000's t)			Males (1000's t)		
Year	East of 166W	West of 166W	EBS total	East of 166W	West of 166W	EBS total
1975	27,594	13,374	40,968	214,202	80,689	294,891
1976	25,420	12,140	37,560	101,958	55,092	157,050
1977	31,435	21,613	53,048	87,463	51,038	138,501
1978	18,406	14,167	32,574	72,913	25,394	98,308
1979	3,448	19,701	23,149	17,978	32,058	50,036
1980	12,883	64,420	77,303	48,979	103,505	152,484
1981	8,577	35,525	44,102	23,390	56,540	79,930
1982	8,107	57,757	65,864	16,602	49,255	65,856
1983	5,350	17,418	22,769	13,337	24,708	38,045
1984	4,800	12,358	17,158	12,020	18,490	30,510
1985	3,160	3,393	6,554	8,231	6,676	14,907
1986	3,504	2,570	6,074	9,625	11,986	21,612
1987	15,009	5,137	20,146	28,863	16,648	45,511
1988	22,885	12,668	35,553	58,130	41,093	99,223
1989	18,975	12,254	31,230	87,718	45,106	132,824
1990	25,022	22,532	47,554	76,879	55,539	132,418
1991	31,341	20,445	51,787	89,825	55,986	145,811
1992	11,358	16,857	28,215	89,918	37,674	127,592
1993	5,325	7,382	12,707	53,394	19,877	73,271
1994	5,332	5,716	11,048	32,303	16,032	48,335
1995	5,982	7,474	13,456	19,672	15,310	34,982
1996	6,548	4,470	11,019	19,979	10,790	30,770
1997	2,914	1,893	4,806	9,088	5,561	14,649
1998	1,752	2,489	4,241	8,404	6,604	15,008
1999	3,360	3,347	6,708	14,835	6,719	21,554
2000	3,613	2,999	6,613	16,429	6,903	23,332
2001	3,931	6,989	10,920	16,231	13,089	29,320
2002	3,469	6,499	9,968	14,402	13,010	27,411
2003	2,795	10,297	13,092	17,164	20,661	37,825
2004	1,131	7,731	8,862	12,455	26,468	38,923
2005	4,493	17,469	21,962	17,443	46,313	63,756
2006	6,476	21,723	28,198	28,636	72,907	101,543
2007	6,612	12,465	19,076	27,938	76,285	104,223
2008	5,079	9,444	14,523	37,177	47,736	84,913
2009	4,553	6,495	11,048	14,786	32,653	47,439
2010	2,910	6,366	9,276	14,426	34,601	49,027
2011	6,615	9,190	15,805	23,390	39,321	62,712
2012	14,245	9,787	24,032	45,367	34,764	80,131
2013	13,398	10,866	24,264	64,580	38,839	103,420
2014	8,648	8,728	17,377	58,196	50,739	108,936
2015	5,304	7,574	12,878	35,093	39,158	74,251
2016	1,479	7,133	8,612	25,520	43,315	68,835
2017	2,144	6,274	8,418	23,952	29,685	53,637
2018	1,588	8,213	9,801	13,769	32,734	46,503

Table 10. Trends in biomass for preferred-size (> 125 mm CW) male Tanner crab in the NMFS EBS summer bottom trawl survey (in 1000's t).

survey	East 166W			West 166W			EBS
year	new shell	old shell	total	new shell	old shell	total	total
1975	152,683	6,522	159,205	56,181	2,509	58,691	217,896
1976	57,034	9,674	66,709	38,107	1,534	39,640	106,349
1977	50,855	7,543	58,399	26,511	6,808	33,319	91,717
1978	40,633	9,780	50,413	3,221	6,626	9,847	60,259
1979	9,767	3,426	13,192	4,115	3,745	7,860	21,052
1980	23,184	10,857	34,041	11,210	1,677	12,887	46,927
1981	3,445	11,286	14,731	5,884	2,167	8,050	22,781
1982	3,009	4,851	7,860	5,763	5,859	11,622	19,481
1983	5,151	2,082	7,233	2,416	3,240	5,655	12,889
1984	4,348	3,077	7,424	571	3,159	3,730	11,154
1985	4,055	1,046	5,101	588	870	1,458	6,559
1986	734	2,546	3,280	142	674	816	4,096
1987	4,911	3,473	8,385	3,505	658	4,163	12,548
1988	15,698	2,715	18,413	9,690	929	10,618	29,031
1989	37,364	3,740	41,104	13,758	2,741	16,499	57,603
1990	35,903	7,084	42,987	21,082	3,274	24,356	67,343
1991	32,973	14,476	47,449	13,386	8,430	21,816	69,265
1992	41,423	16,242	57,665	9,851	6,461	16,311	73,977
1993	22,942	11,990	34,932	3,716	2,596	6,312	41,244
1994	10,000	13,912	23,912	1,248	4,143	5,391	29,303
1995	1,241	13,516	14,757	370	5,392	5,761	20,518
1996	330	13,912	14,242	100	3,580	3,680	17,922
1997	316	4,245	4,561	163	958	1,121	5,681
1998	1,001	2,604	3,605	441	644	1,085	4,689
1999	1,645	1,838	3,483	256	356	612	4,095
2000	4,484	3,045	7,529	250	377	627	8,156
2001	4,473	3,600	8,073	418	1,361	1,780	9,853
2002	944	7,102	8,046	384	838	1,222	9,268
2003	1,558	6,433	7,991	434	2,227	2,661	10,652
2004	1,597	4,916	6,513	980	1,825	2,805	9,318
2005	2,368	5,822	8,190	8,776	5,062	13,839	22,029
2006	2,134	6,794	8,927	3,755	15,328	19,083	28,011
2007	4,143	5,314	9,457	8,523	7,757	16,281	25,737
2008	15,476	3,288	18,764	8,688	4,457	13,145	31,909
2009	2,644	5,139	7,783	6,657	4,156	10,812	18,595
2010	3,006	4,576	7,582	9,593	4,867	14,460	22,042
2011	1,513	6,987	8,500	9,023	6,637	15,660	24,160
2012	3,352	5,026	8,378	2,368	3,997	6,365	14,743
2013	10,871	3,527	14,397	5,383	2,837	8,220	22,618
2014	14,899	9,310	24,210	7,163	4,604	11,766	35,976
2015	9,084	10,217	19,301	8,380	5,925	14,306	33,607
2016	2,640	8,055	10,695	5,799	12,527	18,326	29,021
2017	1,629	10,841	12,470	894	11,659	12,553	25,024
2018	102	7,253	7,355	996	11,875	12,871	20,225

Table 11. 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.

		female								male							
		immature				mature				immature				mature			
		new shell		old shell		new shell		old shell		new shell		old shell		new shell		old shell	
year	Hauls	non-0 hauls	crab	non-0 hauls	crab	non-0 hauls	crab	non-0 hauls	crab	non-0 hauls	crab	non-0 hauls	crab	non-0 hauls	crab	non-0 hauls	crab
1975	136	73	1,040	6	7	91	1,861	39	706	127	2,895	0	0	127	3,993	80	399
1976	214	87	1,095	2	2	91	1,304	39	311	130	2,023	0	0	130	2,469	47	242
1977	155	66	765	9	11	76	1,183	60	738	114	1,778	0	0	114	1,971	79	485
1978	230	87	1,932	8	17	82	638	65	1,307	147	2,957	0	0	147	1,570	104	700
1979	307	71	725	8	8	62	735	42	341	138	1,805	0	0	138	808	68	306
1980	320	101	1,476	10	15	95	1,471	49	570	164	4,602	0	0	164	2,359	71	569
1981	305	71	579	0	0	79	1,319	94	1,206	158	3,809	0	0	158	2,293	116	886
1982	342	85	814	9	9	72	457	103	2,384	181	1,751	0	0	181	1,371	147	2,082
1983	353	102	2,108	4	5	56	201	102	2,154	166	2,484	0	0	166	983	132	1,181
1984	355	135	1,867	9	12	53	284	94	1,531	171	1,965	0	0	171	490	126	1,399
1985	353	140	846	1	1	52	228	65	601	179	1,060	0	0	179	381	86	459
1986	353	162	1,581	4	7	64	191	68	331	213	2,141	0	0	213	528	115	468
1987	355	189	4,230	0	0	105	445	73	392	226	4,659	0	0	226	1,306	103	498
1988	370	206	3,733	2	2	149	1,753	100	530	252	5,627	0	0	252	2,210	101	475
1989	373	204	3,264	4	7	144	1,241	108	882	237	4,977	0	0	237	3,201	135	1,067
1990	370	197	3,105	3	9	155	1,502	126	1,511	247	5,107	0	0	247	3,149	151	1,342
1991	371	159	2,227	9	32	138	1,283	141	2,568	227	4,361	0	0	227	2,692	181	2,893
1992	355	107	1,494	0	0	119	820	123	2,205	215	2,958	0	0	215	2,047	177	1,924
1993	374	99	865	4	4	96	545	122	1,337	207	2,051	0	0	207	1,677	180	1,865
1994	374	97	909	3	12	52	148	104	1,293	175	1,281	0	0	175	724	174	1,827
1995	375	113	830	4	4	35	140	107	1,057	153	958	0	0	153	220	137	1,611
1996	374	114	869	4	14	57	109	98	963	148	1,069	0	0	148	222	134	1,414
1997	375	116	1,325	2	4	62	168	83	504	161	1,336	0	0	161	289	125	582
1998	374	146	1,704	4	6	53	160	73	344	176	2,032	0	0	176	396	128	624
1999	372	137	2,608	6	20	52	255	85	510	170	2,816	0	0	170	550	124	567
2000	371	142	2,249	0	0	61	242	55	345	188	2,836	0	0	188	628	133	653
2001	374	164	3,675	3	3	83	364	72	644	211	4,036	0	0	211	629	145	817
2002	374	154	3,583	2	2	81	350	70	500	186	3,912	0	0	186	458	154	1,089
2003	375	153	2,830	3	4	111	923	83	752	203	4,754	0	0	203	900	153	1,349
2004	374	173	3,563	10	359	90	427	80	656	236	4,568	0	0	236	1,027	179	1,873
2005	372	201	3,349	2	3	103	634	74	928	254	4,496	0	0	254	1,280	185	1,753
2006	375	210	4,355	4	9	143	1,332	125	1,327	254	6,224	0	0	254	1,757	211	4,054
2007	375	185	2,420	6	10	138	1,311	136	1,396	261	4,697	0	0	261	1,982	201	2,907
2008	374	153	1,747	0	0	104	580	120	1,783	240	3,127	0	0	240	2,116	196	2,146
2009	375	171	2,408	0	0	75	363	115	1,317	216	2,879	0	0	216	1,144	187	1,954
2010	375	186	3,171	5	9	67	245	104	941	223	3,654	0	0	223	1,268	166	1,702
2011	375	193	5,044	0	0	90	471	102	705	210	6,095	0	0	210	1,115	167	1,941
2012	375	195	3,577	6	34	100	942	97	720	215	5,526	0	0	215	1,564	139	1,296
2013	375	163	2,900	9	17	116	1,417	101	1,002	207	5,592	0	0	207	2,675	137	1,344
2014	375	165	2,207	3	4	98	482	121	1,584	222	4,746	0	0	222	3,286	167	2,829
2015	375	118	1,455	0	0	60	445	94	1,363	225	2,737	0	0	225	1,859	200	2,817
2016	375	110	1,372	1	1	56	370	82	1,248	222	2,235	0	0	222	1,170	218	3,668
2017	375	129	2,027	1	1	50	213	99	1,125	185	2,233	0	0	185	423	204	3,529

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

Year	Effort (1000's Potlifts) BBRKC Fishery	Effort (1000's Potlifts) Snow Crab Fishery	Year	Effort (1000's Potlifts) BBRKC Fishery	Effort (1000's Potlifts) Snow Crab Fishery
1951/52	--	--	1986/87	175.753	616.113
1952/53	--	--	1987/88	220.971	747.395
1953/54	30.083	--	1988/89	146.179	665.242
1954/55	17.122	--	1989/90	205.528	912.718
1955/56	28.045	--	1990/91	262.761	1382.908
1956/57	41.629	--	1991/92	227.555	1278.502
1957/58	23.659	--	1992/93	206.815	969.209
1958/59	27.932	--	1993/94	254.389	716.524
1959/60	22.187	--	1994/95	0.697	507.603
1960/61	26.347	--	1995/96	0.547	520.685
1961/62	72.646	--	1996/97	77.081	754.14
1962/63	123.643	--	1997/98	91.085	930.794
1963/64	181.799	--	1998/99	145.689	945.533
1964/65	180.809	--	1999/00	151.212	182.634
1965/66	127.973	--	2000/01	104.056	191.2
1966/67	129.306	--	2001/02	66.947	326.977
1967/68	135.283	--	2002/03	72.514	153.862
1968/69	184.666	--	2003/04	134.515	123.709
1969/70	175.374	--	2004/05	97.621	75.095
1970/71	168.059	--	2005/06	116.32	117.375
1971/72	126.305	--	2006/07	72.404	86.288
1972/73	208.469	--	2007/08	113.948	140.857
1973/74	194.095	--	2008/09	139.937	163.537
1974/75	212.915	--	2009/10	118.521	136.477
1975/76	205.096	--	2010/11	131.627	147.244
1976/77	321.01	--	2011/12	45.166	270.602
1977/78	451.273	--	2012/13	38.159	225.489
1978/79	406.165	190.746	2013/14	45.927	225.245
1979/80	315.226	255.102	2014/15	57.725	279.183
1980/81	567.292	435.742	2015/16	48.665	199.133
1981/82	536.646	469.091	2016/17	33.126	118.548
1982/83	140.492	287.127	2017/18	48.242	118.034
1983/84	0	173.591			
1984/85	107.406	370.082			
1985/86	84.443	542.346			

Table 13.Non-selectivity parameters from all model scenarios that were estimated within 1% of bounds.

category	name	case	test	bound	description
fisheries	pLgtRet[1]	17AM	at upper bound	15	TCF: logit-scale max retention (pre-1997)
		17AMu	at upper bound	15	TCF: logit-scale max retention (pre-1997)
		18A	at upper bound	15	TCF: logit-scale max retention (pre-1997)
		18B	at upper bound	15	TCF: logit-scale max retention (pre-1997)
		18C0	at upper bound	15	TCF: logit-scale max retention (pre-1997)
		18C0a	at upper bound	15	TCF: logit-scale max retention (pre-1997)
		18C1	at upper bound	15	TCF: logit-scale max retention (pre-1997)
		18C1a	at upper bound	15	TCF: logit-scale max retention (pre-1997)
		18C2a	at upper bound	15	TCF: logit-scale max retention (pre-1997)
		18C3a	at upper bound	15	TCF: logit-scale max retention (pre-1997)
		18D0	at upper bound	15	TCF: logit-scale max retention (pre-1997)
population processes	pGrBeta[1]	17AMu	at lower bound	0.5	both sexes
		18A	at lower bound	0.5	both sexes
		18B	at lower bound	0.5	both sexes
		18C0	at lower bound	0.5	both sexes
		18C0a	at lower bound	0.5	both sexes
		18D0	at lower bound	0.5	both sexes
	pLgtPrM2M[1]	17AM	at upper bound	15	males (entire model period)
		17AMu	at upper bound	15	males (entire model period)
		18A	at upper bound	15	males (entire model period)
	pLgtPrM2M[2]	17AM	at lower bound	-15	females (entire model period)
		17AMu	at lower bound	-15	females (entire model period)
		18A	at lower bound	-15	females (entire model period)
surveys	pQ[1]	17AM	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
		17AMu	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
		18A	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
		18B	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
		18C0	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
		18C0a	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
		18C1	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
		18C1a	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
		18C2a	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
		18C3a	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
		18D0	at lower bound	0.5	NMFS trawl survey: males, 1975-1981
	pQ[3]	17AM	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
		17AMu	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
		18A	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
		18B	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
		18C0	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
		18C0a	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
		18C1	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
		18C1a	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
		18D0	at lower bound	0.5	NMFS trawl survey: females, 1975-1981
	pQ[4]	18B	at lower bound	0.2	NMFS trawl survey: females, 1982+
		18C0	at lower bound	0.2	NMFS trawl survey: females, 1982+
		18C1	at lower bound	0.2	NMFS trawl survey: females, 1982+
		18D0	at lower bound	0.2	NMFS trawl survey: females, 1982+

Table 14.Selectivity-related parameters from all model scenarios estimated within 1% of bounds.

pS1[1]	17AMu	at upper bound	90 z50 for NMFS survey selectivity (males, pre-1982)
	18A	at upper bound	90 z50 for NMFS survey selectivity (males, pre-1982)
	18B	at upper bound	90 z50 for NMFS survey selectivity (males, pre-1982)
	18C0	at upper bound	90 z50 for NMFS survey selectivity (males, pre-1982)
	18C0a	at upper bound	90 z50 for NMFS survey selectivity (males, pre-1982)
	18C1	at upper bound	90 z50 for NMFS survey selectivity (males, pre-1982)
	18C1a	at upper bound	90 z50 for NMFS survey selectivity (males, pre-1982)
	18D0	at upper bound	90 z50 for NMFS survey selectivity (males, pre-1982)
pS1[20]	17AM	at lower bound	40 z50 for GF.AllGear selectivity (males, 1987-1996)
	17AMu	at lower bound	40 z50 for GF.AllGear selectivity (males, 1987-1996)
	18A	at lower bound	40 z50 for GF.AllGear selectivity (males, 1987-1996)
	18B	at lower bound	40 z50 for GF.AllGear selectivity (males, 1987-1996)
	18C0	at lower bound	40 z50 for GF.AllGear selectivity (males, 1987-1996)
	18C0a	at lower bound	40 z50 for GF.AllGear selectivity (males, 1987-1996)
	18D0	at lower bound	40 z50 for GF.AllGear selectivity (males, 1987-1996)
pS1[23]	17AM	at upper bound	180 z95 for RKF selectivity (males, 1997-2004)
	17AMu	at upper bound	180 z95 for RKF selectivity (males, 1997-2004)
	18A	at upper bound	180 z95 for RKF selectivity (males, 1997-2004)
	18B	at upper bound	180 z95 for RKF selectivity (males, 1997-2004)
	18C0	at upper bound	180 z95 for RKF selectivity (males, 1997-2004)
	18C0a	at upper bound	180 z95 for RKF selectivity (males, 1997-2004)
	18C1	at upper bound	180 z95 for RKF selectivity (males, 1997-2004)
	18C1a	at upper bound	180 z95 for RKF selectivity (males, 1997-2004)
	18C2a	at upper bound	180 z95 for RKF selectivity (males, 1997-2004)
	18C3a	at upper bound	180 z95 for RKF selectivity (males, 1997-2004)
	18D0	at upper bound	180 z95 for RKF selectivity (males, 1997-2004)
pS1[24]	17AM	at upper bound	180 z95 for RKF selectivity (males, 2005+)
	17AMu	at upper bound	180 z95 for RKF selectivity (males, 2005+)
	18A	at upper bound	180 z95 for RKF selectivity (males, 2005+)
	18B	at upper bound	180 z95 for RKF selectivity (males, 2005+)
	18C0	at upper bound	180 z95 for RKF selectivity (males, 2005+)
	18C0a	at upper bound	180 z95 for RKF selectivity (males, 2005+)
	18C1	at upper bound	180 z95 for RKF selectivity (males, 2005+)
	18C1a	at upper bound	180 z95 for RKF selectivity (males, 2005+)
	18C2a	at upper bound	180 z95 for RKF selectivity (males, 2005+)
	18C3a	at upper bound	180 z95 for RKF selectivity (males, 2005+)
	18D0	at upper bound	180 z95 for RKF selectivity (males, 2005+)
pS1[25]	18C3a	at upper bound	140 z95 for RKF selectivity (females, pre-1997)
pS1[27]	17AM	at upper bound	140 z95 for RKF selectivity (females, 2005+)
	17AMu	at upper bound	140 z95 for RKF selectivity (females, 2005+)
	18A	at upper bound	140 z95 for RKF selectivity (females, 2005+)
	18B	at upper bound	140 z95 for RKF selectivity (females, 2005+)
	18C0	at upper bound	140 z95 for RKF selectivity (females, 2005+)
	18C0a	at upper bound	140 z95 for RKF selectivity (females, 2005+)
	18C1	at upper bound	140 z95 for RKF selectivity (females, 2005+)
	18C1a	at upper bound	140 z95 for RKF selectivity (females, 2005+)
	18C2a	at upper bound	140 z95 for RKF selectivity (females, 2005+)
	18D0	at upper bound	140 z95 for RKF selectivity (females, 2005+)
pS1[4]	17AMu	at lower bound	-50 z50 for NMFS survey selectivity (females, 1982+)

Table 14 (cont.).Selectivity-related parameters from all model scenarios estimated within 1% of bounds.

name	case	test	bound	label
pS2[10]	18C2a	at lower bound	0.1	ascending slope for SCF selectivity (males, pre-1997)
	18C3a	at lower bound	0.1	ascending slope for SCF selectivity (males, pre-1997)
pS2[2]	17AMu	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
	18A	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
	18B	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
	18C0	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
	18C1	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
	18D0	at upper bound	100	z95-z50 for NMFS survey selectivity (males, 1982+)
pS2[4]	17AM	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
	17AMu	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
	18B	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
	18C0	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
	18C0a	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
	18C1	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
	18C1a	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
	18D0	at upper bound	100	z95-z50 for NMFS survey selectivity (females, 1982+)
pS3[1]	18C2a	at lower bound	2	ln(dz50-az50) for SCF selectivity (males, pre-1997)
	18C3a	at lower bound	2	ln(dz50-az50) for SCF selectivity (males, pre-1997)
pS4[1]	17AM	at upper bound	0.5	descending slope for SCF selectivity (males, pre-1997)
	18C0a	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)
	18C1a	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)
	18C2a	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)
	18C3a	at lower bound	0.1	descending slope for SCF selectivity (males, pre-1997)
pS4[2]	17AMu	at lower bound	0.1	descending slope for SCF selectivity (males, 1997-2004)
	18A	at lower bound	0.1	descending slope for SCF selectivity (males, 1997-2004)
	18B	at lower bound	0.1	descending slope for SCF selectivity (males, 1997-2004)
	18C0	at lower bound	0.1	descending slope for SCF selectivity (males, 1997-2004)
	18C0a	at lower bound	0.1	descending slope for SCF selectivity (males, 1997-2004)
	18C1	at lower bound	0.1	descending slope for SCF selectivity (males, 1997-2004)
	18C1a	at lower bound	0.1	descending slope for SCF selectivity (males, 1997-2004)
	18C2a	at lower bound	0.1	descending slope for SCF selectivity (males, 1997-2004)
	18C3a	at lower bound	0.1	descending slope for SCF selectivity (males, 1997-2004)
	18D0	at lower bound	0.1	descending slope for SCF selectivity (males, 1997-2004)

Table 15. Comparison of estimated growth, natural mortality, and non-vector recruitment parameters for all model scenarios.

			17AM		17AMu		18A		18B		18C0		18C0a	
process	name	label	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
growth	pGrA[1]	males	33.14	0.00	33.67	0.24	33.50	0.24	34.77	0.30	34.75	0.30	33.63	0.24
	pGrA[2]	females	34.42	0.00	33.94	0.31	34.00	0.31	34.18	0.34	34.34	0.35	33.95	0.33
	pGrB[1]	males	166.79	0.00	157.55	0.49	157.75	0.50	155.62	0.36	155.61	0.36	157.17	0.50
	pGrB[2]	females	115.14	0.00	114.81	0.74	114.64	0.73	114.73	0.74	115.72	0.73	115.88	0.75
	pGrBeta[1]	both sexes	0.82	0.00	0.50	0.00	0.50	0.00	0.50	0.00	0.50	0.00	0.50	0.00
natural mortality	pDM1[1]	multiplier for immature crab	1.00	0.00	0.98	0.04	0.96	0.04	0.91	0.05	0.92	0.05	0.97	0.05
	pDM1[2]	multiplier for mature males	1.15	0.00	1.29	0.04	1.28	0.04	1.38	0.04	1.61	0.03	1.46	0.04
	pDM1[3]	multiplier for mature females	1.37	0.00	1.32	0.03	1.32	0.03	1.41	0.03	1.53	0.03	1.48	0.04
	pDM2[1]	1980-1984 multiplier for mature males	2.60	0.00	2.49	0.23	2.48	0.23	2.49	0.21	2.54	0.15	2.74	0.17
	pDM2[2]	1980-1984 multiplier for mature females	1.32	0.00	1.33	0.11	1.30	0.11	1.34	0.10	1.59	0.09	1.62	0.10
	pM[1]	base ln-scale M	-1.47	0.00	-1.47	0.00	-1.47	0.00	-1.47	0.00	-1.47	0.00	-1.47	0.00
recruitment	pLnR[1]	historical recruitment period	5.62	0.00	6.29	0.37	6.33	0.36	6.52	0.37	6.47	0.38	6.11	0.37
	pLnR[2]	current recruitment period	5.12	0.00	5.68	0.07	5.72	0.07	5.90	0.07	6.08	0.07	5.70	0.08
	pRa[1]	fixed value	2.44	0.00	2.44	0.00	2.44	0.00	2.44	0.00	2.44	0.00	2.44	0.00
	pRb[1]	fixed value	1.39	0.00	1.39	0.00	1.39	0.00	1.39	0.00	1.39	0.00	1.39	0.00
	pRCV[1]	full model period	-0.69	0.00	-0.69	0.00	-0.69	0.00	-0.69	0.00	-0.69	0.00	-0.69	0.00
	pRX[1]	full model period	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

			18C1		18C1a		18C2a		18C3a		18D0	
process	name	label	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
growth	pGrA[1]	males	35.71	0.31	34.22	0.36	34.91	0.36	34.61	0.37	34.86	0.29
	pGrA[2]	females	34.86	0.37	34.25	0.39	34.53	0.37	33.35	0.31	34.11	0.35
	pGrB[1]	males	155.83	0.38	158.19	0.72	0.95	0.01	0.95	0.01	155.34	0.37
	pGrB[2]	females	115.80	0.76	116.18	0.77	0.89	0.01	0.92	0.01	114.87	0.75
	pGrBeta[1]	both sexes	0.57	0.05	0.51	0.06	0.61	0.06	0.52	0.05	0.50	0.00
natural mortality	pDM1[1]	multiplier for immature crab	0.90	0.05	0.98	0.05	0.91	0.04	0.95	0.04	0.93	0.05
	pDM1[2]	multiplier for mature males	1.65	0.03	1.52	0.04	1.50	0.03	1.38	0.03	1.29	0.04
	pDM1[3]	multiplier for mature females	1.54	0.03	1.50	0.04	1.51	0.03	1.75	0.03	1.39	0.03
	pDM2[1]	1980-1984 multiplier for mature males	2.55	0.14	2.80	0.16	3.15	0.16	3.25	0.17	2.09	0.21
	pDM2[2]	1980-1984 multiplier for mature females	1.63	0.09	1.69	0.09	1.79	0.09	1.82	0.08	1.47	0.12
	pM[1]	base ln-scale M	-1.47	0.00	-1.47	0.00	-1.47	0.00	-1.47	0.00	-1.47	0.00
recruitment	pLnR[1]	historical recruitment period	6.38	0.38	6.09	0.38	5.52	0.38	5.46	0.37	6.59	0.38
	pLnR[2]	current recruitment period	6.08	0.06	5.79	0.07	5.06	0.03	5.00	0.03	5.98	0.07
	pRa[1]	fixed value	2.44	0.00	2.44	0.00	2.44	0.00	2.44	0.00	2.44	0.00
	pRb[1]	fixed value	1.39	0.00	1.39	0.00	1.39	0.00	1.39	0.00	1.39	0.00
	pRCV[1]	full model period	-0.69	0.00	-0.69	0.00	-0.69	0.00	-0.69	0.00	-0.69	0.00
	pRX[1]	full model period	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 16. Comparison of historical recruitment devs estimates (1948-1974) for all model scenarios.

	17AM		17AMu		18A		18B		18C0		18C0a	
index	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
1	-1.424	0.000	-1.134	1.435	-1.124	1.434	-1.072	1.443	-0.848	1.455	-0.926	1.440
2	-1.424	0.000	-1.143	1.282	-1.131	1.281	-1.081	1.291	-0.862	1.303	-0.938	1.287
3	-1.423	0.000	-1.157	1.145	-1.144	1.145	-1.098	1.153	-0.887	1.165	-0.961	1.149
4	-1.419	0.000	-1.175	1.027	-1.160	1.026	-1.119	1.034	-0.921	1.044	-0.991	1.029
5	-1.409	0.000	-1.192	0.928	-1.174	0.928	-1.142	0.935	-0.961	0.942	-1.024	0.929
6	-1.390	0.000	-1.203	0.850	-1.181	0.850	-1.160	0.856	-1.001	0.860	-1.055	0.849
7	-1.356	0.000	-1.201	0.791	-1.175	0.791	-1.167	0.796	-1.033	0.797	-1.075	0.789
8	-1.300	0.000	-1.175	0.747	-1.144	0.747	-1.152	0.751	-1.048	0.750	-1.073	0.744
9	-1.210	0.000	-1.108	0.712	-1.073	0.712	-1.100	0.716	-1.027	0.714	-1.030	0.709
10	-1.066	0.000	-0.974	0.683	-0.933	0.683	-0.984	0.686	-0.942	0.683	-0.917	0.679
11	-0.836	0.000	-0.723	0.660	-0.676	0.660	-0.758	0.661	-0.742	0.657	-0.678	0.655
12	-0.459	0.000	-0.270	0.648	-0.220	0.650	-0.334	0.648	-0.329	0.644	-0.218	0.644
13	0.148	0.000	0.429	0.640	0.478	0.642	0.350	0.640	0.373	0.636	0.517	0.635
14	0.956	0.000	1.190	0.619	1.226	0.622	1.131	0.620	1.203	0.615	1.325	0.611
15	1.620	0.000	1.598	0.594	1.619	0.598	1.575	0.595	1.663	0.579	1.696	0.570
16	1.796	0.000	1.573	0.591	1.582	0.594	1.587	0.590	1.522	0.557	1.429	0.555
17	1.621	0.000	1.359	0.600	1.357	0.602	1.393	0.602	1.001	0.570	0.835	0.577
18	1.377	0.000	1.168	0.597	1.149	0.597	1.207	0.601	0.407	0.589	0.235	0.594
19	1.228	0.000	1.078	0.577	1.029	0.578	1.109	0.581	-0.060	0.586	-0.175	0.583
20	1.221	0.000	1.052	0.560	0.970	0.567	1.051	0.562	-0.201	0.555	-0.183	0.549
21	1.300	0.000	0.920	0.554	0.823	0.559	0.867	0.561	0.299	0.523	0.498	0.514
22	1.269	0.000	0.652	0.505	0.584	0.506	0.561	0.515	1.208	0.425	1.357	0.418
23	1.105	0.000	0.672	0.444	0.630	0.444	0.591	0.450	1.308	0.411	1.383	0.408
24	0.696	0.000	0.316	0.450	0.273	0.451	0.327	0.444	0.919	0.416	0.934	0.419
25	0.272	0.000	0.089	0.465	0.076	0.464	0.054	0.462	0.510	0.446	0.587	0.447
26	0.109	0.000	0.355	0.399	0.339	0.399	0.366	0.394	0.447	0.399	0.448	0.403

	18C1		18C1a		18C2a		18C3a		18D0	
index	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
1	-0.806	1.465	-0.873	1.452	-0.974	1.458	-1.016	1.441	-1.207	1.452
2	-0.820	1.314	-0.885	1.301	-0.989	1.307	-1.031	1.289	-1.210	1.301
3	-0.845	1.176	-0.909	1.163	-1.017	1.169	-1.059	1.152	-1.215	1.164
4	-0.880	1.055	-0.940	1.043	-1.056	1.049	-1.097	1.034	-1.219	1.045
5	-0.921	0.953	-0.976	0.942	-1.102	0.949	-1.142	0.935	-1.219	0.945
6	-0.963	0.871	-1.011	0.861	-1.150	0.869	-1.187	0.858	-1.210	0.865
7	-1.001	0.808	-1.038	0.800	-1.195	0.808	-1.227	0.800	-1.187	0.803
8	-1.023	0.761	-1.047	0.754	-1.225	0.764	-1.250	0.757	-1.139	0.756
9	-1.016	0.724	-1.021	0.719	-1.227	0.730	-1.241	0.724	-1.053	0.720
10	-0.953	0.694	-0.934	0.689	-1.178	0.701	-1.178	0.696	-0.904	0.690
11	-0.791	0.667	-0.738	0.663	-1.038	0.673	-1.017	0.669	-0.648	0.666
12	-0.442	0.649	-0.342	0.649	-0.729	0.651	-0.678	0.647	-0.208	0.654
13	0.197	0.642	0.336	0.642	-0.133	0.638	-0.048	0.634	0.475	0.648
14	1.041	0.623	1.171	0.622	0.744	0.615	0.846	0.611	1.231	0.631
15	1.612	0.593	1.675	0.585	1.505	0.587	1.579	0.583	1.649	0.609
16	1.605	0.563	1.549	0.559	1.725	0.554	1.744	0.549	1.667	0.608
17	1.149	0.570	1.008	0.575	1.438	0.551	1.399	0.549	1.507	0.618
18	0.555	0.589	0.388	0.596	0.926	0.567	0.857	0.569	1.366	0.613
19	0.039	0.593	-0.095	0.593	0.429	0.578	0.364	0.579	1.302	0.587
20	-0.212	0.568	-0.248	0.562	0.137	0.563	0.112	0.559	1.244	0.574
21	0.109	0.532	0.243	0.529	0.342	0.526	0.402	0.521	0.980	0.586
22	1.095	0.438	1.265	0.428	1.328	0.454	1.458	0.438	0.529	0.539
23	1.305	0.418	1.394	0.415	1.737	0.418	1.794	0.408	0.381	0.476
24	1.024	0.415	1.024	0.418	1.391	0.415	1.342	0.412	0.024	0.473
25	0.511	0.448	0.569	0.452	0.816	0.452	0.753	0.451	-0.137	0.476
26	0.431	0.401	0.433	0.406	0.491	0.412	0.522	0.408	0.200	0.401

Table 17. Comparison of current recruitment devs estimates (1975-2018) for all model scenarios.

	17AM		17AMu		18A		18B		18C0		18C0a	
index	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
1	1.334	0.000	1.061	0.262	1.032	0.267	0.944	0.243	0.917	0.225	1.072	0.243
2	2.007	0.000	1.930	0.135	1.913	0.136	1.837	0.128	1.821	0.118	1.956	0.126
3	1.749	0.000	1.687	0.146	1.664	0.147	1.701	0.133	1.840	0.112	1.902	0.119
4	0.927	0.000	0.857	0.231	0.811	0.238	1.024	0.192	1.333	0.148	1.178	0.179
5	0.064	0.000	0.074	0.336	0.061	0.337	0.095	0.305	0.021	0.288	-0.017	0.333
6	-0.426	0.000	-0.336	0.388	-0.363	0.396	-0.335	0.348	-0.337	0.294	-0.316	0.332
7	0.066	0.000	0.040	0.237	0.038	0.237	-0.075	0.230	-0.259	0.225	-0.115	0.233
8	-0.504	0.000	-0.333	0.285	-0.368	0.292	-0.291	0.243	-0.309	0.208	-0.346	0.248
9	1.077	0.000	1.049	0.104	1.045	0.104	0.917	0.103	0.703	0.103	0.840	0.105
10	0.883	0.000	0.886	0.127	0.866	0.129	0.862	0.118	0.766	0.110	0.812	0.118
11	1.180	0.000	0.927	0.132	0.898	0.134	0.933	0.121	0.872	0.112	0.857	0.125
12	1.145	0.000	0.970	0.123	0.952	0.124	0.921	0.116	0.880	0.110	0.937	0.116
13	1.137	0.000	0.912	0.117	0.883	0.118	0.905	0.106	0.901	0.099	0.918	0.107
14	0.758	0.000	0.343	0.150	0.304	0.152	0.426	0.135	0.552	0.118	0.413	0.137
15	0.025	0.000	-0.170	0.166	-0.190	0.166	-0.227	0.159	-0.093	0.142	-0.079	0.150
16	-1.158	0.000	-1.326	0.344	-1.378	0.356	-1.181	0.281	-1.047	0.246	-1.278	0.316
17	-1.383	0.000	-1.536	0.318	-1.555	0.319	-1.560	0.300	-1.593	0.286	-1.583	0.303
18	-1.504	0.000	-1.529	0.274	-1.542	0.275	-1.612	0.265	-1.548	0.236	-1.480	0.244
19	-1.502	0.000	-1.434	0.255	-1.438	0.255	-1.551	0.247	-1.427	0.213	-1.348	0.223
20	-1.227	0.000	-1.128	0.212	-1.137	0.214	-1.241	0.203	-1.228	0.189	-1.159	0.201
21	-0.979	0.000	-0.853	0.183	-0.861	0.184	-0.962	0.176	-0.959	0.162	-0.867	0.168
22	-1.063	0.000	-0.957	0.217	-0.972	0.220	-0.997	0.199	-1.016	0.183	-1.023	0.204
23	0.006	0.000	0.086	0.106	0.086	0.106	-0.026	0.102	-0.158	0.100	-0.090	0.103
24	-0.909	0.000	-0.767	0.192	-0.779	0.194	-0.808	0.177	-0.883	0.168	-0.888	0.183
25	0.299	0.000	0.431	0.102	0.438	0.102	0.297	0.100	0.184	0.097	0.294	0.098
26	-0.354	0.000	-0.192	0.188	-0.207	0.192	-0.202	0.169	-0.227	0.154	-0.262	0.175
27	0.831	0.000	0.873	0.095	0.874	0.096	0.775	0.092	0.649	0.089	0.710	0.092
28	-0.303	0.000	-0.142	0.215	-0.153	0.217	-0.143	0.195	-0.213	0.185	-0.231	0.204
29	0.796	0.000	0.881	0.105	0.880	0.105	0.802	0.102	0.800	0.094	0.854	0.097
30	0.770	0.000	0.722	0.106	0.707	0.107	0.702	0.099	0.706	0.094	0.673	0.101
31	-0.533	0.000	-0.436	0.218	-0.458	0.221	-0.421	0.198	-0.277	0.173	-0.326	0.190
32	-0.799	0.000	-0.783	0.263	-0.802	0.265	-0.768	0.239	-0.671	0.215	-0.732	0.239
33	-1.056	0.000	-0.975	0.296	-0.987	0.299	-0.981	0.275	-0.948	0.253	-0.981	0.277
34	-0.625	0.000	-0.679	0.263	-0.636	0.261	-0.817	0.257	-0.736	0.235	-0.573	0.238
35	1.249	0.000	1.338	0.094	1.327	0.091	1.175	0.089	1.140	0.085	1.260	0.086
36	1.128	0.000	1.274	0.095	1.109	0.103	1.231	0.084	1.180	0.080	1.067	0.095
37	0.234	0.000	0.052	0.181	0.026	0.176	0.118	0.162	0.170	0.146	0.078	0.158
38	-1.403	0.000	-1.181	0.381	-1.057	0.346	-0.730	0.275	-0.620	0.237	-0.899	0.290
39	-0.394	0.000	-0.362	0.184	-0.476	0.186	-0.467	0.183	-0.499	0.173	-0.498	0.176
40	-0.683	0.000	-0.637	0.208	-0.799	0.209	-0.758	0.199	-0.759	0.187	-0.813	0.198
41	-1.105	0.000	-1.014	0.266	-1.164	0.264	-1.100	0.251	-1.060	0.234	-1.141	0.248
42	-0.765	0.000	-0.701	0.246	-0.838	0.240	-0.802	0.237	-0.798	0.225	-0.845	0.230
43	1.012	0.000	1.078	0.166	1.016	0.140	1.035	0.141	0.928	0.133	0.895	0.134
44					1.230	0.217	1.353	0.218	1.299	0.198	1.176	0.204

Table 17 (cont). Comparison of current recruitment devs estimates (1975-2018) for all model scenarios.

	18C1		18C1a		18C2a		18C3a		18D0	
index	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
1	0.813	0.191	0.969	0.218	1.404	0.166	1.465	0.170	0.805	0.253
2	1.612	0.110	1.791	0.119	1.997	0.113	2.027	0.116	1.735	0.126
3	1.662	0.106	1.782	0.111	1.959	0.108	1.961	0.110	1.567	0.137
4	1.344	0.122	1.219	0.155	1.497	0.128	1.382	0.139	1.058	0.183
5	0.042	0.242	-0.129	0.305	0.031	0.284	-0.092	0.314	0.037	0.305
6	-0.489	0.266	-0.438	0.288	-0.444	0.285	-0.389	0.280	-0.487	0.381
7	-0.520	0.211	-0.454	0.234	-0.470	0.221	-0.451	0.231	-0.143	0.232
8	-0.545	0.189	-0.541	0.220	-0.600	0.215	-0.584	0.229	-0.243	0.220
9	0.379	0.095	0.490	0.102	0.430	0.097	0.502	0.099	0.858	0.101
10	0.469	0.105	0.538	0.111	0.446	0.121	0.537	0.121	0.779	0.117
11	0.633	0.106	0.573	0.124	0.957	0.095	0.971	0.102	0.849	0.121
12	0.881	0.100	0.941	0.107	1.180	0.092	1.203	0.096	0.913	0.115
13	1.010	0.091	1.037	0.097	1.342	0.076	1.367	0.078	0.876	0.109
14	0.797	0.100	0.658	0.123	0.894	0.107	0.777	0.115	0.478	0.130
15	0.085	0.131	0.070	0.141	0.095	0.138	0.048	0.144	-0.207	0.160
16	-0.764	0.203	-0.980	0.264	-0.804	0.224	-0.912	0.247	-1.158	0.279
17	-1.507	0.273	-1.530	0.296	-1.578	0.300	-1.591	0.313	-1.462	0.283
18	-1.535	0.228	-1.492	0.240	-1.607	0.245	-1.601	0.256	-1.540	0.254
19	-1.469	0.208	-1.396	0.219	-1.527	0.217	-1.514	0.227	-1.530	0.244
20	-1.203	0.174	-1.159	0.188	-1.291	0.181	-1.270	0.188	-1.241	0.202
21	-0.979	0.155	-0.909	0.163	-1.083	0.161	-1.034	0.163	-0.967	0.173
22	-0.925	0.162	-0.940	0.180	-1.030	0.168	-1.032	0.177	-1.015	0.197
23	-0.160	0.094	-0.127	0.098	-0.241	0.094	-0.227	0.097	-0.034	0.101
24	-0.801	0.154	-0.832	0.168	-0.912	0.160	-0.921	0.167	-0.761	0.171
25	0.207	0.090	0.291	0.093	0.117	0.090	0.141	0.091	0.318	0.099
26	-0.192	0.143	-0.240	0.162	-0.324	0.151	-0.364	0.160	-0.177	0.166
27	0.753	0.080	0.803	0.083	0.670	0.081	0.670	0.082	0.802	0.091
28	-0.142	0.171	-0.203	0.194	-0.293	0.183	-0.317	0.193	-0.085	0.190
29	0.832	0.090	0.902	0.092	0.748	0.093	0.736	0.093	0.876	0.100
30	0.846	0.084	0.788	0.094	0.794	0.086	0.705	0.090	0.780	0.099
31	-0.083	0.153	-0.124	0.168	-0.181	0.161	-0.269	0.170	-0.328	0.191
32	-0.522	0.193	-0.599	0.221	-0.602	0.200	-0.696	0.217	-0.754	0.243
33	-0.873	0.229	-0.891	0.254	-0.993	0.243	-0.979	0.251	-0.890	0.257
34	-0.881	0.230	-0.705	0.240	-0.931	0.235	-0.893	0.243	-0.767	0.246
35	0.973	0.081	1.100	0.083	0.760	0.091	0.817	0.087	1.170	0.089
36	1.243	0.068	1.172	0.077	1.211	0.072	1.228	0.071	1.245	0.084
37	0.392	0.132	0.269	0.145	0.477	0.141	0.357	0.149	0.157	0.158
38	-0.526	0.214	-0.762	0.264	-0.946	0.289	-0.887	0.286	-0.775	0.280
39	-0.421	0.161	-0.427	0.166	-0.415	0.155	-0.432	0.163	-0.442	0.178
40	-0.749	0.177	-0.771	0.189	-0.914	0.191	-0.879	0.198	-0.754	0.195
41	-1.071	0.222	-1.117	0.239	-1.196	0.233	-1.156	0.244	-1.076	0.242
42	-0.793	0.212	-0.793	0.218	-0.874	0.216	-0.784	0.219	-0.762	0.225
43	0.838	0.114	0.857	0.115	0.812	0.113	0.897	0.114	0.972	0.133
44	1.339	0.148	1.310	0.153	1.436	0.144	1.483	0.147	1.322	0.197

Table 18. Comparison of logit-scale parameters for the probability of terminal molt for all model scenarios.

			17AM		17AMu		18A		18B		18C0		18C0a	
name	label	index	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
pLgtPrM2M[1]	males (entire model period)	1	-12.08656803	0	-11.79151232	7.355	-11.77500682	7.377	-3.566101558	0.18182	-3.704104329	0.20508	-6.709991812	1.4393
		2	-10.89178064	0	-10.59159766	5.5279	-10.58377262	5.5503	-3.511440792	0.16371	-3.662684063	0.18118	-5.672054352	0.72549
		3	-9.696993775	0	-9.39168298	3.9298	-9.392538369	3.9523	-2.953776635	0.12011	-3.076855556	0.13214	-4.52445519	0.43923
		4	-8.503193435	0	-8.192583968	2.5948	-8.202228412	2.6156	-2.432479321	0.093244	-2.532437907	0.10247	-3.556976904	0.29155
		5	-7.320559446	0	-7.005931301	1.5373	-7.025106529	1.5501	-1.766237501	0.069573	-1.783733721	0.074153	-2.86925348	0.20746
		6	-6.162317254	0	-5.839443967	0.83379	-5.867286102	0.83369	-1.27303942	0.056521	-1.253448891	0.059202	-2.420085481	0.15656
		7	-5.104243949	0	-4.772158618	0.50178	-4.795925031	0.50111	-0.837987444	0.050976	-0.81758164	0.052987	-1.723245126	0.12812
		8	-4.477305015	0	-4.218735863	0.35435	-4.236569532	0.35544	-0.462267104	0.049284	-0.45381377	0.051264	-1.200941561	0.10718
		9	-4.08962769	0	-3.930836323	0.28649	-3.961456348	0.28683	-0.280683159	0.046891	-0.278405131	0.049028	-0.904494584	0.092242
		10	-3.448299296	0	-3.247235414	0.22061	-3.274988833	0.22074	-0.069823702	0.048915	-0.056159049	0.05116	-0.835561727	0.088683
		11	-2.913423547	0	-2.648336344	0.16782	-2.656866642	0.16729	-0.066150232	0.043301	-0.066637623	0.044836	-0.647895108	0.077569
		12	-2.487335154	0	-2.290700393	0.14073	-2.305551488	0.14046	0.486947753	0.054997	0.507694688	0.056798	0.32494847	0.104
		13	-2.020784523	0	-2.012094704	0.11963	-2.036325302	0.11929	1.304685536	0.060908	1.325717007	0.062149	1.318830729	0.10232
		14	-1.430112617	0	-1.39775611	0.10446	-1.410788519	0.10391	1.758904345	0.064089	1.781441394	0.06541	1.685580919	0.082742
		15	-0.936987619	0	-0.93887963	0.089656	-0.957790023	0.088696	1.873171909	0.070336	1.89316287	0.071959	2.057504471	0.14938
		16	-0.667894089	0	-0.684786988	0.077868	-0.665311182	0.076873	3.266426195	0.18327	3.281548597	0.18537	5.040711553	0.57982
		17	-0.536299396	0	-0.604287809	0.075218	-0.619553914	0.074405	5.164054242	0.26334	5.166897189	0.26409	8.410085976	1.0728
		18	-0.092834927	0	-0.463673593	0.068064	-0.435441927	0.067544	7.514564346	0.66908	7.511685118	0.66828	11.78930571	2.032
		19	0.512351235	0	0.442130049	0.10022	0.49955773	0.097649						
		20	1.361919764	0	1.39269893	0.096394	1.434010687	0.095836						
		21	2.70767571	0	1.64548298	0.081704	1.707904289	0.078125						
		22	4.95696935	0	2.023118542	0.15339	2.239264858	0.1718						
		23	7.095871179	0	5.07996104	0.54945	5.511785379	0.52072						
		24	8.917113578	0	8.104134028	0.86034	8.550975873	0.87501						
		25	10.41245426	0	10.48812473	1.2942	10.89667384	1.3325						
		26	11.61526392	0	12.25349008	1.6682	12.59692339	1.7069						
		27	12.5657537	0	13.48731056	1.8374	13.75056925	1.8669						
		28	13.30558155	0	14.2835698	1.7371	14.46208856	1.7554						
		29	13.8767742	0	14.73742065	1.3649	14.83695881	1.3735						
		30	14.32146498	0	14.9443574	0.77674	14.98096276	0.77903						
		31	14.68181693	0	14.99999917	0.0045555	14.99999962	0.0020821						
		32	14.99999921	0	14.9999994	0.0032814	14.99999829	0.0094277						
pLgtPrM2M[2]	females (entire model period)	1	-14.99999969	0	-14.9999997	0.0016466	-14.9999997	0.0016199	-13.12677132	3.1971	-13.07003104	3.3292	-13.15369945	3.3262
		2	-13.76426343	0	-13.77782371	0.78321	-13.78539932	0.78272	-10.71001038	2.1246	-10.6962447	2.2362	-10.77703363	2.2341
		3	-12.4745578	0	-12.50021723	1.1841	-12.51447415	1.183	-8.293790159	1.2526	-8.322896414	1.339	-8.400813228	1.3383
		4	-11.07694451	0	-11.11178	1.2859	-11.1309298	1.2843	-5.885746874	0.62147	-5.956100337	0.67789	-6.031099786	0.67944
		5	-9.517965779	0	-9.55762984	1.1499	-9.579006951	1.1479	-3.553656636	0.24897	-3.647137203	0.2825	-3.720235372	0.28582
		6	-7.748393887	0	-7.787382323	0.86172	-7.807570327	0.8599	-1.708949059	0.10965	-1.727502375	0.1217	-1.80378989	0.12272
		7	-5.743309709	0	-5.775090218	0.52645	-5.79019135	0.52531	-0.369302567	0.083748	-0.358506911	0.088513	-0.431226896	0.089137
		8	-3.583931017	0	-3.605024143	0.2447	-3.611920079	0.24437	0.3325227	0.085942	0.352260554	0.088855	0.285705821	0.08886
		9	-1.780153237	0	-1.789289302	0.10975	-1.792217373	0.10926	0.64771013	0.099175	0.700399797	0.10073	0.628635544	0.10007
		10	-0.432960578	0	-0.453875195	0.084055	-0.456085667	0.083744	1.290038053	0.14694	1.383819812	0.15212	1.304152004	0.15081
		11	0.301718676	0	0.254846265	0.086175	0.253987249	0.085919	2.370183708	0.27171	2.525340456	0.27701	2.456563202	0.27754
		12	0.586246433	0	0.568724112	0.098854	0.565815138	0.098423	3.565579032	0.47077	3.781844962	0.50466	3.741739088	0.50902
		13	1.273966791	0	1.202186017	0.14443	1.189784503	0.143	4.81321621	0.94026	5.093691861	1.019	5.087199533	1.0251
		14	2.574952965	0	2.267821647	0.26622	2.24553011	0.26274						
		15	4.024991967	0	3.454998321	0.46169	3.428497347	0.45399						
		16	5.511702016	0	4.703991672	0.92287	4.673210017	0.90942						

Table 18 (cont.). Comparison of logit-scale parameters for the probability of terminal molt for all model scenarios.

				18C1		18C1a		18C2a		18C3a		18D0	
process	name	label	index	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
maturity	pLgtPrM2M[1]	males (entire model period)	1	-3.71603053	0.20566	-6.533583106	1.3731	-5.198447048	0.55783	-5.445338832	0.56933	-3.247903585	0.19601
			2	-3.62472786	0.18136	-5.492147744	0.69677	-4.590525953	0.37458	-4.805506701	0.37633	-3.383531681	0.17849
			3	-3.010057588	0.13244	-4.366114821	0.43062	-3.876507801	0.28892	-4.01288084	0.28968	-2.86521286	0.13056
			4	-2.503895739	0.10249	-3.480977217	0.28843	-3.461841135	0.21902	-3.555009524	0.2205	-2.326096201	0.099356
			5	-1.801299133	0.074624	-2.855284622	0.20693	-2.870357427	0.15776	-3.002698548	0.15764	-1.684315699	0.071929
			6	-1.235924359	0.059562	-2.33416256	0.15648	-2.001187532	0.13065	-2.170392376	0.14102	-1.2166009	0.058079
			7	-0.775598779	0.053357	-1.600764235	0.12849	-1.287730689	0.10075	-1.389911467	0.10232	-0.805727555	0.052339
			8	-0.418511179	0.051801	-1.163850686	0.10696	-1.052056733	0.088616	-1.134628022	0.086617	-0.439280053	0.050674
			9	-0.277271177	0.049336	-0.83737611	0.091638	-1.059317777	0.084612	-1.119450544	0.080396	-0.273230058	0.048227
			10	-0.086574145	0.052079	-0.845922628	0.091049	-1.21603932	0.081978	-1.281972057	0.086472	-0.054507636	0.049877
			11	-0.056304045	0.046477	-0.551595068	0.089691	-0.537970345	0.11362	-0.680687026	0.13775	-0.061532073	0.044444
			12	0.549257249	0.06088	0.540286494	0.12803	0.851918156	0.13379	0.64288699	0.17295	0.470718863	0.055752
			13	1.391604873	0.066389	1.49062839	0.11503	1.540106034	0.095902	1.43908182	0.094025	1.288183734	0.062227
			14	1.809132839	0.068313	1.706334328	0.087333	1.61260665	0.11913	1.55668244	0.11817	1.75786985	0.065067
			15	1.922882175	0.078333	2.386271428	0.25527	3.626458441	0.39708	3.182913447	0.5331	1.852984595	0.068339
			16	3.425465931	0.18405	5.766308852	0.57692	6.220616439	0.4231	5.972206725	0.48165	3.159403582	0.18276
			17	5.241178766	0.26478	9.28053129	1.1914	8.361942179	0.76558	8.303930711	0.77011	5.083421723	0.26541
			18	7.522505844	0.66887	12.7926366	2.2589	10.48442474	1.6136	10.60563704	1.6287	7.480926771	0.66605
	pLgtPrM2M[2]	females (entire model period)	1	-13.03200451	3.3373	-13.08350998	3.3343	-8.623196742	3.4491	-12.28971008	3.3501	-11.8761921	2.97
			2	-10.65815026	2.2422	-10.71146294	2.2403	-7.124874236	2.3364	-10.04197122	2.2535	-9.726125754	1.9496
			3	-8.284712859	1.3424	-8.339843044	1.3419	-5.62562905	1.414	-7.794688897	1.3508	-7.577683253	1.1389
			4	-5.91771117	0.67808	-5.974645025	0.67966	-4.14588586	0.67803	-5.554659767	0.678	-5.448015983	0.56568
			5	-3.606609856	0.28127	-3.666499133	0.28395	-2.655415191	0.23871	-3.367941794	0.26869	-3.425417186	0.23143
			6	-1.682054977	0.1222	-1.747114782	0.12284	-1.16039716	0.1178	-1.499369618	0.12101	-1.751225253	0.11563
			7	-0.310975259	0.090595	-0.377663862	0.090372	0.002958934	0.091492	-0.156521027	0.089827	-0.443136033	0.087587
			8	0.39731251	0.091646	0.333344831	0.090589	0.591262714	0.092118	0.503748117	0.089679	0.266026825	0.088512
			9	0.733756168	0.10375	0.673671511	0.10154	0.929101828	0.10928	0.881884863	0.10607	0.606187154	0.10057
			10	1.445928251	0.16054	1.379551064	0.15805	1.837277043	0.18902	1.817507271	0.18505	1.219304331	0.14258
			11	2.637801491	0.29687	2.577251741	0.29413	3.358174045	0.38108	3.350591092	0.36822	2.211219896	0.24693
			12	3.937610178	0.55731	3.898683071	0.55	5.030827964	0.79166	5.031589736	0.75873	3.311146845	0.42509
			13	5.28476401	1.1097	5.274517655	1.0935	6.731825441	1.4928	6.740823419	1.444	4.494244542	0.86156

Table 19. Comparison of survey selectivity parameters and ln-scale NMFS survey catchability for all model scenarios.

			17AM		17AMu		18A		18B		18C0		18C0a	
process	**name**	**label**	**estimate**	**std. error**	**estimate**	**std. error**	**estimate**	**std. error**	**estimate**	**std. error**	**estimate**	**std. error**	**estimate**	**std. error**
selectivity	**pS1[1]**	z50 for NMFS survey selectivity (males, pre-1982)	52.31	0.00	90.00	0.00	90.00	0.00	90.00	0.00	90.00	0.00	90.00	0.00
	pS1[2]	z50 for NMFS survey selectivity (males, 1982+)	34.92	0.00	40.72	5.16	38.32	5.27	41.06	6.44	51.19	5.97	40.79	5.95
	pS1[3]	z50 for NMFS survey selectivity (females, pre-1982)	56.29	0.00	80.24	3.34	80.43	3.37	82.39	3.30	99.04	4.34	84.02	4.00
	pS1[4]	z50 for NMFS survey selectivity (females, 1982+)	-29.13	0.00	-50.00	0.02	22.28	54089.00	-35.87	30.78	5.52	12.88	2.14	15.11
	pS2[1]	z95-z50 for NMFS survey selectivity (males, pre-1982)	23.50	0.00	87.72	6.88	87.50	6.81	87.79	6.54	80.21	5.13	81.45	5.45
	pS2[2]	z95-z50 for NMFS survey selectivity (males, 1982+)	75.07	0.00	100.00	0.00	100.00	0.00	100.00	0.00	100.00	0.00	98.41	15.86
	pS2[3]	z95-z50 for NMFS survey selectivity (females, pre-1982)	39.98	0.00	66.13	7.00	66.54	7.06	69.45	7.42	68.83	6.21	59.45	5.60
	pS2[4]	z95-z50 for NMFS survey selectivity (females, 1982+)	100.00	0.00	100.00	0.00	0.54	6211.00	100.00	0.00	100.00	0.00	100.00	0.00
surveys	**pQ[1]**	NMFS trawl survey: males, 1975-1981	-0.69	0.00	-0.69	0.00	-0.69	0.00	-0.69	0.00	-0.69	0.00	-0.69	0.00
	pQ[2]	NMFS trawl survey: males, 1982+	-0.44	0.00	-0.90	0.06	-0.95	0.07	-1.04	0.05	-1.04	0.05	-0.84	0.06
	pQ[3]	NMFS trawl survey: females, 1975-1981	-0.69	0.00	-0.69	0.00	-0.69	0.00	-0.69	0.00	-0.69	0.00	-0.69	0.00
	pQ[4]	NMFS trawl survey: females, 1982+	-0.91	0.00	-1.51	0.08	-1.57	0.08	-1.61	0.00	-1.61	0.00	-1.27	0.09

			18C1		18C1a		18C2a		18C3a		18D0	
process	**name**	**label**	**estimate**	**std. error**	**estimate**	**std. error**	**estimate**	**std. error**	**estimate**	**std. error**	**estimate**	**std. error**
selectivity	**pS1[1]**	z50 for NMFS survey selectivity (males, pre-1982)	90.00	0.00	90.00	0.00	56.57	2.84	54.64	2.19	90.00	0.00
	pS1[2]	z50 for NMFS survey selectivity (all crab, 1982+)							44.50	0.00		
		z50 for NMFS survey selectivity (males and immature females, 1982+)					44.50	0.00				
		z50 for NMFS survey selectivity (males, 1982+)	54.43	4.95	43.28	3.95					38.26	6.95
	pS1[3]	z50 for NMFS survey selectivity (females, pre-1982)	96.14	3.64	83.50	3.09	80.09	17.24	82.24	14.66	99.50	5.61
	pS1[4]	z50 for NMFS survey selectivity (females, 1982+)	14.93	8.70	23.02	10.86					2.11	14.06
		z50 for NMFS survey selectivity (mature females, 1982+)					65.50	0.00				
		z50 for NMFS survey selectivity (not applied, 1982+)							65.50	0.00		
	pS2[1]	z95-z50 for NMFS survey selectivity (males, pre-1982)	76.31	4.37	79.44	5.02	31.86	5.72	28.47	4.19	96.99	7.58
	pS2[2]	z95-z50 for NMFS survey selectivity (males, 1982+)	100.00	0.00	77.68	8.59					100.00	0.00
		z99 for NMFS survey selectivity (all crab, 1982+)							130.00	0.00		
		z99 for NMFS survey selectivity (males and immature females, 1982+)					130.00	0.00				
	pS2[3]	z95-z50 for NMFS survey selectivity (females, pre-1982)	68.73	6.23	58.32	5.33	60.43	14.10	55.92	10.91	77.52	8.45
	pS2[4]	z95-z50 for NMFS survey selectivity (females, 1982+)	100.00	0.00	100.00	0.00					100.00	0.00
		z99 for NMFS survey selectivity (mature females, 1982+)					105.00	0.00				
		z99 for NMFS survey selectivity (not applied, 1982+)							105.00	0.00		
surveys	**pQ[1]**	NMFS trawl survey: males, 1975-1981	-0.69	0.00	-0.69	0.00	-0.69	0.00	-0.69	0.00	-0.69	0.00
	pQ[2]	NMFS trawl survey: all, 1982+							-0.14	0.00		
		NMFS trawl survey: males and immature females, 1982+					-0.14	0.00				
		NMFS trawl survey: males, 1982+	-1.06	0.05	-0.92	0.06					-1.18	0.05
	pQ[3]	NMFS trawl survey: females, 1975-1981	-0.69	0.00	-0.69	0.00	-0.41	0.38	-0.17	0.36	-0.69	0.00
	pQ[4]	NMFS trawl survey: females, 1982+	-1.61	0.00	-1.25	0.09					-1.61	0.00
		NMFS trawl survey: mature females, 1982+					-0.60	0.00				

Table 20. Comparison of selectivity and retention parameters for the directed fishery (TCF) for all model scenarios.

		17AM		17AMu		18A		18B		18C0		18C0a	
label	index	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
ln(z50 devs) for TCF selectivity (males, 1991+)	1	0.03	0.00	0.06	0.02	0.07	0.02	0.07	0.02	0.08	0.02	0.09	0.03
	2	0.12	0.00	0.04	0.01	0.04	0.01	0.04	0.01	0.05	0.01	0.06	0.01
	3	0.10	0.00	0.12	0.01	0.13	0.01	0.12	0.01	0.12	0.01	0.14	0.02
	4	0.08	0.00	0.09	0.02	0.10	0.02	0.08	0.02	0.06	0.02	0.09	0.02
	5	-0.01	0.00	-0.03	0.03	-0.02	0.03	-0.02	0.03	-0.04	0.03	-0.05	0.03
	6	0.12	0.00	0.16	0.04	0.18	0.04	0.16	0.04	0.16	0.04	0.18	0.04
	7	-0.09	0.00	-0.10	0.02	-0.09	0.02	-0.08	0.02	-0.08	0.02	-0.09	0.02
	8	-0.09	0.00	-0.09	0.02	-0.08	0.02	-0.07	0.02	-0.07	0.02	-0.08	0.02
	9	-0.13	0.00	-0.15	0.02	-0.14	0.02	-0.13	0.01	-0.12	0.01	-0.14	0.02
	10	0.01	0.00	0.02	0.02	0.03	0.02	0.02	0.01	0.03	0.01	0.03	0.02
	11	0.18	0.00	0.20	0.02	0.22	0.02	0.19	0.02	0.19	0.02	0.22	0.02
	12	-0.05	0.00	-0.03	0.01	-0.02	0.01	-0.02	0.01	-0.02	0.01	-0.02	0.01
	13	-0.11	0.00	-0.11	0.01	-0.11	0.01	-0.10	0.01	-0.09	0.01	-0.11	0.01
	14	-0.15	0.00	-0.18	0.01	-0.18	0.01	-0.15	0.01	-0.15	0.01	-0.19	0.01
	15					-0.12	0.01	-0.11	0.01	-0.11	0.01	-0.13	0.01
z50 for TCF retention (2005-2009)	1	138.72	0.00	140.28	1.04	140.32	1.04	140.25	1.04	140.21	1.05	140.28	1.04
z50 for TCF retention (2013+)	1					125.06	0.13	125.33	0.13	125.29	0.14	125.07	0.13
z50 for TCF retention (2013-2015)	1	125.04	0.00	124.98	0.14								
z50 for TCF retention (pre-1991)	1	137.99	0.00	138.83	0.51	138.93	0.52	138.25	0.41	138.46	0.43	139.22	0.55
ln(z50) for TCF selectivity (males)	1	4.87	0.00	4.92	0.01	4.91	0.01	4.92	0.01	4.92	0.01	4.92	0.01
z50 for TCF selectivity (females)	1	96.58	0.00	96.80	2.75	96.63	2.71	97.13	2.76	96.02	2.51	95.58	2.46
slope for TCF retention (2005-2009)	1	0.89	0.00	0.58	0.16	0.58	0.15	0.58	0.16	0.59	0.16	0.58	0.16
slope for TCF retention (2013+)	1					0.57	0.02	0.53	0.01	0.53	0.01	0.57	0.02
slope for TCF retention (2013-2015)	1	0.58	0.00	0.57	0.02								
slope for TCF retention (pre-1991)	1	0.69	0.00	0.63	0.11	0.62	0.10	0.70	0.12	0.68	0.12	0.59	0.09
slope for TCF retention (1997+)	1	0.96	0.00	0.83	0.17	0.83	0.17	0.84	0.17	0.78	0.14	0.81	0.16
slope for TCF selectivity (males, pre-1997)	1	0.12	0.00	0.10	0.01	0.10	0.00	0.11	0.00	0.11	0.00	0.10	0.00
slope for TCF selectivity (males, 1997+)	1	0.16	0.00	0.13	0.01	0.13	0.01	0.14	0.00	0.14	0.00	0.13	0.01
slope for TCF selectivity (females)	1	0.19	0.00	0.19	0.02	0.18	0.02	0.18	0.02	0.19	0.02	0.19	0.02

		18C1		18C1a		18C2a		18C3a		18D0	
label	index	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
ln(z50 devs) for TCF selectivity (males, 1991+)	1	0.10	0.02	0.11	0.03	0.09	0.02	0.10	0.03	0.07	0.02
	2	0.05	0.01	0.06	0.01	0.05	0.01	0.05	0.01	0.04	0.01
	3	0.11	0.01	0.13	0.02	0.11	0.01	0.11	0.01	0.12	0.01
	4	0.05	0.02	0.07	0.02	0.09	0.02	0.10	0.02	0.08	0.02
	5	-0.05	0.03	-0.07	0.03	-0.01	0.03	-0.01	0.03	-0.02	0.02
	6	0.16	0.04	0.18	0.05	0.19	0.04	0.19	0.04	0.16	0.04
	7	-0.08	0.02	-0.09	0.02	-0.09	0.02	-0.09	0.02	-0.08	0.02
	8	-0.07	0.02	-0.08	0.02	-0.09	0.02	-0.09	0.02	-0.07	0.02
	9	-0.12	0.01	-0.13	0.02	-0.13	0.02	-0.14	0.02	-0.12	0.01
	10	0.03	0.01	0.04	0.02	0.03	0.02	0.03	0.02	0.03	0.01
	11	0.20	0.02	0.23	0.03	0.23	0.03	0.23	0.03	0.19	0.02
	12	-0.02	0.01	-0.02	0.01	-0.01	0.01	-0.01	0.01	-0.02	0.01
	13	-0.10	0.01	-0.12	0.01	-0.12	0.01	-0.12	0.01	-0.10	0.01
	14	-0.16	0.01	-0.19	0.01	-0.21	0.01	-0.22	0.02	-0.15	0.01
	15	-0.11	0.01	-0.12	0.01	-0.13	0.01	-0.13	0.01	-0.11	0.01
z50 for TCF retention (2005-2009)	1	140.24	1.04	140.31	1.04	140.07	1.05	140.05	1.05	140.31	1.04
z50 for TCF retention (2013+)	1	125.18	0.13	124.98	0.13	124.62	0.11	124.63	0.12	125.36	0.14
z50 for TCF retention (pre-1991)	1	138.06	0.37	138.86	0.50	136.94	0.38	136.80	0.39	138.52	0.44
ln(z50) for TCF selectivity (males)	1	4.92	0.01	4.92	0.01	4.91	0.01	4.91	0.01	4.92	0.01
z50 for TCF selectivity (females)	1	96.04	2.46	95.72	2.43	94.69	2.10	95.34	2.23	95.81	2.41
slope for TCF retention (2005-2009)	1	0.59	0.16	0.58	0.15	0.61	0.17	0.61	0.17	0.58	0.15
slope for TCF retention (2013+)	1	0.54	0.01	0.58	0.02	0.63	0.02	0.63	0.02	0.53	0.01
slope for TCF retention (pre-1991)	1	0.72	0.12	0.64	0.11	0.72	0.12	0.73	0.13	0.70	0.12
slope for TCF retention (1997+)	1	0.73	0.12	0.75	0.13	0.89	0.17	0.88	0.16	0.80	0.15
slope for TCF selectivity (males, pre-1997)	1	0.11	0.00	0.10	0.00	0.11	0.01	0.11	0.01	0.11	0.00
slope for TCF selectivity (males, 1997+)	1	0.13	0.00	0.12	0.00	0.13	0.01	0.13	0.01	0.14	0.00
slope for TCF selectivity (females)	1	0.19	0.02	0.19	0.02	0.20	0.02	0.20	0.02	0.19	0.02

Table 21. Comparison of selectivity parameter estimates for the snow crab fishery (SCF) for all model scenarios.

		17AM		17AMu		18A		18B		18C0		18C0a	
label	index	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
ascending z50 for SCF selectivity (males, pre-1997)	1	87.70	0.00	86.31	2.38	86.07	2.36	88.69	2.68	89.06	2.65	86.49	2.50
ascending z50 for SCF selectivity (males, 1997-2004)	1	95.70	0.00	98.99	3.89	98.97	3.98	101.82	4.22	102.52	4.31	98.77	3.90
ascending z50 for SCF selectivity (males, 2005+)	1	105.61	0.00	107.02	1.43	106.90	1.45	109.84	1.39	110.27	1.41	106.42	1.44
ascending z50 for SCF selectivity (females, pre-1997)	1	70.26	0.00	75.41	4.38	75.47	4.39	75.76	4.38	75.29	4.36	74.95	4.34
ascending z50 for SCF selectivity (females, 1997-2004)	1	76.29	0.00	78.91	4.59	78.95	4.60	79.24	4.62	78.96	4.61	78.77	4.55
ascending z50 for SCF selectivity (females, 2005+)	1	85.22	0.00	81.83	4.76	81.59	4.66	82.39	4.85	81.70	4.58	81.31	4.50
ascending slope for SCF selectivity (males, pre-1997)	1	0.37	0.00	0.32	0.14	0.32	0.14	0.24	0.10	0.24	0.09	0.31	0.14
ascending slope for SCF selectivity (males, 1997-2004)	1	0.21	0.00	0.19	0.05	0.19	0.05	0.17	0.04	0.17	0.04	0.19	0.05
ascending slope for SCF selectivity (males, 2005+)	1	0.17	0.00	0.17	0.01	0.17	0.01	0.17	0.01	0.17	0.01	0.18	0.01
slope for SCF selectivity (females, pre-1997)	1	0.22	0.00	0.20	0.09	0.19	0.09	0.19	0.08	0.20	0.09	0.20	0.09
slope for SCF selectivity (females, 1997-2004)	1	0.26	0.00	0.26	0.12	0.25	0.12	0.25	0.12	0.26	0.12	0.26	0.12
slope for SCF selectivity (females, 2005+)	1	0.16	0.00	0.19	0.06	0.19	0.06	0.18	0.06	0.19	0.06	0.19	0.06
ln(dz50-az50) for SCF selectivity (males, pre-1997)	1	3.96	0.00	4.15	0.07	4.15	0.07	4.12	0.08	4.13	0.07	4.06	0.14
ln(dz50-az50) for SCF selectivity (males, 1997-2004)	1	3.73	0.00	3.57	0.28	3.56	0.29	3.60	0.31	3.55	0.33	3.50	0.29
ln(dz50-az50) for SCF selectivity (males, 2005+)	1	3.45	0.00	3.41	0.09	3.41	0.09	3.35	0.10	3.34	0.10	3.41	0.09
descending slope for SCF selectivity (males, pre-1997)	1	0.50	0.00	0.36	0.41	0.37	0.41	0.44	0.50	0.50	0.33	0.10	0.00
descending slope for SCF selectivity (males, 1997-2004	1	0.13	0.00	0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.00
descending slope for SCF selectivity (males, 2005+)	1	0.18	0.00	0.16	0.02	0.16	0.02	0.16	0.03	0.16	0.03	0.16	0.02

		18C1		18C1a		18C2a		18C3a		18D0	
label	index	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
ascending z50 for SCF selectivity (males, pre-1997)	1	89.00	2.61	87.03	2.53	109.87	1.87	110.05	1.87	89.27	2.68
ascending z50 for SCF selectivity (males, 1997-2004)	1	101.85	4.09	98.09	3.62	98.79	3.57	98.46	3.49	101.82	4.29
ascending z50 for SCF selectivity (males, 2005+)	1	109.93	1.40	106.11	1.39	106.47	1.46	106.11	1.40	109.75	1.39
ascending z50 for SCF selectivity (females, pre-1997)	1	75.51	4.35	75.39	4.28	76.69	4.03	75.84	4.45	75.26	4.37
ascending z50 for SCF selectivity (females, 1997-2004)	1	78.92	4.62	78.83	4.56	79.13	4.52	79.37	4.49	78.84	4.57
ascending z50 for SCF selectivity (females, 2005+)	1	81.35	4.47	81.18	4.40	81.04	3.89	81.61	3.93	81.64	4.61
ascending slope for SCF selectivity (males, pre-1997)	1	0.24	0.09	0.29	0.12	0.10	0.00	0.10	0.00	0.23	0.09
ascending slope for SCF selectivity (males, 1997-2004)	1	0.17	0.04	0.20	0.05	0.20	0.05	0.20	0.05	0.17	0.04
ascending slope for SCF selectivity (males, 2005+)	1	0.17	0.01	0.18	0.01	0.18	0.01	0.18	0.01	0.17	0.01
slope for SCF selectivity (females, pre-1997)	1	0.20	0.09	0.20	0.09	0.20	0.08	0.19	0.08	0.20	0.09
slope for SCF selectivity (females, 1997-2004)	1	0.25	0.12	0.26	0.12	0.26	0.12	0.26	0.12	0.26	0.12
slope for SCF selectivity (females, 2005+)	1	0.19	0.06	0.19	0.06	0.20	0.06	0.20	0.06	0.19	0.06
ln(dz50-az50) for SCF selectivity (males, pre-1997)	1	4.13	0.08	4.03	0.14	2.00	0.00	2.00	0.00	4.11	0.08
ln(dz50-az50) for SCF selectivity (males, 1997-2004)	1	3.57	0.30	3.56	0.26	3.52	0.27	3.52	0.26	3.58	0.32
ln(dz50-az50) for SCF selectivity (males, 2005+)	1	3.34	0.10	3.43	0.09	3.35	0.10	3.35	0.10	3.35	0.10
descending slope for SCF selectivity (males, pre-1997)	1	0.38	0.53	0.10	0.00	0.10	0.00	0.10	0.00	0.43	0.51
descending slope for SCF selectivity (males, 1997-2004	1	0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.00	0.10	0.00
descending slope for SCF selectivity (males, 2005+)	1	0.16	0.02	0.16	0.02	0.15	0.02	0.15	0.02	0.16	0.03

Table 22. Comparison of selectivity parameter estimates for the BBRKC fishery (RKF) for all model scenarios.

		17AM		17AMu		18A		18B		18C0		18C0a	
label	index	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
z95 for RKF selectivity (males, pre-1997)	1	158.21	0.00	161.91	5.81	161.36	5.78	162.69	5.36	162.77	5.17	161.74	5.77
z95 for RKF selectivity (males, 1997-2004)	1	180.00	0.00	180.00	0.00	180.00	0.00	180.00	0.00	180.00	0.00	180.00	0.00
z95 for RKF selectivity (males, 2005+)	1	180.00	0.00	180.00	0.00	180.00	0.00	180.00	0.00	180.00	0.00	180.00	0.00
z95 for RKF selectivity (females, pre-1997)	1	121.57	0.00	121.67	32.41	121.96	33.24	123.30	36.93	120.90	31.06	120.08	30.10
z95 for RKF selectivity (females, 1997-2004)	1	121.22	0.00	125.40	65.48	126.49	70.41	126.80	72.07	125.15	66.09	123.45	60.17
z95 for RKF selectivity (females, 2005+)	1	140.00	0.00	140.00	0.03	140.00	0.03	140.00	0.03	140.00	0.04	140.00	0.04
ln(z95-z50) for RKF selectivity (males, pre-1997)	1	3.08	0.00	3.08	0.14	3.07	0.14	3.04	0.13	3.03	0.13	3.08	0.14
ln(z95-z50) for RKF selectivity (males, 1997-2004)	1	3.55	0.00	3.44	0.08	3.44	0.08	3.40	0.08	3.41	0.08	3.47	0.09
ln(z95-z50) for RKF selectivity (males, 2005+)	1	3.49	0.00	3.35	0.04	3.38	0.04	3.34	0.04	3.33	0.04	3.38	0.04
ln(z95-z50) for RKF selectivity (males, pre-1997)	1	2.79	0.00	2.78	0.59	2.78	0.60	2.79	0.60	2.77	0.60	2.77	0.61
ln(z95-z50) for RKF selectivity (males, 1997-2004)	1	2.85	0.00	2.89	0.88	2.90	0.88	2.89	0.87	2.89	0.90	2.88	0.90
ln(z95-z50) for RKF selectivity (males, 2005+)	1	2.99	0.00	2.96	0.22	2.96	0.21	2.94	0.21	2.97	0.21	2.98	0.21

		18C1		18C1a		18C2a		18C3a		18D0	
label	index	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
z95 for RKF selectivity (males, pre-1997)	1	163.00	5.30	162.02	5.77	162.15	6.01	161.72	6.13	162.59	5.45
z95 for RKF selectivity (males, 1997-2004)	1	180.00	0.00	180.00	0.00	180.00	0.00	180.00	0.00	180.00	0.00
z95 for RKF selectivity (males, 2005+)	1	180.00	0.00	180.00	0.00	180.00	0.00	180.00	0.00	180.00	0.00
z95 for RKF selectivity (females, pre-1997)	1	120.98	31.72	120.54	31.37	116.49	24.69	140.00	0.03	118.99	26.41
z95 for RKF selectivity (females, 1997-2004)	1	124.87	65.66	123.12	59.57	118.50	48.59	120.42	27.23	123.53	59.43
z95 for RKF selectivity (females, 2005+)	1	140.00	0.03	140.00	0.04	140.00	0.05	137.88	28.85	140.00	0.04
ln(z95-z50) for RKF selectivity (males, pre-1997)	1	3.05	0.13	3.09	0.14	3.08	0.15	3.08	0.15	3.05	0.13
ln(z95-z50) for RKF selectivity (males, 1997-2004)	1	3.42	0.08	3.48	0.09	3.48	0.09	3.49	0.09	3.41	0.08
ln(z95-z50) for RKF selectivity (males, 2005+)	1	3.34	0.04	3.38	0.04	3.41	0.04	3.42	0.04	3.35	0.04
ln(z95-z50) for RKF selectivity (males, pre-1997)	1	2.77	0.60	2.77	0.61	2.69	0.60	2.96	0.19	2.74	0.57
ln(z95-z50) for RKF selectivity (males, 1997-2004)	1	2.89	0.91	2.87	0.91	2.81	0.94	2.80	0.64	2.87	0.90
ln(z95-z50) for RKF selectivity (males, 2005+)	1	2.97	0.21	2.98	0.21	3.00	0.21	2.97	0.29	2.98	0.21

Table 23. Comparison of selectivity parameter estimates for the groundfish fisheries (GTF) for all model scenarios.

		17AM		17AMu		18A		18B		18C0		18C0a	
label	index	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
z50 for GF.AllGear selectivity (males, pre-1987)	1	55.02	0.00	57.32	2.25	57.16	2.23	60.26	3.35	68.19	4.27	59.82	2.14
z50 for GF.AllGear selectivity (males, 1987-1996)	1	59.07	0.00	64.85	7.59	64.65	7.76	82.01	11.69	86.90	9.70	61.46	5.48
z50 for GF.AllGear selectivity (males, 1997+)	1	80.84	0.00	90.45	2.63	90.09	2.58	108.53	3.41	110.06	3.20	87.45	2.31
z50 for GF.AllGear selectivity (males, pre-1987)	1	41.20	0.00	40.82	1.70	40.59	1.71	40.39	1.68	42.94	1.75	44.63	1.95
z50 for GF.AllGear selectivity (males, 1987-1996)	1	40.00	0.00	40.00	0.00	40.00	0.00	40.00	0.00	40.00	0.00	40.00	0.00
z50 for GF.AllGear selectivity (males, 1997+)	1	76.11	0.00	81.13	2.87	81.40	2.90	89.73	3.38	90.19	3.62	81.74	2.75
slope for GF.AllGear selectivity (males, pre-1987)	1	0.10	0.00	0.09	0.01	0.09	0.01	0.08	0.01	0.06	0.01	0.09	0.01
slope for GF.AllGear selectivity (males, 1987-1996)	1	0.06	0.00	0.04	0.01	0.04	0.01	0.03	0.00	0.03	0.00	0.05	0.01
slope for GF.AllGear selectivity (males, 1997+)	1	0.07	0.00	0.06	0.00	0.06	0.00	0.05	0.00	0.05	0.00	0.07	0.00
slope for GF.AllGear selectivity (females, pre-1987)	1	0.14	0.00	0.13	0.02	0.13	0.02	0.14	0.02	0.13	0.02	0.11	0.02

		18C1		18C1a		18C2a		18C3a		18D0	
label	index	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error	estimate	std. error
z50 for GF.AllGear selectivity (males, pre-1987)	1	65.16	3.86	59.55	2.19	58.09	1.98	57.33	1.87	54.44	2.69
z50 for GF.AllGear selectivity (males, 1987-1996)	1	84.46	7.26	66.69	4.79	69.43	5.03	65.08	5.20	65.34	8.09
z50 for GF.AllGear selectivity (males, 1997+)	1	107.66	3.14	86.90	2.28	86.05	2.04	84.16	1.97	108.00	3.46
z50 for GF.AllGear selectivity (males, pre-1987)	1	41.65	1.62	43.65	1.81	42.69	1.59	47.74	1.89	40.74	1.69
z50 for GF.AllGear selectivity (males, 1987-1996)	1	42.11	1.99	41.62	1.86	41.80	1.94	46.07	2.67	40.00	0.00
z50 for GF.AllGear selectivity (males, 1997+)	1	88.83	3.51	80.02	2.63	78.82	2.48	79.77	2.31	95.26	3.57
slope for GF.AllGear selectivity (males, pre-1987)	1	0.07	0.01	0.09	0.01	0.09	0.01	0.09	0.01	0.09	0.01
slope for GF.AllGear selectivity (males, 1987-1996)	1	0.04	0.00	0.05	0.01	0.05	0.01	0.05	0.01	0.03	0.01
slope for GF.AllGear selectivity (males, 1997+)	1	0.05	0.00	0.07	0.00	0.07	0.00	0.07	0.00	0.05	0.00
slope for GF.AllGear selectivity (females, pre-1987)	1	0.13	0.02	0.12	0.02	0.13	0.02	0.11	0.01	0.13	0.02

Table 24. 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	fit.type	x	17AM	17AMu	18A	18B	18C0	18C0a	18C1	18C1a	18C2a	18C3a	18D0
GTF	total catch	abundance	BY_TOTAL	all sexes	0.00	1.23	1.19	1.34	1.33	1.18	1.28	1.17	1.27	1.31	1.41
		biomass	BY_TOTAL	all sexes	0.06	0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.09	0.10	0.06
		n.at.z	BY_XE	female	411.55	375.73	374.07	370.62	392.96	401.93	386.04	394.18	390.27	378.12	364.70
				male	402.22	368.74	371.14	318.81	313.14	342.07	313.58	352.02	310.12	313.03	332.45
RKF	total catch	abundance	BY_X	female	16.84	29.73	26.16	24.43	27.50	31.38	30.15	33.22	25.63	243.70	25.37
				male	8.34	19.22	19.04	18.12	18.30	19.27	18.48	19.34	19.74	19.86	18.31
		biomass	BY_X	female	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01
				male	0.18	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.19	0.19	0.17
		n.at.z	BY_X	female	50.11	51.08	50.27	49.28	50.43	51.18	49.65	49.89	51.16	42.02	53.59
				male	62.14	71.49	67.04	67.88	67.46	64.88	68.12	66.73	65.41	64.38	69.35
SCF	total catch	abundance	BY_X	female	11.76	12.38	12.21	12.73	12.31	13.38	11.70	12.71	11.12	14.30	12.20
				male	5.43	2.75	2.71	2.69	2.68	2.70	2.70	2.71	3.01	2.95	2.67
		biomass	BY_X	female	0.32	0.09	0.09	0.09	0.09	0.08	0.09	0.08	0.05	0.07	0.09
				male	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.07
		n.at.z	BY_X	female	63.54	68.98	69.38	71.22	69.80	68.30	70.41	69.35	72.79	74.39	69.30
				male	281.02	327.22	346.62	351.28	341.70	333.22	311.33	309.99	270.11	280.42	361.13
TCF	retained catch	abundance	BY_X	female	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				male	3.27	3.82	3.99	3.98	4.04	4.06	4.06	4.03	4.46	4.50	3.94
		biomass	BY_X	female	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
				male	0.21	0.18	0.19	0.19	0.17	0.19	0.16	0.17	0.24	0.26	0.18
		n.at.z	BY_X	male	505.37	520.42	527.37	403.22	407.14	537.08	412.10	548.23	463.03	460.23	416.42
	total catch	abundance	BY_X	female		68.23	70.98	56.84	61.45	74.72	66.15	80.57	58.00	59.75	66.17
				male		1.22	1.16	1.09	1.11	1.20	1.12	1.20	1.10	1.09	1.06
		biomass	BY_X	female	0.56	0.29	0.28	0.28	0.30	0.30	0.31	0.31	0.28	0.28	0.29
				male	0.20	0.19	0.19	0.18	0.18	0.20	0.18	0.19	0.20	0.20	0.18
		n.at.z	BY_X	female	207.47	195.18	184.36	185.71	192.13	189.51	199.10	196.16	205.96	201.38	187.44
				male	455.17	348.77	346.02	413.43	410.06	337.85	405.06	334.33	317.20	309.97	406.67

Table 25. Root mean square errors (RMSE) for non-fishery-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.

category	fleet	catch.type	data.type	fit.type	x	17AM	17AMu	18A	18B	18C0	18C0a	18C1	18C1a	18C2a	18C3a	18D0
growth data	(blank)	(blank)	EBS	(blank)	female	0.30	0.34	0.34	0.36	0.39	0.36	0.42	0.39	0.46	0.41	0.35
					male	0.54	0.50	0.48	0.59	0.59	0.49	0.67	0.56	0.66	0.66	0.60
maturity data	(blank)	(blank)	MATURITY_OGIVES	(blank)	male	820.77	8,948.99	7,054.98	1.80	1.82	6.21	1.84	8.62	5.66	5.59	1.74
surveys data	NMFS (all by XM)	index catch	abundance	BY_XM	female	2.94	2.94	2.93	2.99	2.74	2.76	2.46	2.48	2.44	2.67	2.79
					male	3.07	3.05	3.05	3.13	3.05	3.15	2.65	2.78	2.55	2.68	3.32
			biomass	BY_X_MATONLY	female	2.28	2.37	2.37	2.43	2.28	2.25	2.30	2.29	2.03	2.37	2.42
					male	2.18	2.40	2.42	2.47	2.56	2.48	2.40	2.41	2.11	2.06	2.88
			n.at.z	BY_XME	female	444.33	433.14	425.44	400.73	400.38	403.24	317.22	335.14	414.03	226.70	370.93
					male	467.32	452.57	456.14	520.94	513.95	393.65	495.45	388.14	323.05	324.67	518.19
	NMFS (females by XM)	index catch	abundance	BY_X	female			3.02	3.01	2.72	2.78	2.36	2.40	2.47	2.49	2.75
					male			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			biomass	BY_X	female			2.48	2.50	2.30	2.31	2.22	2.23	2.05	2.26	2.40
					male			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			n.at.z	BY_X_ME	female			172.54	170.56	220.98	229.80	148.23	160.05	191.31	119.83	191.30
	NMFS (females by XMS)	index catch	abundance	BY_X	female			3.02	3.01	2.72	2.78	2.36	2.40	2.47	2.49	2.75
					male			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			biomass	BY_X	female			2.48	2.50	2.30	2.31	2.22	2.23	2.05	2.26	2.40
					male			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
			n.at.z	BY_XM_SE	female			174.26	177.28	208.97	211.05	186.43	198.27	203.21	145.63	177.33
	NMFS (males by X)	index catch	abundance	BY_X	female			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
					male			3.48	3.48	3.38	3.39	2.76	2.82	2.77	2.86	3.51
			biomass	BY_X	female			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
					male			2.57	2.58	2.67	2.62	2.38	2.42	2.25	2.18	2.85
			n.at.z	BY_X	male			203.11	189.35	191.12	201.79	189.09	193.18	159.00	154.78	191.06
	NMFS (males by XS)	index catch	abundance	BY_X	female			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
					male			3.48	3.48	3.38	3.39	2.76	2.82	2.77	2.86	3.51
			biomass	BY_X	female			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
					male			2.57	2.58	2.67	2.62	2.38	2.42	2.25	2.18	2.85
			n.at.z	BY_X_SE	male			254.38	284.67	328.50	234.20	326.16	248.80	225.49	210.51	251.80

Table 26. Effective sample sizes used for NMFS EBS trawl survey size composition data for the 2017 assessment model (17AM) and the author's preferred model (18C2a). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	17AM				18C2a			
	male		female		male		female	
year	input	effective	input	effective	input	effective	input	effective
1975	200	486.5	200	215.2	200	406.6	200	248.0
1976	201	531.8	201	309.2	201	580.7	201	254.3
1977	202	625.4	202	257.4	202	493.4	202	245.4
1978	203	548.6	203	348.6	203	516.5	203	348.6
1979	204	737.0	204	393.7	204	608.9	204	461.1
1980	205	385.9	205	1045.9	205	345.9	205	554.8
1981	206	947.9	206	190.9	206	693.5	206	251.0
1982	207	400.5	207	122.0	207	257.1	207	141.5
1983	208	638.7	208	415.6	208	240.2	208	190.8
1984	209	353.5	209	227.0	209	361.1	209	266.9
1985	210	170.8	210	160.4	210	177.4	210	145.6
1986	211	350.9	211	336.0	211	326.8	211	376.9
1987	212	614.8	212	187.7	212	372.7	212	391.6
1988	213	766.8	213	353.9	213	451.3	213	218.2
1989	214	2,211.2	214	275.2	214	634.7	214	393.3
1990	215	2,181.6	215	642.5	215	1242.9	215	372.3
1991	216	2,335.1	216	978.5	216	1209.4	216	478.8
1992	217	1,588.9	217	1108.2	217	909.7	217	2662.7
1993	218	1,248.3	218	693.8	218	1104.0	218	652.9
1994	219	1,306.2	219	320.7	219	672.0	219	625.7
1995	220	1,098.2	220	668.1	220	942.7	220	586.3
1996	221	1,214.6	221	786.0	221	1177.4	221	642.9
1997	222	1,355.8	222	534.6	222	507.2	222	503.4
1998	223	1,483.2	223	573.7	223	559.4	223	368.0
1999	224	576.7	224	563.7	224	398.4	224	491.1
2000	225	921.7	225	639.8	225	718.2	225	633.9
2001	226	1,532.9	226	651.4	226	721.8	226	479.6
2002	227	1,033.1	227	906.4	227	623.1	227	1117.5
2003	228	1,003.3	228	516.0	228	777.6	228	593.9
2004	229	467.3	229	500.9	229	338.2	229	479.1
2005	230	1,526.7	230	1691.6	230	978.1	230	5153.1
2006	231	745.9	231	762.2	231	897.6	231	1734.4
2007	232	496.4	232	802.7	232	461.3	232	682.3
2008	233	871.8	233	1450.9	233	1395.1	233	1376.9
2009	234	370.5	234	1082.1	234	519.5	234	2468.6
2010	235	516.2	235	11880.8	235	768.8	235	3865.0
2011	236	1,319.7	236	522.7	236	782.3	236	597.2
2012	237	755.3	237	731.4	237	701.6	237	750.0
2013	238	1,225.7	238	1442.4	238	578.9	238	1314.8
2014	239	806.5	239	447.3	239	483.2	239	583.2
2015	240	1,555.6	240	1005.3	240	825.8	240	631.2
2016	241	619.4	241	591.1	241	464.2	241	432.4
2017	242	262.6	242	878.4	242	293.2	242	621.1
2018	243	0.0	243	0.0	243	909.8	243	1048.5

Table 27. Effective sample sizes used for retained catch size composition data from the directed fishery for the 2017 assessment model (17AM) and the author's preferred model (18C2a). Effective sample sizes were estimated using the McAllister-Ianelli approach.

year	17AM		18C2a	
	input	effective	input	effective
1980	97.8	25.9	97.8	9.8
1981	83.1	1700.9	83.1	70.7
1982	99.3	1473.4	99.3	101.5
1983	12.3	49.0	12.3	279.6
1984	18.7	477.4	18.7	114.8
1988	91.0	134.6	91.0	25.1
1989	30.3	1665.3	30.3	40.7
1990	200.0	267.2	200.0	16.0
1991	200.0	155.0	200.0	38.6
1992	200.0	96.0	200.0	52.9
1993	200.0	138.3	200.0	81.5
1994	200.0	149.2	200.0	74.8
1995	11.2	187.1	11.2	79.2
1996	32.6	185.4	32.6	222.3
2005	5.2	14.2	5.2	23.8
2006	21.6	303.7	21.6	78.1
2007	51.0	1928.6	51.0	132.1
2008	25.6	967.3	25.6	242.0
2009	17.8	127.9	17.8	217.5
2013	35.0	704.9	4760.0	467.3
2014	103.3	209.1	14055.0	4671.6
2015	200.0	157.7	24420.0	3097.7
2017	0.0	0.0	3470.0	511.9

Table 28. Effective sample sizes used for total catch size composition data from the directed fishery for the 2017 assessment model (17AM) and the author's preferred model (18C2a). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	17AM				18C2a			
	male		female		male		female	
year	input	effective	input	effective	input	effective	input	effective
1991	200.00	1323.53	41.19	512.91	200.00	427.09	41.19	214.98
1992	200.00	120.13	64.33	459.45	200.00	205.99	64.33	943.22
1993	200.00	266.87	76.94	346.24	200.00	281.21	76.94	461.54
1994	42.56	593.18	15.67	58.50	42.56	158.96	15.67	66.16
1995	41.07	297.71	22.92	90.45	41.07	526.66	22.92	100.21
1996	5.00	30.88	2.50	260.92	2.59	24.38	1.23	172.90
2005	144.87	97.45	8.13	39.41	144.87	292.09	8.13	40.23
2006	178.02	287.59	32.57	422.51	178.02	645.69	32.57	369.75
2007	200.00	374.32	24.38	317.54	200.00	390.77	24.38	302.29
2008	200.00	1149.76	4.75	45.79	200.00	467.14	4.75	45.83
2009	127.04	164.63	1.08	24.43	127.04	510.32	1.08	24.13
2013	127.03	1339.32	5.22	64.75	127.06	191.84	5.22	47.40
2014	200.00	199.41	8.75	188.58	200.00	222.97	8.75	168.28
2015	200.00	127.59	11.91	73.04	200.00	174.26	11.92	79.02
2017	0.00	0.00	0.00	0.00	138.04	238.55	12.65	53.46

Table 29. Effective sample sizes used for bycatch size composition data from the snow crab fishery for the 2017 assessment model (17AM) and the author's preferred model (18C2a). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	17AM				18C2a			
	male		female		male		female	
year	input	effective	input	effective	input	effective	input	effective
1992	46.15	191.77	6.31	18.28	46.15	22.93	6.31	35.71
1993	51.21	118.05	11.33	30.66	51.21	43.21	11.33	34.70
1994	21.91	38.14	11.19	40.69	21.91	71.15	11.19	45.74
1995	13.95	87.31	3.15	41.80	13.95	23.77	3.15	28.10
1996	23.99	281.38	4.86	46.14	23.99	85.80	4.86	48.69
1997	29.17	446.96	4.83	111.24	29.17	204.61	4.83	218.63
1998	14.04	1013.79	2.38	21.37	14.04	470.54	2.38	133.39
1999	7.17	131.62	0.60	30.21	7.17	964.43	0.60	26.27
2000	9.09	273.09	0.54	30.53	9.09	164.16	0.54	41.20
2001	22.88	558.67	1.18	121.11	22.88	467.82	1.18	58.96
2002	7.22	59.52	0.87	45.45	7.22	600.53	0.87	190.70
2003	5.06	109.24	1.12	44.80	5.06	48.09	1.12	79.61
2004	6.23	23.03	5.20	30.57	6.23	100.23	5.20	68.31
2005	71.95	122.62	2.70	158.05	71.95	89.00	2.70	65.87
2006	76.36	77.06	9.23	51.76	76.36	77.80	9.23	31.44
2007	101.38	380.47	5.35	45.61	101.38	314.96	5.35	30.07
2008	62.13	95.87	5.31	14.70	62.13	89.39	5.31	18.57
2009	81.25	456.01	3.48	20.61	81.25	313.78	3.48	32.45
2010	88.72	370.05	1.84	74.01	88.72	372.14	1.84	97.69
2011	69.46	231.47	1.39	61.71	69.46	336.07	1.39	59.18
2012	53.91	205.80	1.40	46.53	80.86	176.76	1.98	86.06
2013	95.03	248.26	2.62	210.49	95.05	170.51	2.62	119.85
2014	182.80	537.54	5.91	65.09	182.81	477.46	5.91	147.47
2015	146.46	519.16	1.70	111.32	145.78	505.37	1.69	62.05
2016	142.83	448.51	1.71	115.68	120.28	511.10	1.93	28.79
2017	0.00	0.00	0.00	0.00	41.14	321.14	0.80	102.96

Table 30. Effective sample sizes used for bycatch size composition data from the BBRKC fishery for the 2017 assessment model (17AM) and the author's preferred model (18C2a). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	17AM				18C2a			
	male		female		male		female	
year	input	effective	input	effective	input	effective	input	effective
1992	15.11	34.62	0.77	83.03	15.11	17.19	0.77	79.43
1993	54.08	34.67	8.79	279.54	54.08	21.54	8.79	265.07
1996	0.84	13.20	0.04	3.42	0.84	9.90	0.04	3.40
1997	7.57	20.27	0.30	24.25	7.57	13.72	0.30	25.76
1998	3.36	58.36	0.15	20.90	3.36	32.90	0.15	20.99
1999	1.52	50.29	0.10	17.39	1.52	46.02	0.10	17.83
2000	6.21	130.21	0.32	40.38	6.21	142.75	0.32	42.06
2001	3.35	112.01	0.29	50.48	3.35	60.08	0.29	55.91
2002	5.51	85.55	0.37	36.40	5.51	56.76	0.37	34.28
2003	4.08	57.06	0.34	53.49	4.08	54.71	0.34	52.61
2004	3.58	31.09	0.32	20.59	3.58	25.79	0.32	19.74
2005	7.22	37.83	0.51	12.73	7.22	31.99	0.51	12.01
2006	5.86	20.34	0.56	23.89	5.86	16.72	0.56	27.09
2007	10.28	73.02	0.67	102.12	10.28	64.28	0.67	78.00
2008	27.90	76.04	0.89	92.39	27.90	34.28	0.89	86.18
2009	24.95	20.48	0.53	108.02	24.95	14.64	0.53	154.77
2010	4.37	46.30	0.22	35.97	4.37	29.41	0.22	47.60
2011	2.53	59.79	0.03	5.97	2.53	42.02	0.03	5.87
2012	4.54	55.23	0.35	6.85	4.54	40.29	0.35	7.56
2013	15.50	94.38	0.44	9.65	15.50	139.71	0.44	10.57
2014	22.85	156.60	0.24	19.20	22.85	400.53	0.24	21.47
2015	16.07	139.96	1.34	86.70	15.98	196.65	1.37	111.66
2016	22.50	21.96	1.81	19.16	23.66	24.23	1.81	18.09
2017	0.00	0.00	0.00	0.00	27.79	53.65	0.63	29.82

Table 31. Effective sample sizes used for bycatch size composition data from the groundfish fisheries for the 2017 assessment model (17AM) and the author's preferred model (18C2a). Effective sample sizes were estimated using the McAllister-Ianelli approach.

	17AM				18C2a			
	male		female		male		female	
year	input	effective	input	effective	input	effective	input	effective
1973	39.92	371.37	39.92	232.67	39.92	308.38	39.92	201.35
1974	30.07	709.87	30.07	212.46	30.07	98.82	30.07	180.80
1975	15.36	333.21	15.36	199.27	15.36	129.55	15.36	167.93
1976	100.18	178.33	100.18	108.29	100.18	126.50	100.18	150.62
1977	140.14	233.89	140.14	325.53	140.14	214.78	140.14	337.34
1978	237.06	248.60	237.06	192.12	237.06	247.21	237.06	205.13
1979	223.45	584.09	223.45	875.10	223.45	622.40	223.45	775.29
1980	137.58	1080.51	137.58	424.17	137.58	656.54	137.58	783.23
1981	74.68	1035.30	74.68	56.30	74.68	451.18	74.68	62.71
1982	157.58	528.13	157.58	62.30	157.58	292.38	157.58	71.41
1983	195.96	347.14	195.96	135.20	195.96	445.54	195.96	168.16
1984	301.19	351.98	301.19	236.79	301.19	466.57	301.19	349.50
1985	263.48	169.12	263.48	280.17	263.48	183.55	263.48	290.60
1986	165.23	281.86	165.23	193.44	165.23	230.69	165.23	128.18
1987	289.26	266.60	289.26	672.50	289.26	198.16	289.26	470.49
1988	130.15	402.17	130.15	225.05	130.15	314.26	130.15	168.47
1989	400.00	810.58	400.00	606.73	400.00	457.50	400.00	852.72
1990	255.40	1013.39	255.40	312.90	255.40	649.57	255.40	306.58
1991	75.92	338.22	75.92	188.22	75.66	183.32	75.66	252.15
1992	30.53	179.85	30.53	63.30	31.62	114.87	31.62	62.18
1993	11.63	77.64	11.63	92.64	11.57	68.40	11.57	84.21
1994	40.22	241.29	40.22	426.54	40.03	210.69	40.03	598.33
1995	48.45	59.19	48.45	60.04	48.30	42.81	48.30	60.34
1996	85.93	181.81	85.93	584.16	86.02	126.48	86.02	713.26
1997	101.10	50.68	101.10	187.63	101.77	42.16	101.77	227.36
1998	119.95	124.55	119.95	325.76	121.58	96.89	121.58	322.34
1999	111.46	489.96	111.46	1176.86	114.45	313.16	114.45	990.75
2000	116.16	563.66	116.16	892.08	117.44	368.48	117.44	885.54
2001	135.38	756.03	135.38	1123.22	138.67	706.42	138.67	1245.99
2002	135.16	423.50	135.16	896.60	137.04	382.40	137.04	861.02
2003	89.37	197.86	89.37	299.08	90.42	192.77	90.42	286.79
2004	134.71	112.19	134.71	30.76	134.50	105.60	134.50	29.86
2005	157.52	1404.50	157.52	1906.46	157.94	1427.80	157.94	1306.29
2006	139.32	169.75	139.32	136.31	139.25	156.21	139.25	121.27
2007	146.56	159.69	146.56	83.73	146.72	176.60	146.72	109.52
2008	223.55	169.39	223.55	161.29	223.43	258.86	223.43	169.91
2009	160.43	292.38	160.43	514.35	160.04	224.74	160.04	463.05
2010	128.33	556.08	128.33	1997.06	127.90	436.35	127.90	1323.67
2011	150.25	86.39	150.25	69.21	149.63	71.11	149.63	62.53
2012	118.59	415.28	118.59	104.28	118.09	417.08	118.09	96.24
2013	244.77	354.67	244.77	427.18	244.56	277.86	244.56	346.96
2014	231.10	919.02	231.10	755.99	230.95	847.59	230.95	858.89
2015	242.33	204.96	242.33	201.14	242.14	276.33	242.14	194.37
2016	162.13	222.90	162.13	53.38	166.16	248.12	166.16	60.94
2017	0.00	0.00	0.00	0.00	98.61	88.47	98.61	158.03

Table 32. Comparison of fits to mature survey biomass by sex (in 1000's t) from the 2017 assessment model (17AM) and the author's preferred model (18C2a).

	17AM				18C2a			
	male		female		male		female	
year	observed	predicted	observed	predicted	observed	predicted	observed	predicted
1975	246.0	151.3	31.4	47.6	246.0	88.5	31.4	35.7
1976	126.2	135.6	31.2	42.2	126.2	103.4	31.2	35.5
1977	111.3	108.3	38.6	36.8	111.3	93.8	38.6	32.5
1978	77.9	79.5	25.8	34.1	77.9	72.0	25.8	30.8
1979	32.6	71.3	19.3	35.8	32.6	68.4	19.3	32.8
1980	86.8	74.2	63.8	38.8	86.8	79.7	63.8	36.2
1981	50.3	65.6	42.6	35.7	50.3	60.6	42.6	29.4
1982	51.7	71.8	64.1	26.1	51.7	89.1	64.1	27.3
1983	29.9	53.0	20.4	19.9	29.9	60.2	20.4	17.7
1984	25.8	36.0	14.9	15.1	25.8	32.2	14.9	11.3
1985	11.9	24.9	5.6	12.1	11.9	17.3	5.6	7.8
1986	13.3	30.2	3.4	12.3	13.3	22.8	3.4	8.4
1987	24.6	40.8	5.1	14.0	24.6	31.9	5.1	10.3
1988	61.0	55.2	25.4	16.2	61.0	45.3	25.4	13.2
1989	93.3	68.3	19.4	18.4	93.3	61.6	19.4	17.1
1990	97.8	73.2	37.7	19.8	97.8	75.2	37.7	20.8
1991	112.6	67.4	44.8	19.7	112.6	78.7	44.8	22.1
1992	105.5	60.5	26.2	17.8	105.5	80.0	26.2	19.9
1993	62.0	46.5	11.6	14.6	62.0	63.3	11.6	16.1
1994	43.8	34.9	9.8	11.3	43.8	48.2	9.8	12.2
1995	32.7	25.7	12.4	8.6	32.7	34.4	12.4	9.1
1996	27.5	19.1	9.6	6.7	27.5	24.3	9.6	6.9
1997	11.3	15.8	3.4	5.3	11.3	18.6	3.4	5.4
1998	10.9	13.9	2.3	4.5	10.9	15.6	2.3	4.6
1999	13.0	13.3	3.8	4.1	13.0	14.9	3.8	4.3
2000	16.9	14.3	4.1	4.2	16.9	15.9	4.1	4.4
2001	18.7	17.2	4.6	4.6	18.7	18.8	4.6	4.8
2002	19.0	20.8	4.5	5.2	19.0	22.1	4.5	5.5
2003	24.6	25.1	8.4	6.1	24.6	26.7	8.4	6.6
2004	27.0	31.2	4.7	7.4	27.0	33.8	4.7	8.0
2005	45.2	38.6	11.6	8.7	45.2	42.4	11.6	9.5
2006	67.9	45.7	14.9	9.9	67.9	50.4	14.9	11.0
2007	69.5	51.3	13.4	11.1	69.5	57.4	13.4	12.7
2008	65.1	57.4	11.7	11.3	65.1	66.9	11.7	12.9
2009	38.2	57.6	8.5	10.1	38.2	67.9	8.5	11.4
2010	39.1	51.0	5.5	8.6	39.1	58.7	5.5	9.5
2011	43.3	44.4	5.4	8.0	43.3	48.8	5.4	8.6
2012	42.2	42.9	12.4	9.5	42.2	43.7	12.4	9.9
2013	67.0	53.5	17.8	12.4	67.0	52.2	17.8	13.3
2014	82.4	68.9	14.9	13.9	82.4	71.2	14.9	15.2
2015	62.9	70.1	11.2	12.9	62.9	76.5	11.2	14.1
2016	61.6	58.4	7.6	10.9	61.6	62.6	7.6	11.7
2017	50.2	50.4	7.1	9.1	50.3	52.5	7.1	9.6
2018	0.0	0.0	0.0	0.0	39.7	43.0	5.0	8.0

Table 33. Comparison of estimates of mature biomass-at-mating by sex (in 1000's t) from the 2017 assessment model (17AM) and the author's preferred model (18C2a).

	17AM		18C2a	
year	male	female	male	female
1948	0	0	0	0
1949	0	0	0	0
1950	0.009753246	0.02774891	0.00874904	0.063202653
1951	0.131970629	0.234701881	0.153484831	0.507529769
1952	0.94871004	0.955164729	1.245953272	1.865309449
1953	3.611103293	2.1565015	5.116882387	3.743586777
1954	7.711396607	3.356105544	10.92030416	5.28604712
1955	11.36358993	4.289904136	15.35141915	6.302834771
1956	14.12832281	4.983967485	18.13181045	6.91177379
1957	16.23377022	5.515314578	19.73673808	7.229582135
1958	17.89033963	5.95230712	20.5047403	7.352622163
1959	19.30241872	6.361197085	20.73697447	7.368535699
1960	20.66622422	6.819618995	20.67824603	7.367338971
1961	22.21038807	7.447216376	20.55064775	7.468021182
1962	24.3603082	8.495310734	20.69920679	7.904642326
1963	28.0423788	10.61954333	21.76850483	9.317730615
1964	35.73069743	15.50247038	25.51939418	13.47019591
1965	51.93156306	26.23931466	34.84234646	23.61984104
1966	88.91861151	45.2957339	61.16149567	41.77768569
1967	140.4952734	69.41270987	99.14493065	62.70222638
1968	203.7600725	90.06541092	147.126059	76.15944763
1969	243.2097499	101.1500084	166.3206347	77.14605774
1970	258.7122044	103.8018915	155.0949832	69.48814462
1971	260.1266115	102.6802251	127.1457559	59.89244434
1972	258.1504522	101.3005337	98.32720828	54.85721617
1973	254.6861908	99.14715773	80.95080357	58.6241976
1974	242.2662247	94.6383325	85.00025941	69.18941281
1975	227.1891916	87.69785555	115.1034442	77.43643104
1976	186.473773	77.66089208	124.5354207	75.9081575
1977	129.9684253	67.54734665	99.25062151	69.16509941
1978	95.81290675	62.74041265	82.42598617	66.64668533
1979	74.51406023	65.25531191	76.57220979	71.76222219
1980	70.18970225	67.02610086	58.81168532	66.44845085
1981	75.02368911	61.86011113	53.52160482	53.24584419
1982	70.13278496	51.22428422	48.94717294	38.44339845
1983	53.38830743	39.19031505	34.10106179	24.85826882
1984	34.57446477	29.53862013	16.85432733	15.75811423
1985	32.59021079	25.25788251	15.91052502	13.15946734
1986	39.33706895	25.72031401	20.90435257	14.47862191
1987	51.54242586	29.25465741	28.27547938	17.75490823
1988	68.26934259	33.91815334	38.53393876	22.92489412
1989	74.35445555	38.16349517	43.33991811	29.51888907
1990	68.62533782	40.64741485	43.2399229	35.18588676
1991	65.90342978	40.24607632	52.52931102	36.40506185
1992	56.56527702	35.95282087	51.30683818	32.7786777
1993	48.76682348	29.7159847	48.35421119	26.44039567
1994	39.40827912	23.17953613	38.77828929	20.06072731
1995	29.66394491	17.71933308	28.19427921	14.984796
1996	23.8983033	13.72675195	20.80695368	11.27135785
1997	20.05324655	10.98545369	16.16618072	8.996619619
1998	17.68383935	9.287774047	13.96569586	7.721231384
1999	17.49505639	8.580260225	13.60086626	7.282752287
2000	19.0550529	8.852241446	14.54325435	7.624894698
2001	22.75580371	9.696135921	16.93966883	8.310527636
2002	27.79133714	11.01504722	20.34417499	9.558627064
2003	33.81032102	12.9270149	24.83492644	11.45243119
2004	41.86846477	15.5717348	31.32421886	13.9981476
2005	51.22648645	18.28719406	38.70198015	16.40227927
2006	59.78152957	20.81058775	45.41569938	19.07777358
2007	66.96955261	23.27900883	51.66465136	21.85529938
2008	75.93886678	23.67594905	61.06559399	21.93125849
2009	76.54785201	21.19296441	62.26036174	19.2000384
2010	68.34174694	18.01164494	54.36614907	16.06442724
2011	59.11264433	16.78623438	44.94389376	14.7268673
2012	57.8271061	20.06170466	40.53921435	17.49253455
2013	70.60763208	26.14124162	46.93583482	23.13170534
2014	84.80739378	29.20067585	58.70050211	25.95901614
2015	83.77828898	27.13037226	60.99617582	23.74779873
2016	77.96516575	22.90670902	57.69865264	19.74438003
2017	0	0	47.03929982	16.20287345

Table 34. Estimated population size (millions) for females on July 1 of year. from the author's preferred model, Model 18C2a.
<<Table too large: available online in the zip file "TannerPopSizeStrucFemale.csvs.zip".>>

Table 35. Estimated population size (millions) for males on July 1 of year. from the author's preferred mode, Model 18C2a.
<<Table too large: available online as a zipped csv file "TannerCrab.PopSizeStructure.csvs.zip".>>

Table 36. Comparison of estimates of recruitment (in millions) from the 2017 assessment model (17AM) and the author's preferred model (18C2a).

year	17AM	18C2a	year	17AM	18C2a
1948	66.59	93.87	1986	519.28	602.84
1949	66.58	92.48	1987	355.29	385.04
1950	66.64	89.91	1988	170.75	173.17
1951	66.90	86.48	1989	52.30	70.47
1952	67.56	82.58	1990	41.79	32.49
1953	68.86	78.67	1991	36.99	31.57
1954	71.24	75.26	1992	37.07	34.21
1955	75.36	73.01	1993	48.83	43.33
1956	82.49	72.86	1994	62.53	53.33
1957	95.22	76.53	1995	57.52	56.23
1958	119.81	88.03	1996	167.46	123.75
1959	174.76	119.88	1997	67.08	63.29
1960	320.74	217.60	1998	224.50	177.06
1961	719.29	522.83	1999	116.92	113.95
1962	1397.35	1119.44	2000	382.14	307.76
1963	1665.55	1395.47	2001	122.98	117.46
1964	1398.08	1046.78	2002	369.14	332.86
1965	1095.79	627.47	2003	359.66	348.56
1966	943.74	381.65	2004	97.76	131.48
1967	937.10	285.05	2005	74.94	86.24
1968	1014.12	349.91	2006	57.91	58.33
1969	983.26	938.10	2007	89.13	62.10
1970	834.92	1411.49	2008	580.85	336.64
1971	554.32	999.11	2009	514.37	528.84
1972	362.83	561.77	2010	210.36	253.74
1973	308.42	406.02	2011	40.96	61.14
1974	632.20	641.55	2012	112.31	104.03
1975	1239.52	1160.31	2013	84.14	63.12
1976	957.43	1116.79	2014	55.17	47.62
1977	420.64	703.67	2015	77.52	65.74
1978	177.55	162.54	2016	457.92	354.62
1979	108.77	101.02	2017	0.00	662.47
1980	177.84	98.44			
1981	100.63	86.47			
1982	488.76	242.07			
1983	402.54	246.14			
1984	541.74	410.08			
1985	523.34	512.78			

Table 37. Comparison of exploitation rates (i.e., catch divided by biomass) from the 2017 assessment model 17AM) and the author's preferred model (18C2a).

year	17AM	18C2a	year	17AM	18C2a
1949	0.0018	0.0019	1986	0.0195	0.0104
1950	0.0029	0.0033	1987	0.0319	0.0199
1951	0.0045	0.0051	1988	0.0407	0.0312
1952	0.0066	0.0070	1989	0.0915	0.0861
1953	0.0097	0.0096	1990	0.1524	0.1513
1954	0.0130	0.0125	1991	0.1473	0.1319
1955	0.0152	0.0144	1992	0.1748	0.1604
1956	0.0164	0.0156	1993	0.1302	0.1023
1957	0.0167	0.0158	1994	0.0983	0.0823
1958	0.0170	0.0161	1995	0.0872	0.0723
1959	0.0168	0.0160	1996	0.0481	0.0548
1960	0.0165	0.0159	1997	0.0394	0.0415
1961	0.0160	0.0159	1998	0.0381	0.0260
1962	0.0144	0.0147	1999	0.0172	0.0151
1963	0.0123	0.0123	2000	0.0141	0.0163
1964	0.0107	0.0104	2001	0.0157	0.0215
1965	0.0167	0.0189	2002	0.0096	0.0117
1966	0.0167	0.0188	2003	0.0066	0.0070
1967	0.0452	0.0538	2004	0.0074	0.0077
1968	0.0499	0.0616	2005	0.0123	0.0140
1969	0.0656	0.0878	2006	0.0184	0.0191
1970	0.0612	0.0904	2007	0.0220	0.0213
1971	0.0521	0.0832	2008	0.0146	0.0162
1972	0.0464	0.0755	2009	0.0121	0.0142
1973	0.0561	0.0927	2010	0.0064	0.0078
1974	0.0747	0.1109	2011	0.0088	0.0095
1975	0.0648	0.0812	2012	0.0053	0.0070
1976	0.1007	0.1102	2013	0.0153	0.0189
1977	0.1398	0.1413	2014	0.0522	0.0604
1978	0.1176	0.1010	2015	0.0707	0.0833
1979	0.1509	0.1039	2016	0.0098	0.0117
1980	0.0926	0.0692	2017	0.0000	0.0245
1981	0.0468	0.0355			
1982	0.0253	0.0207			
1983	0.0132	0.0124			
1984	0.0262	0.0293			
1985	0.0156	0.0085			

Table 38. 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 18C2a) are highlighted in green.

Model Scenario	average recruitment	Final MMB	B0	Bmsy	Fmsy	MSY	Fofl	OFL	projected MMB	projected MMB / Bmsy
	millions	1000's t	1000's t	1000's t		1000's t		1000's t	1000's t	
17AM (B2b)	213.96	80.58	83.34	29.17	0.75	12.26	0.75	25.42	43.32	1.49
17AMu	371.11	136.48	111.38	38.98	1.25	18.03	1.25	50.85	63.55	1.63
18A	391.22	114.10	120.00	42.00	1.22	19.24	1.22	42.01	53.87	1.28
18B	464.60	124.18	130.45	45.66	2.61	22.35	2.61	55.40	48.01	1.05
18C0	536.07	122.84	124.39	43.54	3.06	24.32	3.04	56.15	43.25	0.99
18C0a	366.37	99.63	100.92	35.32	1.07	18.13	1.07	35.44	46.25	1.31
18C1	540.64	128.64	129.28	45.25	2.79	25.90	2.78	58.26	45.12	1.00
18C1a	404.67	110.14	109.74	38.41	1.14	20.41	1.14	39.87	49.67	1.29
18C2a	199.49	50.12	63.01	22.05	0.91	11.54	0.91	16.76	24.06	1.09
18C3a	188.34	49.93	63.61	22.26	0.79	10.84	0.79	15.93	25.44	1.14
18D0	503.62	145.40	149.02	52.16	2.64	24.09	2.64	65.30	57.35	1.10

Figures

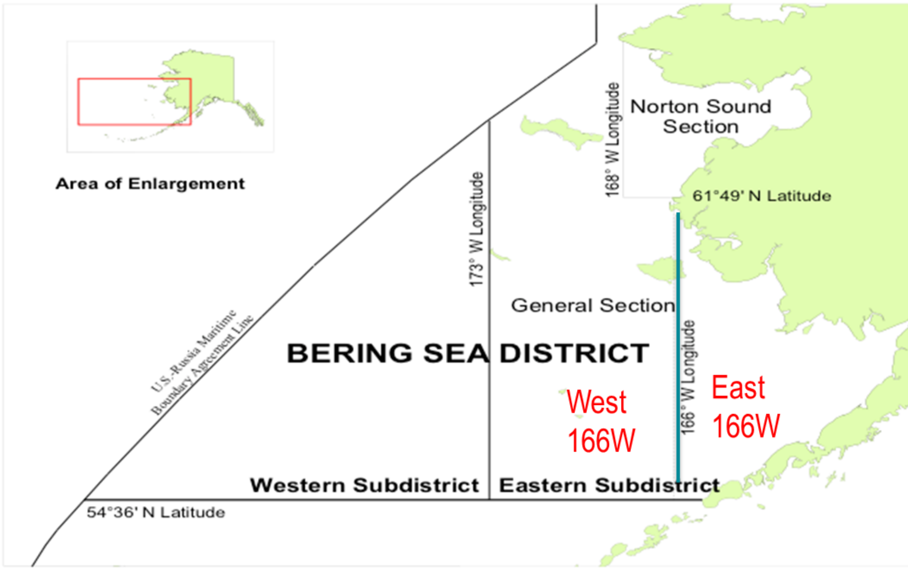


Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008).

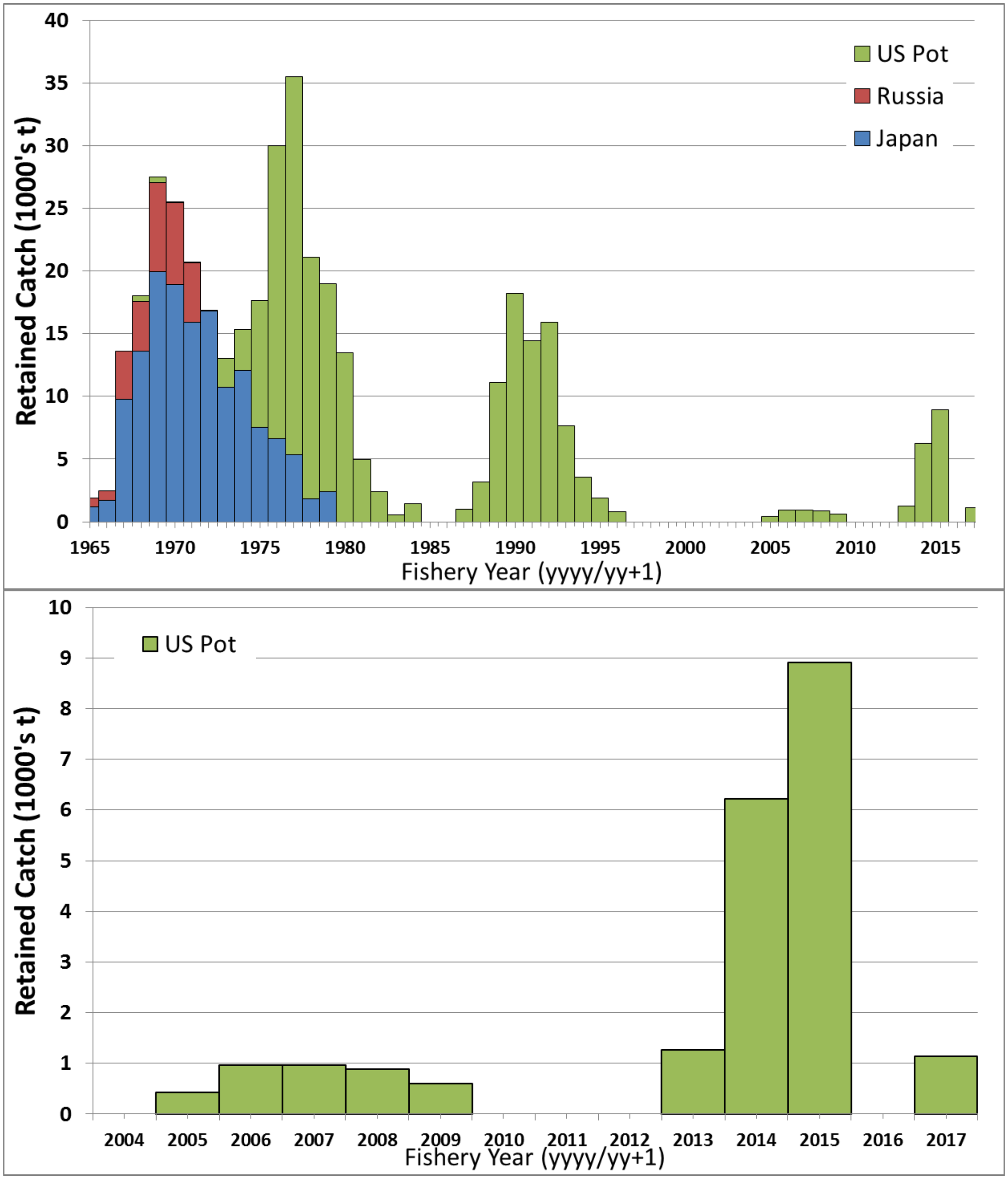


Figure 2. Upper: retained catch (males, 1000's t) in the directed fisheries (US pot fishery [green bars], Russian tangle net fishery [red bars], and Japanese tangle net fisheries [blue bars]) for Tanner crab since 1965/66. Lower: Retained catch (males, 1000's t) in directed fishery since 2001/02. The directed fishery was closed from 1996/97 to 2004/05, from 2010/11 to 2012/13, and in 2016/17.

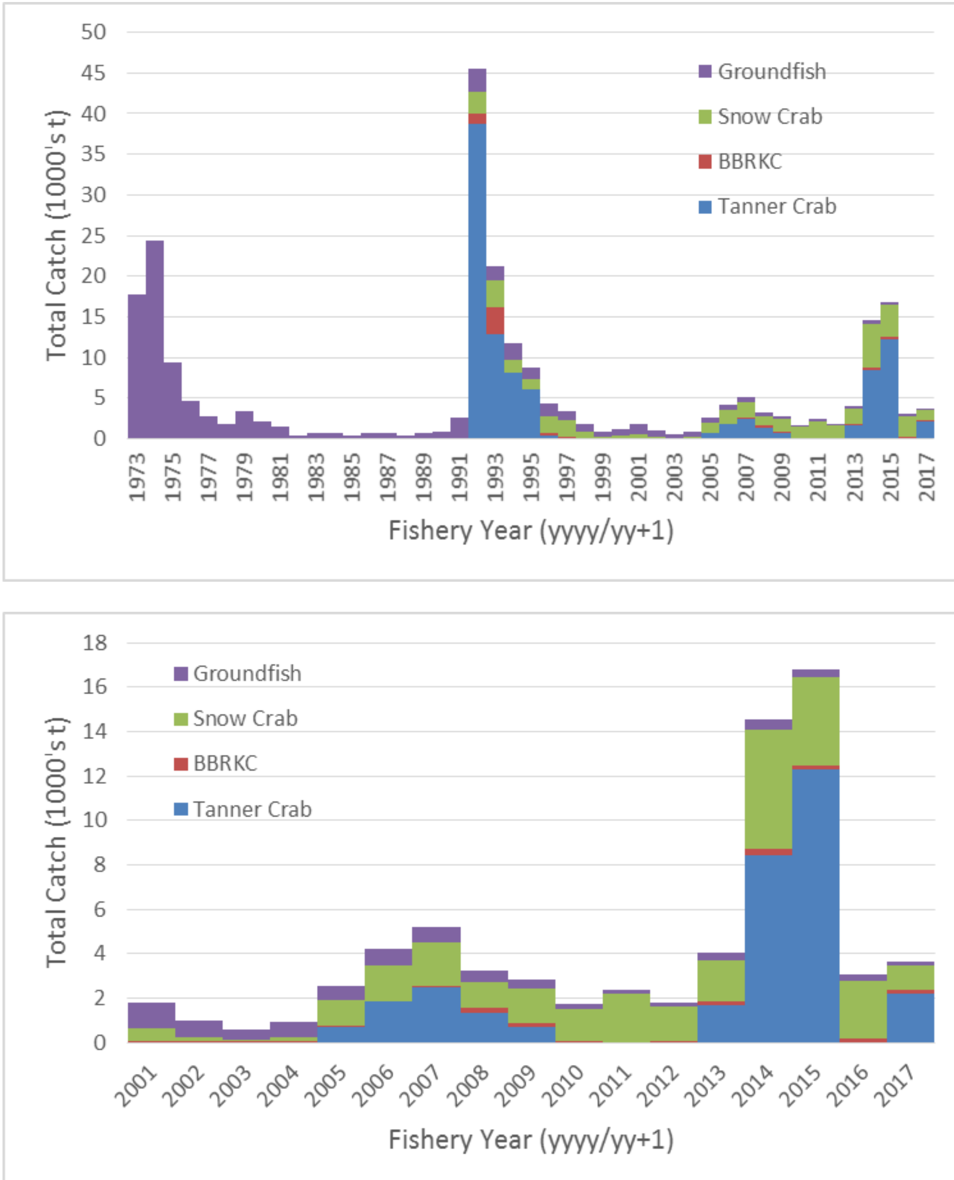


Figure 3. Upper: total catch (retained + discards) of Tanner crab (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Bycatch reporting began in 1973 for the groundfish fisheries and in 1992 for the crab fisheries. Lower: detail since 2001.

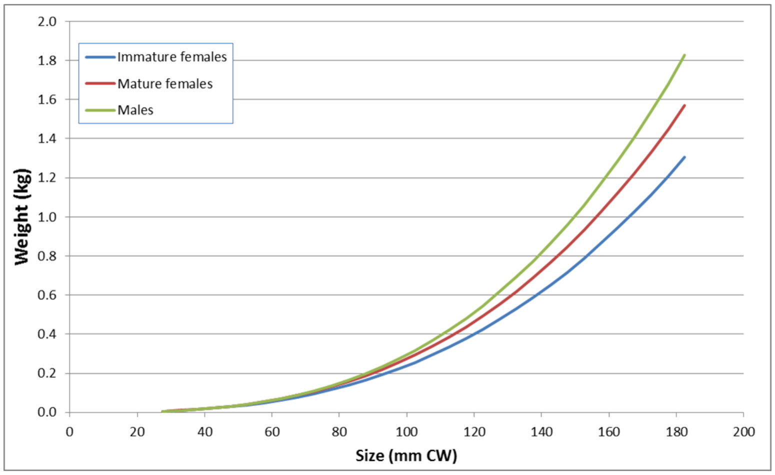


Figure 4. Size-weight relationships developed from NMFS EBS summer trawl survey data.

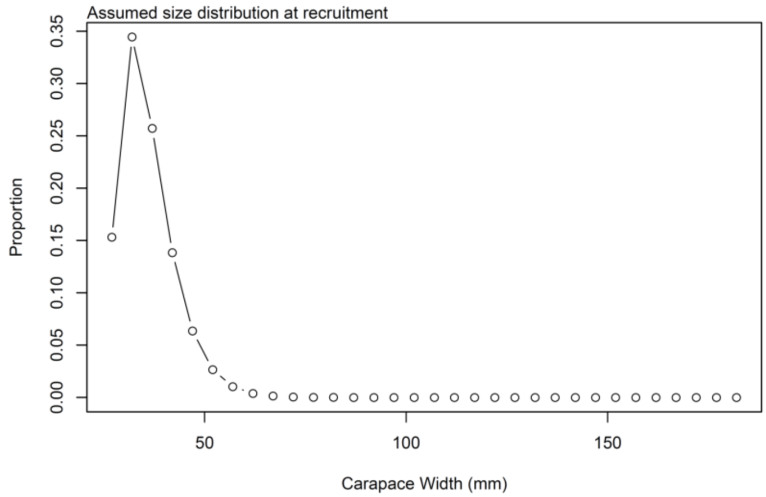


Figure 5. Assumed size distribution for recruits entering the population.

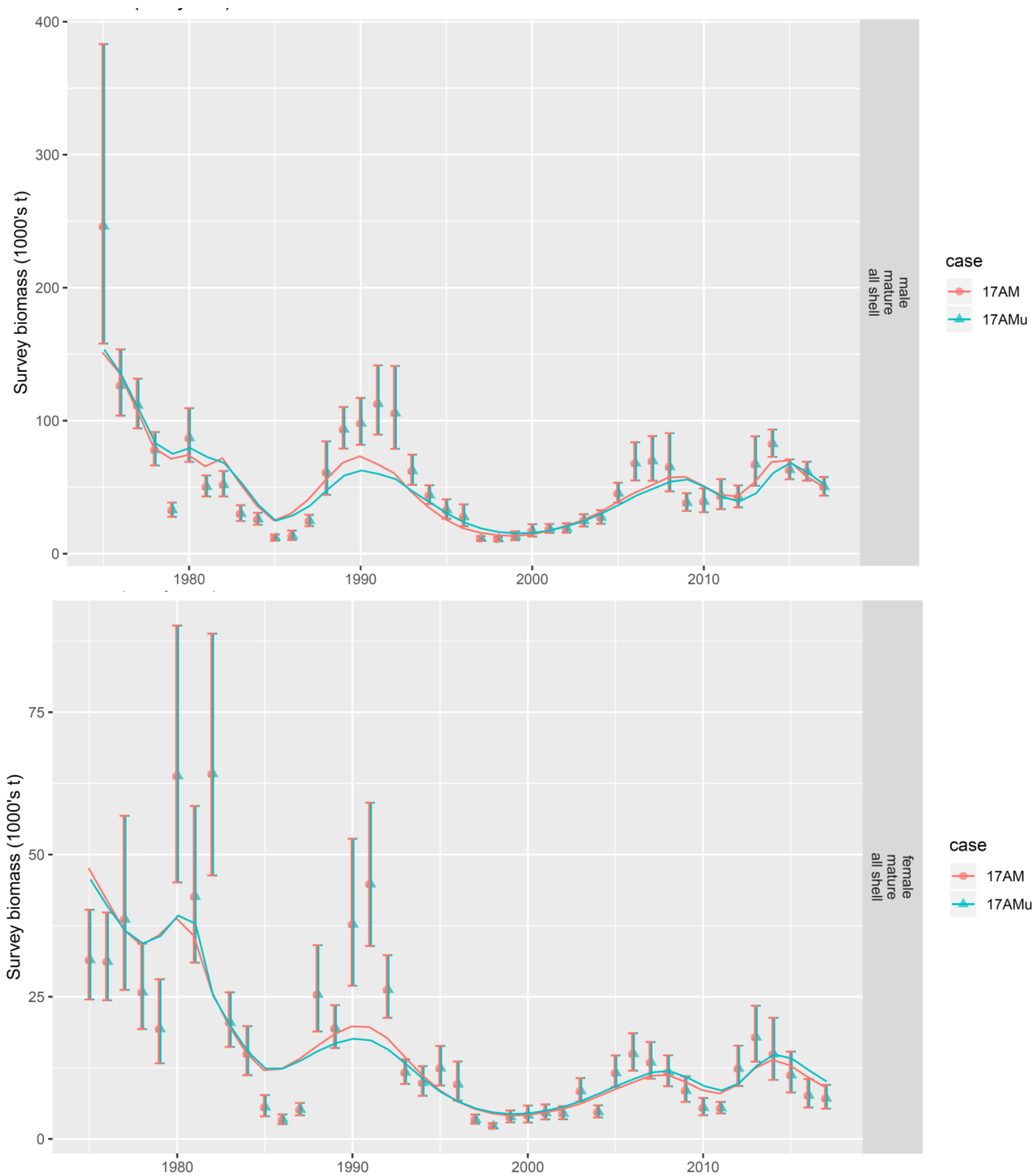


Figure 6. Fits to mature survey biomass for scenarios 17AM and 17AMu. Points: input data; lines: model estimates.

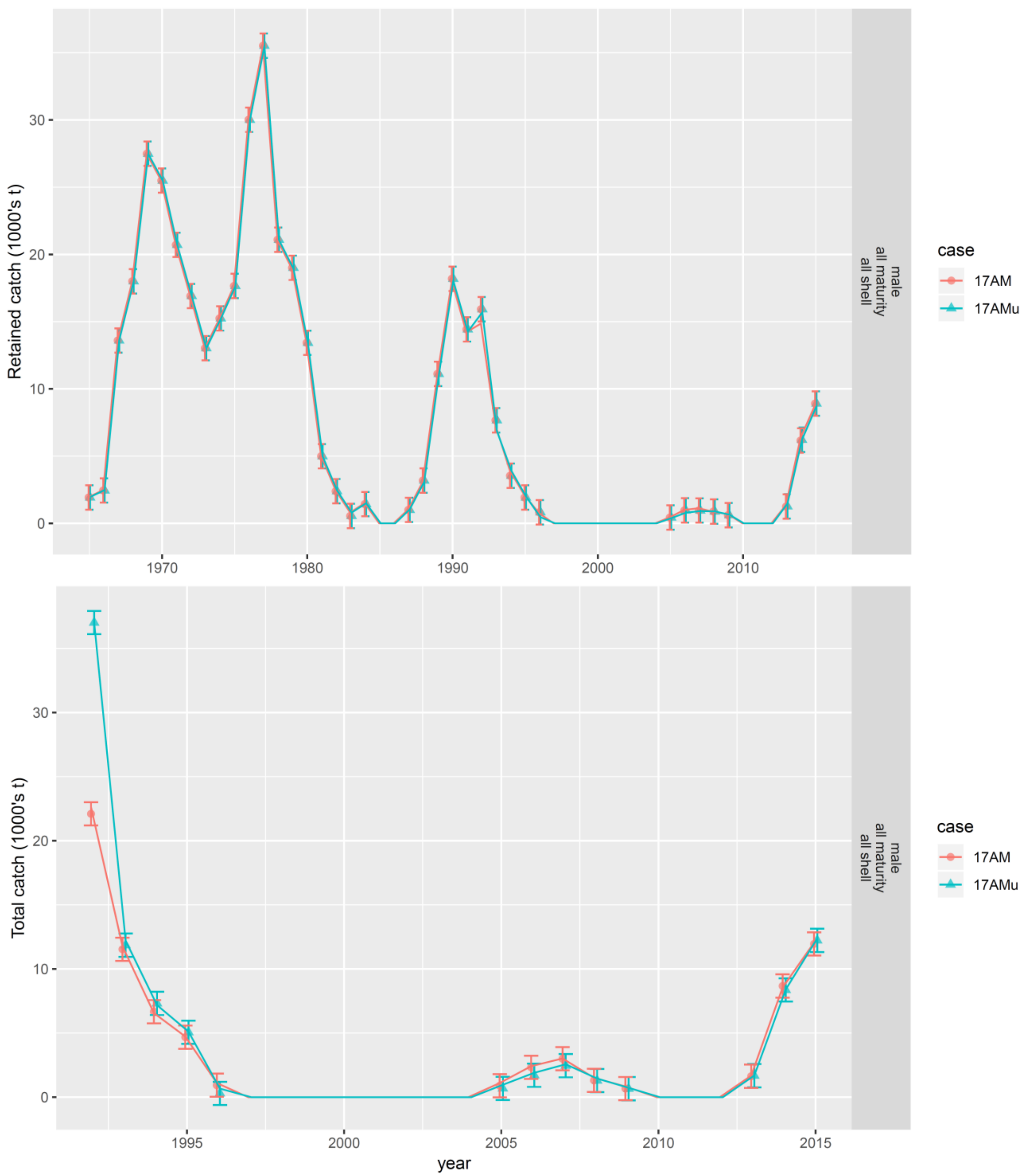


Figure 7. Fits to retained catch biomass (upper) and total male catch biomass (lower) for the directed fishery for scenarios 17AM and 17AMu. Points: input data; lines: model estimates.

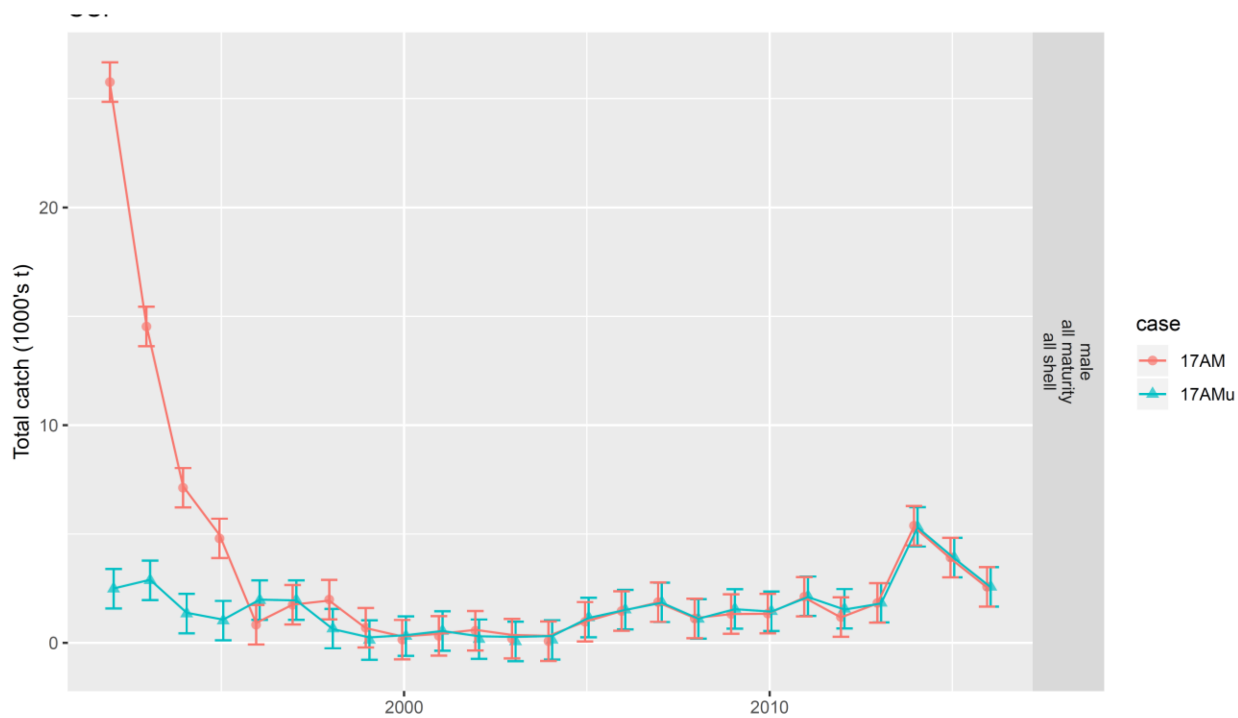


Figure 8. Fits to total male bycatch biomass for the snow crab fishery for scenarios 17AM and 17AMu. Points: input data; lines: model estimates.

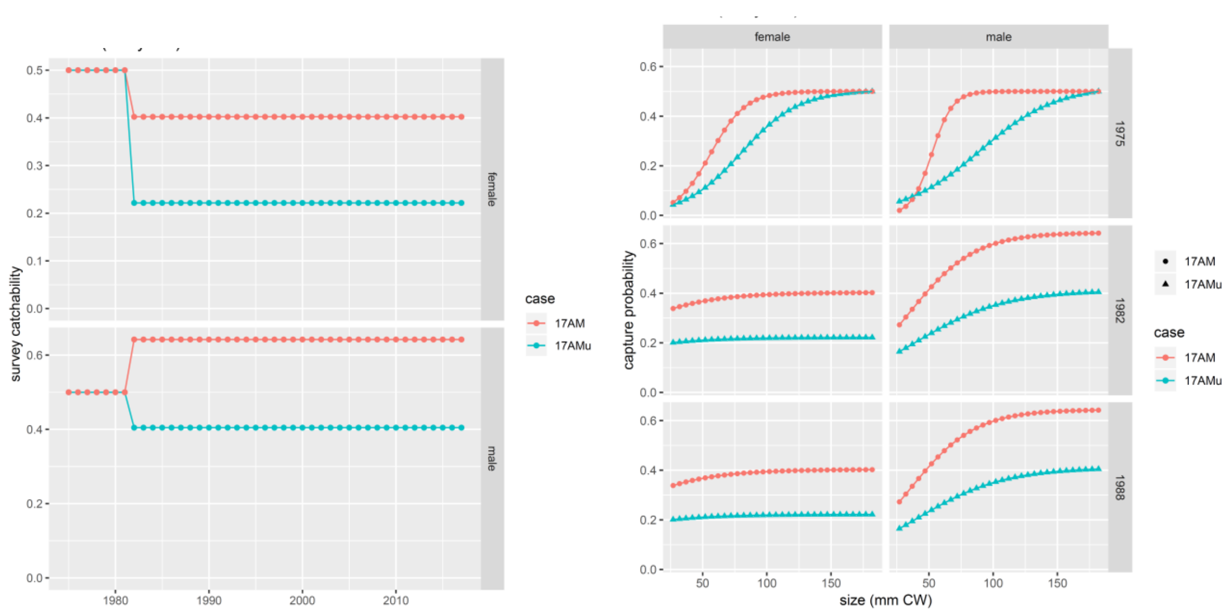


Figure 9. Estimated survey catchabilities (left) and capture probabilities (catchability x selectivity; right) for scenarios 17AM and 17AMu.

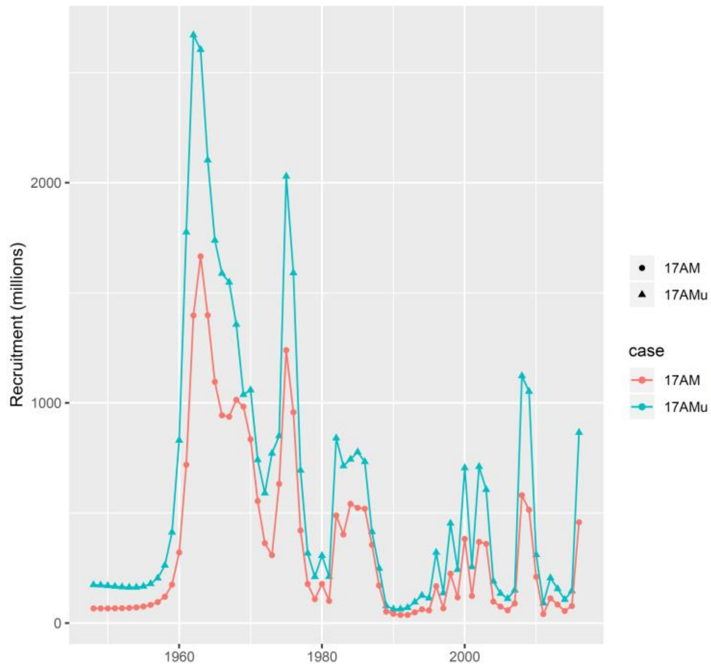


Figure 10. Estimated recruitment for scenarios 17AM and 17AMu.

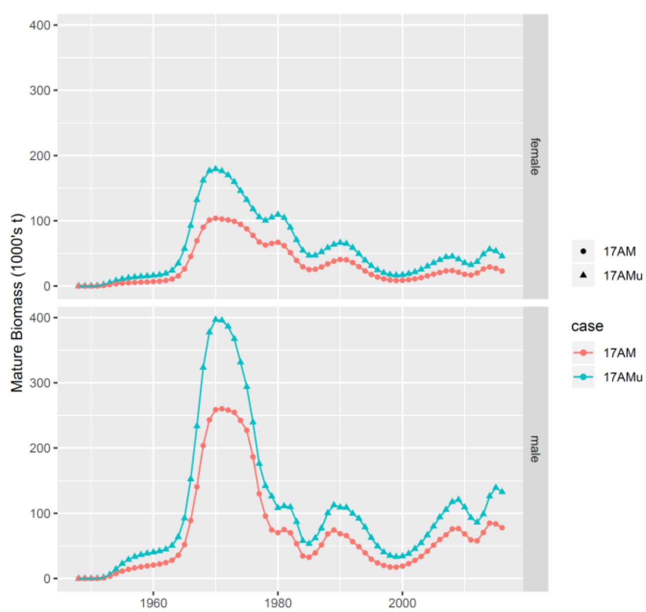


Figure 11. Estimated mature biomass for scenarios 17AM and 17AMu.

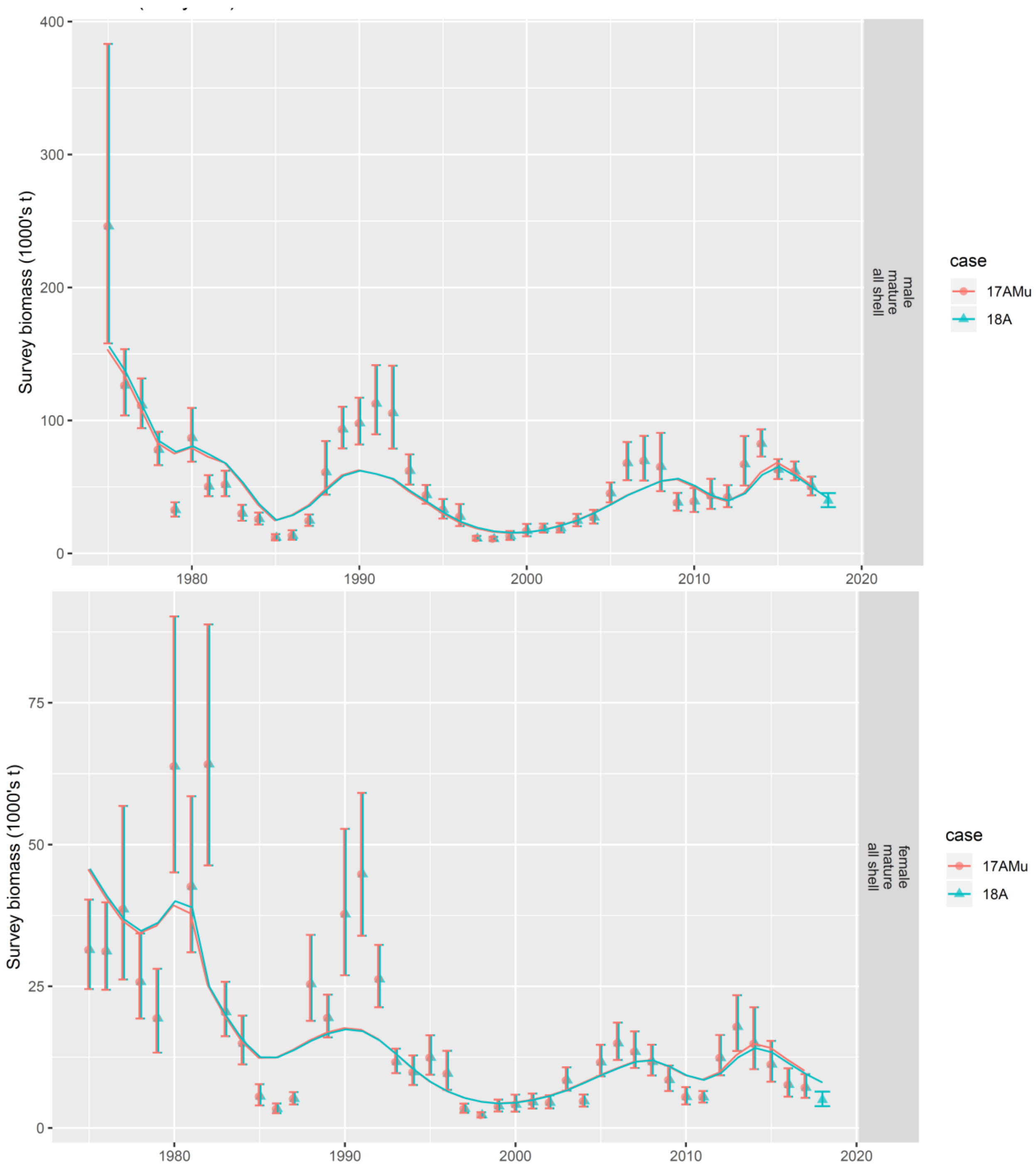
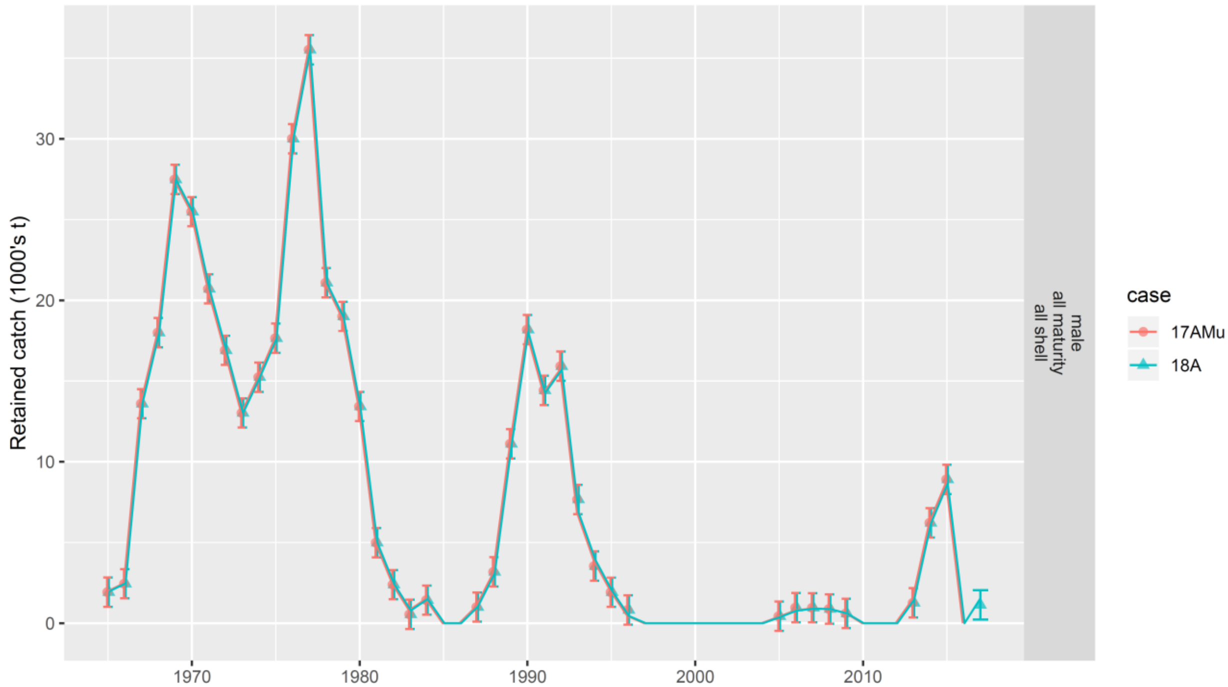


Figure 12. Fits to mature survey biomass for scenarios 17AMu and 18A. Points: input data; lines: model estimates.



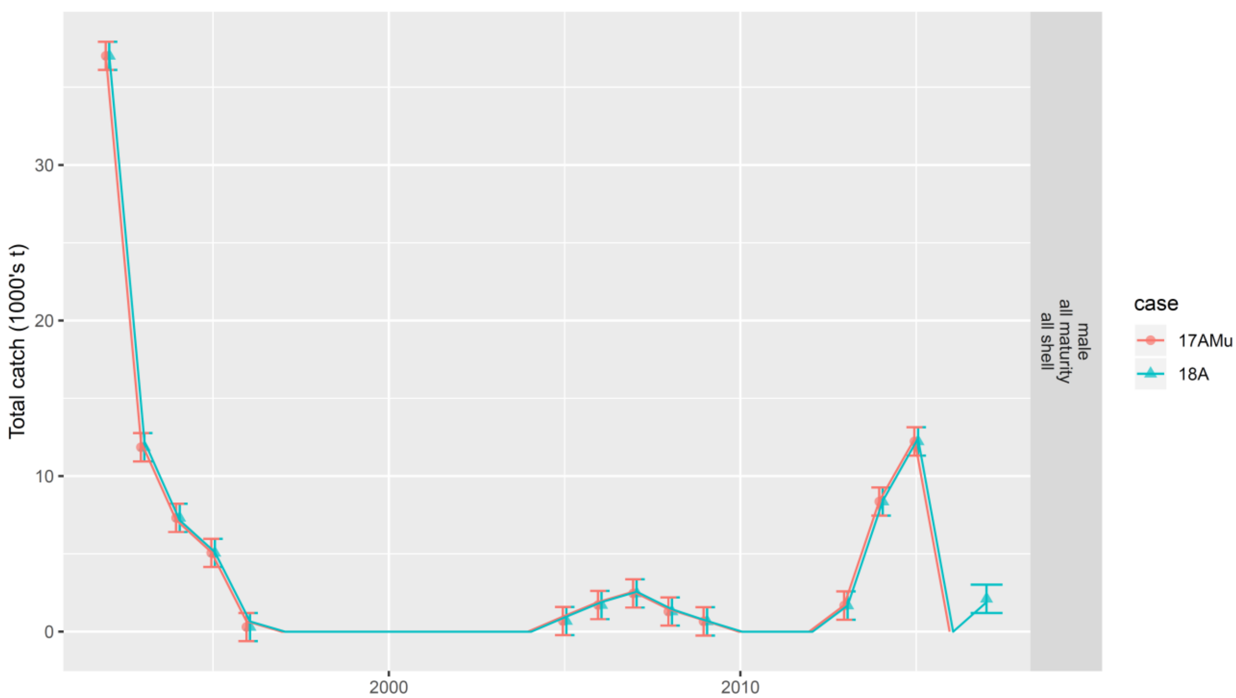


Figure 13. Fits to retained catch biomass (upper) and total male catch biomass (lower) for the directed fishery for scenarios 17AMu and 18A. Points: input data; lines: model estimates.

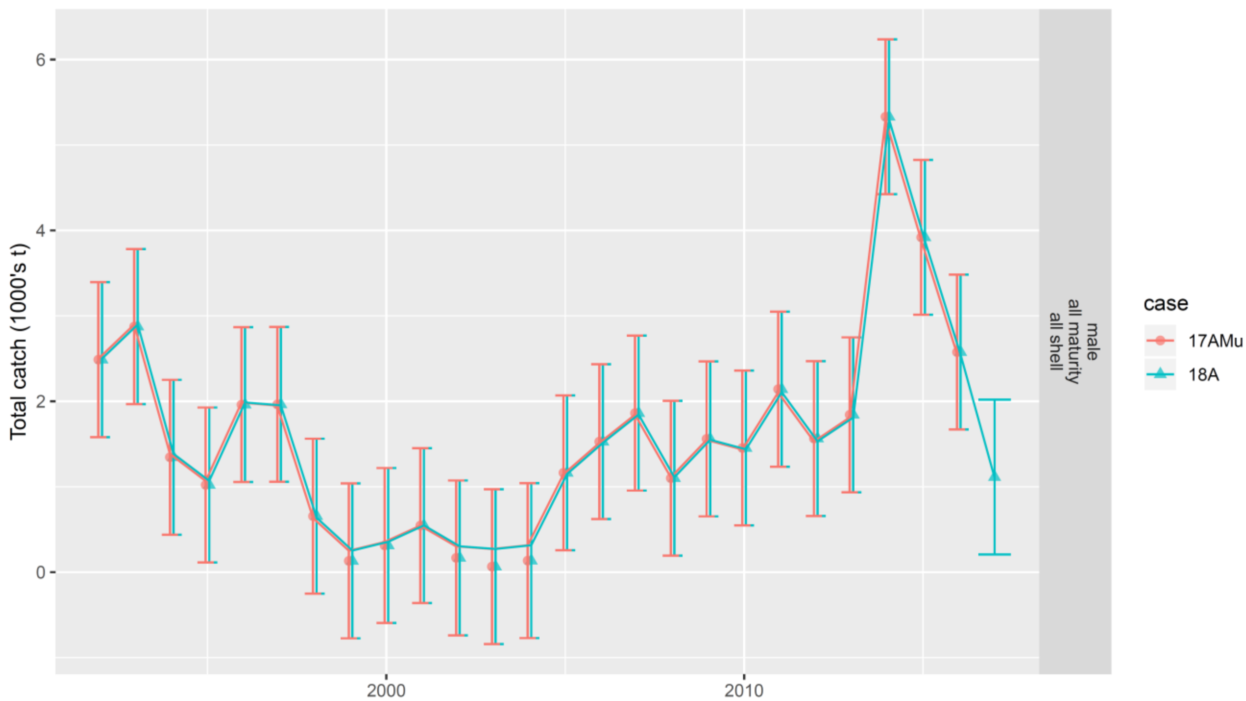


Figure 14. Fits to total male bycatch biomass for the snow crab fishery for scenarios 17AMu and 17AMu. Points: input data; lines: model estimates.

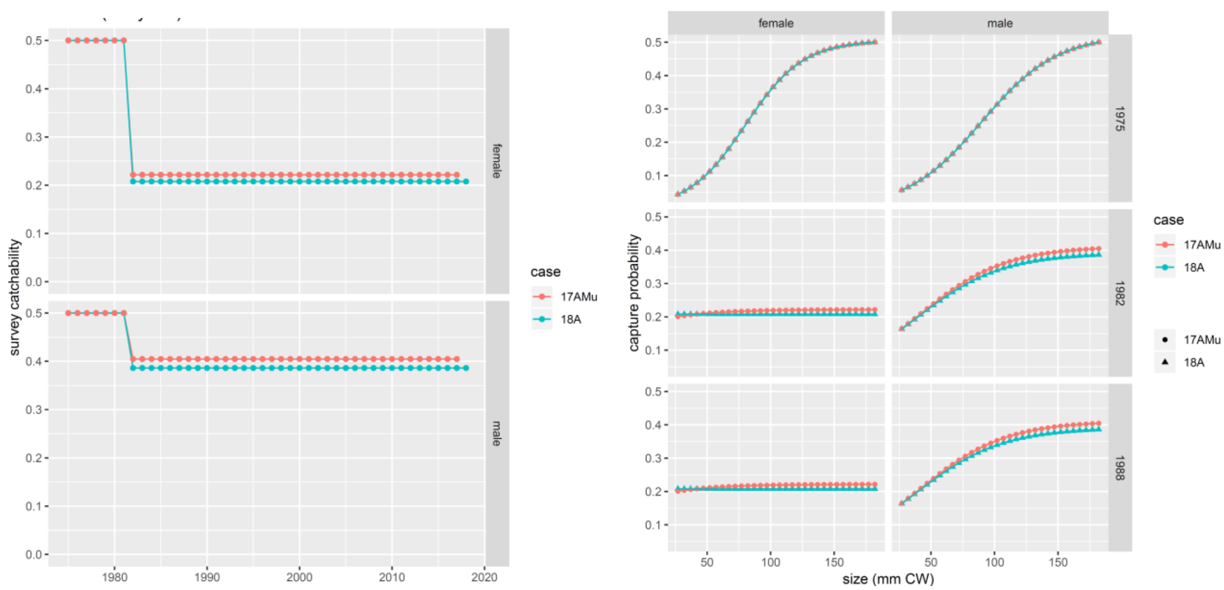


Figure 15. Estimated survey catchabilities (left) and capture probabilities (catchability x selectivity; right) for scenarios 17AMu and 18A.

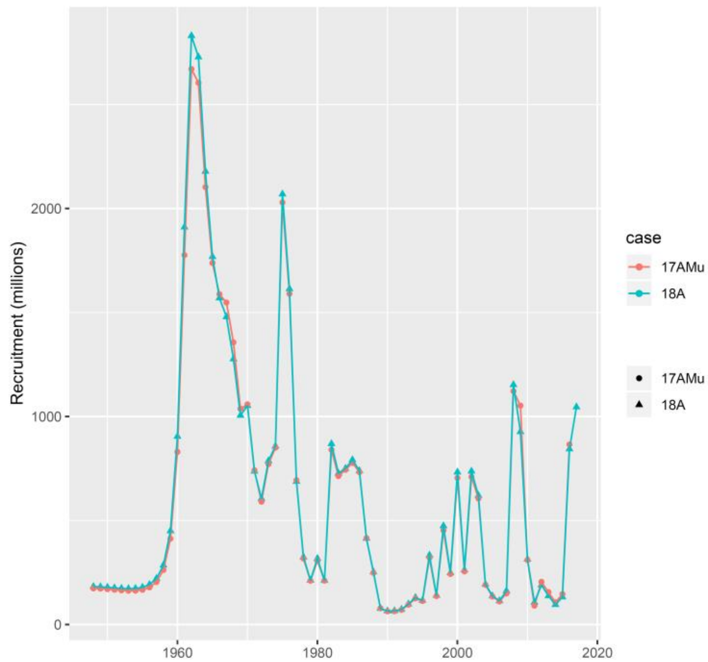


Figure 16. Estimated recruitment for scenarios 17AMu and 18A.

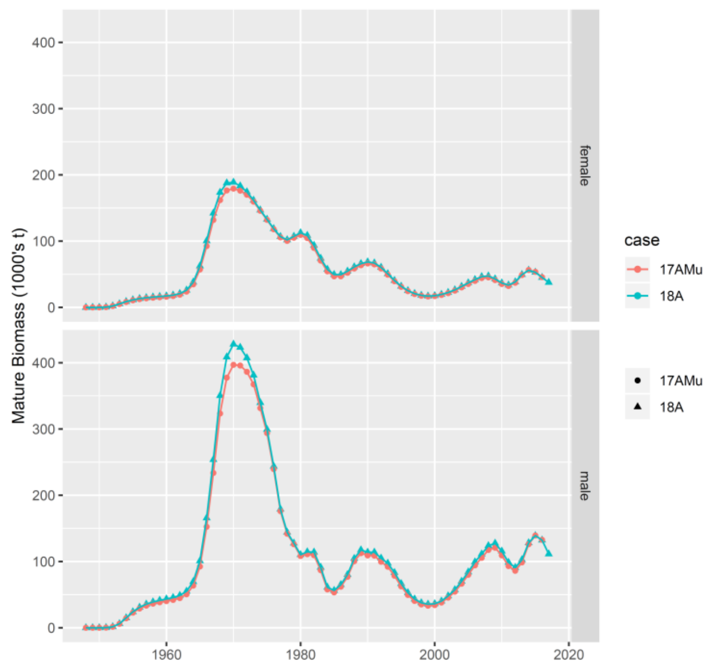


Figure 17. Estimated mature biomass for scenarios 17AMu and 18A.

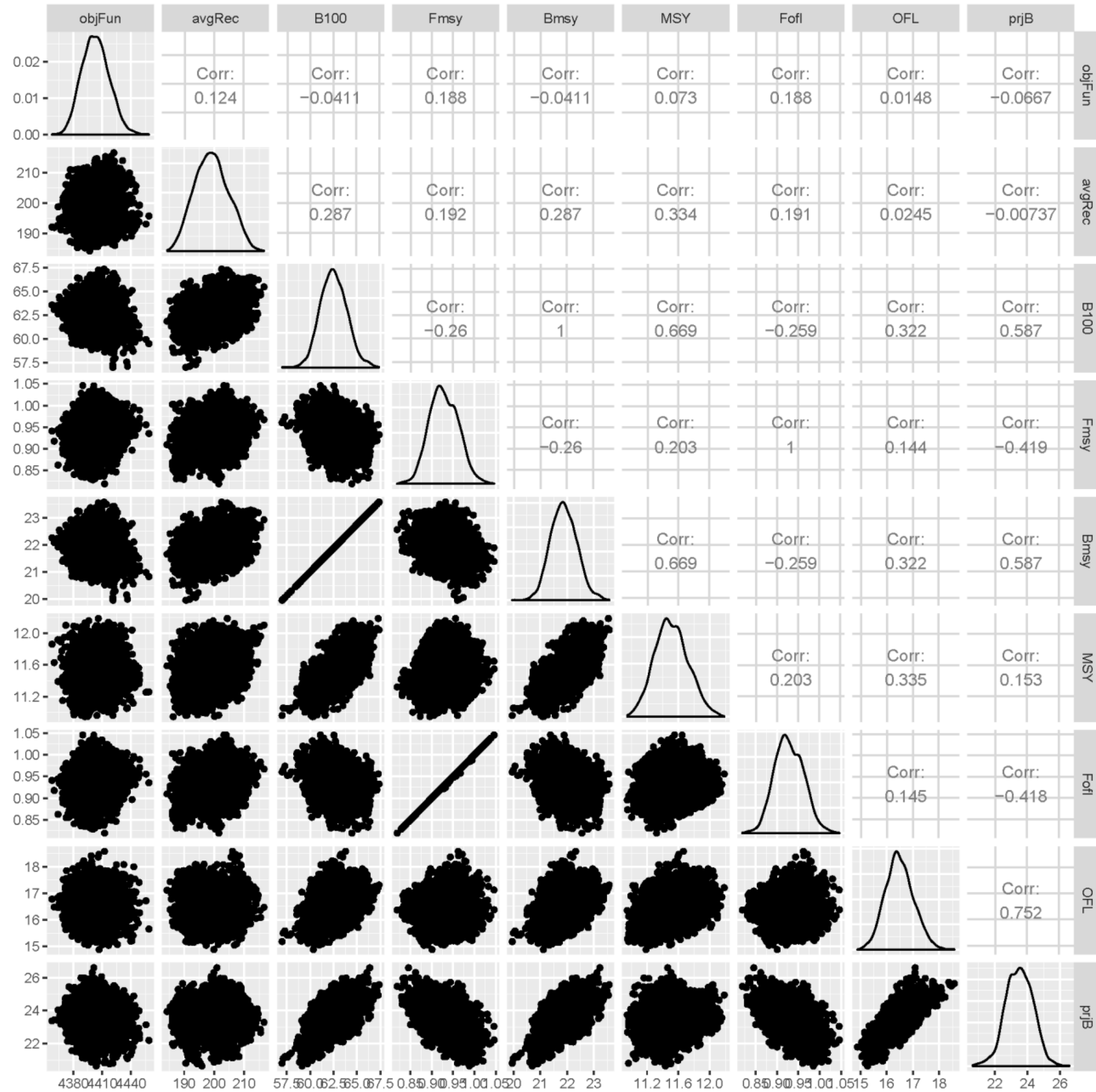


Figure 18. MCMC results from scenario 18C2a, the author's preferred model, for OFL-related quantities.

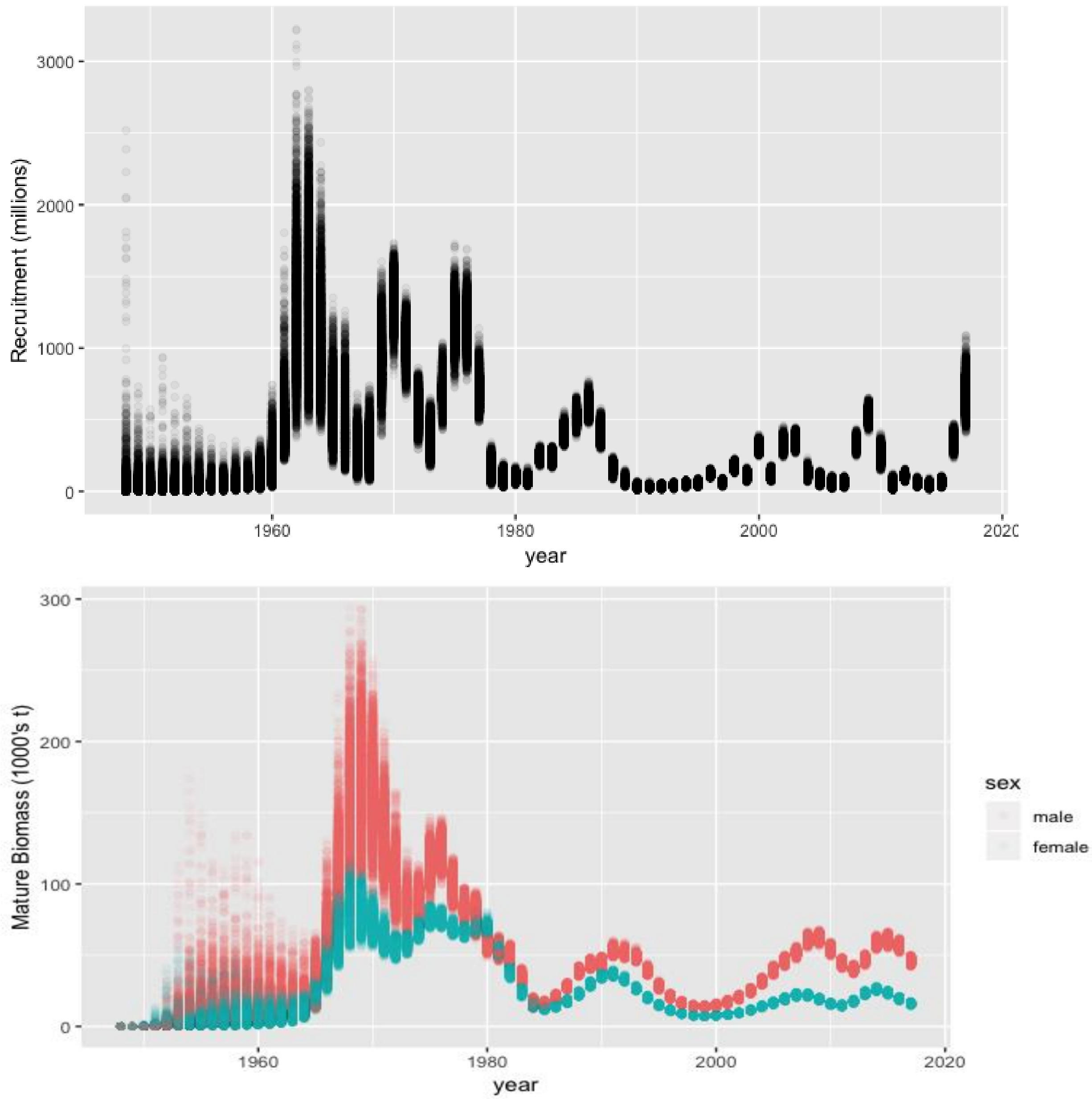


Figure 19. MCMC results from scenario 18C2a, the author's preferred model, for recruitment (upper plot) and mature biomass-at-mating (lower plot; males in red, females in green).

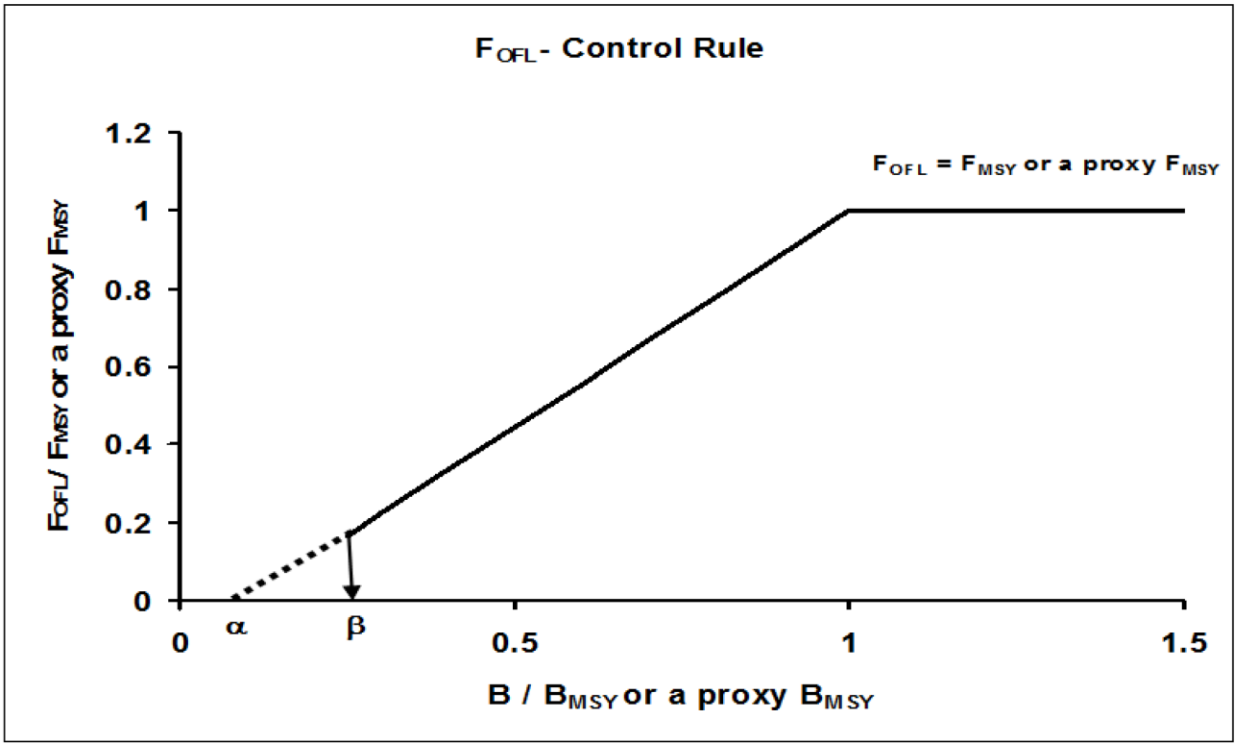


Figure 20. The F_{OFL} harvest control rule.

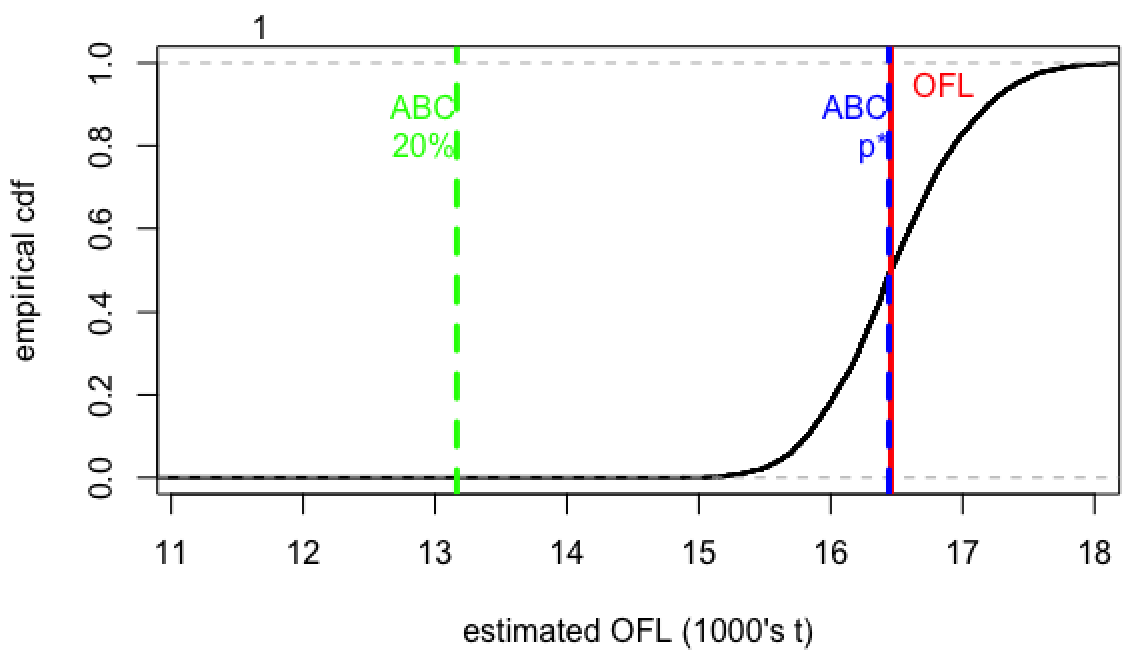


Figure 21. The OFL and ABC from the author's preferred model, scenario 18C2a.

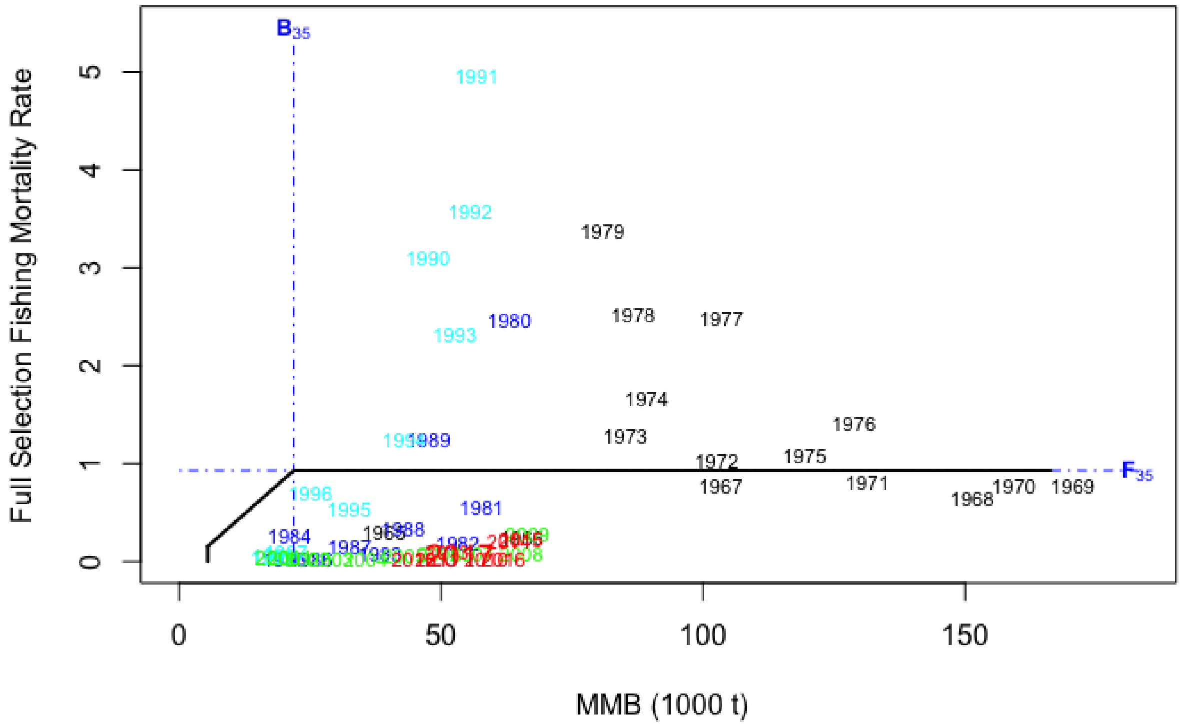


Figure 22. Quad plot for the author's preferred model, scenario B2b.

Appendix A:
Retained Catch Data from ADFG for the Tanner Crab Assessment

William Stockhausen

21 August, 2018

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Introduction

This report calculates time series of retained catch abundance and biomass of Tanner crab from fish ticket data, as well as retained catch size compositions from observer "dockside" sampling. Although Tanner crab are incidentally retained in the BBRKC and snow crab fisheries, this incidental catch is a small fraction of the retained catch in the directed fisheries and is currently, as a model simplification, included in the retained catch for the directed fisheries in the assessment model.

Retained catch abundance and biomass

Time series of retained catch abundance and biomass are calculated in this section. First, the retained catch ispresented categorized by the fishery in which it occurs. Then it is presented as it occurs in the assessment model, where incidentally-retained catch in the snow crab and BRKC fisheries is lumped in with that in the directed fisheries.

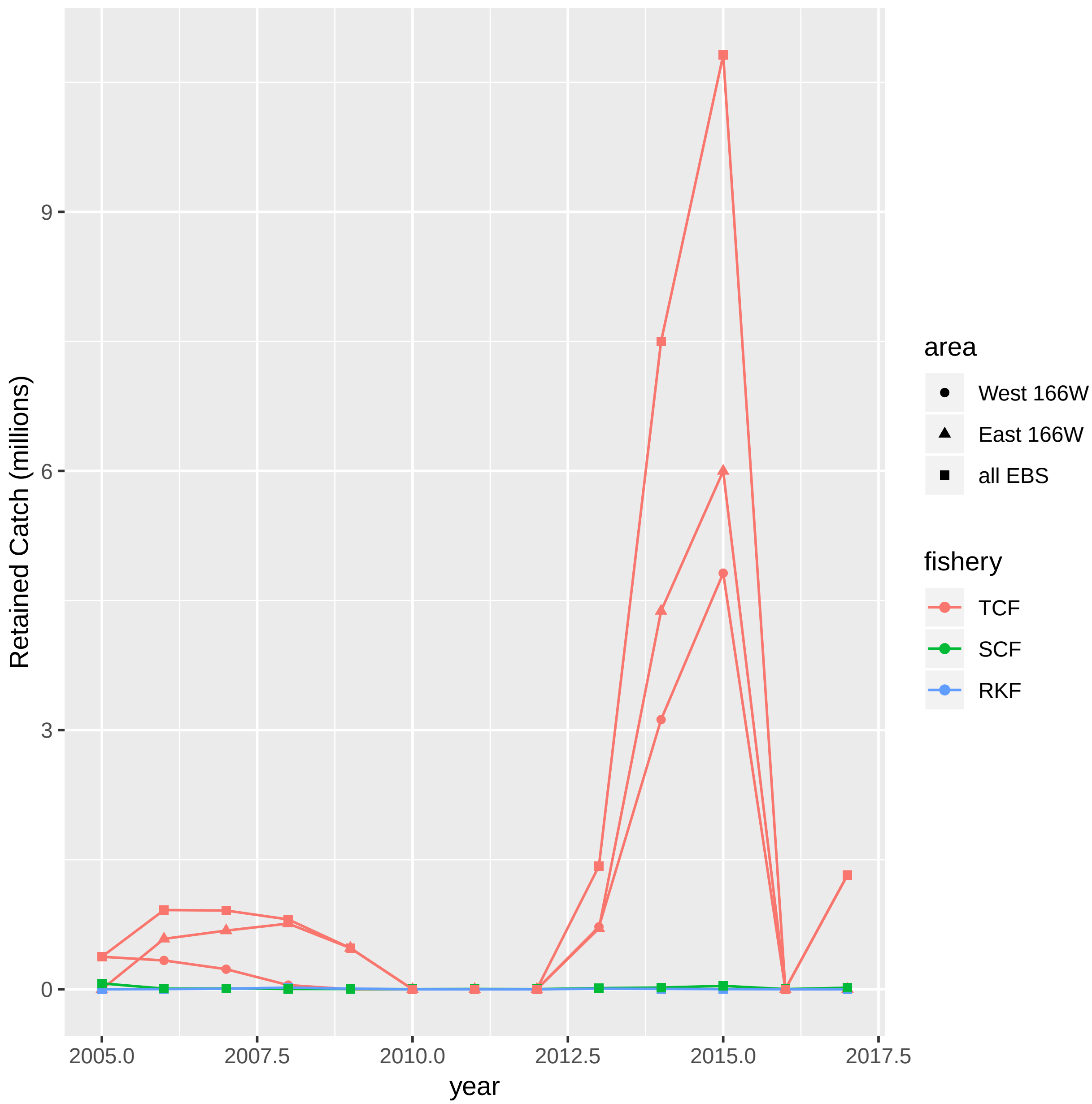

Figure 1: Retained Tanner crab catch, in millions of crab. TCF: Tanner crab fisheries; SCF: snow crab fishery; RKF: BBRKC fishery.

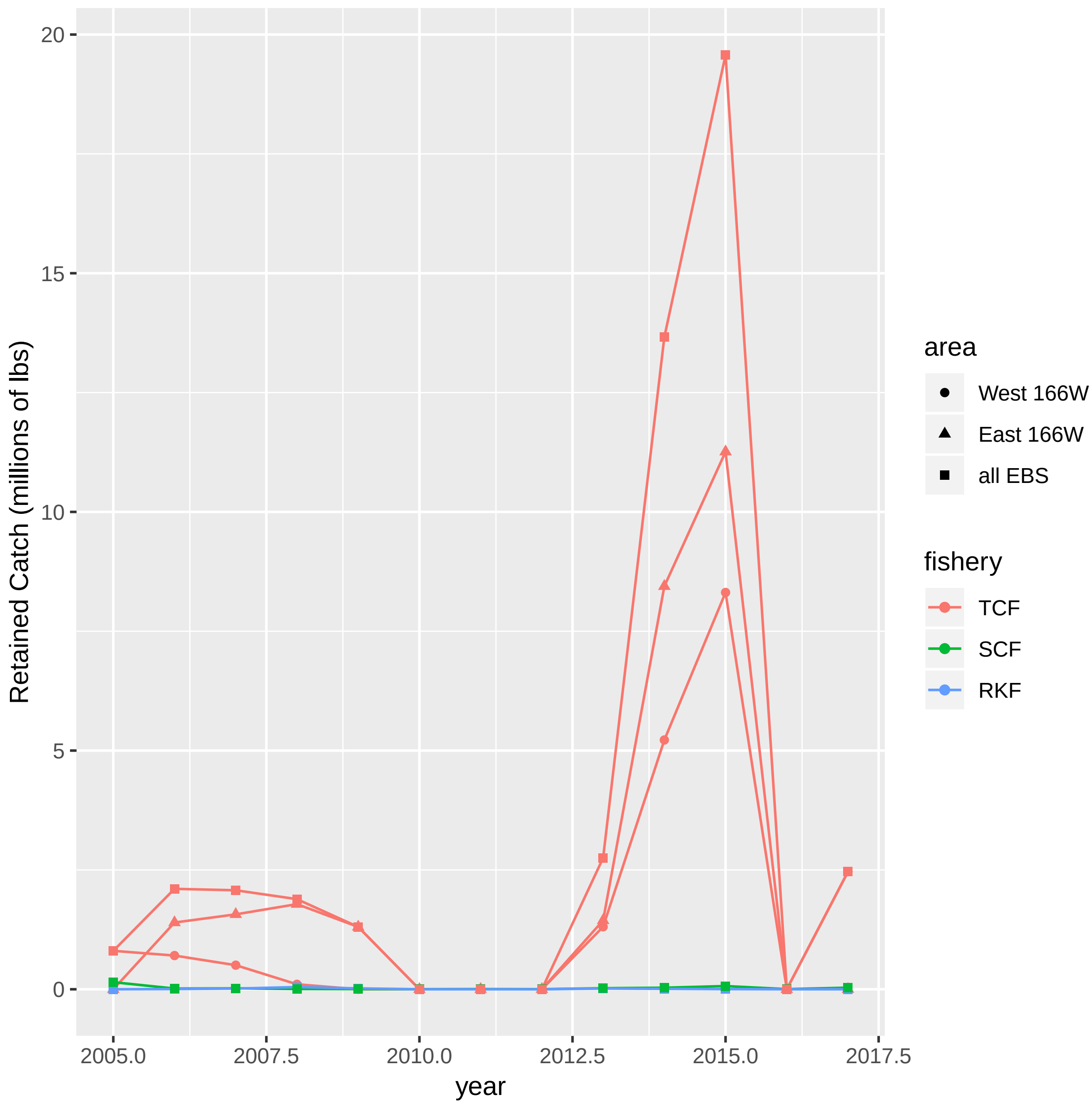

Figure 2: Retained Tanner crab catch, in millions of pounds. TCF: Tanner crab fisheries; SCF: snow crab fishery; RKF: BBRKC fishery.

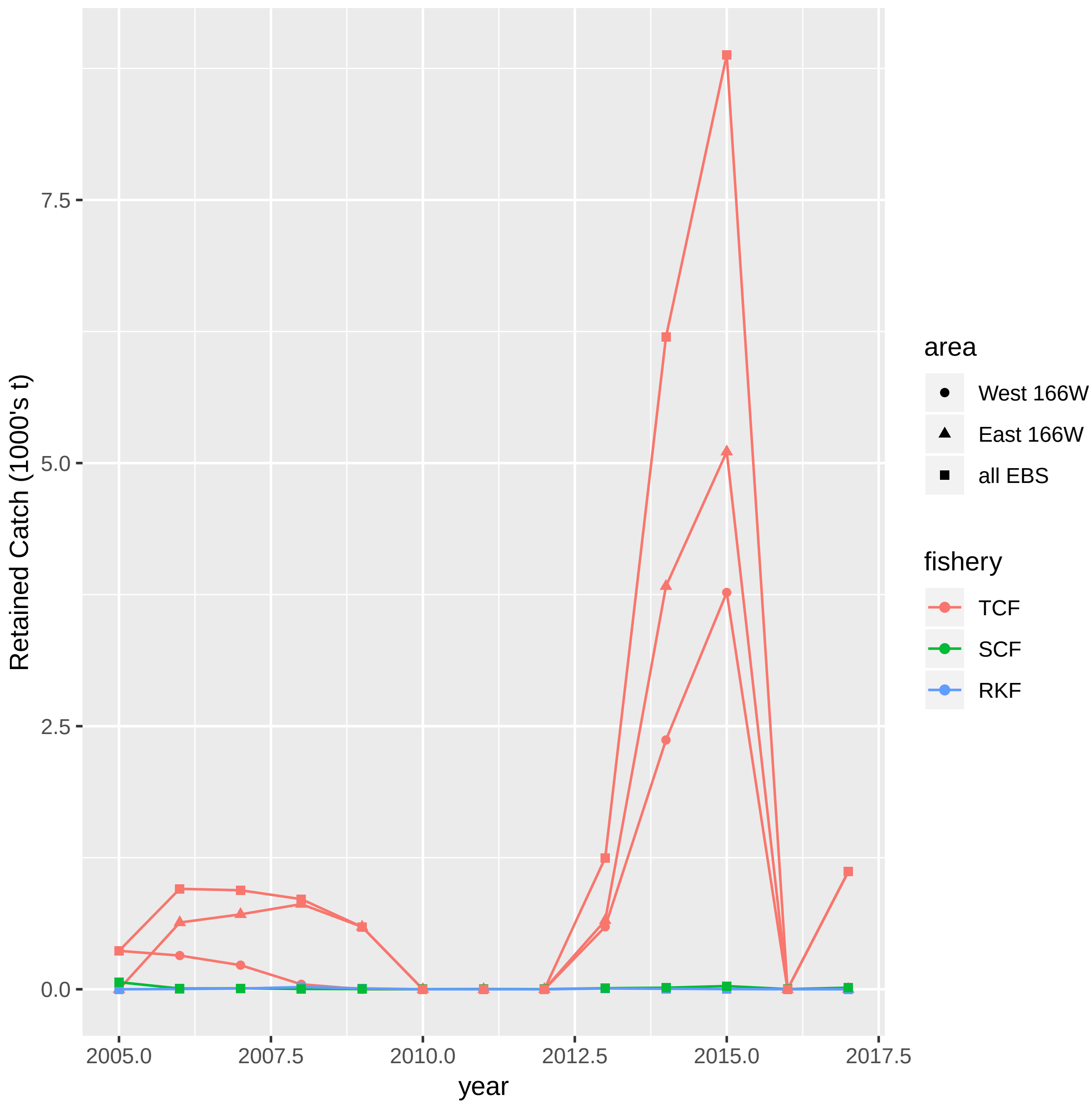

Figure 3: Retained Tanner crab catch, in 1000's t. TCF: Tanner crab fisheries; SCF: snow crab fishery; RKF: BBRKC fishery.

Table 1: Retained catch of Tanner crab since 2005, by fishery. TCF: Tanner crab fisheries, SCF: snow crab fishery, RKF: BBRKC fishery.

	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

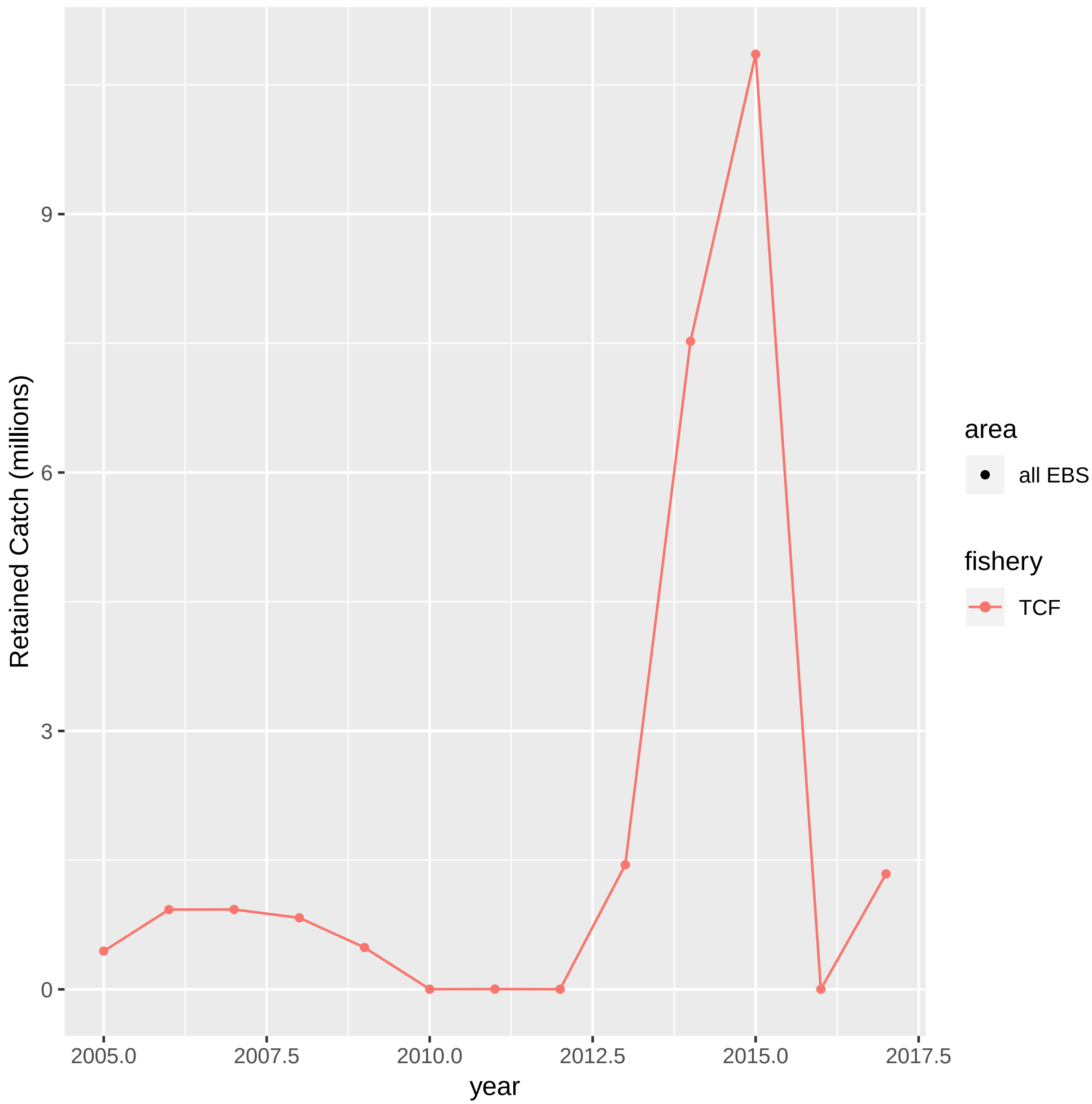

Figure 4: Total retained Tanner crab catch, in millions of crab.

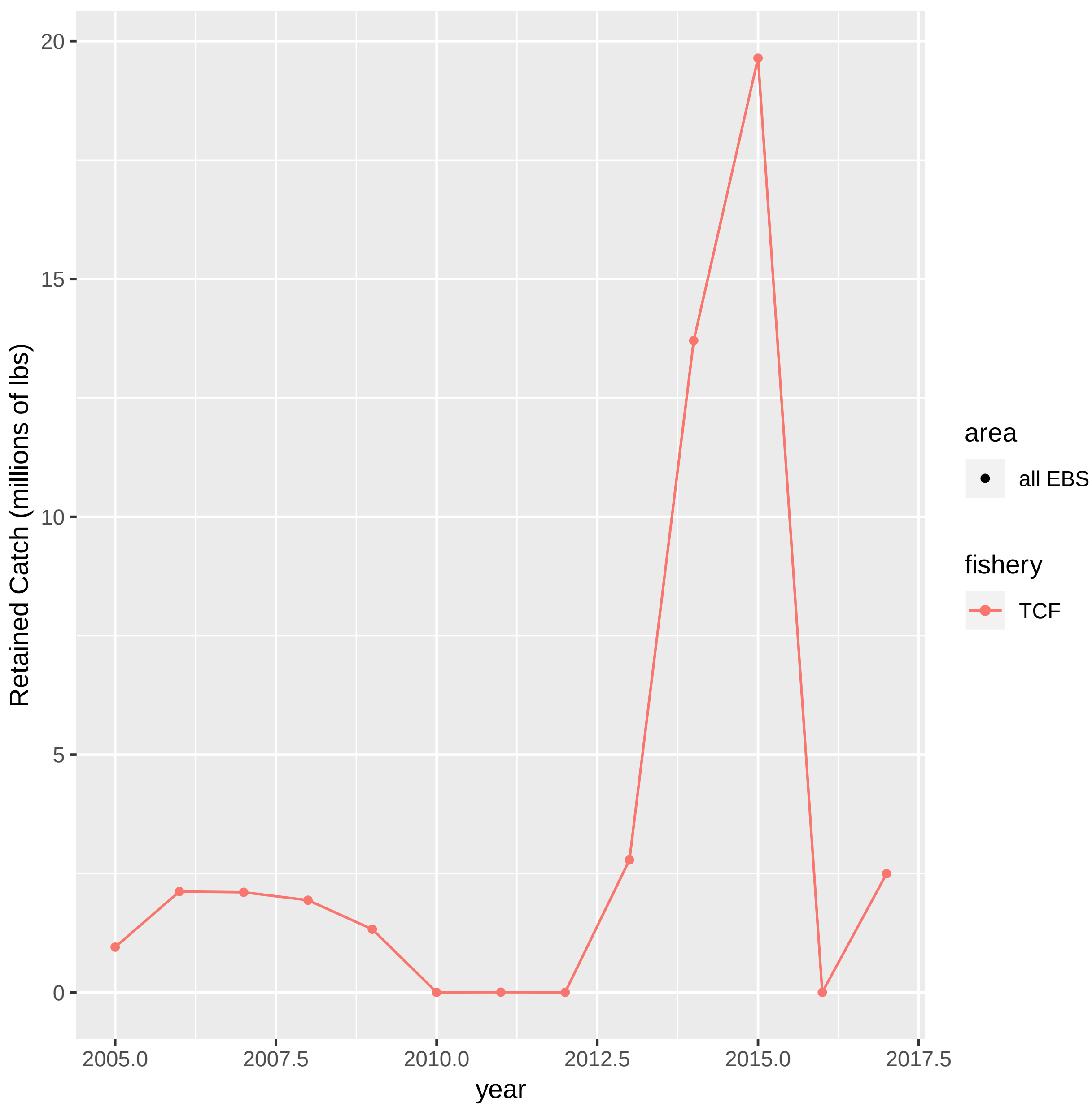

Figure 5: Total retained Tanner crab catch, in millions of pounds.

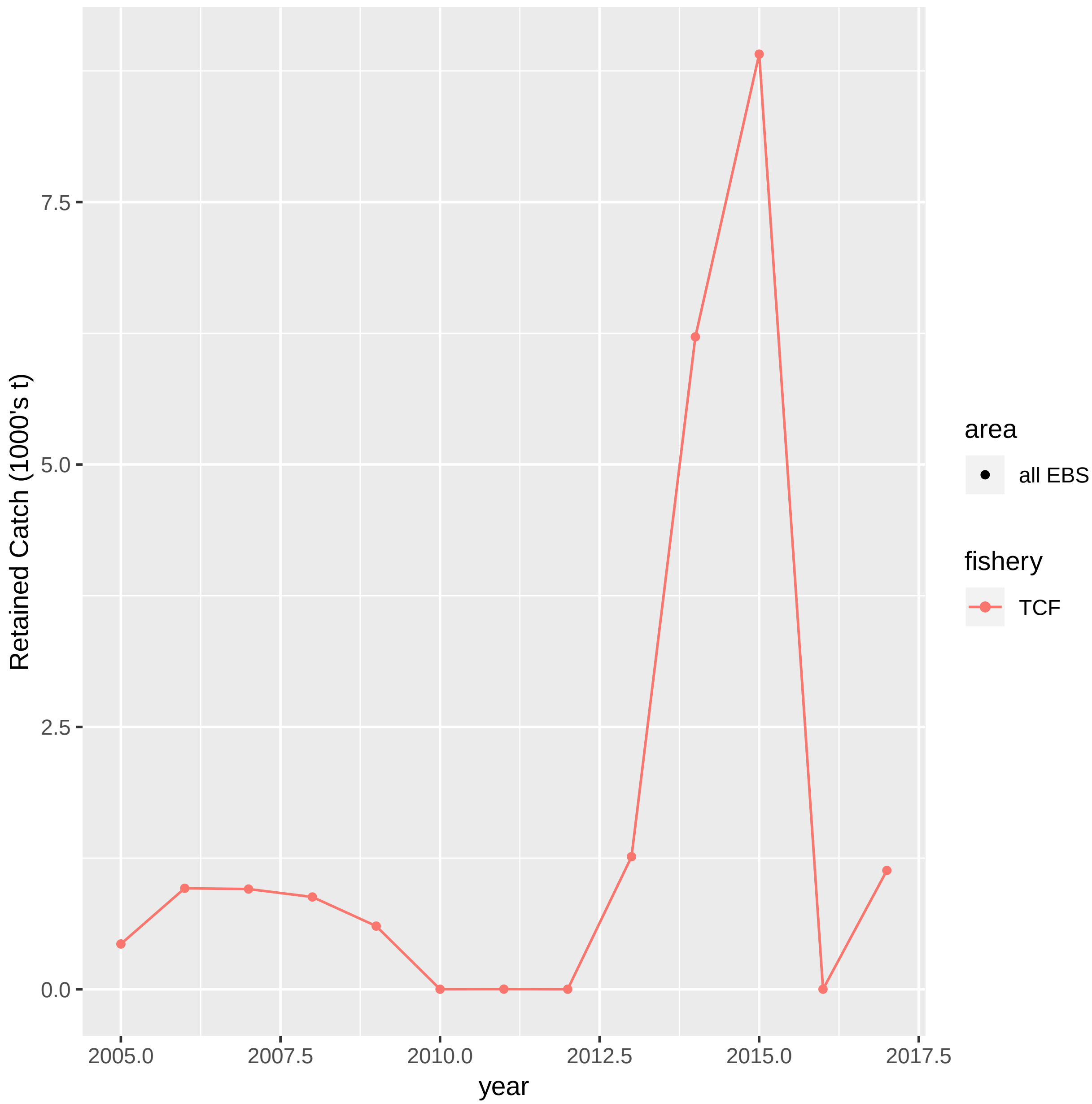

Figure 6: Total retained Tanner crab catch, in 1000's t.

Table 2: All retained catch of Tanner crab since 2005.

year	Abundance	Biomass (lbs)	Biomass (kg)
2005	443,977	952,887	432,222
2006	926,103	2,122,589	962,791
2007	927,164	2,106,654	955,564
2008	830,369	1,939,583	879,782
2009	485,963	1,328,356	602,533
2010	1,695	2,550	1,157
2011	3,095	4,612	2,092
2012	1,647	2,456	1,114
2013	1,445,768	2,786,845	1,264,092
2014	7,522,844	13,704,427	6,216,231
2015	10,856,418	19,642,378	8,909,643
2016	1,766	2,642	1,198
2017	1,340,394	2,497,033	1,132,637

Size compositions

This section calculates size compositions from ADFG dockside sampling for retained Tanner crab in the directed fisheries.

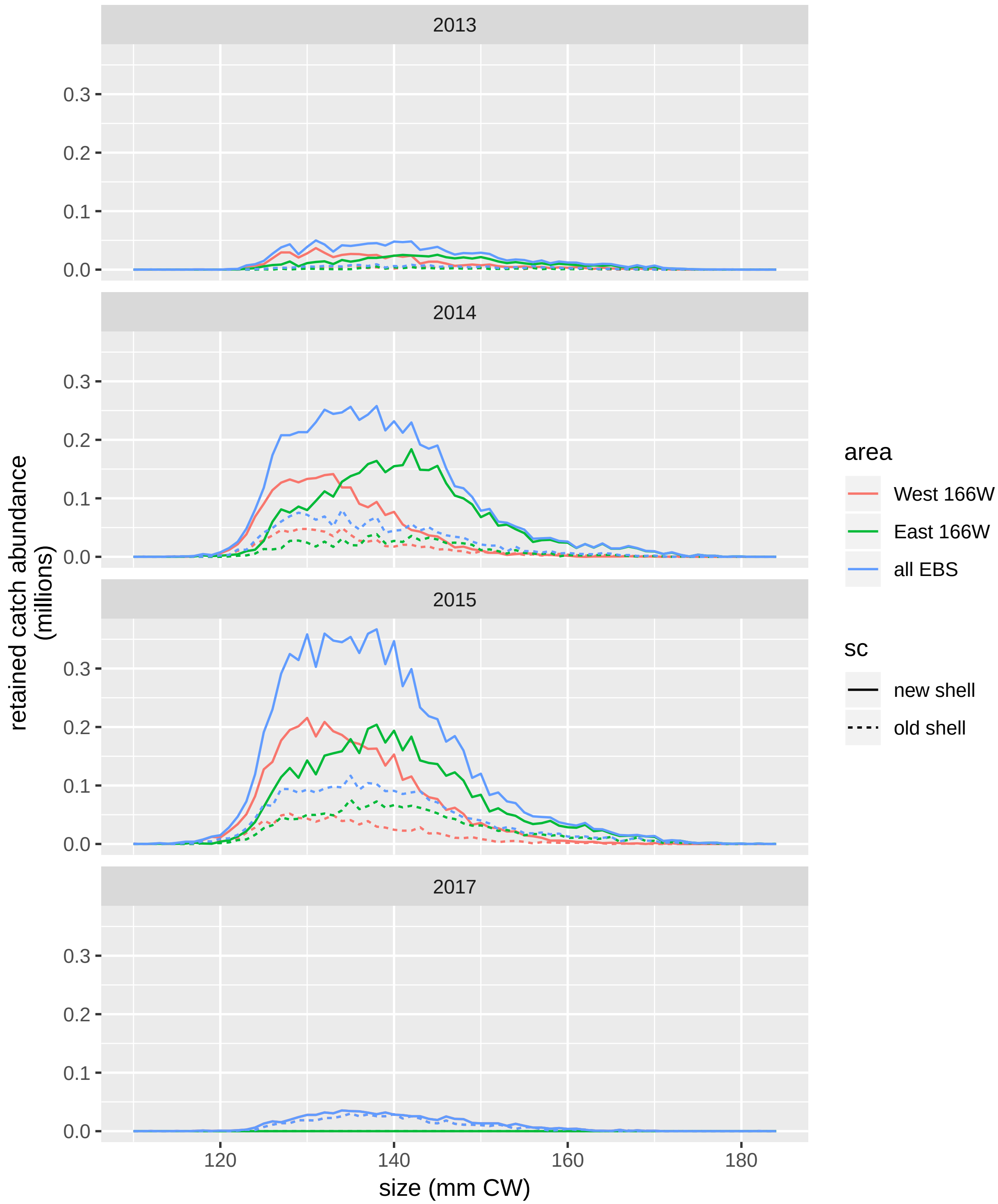

Figure 7: Retained catch size compositions at 1-mm bin size.

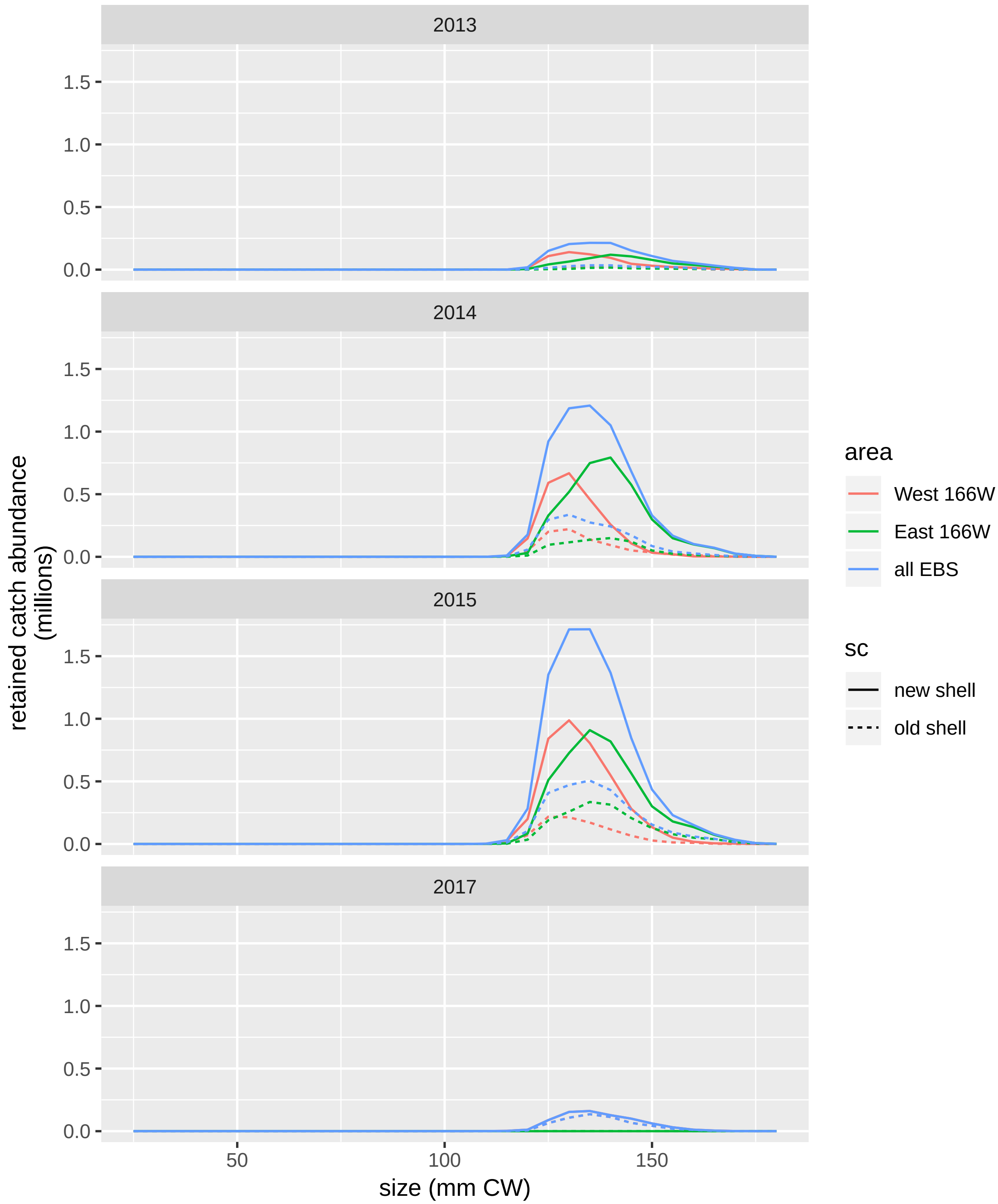

Figure 8: Retained catch size compositions at 5-mm bin size.

Appendix B:

Total Catch Data from ADFG for the Tanner Crab Assessment

William Stockhausen

01 September, 2018

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List of Figures

Introduction

This report calculates total catch abundance and biomass, as well as total catch size compositions, of Tanner crab in the crab fisheries from “at sea” observer sampling.

Total catch abundance and biomass

Time series of total catch abundance and biomass, based on ADFG “at sea” observer sampling in the crab fisheries, are calculated in this section.

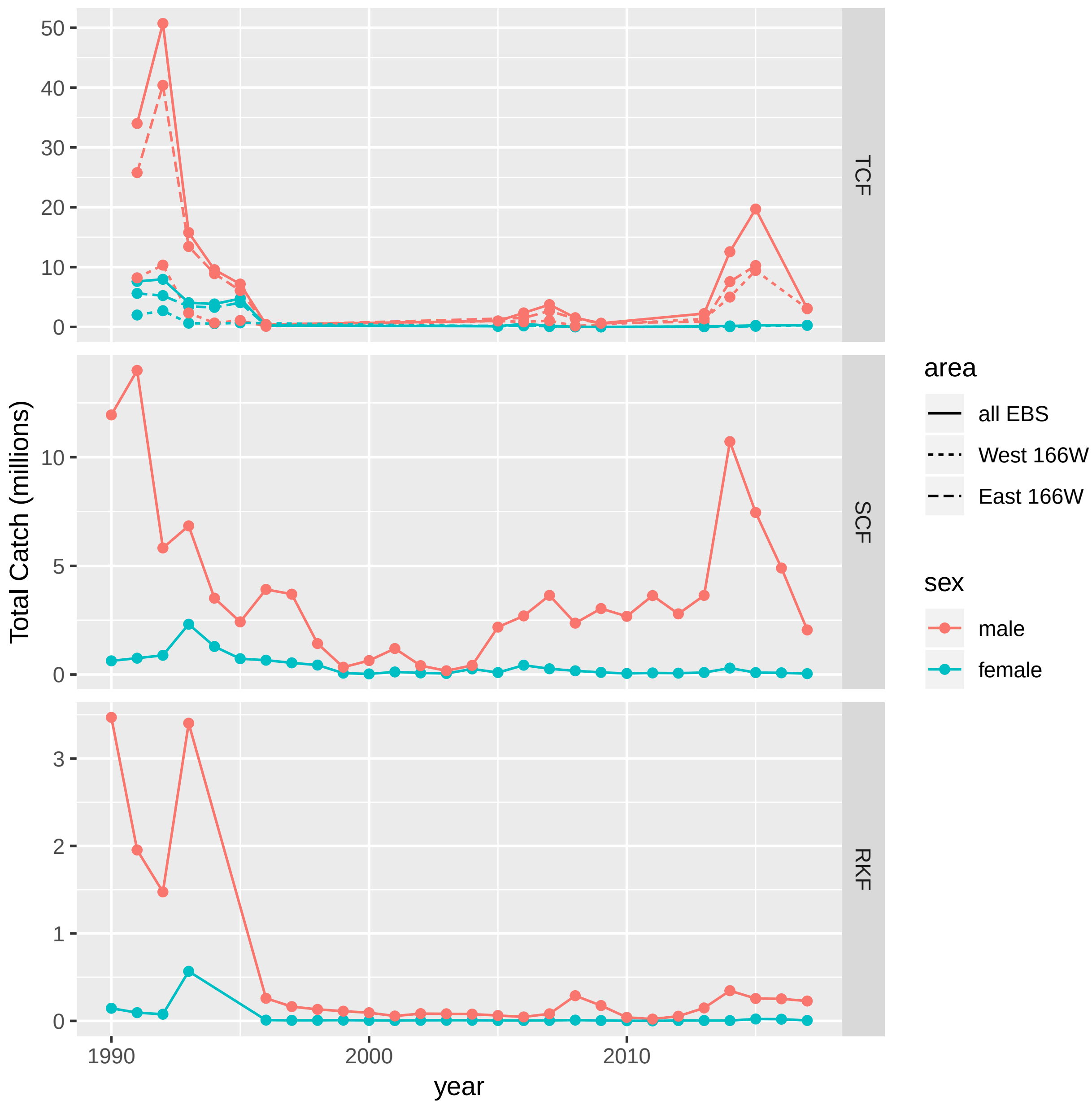

Figure 1: Total Tanner crab catch, in millions of crab. TCF: directed Tanner crab fisheries; SCF: snow crab fishery; RKF: BBRKC fishery.

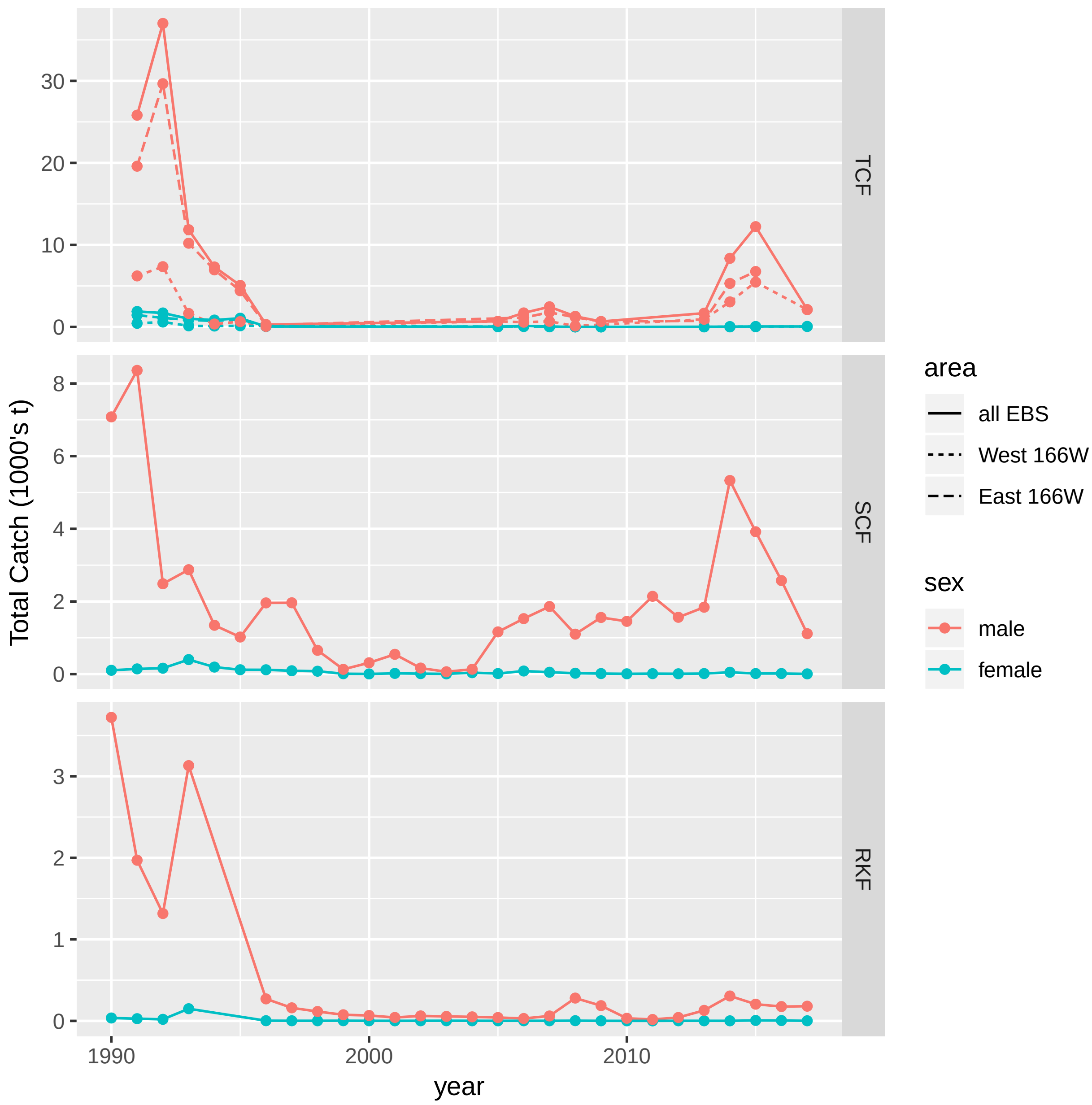

Figure 2: Total Tanner crab catch, in 1000's t. TCF: directed Tanner crab fisheries; SCF: snow crab fishery; RKF: BBRKC fishery.

Table 1: Total catch biomass of Tanner crab, by fishery. TCF: directed Tanner crab fisheries, SCF: snow crab fishery, RKF: BBRKC fishery.

	RKF		SCF		TCF					
	female	male	female	male	female			male		
	all EBS	all EBS	all EBS	all EBS	all EBS	East 166W	West 166W	all EBS	East 166W	West 166W
year	mt	mt	mt	mt	mt	mt	mt	mt	mt	mt
1990	35.64	3,722.41	105.73	7,081.22	0.00	0.00	0.00	0.00	0.00	0.00
1991	27.18	1,970.28	144.02	8,360.16	1,886.07	1,445.22	440.85	25,817.33	19,596.68	6,220.65
1992	19.04	1,316.69	162.54	2,487.22	1,703.58	1,104.00	599.58	37,007.42	29,660.41	7,347.01
1993	149.30	3,130.82	400.37	2,874.41	996.27	860.14	136.13	11,853.88	10,209.95	1,643.92
1994	0.00	0.00	194.21	1,345.11	841.65	729.27	112.37	7,315.42	6,958.13	357.29
1995	0.00	0.00	120.90	1,021.03	1,064.94	924.20	140.74	5,065.51	4,415.22	650.29
1996	2.42	269.98	119.63	1,960.72	56.68	56.68	0.00	300.43	228.61	71.82
1997	1.66	160.14	92.66	1,963.67	0.00	0.00	0.00	0.00	0.00	0.00
1998	1.66	115.22	80.36	655.94	0.00	0.00	0.00	0.00	0.00	0.00
1999	2.24	75.09	11.19	131.78	0.00	0.00	0.00	0.00	0.00	0.00
2000	1.36	66.40	6.06	312.83	0.00	0.00	0.00	0.00	0.00	0.00
2001	0.96	42.20	20.53	545.31	0.00	0.00	0.00	0.00	0.00	0.00
2002	1.58	61.25	13.81	167.18	0.00	0.00	0.00	0.00	0.00	0.00
2003	1.85	54.94	7.01	64.74	0.00	0.00	0.00	0.00	0.00	0.00
2004	1.65	49.76	39.90	134.62	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.99	41.42	16.26	1,162.84	23.75	0.00	23.75	684.59	0.00	684.59
2006	1.48	29.52	85.52	1,527.25	121.12	48.83	72.29	1,711.37	1,132.14	579.23
2007	1.42	60.56	52.06	1,861.59	44.11	29.30	14.81	2,458.98	1,779.10	679.88
2008	2.54	279.90	24.93	1,100.27	8.15	6.66	1.50	1,296.93	1,177.78	119.14
2009	1.14	186.51	15.67	1,559.56	2.27	2.27	0.00	664.59	664.59	0.00
2010	0.55	31.92	9.18	1,453.26	0.00	0.00	0.00	0.00	0.00	0.00
2011	0.07	17.47	13.27	2,141.35	0.00	0.00	0.00	0.00	0.00	0.00
2012	1.31	42.11	10.30	1,564.34	0.00	0.00	0.00	0.00	0.00	0.00
2013	1.26	128.94	15.63	1,841.75	23.47	12.11	11.36	1,679.31	746.21	933.10
2014	1.00	305.41	50.67	5,330.04	39.23	8.77	30.47	8,363.59	5,306.59	3,057.01
2015	5.58	204.96	16.82	3,919.18	57.61	28.22	29.39	12,228.99	6,761.44	5,467.55
2016	4.22	175.69	16.70	2,575.70	0.00	0.00	0.00	0.00	0.00	0.00
2017	1.41	180.09	7.04	1,113.36	59.68	0.00	59.68	2,112.81	0.00	2,112.81

Table 2: Total catch abundance of Tanner crab, by fishery. TCF: directed Tanner crab fisheries, SCF: snow crab fishery, RKF: BBRKC fishery.

	RKF		SCF		TCF					
	female	male	female	male		female			male	
	all EBS	all EBS	all EBS	all EBS	all EBS	East 166W	West 166W	all EBS	East 166W	West 166W
year	abundance	abundance	abundance	abundance	abundance	abundance	abundance	abundance	abundance	abundance
1990	144,519	3,470,323	628,540	11,946,455	0	0	0	0	0	0
1991	94,536	1,954,295	752,183	13,995,237	7,613,128	5,611,845	2,001,283	34,001,956	25,791,525	8,210,431
1992	76,307	1,474,805	883,319	5,822,832	7,963,454	5,244,846	2,718,608	50,720,836	40,384,938	10,335,898
1993	567,133	3,403,707	2,314,901	6,841,229	4,063,605	3,429,524	634,081	15,784,117	13,437,551	2,346,566
1994	0	0	1,288,914	3,513,409	3,843,603	3,276,083	567,520	9,574,296	8,907,460	666,836
1995	0	0	727,241	2,422,642	4,741,446	4,057,738	683,708	7,177,419	6,083,963	1,093,456
1996	9,176	258,772	659,274	3,916,480	237,860	237,860	0	429,188	327,545	101,643
1997	6,484	163,621	536,997	3,696,981	0	0	0	0	0	0
1998	6,572	131,814	435,096	1,424,578	0	0	0	0	0	0
1999	8,495	111,285	62,286	336,764	0	0	0	0	0	0
2000	5,566	93,543	27,541	641,659	0	0	0	0	0	0
2001	3,930	56,106	118,268	1,196,100	0	0	0	0	0	0
2002	6,551	83,234	71,990	407,593	0	0	0	0	0	0
2003	7,360	81,335	46,737	172,053	0	0	0	0	0	0
2004	7,285	77,404	256,238	419,793	0	0	0	0	0	0
2005	4,640	61,828	90,020	2,182,048	112,562	0	112,562	1,003,858	0	1,003,858
2006	4,295	45,446	429,048	2,696,848	532,434	187,476	344,958	2,351,931	1,503,408	848,523
2007	5,406	81,214	263,568	3,641,695	193,293	121,601	71,692	3,741,140	2,681,282	1,059,858
2008	9,158	288,275	169,656	2,363,835	35,497	28,094	7,403	1,545,746	1,377,918	167,828
2009	4,254	175,411	97,010	3,034,582	8,471	8,471	0	622,584	622,584	0
2010	1,949	40,511	49,219	2,676,927	0	0	0	0	0	0
2011	260	21,026	72,766	3,633,089	0	0	0	0	0	0
2012	4,191	54,052	63,171	2,790,123	0	0	0	0	0	0
2013	4,334	148,057	90,977	3,640,531	94,077	42,504	51,573	2,241,471	898,607	1,342,864
2014	3,663	345,462	295,965	10,716,381	170,337	36,662	133,675	12,568,858	7,570,310	4,998,548
2015	21,917	256,287	87,919	7,455,464	267,821	119,577	148,244	19,705,314	10,264,176	9,441,138
2016	19,731	252,335	78,433	4,899,984	0	0	0	0	0	0
2017	5,167	227,212	39,956	2,052,032	281,056	0	281,056	3,069,551	0	3,069,551

Size compositions

This section calculates size compositions from ADFG at-sea observer sampling for total Tanner crab in the crab fisheries.

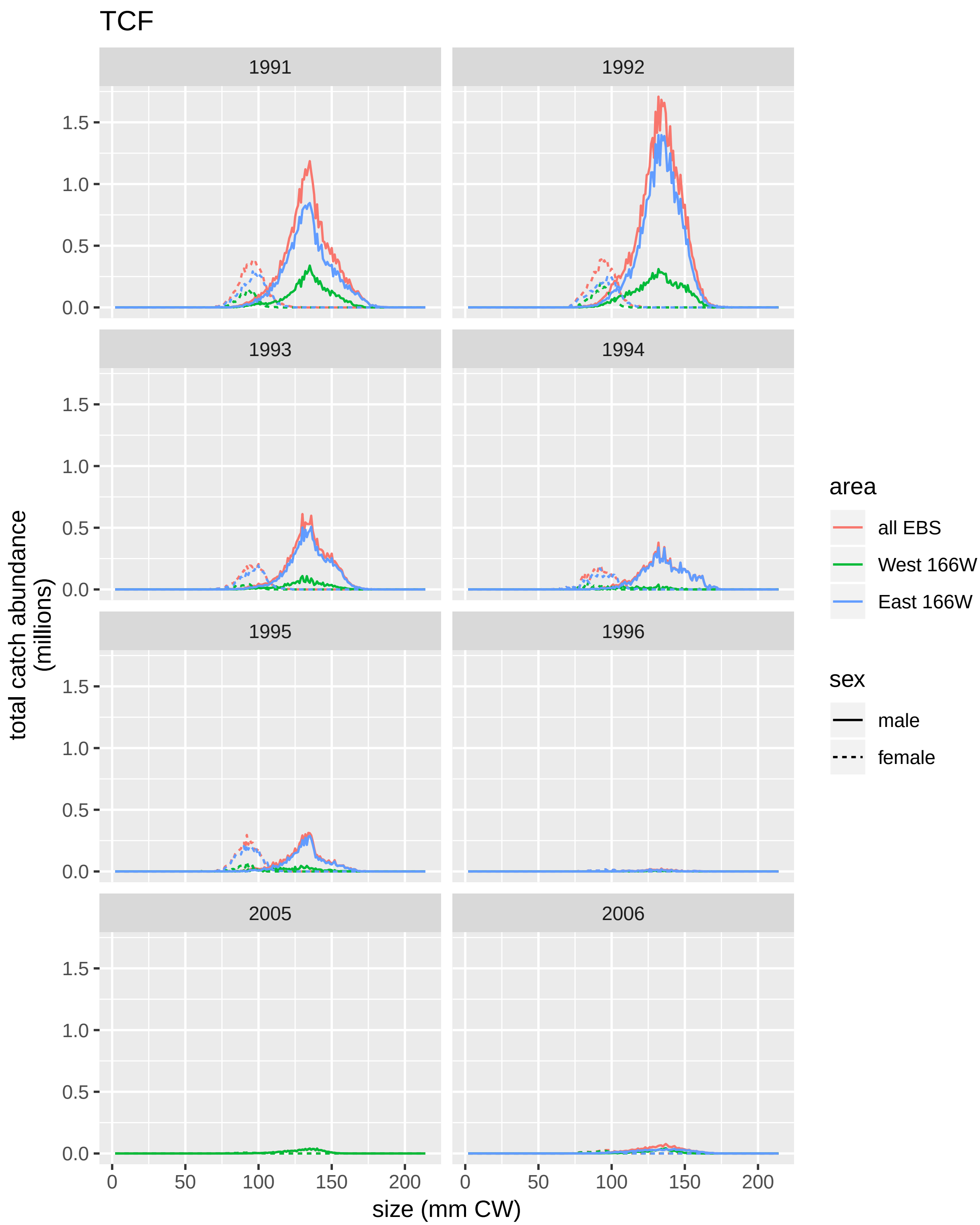

Figure 3: Total catch size compositions for TCF at 1-mm bin size.

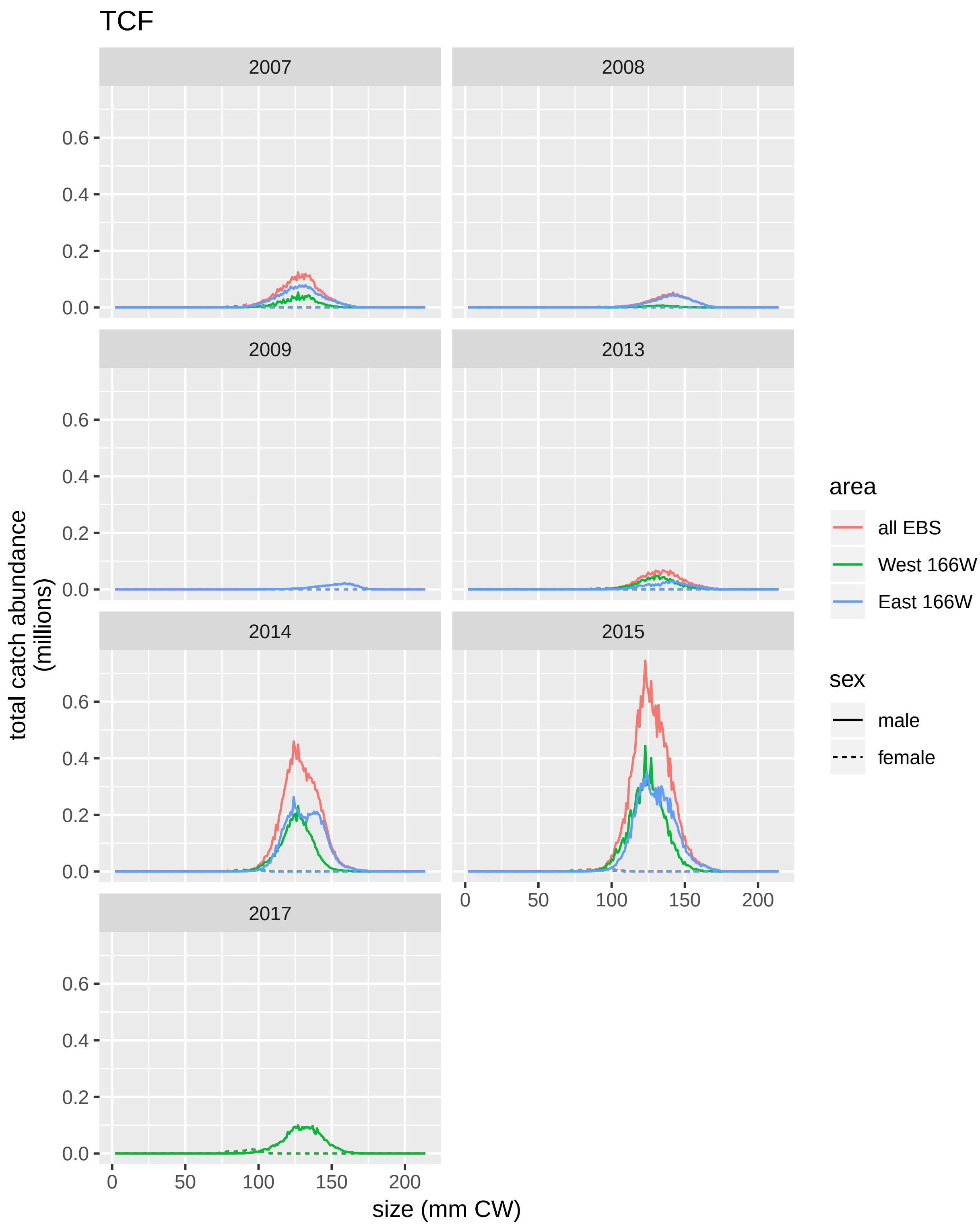

Figure 4: Total catch size compositions for TCF at 1-mm bin size.

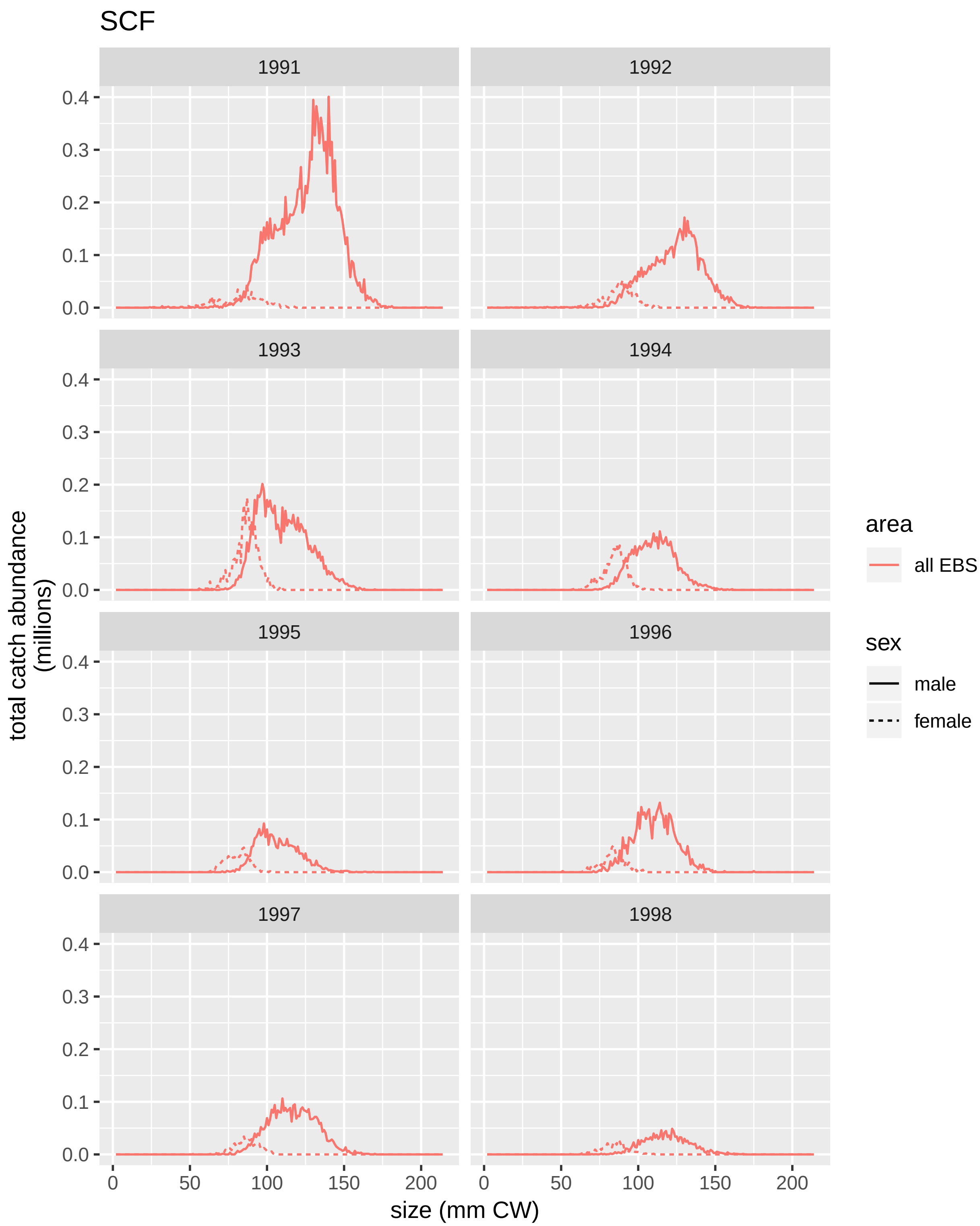

Figure 5: Total catch size compositions for SCF at 1-mm bin size.

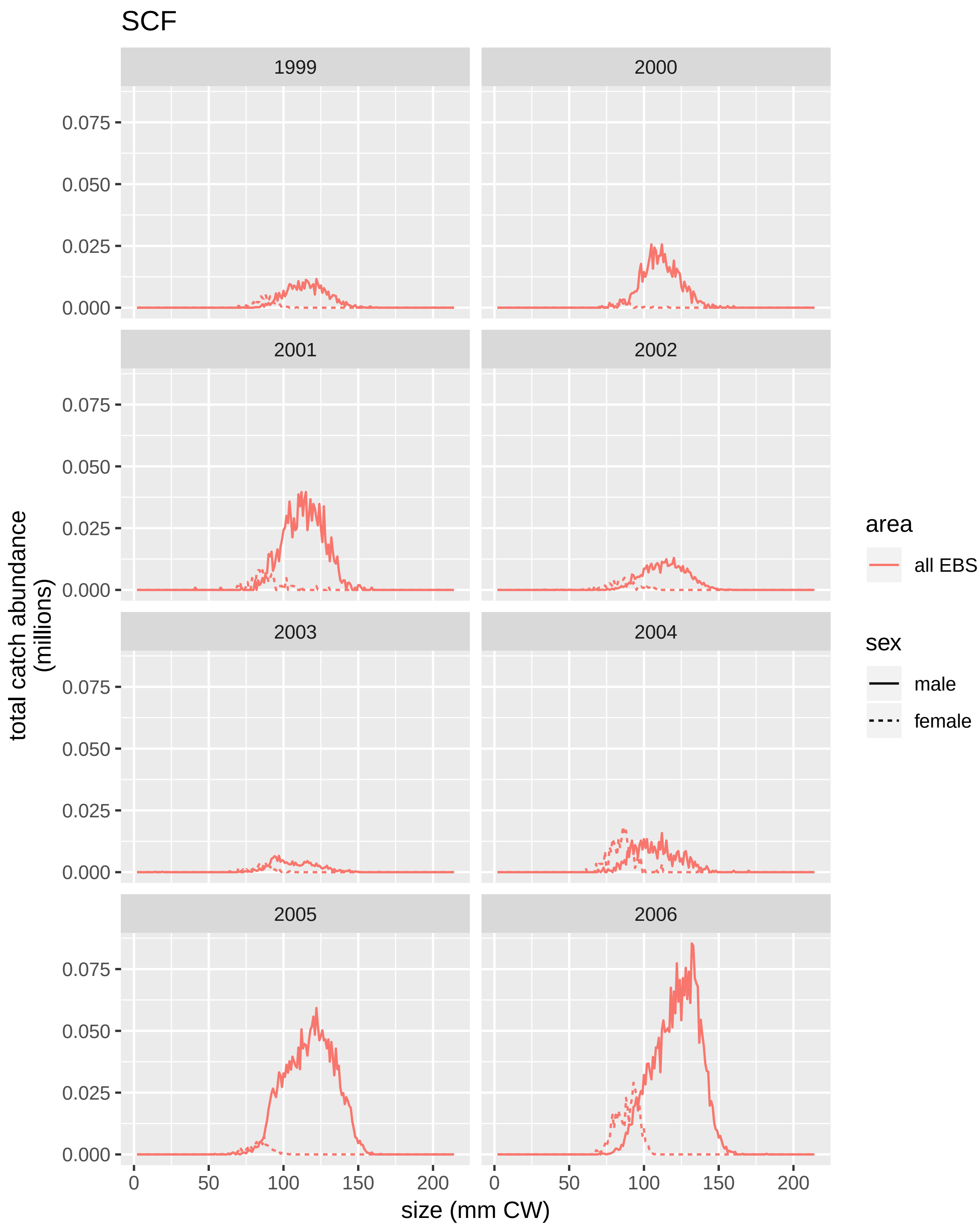

Figure 6: Total catch size compositions for SCF at 1-mm bin size.

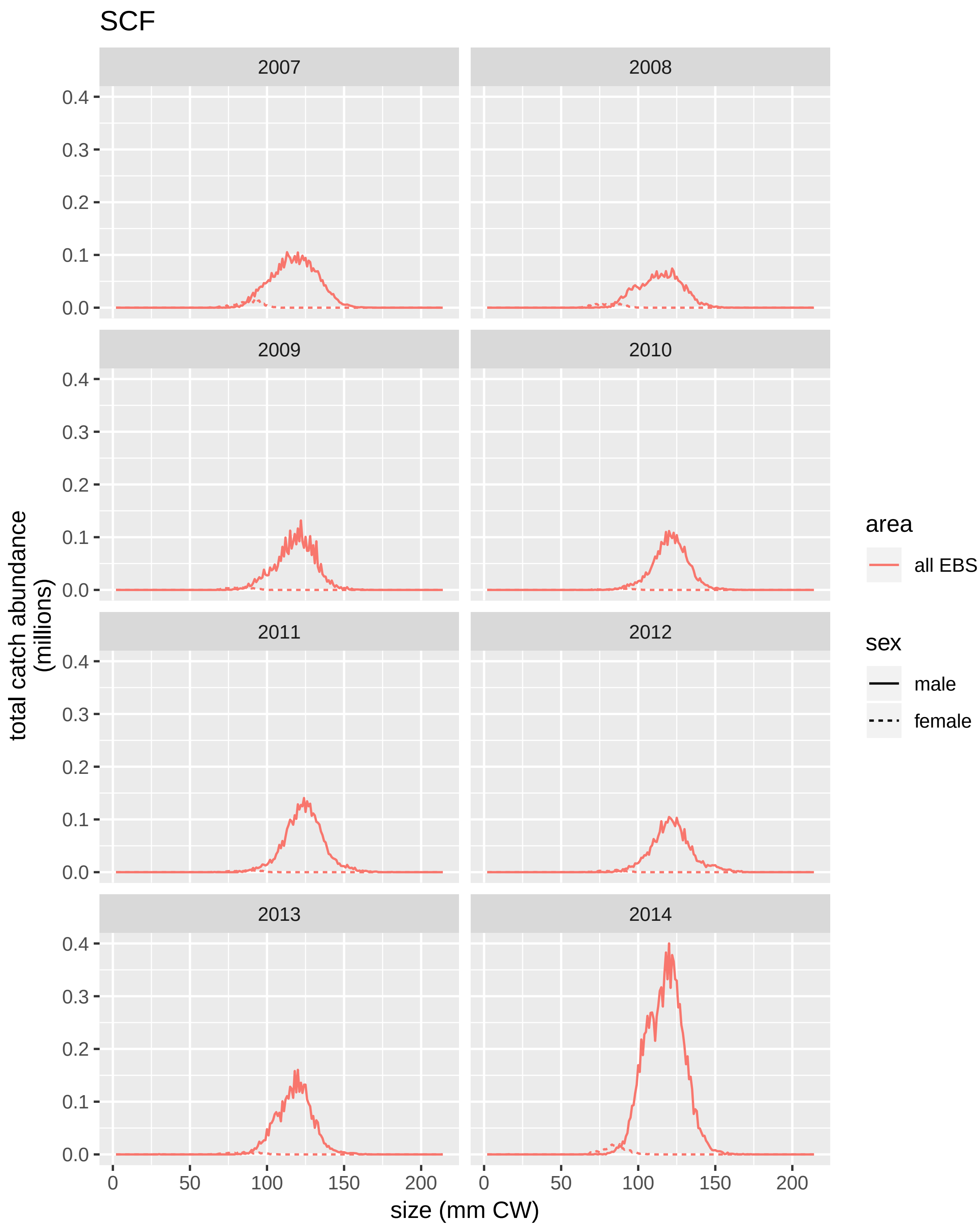

Figure 7: Total catch size compositions for SCF at 1-mm bin size.

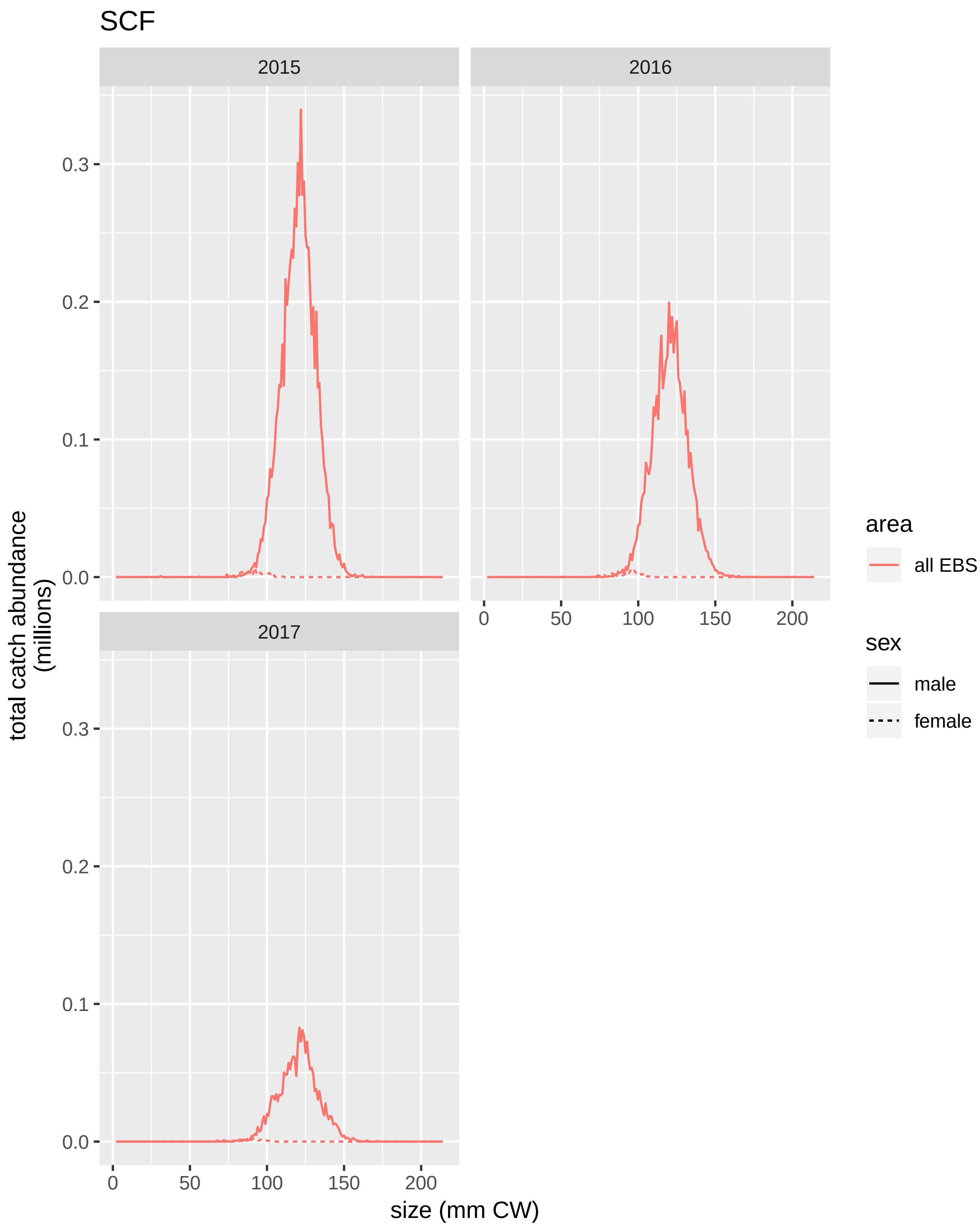

Figure 8: Total catch size compositions for SCF at 1-mm bin size.

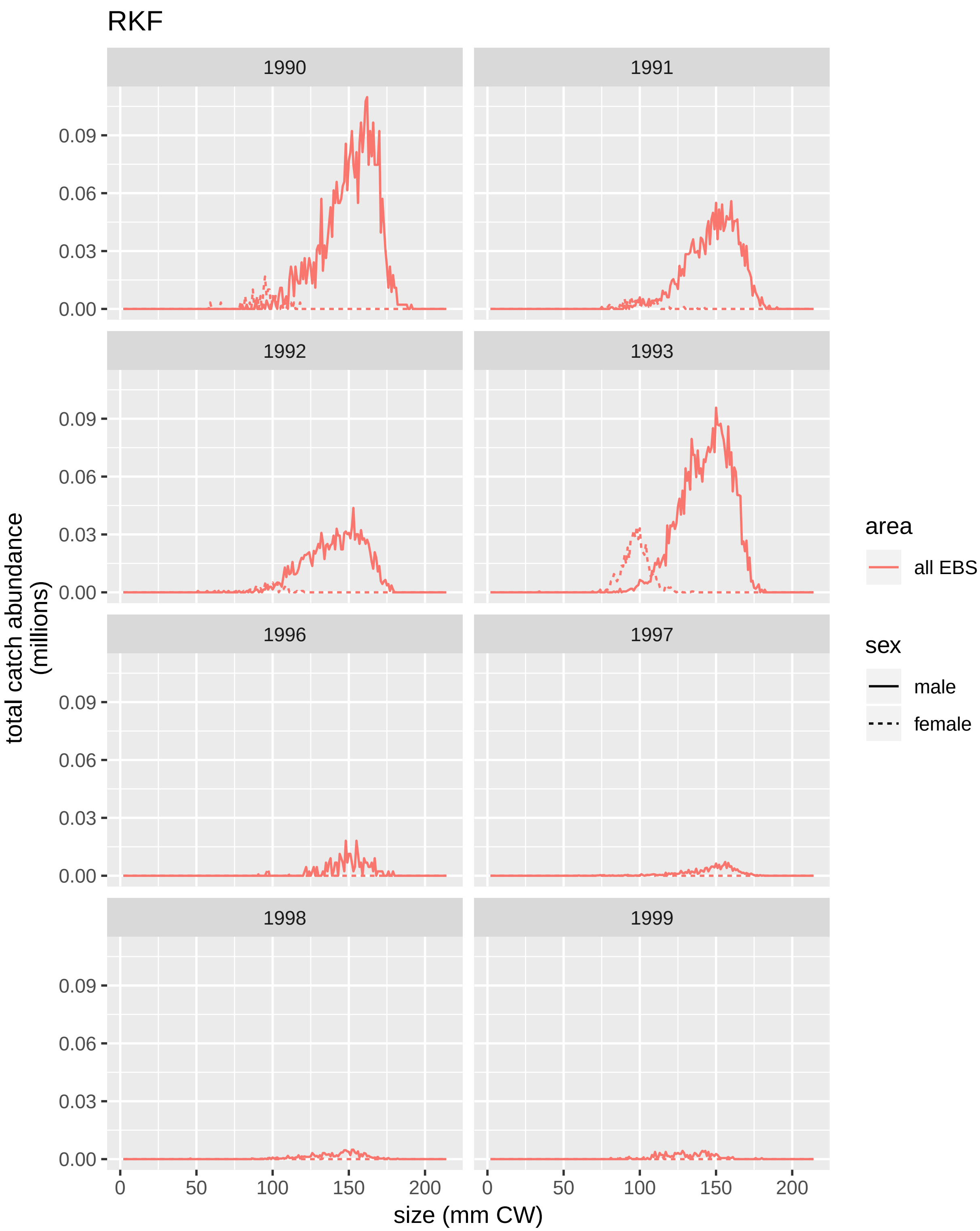

Figure 9: Total catch size compositions for RKF at 1-mm bin size.

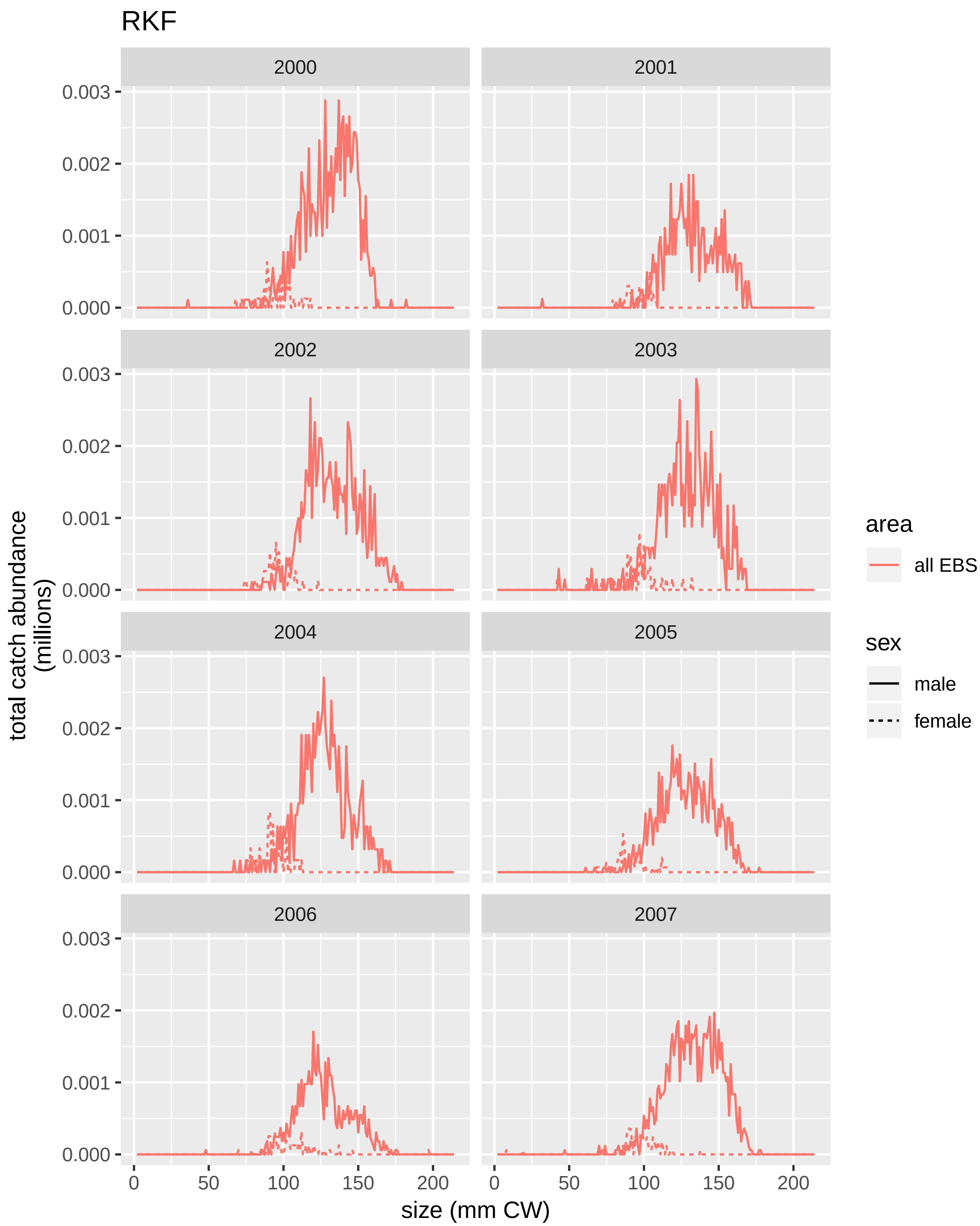

Figure 10: Total catch size compositions for RKF at 1-mm bin size.

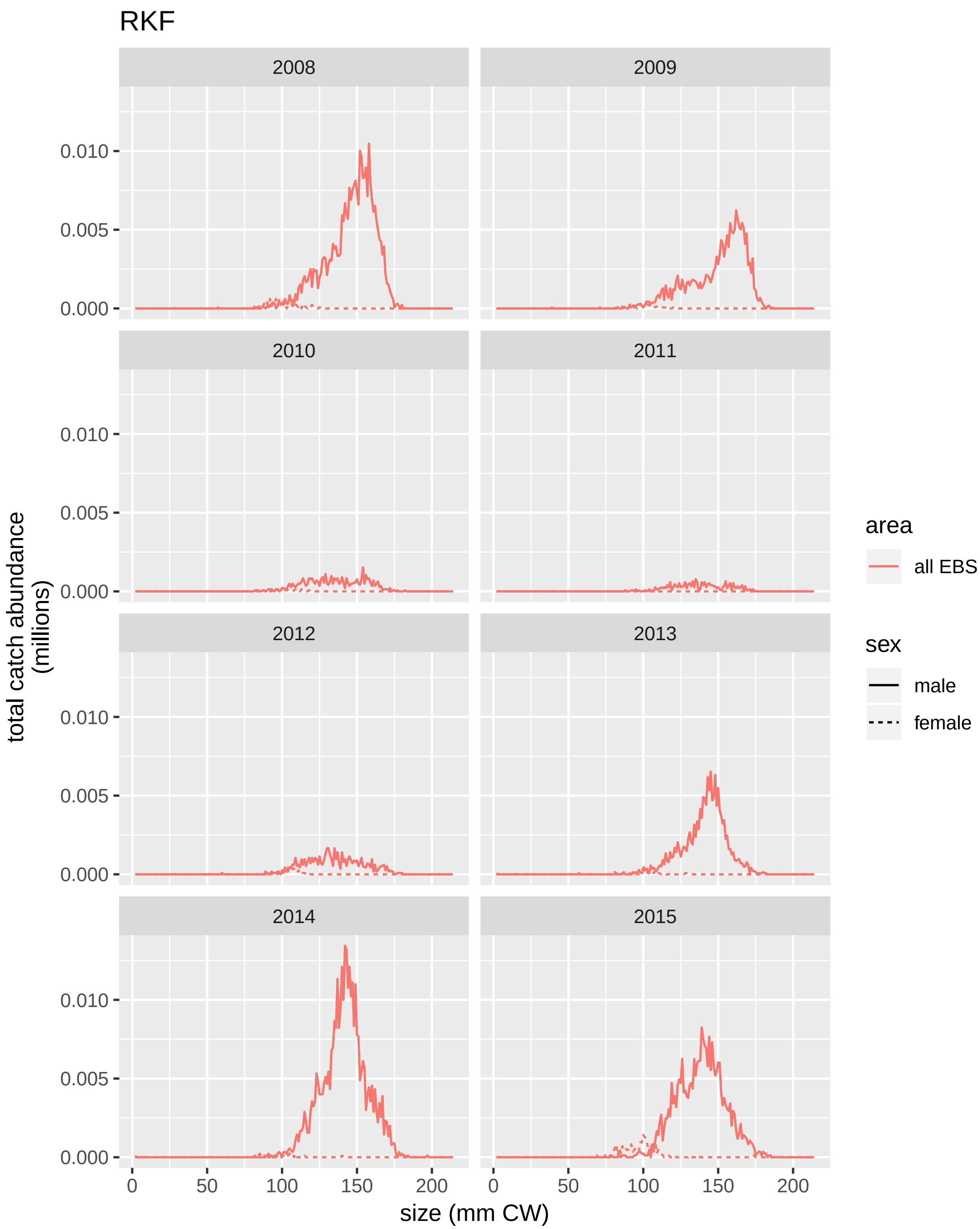

Figure 11: Total catch size compositions for RKF at 1-mm bin size.

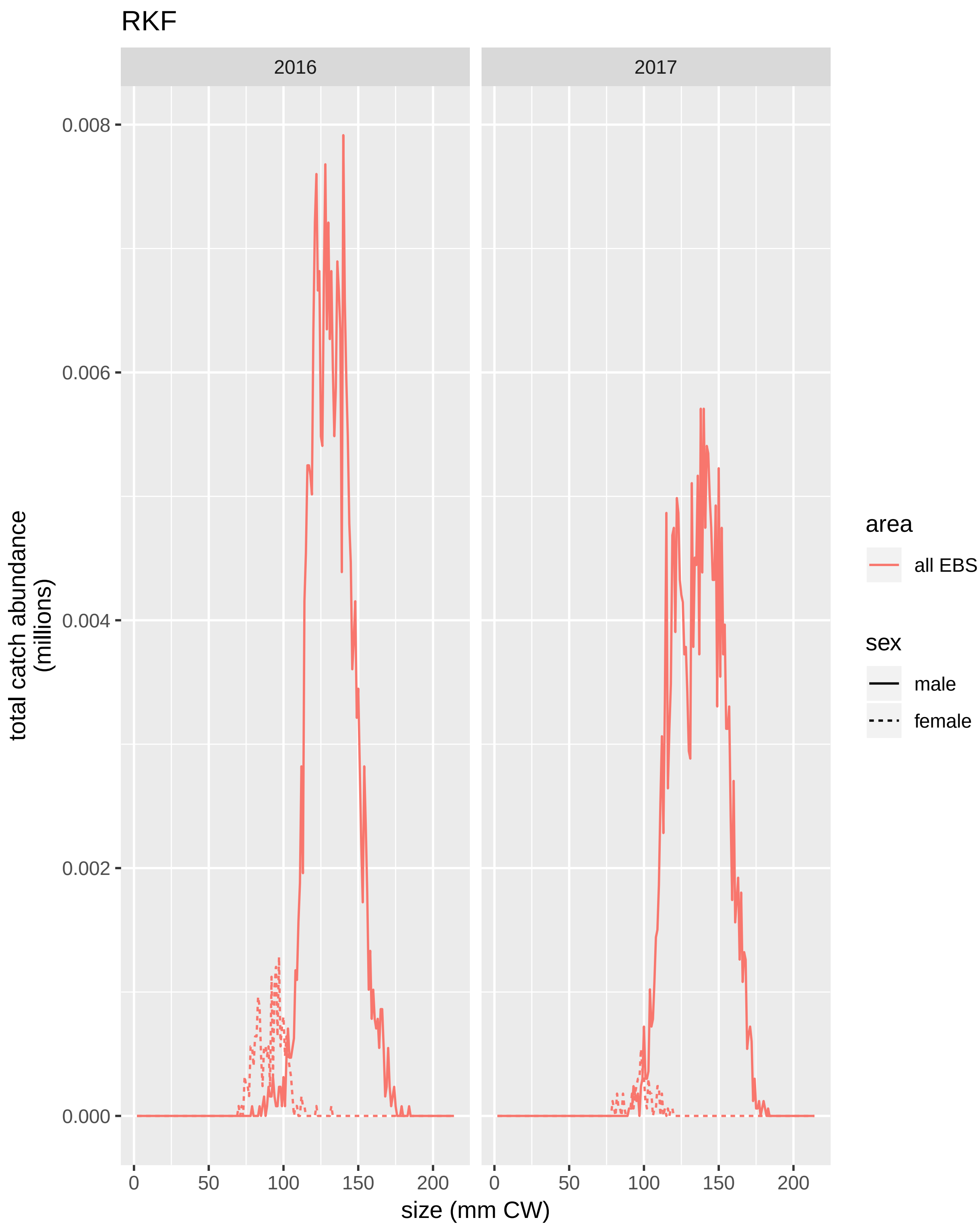

Figure 12: Total catch size compositions for RKF at 1-mm bin size.

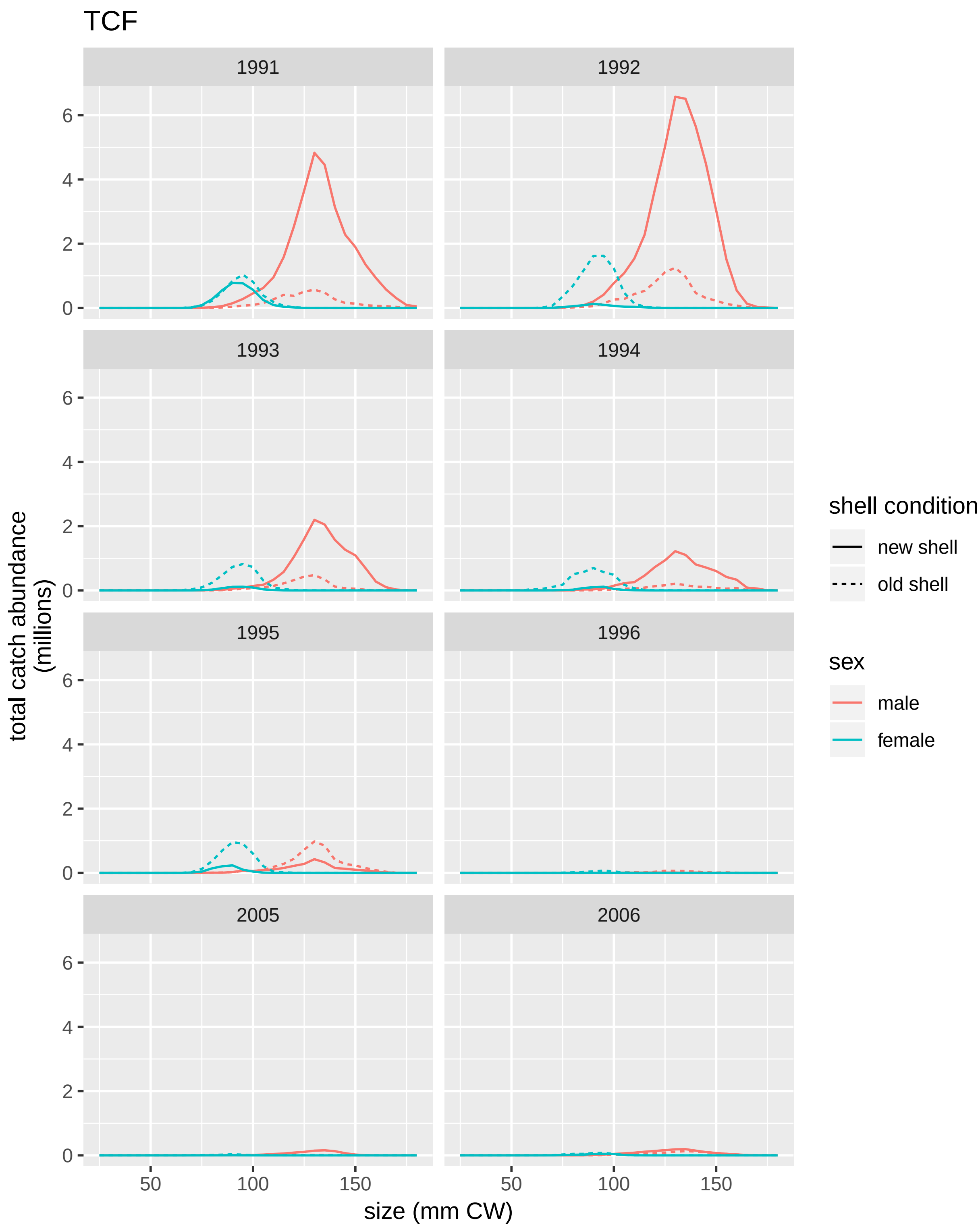

Figure 13: Total catch size compositions for TCF at 5-mm bin size.

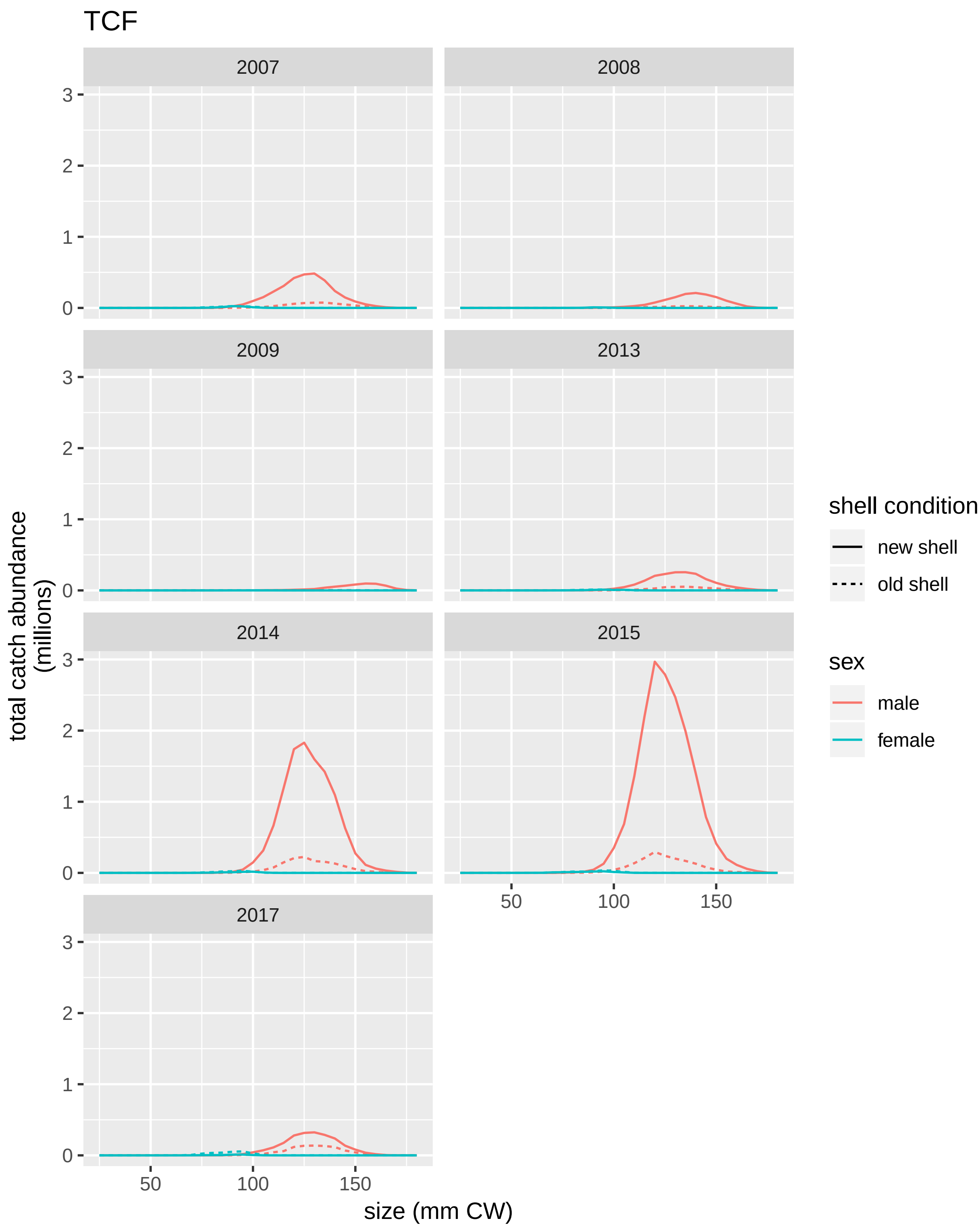

Figure 14: Total catch size compositions for TCF at 5-mm bin size.

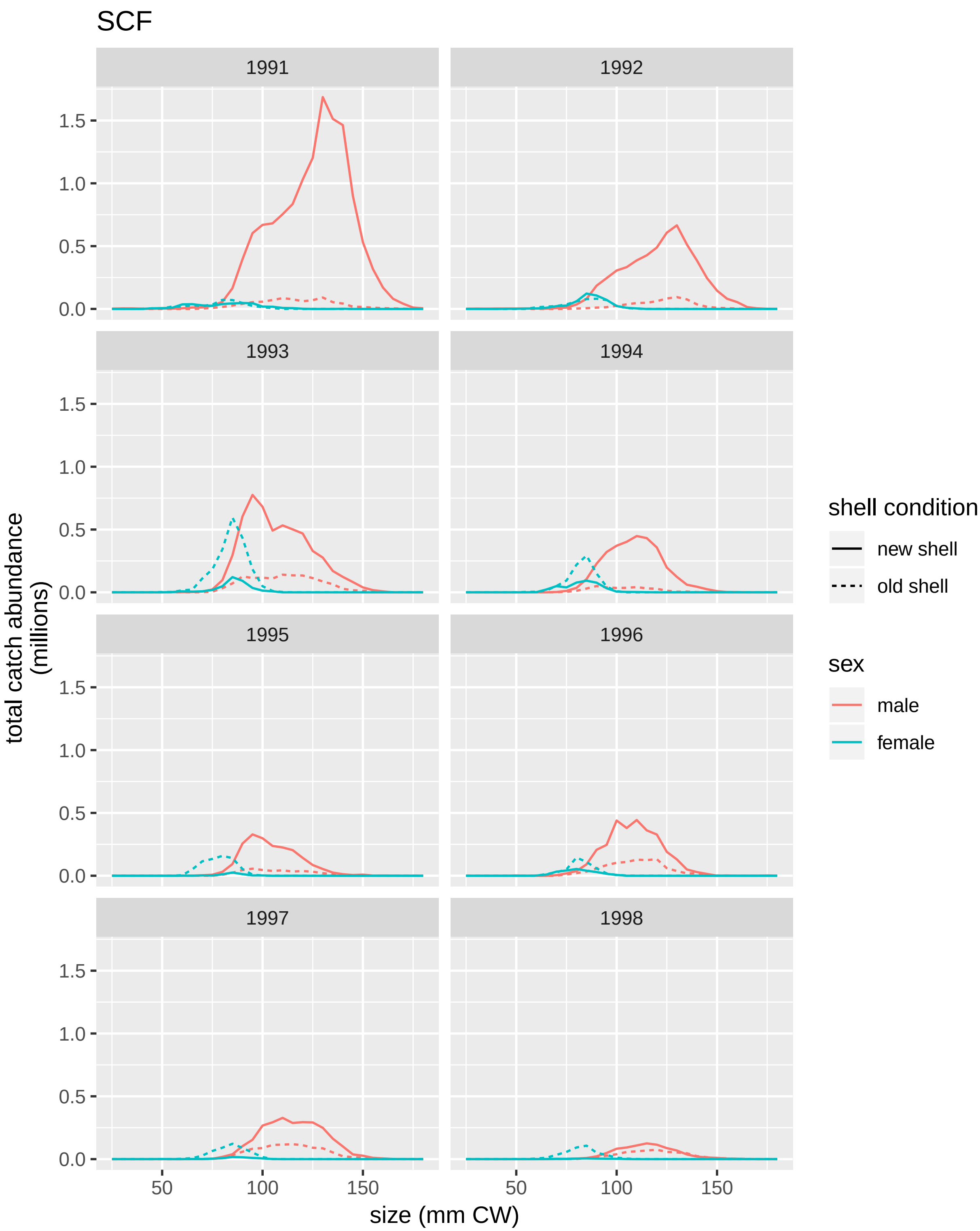

Figure 15: Total catch size compositions for SCF at 5-mm bin size.

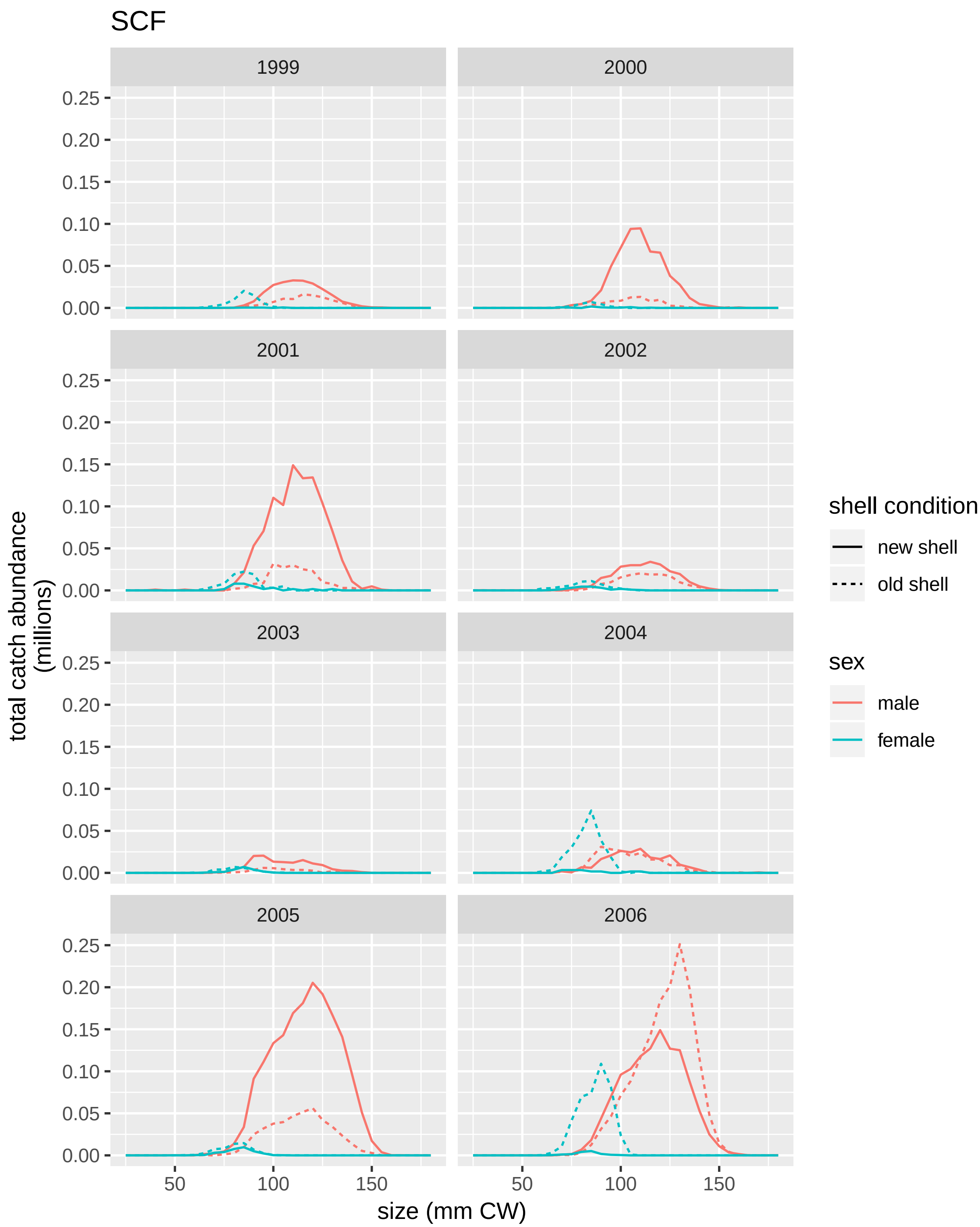

Figure 16: Total catch size compositions for SCF at 5-mm bin size.

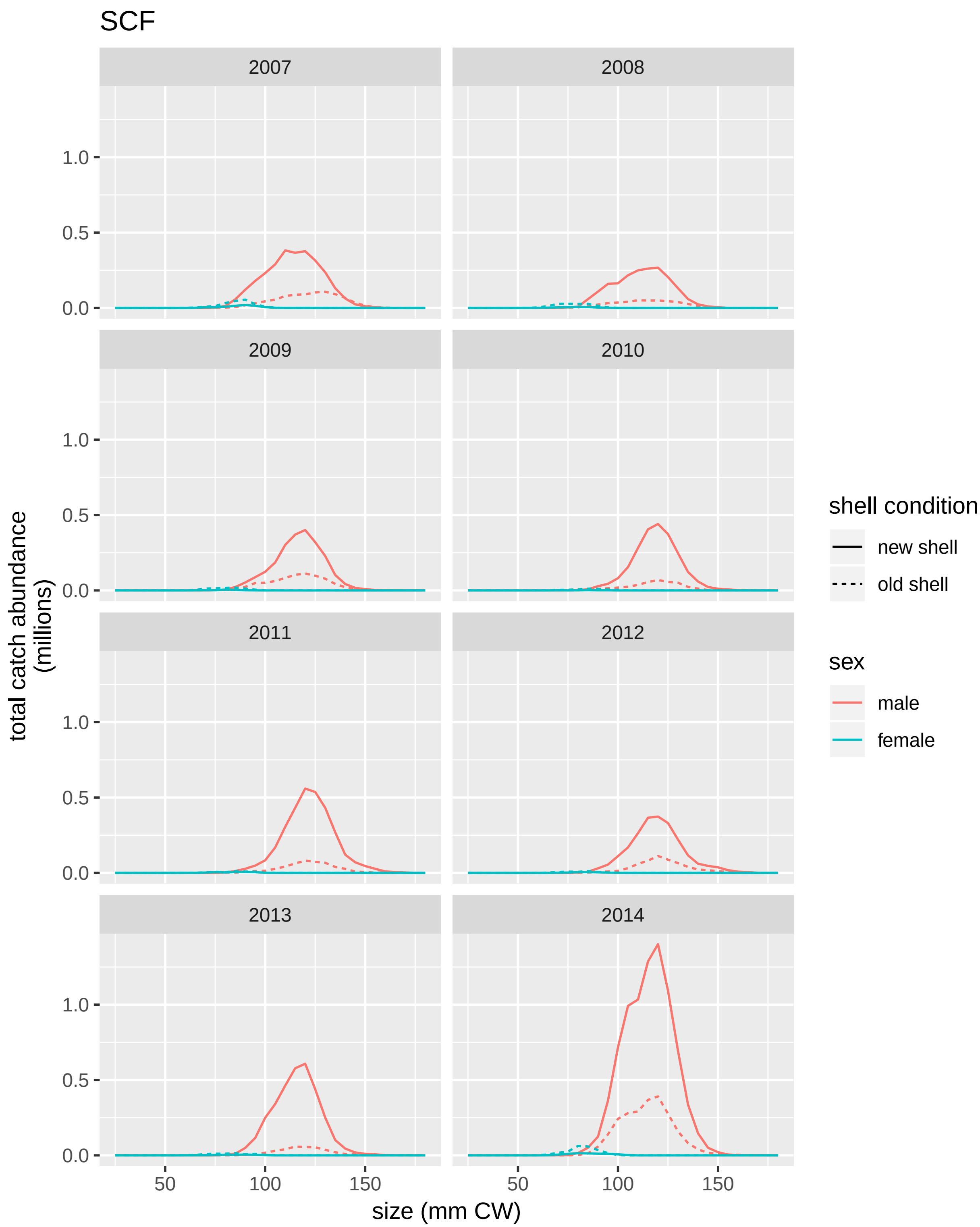

Figure 17: Total catch size compositions for SCF at 5-mm bin size.

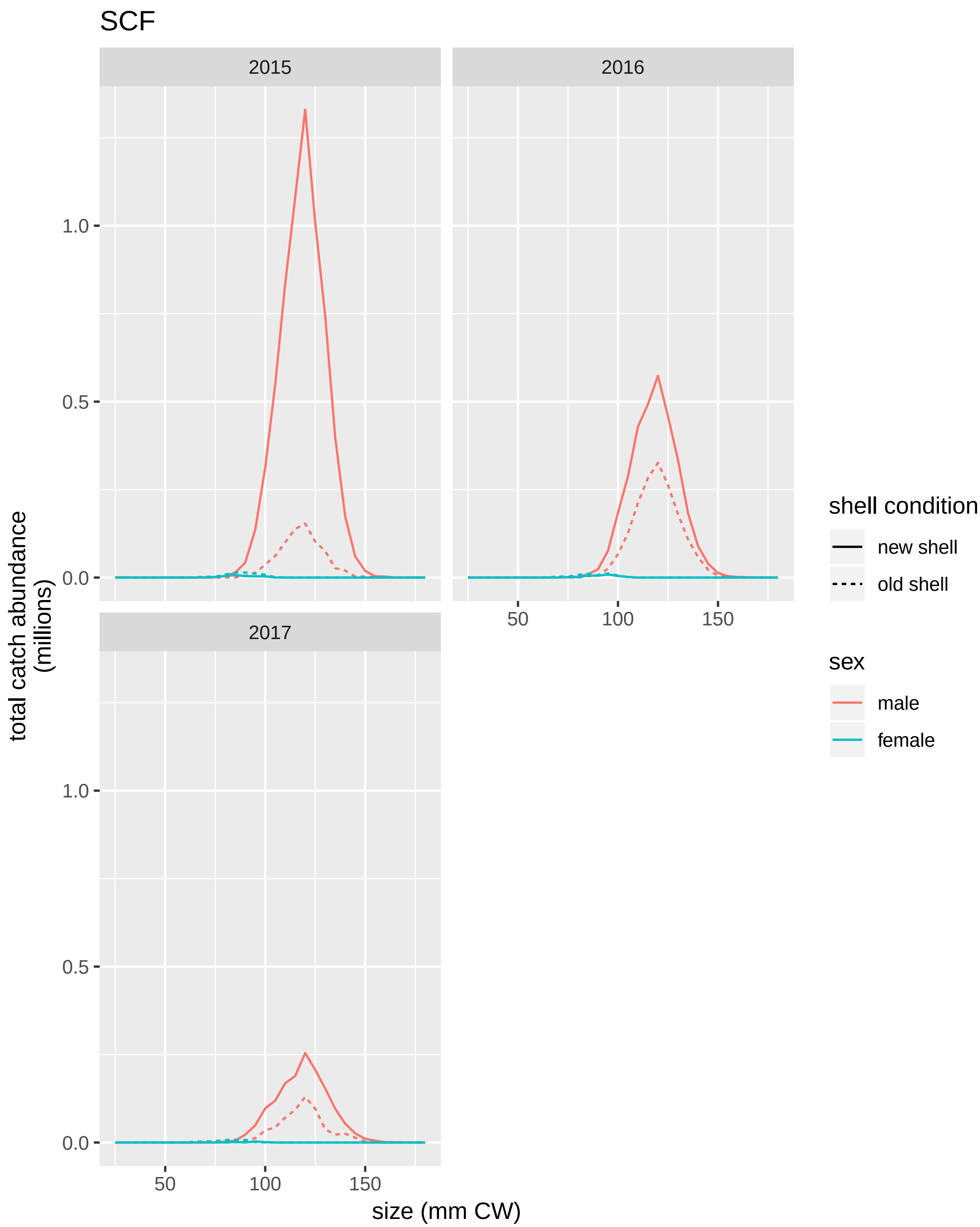

Figure 18: Total catch size compositions for SCF at 5-mm bin size.

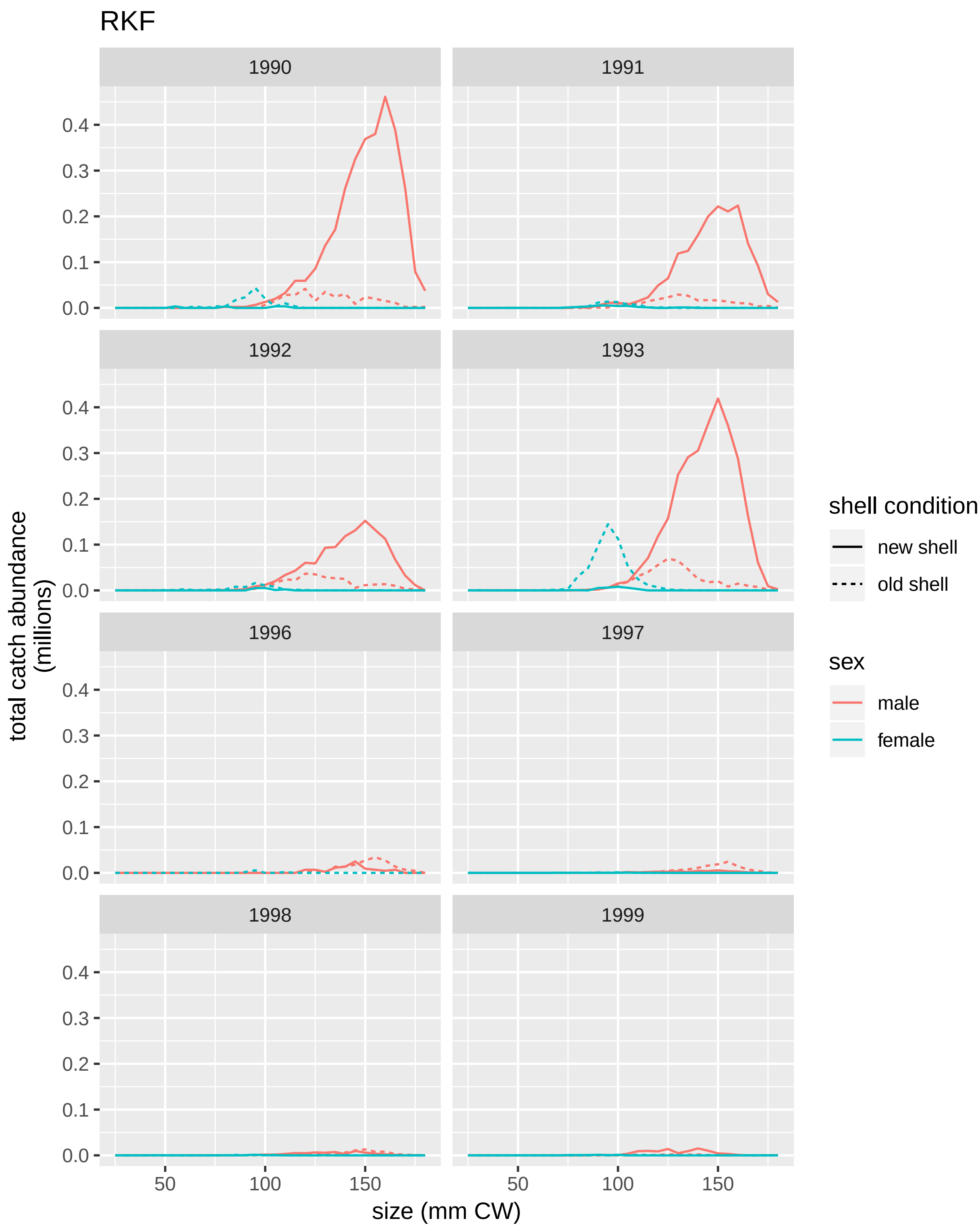

Figure 19: Total catch size compositions for RKF at 5-mm bin size.

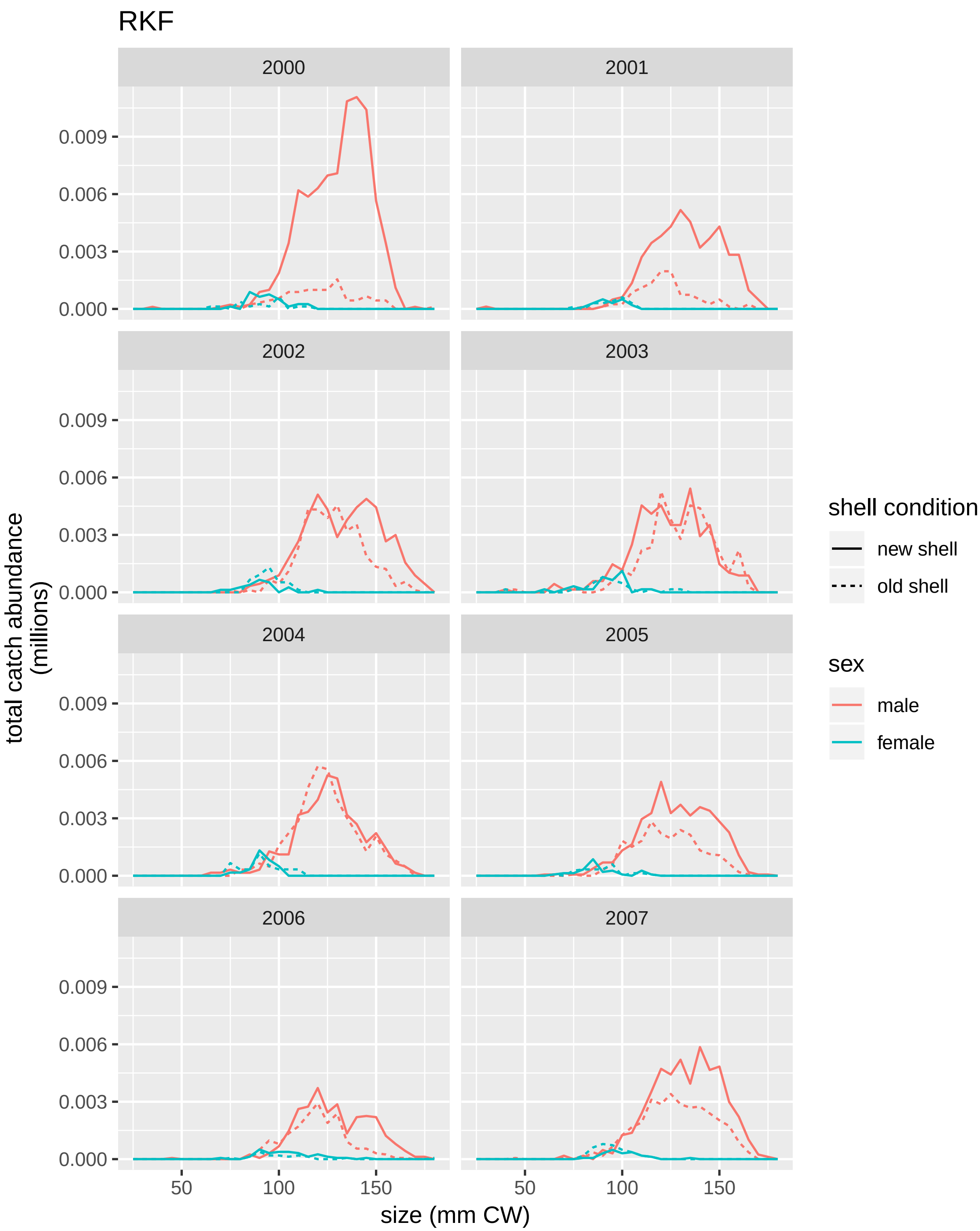

Figure 20: Total catch size compositions for RKF at 5-mm bin size.

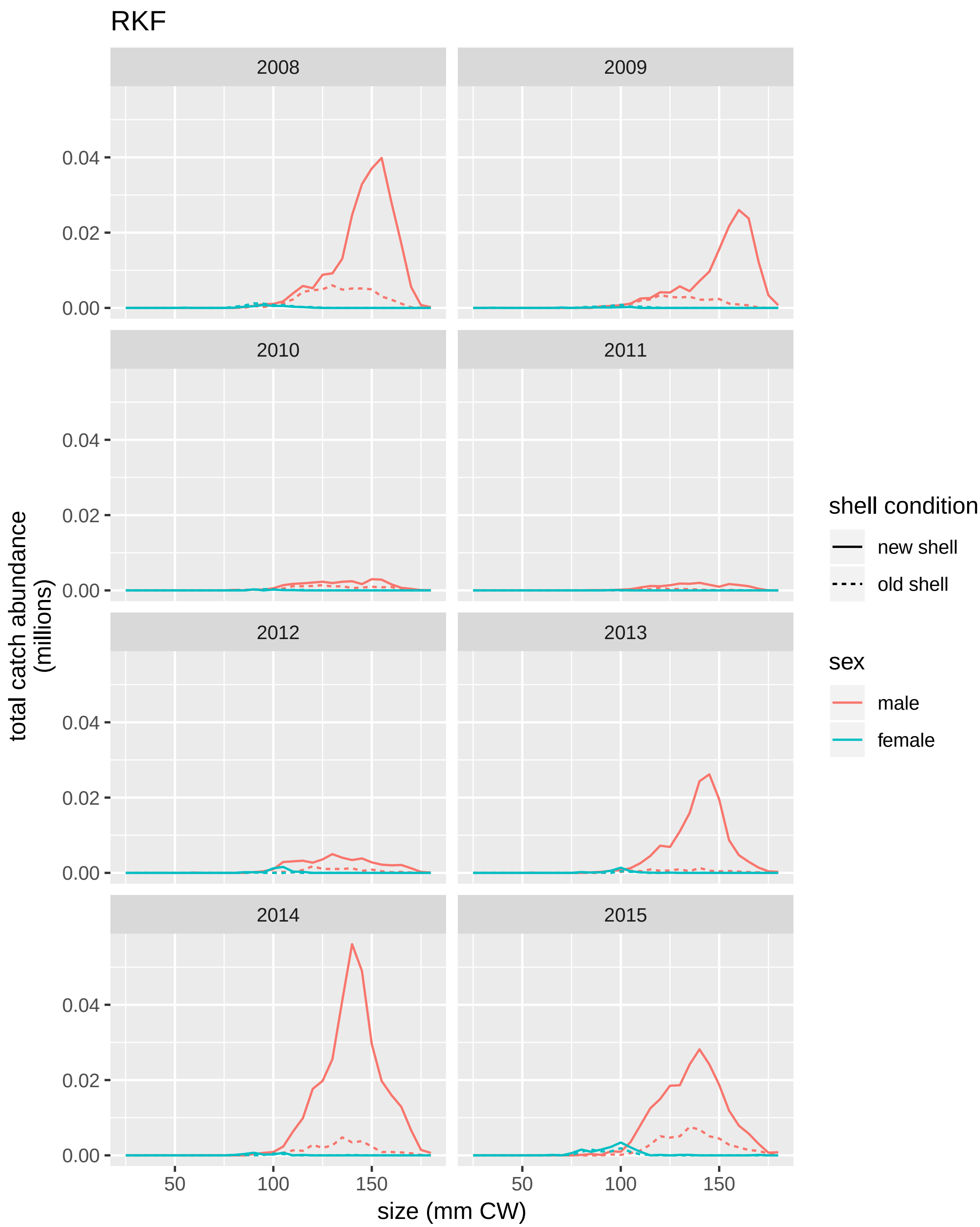

Figure 21: Total catch size compositions for RKF at 5-mm bin size.

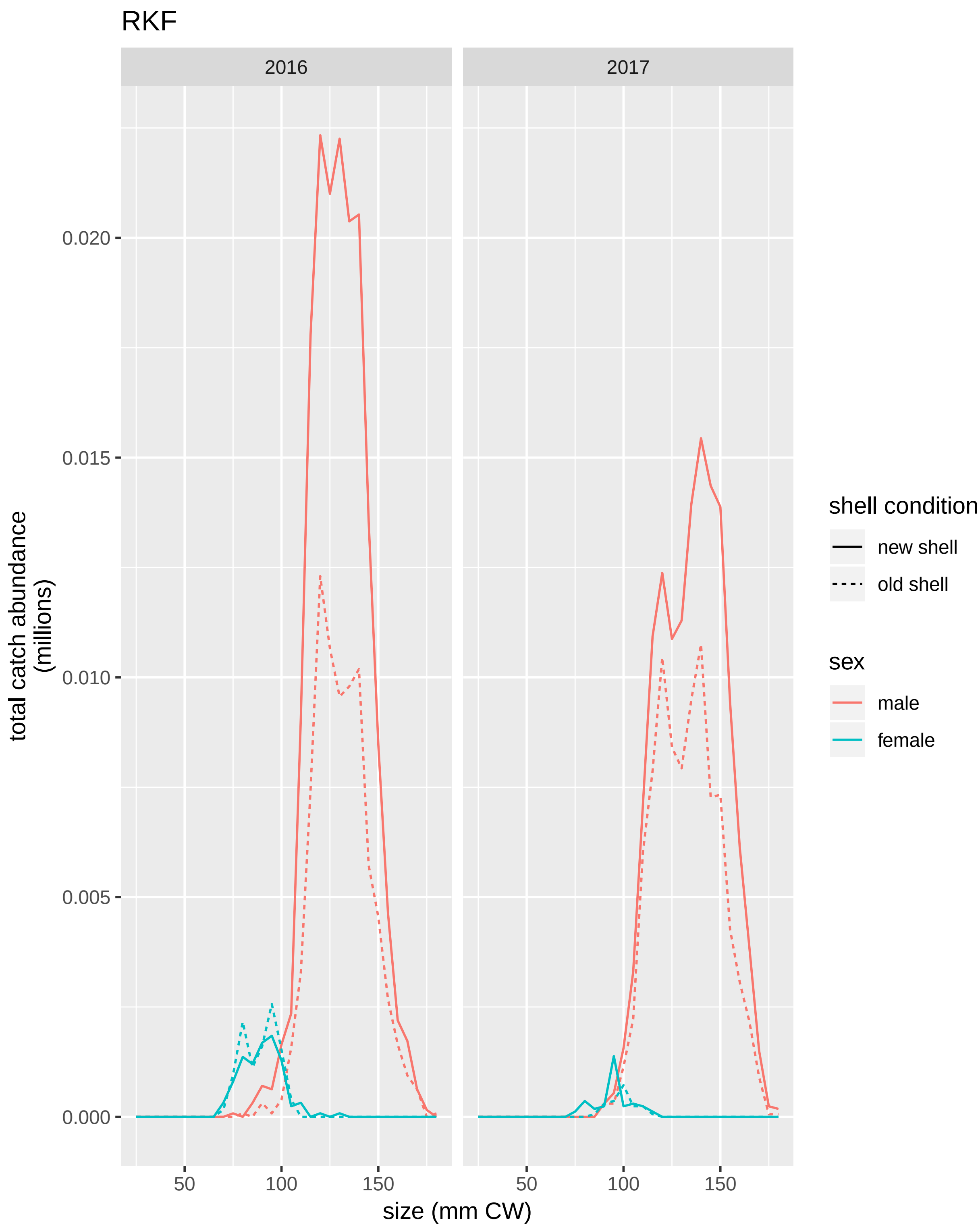

Figure 22: Total catch size compositions for RKF at 5-mm bin size.

Appendix C:
Effort in the Crab Fisheries:
A Comparison of Two Datasets from ADFG

William Stockhausen

01 September, 2018

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Introduction

This report calculates annual fishing effort by crab fishery as the total number of potlifts conducted for each target species (Tanner crab, snow crab, and red king crab in Bristol Bay) across the EBS. Two datasets were provided by ADFG, one starting in 1990 that separately compiled effort east and west of 166^oW longitude for all three target species and the second starting in 2005 that separately compiled effort east/west of 166^oW only for the directed Tanner crab fisheries. Here, effort is summed annually to total effort across the EBS for each target species. As indicated in Table 1 below, the two effort datasets are not always consistent with one another. The first dataset is consistent with effor data previously used in the Tanner crab assessment.

Fishery effort dataset 1

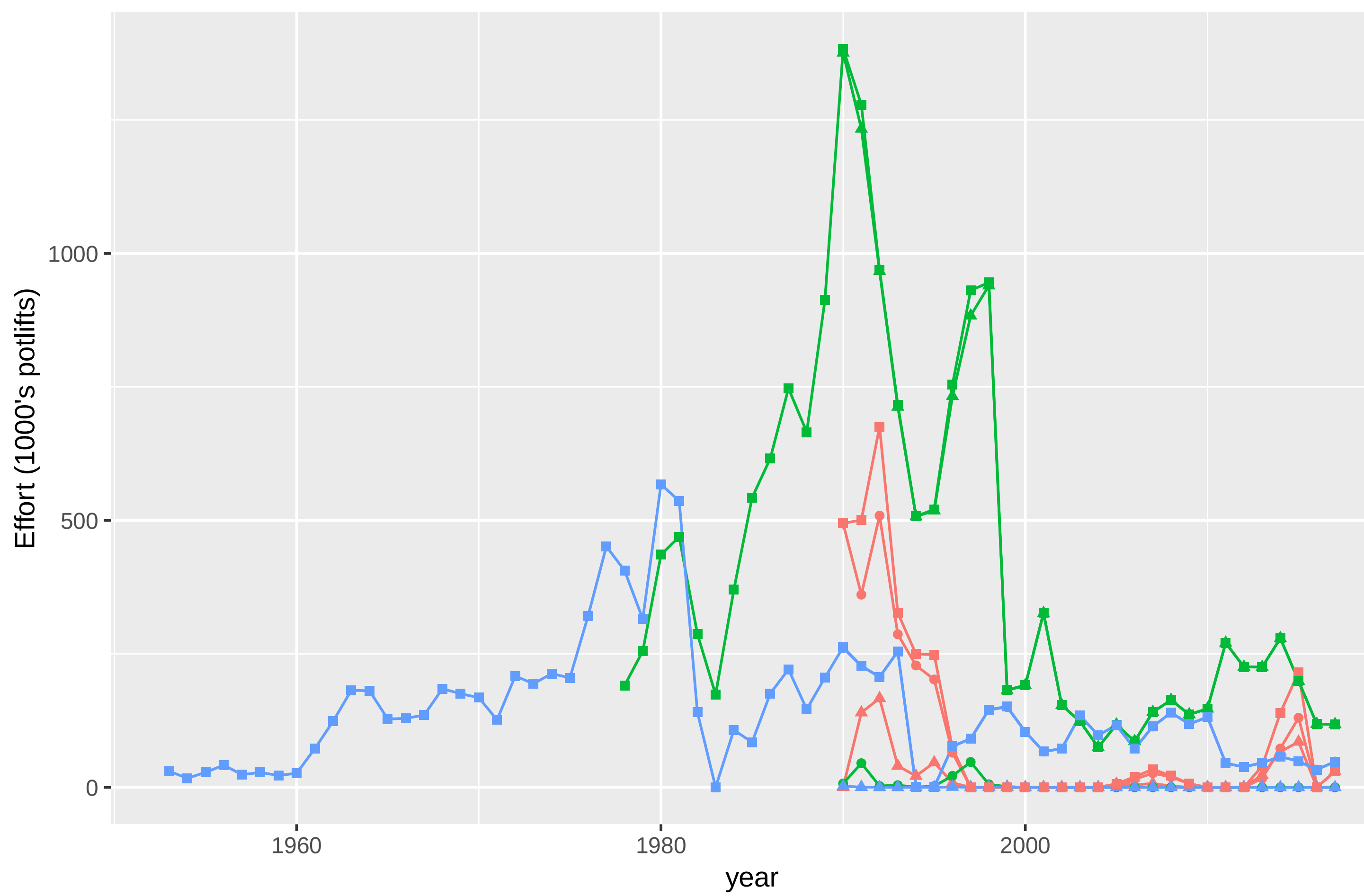

Figure 1: Fishery effort from 1990+ dataset. TCF: Tanner crab fisheries; SCF: snow crab fishery; RKF: BBRKC

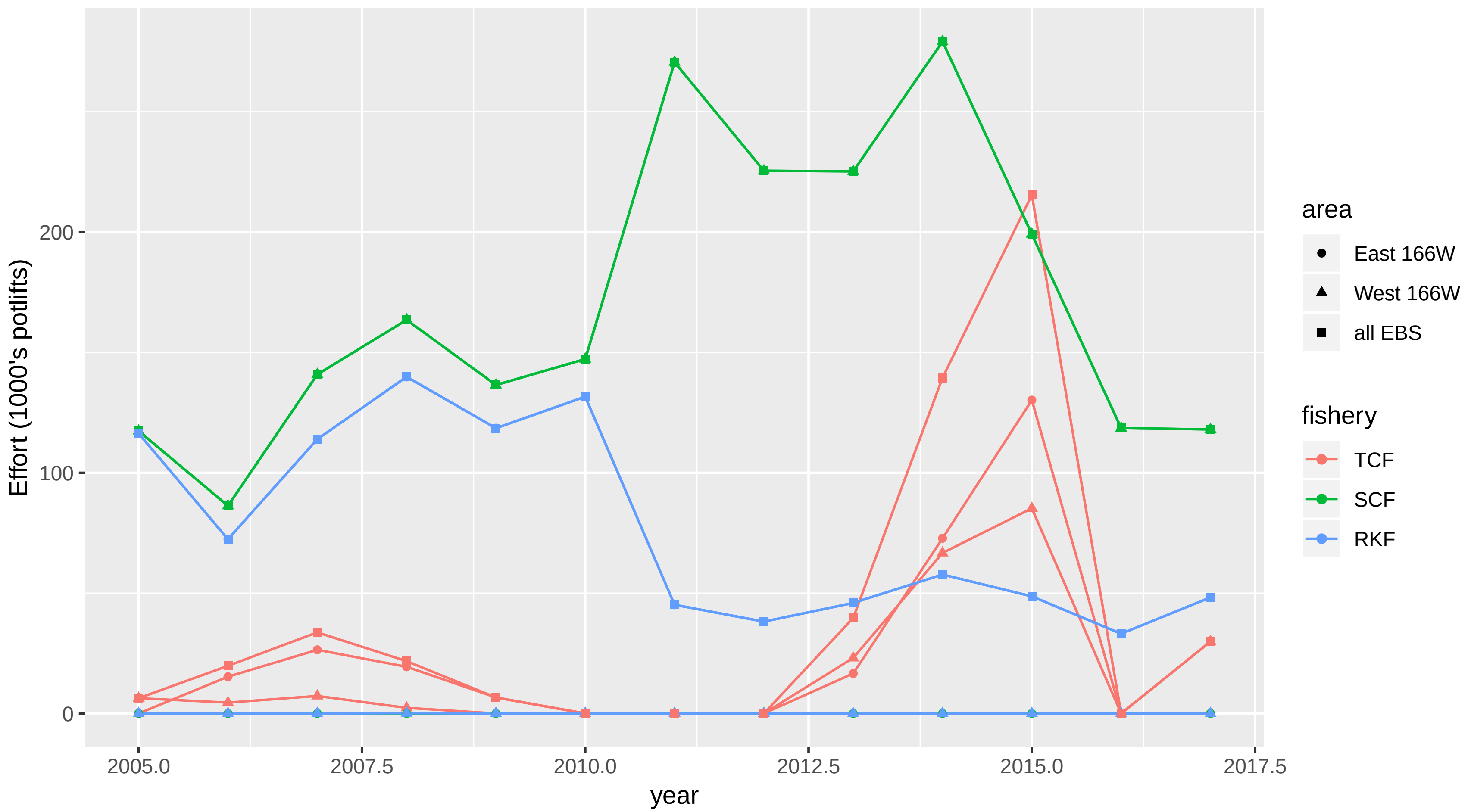

Figure 2: Fishery effort from 1990+ dataset, only 2005+ is shown. TCF: Tanner crab fisheries; SCF: snow crab fishery; RKF: BBRKC fishery.

Table 1: Total annual fishing effort (potlifts) from the 'standard' dataset. TCF: Tanner crab fisheries, SCF: snow crab fishery, RKF: BBRKC fishery.

year	TCF all EBS potlifts	SCF all EBS potlifts	RKF all EBS potlifts
1953	NA	NA	30,083
1954	NA	NA	17,122
1955	NA	NA	28,045
1956	NA	NA	41,629
1957	NA	NA	23,659
1958	NA	NA	27,932
1959	NA	NA	22,187
1960	NA	NA	26,347
1961	NA	NA	72,646
1962	NA	NA	123,643
1963	NA	NA	181,799
1964	NA	NA	180,809
1965	NA	NA	127,973
1966	NA	NA	129,306
1967	NA	NA	135,283
1968	NA	NA	184,666
1969	NA	NA	175,374
1970	NA	NA	168,059
1971	NA	NA	126,305
1972	NA	NA	208,469
1973	NA	NA	194,095
1974	NA	NA	212,915
1975	NA	NA	205,096
1976	NA	NA	321,010
1977	NA	NA	451,273
1978	NA	190,746	406,165
1979	NA	255,102	315,226
1980	NA	435,742	567,292
1981	NA	469,091	536,646
1982	NA	287,127	140,492
1983	NA	173,591	0
1984	NA	370,082	107,406
1985	NA	542,346	84,443

Table 2: Total annual fishing effort (potlifts) from the 'standard' dataset. TCF: Tanner crab fisheries, SCF: snow crab fishery, RKF: BBRKC fishery.

	TCF			SCF			RKF		
	East 166W	West 166W	all EBS	East 166W	West 166W	all EBS	East 166W	West 166W	all EBS
year	potlifts	potlifts	potlifts	potlifts	potlifts	potlifts	potlifts	potlifts	potlifts
1986	0	0	NA	0	0	616,113	0	0	175,753
1987	0	0	NA	0	0	747,395	0	0	220,971
1988	0	0	NA	0	0	665,242	0	0	146,179
1989	0	0	NA	0	0	912,718	0	0	205,528
1990	493,820	479	494,299	7,125	1,375,783	1,382,908	260,732	2,029	262,761
1991	360,864	140,050	500,914	45,184	1,233,318	1,278,502	227,075	480	227,555
1992	508,922	166,670	675,592	2,514	966,695	969,209	206,717	98	206,815
1993	286,620	40,100	326,720	3,979	712,545	716,524	254,389	0	254,389
1994	228,254	21,282	249,536	350	507,253	507,603	697	0	697
1995	201,988	46,454	248,442	2,318	518,367	520,685	547	0	547
1996	64,989	8,533	73,522	21,517	732,623	754,140	76,381	700	77,081
1997	0	0	0	47,421	883,373	930,794	91,085	0	91,085
1998	0	0	0	5,632	939,901	945,533	145,230	459	145,689
1999	0	0	0	1,194	181,440	182,634	150,233	979	151,212
2000	0	0	0	0	191,200	191,200	104,056	0	104,056
2001	0	0	0	801	326,176	326,977	66,947	0	66,947
2002	0	0	0	0	153,862	153,862	72,514	0	72,514
2003	0	0	0	0	123,709	123,709	134,515	0	134,515
2004	0	0	0	0	75,095	75,095	97,621	0	97,621
2005	0	6,346	6,346	0	117,375	117,375	116,320	0	116,320
2006	15,273	4,517	19,790	0	86,288	86,288	72,404	0	72,404
2007	26,441	7,268	33,709	0	140,857	140,857	113,948	0	113,948
2008	19,401	2,336	21,737	0	163,537	163,537	139,837	100	139,937
2009	6,635	0	6,635	0	136,477	136,477	118,521	0	118,521
2010	0	0	0	0	147,244	147,244	131,627	0	131,627
2011	0	0	0	0	270,602	270,602	45,166	0	45,166
2012	0	0	0	0	225,489	225,489	38,159	0	38,159
2013	16,613	23,062	39,675	0	225,245	225,245	45,927	0	45,927
2014	72,781	66,685	139,466	0	279,183	279,183	57,725	0	57,725
2015	130,221	85,244	215,465	0	199,133	199,133	48,665	0	48,665
2016	0	0	0	0	118,548	118,548	33,126	0	33,126
2017	0	29,903	29,903	0	118,034	118,034	48,242	0	48,242

Fishery effort dataset 2

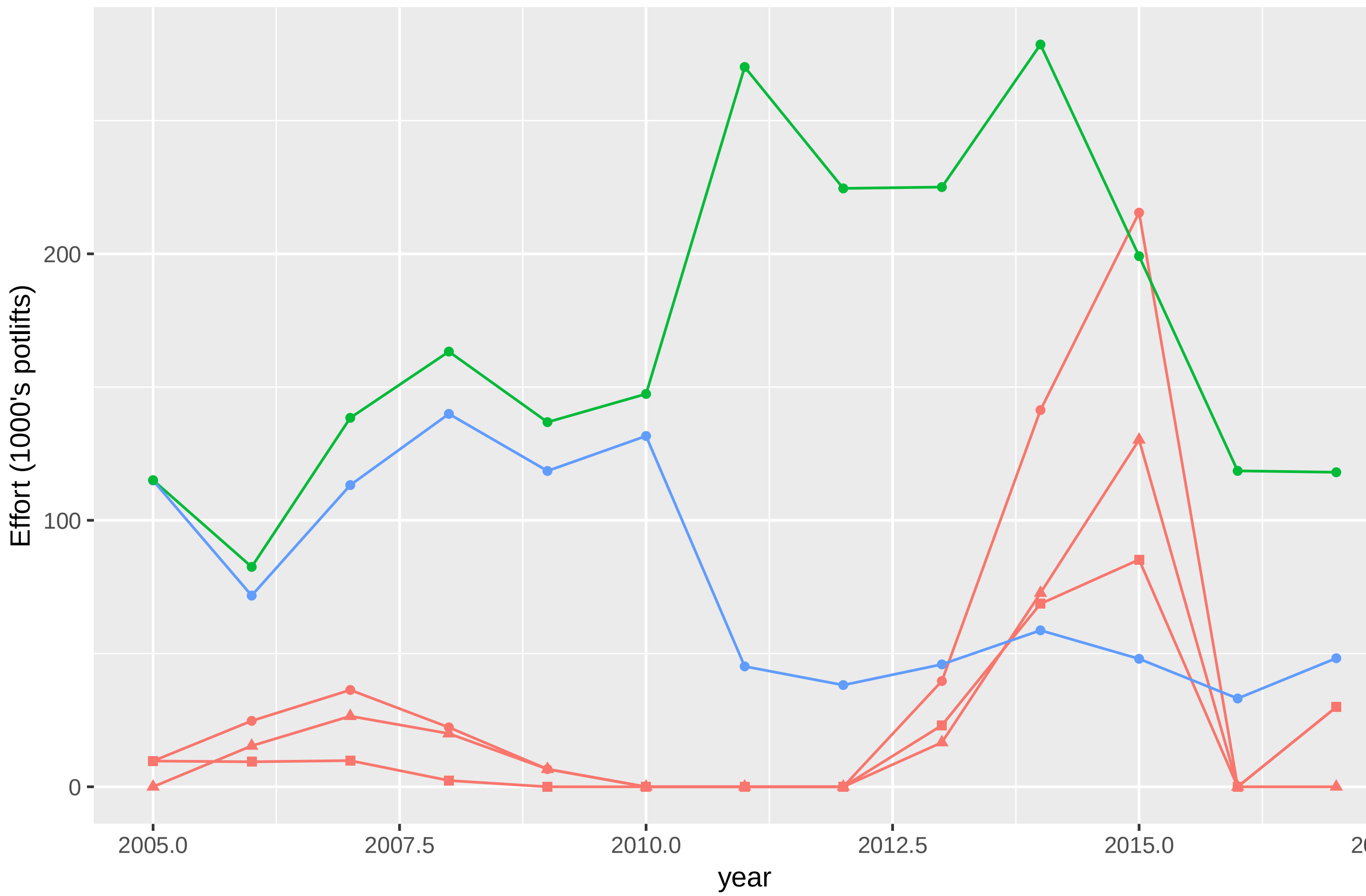

Figure 3: Fishery effort from 2005+ dataset. TCF: Tanner crab fisheries; SCF: snow crab fishery; RKF: BBRKC

A consistency check

Table 3: Comparison of total annual fishing effort (potlifts) since 2005 from two ADFG datasets.
TCF: Tanner crab fisheries, SCF: snow crab fishery, RKF: BBRKC fishery.

	TCF			SCF			RKF		
year	Effort Type 1	Effort Type 2	Difference	Effort Type 1	Effort Type 2	Difference	Effort Type 1	Effort Type 2	Difference
2005	6,346	9,653	−3,307	117,375	115,059	2,316	116,320	114,944	1,376
2006	19,790	24,728	−4,938	86,288	82,515	3,773	72,404	71,735	669
2007	33,709	36,323	−2,614	140,857	138,451	2,406	113,948	113,214	734
2008	21,737	22,293	−556	163,537	163,317	220	139,937	139,937	0
2009	6,635	6,616	19	136,477	136,838	−361	118,521	118,521	0
2010	0	0	0	147,244	147,421	−177	131,627	131,627	0
2011	0	0	0	270,602	270,122	480	45,166	45,166	0
2012	0	0	0	225,489	224,557	932	38,159	38,159	0
2013	39,675	39,676	−1	225,245	225,048	197	45,927	45,927	0
2014	139,466	141,362	−1,896	279,183	278,559	624	57,725	58,702	−977
2015	215,465	215,465	0	199,133	199,133	0	48,665	48,008	657
2016	0	0	0	118,548	118,548	0	33,126	33,126	0
2017	29,903	29,903	0	118,034	118,034	0	48,242	48,242	0

Appendix D:
Bycatch in the Groundfish Fisheries for the Tanner Crab Assessment

William Stockhausen

01 September, 2018

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Introduction

This paper documents the calculations for the annual abundance and biomass time series and the sex-specific size compositions for Tanner crab bycatch in the groundfish fisheries used in the Tanner crab stock assessment model for 1991-2017. Briefly, total bycatch estimates were obtained from AKFIN for 1991-2008 from the NMFS Alaska Regional Office's (AKRO) Catch Accounting System/Blend database (CAS; Cahalan et al., 2009) and for 2009 to the present from the AKRO's Catch-in-Areas database (CIA). Annual sampling data for size frequencies of Tanner crab bycatch in the EBS groundfish fisheries was extracted from the NORPAC observer database (via AKFIN) by sex, gear ("trawl" and "fixed"), ADFG stat area and NMFS reporting area. These observed size frequency data were then scaled to total estimated bycatch size compositions using year/gear/area expansion factors based on the annual total bycatch estimates from the CAS and CIA database.

Sex-specific size compositions for Tanner crab bycatch in the groundfish fisheries during 1973-1990 are also incorporated in the assessment model. These size compositions are based on data from the former "joint venture"" and foreign fishing fleets, and remain unchanged from the previous assessment.

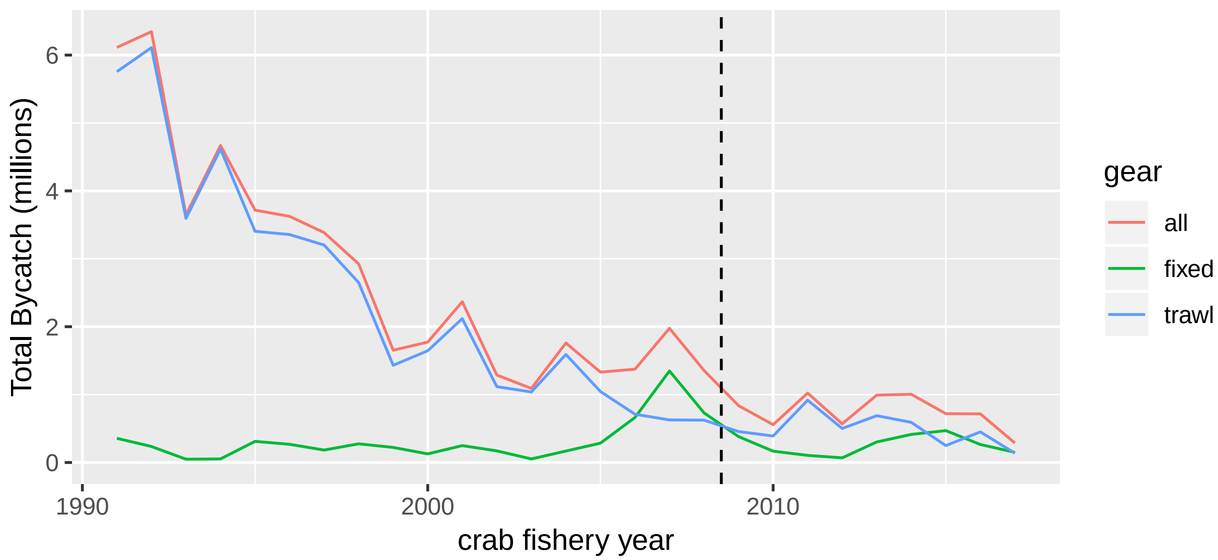


Figure 1: Estimated total bycatch abundance, by gear type, from the CAS/Blend and CIA databases for 1991-2017.

Estimated total bycatch by gear type

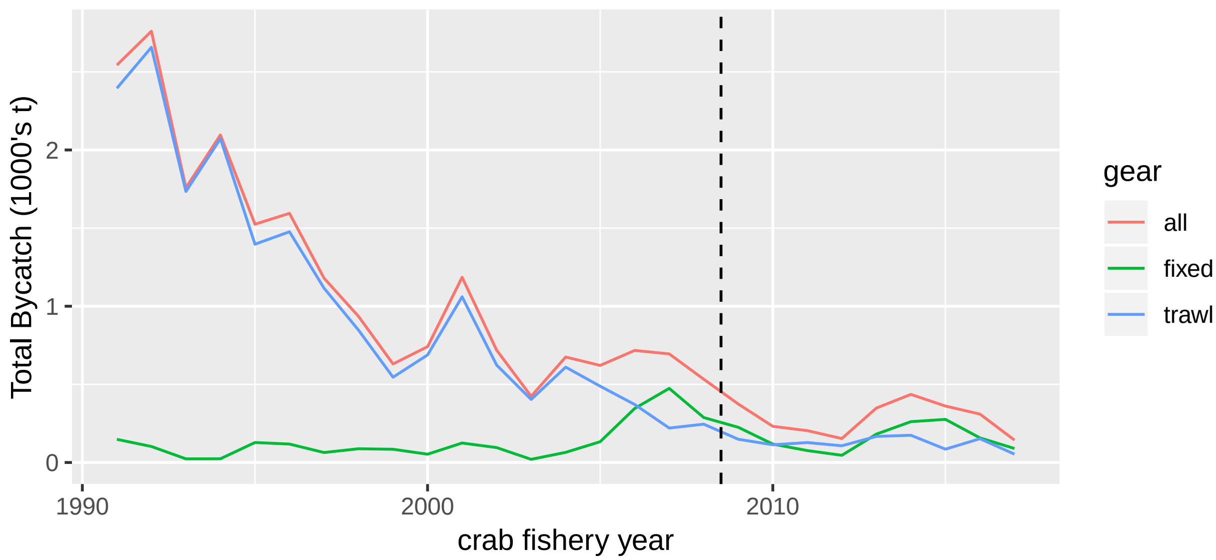


Figure 2: Estimated total bycatch biomass, by gear type, from the CAS/Blend and CIA databases for 1991-2017.

Table 1: Estimated total bycatch of Tanner crab by gear type from the combined CAS/Blend and CIA databases for 1991-2008.

	all		fixed		trawl	
	num	wgt	num	wgt	num	wgt
year	millions	1000's t	millions	1000's t	millions	1000's t
1991	6.1125	2.5432	0.35636	0.14827	5.7561	2.39491
1992	6.3447	2.7596	0.23614	0.10271	6.1086	2.65693
1993	3.6442	1.7580	0.04869	0.02349	3.5955	1.73451
1994	4.6688	2.0960	0.05320	0.02388	4.6156	2.07211
1995	3.7164	1.5249	0.31161	0.12786	3.4048	1.39702
1996	3.6250	1.5945	0.26818	0.11796	3.3568	1.47653
1997	3.3856	1.1800	0.18346	0.06394	3.2022	1.11602
1998	2.9243	0.9350	0.27512	0.08797	2.6491	0.84707
1999	1.6541	0.6306	0.22233	0.08476	1.4318	0.54585
2000	1.7727	0.7415	0.12702	0.05313	1.6457	0.68840
2001	2.3674	1.1852	0.24904	0.12467	2.1184	1.06052
2002	1.2882	0.7191	0.17112	0.09552	1.1171	0.62355
2003	1.0908	0.4238	0.05255	0.02042	1.0382	0.40339
2004	1.7598	0.6751	0.16907	0.06486	1.5907	0.61020
2005	1.3309	0.6212	0.28508	0.13306	1.0458	0.48812
2006	1.3743	0.7171	0.66295	0.34594	0.7114	0.37120
2007	1.9757	0.6949	1.34861	0.47437	0.6270	0.22056
2008	1.3552	0.5329	0.73133	0.28755	0.6239	0.24531
2009	0.8369	0.3742	0.38142	0.22535	0.4555	0.14884
2010	0.5573	0.2314	0.16702	0.11789	0.3903	0.11347
2011	1.0228	0.2040	0.10496	0.07636	0.9178	0.12762
2012	0.5698	0.1533	0.06867	0.04608	0.5011	0.10718
2013	0.9919	0.3484	0.30248	0.18155	0.6894	0.16682
2014	1.0050	0.4357	0.41362	0.26133	0.5914	0.17440
2015	0.7191	0.3612	0.46973	0.27596	0.2494	0.08526
2016	0.7162	0.3099	0.26532	0.15768	0.4509	0.15221
2017	0.2869	0.1433	0.14978	0.08964	0.1371	0.05361

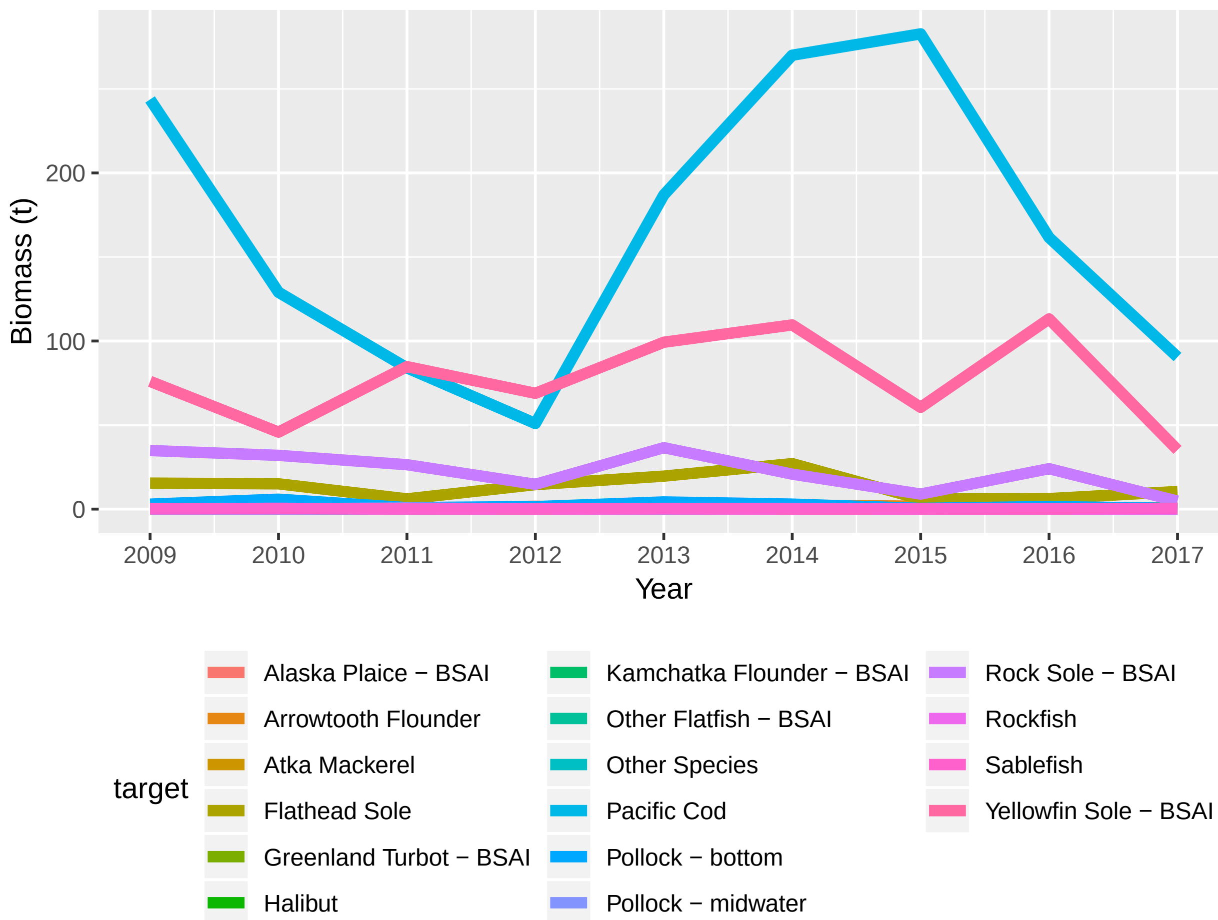


Figure 3: Bycatch of Tanner crab in the groundfish fisheries, by target type.

Estimated total catch by target type (2009/10-2017/18)

Table 2: Bycatch of Tanner crab in the groundfish fisheries, by target type. Biomass is in metric tons, numbers in 1000's of crab. Targets with less than 10 kg bycatch have been dropped.

target	year	vessel count	haul count	biomass (t)	number (1000's)
Alaska Plaice - BSAI	2009	0	0	0.0	0.0
	2010	113	1563	0.6	3.2
	2011	35	563	0.1	0.2
	2012	181	2735	1.7	6.2
	2013	0	0	0.0	0.0
	2014	41	495	2.6	11.2
	2015	84	1452	0.6	2.1
	2016	16	148	1.1	1.8
	2017	293	4215	0.6	1.8
Arrowtooth Flounder	2009	246	9548	0.7	1.3
	2010	252	3555	2.2	3.5
	2011	998	15788	1.0	2.1
	2012	599	11571	0.8	3.4
	2013	1042	21590	1.0	5.0
	2014	734	15528	2.2	8.9
	2015	552	11491	1.7	8.7
	2016	372	6938	1.3	7.1
	2017	198	3430	0.6	2.8
Flathead Sole	2009	1133	23983	15.4	44.6
	2010	1191	22108	15.0	51.7
	2011	496	8408	6.1	41.8
	2012	833	14517	14.6	52.9
	2013	845	15216	19.6	64.2
	2014	865	16919	27.1	92.7
	2015	500	8984	5.9	19.0
	2016	871	18483	6.2	19.0
	2017	944	19757	10.4	26.4
Greenland Turbot - BSAI	2009	0	0	0.0	0.0
	2010	0	0	0.0	0.0
	2011	0	0	0.0	0.0
	2012	0	0	0.0	0.0
	2013	0	0	0.0	0.0
	2014	0	0	0.0	0.0
	2015	0	0	0.0	0.0
	2016	654	8410	0.6	3.6
	2017	393	4127	0.2	1.2
Other Flatfish - BSAI	2009	0	0	0.0	0.0
	2010	16	150	0.1	0.4
	2011	0	0	0.0	0.0
	2012	0	0	0.0	0.0
	2013	0	0	0.0	0.0
	2014	0	0	0.0	0.0
	2015	0	0	0.0	0.0

	2016	89	791	0.1	0.5
	2017	0	0	0.0	0.0
Pacific Cod	2009	10946	376241	243.8	414.2
	2010	11524	261032	129.0	178.8
	2011	14283	437602	84.0	117.6
	2012	14959	452023	50.9	80.7
	2013	19482	388896	186.9	318.9
	2014	18590	427599	270.1	431.1
	2015	17983	572272	282.8	483.0
	2016	16080	425908	161.6	273.7
	2017	13079	343706	90.5	151.3
Pollock - bottom	2009	1132	138860	2.9	5.5
	2010	1651	87126	5.9	14.7
	2011	1467	62223	0.9	4.8
	2012	1222	37912	1.5	7.5
	2013	791	16540	4.2	14.3
	2014	402	22662	2.9	11.3
	2015	364	19261	0.4	1.1
	2016	389	16764	1.5	7.5
	2017	240	21683	0.4	1.4
Pollock - midwater	2009	7520	249359	0.2	0.9
	2010	8297	252803	0.2	2.1
	2011	11584	306397	0.7	1.8
	2012	10130	262878	0.2	1.1
	2013	10399	272557	0.4	1.8
	2014	10554	278796	0.4	1.6
	2015	10074	276591	0.1	0.5
	2016	10818	275690	0.2	0.5
	2017	10306	251555	0.1	0.6
Rock Sole - BSAI	2009	2614	50187	34.8	73.8
	2010	3232	56049	32.0	85.8
	2011	2931	46400	26.4	91.1
	2012	2020	29627	14.7	39.8
	2013	3150	61903	36.5	108.1
	2014	3237	72179	20.8	55.1
	2015	4446	92725	8.9	21.9
	2016	2783	52700	24.0	74.8
	2017	2655	59563	4.7	10.6
Rockfish	2009	23	97	0.1	0.2
	2010	180	2586	0.1	0.5
	2011	0	0	0.0	0.0
	2012	0	0	0.0	0.0
	2013	197	3040	0.1	0.3
	2014	0	0	0.0	0.0
	2015	0	0	0.0	0.0
	2016	0	0	0.0	0.0
	2017	0	0	0.0	0.0
Sablefish	2009	76	128498	0.2	0.4

	2010	67	182129	0.4	0.8
	2011	0	0	0.0	0.0
	2012	0	0	0.0	0.0
	2013	58	61907	0.2	0.3
	2014	0	0	0.0	0.0
	2015	0	0	0.0	0.0
	2016	0	0	0.0	0.0
	2017	151	16875	0.4	0.7
Yellowfin Sole - BSAI	2009	6067	129005	76.0	295.9
	2010	6200	119756	45.8	215.8
	2011	6445	122233	84.8	762.8
	2012	7348	138839	68.9	378.0
	2013	7731	150735	99.3	478.8
	2014	6906	132814	109.6	392.7
	2015	8315	168488	60.5	182.4
	2016	9077	175809	113.2	327.7
	2017	9766	241335	35.2	89.6

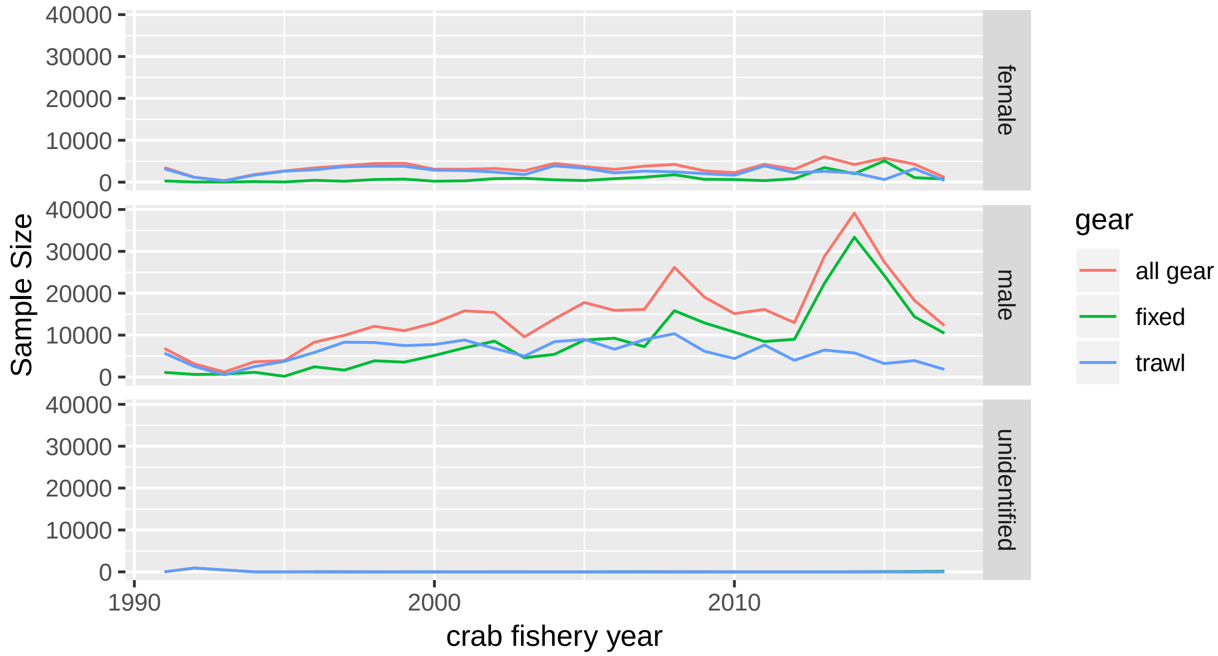


Figure 4: Sample sizes from observer sampling for Tanner crab (> 24 mm CW) bycatch size frequencies in the groundfish fisheries.

Size frequencies from observer sampling

Observers sampled Tanner crab bycatch in the groundfish fisheries to obtain sex and size information starting in 1985. Observer coverage varied by year across target fisheries and gear types, hence "raw" size frequencies are not necessarily directly comparable across these categories. Here, I assume it is valid to aggregate observations across target fisheries and to categorize gear types as "fixed" (longline and pot gear) and "trawl" (pelagic, non-pelagic, and unspecified trawl gear) to obtain annual sex- and gear-specific observed size frequencies by NMFS reporting area.

Sample sizes

Raw size frequencies

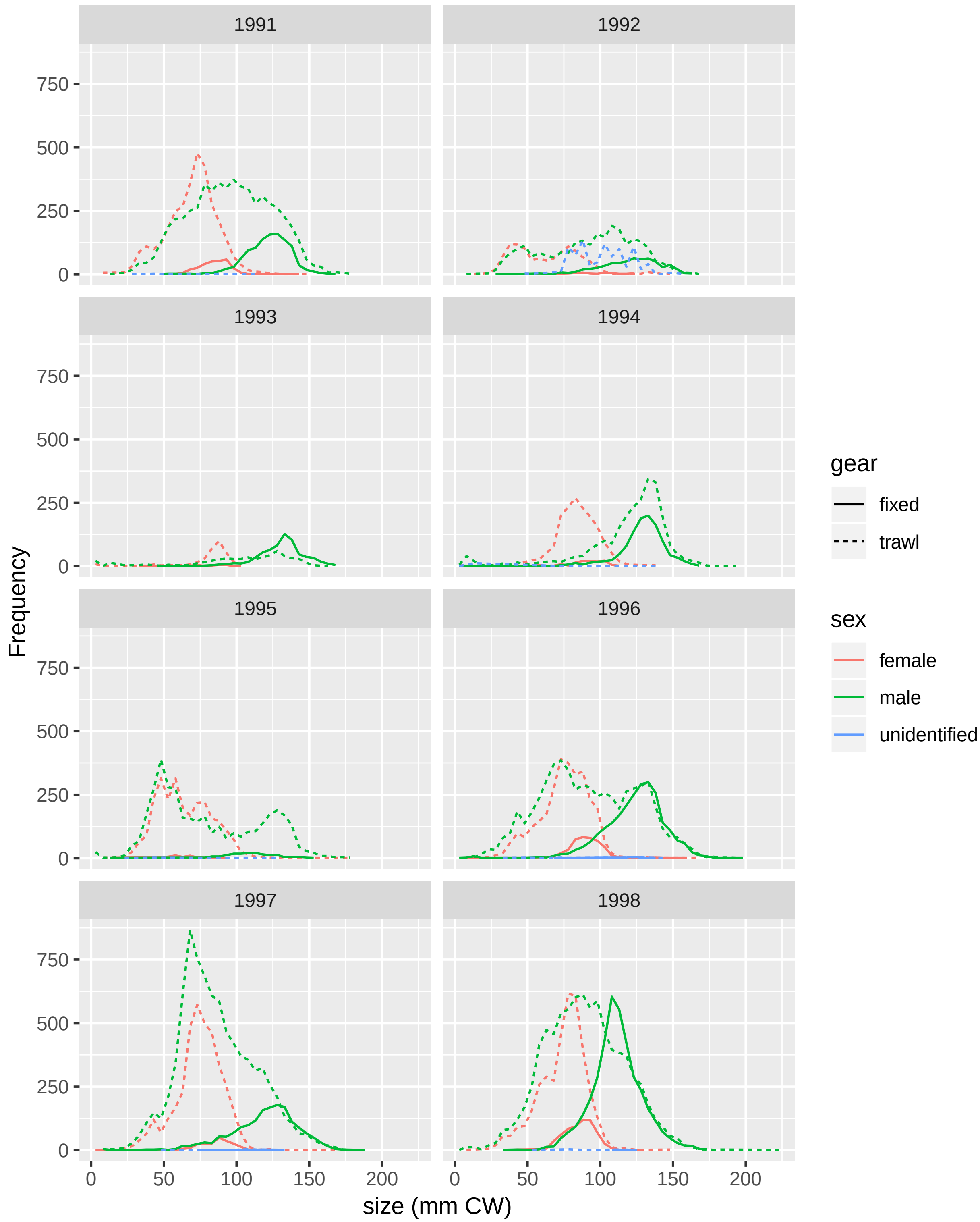


Figure 5: Raw (unscaled) size frequencies by 1-mm size bin from observer sampling for Tanner crab bycatch in the groundfish fisheries.

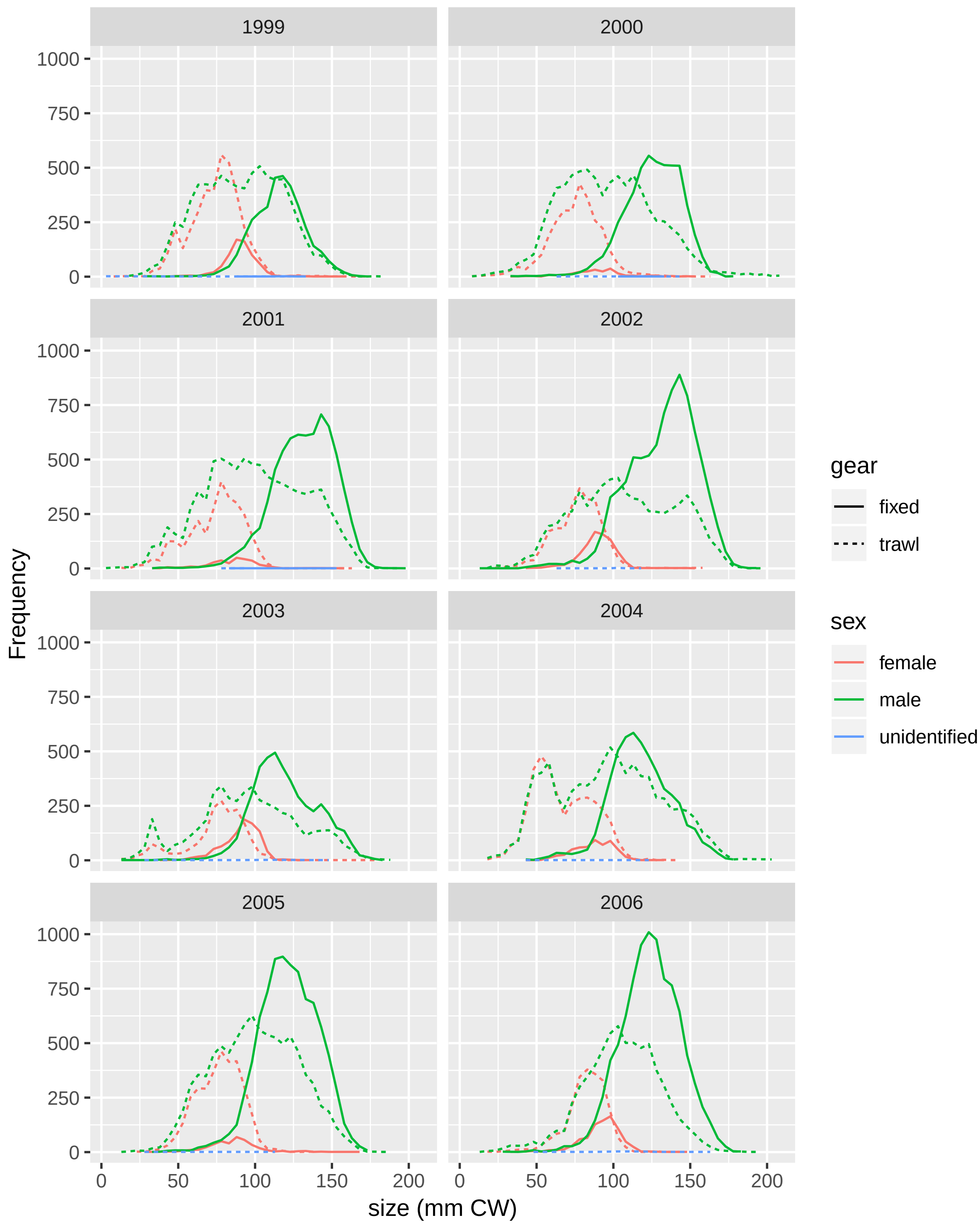


Figure 6: Raw (unscaled) size frequencies by 1-mm size bin from observer sampling for Tanner crab bycatch in the groundfish fisheries.

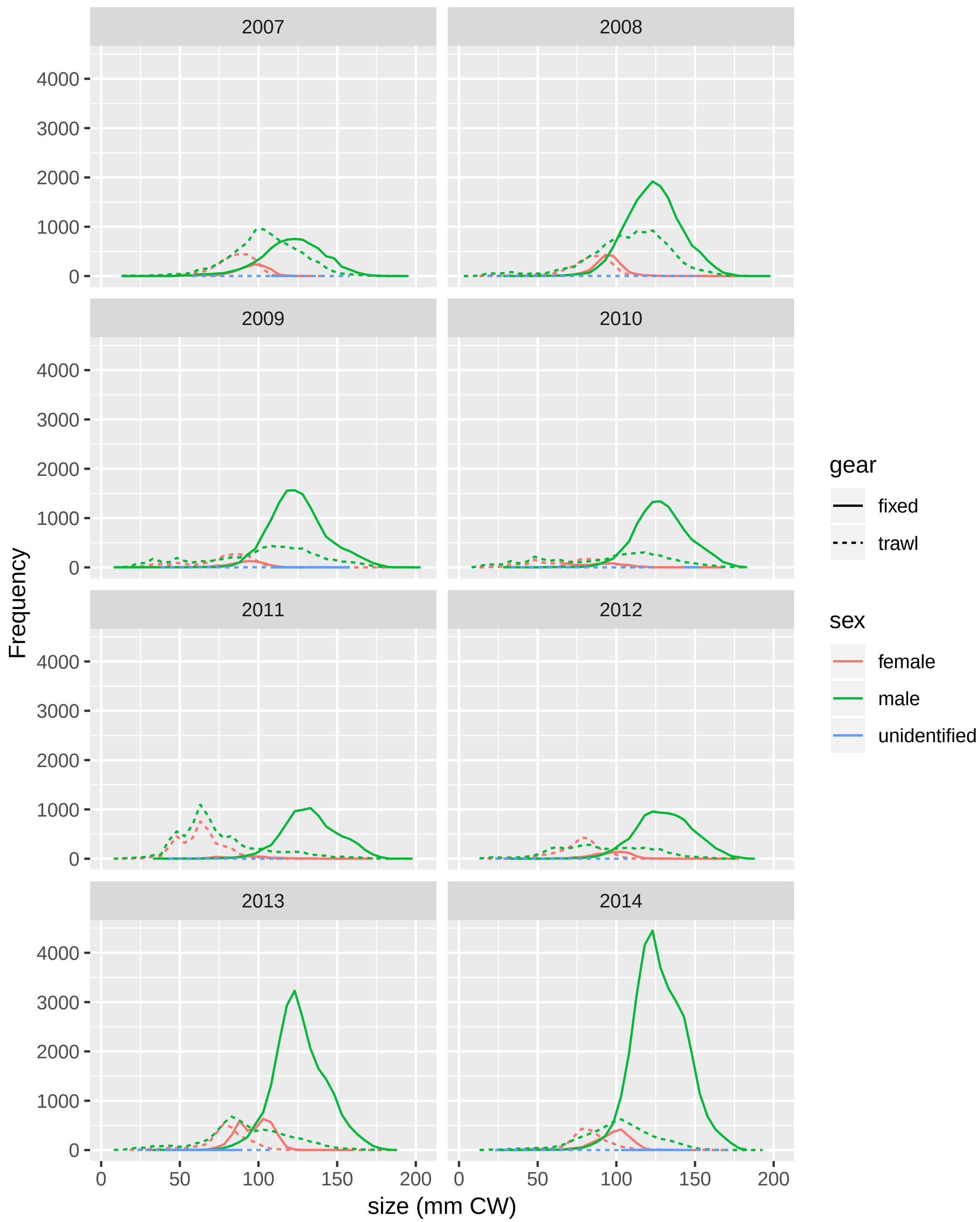


Figure 7: Raw (unscaled) size frequencies by 1-mm size bin from observer sampling for Tanner crab bycatch in the groundfish fisheries.

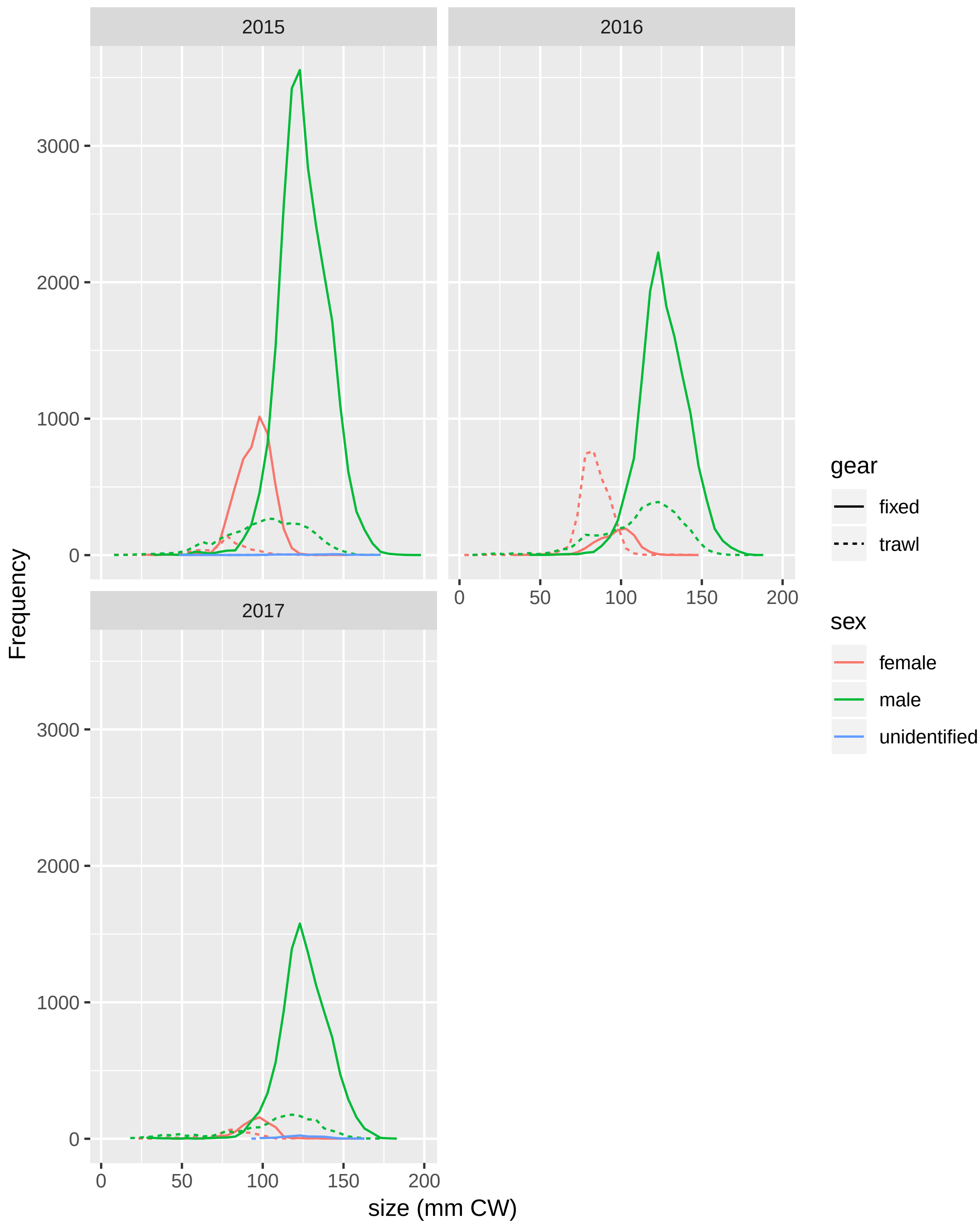


Figure 8: Raw (unscaled) size frequencies by 1-mm size bin from observer sampling for Tanner crab bycatch in the groundfish fisheries.

Expansion factors

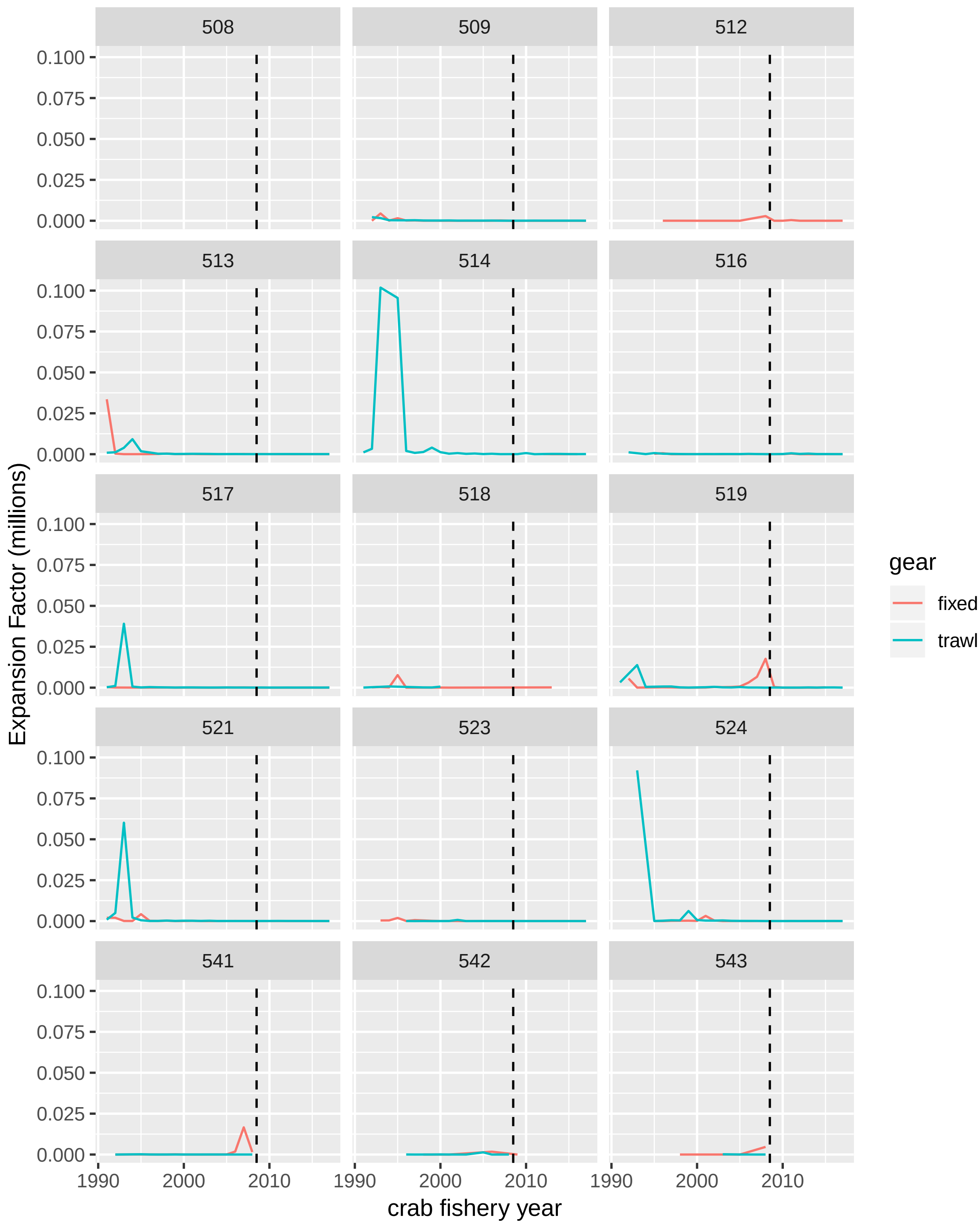


Figure 9: Expansion factors from observed size frequencies to total bycatch, by gear type and reporting area.

Table 3: Observed bycatch numbers, expanded numbers, ans expansion factors from observed size frequencies to total bycatch, by gear type and reporting area.

		fixed			trawl		
area	year	obs N	est N	expansion	obs N	est N	expansion
508	1996	3	$3.996e-05$	$1.332e-05$	–	–	–
509	1992	305	$1.489e-03$	$4.882e-06$	436	$9.628e-01$	$2.208e-03$
	1993	2	$8.905e-03$	$4.453e-03$	409	$6.637e-01$	$1.623e-03$
	1994	180	$1.404e-02$	$7.801e-05$	2656	$8.653e-01$	$3.258e-04$
	1995	89	$1.372e-01$	$1.541e-03$	3063	$8.356e-01$	$2.728e-04$
	1996	1384	$1.701e-01$	$1.229e-04$	4759	$1.199e+00$	$2.520e-04$
	1997	504	$9.145e-02$	$1.815e-04$	2232	$7.367e-01$	$3.301e-04$
	1998	2660	$5.631e-02$	$2.117e-05$	4107	$6.712e-01$	$1.634e-04$
	1999	1357	$8.871e-02$	$6.537e-05$	3621	$4.511e-01$	$1.246e-04$
	2000	2536	$4.564e-02$	$1.800e-05$	2680	$3.682e-01$	$1.374e-04$
	2001	4481	$6.574e-02$	$1.467e-05$	3791	$6.565e-01$	$1.732e-04$
	2002	6173	$7.997e-02$	$1.295e-05$	3229	$2.797e-01$	$8.662e-05$
	2003	2483	$2.138e-02$	$8.609e-06$	1549	$1.547e-01$	$9.985e-05$
	2004	2445	$4.681e-02$	$1.915e-05$	2714	$2.417e-01$	$8.904e-05$
	2005	4950	$8.315e-02$	$1.680e-05$	2283	$1.988e-01$	$8.707e-05$
	2006	6097	$2.813e-01$	$4.614e-05$	1716	$1.902e-01$	$1.108e-04$
	2007	4471	$6.707e-01$	$1.500e-04$	2706	$1.210e-01$	$4.471e-05$
	2008	8151	$2.143e-01$	$2.629e-05$	3648	$1.742e-01$	$4.776e-05$
	2009	9320	$1.966e-01$	$2.109e-05$	3203	$1.483e-01$	$4.630e-05$
	2010	6995	$1.120e-01$	$1.601e-05$	2417	$1.526e-01$	$6.314e-05$
	2011	5717	$7.008e-02$	$1.226e-05$	4310	$3.421e-01$	$7.938e-05$
	2012	7647	$5.981e-02$	$7.822e-06$	1234	$8.571e-02$	$6.946e-05$
	2013	21534	$2.660e-01$	$1.235e-05$	4175	$2.828e-01$	$6.773e-05$
	2014	22377	$3.223e-01$	$1.440e-05$	2067	$1.360e-01$	$6.577e-05$
	2015	13162	$2.911e-01$	$2.211e-05$	509	$3.994e-02$	$7.847e-05$
	2016	8505	$2.147e-01$	$2.525e-05$	2389	$1.566e-01$	$6.553e-05$
	2017	4675	$1.086e-01$	$2.324e-05$	598	$3.534e-02$	$5.909e-05$
512	1996	32	$6.925e-04$	$2.164e-05$	–	–	–
	1998	7	$1.640e-04$	$2.343e-05$	–	–	–
	2000	2	$7.685e-06$	$3.843e-06$	–	–	–
	2001	48	$4.364e-04$	$9.092e-06$	–	–	–
	2002	8	$2.089e-05$	$2.611e-06$	–	–	–
	2003	5	$2.143e-05$	$4.286e-06$	–	–	–
	2004	106	$6.108e-04$	$5.762e-06$	–	–	–
	2005	1	$4.931e-07$	$4.931e-07$	–	–	–
	2008	4	$1.142e-02$	$2.855e-03$	–	–	–
	2009	13	$3.312e-05$	$2.547e-06$	–	–	–
	2010	2	$6.836e-06$	$3.418e-06$	–	–	–
	2011	2	$8.076e-04$	$4.038e-04$	–	–	–
	2012	2	$8.272e-06$	$4.136e-06$	–	–	–
	2013	440	$3.071e-03$	$6.980e-06$	–	–	–
	2014	279	$3.712e-03$	$1.331e-05$	–	–	–
	2015	2301	$2.952e-02$	$1.283e-05$	–	–	–

	2016	917	$1.559e-02$	$1.700e-05$	–	–	–
	2017	59	$1.746e-03$	$2.960e-05$	–	–	–
513	1991	1	$3.358e-02$	$3.358e-02$	1749	$1.556e+00$	$8.894e-04$
	1992	63	$2.162e-02$	$3.432e-04$	1694	$2.006e+00$	$1.184e-03$
	1993	161	$3.088e-03$	$1.918e-05$	494	$1.922e+00$	$3.892e-03$
	1994	314	$7.488e-03$	$2.385e-05$	321	$2.950e+00$	$9.191e-03$
	1995	–	–	–	1148	$2.066e+00$	$1.799e-03$
	1996	304	$1.658e-02$	$5.454e-05$	1353	$1.452e+00$	$1.073e-03$
	1997	147	$2.025e-02$	$1.377e-04$	6778	$1.860e+00$	$2.745e-04$
	1998	312	$1.270e-01$	$4.072e-04$	3928	$1.287e+00$	$3.275e-04$
	1999	479	$3.393e-02$	$7.084e-05$	3744	$4.898e-01$	$1.308e-04$
	2000	412	$1.733e-02$	$4.205e-05$	4043	$7.218e-01$	$1.785e-04$
	2001	547	$7.169e-02$	$1.311e-04$	2955	$6.856e-01$	$2.320e-04$
	2002	296	$9.485e-03$	$3.204e-05$	1779	$3.666e-01$	$2.061e-04$
	2003	2052	$1.156e-02$	$5.636e-06$	1197	$1.947e-01$	$1.627e-04$
	2004	2155	$5.926e-02$	$2.750e-05$	1513	$1.158e-01$	$7.652e-05$
	2005	1528	$6.635e-02$	$4.342e-05$	3277	$2.580e-01$	$7.873e-05$
	2006	1929	$8.681e-02$	$4.500e-05$	1377	$1.614e-01$	$1.172e-04$
	2007	1276	$1.765e-01$	$1.383e-04$	1933	$1.029e-01$	$5.323e-05$
	2008	1602	$6.240e-02$	$3.895e-05$	2726	$1.400e-01$	$5.134e-05$
	2009	1384	$9.890e-02$	$7.146e-05$	1979	$1.303e-01$	$6.584e-05$
	2010	1103	$2.936e-02$	$2.662e-05$	1333	$6.849e-02$	$5.138e-05$
	2011	385	$2.892e-03$	$7.511e-06$	6270	$4.828e-01$	$7.700e-05$
	2012	257	$9.284e-04$	$3.613e-06$	1900	$1.609e-01$	$8.466e-05$
	2013	809	$1.788e-03$	$2.211e-06$	2589	$2.131e-01$	$8.229e-05$
	2014	2534	$1.830e-02$	$7.223e-06$	3198	$2.376e-01$	$7.431e-05$
	2015	5213	$1.960e-02$	$3.761e-06$	1599	$9.455e-02$	$5.913e-05$
	2016	3368	$8.555e-03$	$2.540e-06$	2466	$1.671e-01$	$6.777e-05$
	2017	2234	$8.176e-03$	$3.660e-06$	966	$6.313e-02$	$6.535e-05$
514	1991	–	–	–	949	$1.056e+00$	$1.113e-03$
	1992	–	–	–	286	$9.474e-01$	$3.312e-03$
	1993	–	–	–	4	$4.074e-01$	$1.018e-01$
	1995	–	–	–	2	$1.910e-01$	$9.550e-02$
	1996	–	–	–	26	$5.177e-02$	$1.991e-03$
	1997	–	–	–	29	$2.299e-02$	$7.927e-04$
	1998	–	–	–	23	$3.045e-02$	$1.324e-03$
	1999	–	–	–	18	$7.241e-02$	$4.023e-03$
	2000	–	–	–	32	$3.995e-02$	$1.249e-03$
	2001	–	–	–	14	$4.325e-03$	$3.089e-04$
	2002	–	–	–	73	$4.944e-02$	$6.772e-04$
	2003	–	–	–	549	$1.172e-01$	$2.135e-04$
	2004	–	–	–	1470	$6.126e-01$	$4.167e-04$
	2005	–	–	–	321	$2.618e-02$	$8.157e-05$
	2006	–	–	–	4	$1.063e-03$	$2.658e-04$
	2007	–	–	–	921	$3.217e-02$	$3.493e-05$
	2008	–	–	–	233	$1.076e-02$	$4.619e-05$
	2009	–	–	–	10	$6.687e-04$	$6.687e-05$
	2010	–	–	–	2	$1.372e-03$	$6.860e-04$

	2011	–	–	–	5	$7.568e-05$	$1.514e-05$
	2012	1	$1.326e-04$	$1.326e-04$	51	$5.723e-03$	$1.122e-04$
	2013	2	$2.982e-05$	$1.491e-05$	24	$4.440e-03$	$1.850e-04$
	2014	39	$2.308e-04$	$5.919e-06$	260	$4.463e-02$	$1.717e-04$
	2015	156	$3.885e-04$	$2.491e-06$	1105	$8.002e-02$	$7.241e-05$
	2016	13	$9.698e-05$	$7.460e-06$	541	$2.912e-02$	$5.383e-05$
	2017	–	–	–	84	$7.489e-03$	$8.915e-05$
516	1992	–	–	–	54	$6.211e-02$	$1.150e-03$
	1994	–	–	–	317	$1.922e-02$	$6.062e-05$
	1995	76	$1.815e-02$	$2.388e-04$	36	$2.493e-02$	$6.925e-04$
	1996	2	$1.178e-03$	$5.891e-04$	32	$9.490e-03$	$2.966e-04$
	1997	259	$3.166e-03$	$1.222e-05$	288	$5.480e-02$	$1.903e-04$
	1998	81	$9.606e-04$	$1.186e-05$	709	$8.461e-02$	$1.193e-04$
	1999	29	$1.338e-04$	$4.612e-06$	1	$6.425e-05$	$6.425e-05$
	2000	42	$4.031e-04$	$9.599e-06$	284	$1.508e-02$	$5.310e-05$
	2001	263	$1.836e-03$	$6.979e-06$	389	$4.163e-02$	$1.070e-04$
	2002	119	$1.067e-03$	$8.969e-06$	551	$4.006e-02$	$7.270e-05$
	2003	16	$1.536e-04$	$9.602e-06$	333	$3.784e-02$	$1.136e-04$
	2004	87	$1.400e-03$	$1.609e-05$	309	$3.064e-02$	$9.916e-05$
	2005	43	$2.826e-04$	$6.572e-06$	102	$7.739e-03$	$7.587e-05$
	2006	74	$8.627e-03$	$1.166e-04$	54	$1.107e-02$	$2.050e-04$
	2007	21	$2.447e-03$	$1.165e-04$	125	$1.113e-02$	$8.905e-05$
	2008	383	$1.632e-03$	$4.262e-06$	121	$5.746e-03$	$4.749e-05$
	2009	126	$5.162e-04$	$4.097e-06$	382	$2.016e-02$	$5.278e-05$
	2010	12	$4.288e-04$	$3.573e-05$	90	$1.142e-02$	$1.269e-04$
	2011	8	$2.655e-03$	$3.318e-04$	20	$1.100e-02$	$5.501e-04$
	2012	219	$1.148e-03$	$5.240e-06$	17	$2.719e-03$	$1.599e-04$
	2013	728	$3.117e-03$	$4.281e-06$	155	$5.335e-02$	$3.442e-04$
	2014	4776	$3.205e-02$	$6.710e-06$	169	$1.679e-02$	$9.932e-05$
	2015	4330	$7.023e-02$	$1.622e-05$	133	$1.116e-02$	$8.395e-05$
	2016	143	$5.995e-04$	$4.192e-06$	78	$5.240e-03$	$6.718e-05$
	2017	1187	$3.711e-03$	$3.127e-06$	40	$1.936e-03$	$4.840e-05$
517	1991	340	$1.148e-01$	$3.377e-04$	1990	$4.821e-01$	$2.422e-04$
	1992	149	$1.070e-02$	$7.185e-05$	789	$8.216e-01$	$1.041e-03$
	1993	170	$7.590e-03$	$4.465e-05$	5	$1.953e-01$	$3.907e-02$
	1994	405	$1.003e-02$	$2.476e-05$	860	$5.595e-01$	$6.506e-04$
	1995	–	–	–	1462	$1.924e-01$	$1.316e-04$
	1996	628	$1.495e-02$	$2.381e-05$	1533	$5.283e-01$	$3.446e-04$
	1997	464	$1.562e-02$	$3.365e-05$	2189	$4.890e-01$	$2.234e-04$
	1998	345	$1.823e-02$	$5.284e-05$	2414	$3.692e-01$	$1.529e-04$
	1999	484	$1.286e-02$	$2.656e-05$	2802	$2.072e-01$	$7.395e-05$
	2000	1271	$1.603e-02$	$1.261e-05$	3152	$4.054e-01$	$1.286e-04$
	2001	1364	$3.384e-02$	$2.481e-05$	1505	$1.862e-01$	$1.237e-04$
	2002	1435	$1.856e-02$	$1.293e-05$	934	$8.565e-02$	$9.170e-05$
	2003	436	$2.494e-03$	$5.720e-06$	1087	$7.370e-02$	$6.780e-05$
	2004	673	$6.313e-03$	$9.380e-06$	2721	$2.131e-01$	$7.830e-05$
	2005	1725	$7.832e-02$	$4.540e-05$	1142	$1.335e-01$	$1.169e-04$
	2006	1200	$7.915e-02$	$6.596e-05$	1172	$8.737e-02$	$7.455e-05$

	2007	1097	$1.081e-01$	$9.856e-05$	2454	$1.484e-01$	$6.047e-05$
	2008	4229	$2.322e-01$	$5.491e-05$	3116	$1.521e-01$	$4.881e-05$
	2009	1467	$5.084e-02$	$3.466e-05$	890	$6.612e-02$	$7.429e-05$
	2010	1970	$2.030e-02$	$1.030e-05$	803	$4.123e-02$	$5.135e-05$
	2011	2105	$1.592e-02$	$7.562e-06$	351	$1.968e-02$	$5.606e-05$
	2012	966	$3.620e-03$	$3.748e-06$	642	$4.645e-02$	$7.236e-05$
	2013	1287	$2.410e-02$	$1.872e-05$	412	$1.897e-02$	$4.605e-05$
	2014	1973	$1.483e-02$	$7.518e-06$	674	$4.635e-02$	$6.877e-05$
	2015	2836	$5.141e-02$	$1.813e-05$	170	$1.072e-02$	$6.309e-05$
	2016	1039	$2.069e-02$	$1.991e-05$	694	$3.505e-02$	$5.050e-05$
	2017	475	$9.872e-03$	$2.078e-05$	189	$1.432e-02$	$7.576e-05$
518	1991	–	–	–	7	$3.656e-04$	$5.223e-05$
	1992	14	$2.840e-03$	$2.029e-04$	–	–	–
	1993	1	$3.340e-04$	$3.340e-04$	–	–	–
	1994	11	$1.595e-03$	$1.450e-04$	11	$8.027e-03$	$7.297e-04$
	1995	1	$7.681e-03$	$7.681e-03$	–	–	–
	1996	189	$1.069e-03$	$5.655e-06$	–	–	–
	1997	80	$7.847e-04$	$9.809e-06$	–	–	–
	1998	257	$1.947e-03$	$7.576e-06$	7	$9.907e-04$	$1.415e-04$
	1999	295	$2.825e-03$	$9.575e-06$	1	$1.178e-04$	$1.178e-04$
	2000	2	$1.086e-04$	$5.432e-05$	1	$6.279e-04$	$6.279e-04$
	2001	7	$6.124e-05$	$8.749e-06$	–	–	–
	2002	3	$5.678e-05$	$1.893e-05$	–	–	–
	2003	1	$3.198e-05$	$3.198e-05$	–	–	–
	2013	3	$4.346e-04$	$1.449e-04$	–	–	–
519	1991	–	–	–	1	$3.230e-03$	$3.230e-03$
	1992	1	$5.590e-03$	$5.590e-03$	–	–	–
	1993	11	$3.215e-04$	$2.922e-05$	1	$1.380e-02$	$1.380e-02$
	1994	–	–	–	11	$5.127e-03$	$4.661e-04$
	1996	7	$1.278e-03$	$1.826e-04$	4	$2.737e-03$	$6.842e-04$
	1997	157	$2.234e-02$	$1.423e-04$	3	$2.139e-03$	$7.131e-04$
	1998	457	$1.385e-02$	$3.030e-05$	112	$1.889e-02$	$1.686e-04$
	1999	314	$3.624e-03$	$1.154e-05$	516	$2.903e-02$	$5.627e-05$
	2000	150	$1.240e-03$	$8.269e-06$	15	$2.357e-03$	$1.572e-04$
	2001	130	$6.717e-03$	$5.167e-05$	45	$1.153e-02$	$2.563e-04$
	2002	44	$1.687e-02$	$3.835e-04$	20	$9.892e-03$	$4.946e-04$
	2003	37	$1.135e-02$	$3.069e-04$	81	$1.479e-02$	$1.826e-04$
	2004	99	$3.949e-02$	$3.989e-04$	175	$1.988e-02$	$1.136e-04$
	2005	47	$3.284e-02$	$6.988e-04$	21	$7.475e-03$	$3.559e-04$
	2006	41	$1.259e-01$	$3.071e-03$	20	$1.442e-03$	$7.210e-05$
	2007	39	$2.580e-01$	$6.616e-03$	39	$3.233e-03$	$8.290e-05$
	2008	8	$1.410e-01$	$1.763e-02$	27	$4.533e-04$	$1.679e-05$
	2009	5	$1.863e-03$	$3.727e-04$	4	$3.281e-04$	$8.202e-05$
	2010	201	$6.605e-04$	$3.286e-06$	10	$5.612e-04$	$5.612e-05$
	2011	–	–	–	10	$3.908e-04$	$3.908e-05$
	2012	18	$4.140e-04$	$2.300e-05$	5	$1.882e-04$	$3.764e-05$
	2013	11	$1.120e-04$	$1.018e-05$	3	$3.814e-04$	$1.271e-04$
	2014	83	$7.485e-04$	$9.018e-06$	2	$8.963e-05$	$4.481e-05$

	2015	17	$2.520e-03$	$1.482e-04$	3	$3.649e-04$	$1.216e-04$
	2016	–	–	–	2	$2.520e-04$	$1.260e-04$
	2017	–	–	–	4	$1.615e-04$	$4.037e-05$
521	1991	102	$2.080e-01$	$2.039e-03$	2985	$2.659e+00$	$8.908e-04$
	1992	96	$1.939e-01$	$2.020e-03$	263	$1.309e+00$	$4.977e-03$
	1993	361	$2.768e-02$	$7.669e-05$	5	$3.007e-01$	$6.014e-02$
	1994	348	$1.905e-02$	$5.475e-05$	96	$2.081e-01$	$2.167e-03$
	1995	34	$1.443e-01$	$4.243e-03$	86	$4.434e-02$	$5.155e-04$
	1996	323	$6.127e-02$	$1.897e-04$	942	$7.360e-02$	$7.814e-05$
	1997	257	$2.813e-02$	$1.095e-04$	306	$3.163e-02$	$1.034e-04$
	1998	219	$4.598e-02$	$2.100e-04$	574	$1.712e-01$	$2.982e-04$
	1999	896	$2.442e-02$	$2.726e-05$	489	$4.863e-02$	$9.945e-05$
	2000	844	$4.507e-02$	$5.340e-05$	267	$6.328e-02$	$2.370e-04$
	2001	357	$5.847e-02$	$1.638e-04$	2335	$4.745e-01$	$2.032e-04$
	2002	1267	$3.077e-02$	$2.428e-05$	2222	$2.358e-01$	$1.061e-04$
	2003	401	$4.275e-03$	$1.066e-05$	1583	$3.241e-01$	$2.047e-04$
	2004	259	$6.905e-03$	$2.666e-05$	1990	$1.167e-01$	$5.864e-05$
	2005	840	$2.025e-02$	$2.411e-05$	4804	$3.875e-01$	$8.066e-05$
	2006	697	$6.237e-02$	$8.949e-05$	4410	$2.525e-01$	$5.726e-05$
	2007	1443	$6.147e-02$	$4.260e-05$	3186	$1.964e-01$	$6.164e-05$
	2008	3036	$5.529e-02$	$1.821e-05$	2900	$1.378e-01$	$4.751e-05$
	2009	1081	$2.863e-02$	$2.648e-05$	1770	$8.889e-02$	$5.022e-05$
	2010	1013	$4.063e-03$	$4.010e-06$	1510	$1.142e-01$	$7.564e-05$
	2011	558	$1.238e-02$	$2.218e-05$	603	$6.132e-02$	$1.017e-04$
	2012	671	$2.441e-03$	$3.638e-06$	2450	$1.987e-01$	$8.112e-05$
	2013	980	$3.562e-03$	$3.635e-06$	1741	$1.154e-01$	$6.628e-05$
	2014	3269	$2.126e-02$	$6.504e-06$	1599	$1.099e-01$	$6.875e-05$
	2015	1212	$4.567e-03$	$3.769e-06$	293	$1.016e-02$	$3.469e-05$
	2016	1383	$4.320e-03$	$3.123e-06$	969	$5.479e-02$	$5.654e-05$
	2017	2447	$1.689e-02$	$6.903e-06$	350	$1.451e-02$	$4.147e-05$
523	1993	2	$7.714e-04$	$3.857e-04$	–	–	–
	1994	2	$8.094e-04$	$4.047e-04$	–	–	–
	1995	2	$3.853e-03$	$1.927e-03$	–	–	–
	1996	9	$6.724e-04$	$7.471e-05$	6	$2.666e-04$	$4.444e-05$
	1997	2	$1.235e-03$	$6.177e-04$	25	$1.190e-04$	$4.759e-06$
	1998	4	$1.608e-03$	$4.021e-04$	16	$5.474e-04$	$3.421e-05$
	1999	9	$1.496e-03$	$1.662e-04$	2	$1.177e-05$	$5.885e-06$
	2000	7	$4.005e-04$	$5.721e-05$	1	$2.190e-06$	$2.190e-06$
	2001	6	$4.033e-04$	$6.722e-05$	6	$3.365e-04$	$5.609e-05$
	2002	2	$9.749e-05$	$4.875e-05$	1	$7.258e-04$	$7.258e-04$
	2003	4	$4.311e-05$	$1.078e-05$	1	$3.132e-06$	$3.132e-06$
	2004	7	$8.509e-05$	$1.216e-05$	–	–	–
	2005	17	$2.906e-04$	$1.709e-05$	1	$4.040e-05$	$4.040e-05$
	2006	12	$1.826e-04$	$1.521e-05$	–	–	–
	2007	4	$1.026e-04$	$2.566e-05$	–	–	–
	2008	6	$1.031e-04$	$1.719e-05$	–	–	–
	2009	7	$9.055e-05$	$1.294e-05$	–	–	–
	2010	29	$4.350e-05$	$1.500e-06$	–	–	–

	2011	21	$1.275e-04$	$6.072e-06$	–	–	–
	2012	18	$9.006e-05$	$5.003e-06$	–	–	–
	2013	10	$1.651e-04$	$1.651e-05$	–	–	–
	2014	12	$6.043e-05$	$5.036e-06$	–	–	–
	2015	4	$6.020e-05$	$1.505e-05$	–	–	–
	2016	1	$1.999e-05$	$1.999e-05$	–	–	–
	2017	2	$1.227e-05$	$6.136e-06$	1	$9.721e-07$	$9.721e-07$
524	1993	–	–	–	1	$9.212e-02$	$9.212e-02$
	1995	6	$4.832e-04$	$8.053e-05$	605	$4.890e-02$	$8.082e-05$
	1996	15	$3.624e-04$	$2.416e-05$	162	$3.613e-02$	$2.230e-04$
	1997	3	$4.883e-04$	$1.628e-04$	5	$2.463e-03$	$4.926e-04$
	1998	43	$8.583e-03$	$1.996e-04$	25	$1.059e-02$	$4.235e-04$
	1999	39	$8.621e-03$	$2.211e-04$	21	$1.297e-01$	$6.179e-03$
	2000	1	$1.124e-04$	$1.124e-04$	38	$2.434e-02$	$6.404e-04$
	2001	3	$9.523e-03$	$3.174e-03$	142	$4.375e-02$	$3.081e-04$
	2002	38	$1.415e-02$	$3.723e-04$	132	$3.761e-02$	$2.849e-04$
	2003	76	$1.215e-03$	$1.599e-05$	285	$1.134e-01$	$3.977e-04$
	2004	140	$8.143e-03$	$5.816e-05$	1433	$2.379e-01$	$1.660e-04$
	2005	51	$3.458e-03$	$6.780e-05$	196	$2.312e-02$	$1.180e-04$
	2006	34	$5.444e-04$	$1.601e-05$	50	$5.294e-03$	$1.059e-04$
	2007	57	$4.737e-03$	$8.310e-05$	116	$1.088e-02$	$9.376e-05$
	2008	178	$2.180e-03$	$1.225e-05$	63	$1.560e-03$	$2.476e-05$
	2009	196	$3.977e-03$	$2.029e-05$	19	$6.764e-04$	$3.560e-05$
	2010	20	$1.420e-04$	$7.098e-06$	36	$3.655e-04$	$1.015e-05$
	2011	36	$1.072e-04$	$2.977e-06$	7	$4.352e-04$	$6.217e-05$
	2012	15	$7.533e-05$	$5.022e-06$	19	$6.833e-04$	$3.596e-05$
	2013	20	$9.159e-05$	$4.580e-06$	19	$1.031e-03$	$5.428e-05$
	2014	44	$1.371e-04$	$3.115e-06$	–	–	–
	2015	93	$3.482e-04$	$3.745e-06$	44	$2.470e-03$	$5.613e-05$
	2016	107	$7.355e-04$	$6.874e-06$	33	$2.758e-03$	$8.358e-05$
	2017	91	$7.223e-04$	$7.937e-06$	6	$2.290e-04$	$3.817e-05$
541	1992	12	$0.000e+00$	$0.000e+00$	155	$5.679e-06$	$3.664e-08$
	1994	6	$1.824e-04$	$3.040e-05$	–	–	–
	1995	–	–	–	11	$1.799e-03$	$1.635e-04$
	1996	–	–	–	66	$3.179e-03$	$4.817e-05$
	1997	–	–	–	127	$1.954e-03$	$1.539e-05$
	1998	21	$2.224e-04$	$1.059e-05$	182	$4.956e-03$	$2.723e-05$
	1999	367	$4.570e-02$	$1.245e-04$	101	$3.512e-03$	$3.477e-05$
	2000	16	$9.806e-05$	$6.129e-06$	135	$4.225e-03$	$3.129e-05$
	2001	41	$2.627e-04$	$6.407e-06$	483	$1.395e-02$	$2.888e-05$
	2002	18	$7.918e-05$	$4.399e-06$	326	$1.159e-02$	$3.556e-05$
	2003	2	$1.849e-05$	$9.247e-06$	193	$7.128e-03$	$3.693e-05$
	2004	2	$4.974e-05$	$2.487e-05$	47	$1.565e-03$	$3.330e-05$
	2005	2	$1.313e-04$	$6.563e-05$	127	$1.329e-03$	$1.046e-05$
	2006	9	$1.631e-02$	$1.812e-03$	53	$8.119e-04$	$1.532e-05$
	2007	4	$6.647e-02$	$1.662e-02$	89	$8.771e-04$	$9.854e-06$
	2008	4	$6.125e-03$	$1.531e-03$	92	$1.070e-03$	$1.163e-05$
542	1996	–	–	–	1	$4.647e-05$	$4.647e-05$

	1997	–	–	–	28	$2.042e-04$	$7.291e-06$
	1998	89	$2.007e-04$	$2.255e-06$	4	$4.094e-05$	$1.023e-05$
	1999	3	$1.928e-05$	$6.428e-06$	6	$9.961e-05$	$1.660e-05$
	2000	62	$1.927e-04$	$3.108e-06$	9	$4.938e-04$	$5.487e-05$
	2001	3	$2.447e-05$	$8.156e-06$	4	$5.519e-05$	$1.380e-05$
	2003	–	–	–	1	$1.878e-05$	$1.878e-05$
	2005	–	–	–	1	$1.349e-03$	$1.349e-03$
	2006	1	$1.732e-03$	$1.732e-03$	10	$5.294e-05$	$5.294e-06$
	2007	–	–	–	2	$8.540e-06$	$4.270e-06$
	2008	–	–	–	3	$1.040e-04$	$3.468e-05$
	2009	2	$3.968e-07$	$1.984e-07$	–	–	–
543	1998	2	$1.176e-05$	$5.881e-06$	–	–	–
	2000	26	$3.906e-04$	$1.502e-05$	–	–	–
	2001	3	$2.986e-05$	$9.952e-06$	–	–	–
	2003	–	–	–	4	$6.609e-04$	$1.652e-04$
	2004	–	–	–	10	$9.089e-04$	$9.089e-05$
	2005	1	$4.439e-06$	$4.439e-06$	27	$8.098e-04$	$2.999e-05$
	2006	–	–	–	6	$1.870e-04$	$3.117e-05$
	2007	–	–	–	13	$1.090e-04$	$8.387e-06$
	2008	1	$4.661e-03$	$4.661e-03$	12	$1.653e-04$	$1.377e-05$

Total bycatch size compositions

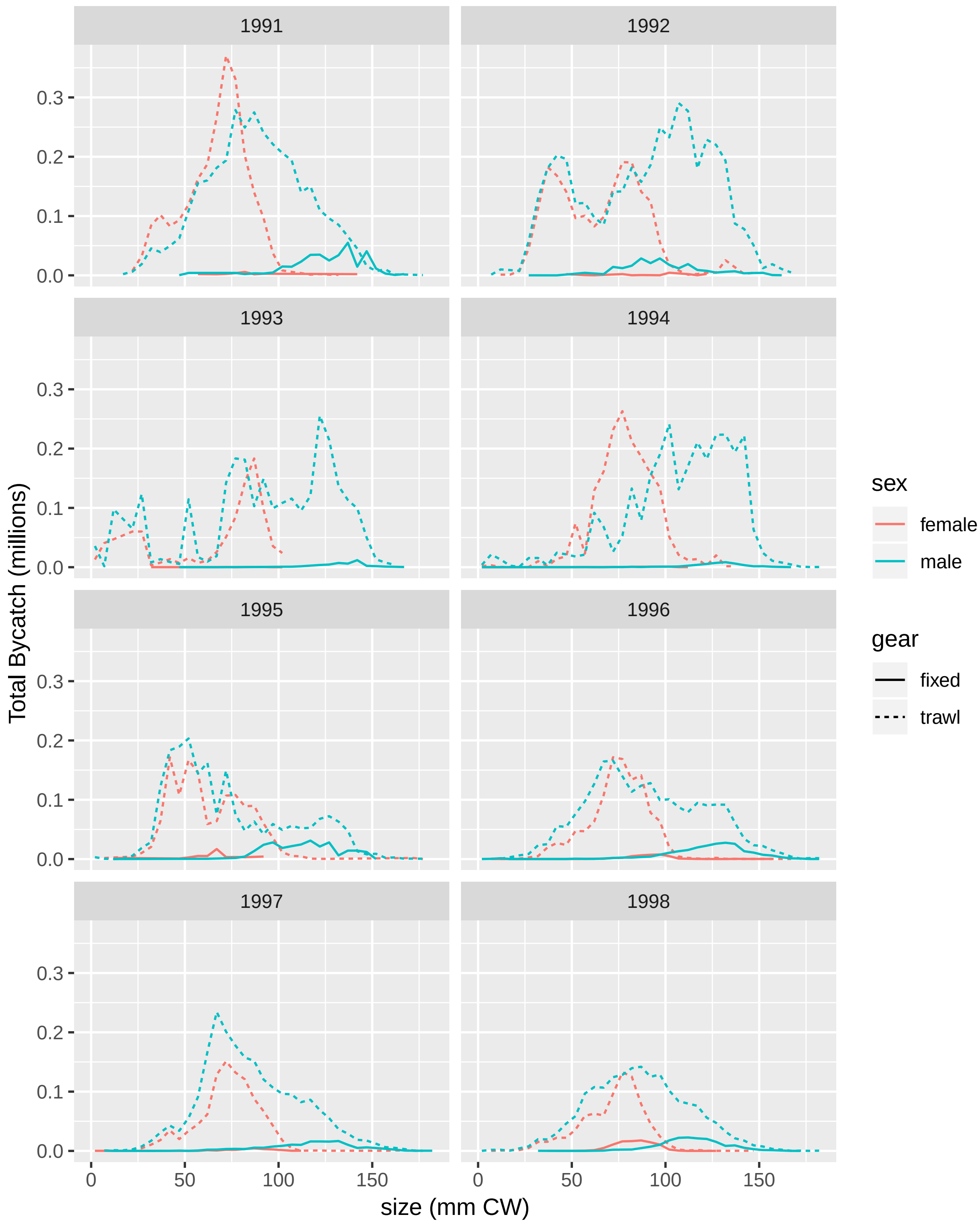


Figure 10: Total bycatch size frequencies, by year, gear type and sex.

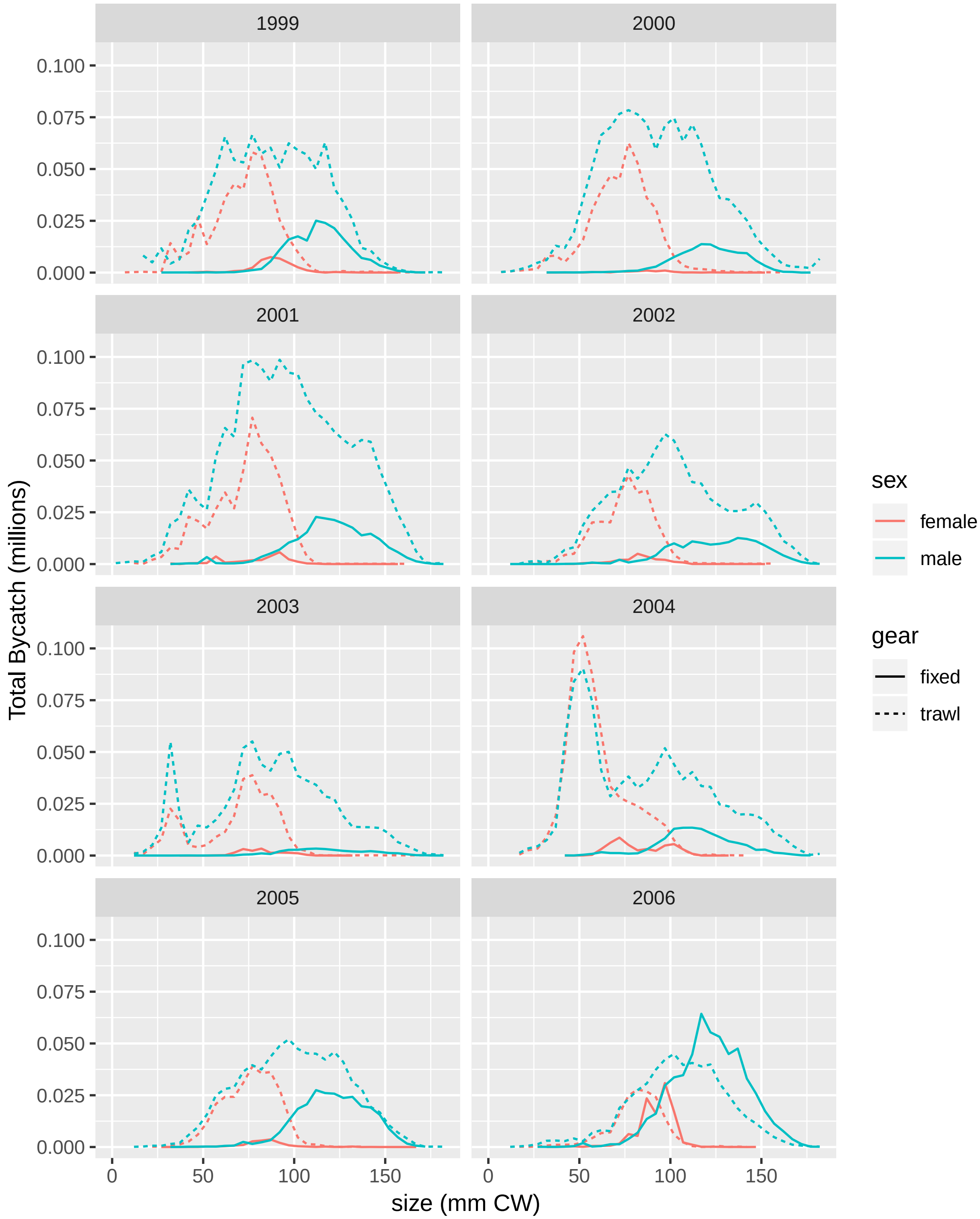


Figure 11: Total bycatch size frequencies, by year, gear type and sex.

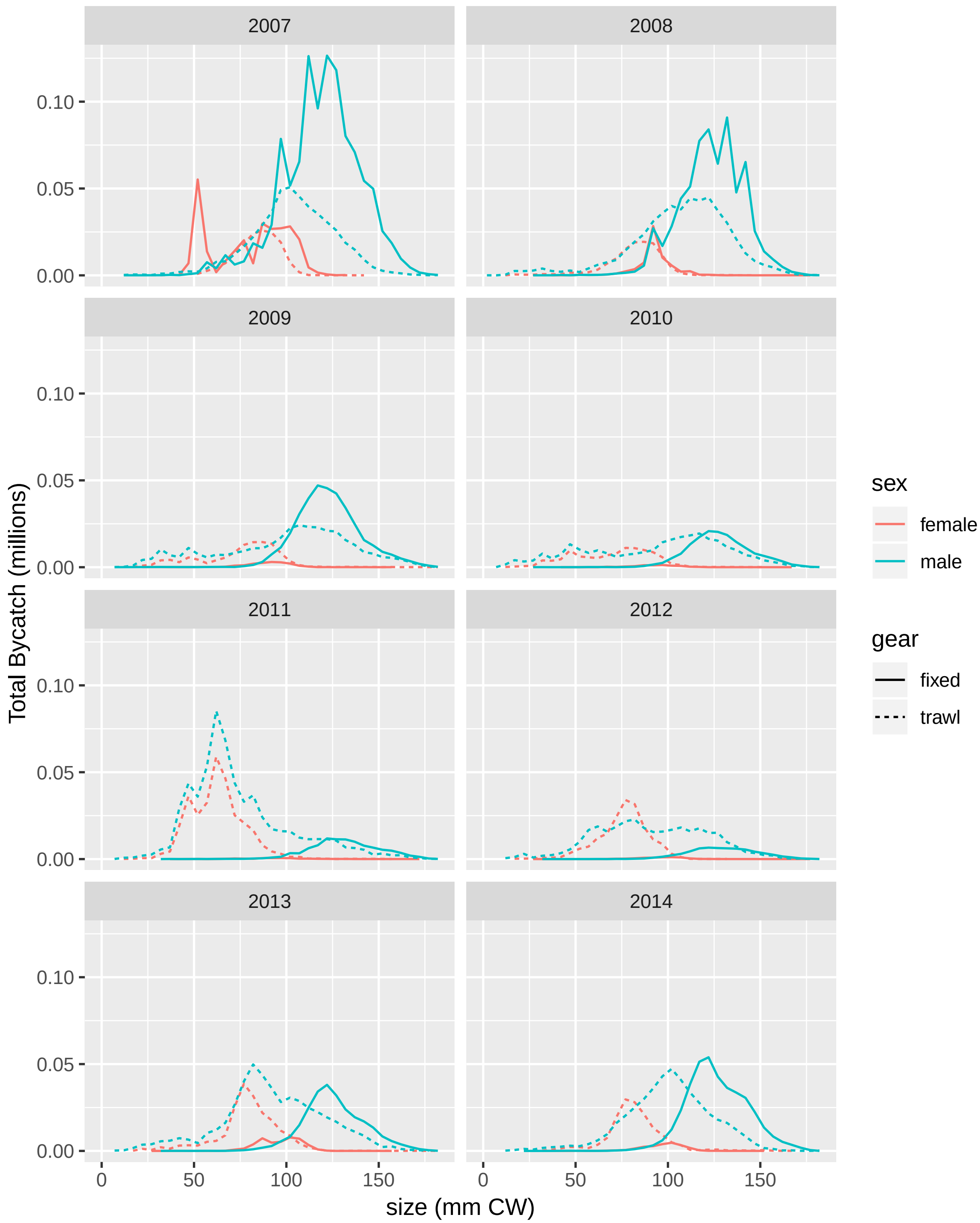


Figure 12: Total bycatch size frequencies, by year, gear type and sex.

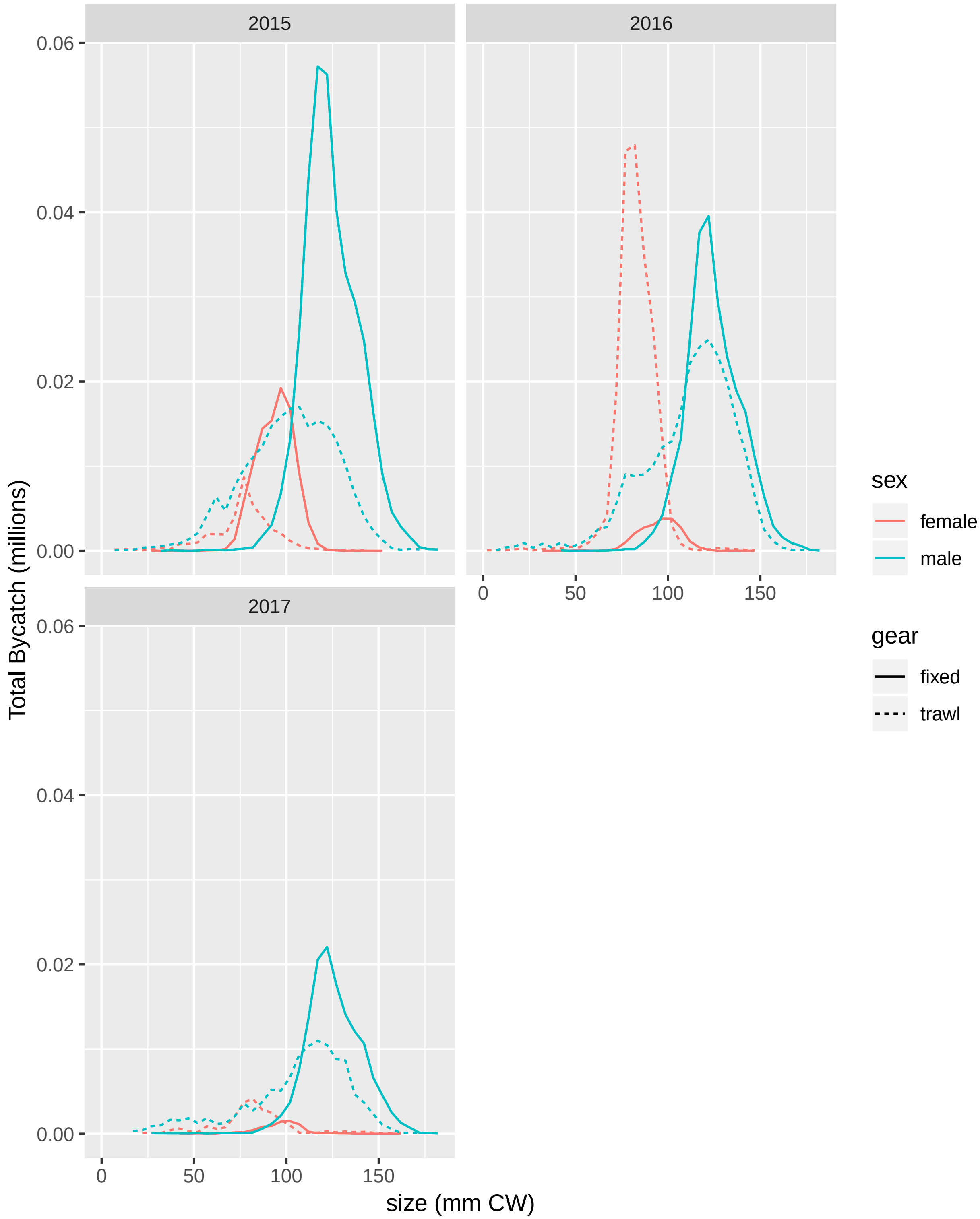


Figure 13: Total bycatch size frequencies, by year, gear type and sex.

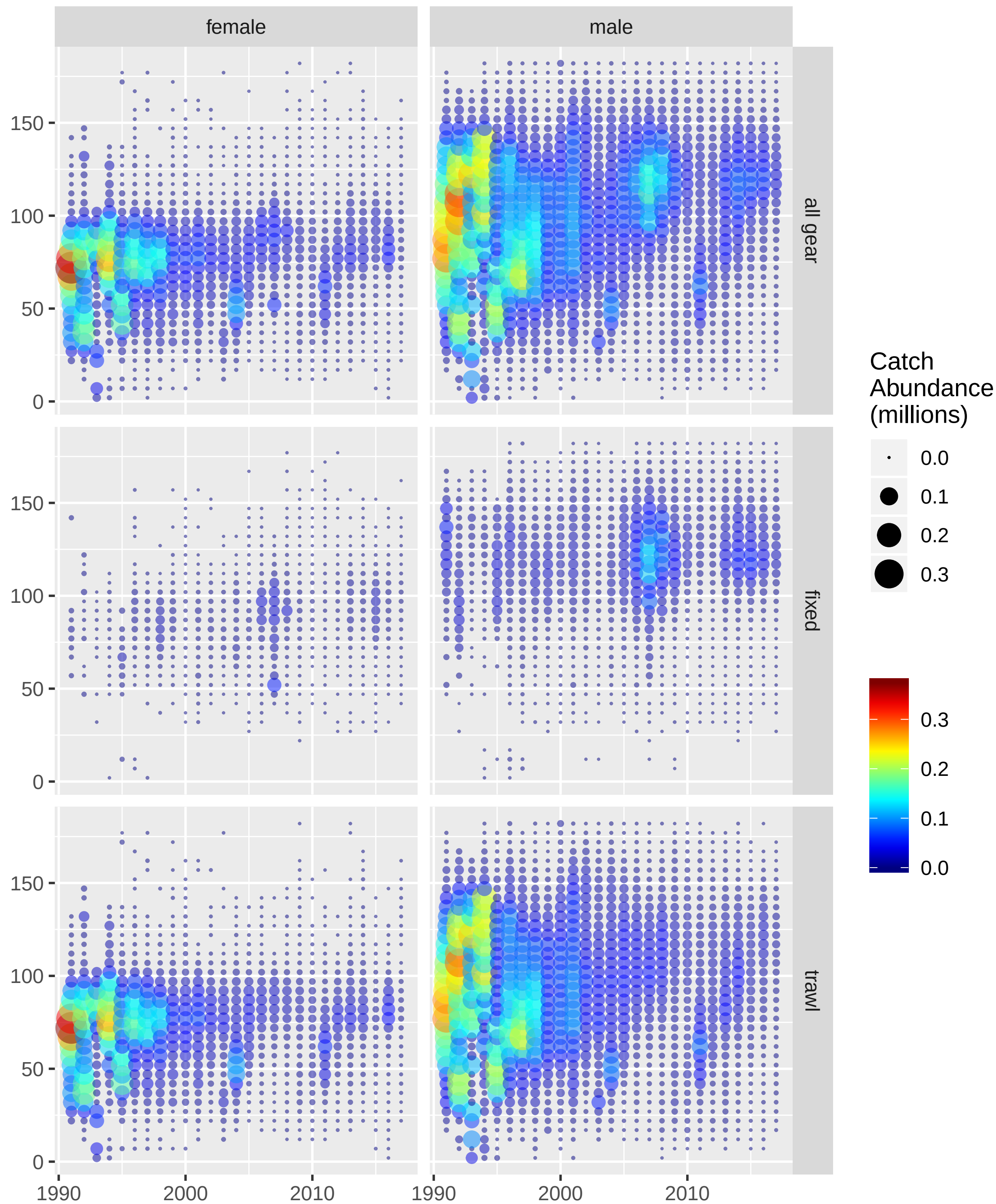


Figure 14: Total bycatch size frequencies, by year, gear type and sex. Bubble area scales with catch abundance.

Size compositions aggregated over gear type

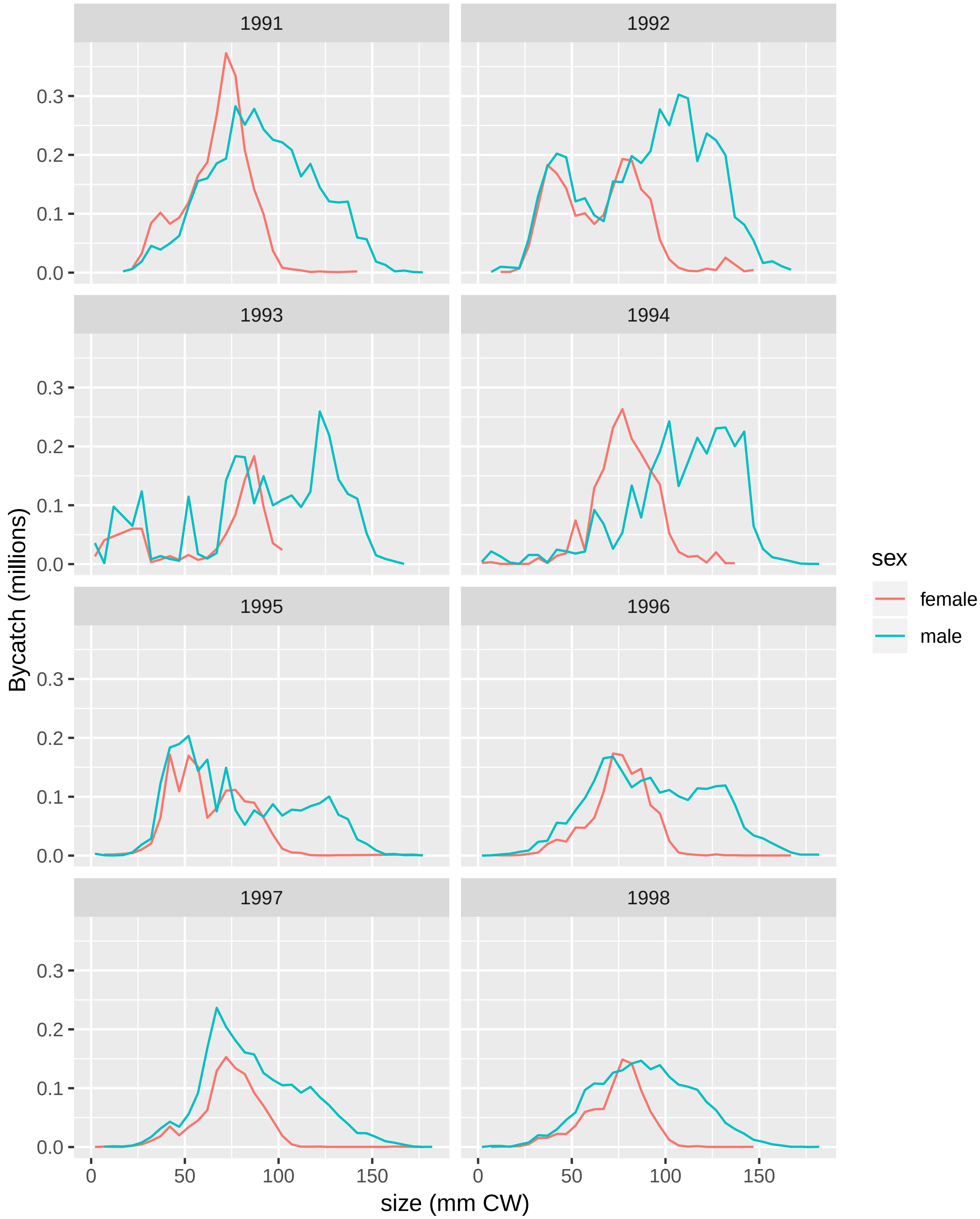


Figure 15: Total bycatch size frequencies, by year and sex, aggregated over gear type.

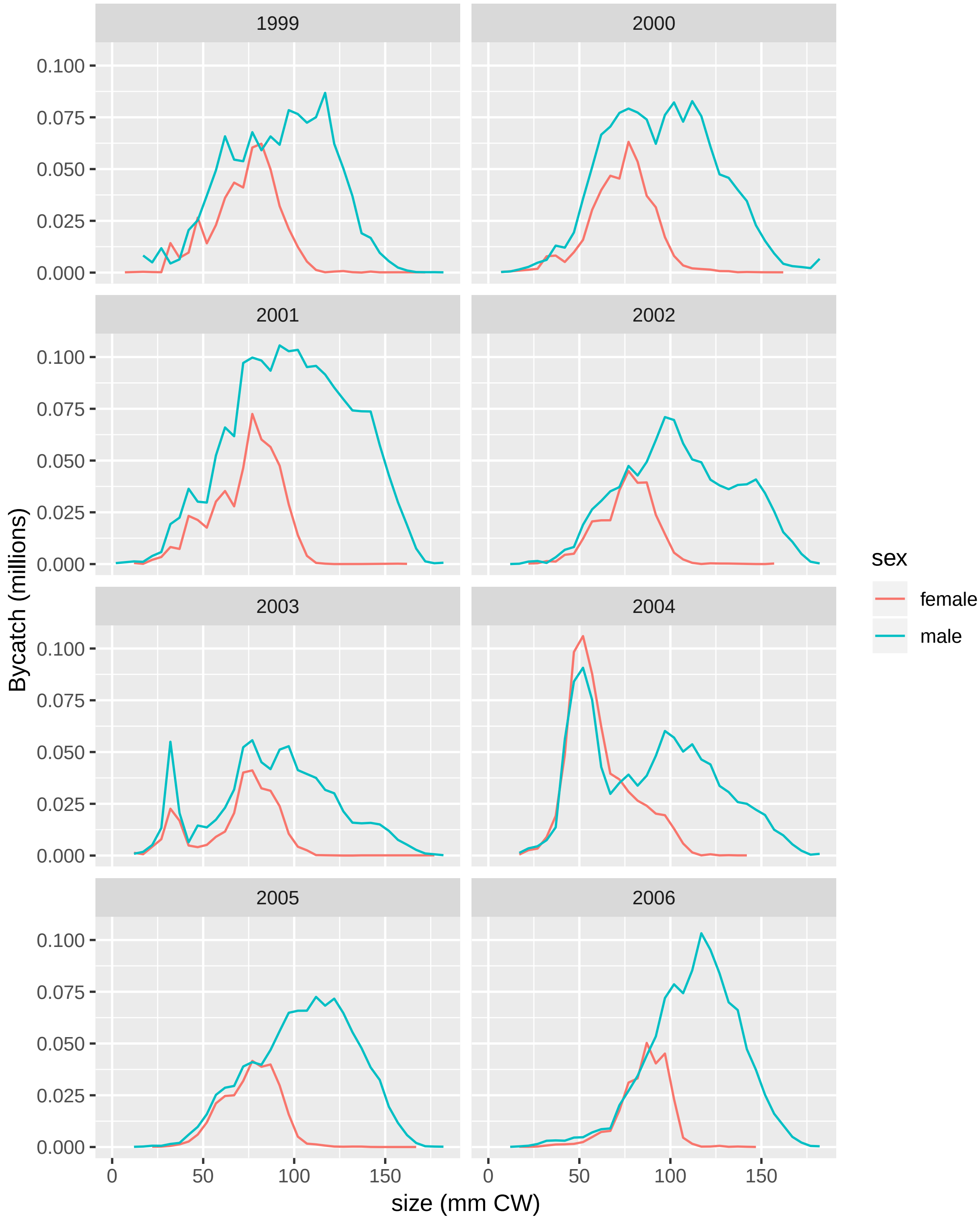


Figure 16: Total bycatch size frequencies, by year and sex, aggregated over gear type.

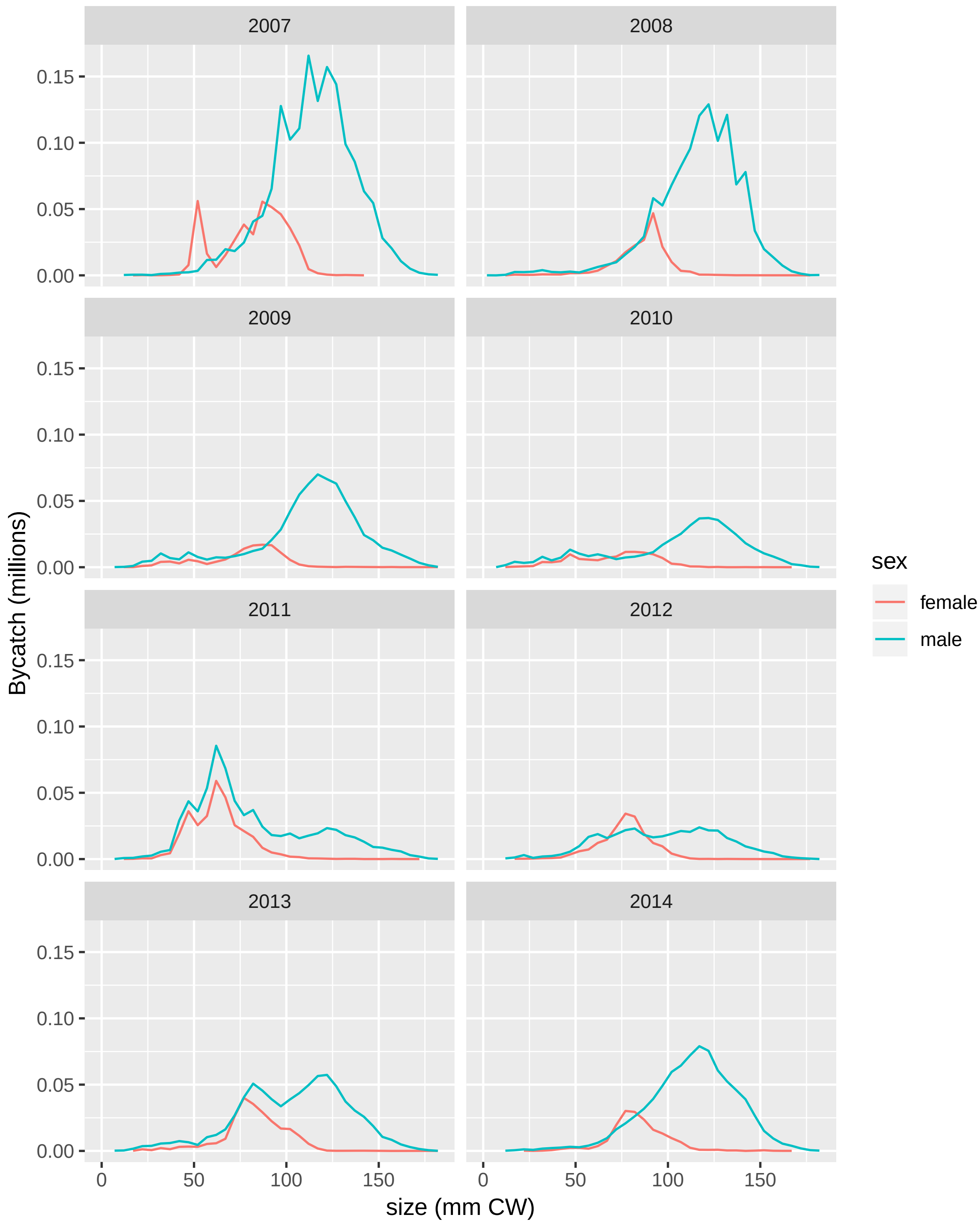


Figure 17: Total bycatch size frequencies, by year and sex, aggregated over gear type.

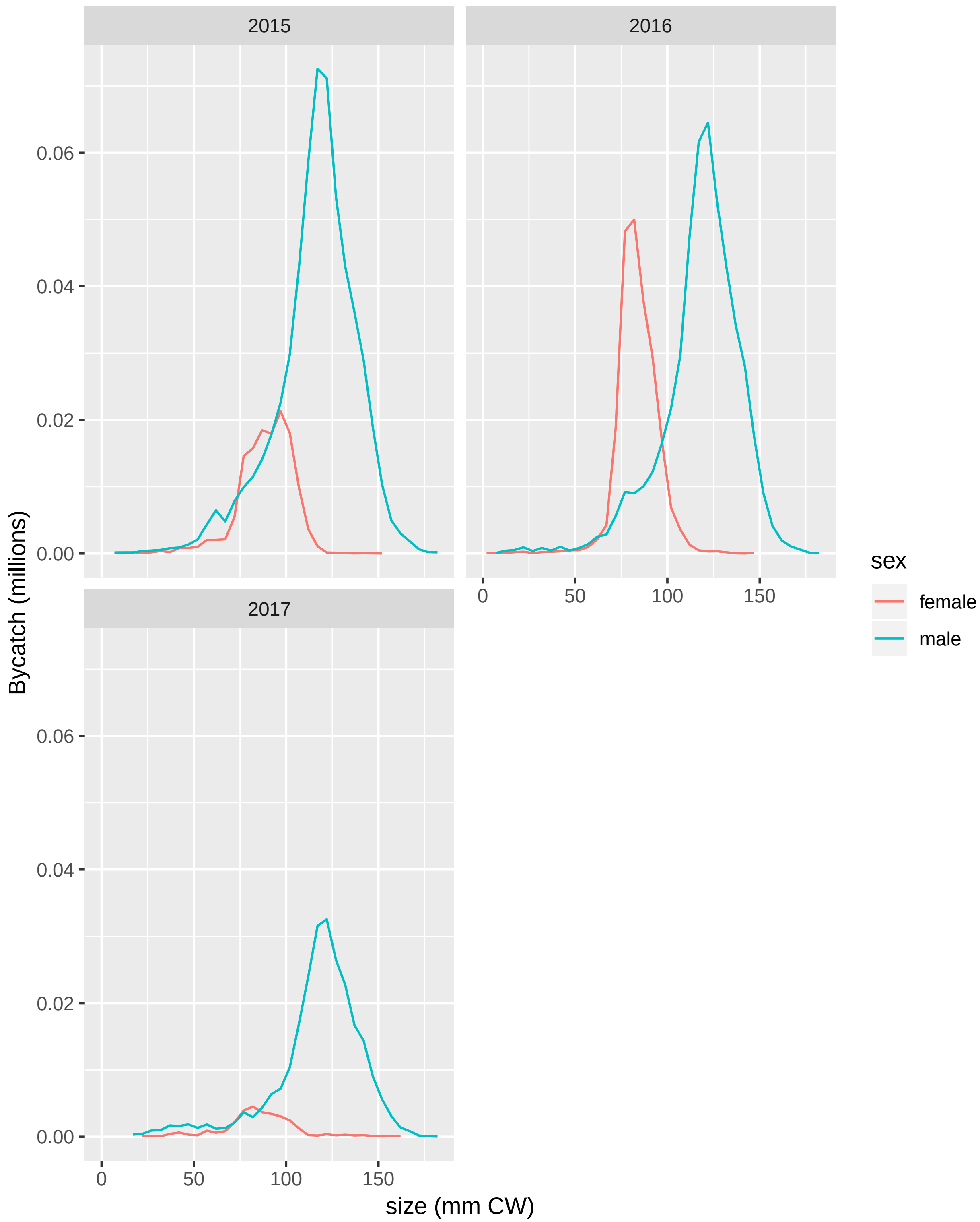
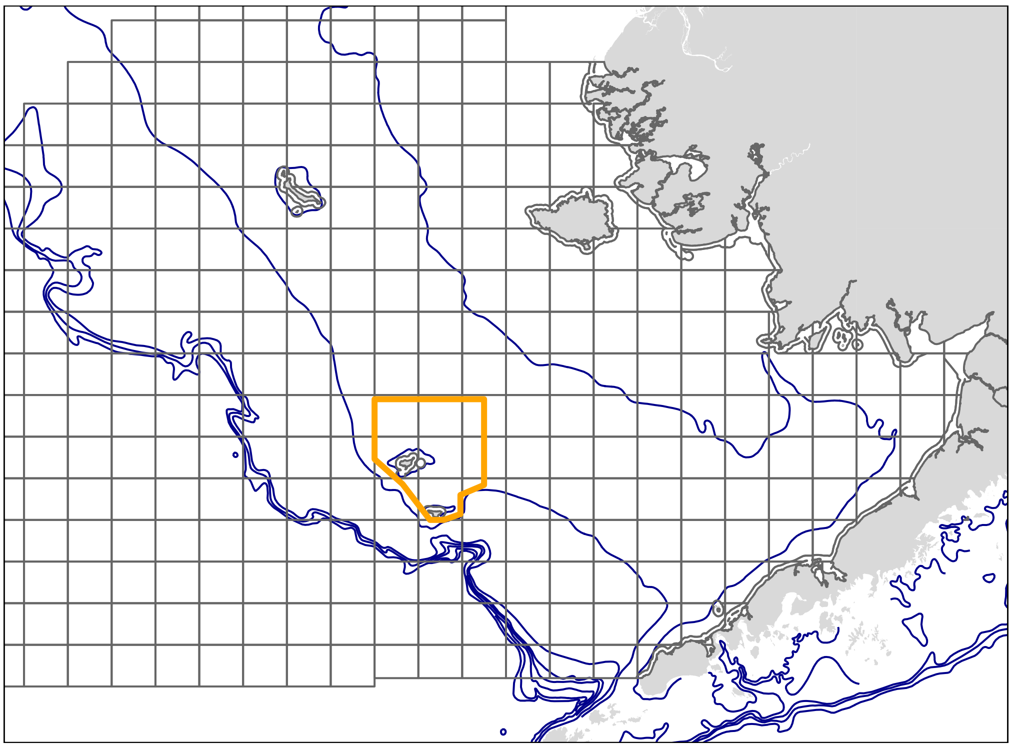


Figure 18: Total bycatch size frequencies, by year and sex, aggregated over gear type.

Spatial patterns of bycatch

Spatial patterns of Tanner crab bycatch in the groundfish fisheries, by ADFG stat area for 2009-2017, are illustrated by gear type in Figures 20-21 below. Bycatch less than 0.1 t in a stat area is not shown.



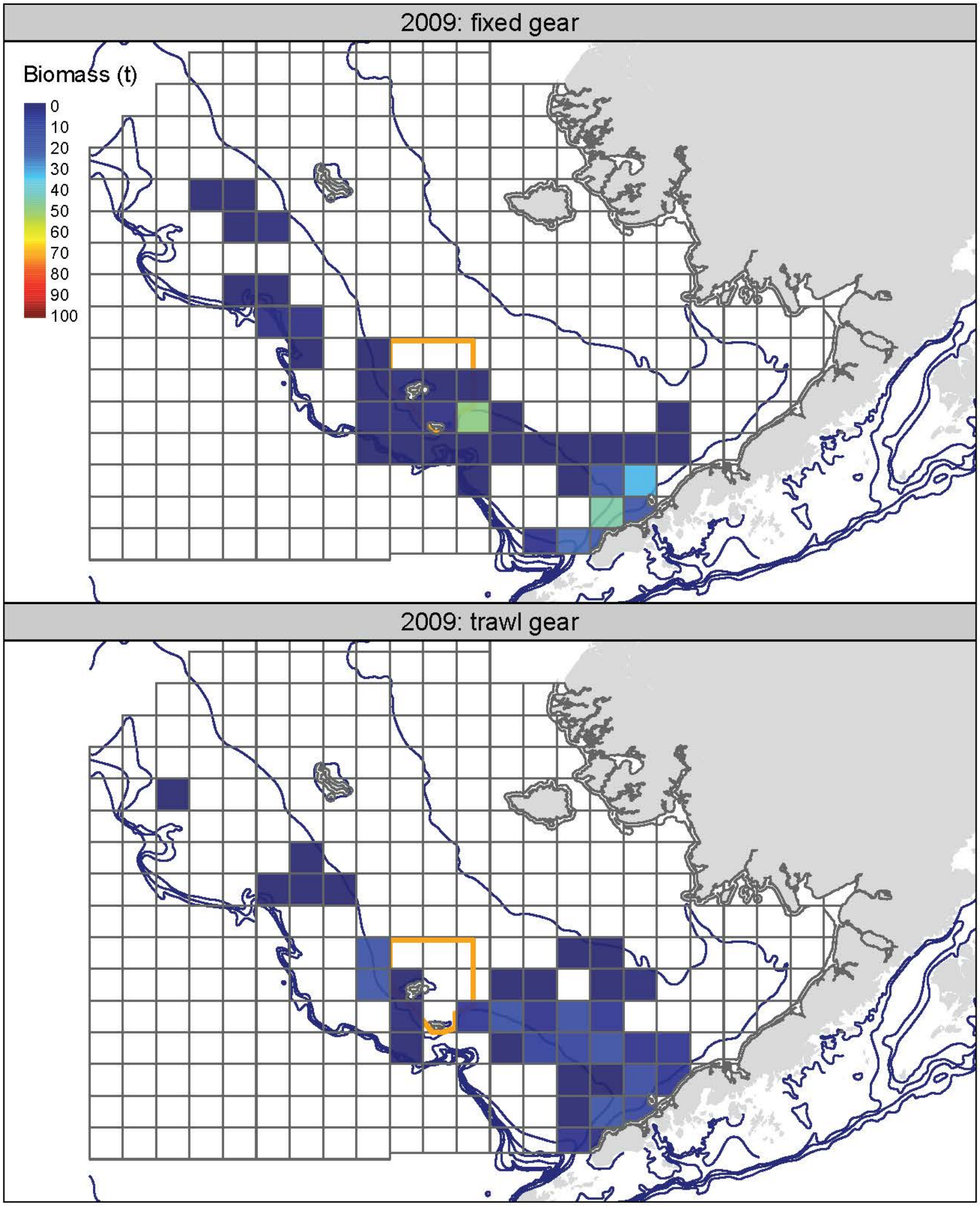


Figure 19: Bycatch of Tanner crab, by ADFG stat area, in the groundfish fisheries during 2009/10.

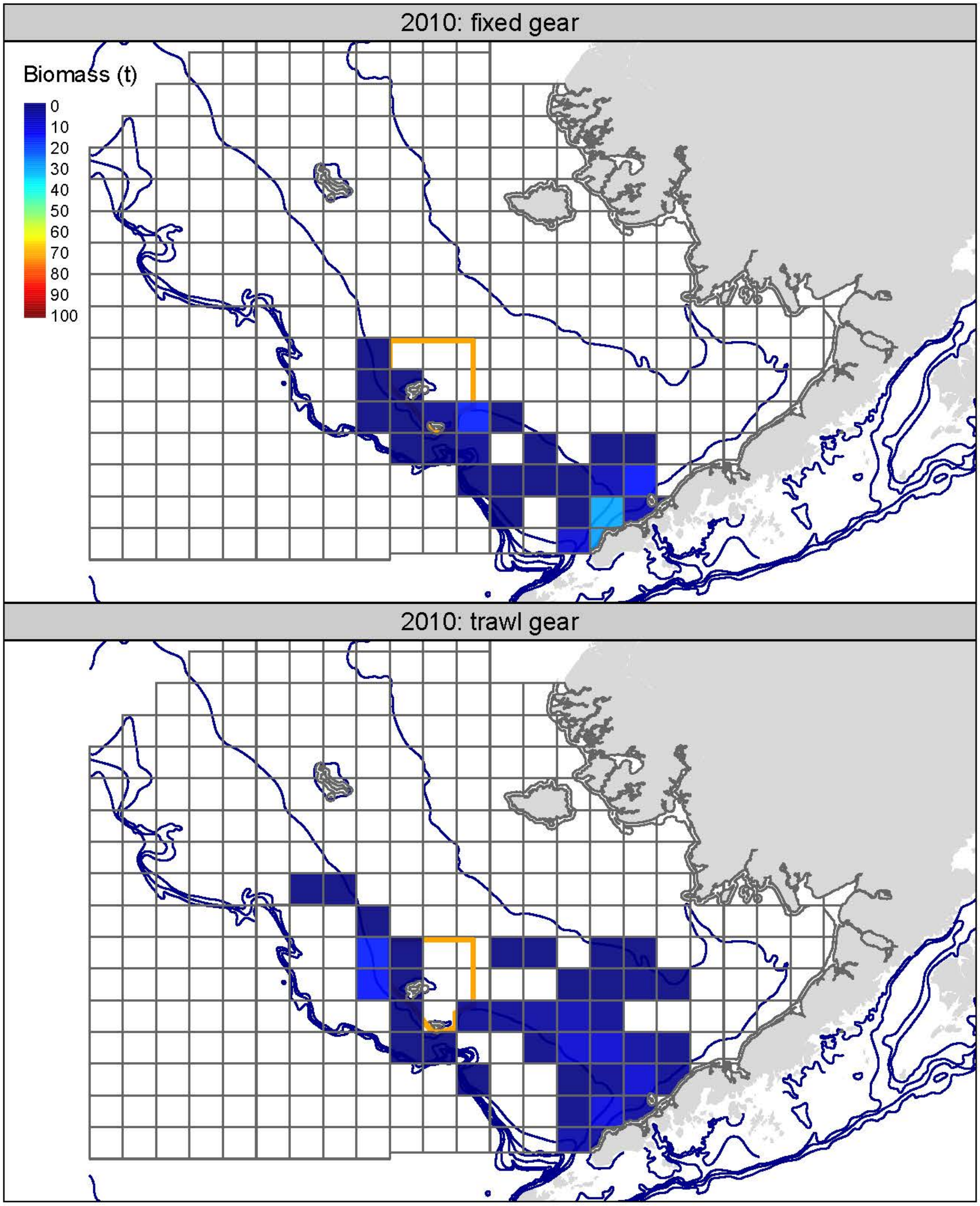


Figure 20: Bycatch of Tanner crab, by ADFG stat area, in the groundfish fisheries during 2010/11.

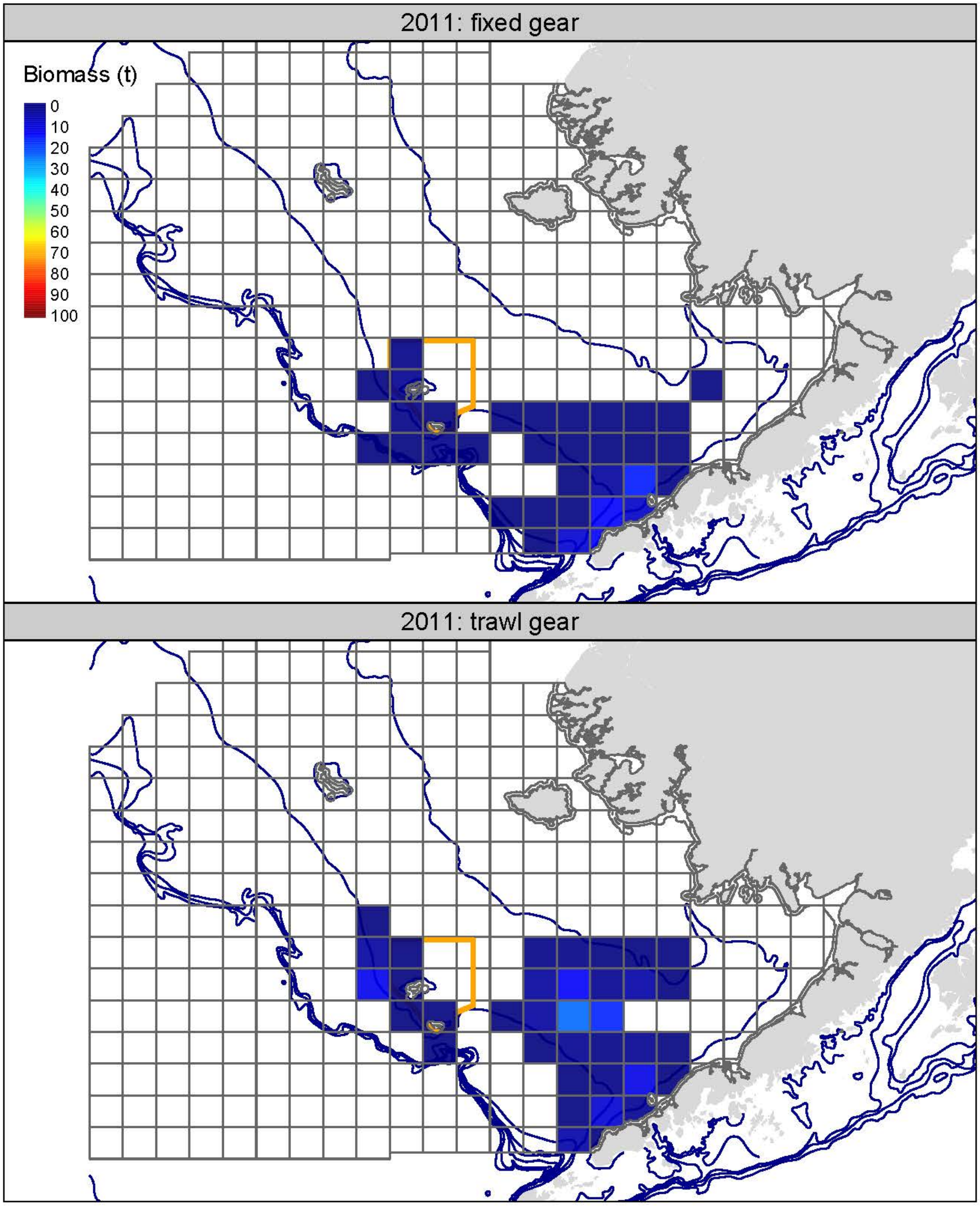


Figure 21: Bycatch of Tanner crab, by ADFG stat area, in the groundfish fisheries during 2011/12.

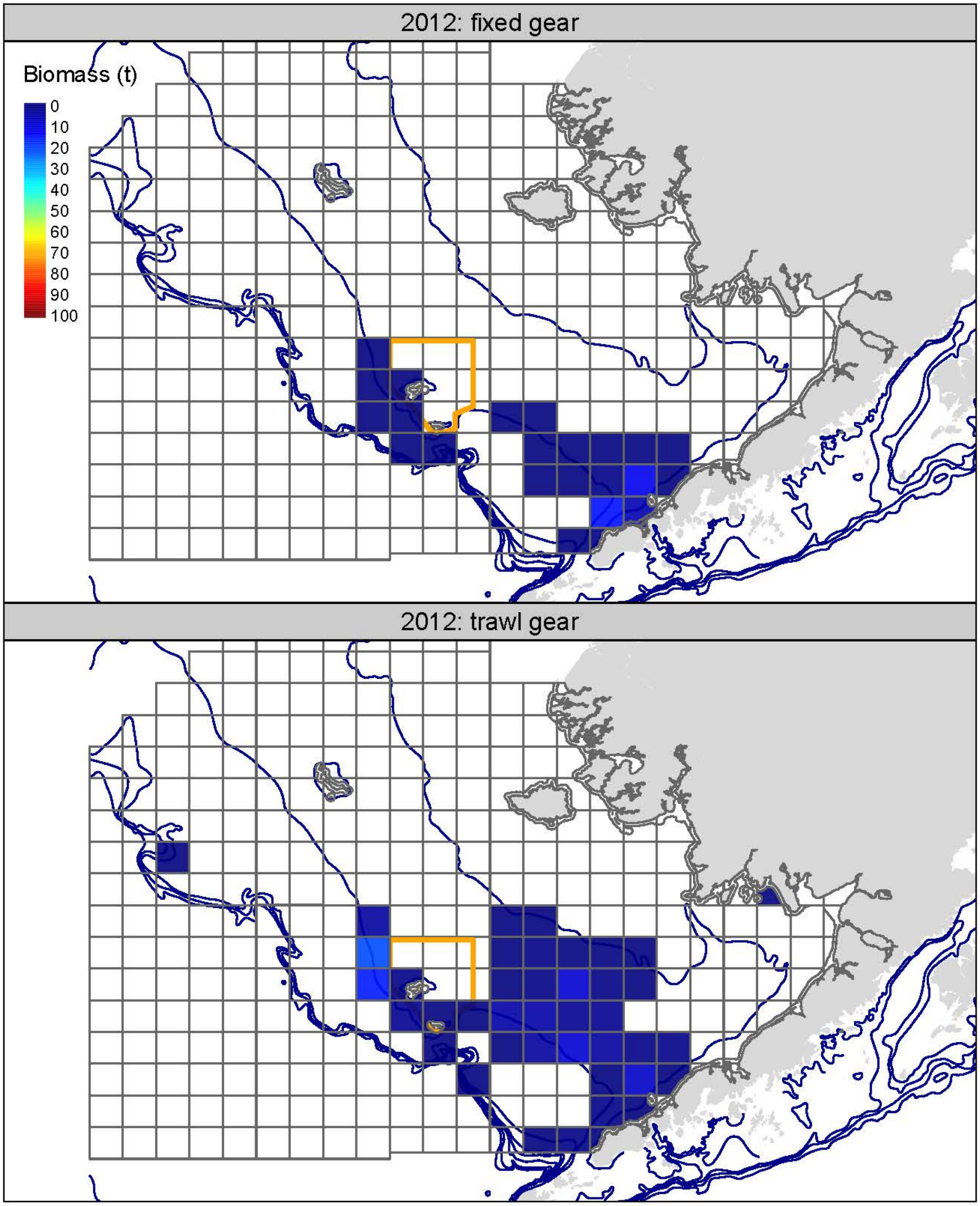


Figure 22: Bycatch of Tanner crab, by ADFG stat area, in the groundfish fisheries during 2012/13.

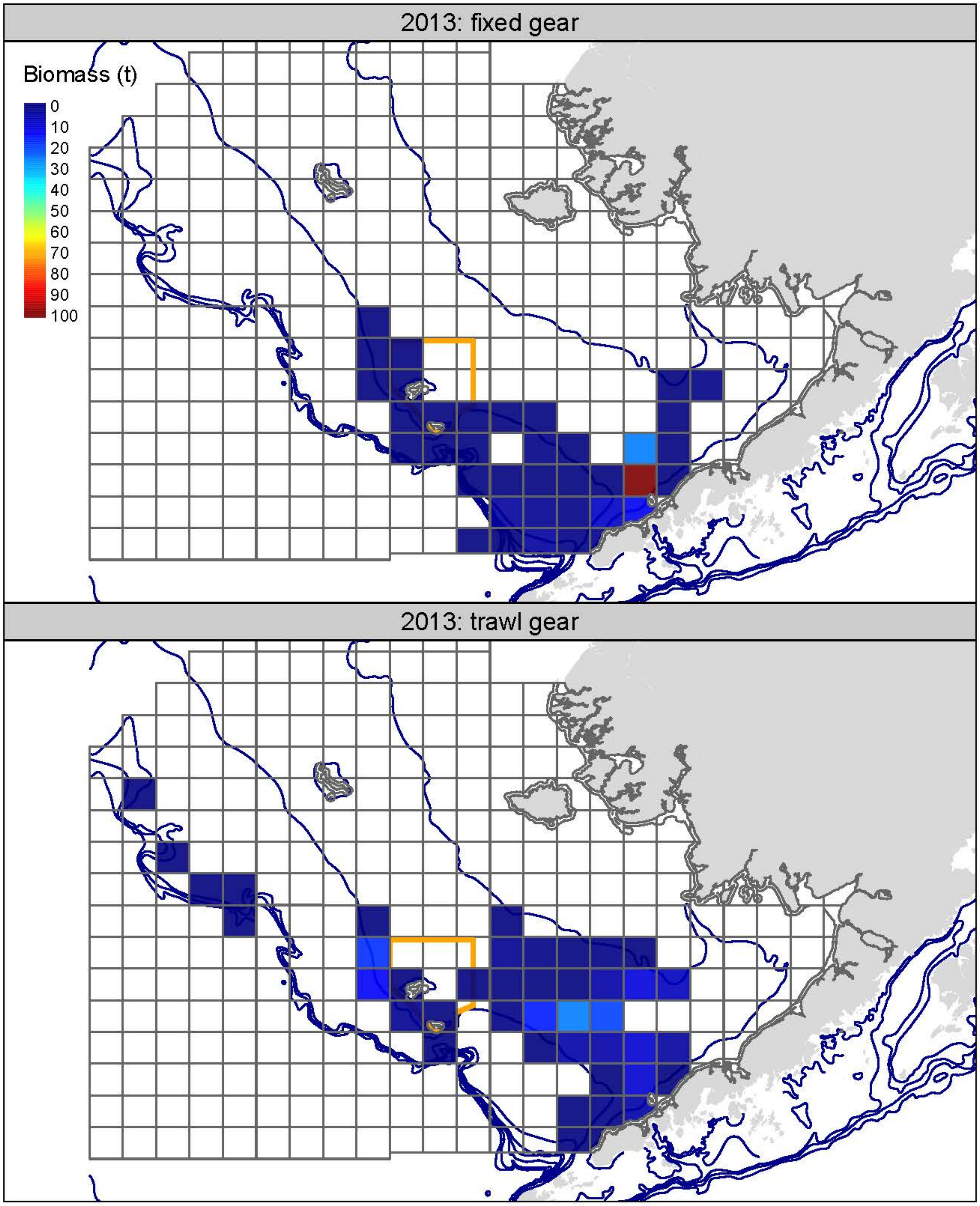


Figure 23: Bycatch of Tanner crab, by ADFG stat area, in the groundfish fisheries during 2013/14.

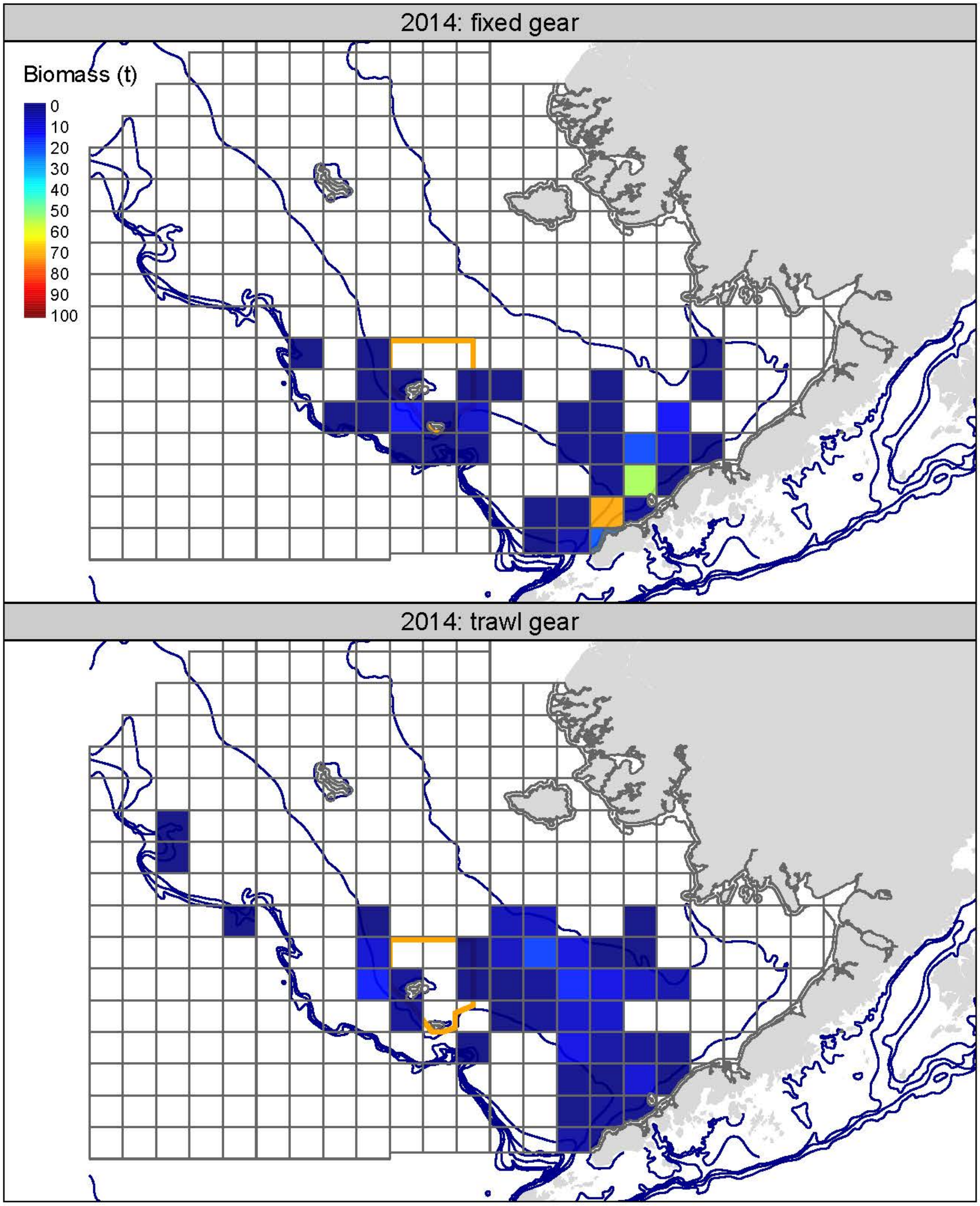


Figure 24: Bycatch of Tanner crab, by ADFG stat area, in the groundfish fisheries during 2014/15.

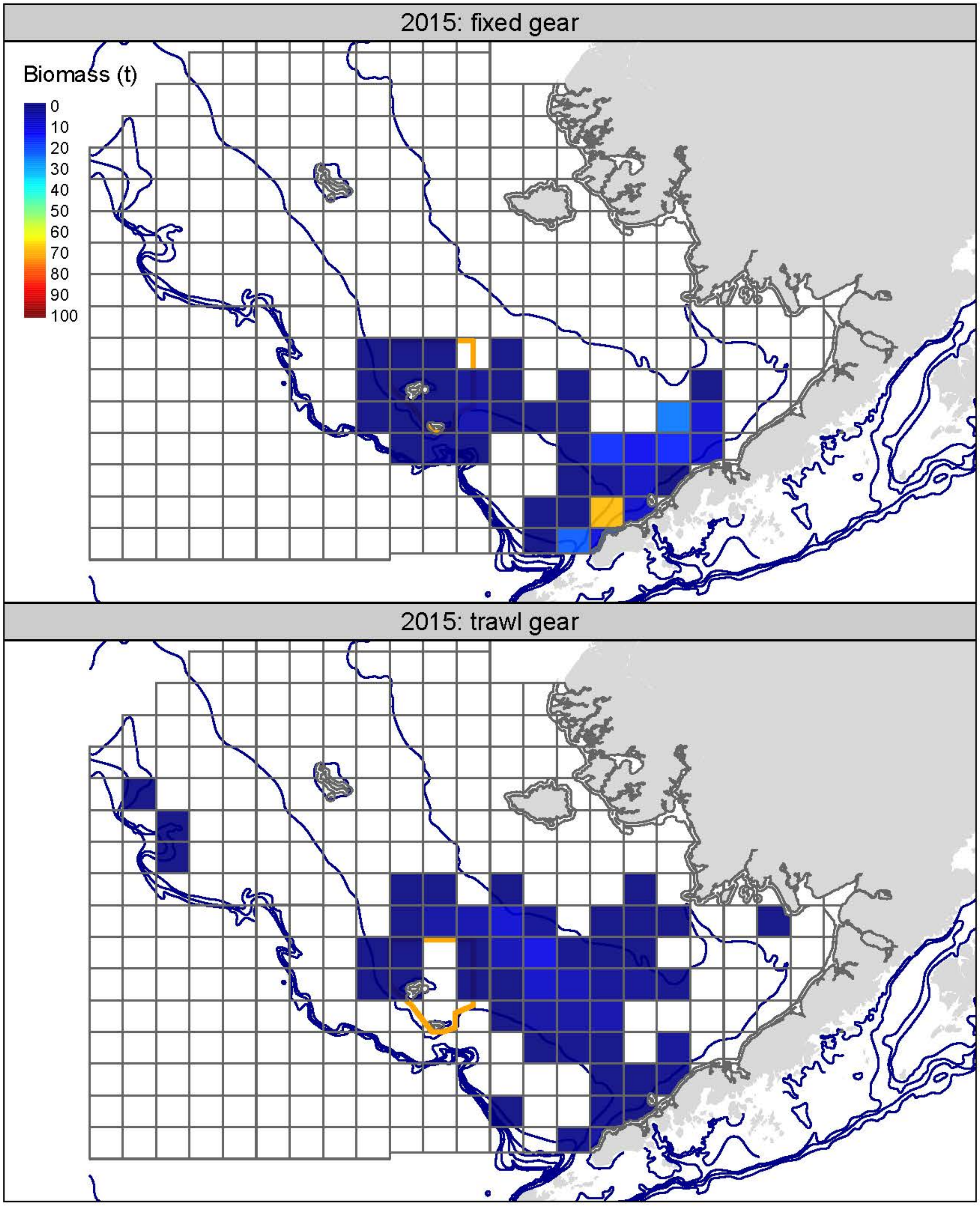


Figure 25: Bycatch of Tanner crab, by ADFG stat area, in the groundfish fisheries during 2015/16.

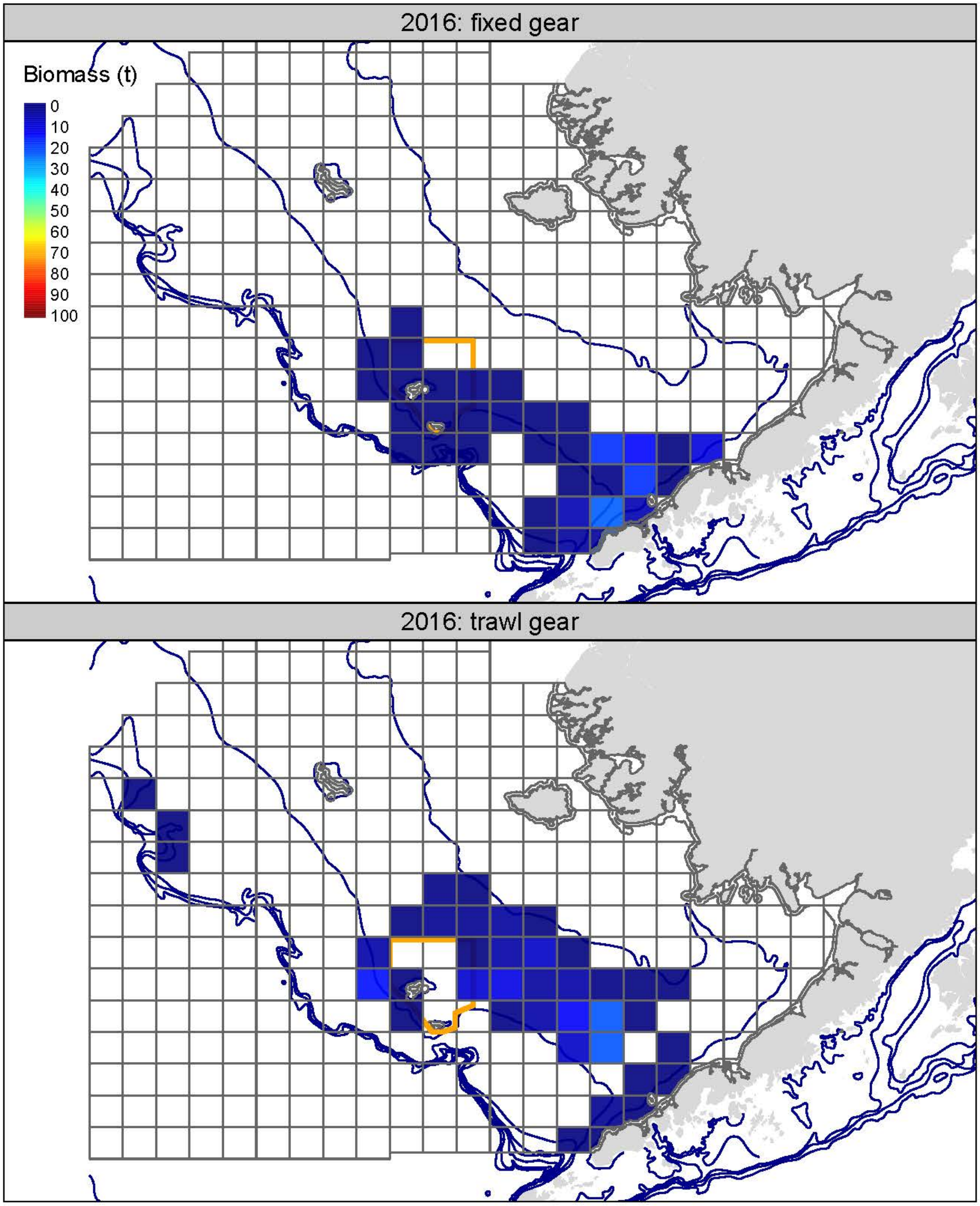


Figure 26: Bycatch of Tanner crab, by ADFG stat area, in the groundfish fisheries during 2016/17.

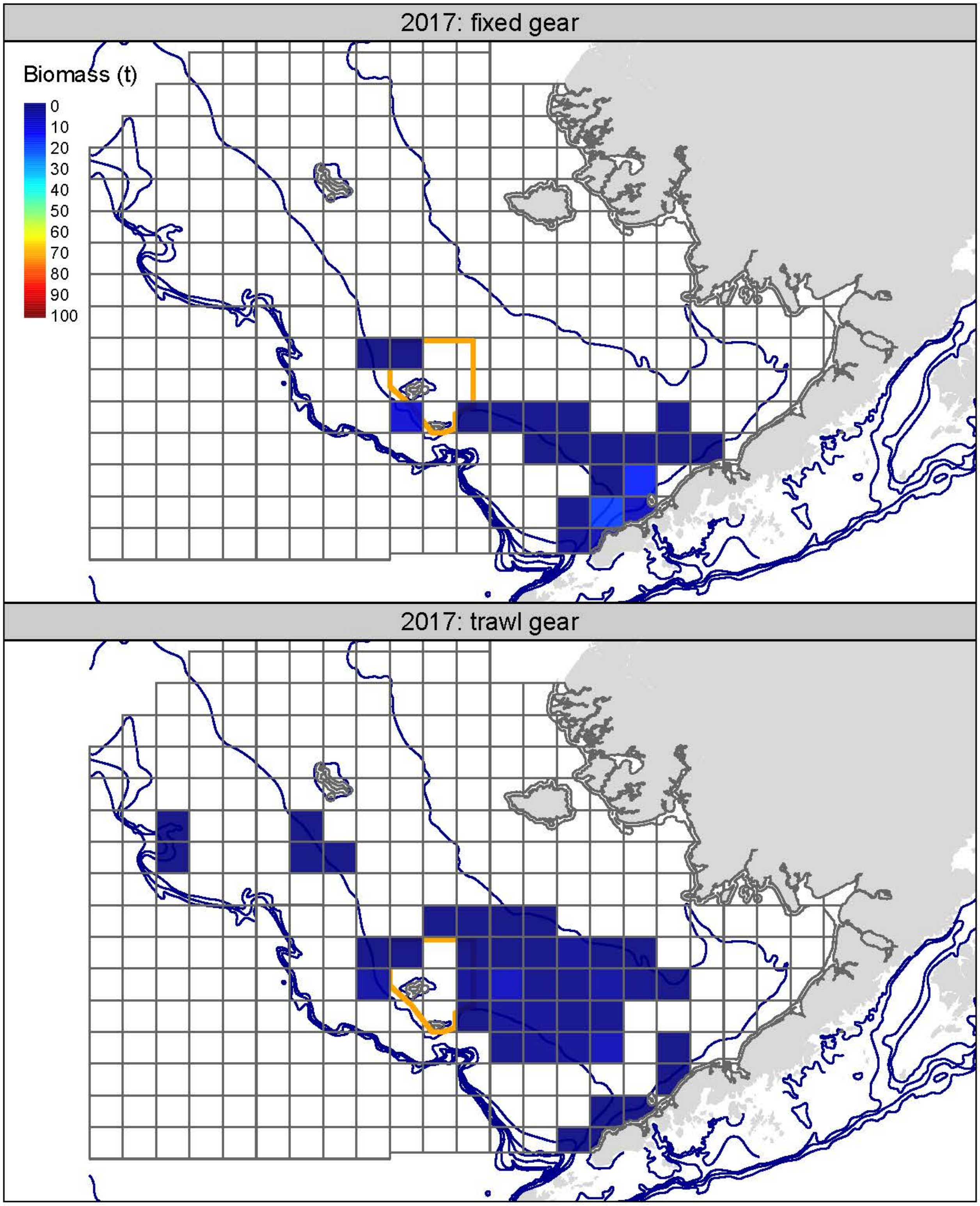


Figure 27: Bycatch of Tanner crab, by ADFG stat area, in the groundfish fisheries during 2017/18.

Appendix E:
Overview of NMFS Survey Data for the Tanner Crab Assessment

William Stockhausen

01 September, 2018

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List of Figures

Introduction

This report calculates NMFS survey data time series (aggregate abundance, mature biomass and size compositions) for Tanner crab based on CRABHAUL files and a haul/station strata file downloaded from AKFIN.

The survey data were processed using the following parameters:

Table 1: Parameters used to process crab haul data.

	Quantity	Value
1	min size (mm CW)	25
2	max size (mm CW)	185
3	bin size (mm CW)	5
4	strata type	2015
5	haul types	all

Annual survey abundance and biomass

Annual survey abundance and biomass for Tanner crab for the EBS and the areas east and west of 166^oW longitude were calculated from the survey haul data as if the survey were conducted using a random-stratified sampling design (it uses a fixed grid), with survey strata defined for the Pribilof Islands high density sampling area, the St. Matthew Island high density sampling area, the standard-density sampling area west of 166^oW longitude, and the standard-density area east of 166^oW longitude. Abundance and biomass estimates from the four strata were then aggregated appropriately to the areas east and west of 166^oW and to the entire EBS.

By sex

The following plots illustrate time series trends in Tanner crab survey abundance and biomass by sex and area.

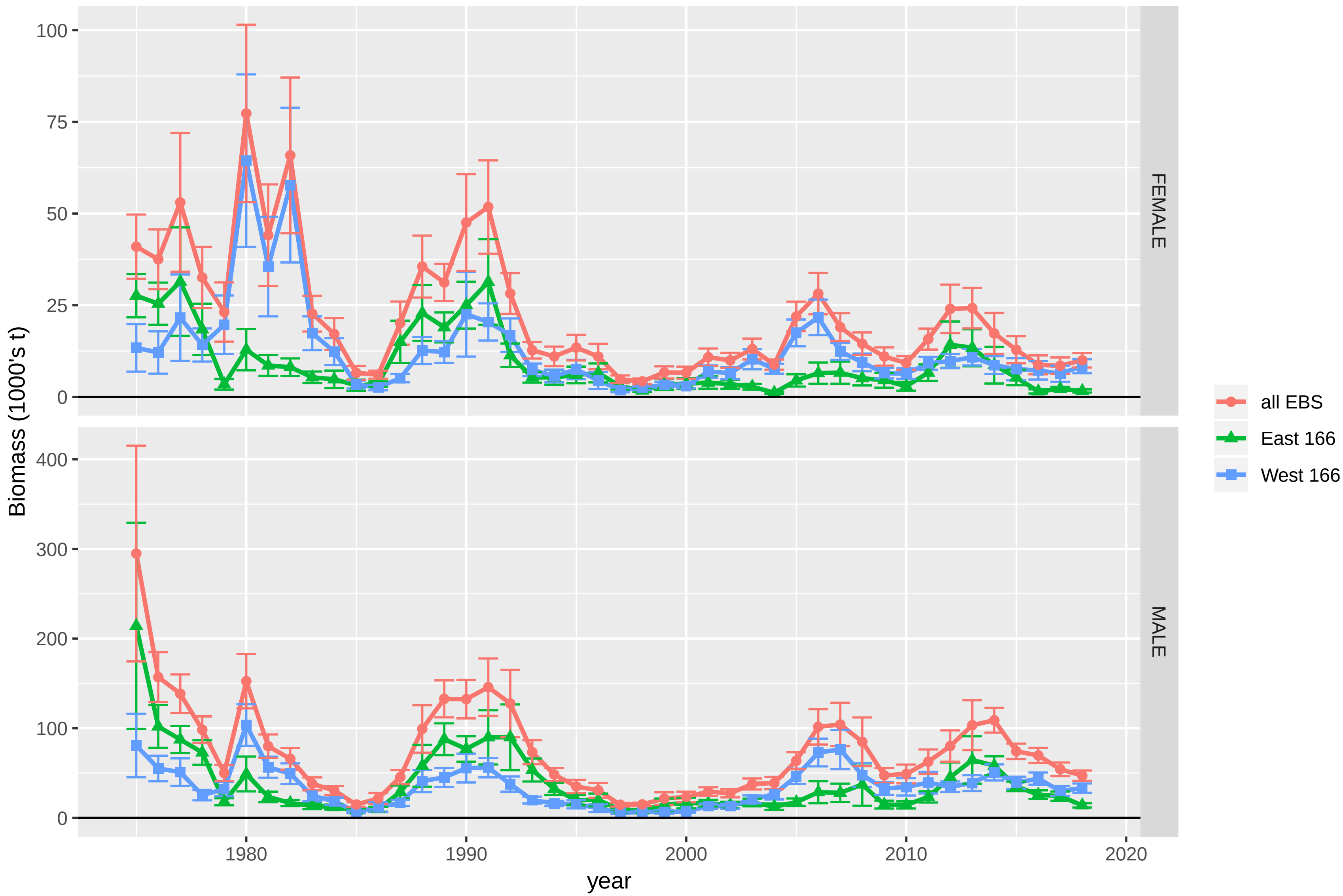


Figure 1: Tanner crab biomass in the NMFS EBS trawl survey, by sex and area.

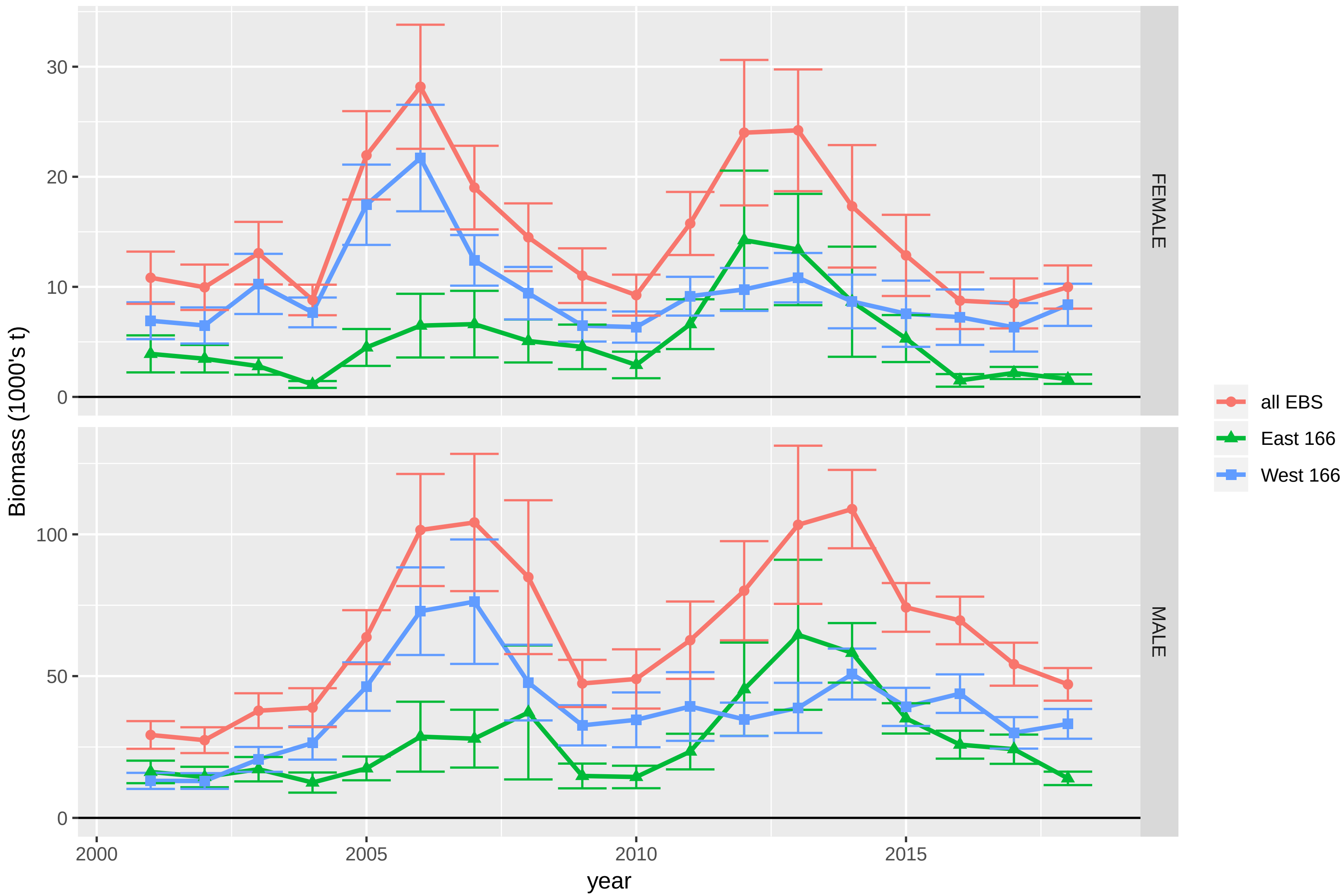


Figure 2: Tanner crab biomass in the NMFS EBS trawl survey, by sex and area, since 2001.

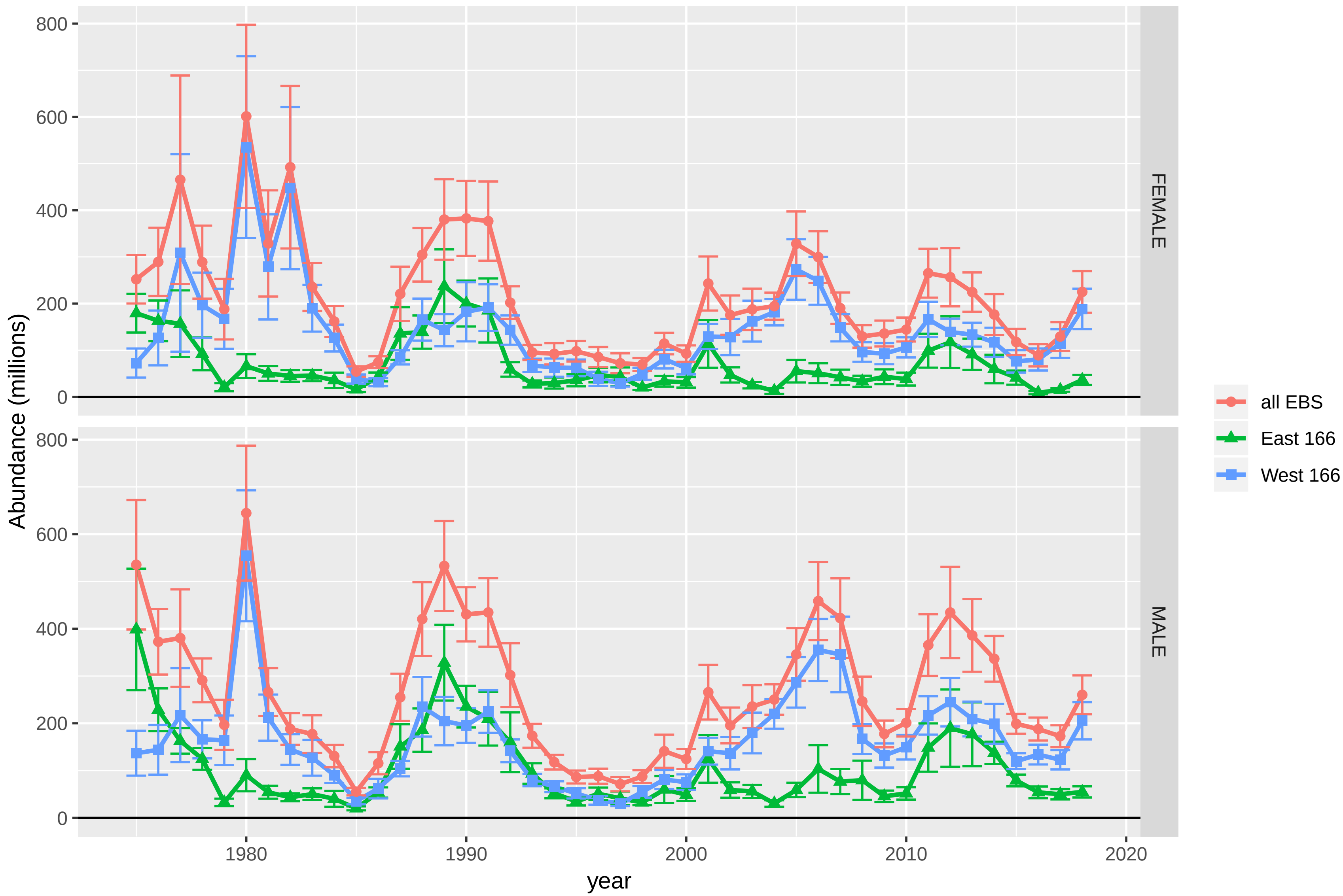


Figure 3: Tanner crab abundance in the NMFS EBS trawl survey, by sex and area.

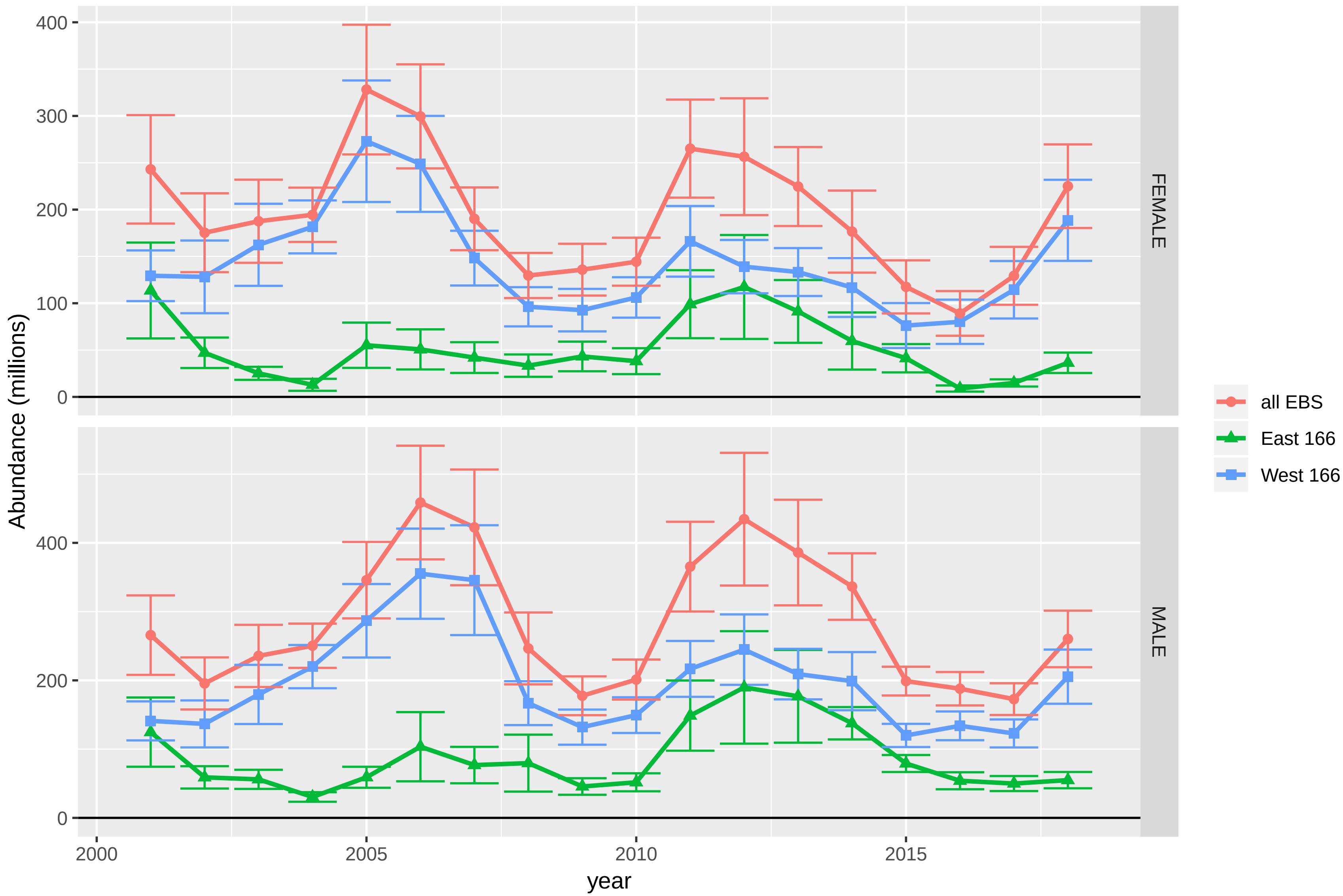


Figure 4: Tanner crab abundance in the NMFS EBS trawl survey, by sex and area, since 2001.

By sex and maturity state

The following plots illustrate the time series trends for Tanner crab survey abundance and biomass by sex, maturity state, and area.

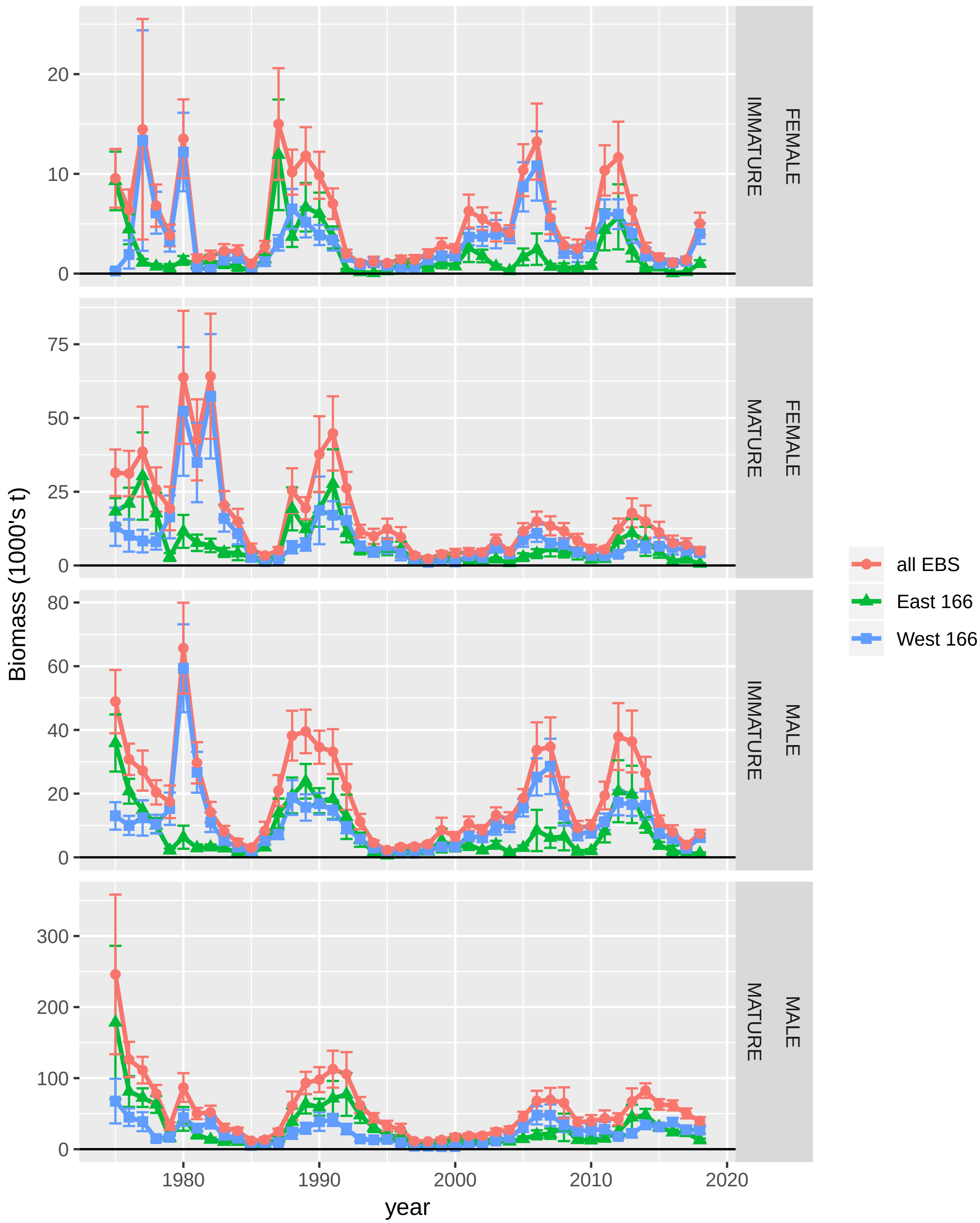


Figure 5: Tanner crab biomass in the NMFS EBS trawl survey, by sex, maturity state and area.

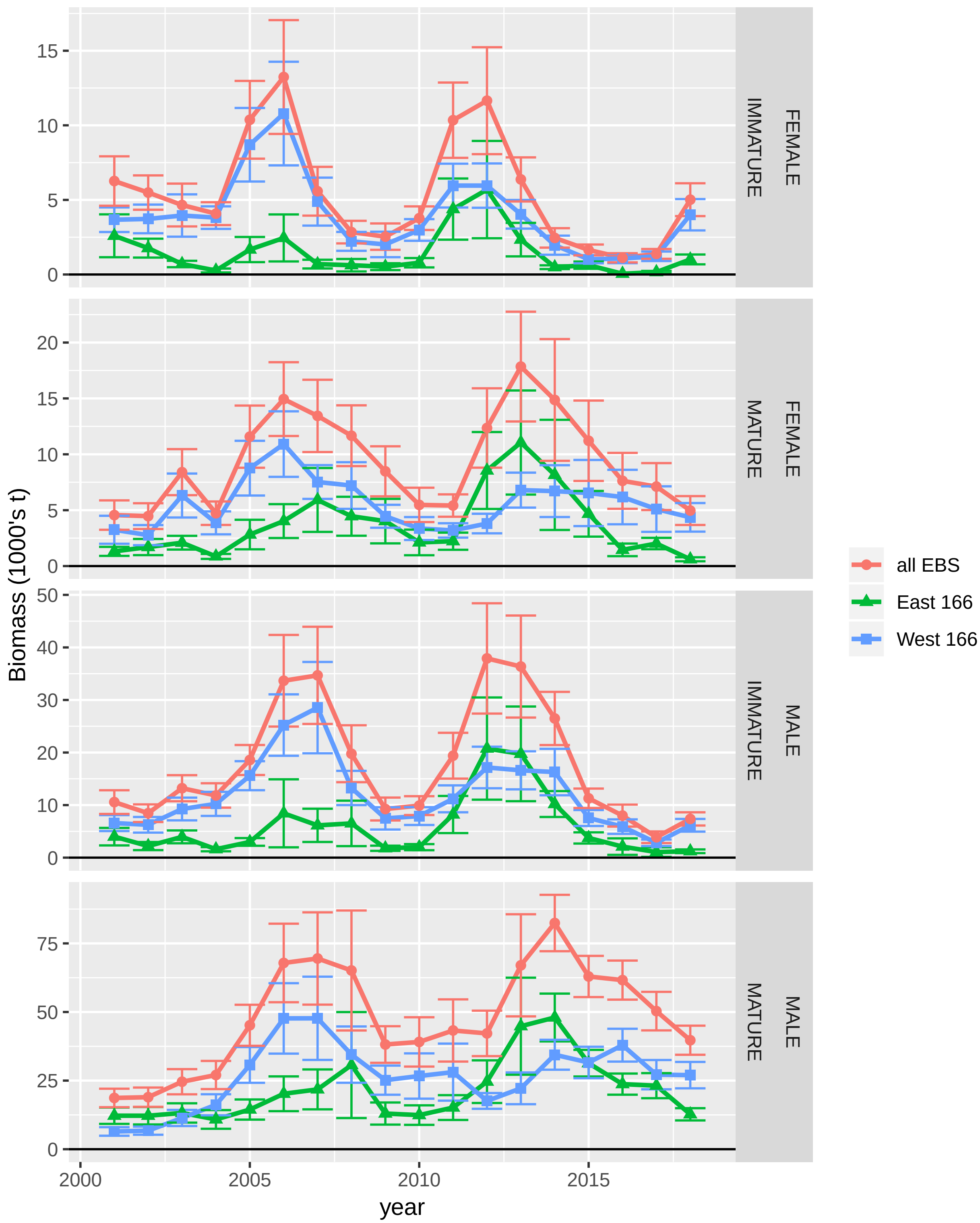


Figure 6: Tanner crab biomass in the NMFS EBS trawl survey, by sex, maturity state and area, since 2001.

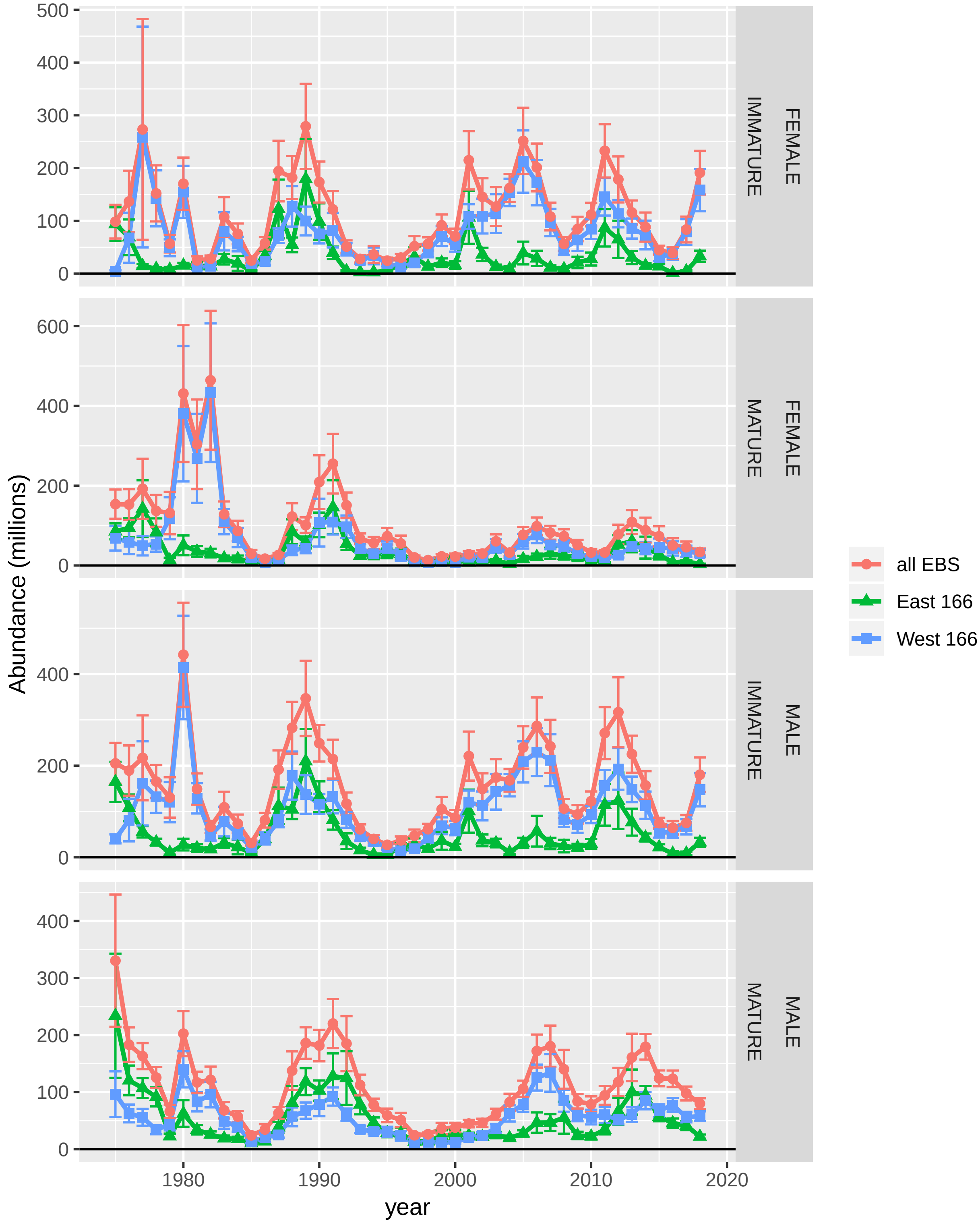


Figure 7: Tanner crab abundance in the NMFS EBS trawl survey, by sex, maturity state and area.

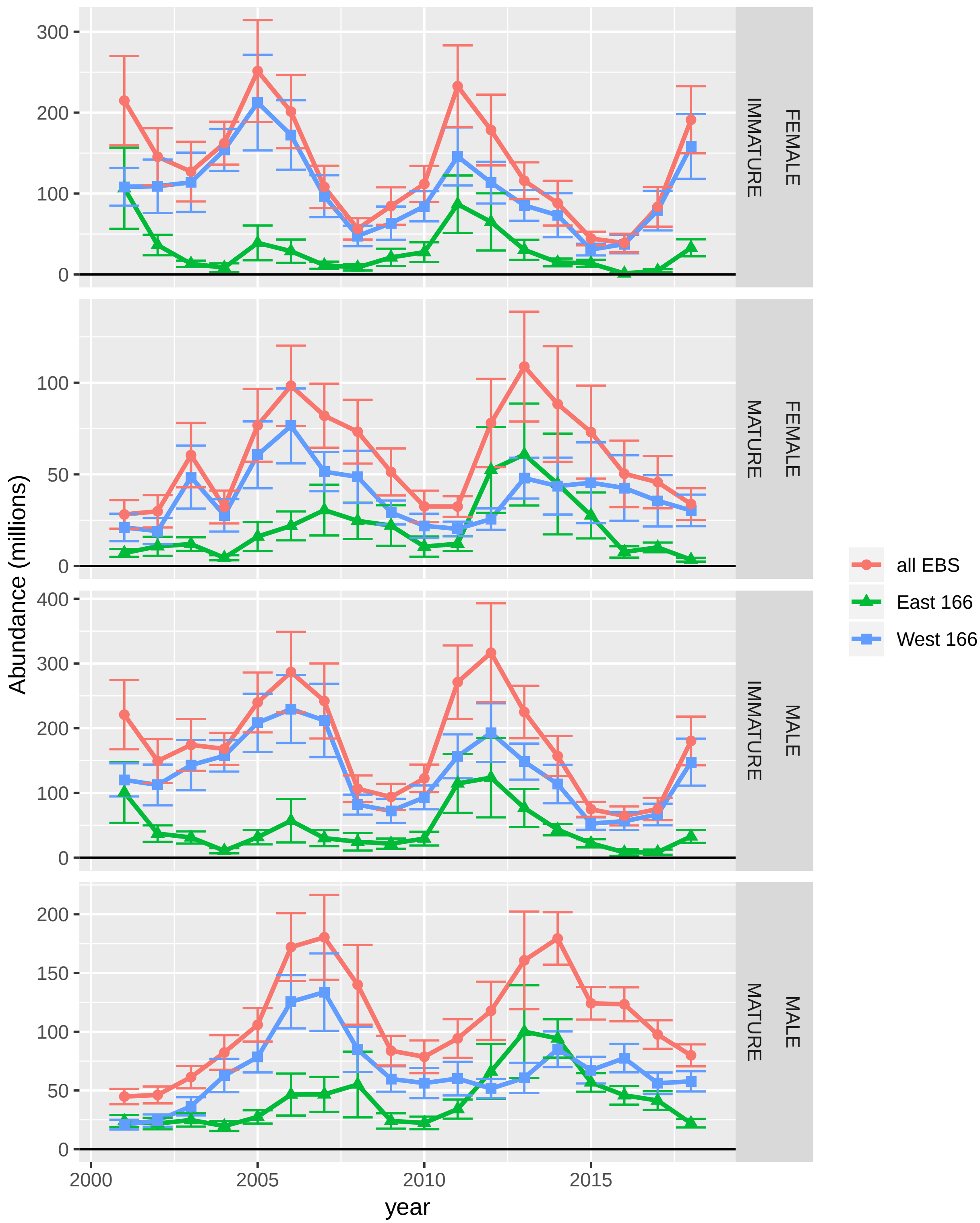


Figure 8: Tanner crab abundance in the NMFS EBS trawl survey, by sex, maturity state and area, since 2001.

Time series survey trends in industry preferred-sized males

The Tanner crab fishery is managed separately east and west of 166^{o}W longitude, and separate TACs are set for each area. Abundance and biomass trends from the NMFS EBS bottom trawl survey are shown in subsequent figures for the current industry-preferred size of legal crab (i.e., $\geq$ 125 mm CW).

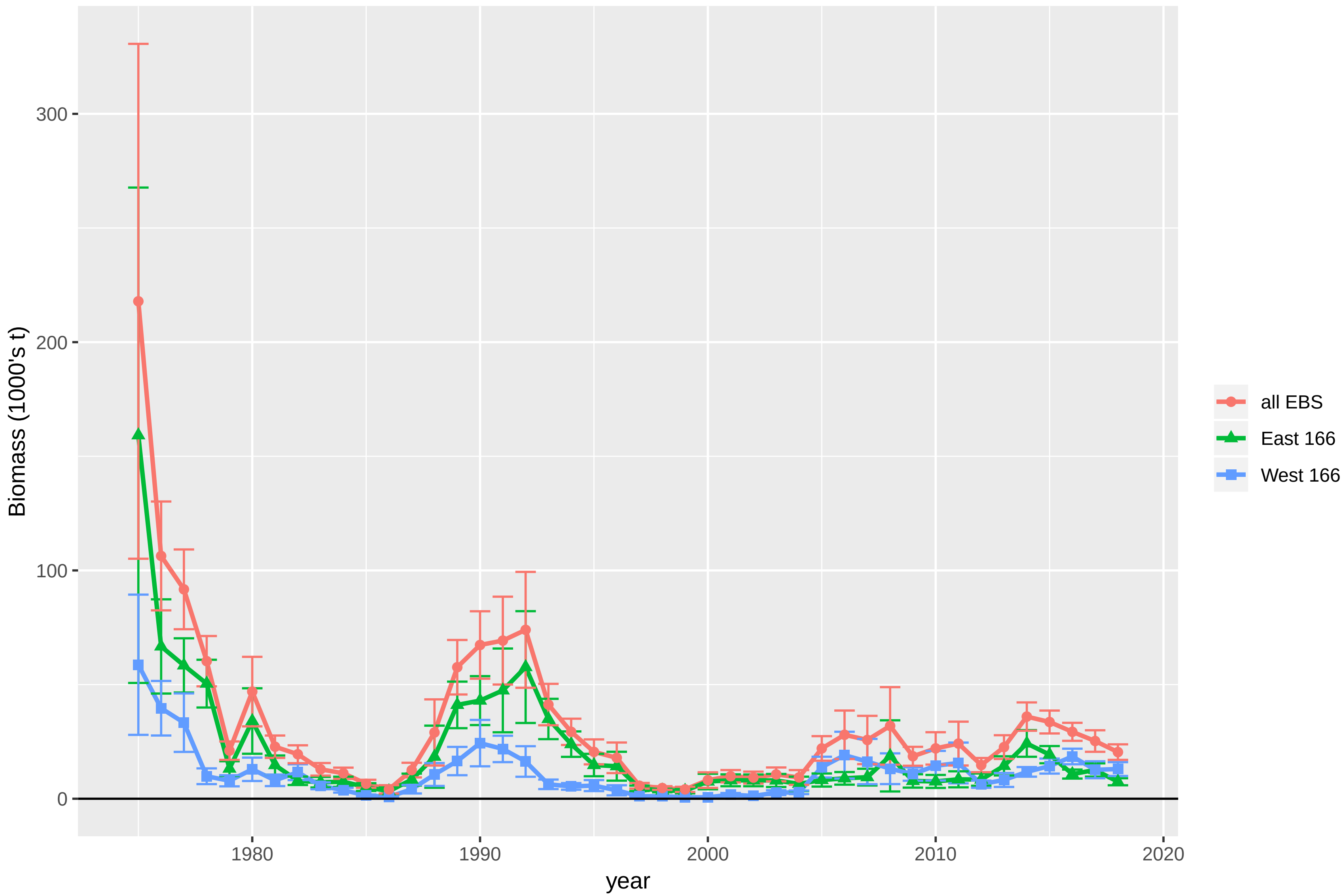


Figure 9: Legal male Tanner crab biomass in the NMFS EBS trawl survey, by area.

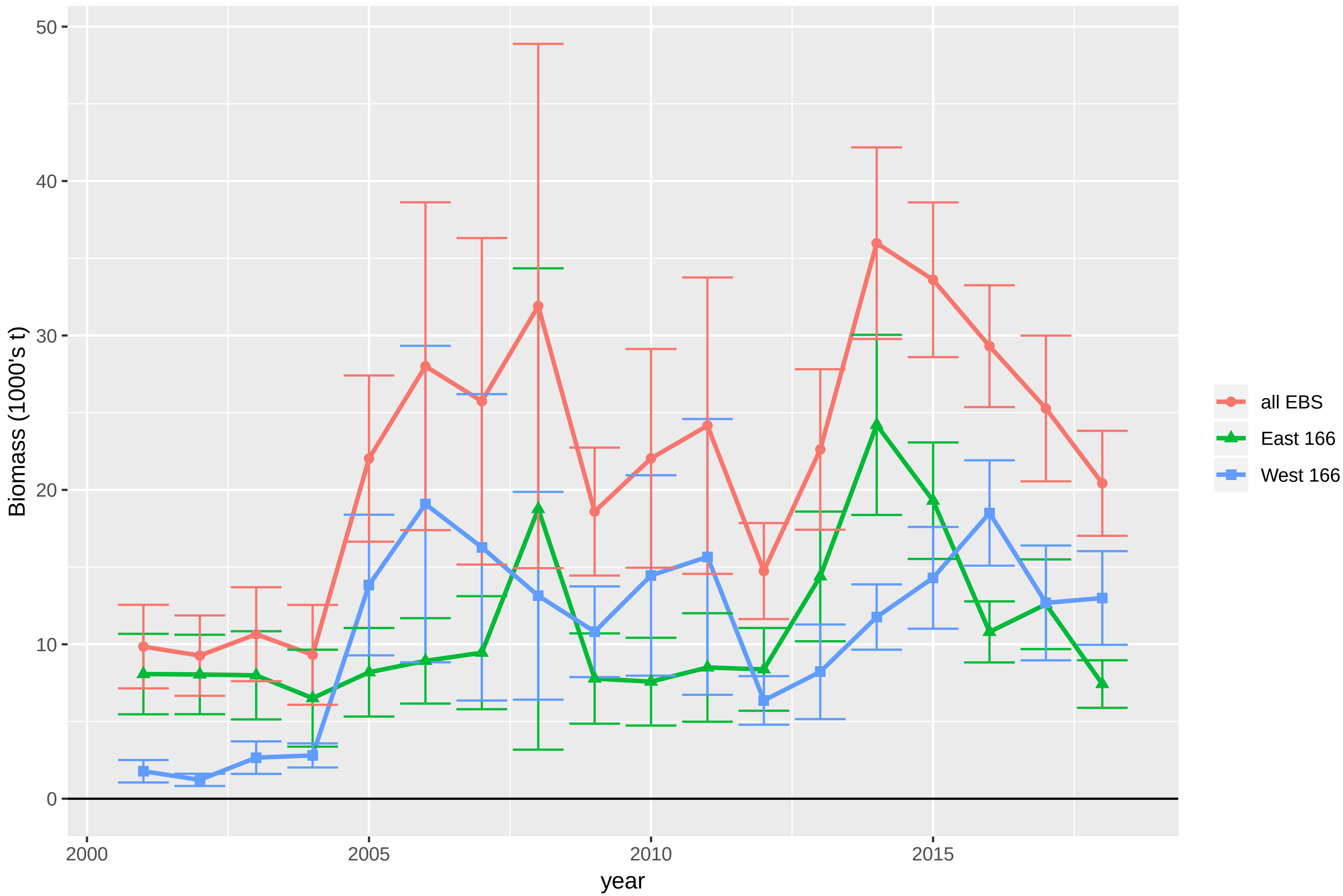


Figure 10: Industry-preferred male Tanner crab biomass in the NMFS EBS trawl survey, by area, since 2001.

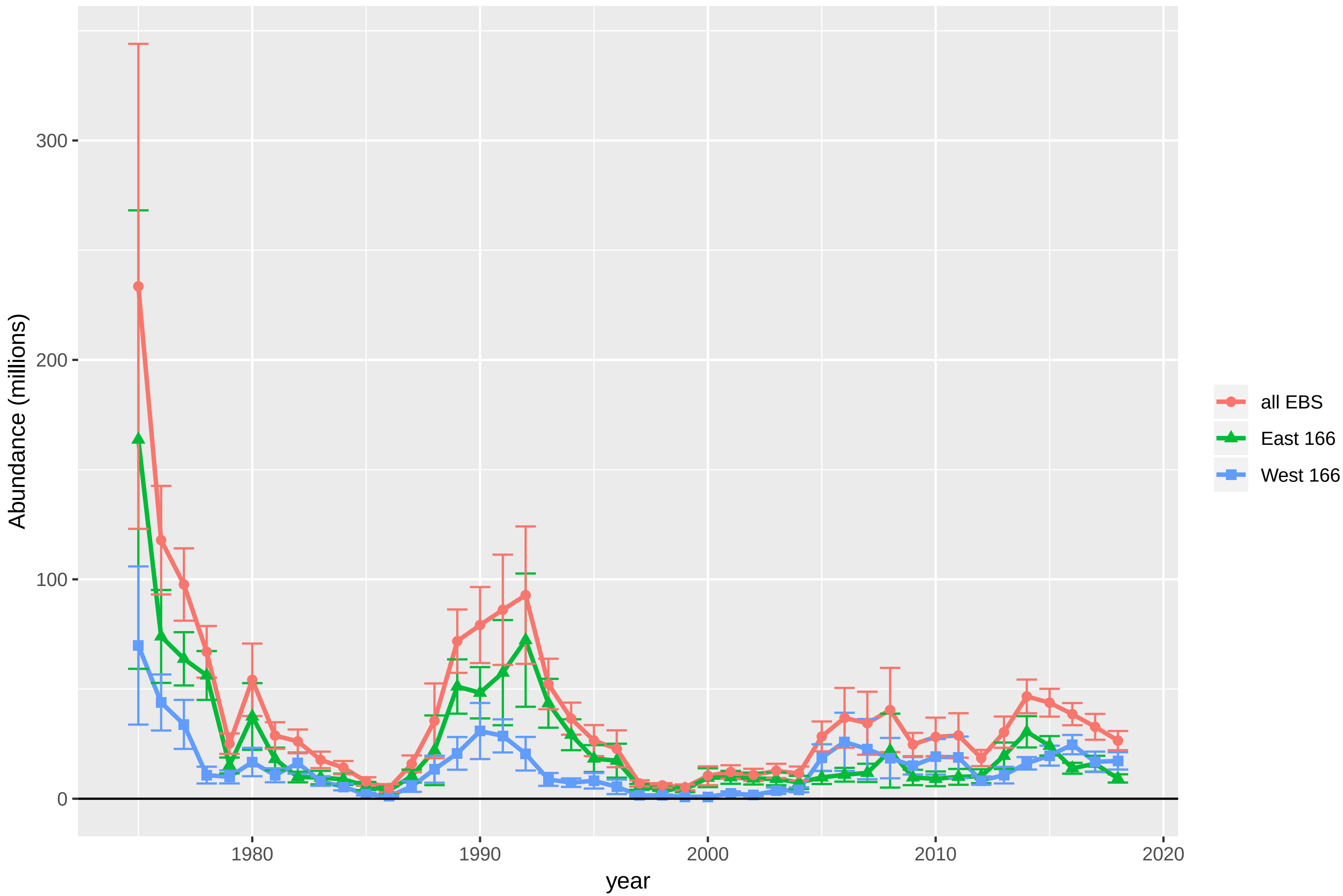


Figure 11: Legal male Tanner crab abundance in the NMFS EBS trawl survey, by area.

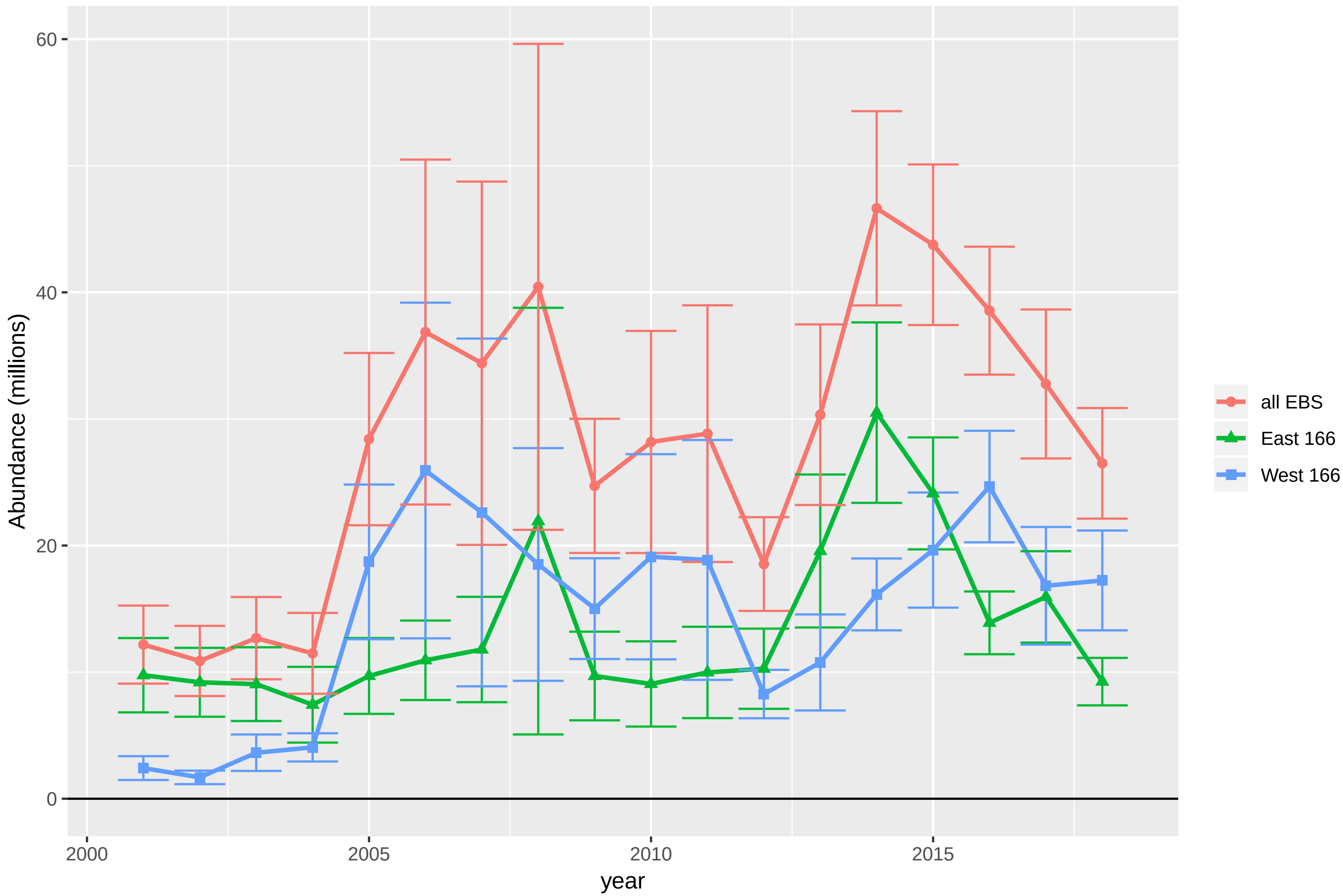


Figure 12: Industry-preferred male Tanner crab abundance in the NMFS EBS trawl survey, by area, since 2001.

Size compositions

Annual size compositions for Tanner crab in the NMFS EBS trawl survey were calculated by sex, maturity state, shell condition, and 5mm size (carapace width) bin, excluding individuals with sizes $<$ 25mm CW and accumulating individuals in the last size bin (180-185 mm CW) for sizes $>$ 185 mm CW. Individuals classified in the survey as “immature, old shell” crab were assumed to really be “immature, new shell”" crab and were re-classified as such.

By sex

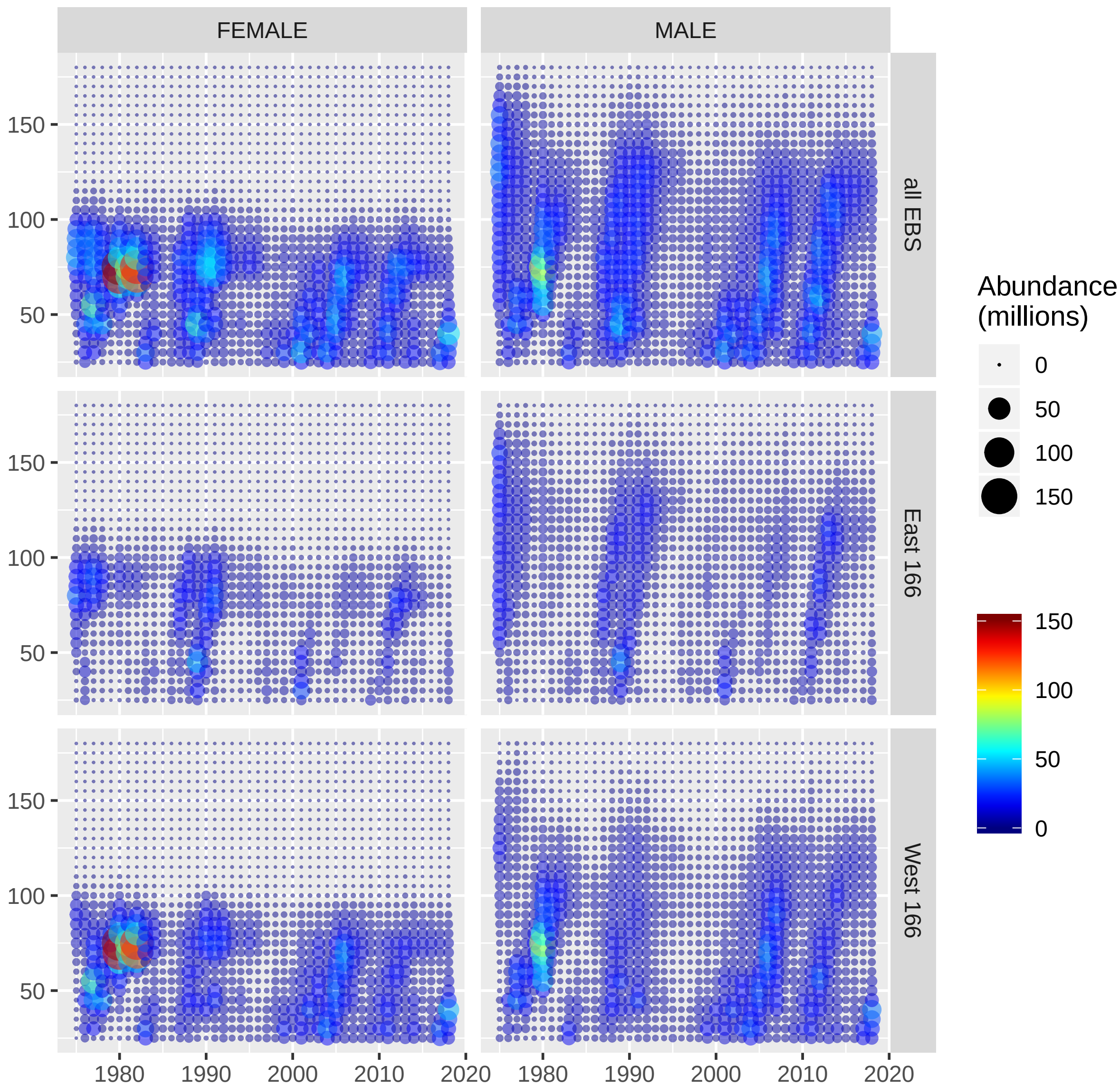


Figure 13: Annual size compositions for Tanner crab in the NMFS EBS trawl survey, by sex and area.

By shell condition for males

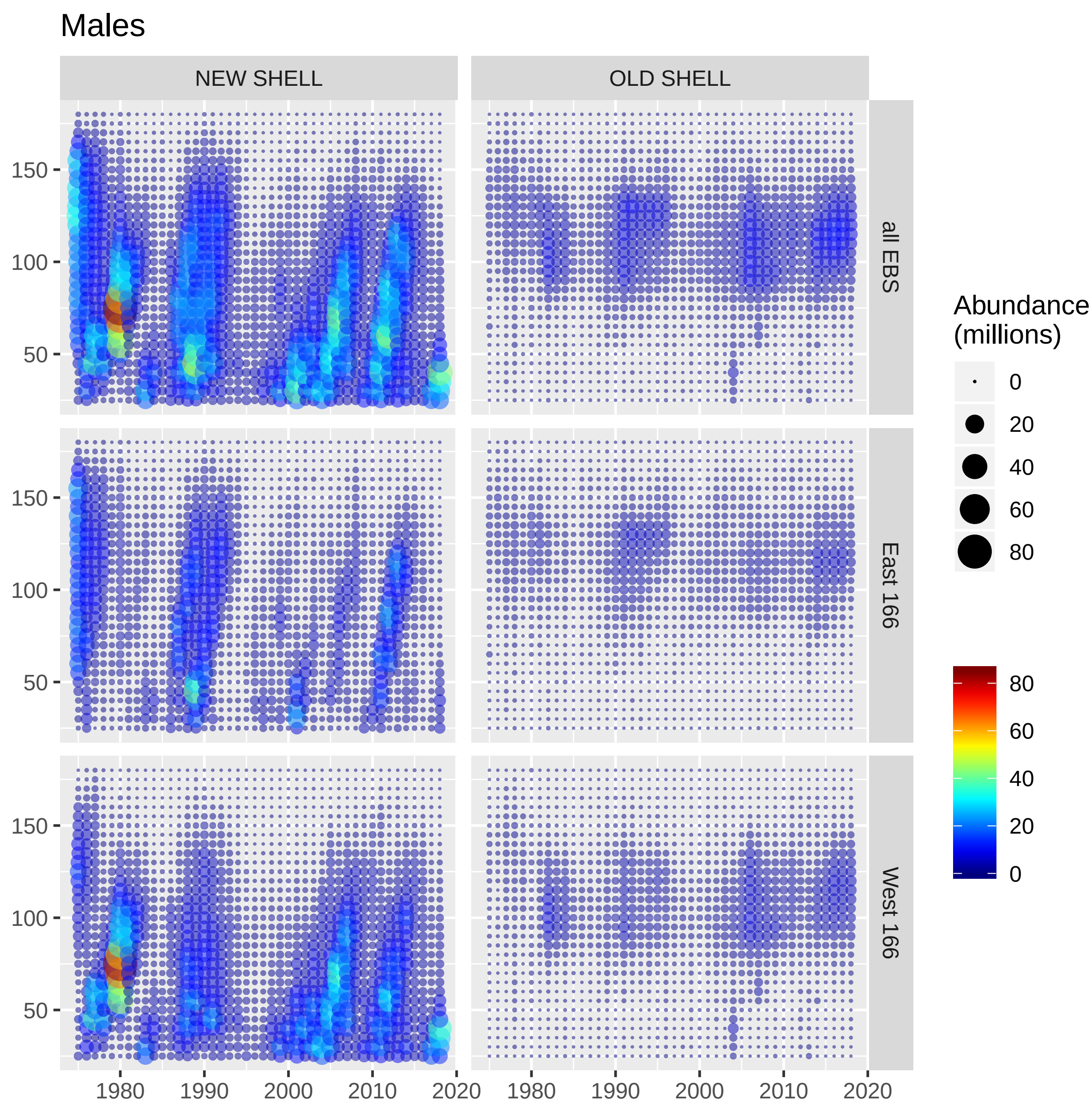


Figure 14: Annual size compositions for male Tanner crab in the NMFS EBS trawl survey, by shell condition and area.

By maturity state for females

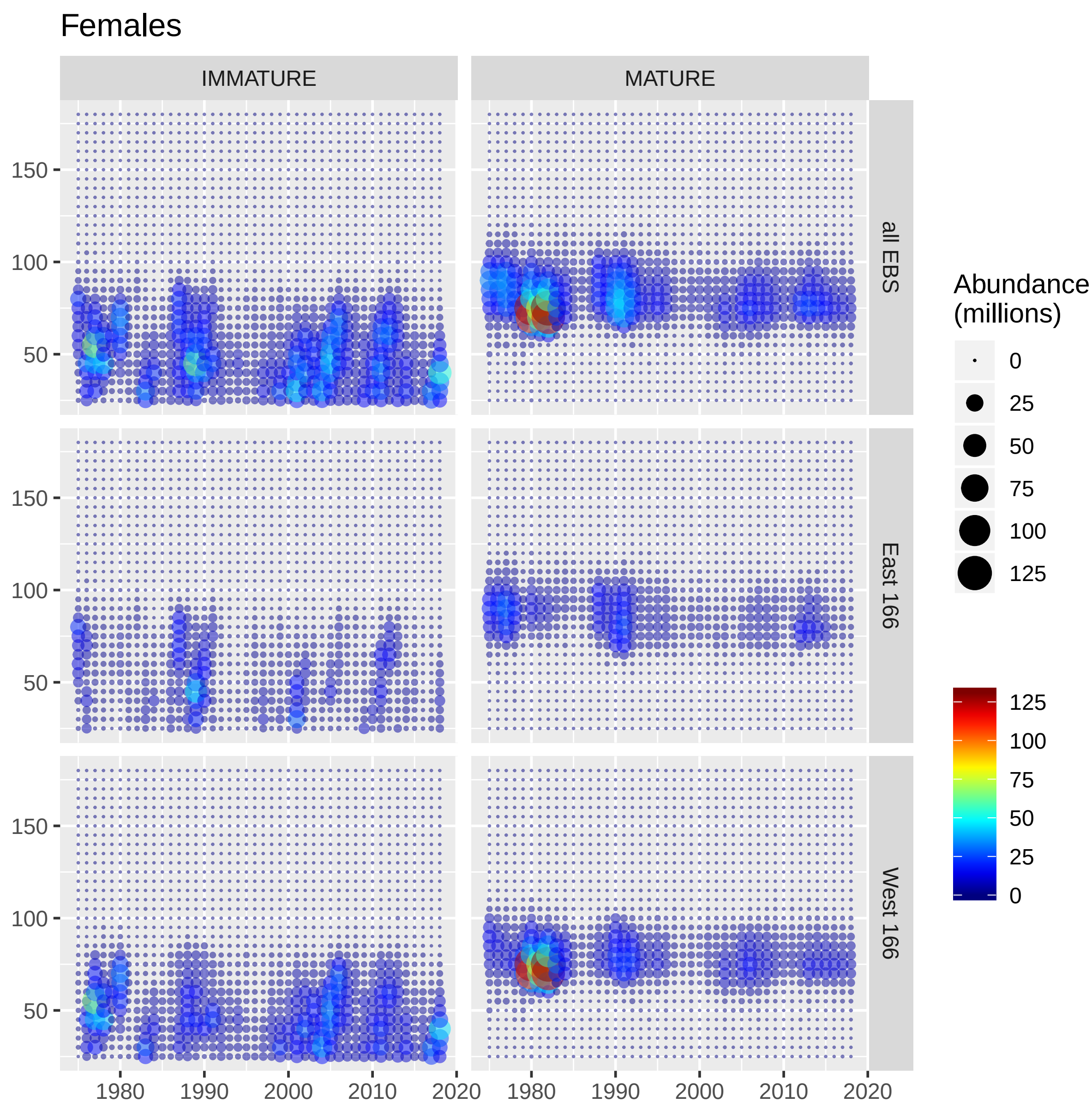


Figure 15: Annual size compositions for female Tanner crab in the NMFS EBS trawl survey, by shell condition and area.

Sample sizes

The following tables summarize sample sizes for Tanner crab in the NMFS EBS bottom trawl survey.

Table 2: Observed numbers of Tanner crab in the annual NMFS EBS bottom trawl survey, by sex, maturity state, and shell condition.

	female				male	
	immature		mature		unknown	
year	new shell	old shell	new shell	old shell	new shell	old shell
1975	1,040	7	1,861	706	6,888	399
1976	1,095	2	1,304	311	4,492	242
1977	765	11	1,183	738	3,749	485
1978	1,932	17	638	1,307	4,527	700
1979	725	8	735	341	2,613	306
1980	1,476	15	1,471	570	6,961	569
1981	579	0	1,319	1,206	6,102	886
1982	814	9	457	2,384	3,122	2,082
1983	2,108	5	201	2,154	3,467	1,181
1984	1,867	12	284	1,531	2,455	1,399
1985	846	1	228	601	1,441	459
1986	1,581	7	191	331	2,669	468
1987	4,230	0	445	392	5,965	498
1988	3,733	2	1,753	530	7,837	475
1989	3,264	7	1,241	882	8,178	1,067
1990	3,105	9	1,502	1,511	8,256	1,342
1991	2,227	32	1,283	2,568	7,053	2,893
1992	1,494	0	820	2,205	5,005	1,924
1993	865	4	545	1,337	3,728	1,865
1994	909	12	148	1,293	2,005	1,827
1995	830	4	140	1,057	1,178	1,611
1996	869	14	109	963	1,291	1,414
1997	1,325	4	168	504	1,625	582
1998	1,704	6	160	344	2,428	624
1999	2,608	20	255	510	3,366	567
2000	2,249	0	242	345	3,464	653
2001	3,675	3	364	644	4,665	817
2002	3,583	2	350	500	4,370	1,089
2003	2,830	4	923	752	5,654	1,349
2004	3,563	359	427	656	5,595	1,873
2005	3,349	3	634	928	5,776	1,753
2006	4,355	9	1,332	1,327	7,981	4,054
2007	2,420	10	1,311	1,396	6,679	2,907
2008	1,747	0	580	1,783	5,243	2,146
2009	2,408	0	363	1,317	4,023	1,954
2010	3,171	9	245	941	4,922	1,702
2011	5,044	0	471	705	7,210	1,941
2012	3,577	34	942	720	7,090	1,296
2013	2,900	17	1,417	1,002	8,267	1,344
2014	2,207	4	482	1,584	8,032	2,829
2015	1,455	0	445	1,363	4,596	2,817
2016	1,372	1	370	1,248	3,405	3,668
2017	2,032	1	213	1,125	2,665	3,541
2018	4,665	1	525	703	5,503	2,748

Table 3: Number of hauls, numbers of hauls with Tanner crab, and number of observed Tanner crab in the annual NMFS EBS bottom trawl survey, by sex, maturity state, and shell condition.

		female								male							
		immature				mature				immature				mature			
		new shell		old shell		new shell		old shell		new shell		old shell		new shell		old shell	
year	Hauls	non-0 hauls	crab	non-0 hauls	crab	non-0 hauls	crab	non-0 hauls	crab	non-0 hauls	crab	non-0 hauls	crab	non-0 hauls	crab	non-0 hauls	crab
1975	136	73	1,040	6	7	91	1,861	39	706	127	2,895	0	0	127	3,993	80	399
1976	214	87	1,095	2	2	91	1,304	39	311	130	2,023	0	0	130	2,469	47	242
1977	155	66	765	9	11	76	1,183	60	738	114	1,778	0	0	114	1,971	79	485
1978	230	87	1,932	8	17	82	638	65	1,307	147	2,957	0	0	147	1,570	104	700
1979	307	71	725	8	8	62	735	42	341	138	1,805	0	0	138	808	68	306
1980	320	101	1,476	10	15	95	1,471	49	570	164	4,602	0	0	164	2,359	71	569
1981	305	71	579	0	0	79	1,319	94	1,206	158	3,809	0	0	158	2,293	116	886
1982	342	85	814	9	9	72	457	103	2,384	181	1,751	0	0	181	1,371	147	2,082
1983	353	102	2,108	4	5	56	201	102	2,154	166	2,484	0	0	166	983	132	1,181
1984	355	135	1,867	9	12	53	284	94	1,531	171	1,965	0	0	171	490	126	1,399
1985	353	140	846	1	1	52	228	65	601	179	1,060	0	0	179	381	86	459
1986	353	162	1,581	4	7	64	191	68	331	213	2,141	0	0	213	528	115	468
1987	355	189	4,230	0	0	105	445	73	392	226	4,659	0	0	226	1,306	103	498
1988	370	206	3,733	2	2	149	1,753	100	530	252	5,627	0	0	252	2,210	101	475
1989	373	204	3,264	4	7	144	1,241	108	882	237	4,977	0	0	237	3,201	135	1,067
1990	370	197	3,105	3	9	155	1,502	126	1,511	247	5,107	0	0	247	3,149	151	1,342
1991	371	159	2,227	9	32	138	1,283	141	2,568	227	4,361	0	0	227	2,692	181	2,893
1992	355	107	1,494	0	0	119	820	123	2,205	215	2,958	0	0	215	2,047	177	1,924
1993	374	99	865	4	4	96	545	122	1,337	207	2,051	0	0	207	1,677	180	1,865
1994	374	97	909	3	12	52	148	104	1,293	175	1,281	0	0	175	724	174	1,827
1995	375	113	830	4	4	35	140	107	1,057	153	958	0	0	153	220	137	1,611
1996	374	114	869	4	14	57	109	98	963	148	1,069	0	0	148	222	134	1,414
1997	375	116	1,325	2	4	62	168	83	504	161	1,336	0	0	161	289	125	582
1998	374	146	1,704	4	6	53	160	73	344	176	2,032	0	0	176	396	128	624
1999	372	137	2,608	6	20	52	255	85	510	170	2,816	0	0	170	550	124	567
2000	371	142	2,249	0	0	61	242	55	345	188	2,836	0	0	188	628	133	653
2001	374	164	3,675	3	3	83	364	72	644	211	4,036	0	0	211	629	145	817
2002	374	154	3,583	2	2	81	350	70	500	186	3,912	0	0	186	458	154	1,089
2003	375	153	2,830	3	4	111	923	83	752	203	4,754	0	0	203	900	153	1,349
2004	374	173	3,563	10	359	90	427	80	656	236	4,568	0	0	236	1,027	179	1,873
2005	372	201	3,349	2	3	103	634	74	928	254	4,496	0	0	254	1,280	185	1,753
2006	375	210	4,355	4	9	143	1,332	125	1,327	254	6,224	0	0	254	1,757	211	4,054
2007	375	185	2,420	6	10	138	1,311	136	1,396	261	4,697	0	0	261	1,982	201	2,907
2008	374	153	1,747	0	0	104	580	120	1,783	240	3,127	0	0	240	2,116	196	2,146
2009	375	171	2,408	0	0	75	363	115	1,317	216	2,879	0	0	216	1,144	187	1,954
2010	375	186	3,171	5	9	67	245	104	941	223	3,654	0	0	223	1,268	166	1,702
2011	375	193	5,044	0	0	90	471	102	705	210	6,095	0	0	210	1,115	167	1,941
2012	375	195	3,577	6	34	100	942	97	720	215	5,526	0	0	215	1,564	139	1,296
2013	375	163	2,900	9	17	116	1,417	101	1,002	207	5,592	0	0	207	2,675	137	1,344
2014	375	165	2,207	3	4	98	482	121	1,584	222	4,746	0	0	222	3,286	167	2,829
2015	375	118	1,455	0	0	60	445	94	1,363	225	2,737	0	0	225	1,859	200	2,817
2016	375	110	1,372	1	1	56	370	82	1,248	222	2,235	0	0	222	1,170	218	3,668
2017	375	130	2,032	1	1	50	213	99	1,125	186	2,241	0	0	186	424	205	3,541
2018	375	196	4,665	1	1	68	525	93	703	222	4,990	0	0	222	513	190	2,748

Appendix F:
Recent Tanner crab spatial patterns in the NMFS trawl survey

William Stockhausen

01 September, 2018

Contents

Introduction

This report creates a time series of maps of Tanner crab CPUE and bottom temperature from the NMFS EBS bottom trawl survey.

Basemap

The following figure illustrates the base map for subsequent maps of bottom temperature and survey CPUE.

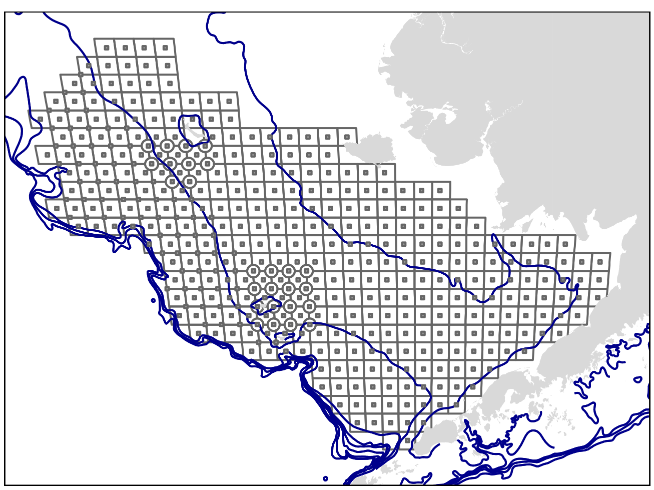


Figure 1: Basemap for future maps, with EBS bathymetry (blue lines) and the NMFS EBS bottom trawl survey station grid.

Survey CPUE

The following maps present survey CPUE (in biomass) for components of the Tanner crab stock superimposed on bottom temperature at the time of the survey for each year of the NMFS bottom trawl survey.

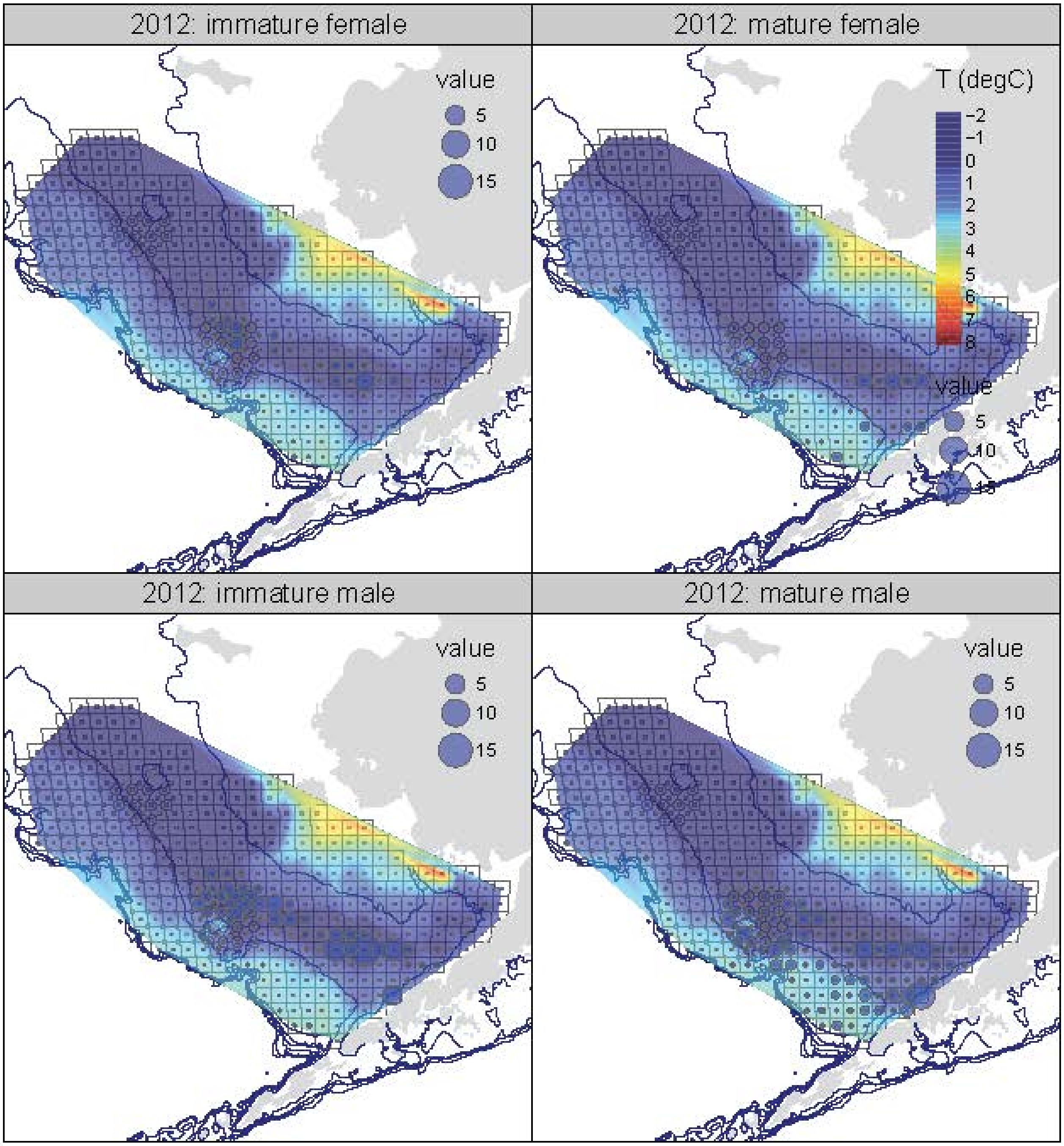


Figure 2: Tanner crab CPUE (biomass) from the 2012 NMFS EBS bottom trawl survey.

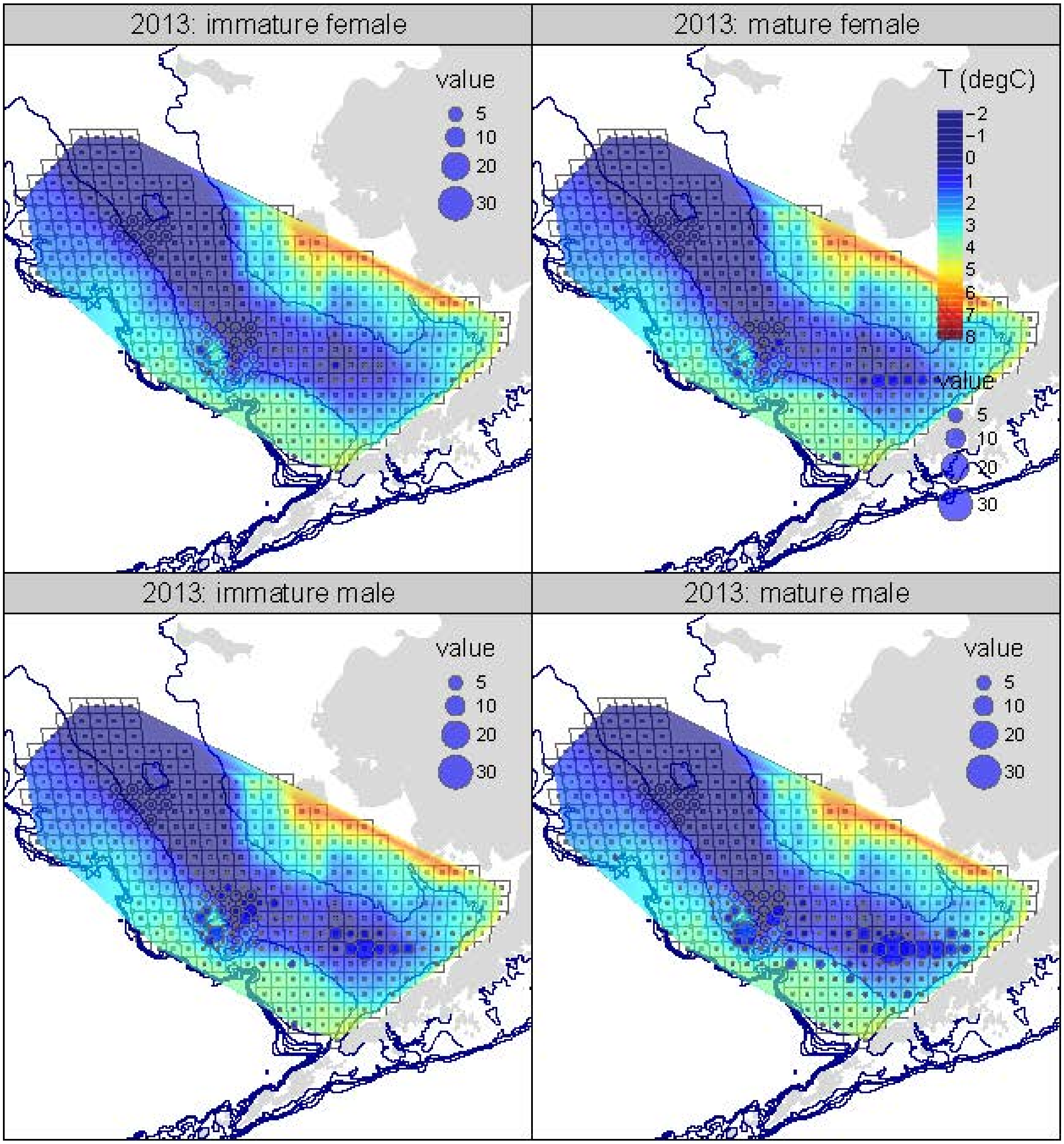


Figure 3: Tanner crab CPUE (biomass) from the 2013 NMFS EBS bottom trawl survey.

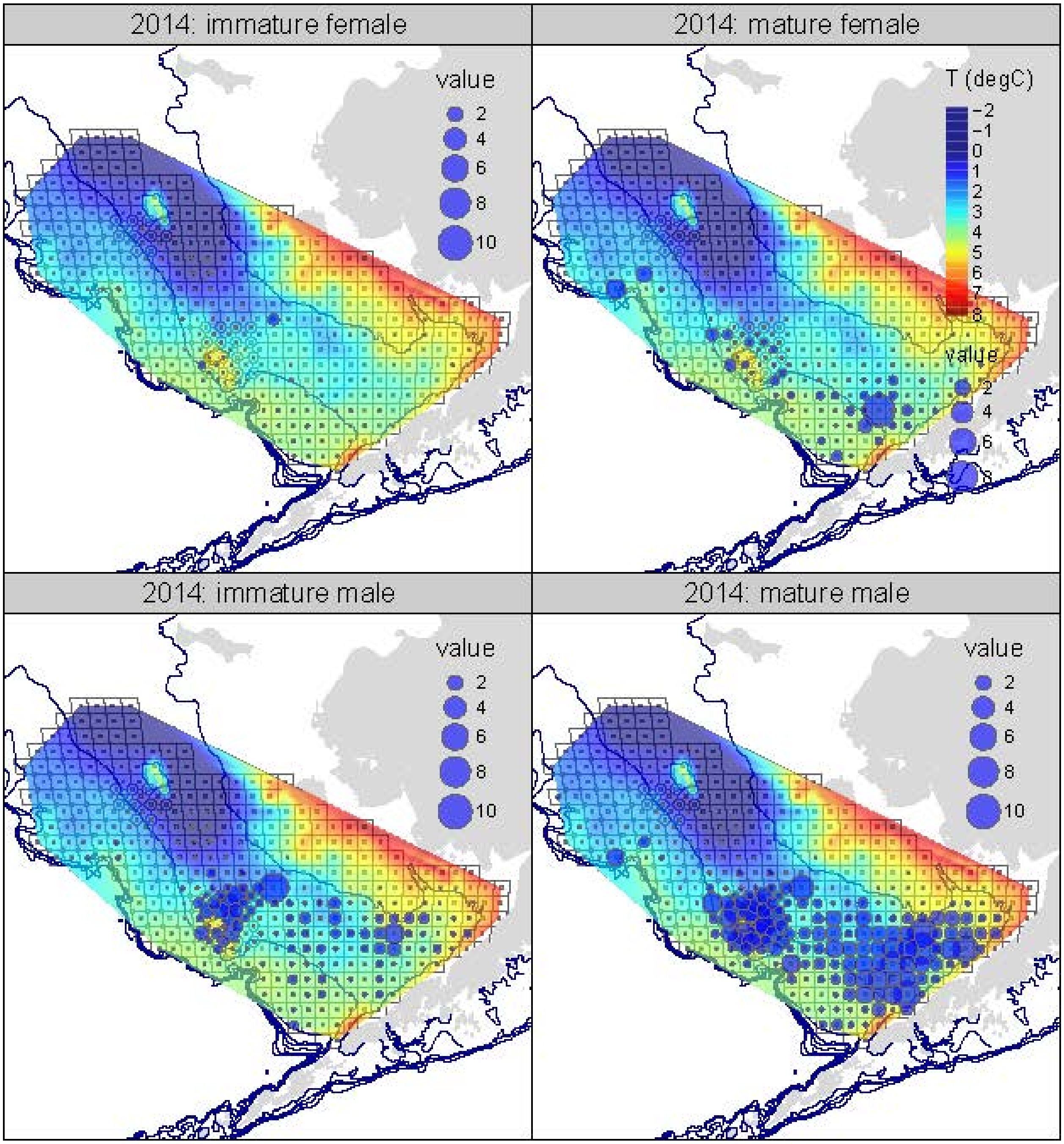


Figure 4: Tanner crab CPUE (biomass) from the 2014 NMFS EBS bottom trawl survey.

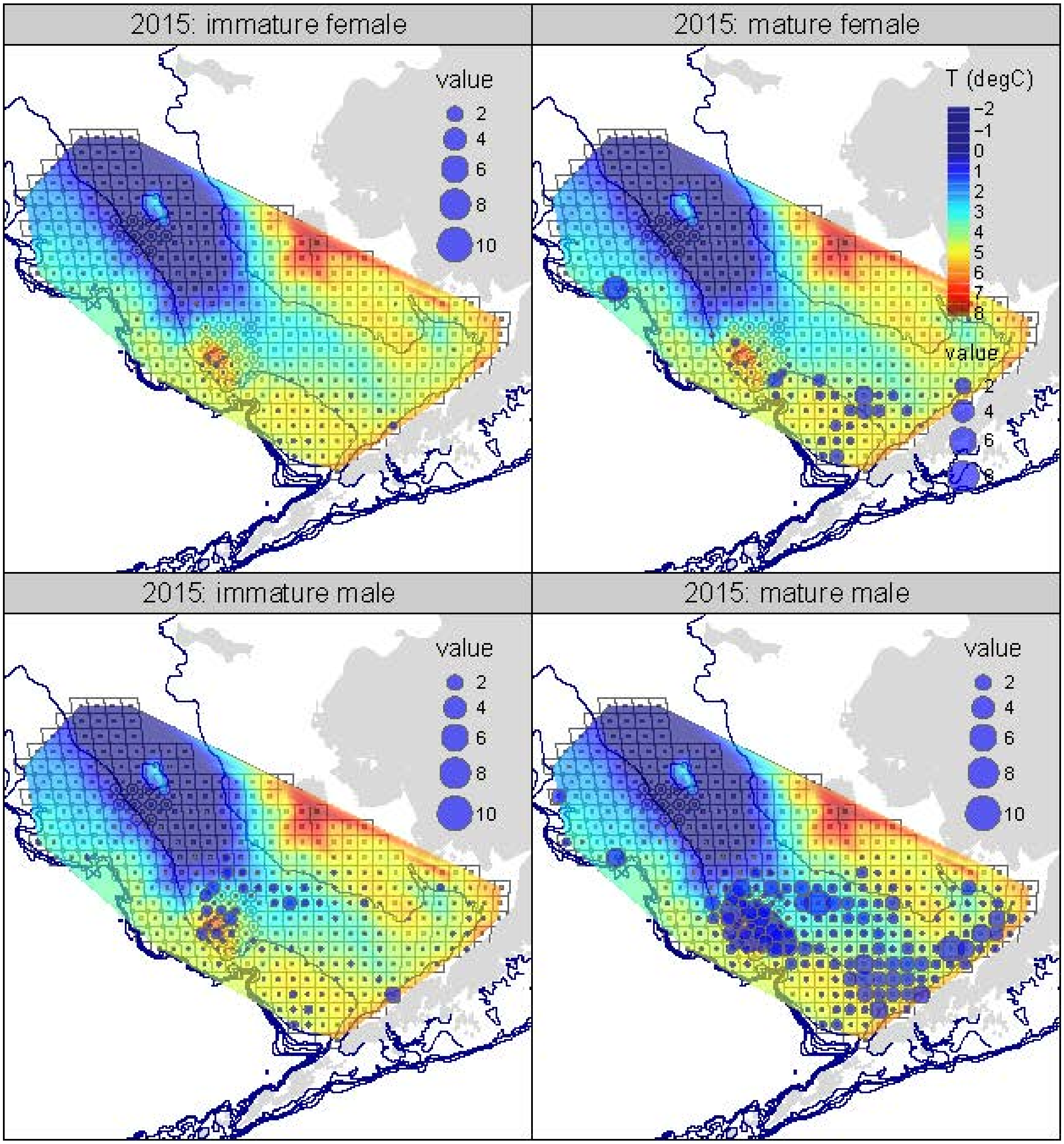


Figure 5: Tanner crab CPUE (biomass) from the 2015 NMFS EBS bottom trawl survey.

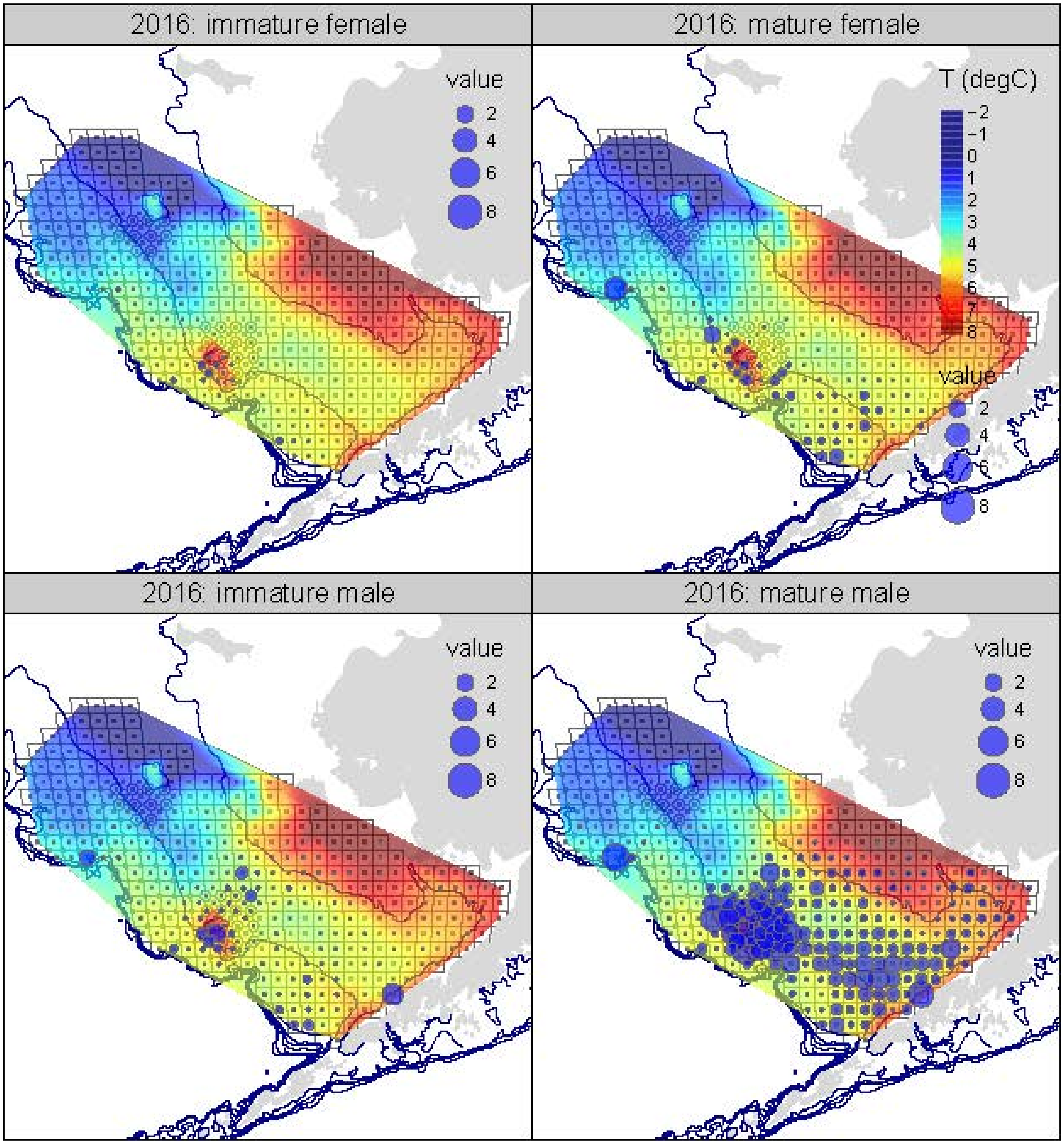


Figure 6: Tanner crab CPUE (biomass) from the 2016 NMFS EBS bottom trawl survey.

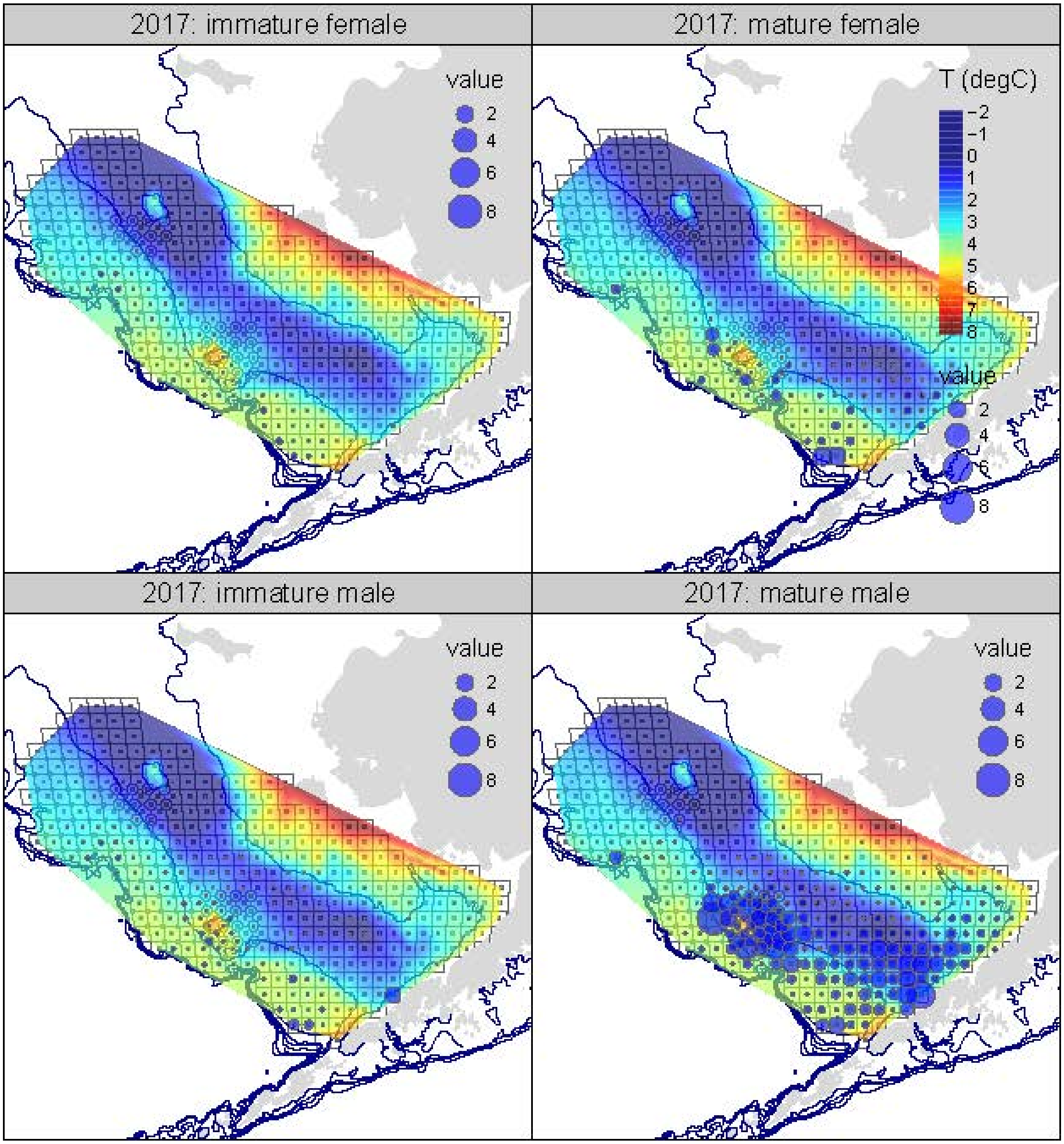


Figure 7: Tanner crab CPUE (biomass) from the 2017 NMFS EBS bottom trawl survey.

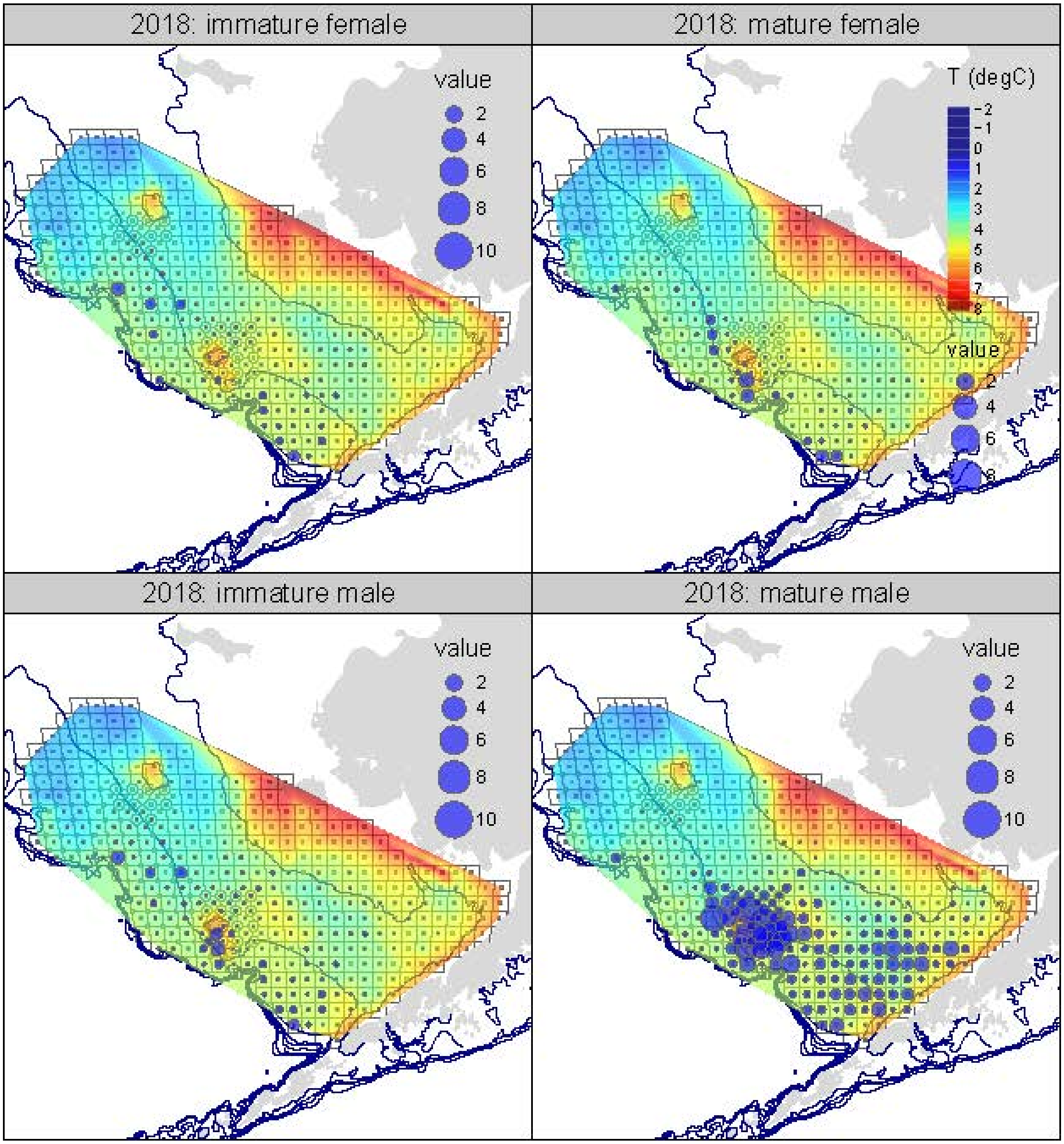


Figure 8: Tanner crab CPUE (biomass) from the 2018 NMFS EBS bottom trawl survey.

Appendix G:
Male Maturity Data
From the NMFS Survey

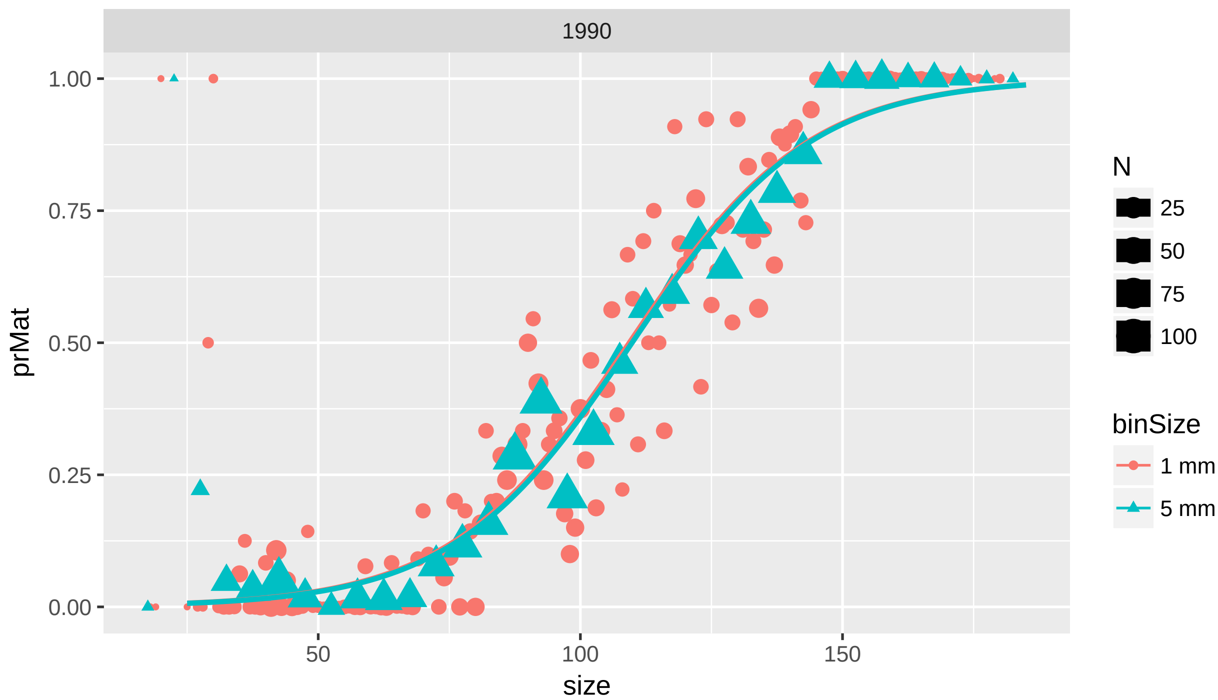
William Stockhausen

26 February, 2018

Chela height data and maturity state

Individuals can be classified as functionally "mature" or "immature" on the basis of the ratio of chela height (CH) to carapace width (CW). For example, based on a cutpoint analysis to separate two mixed distributions of Tanner crab collected in Glacier Bay in the Gulf of Alaska, Tamone et al. (2007) classified crab exhibiting a ratio > 0.18 as functionally "mature" whereas crab exhibiting a ratio < 0.18 were classified as functionally "immature".

Chela height data from the NMFS EBS bottom trawl survey are available for male Tanner crab for specific years for surveys from 1975 to 2017. Robert Foy (AFSC) used a cutpoint analysis on 10-mm CW size bins to classify individual male Tanner crab as immature or mature based on their CH/CW ratio. "Raw"" maturity ogives were then calculated for each year in which chela height data were collected as the ratio of the number of mature to total new shell crab by size bin. The raw ogives were calculated using both 1-mm and 5-mm size bins, and fit using with logistic curves using the glm package in R with binomial family and logit link. The resulting raw and fitted maturity ogives are shown in the following plots.



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100
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75
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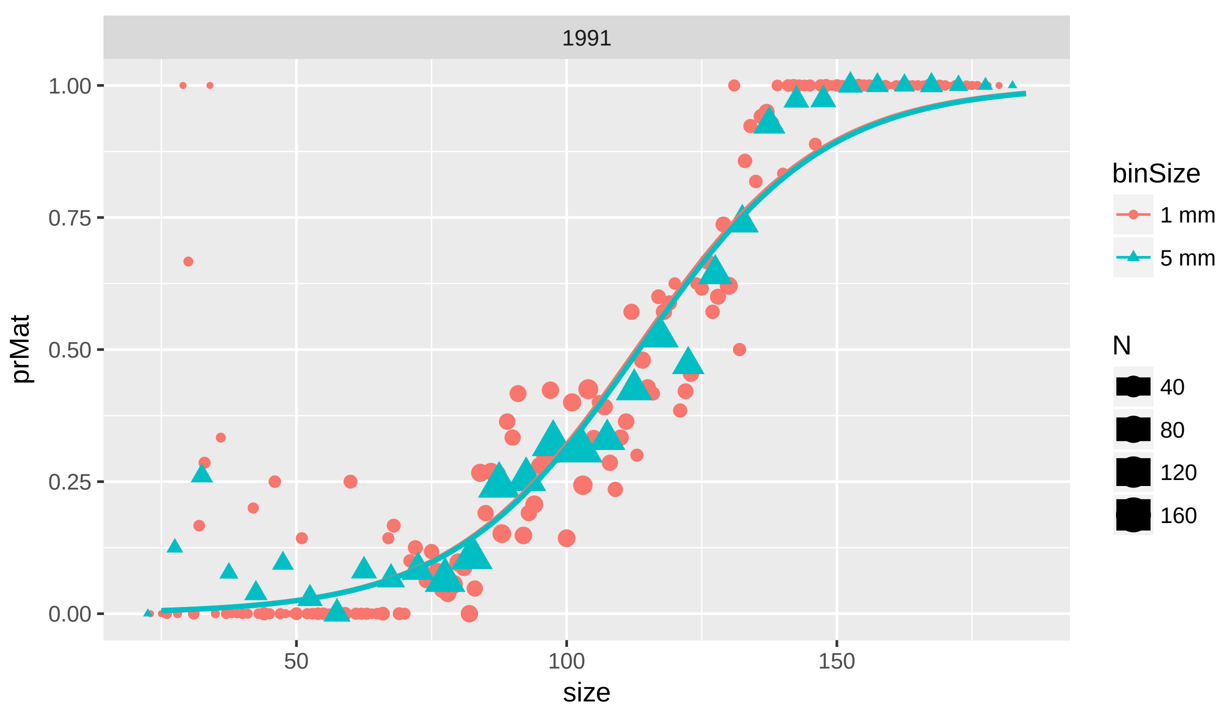
5 mm



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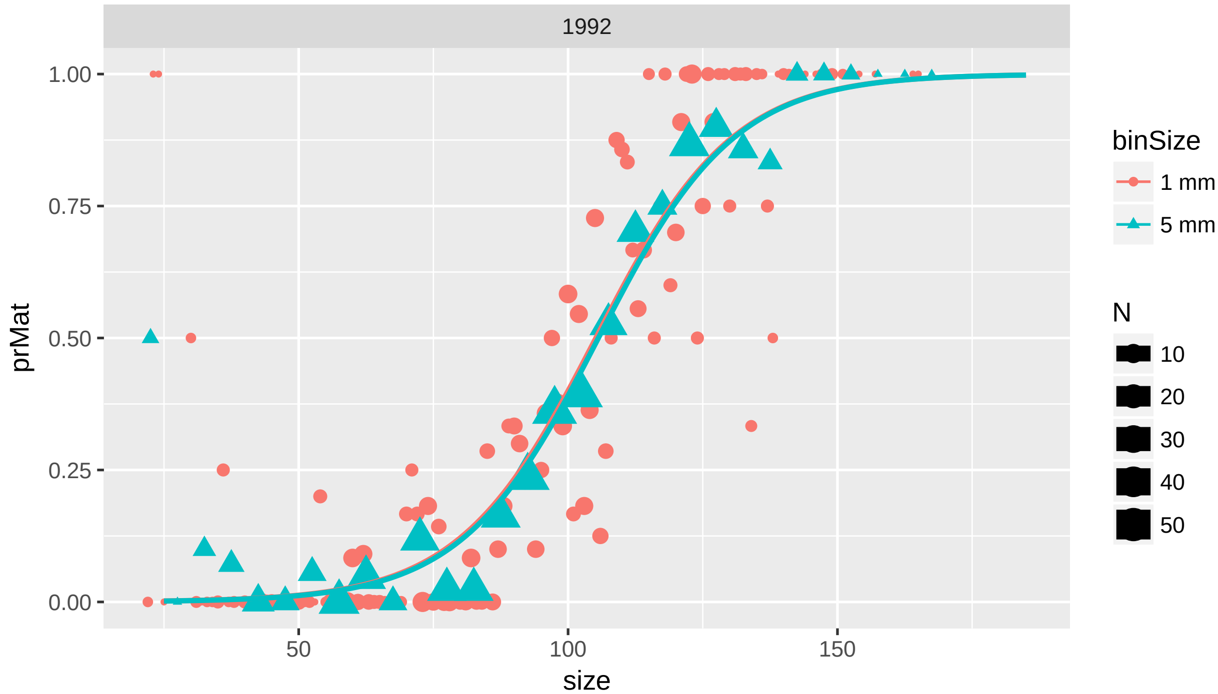
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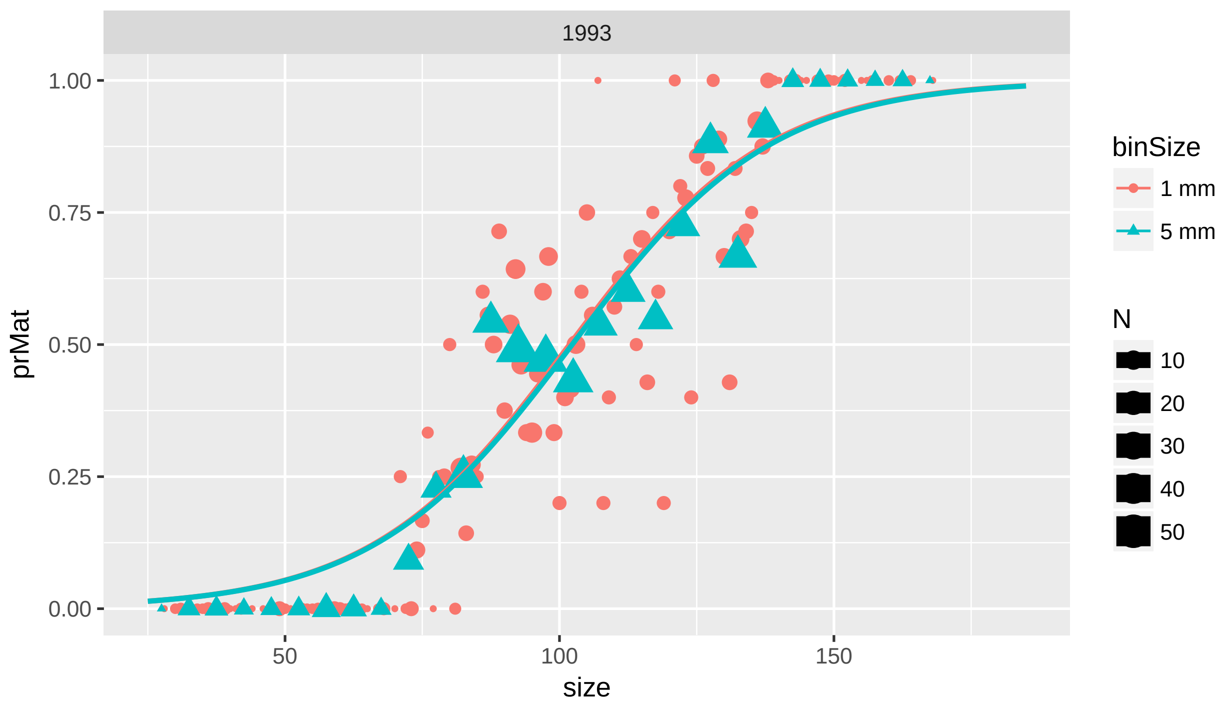
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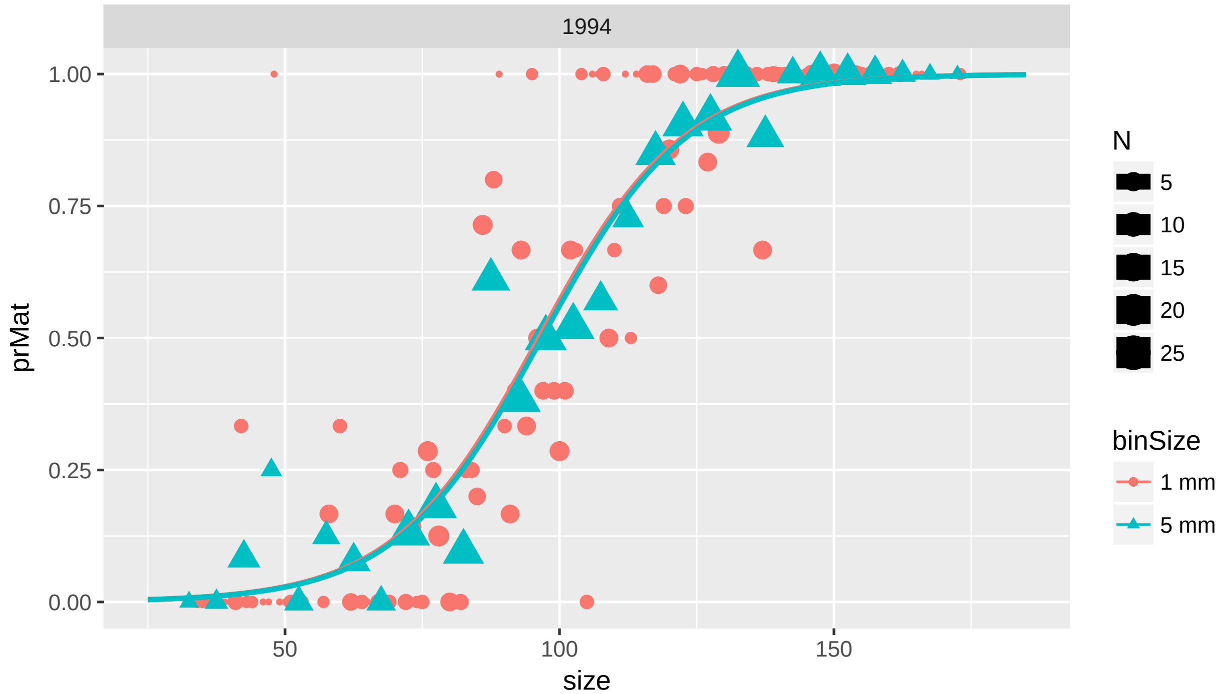
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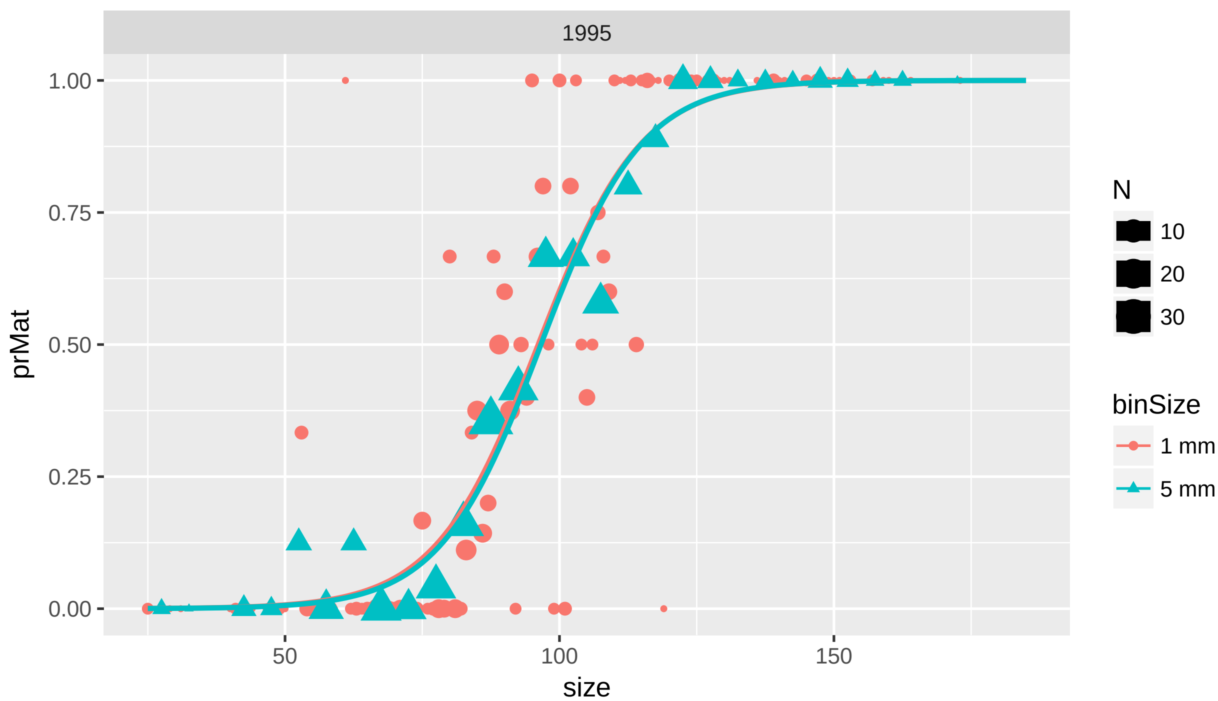
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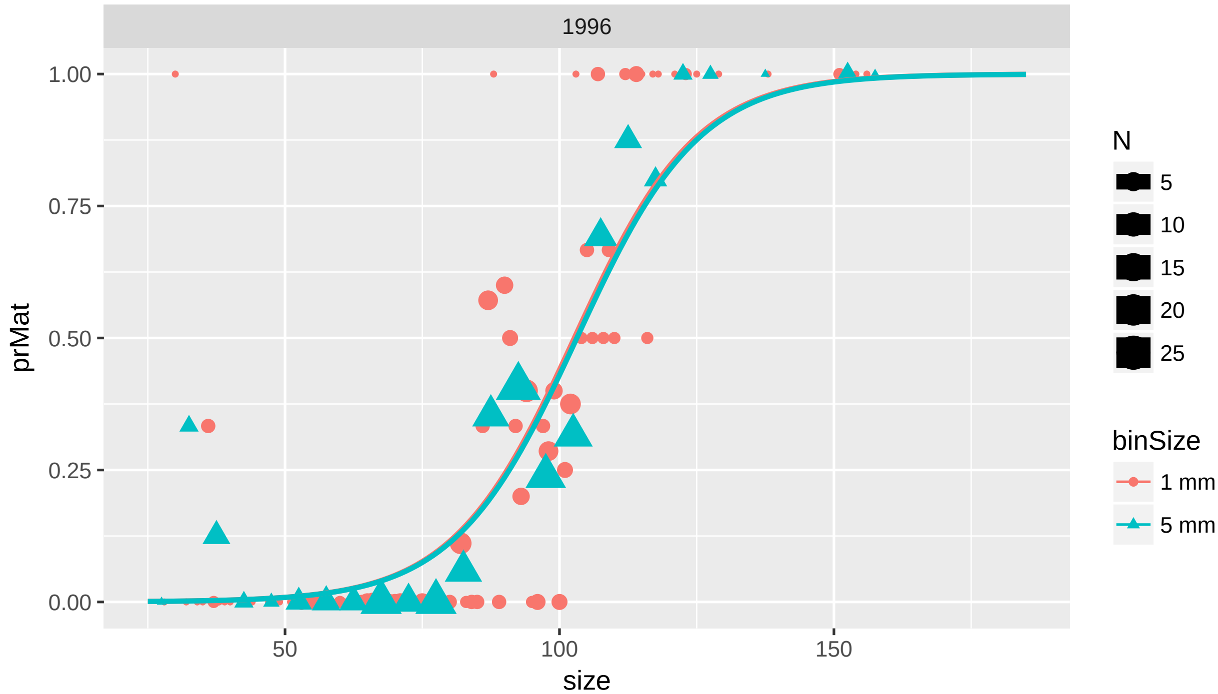
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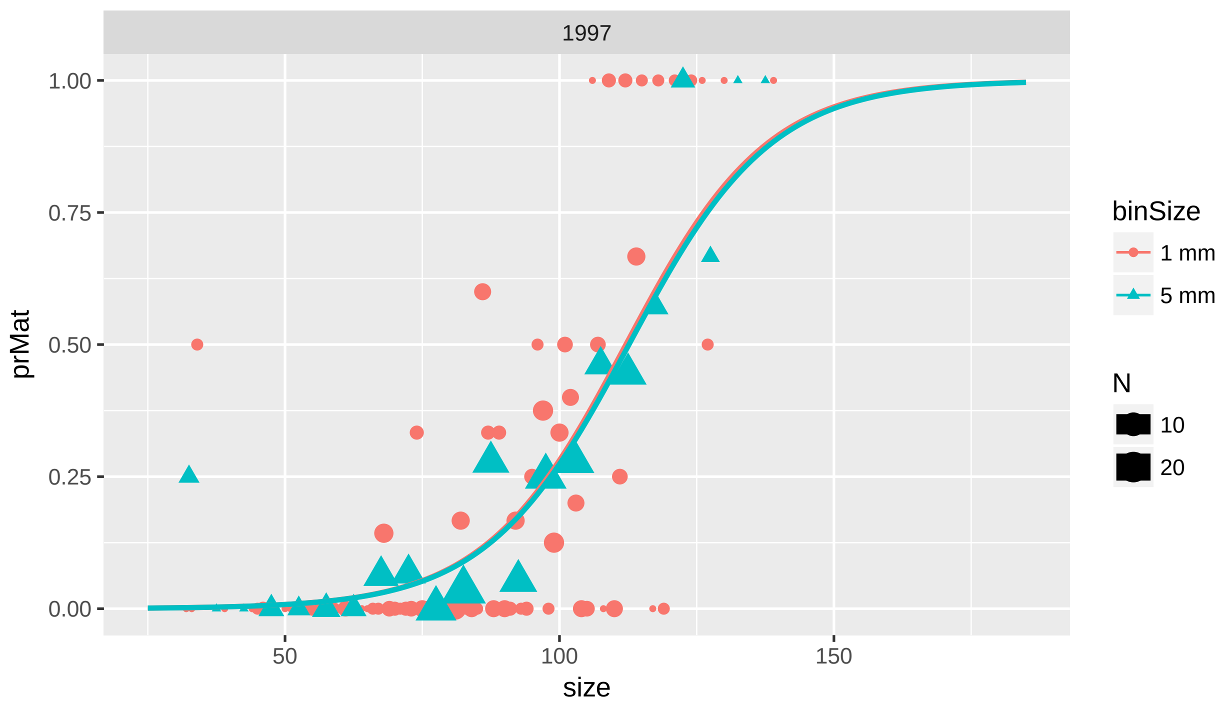
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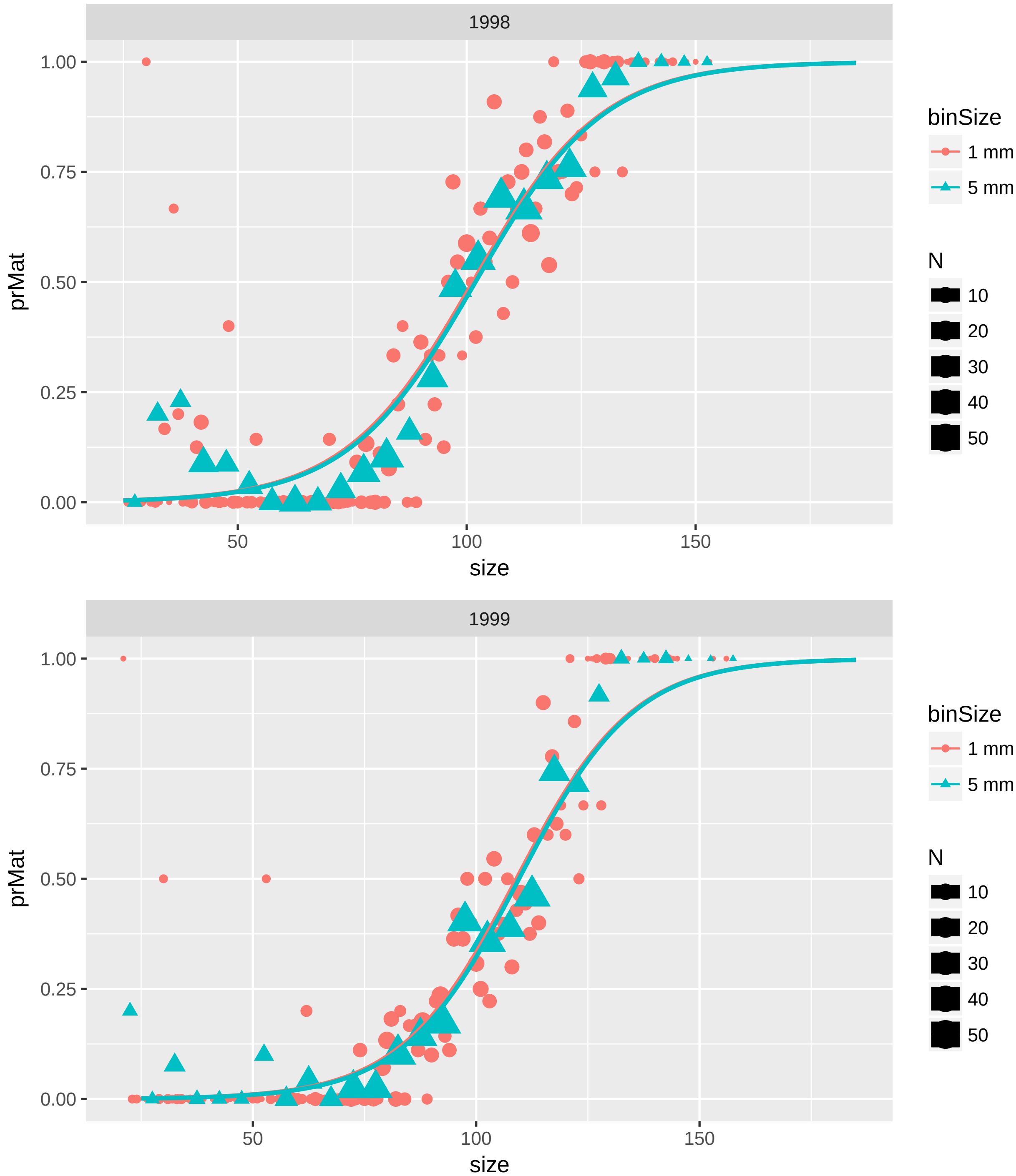
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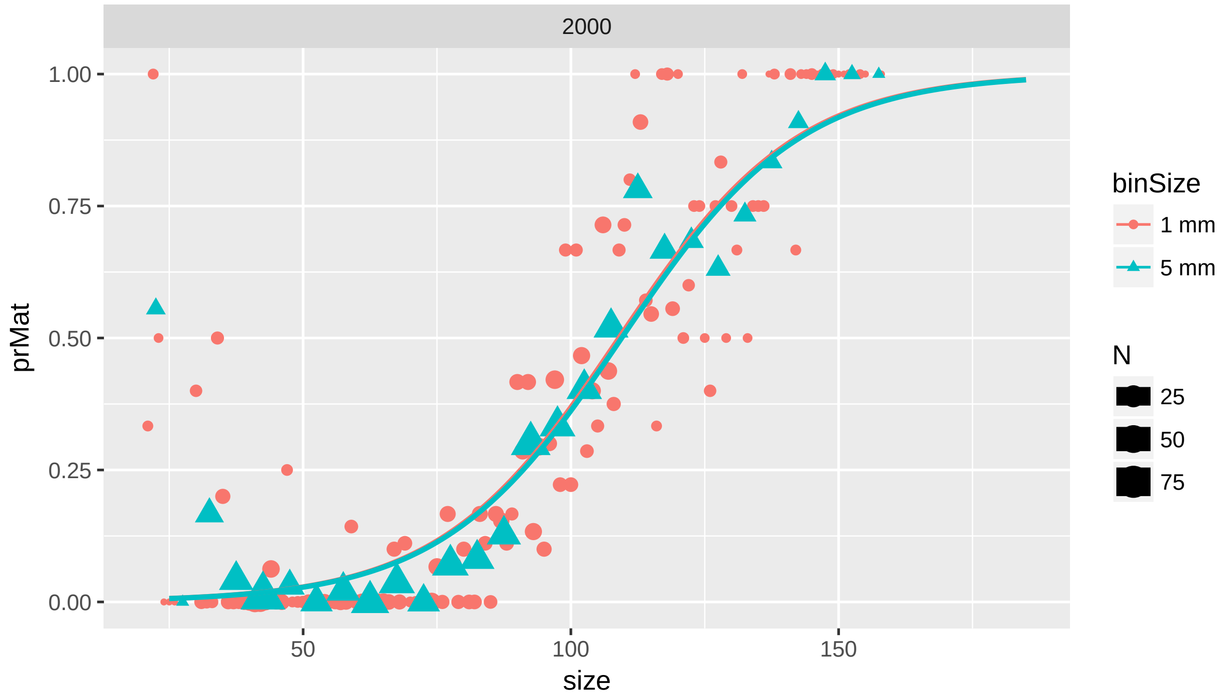
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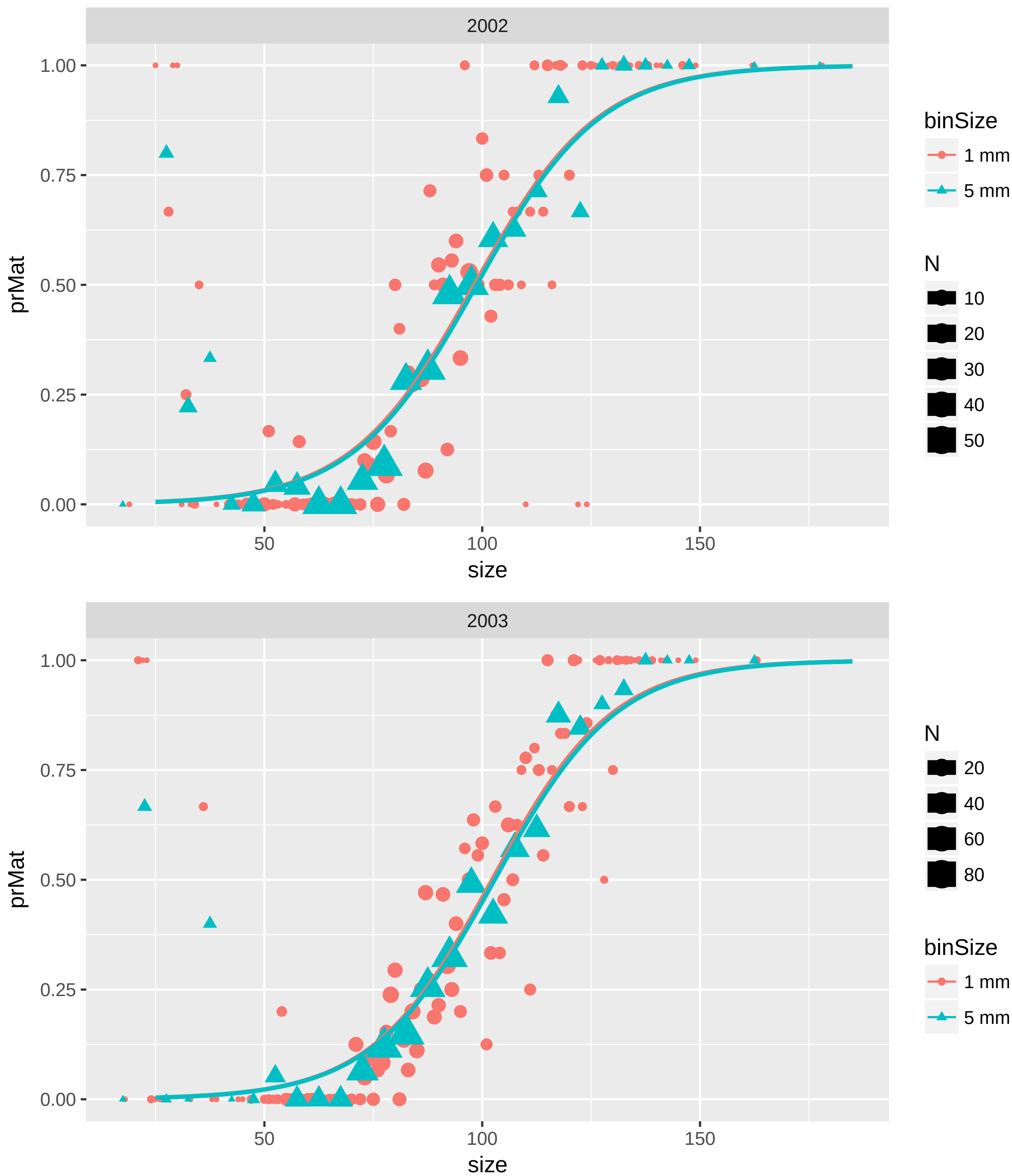
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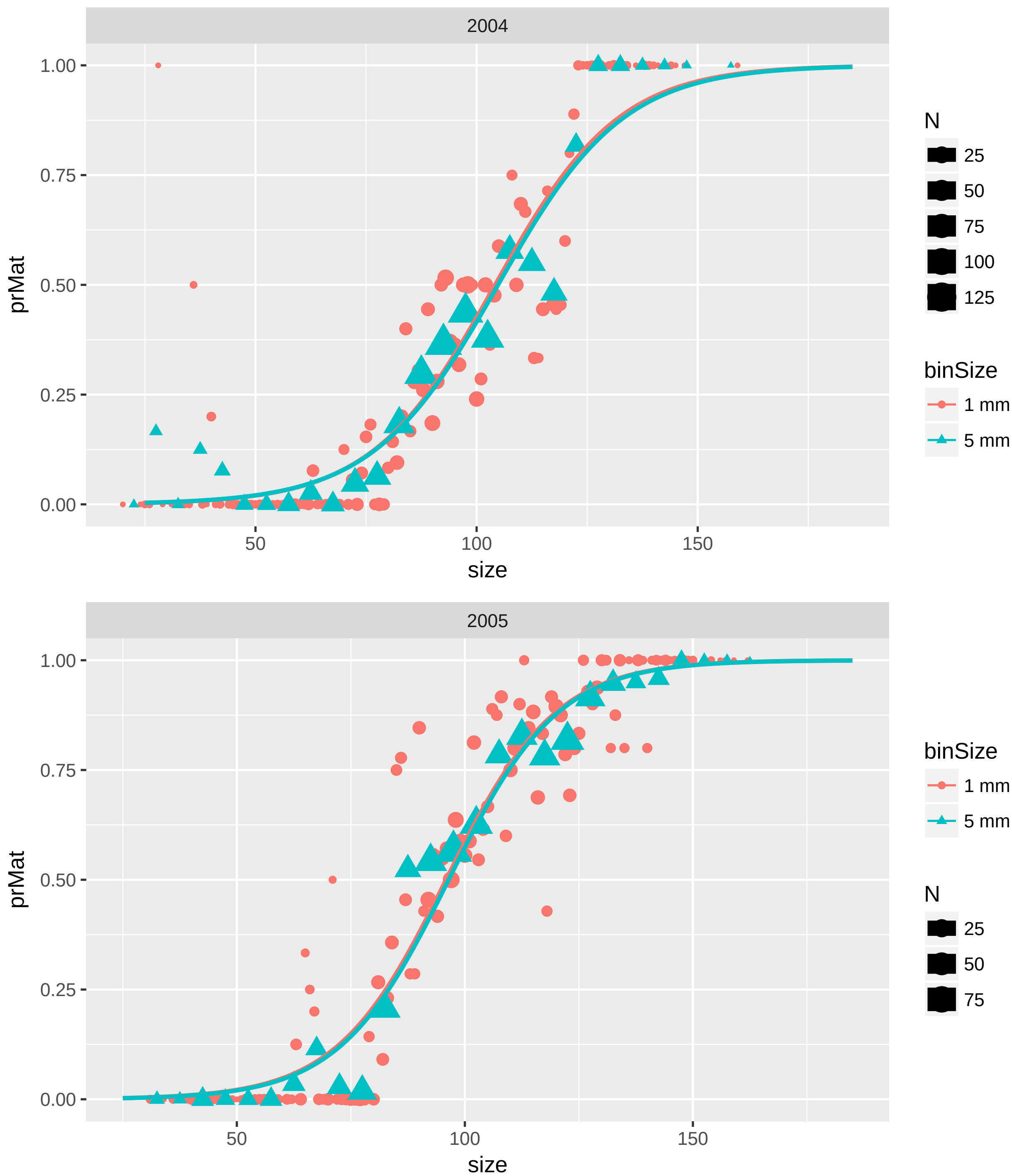
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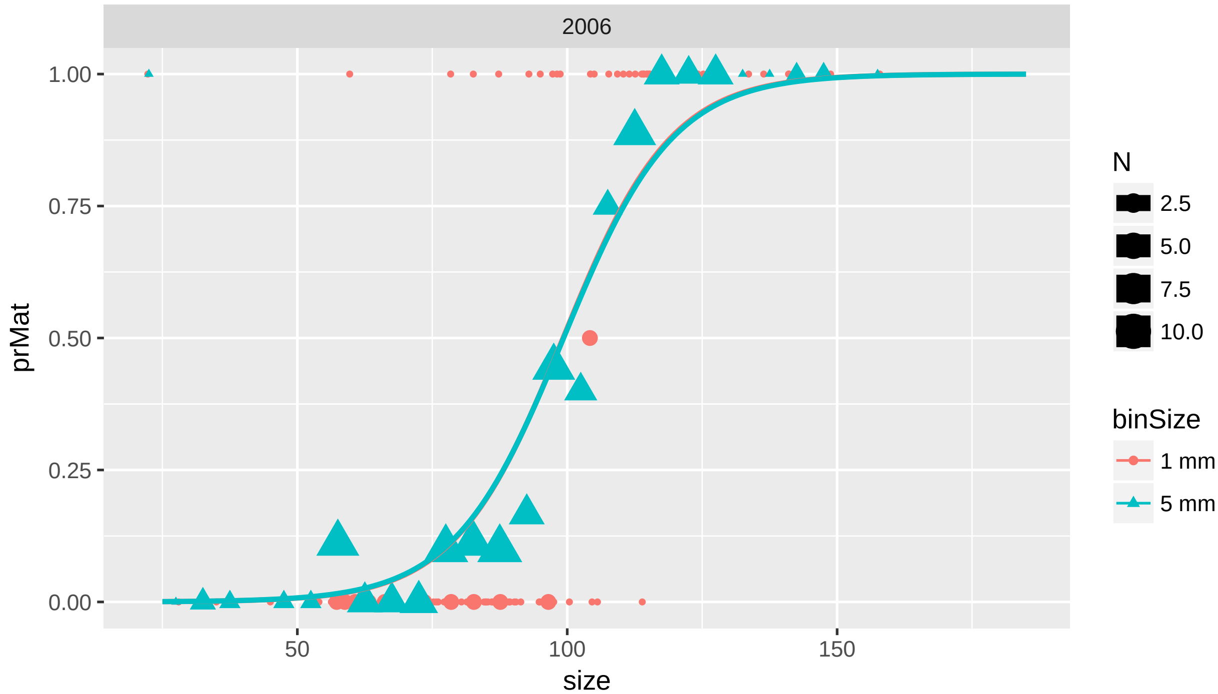
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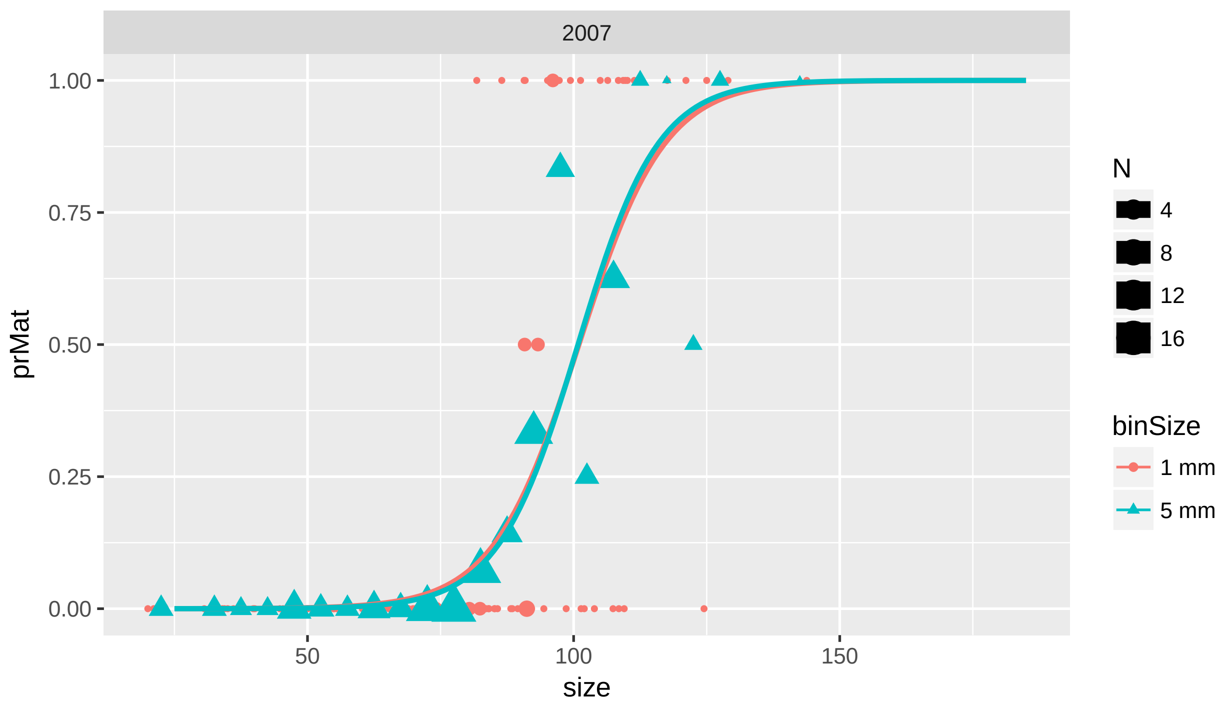
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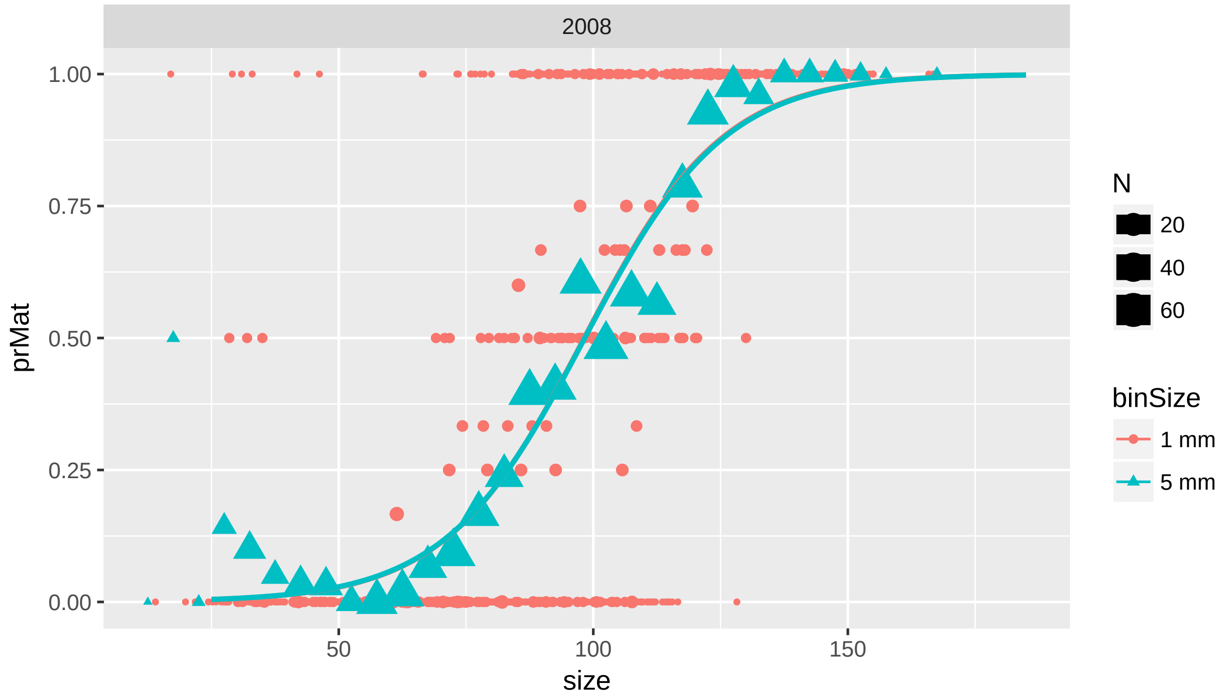
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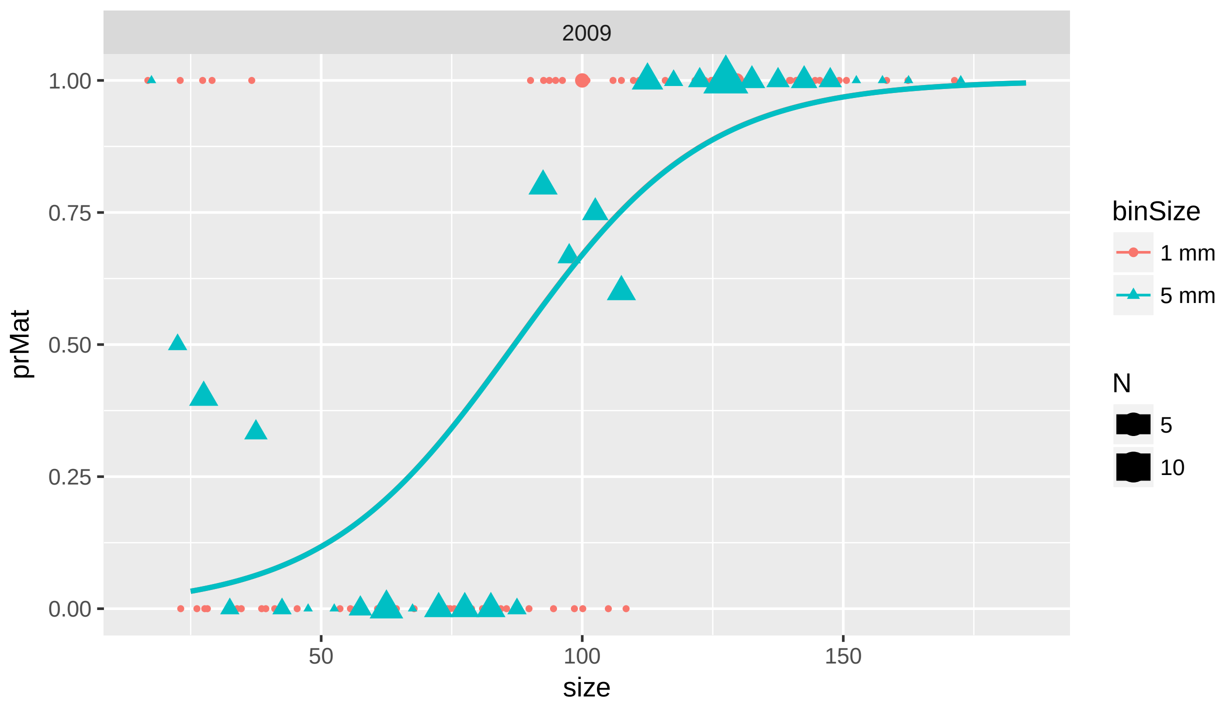
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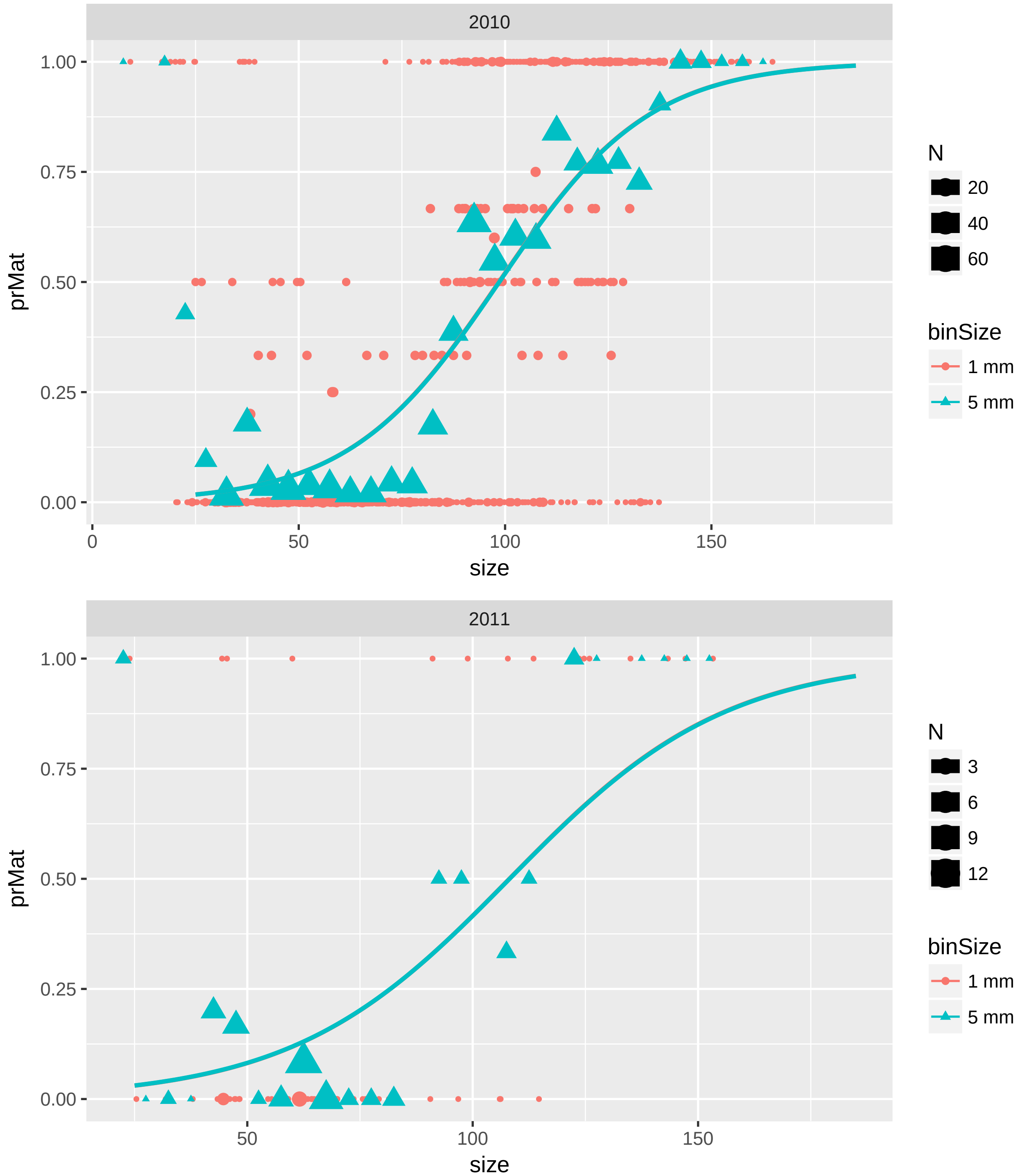
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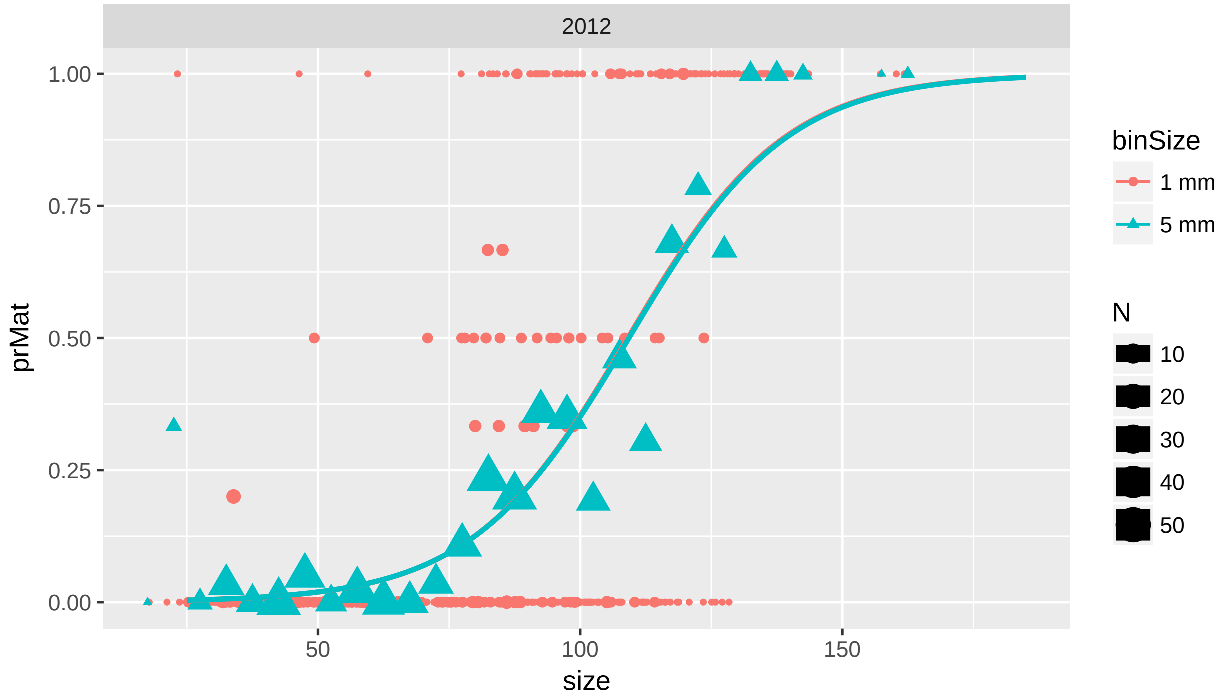
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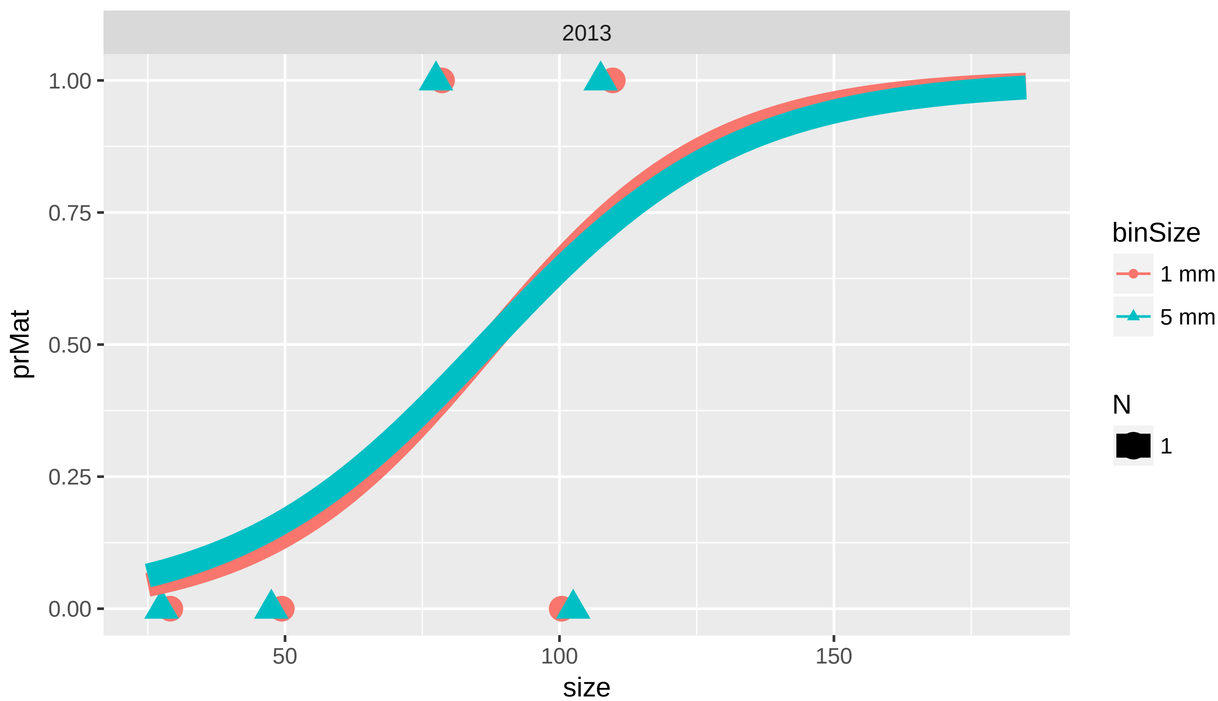
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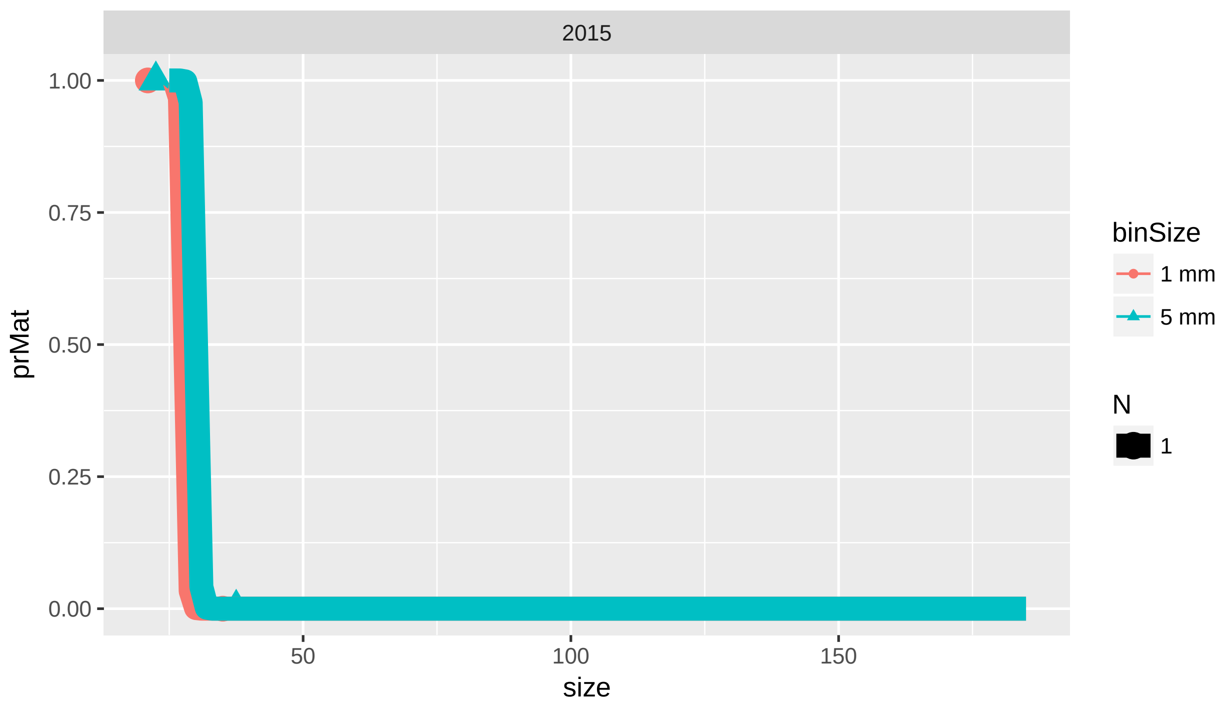
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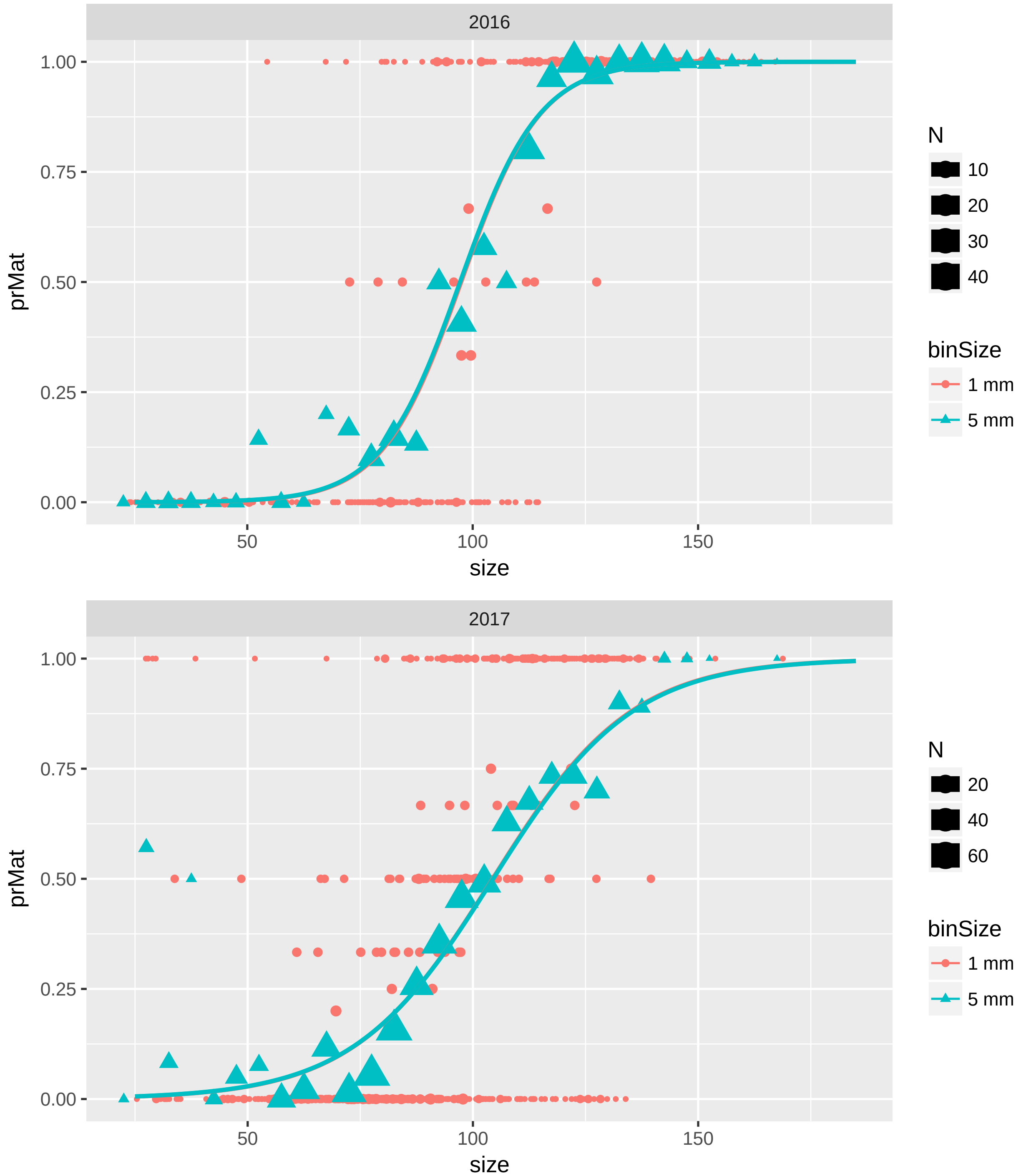
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5 mm
2017
1.00
0.75
0.50
0.25
0.00
prMat
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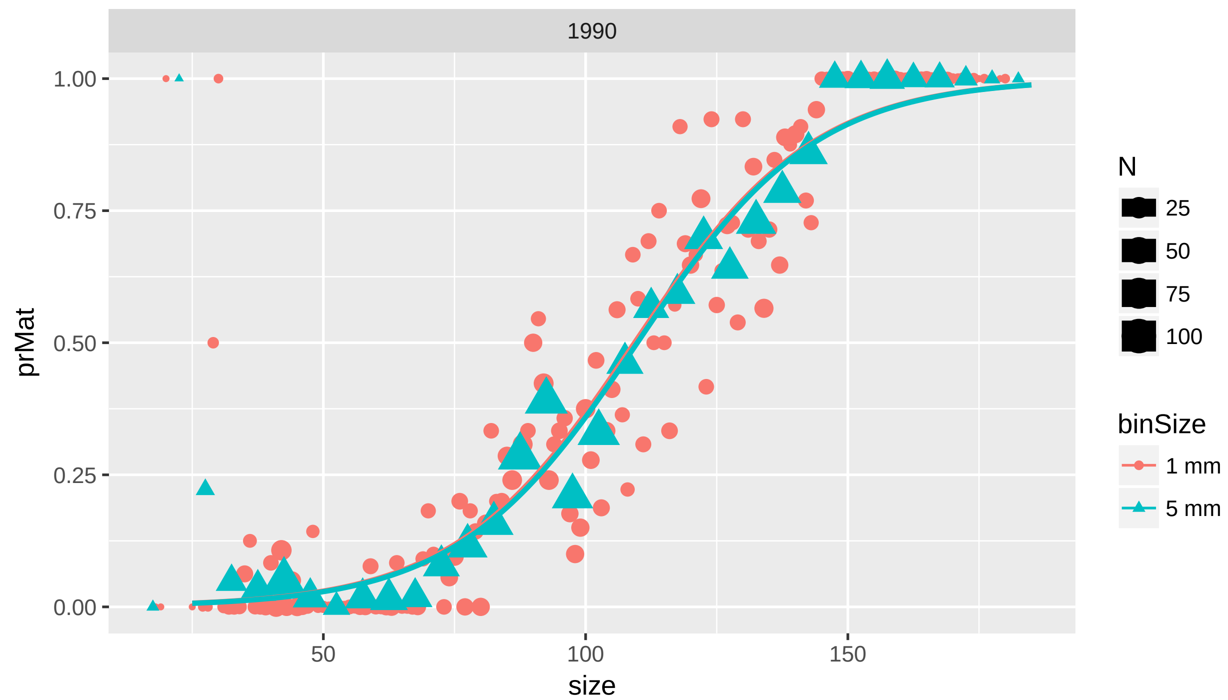

Figure 1: Figure 1. Estimated male maturity ogives for 1990.

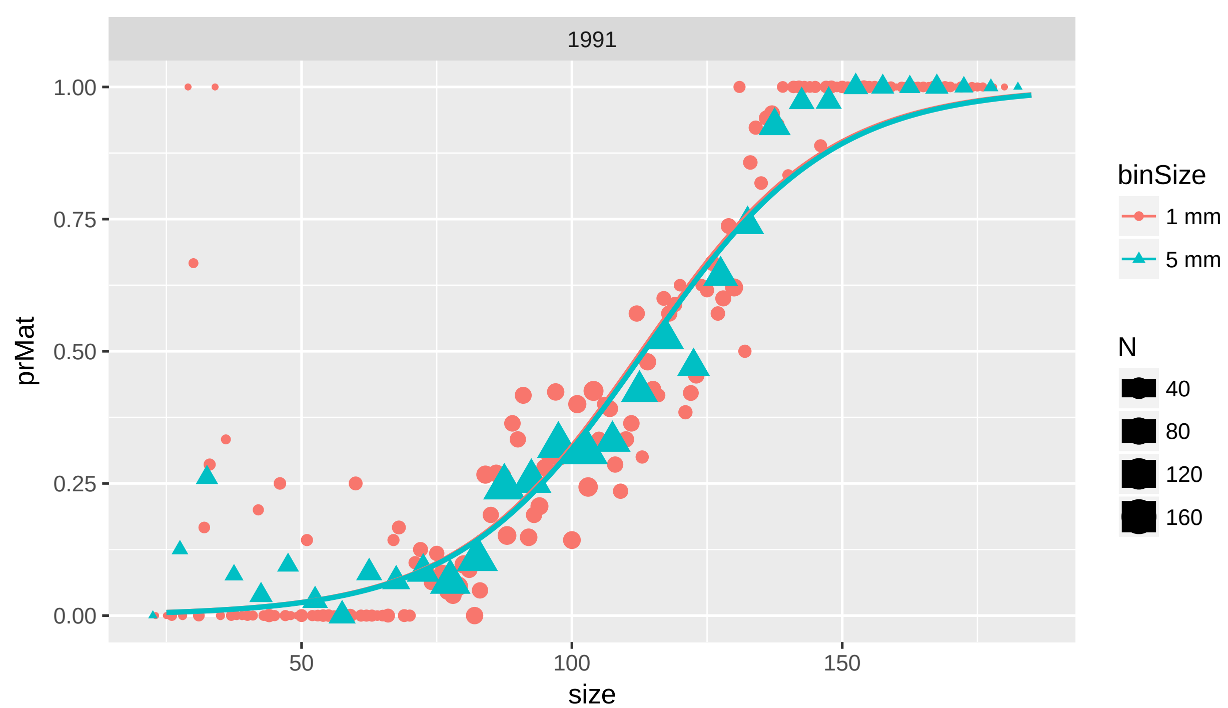

Figure 2: Figure 1. Estimated male maturity ogives for 1991.

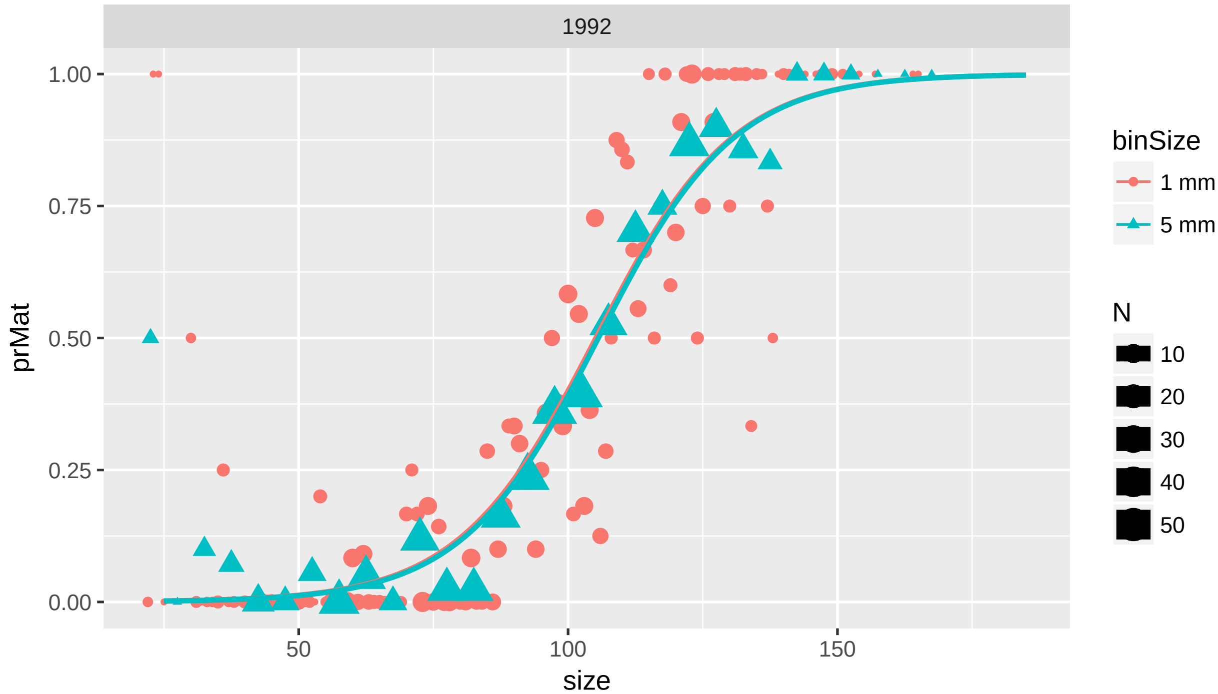

Figure 3: Figure 1. Estimated male maturity ogives for 1992.

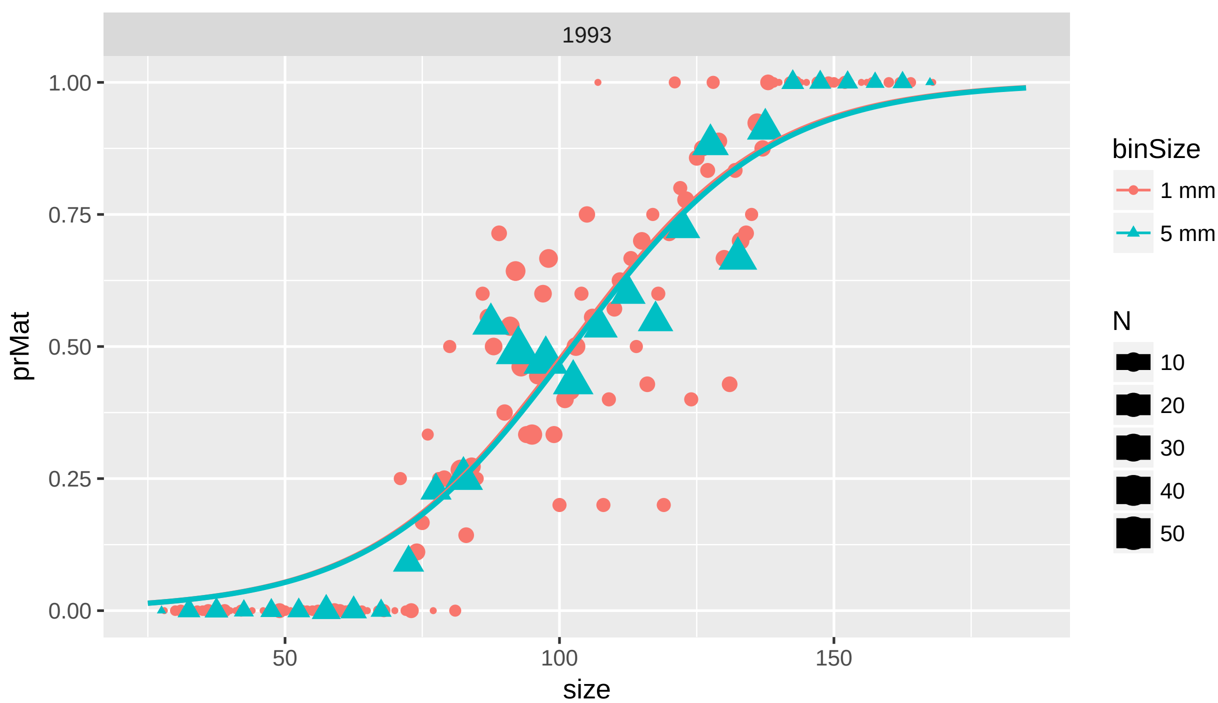

Figure 4: Figure 1. Estimated male maturity ogives for 1993.

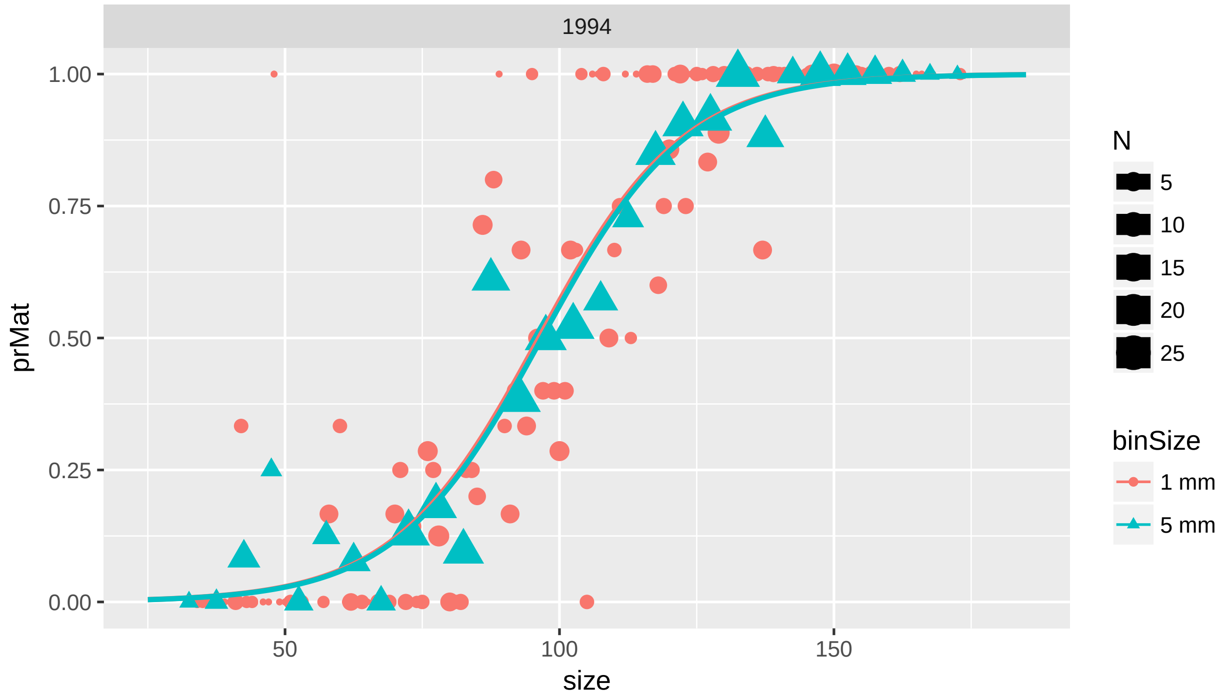

Figure 5: Figure 1. Estimated male maturity ogives for 1994.

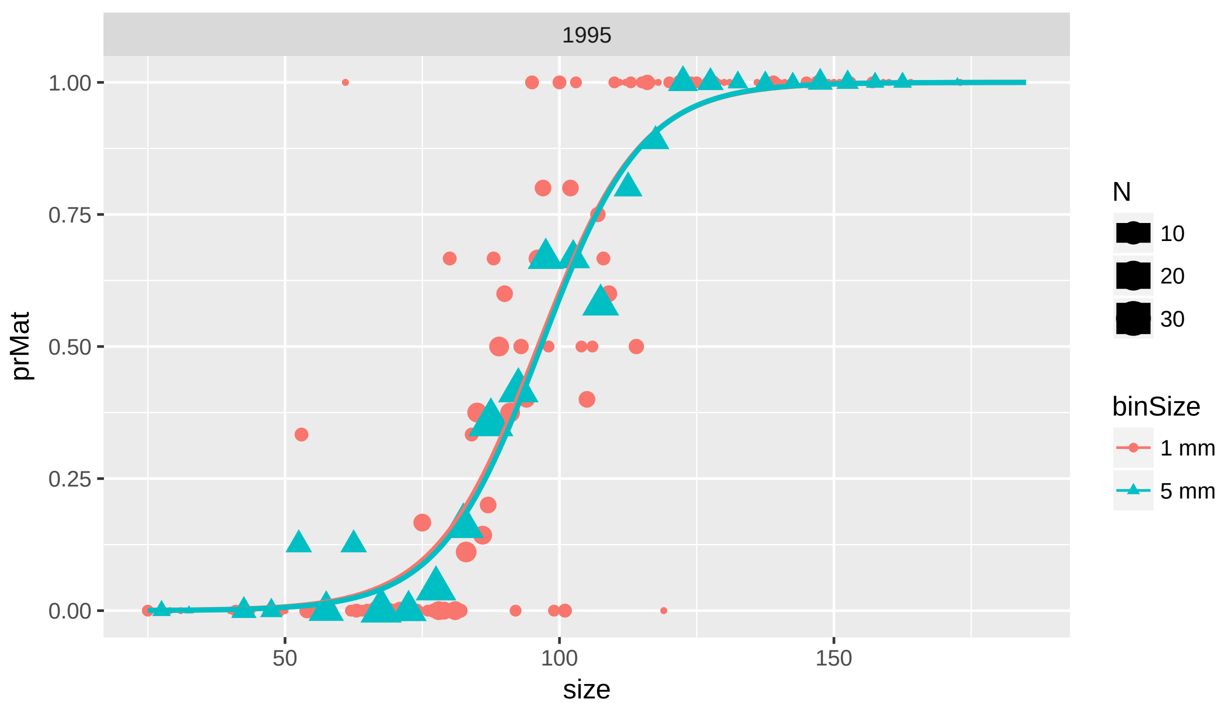

Figure 6: Figure 1. Estimated male maturity ogives for 1995.

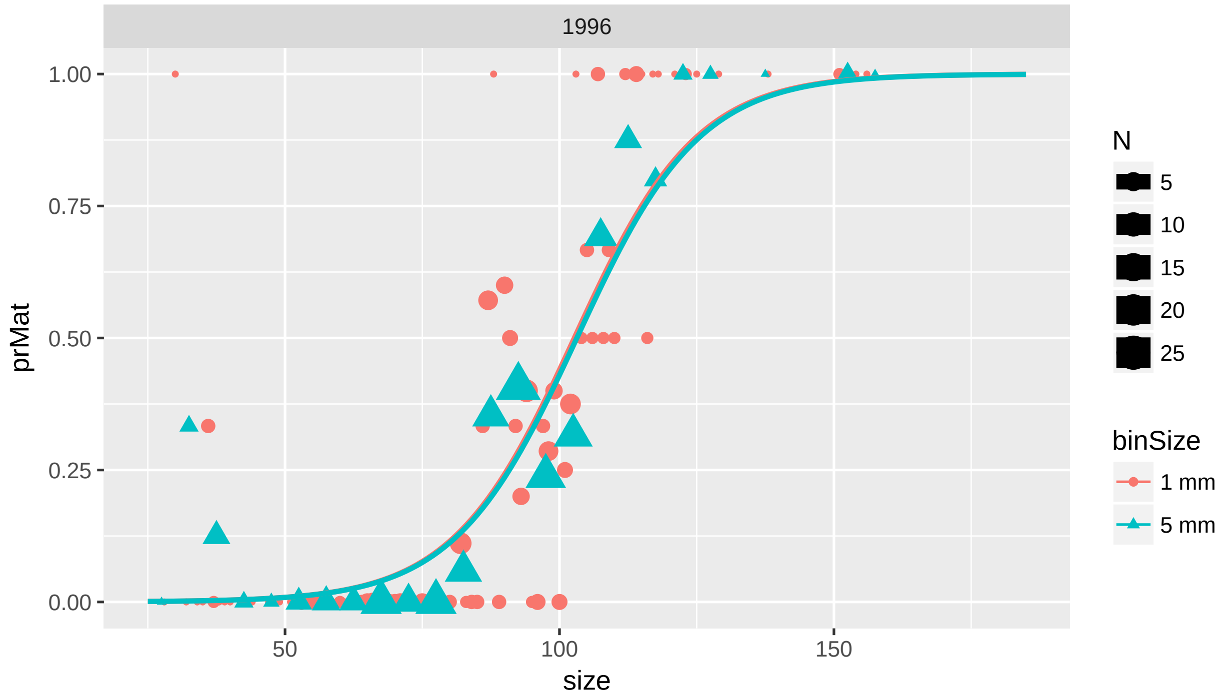

Figure 7: Figure 1. Estimated male maturity ogives for 1996.

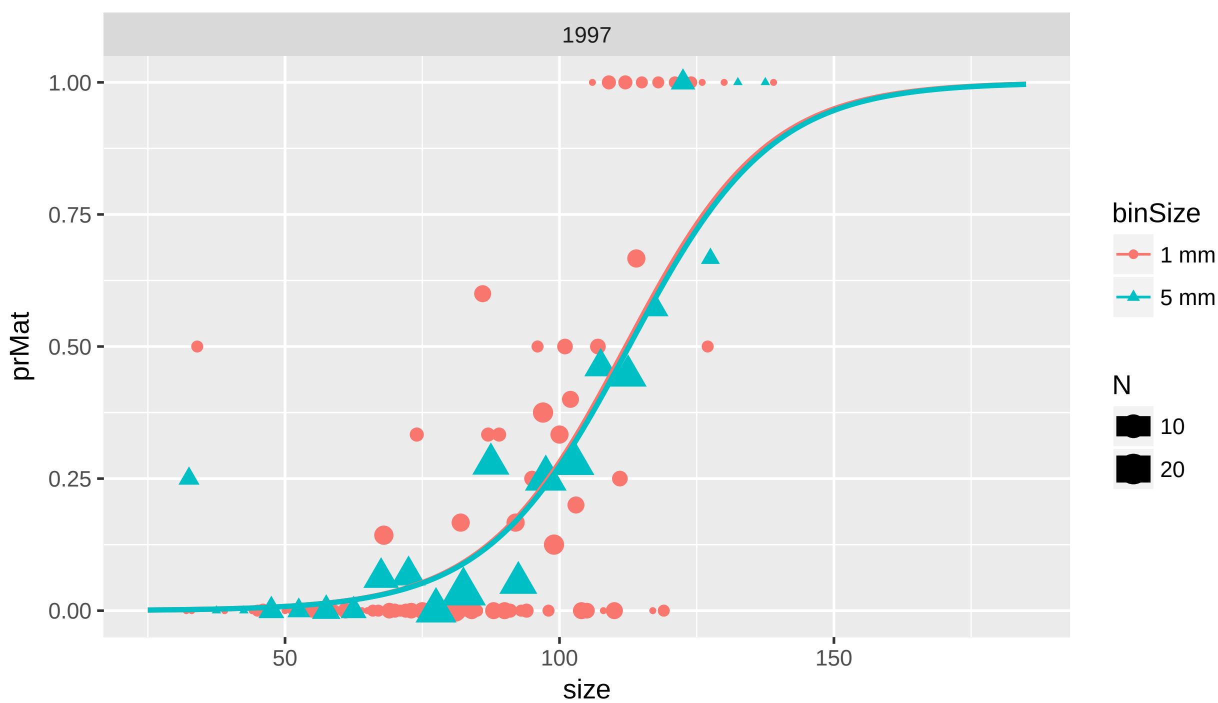

Figure 8: Figure 1. Estimated male maturity ogives for 1997.

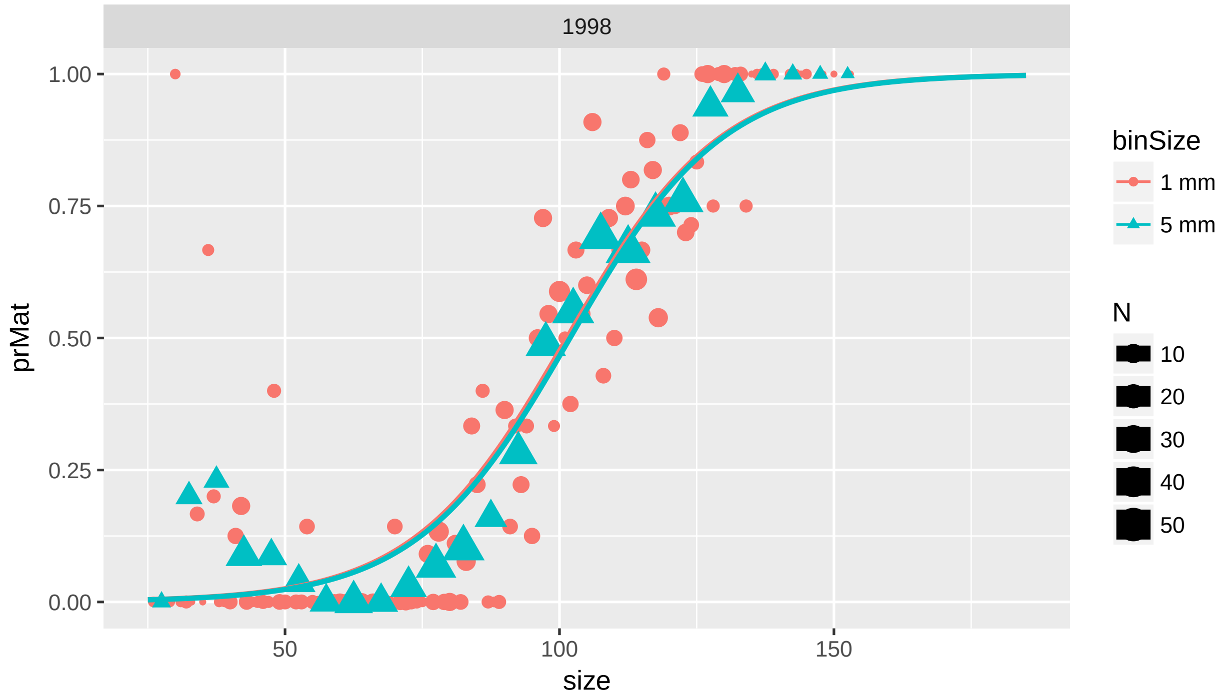

Figure 9: Figure 1. Estimated male maturity ogives for 1998.

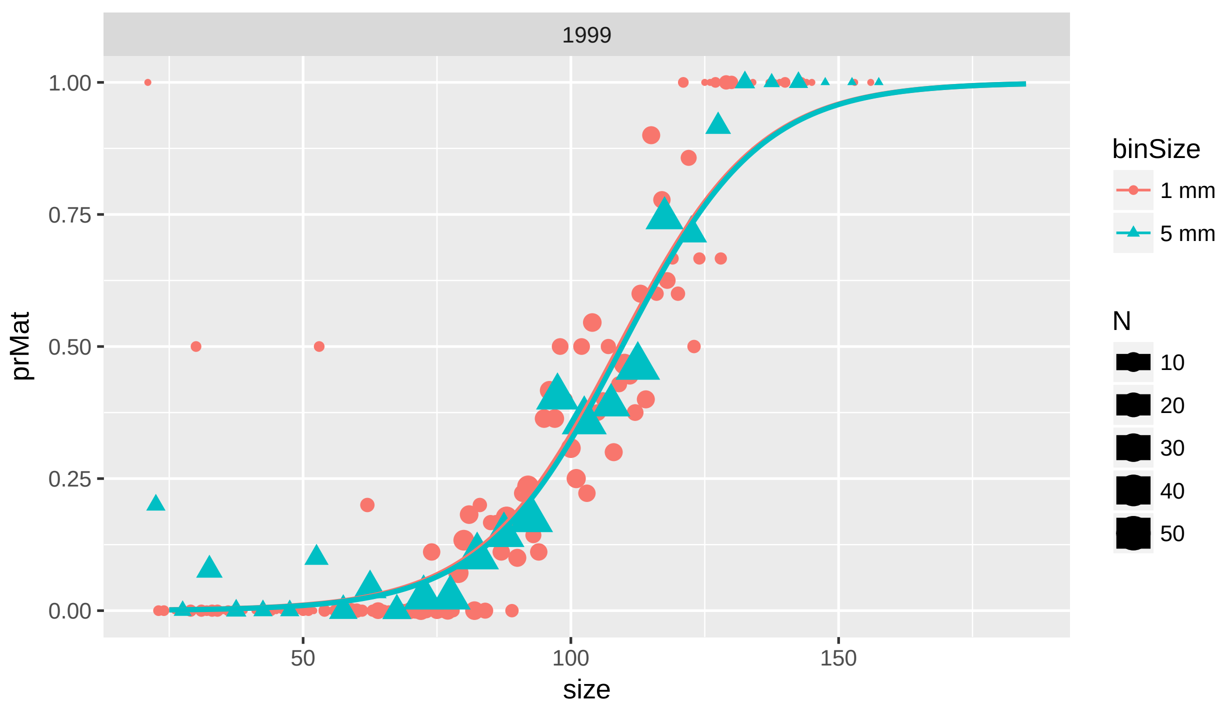

Figure 10: Figure 1. Estimated male maturity ogives for 1999.

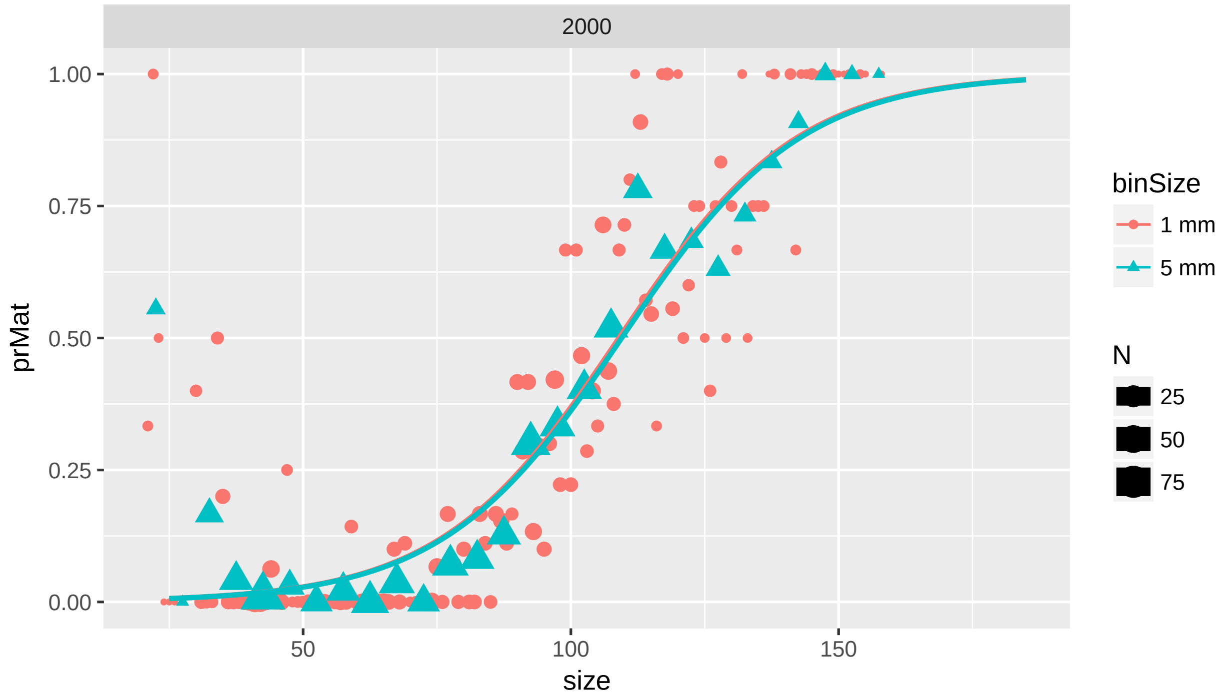

Figure 11: Figure 1. Estimated male maturity ogives for 2000.

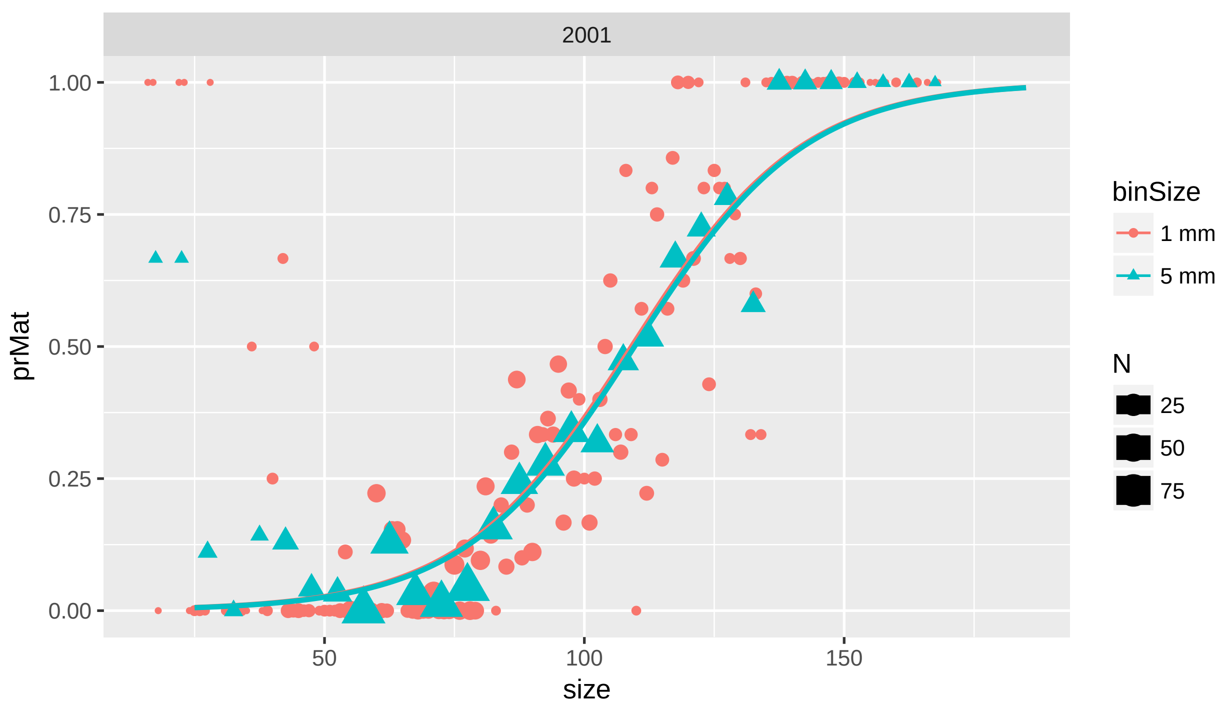

Figure 12: Figure 1. Estimated male maturity ogives for 2001.

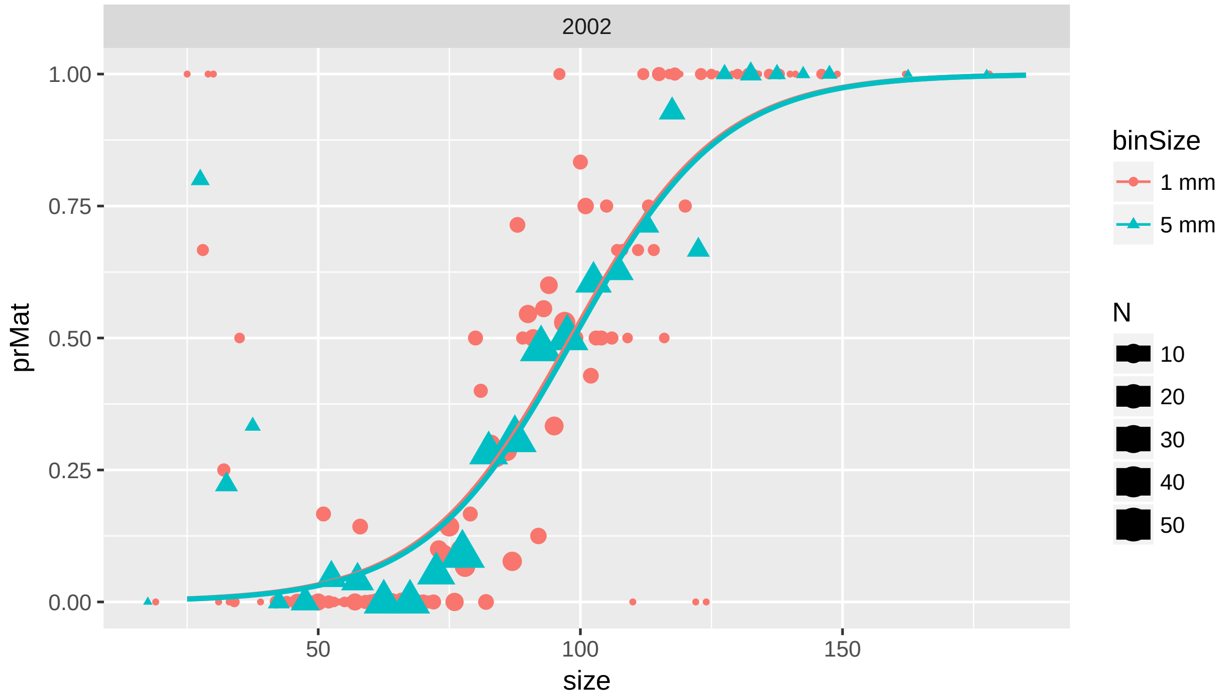

Figure 13: Figure 1. Estimated male maturity ogives for 2002.

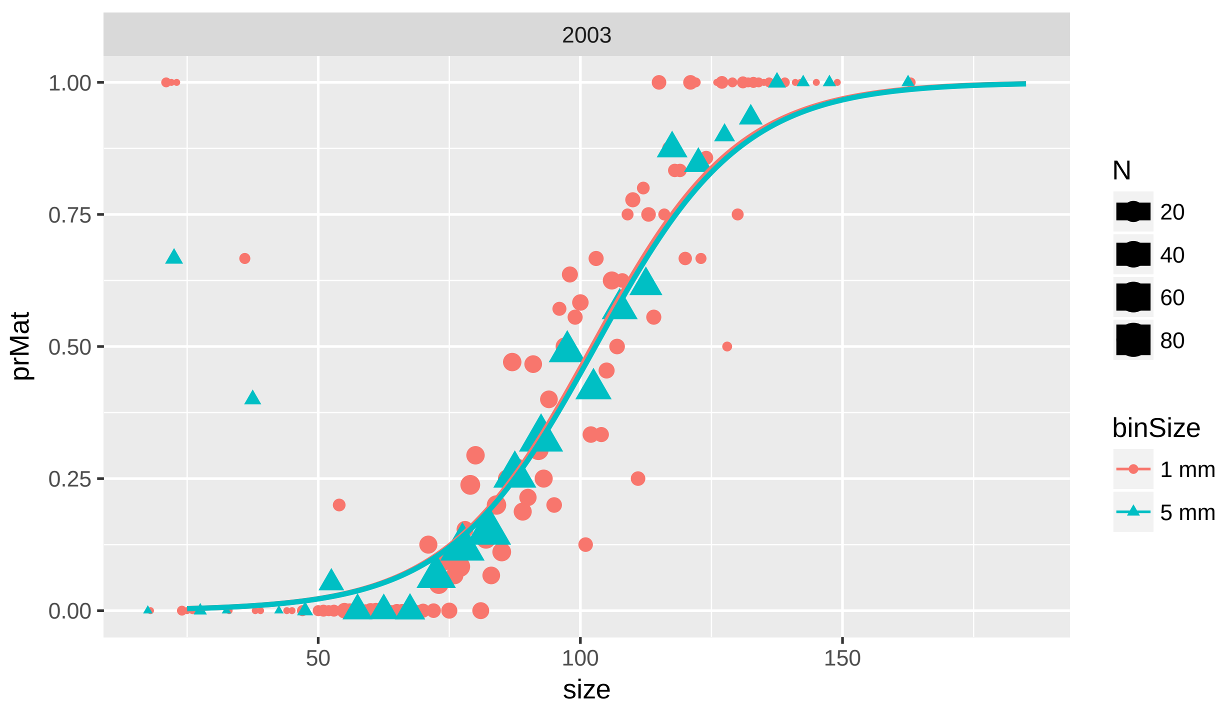

Figure 14: Figure 1. Estimated male maturity ogives for 2003.

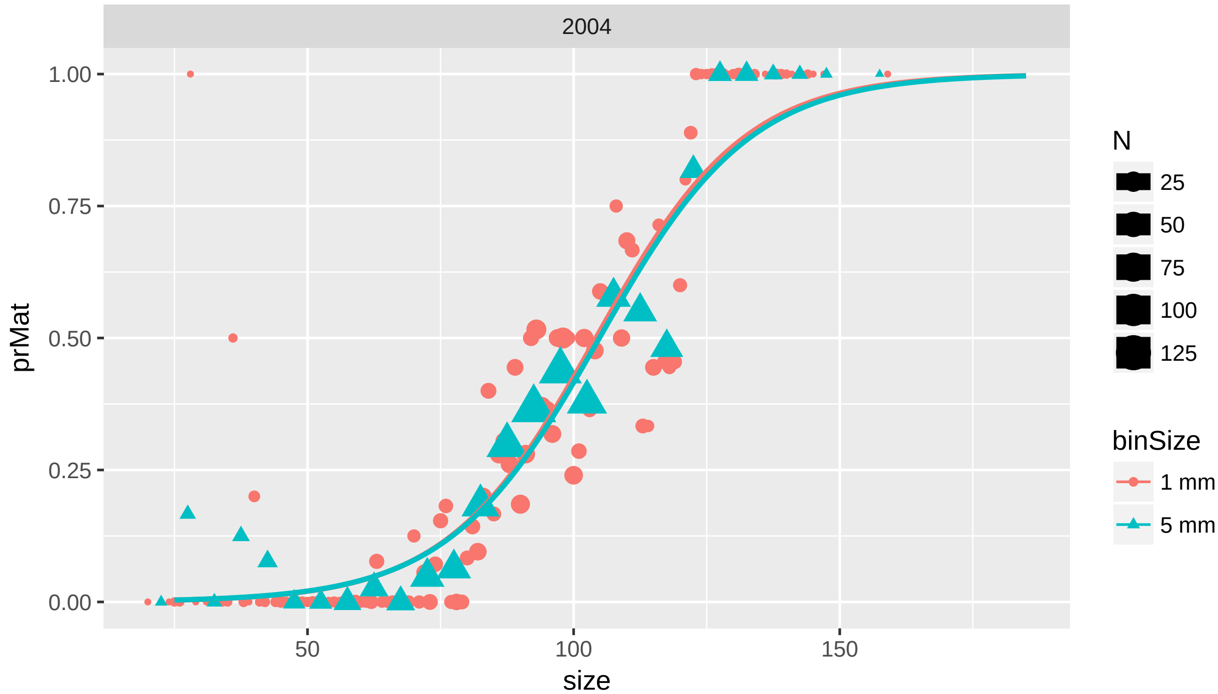

Figure 15: Figure 1. Estimated male maturity ogives for 2004.

Figure 16: Figure 1. Estimated male maturity ogives for 2005.

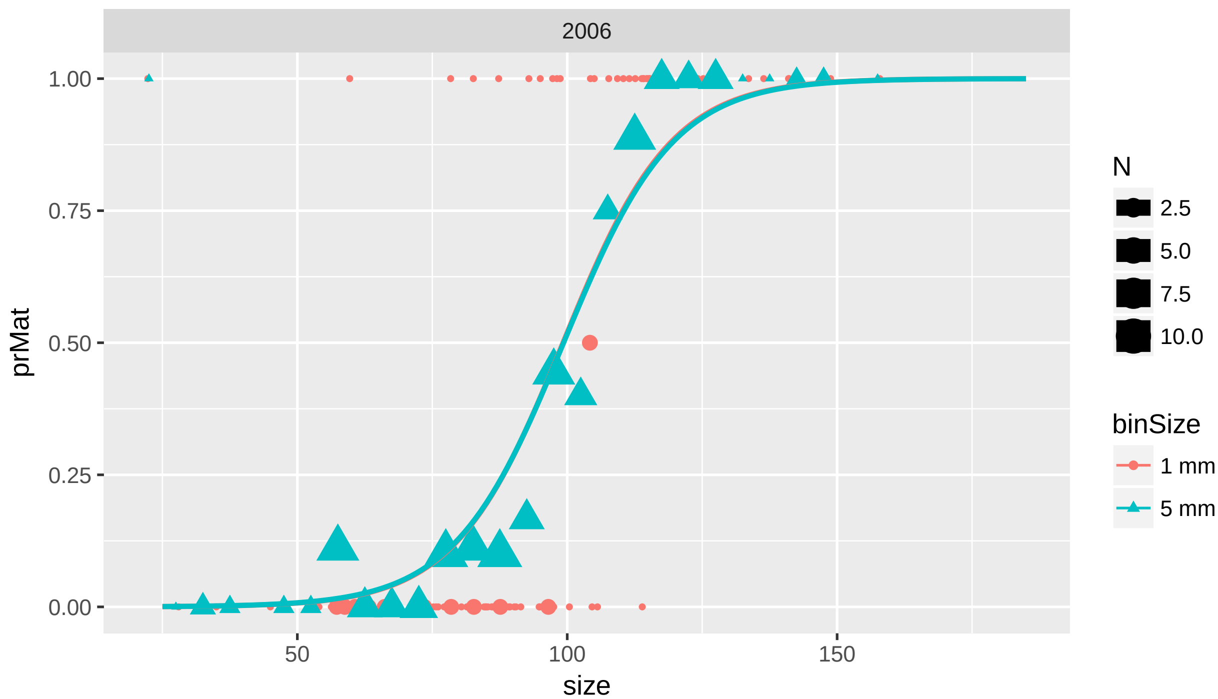

Figure 17: Figure 1. Estimated male maturity ogives for 2006.

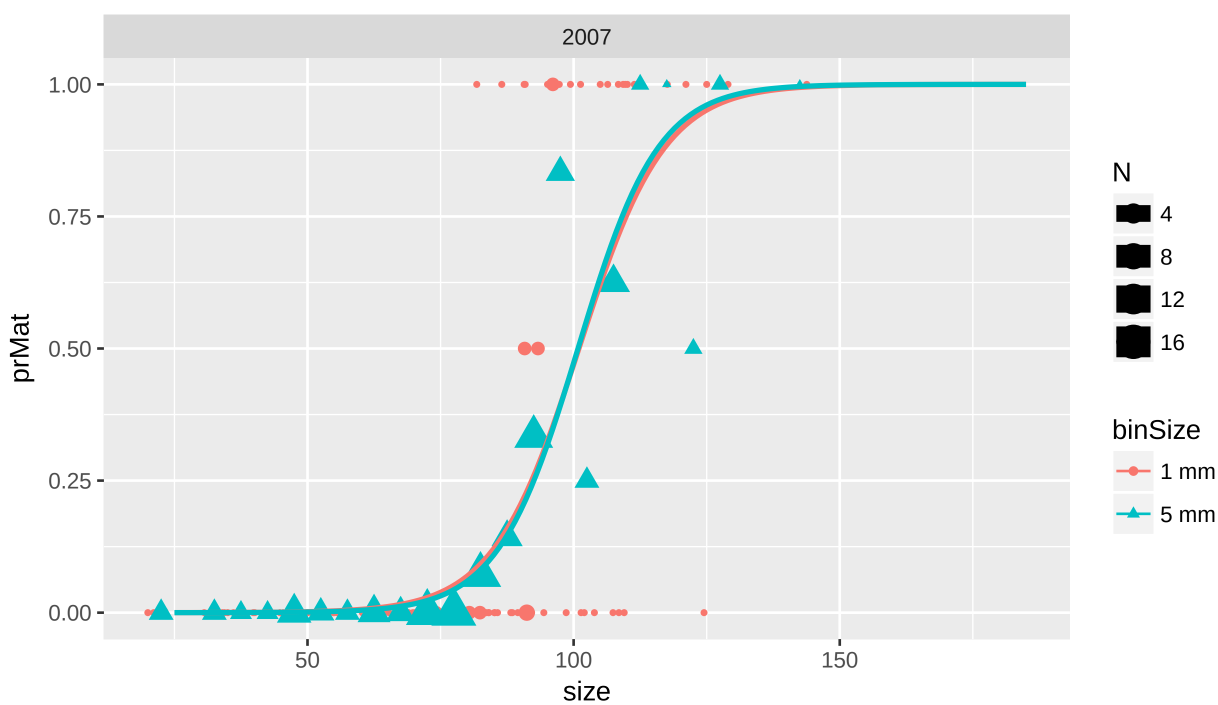

Figure 18: Figure 1. Estimated male maturity ogives for 2007.

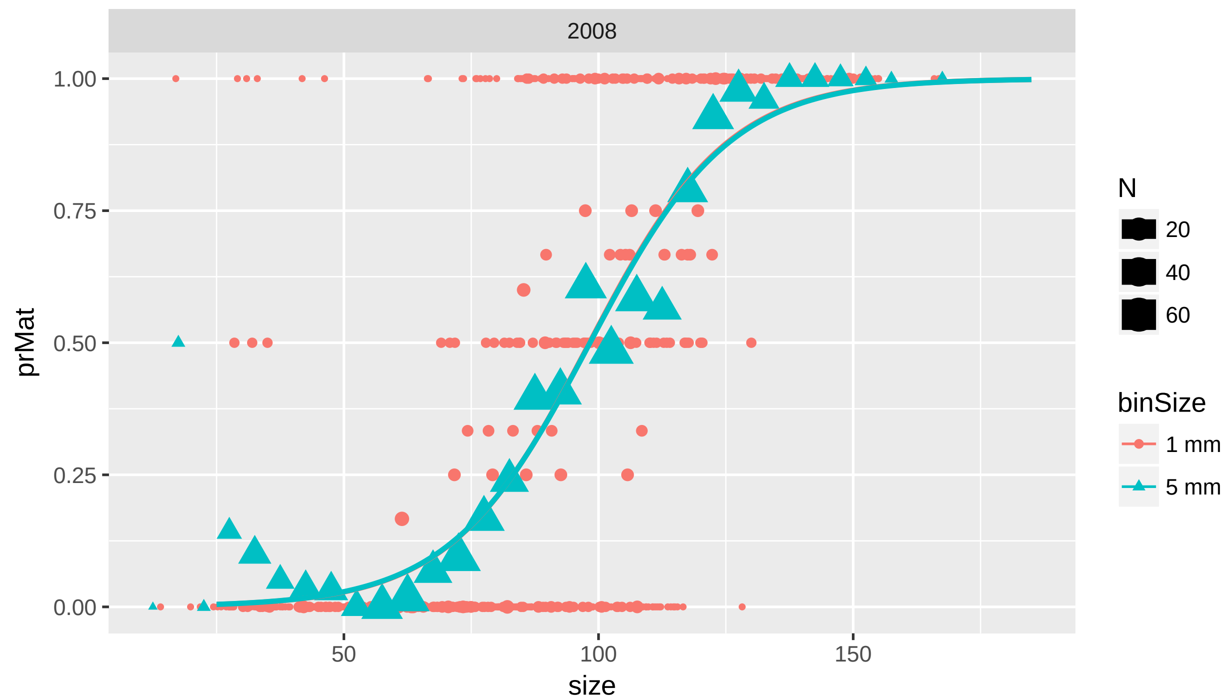

Figure 19: Figure 1. Estimated male maturity ogives for 2008.

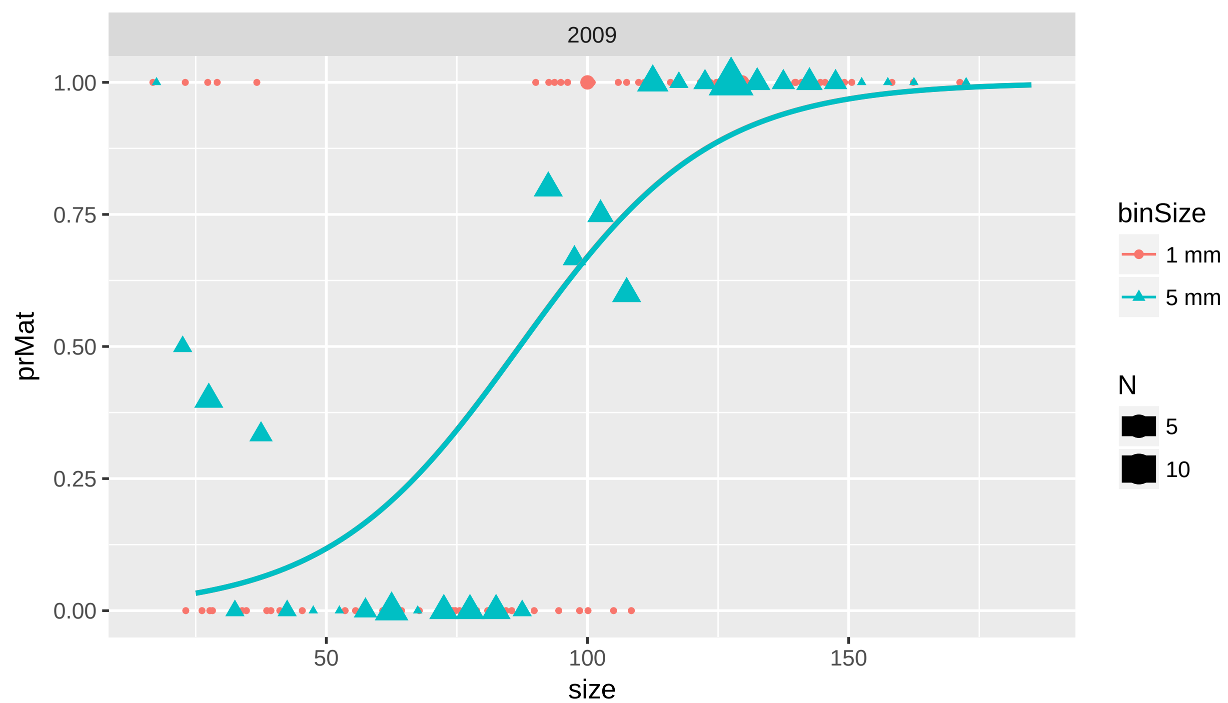

Figure 20: Figure 1. Estimated male maturity ogives for 2009.

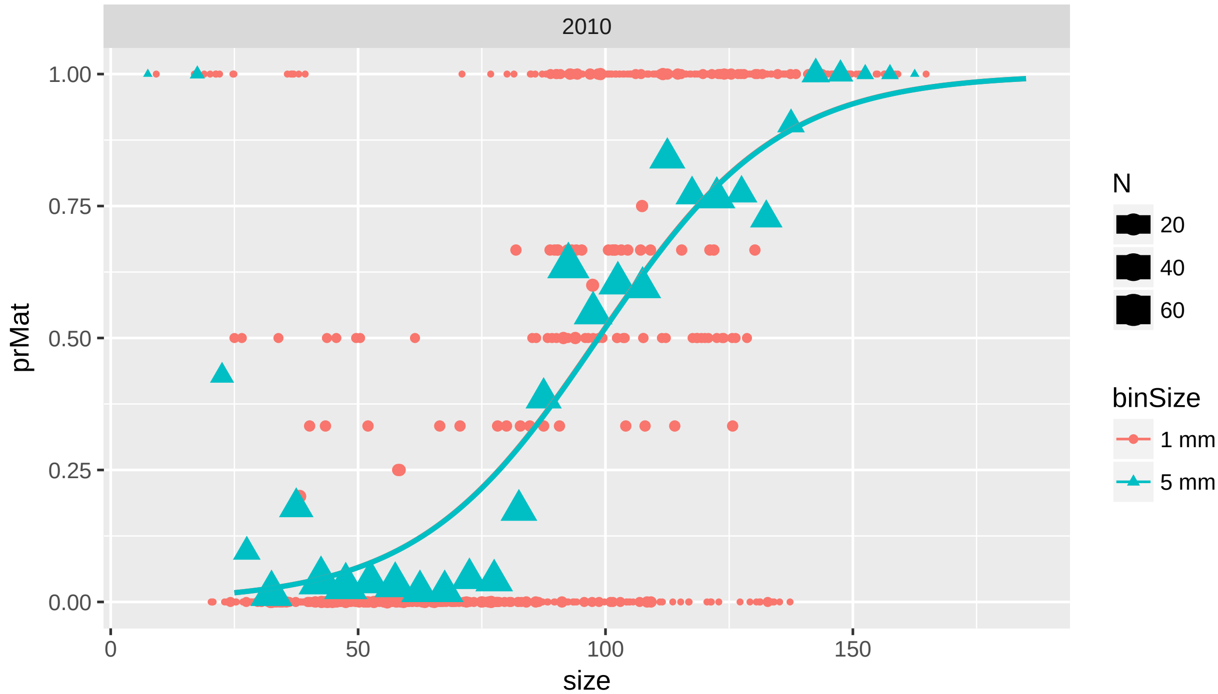

Figure 21: Figure 1. Estimated male maturity ogives for 2010.

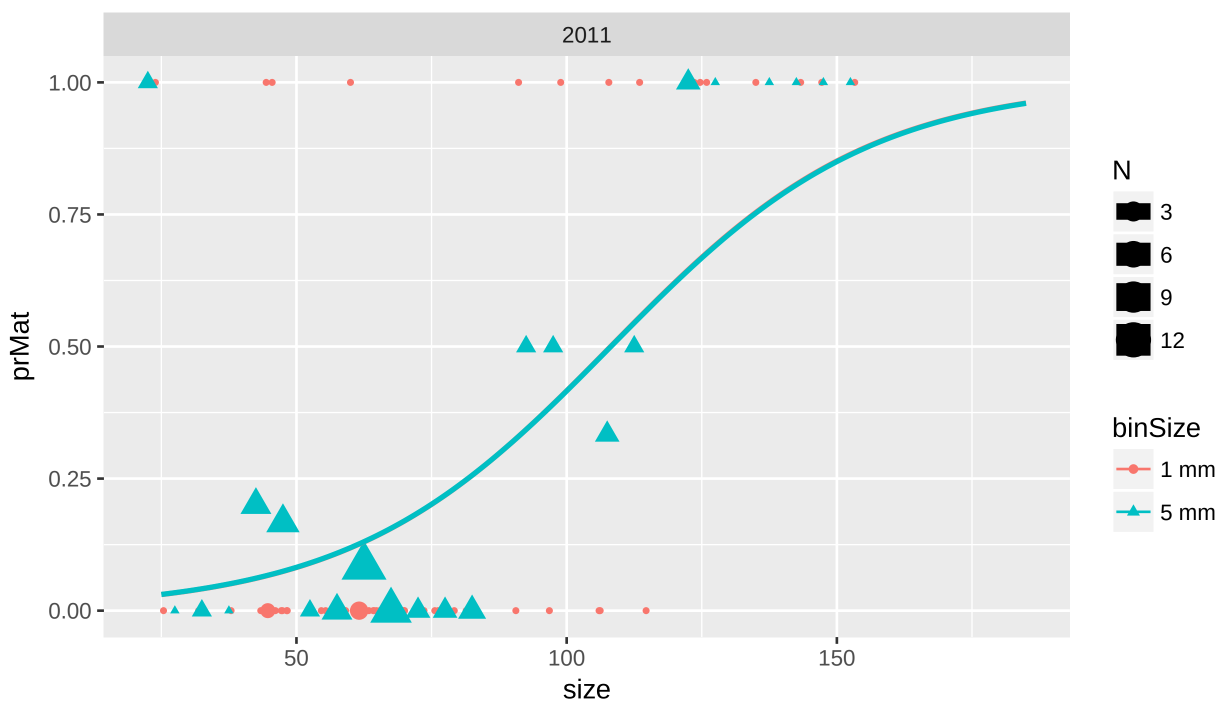

Figure 22: Figure 1. Estimated male maturity ogives for 2011.

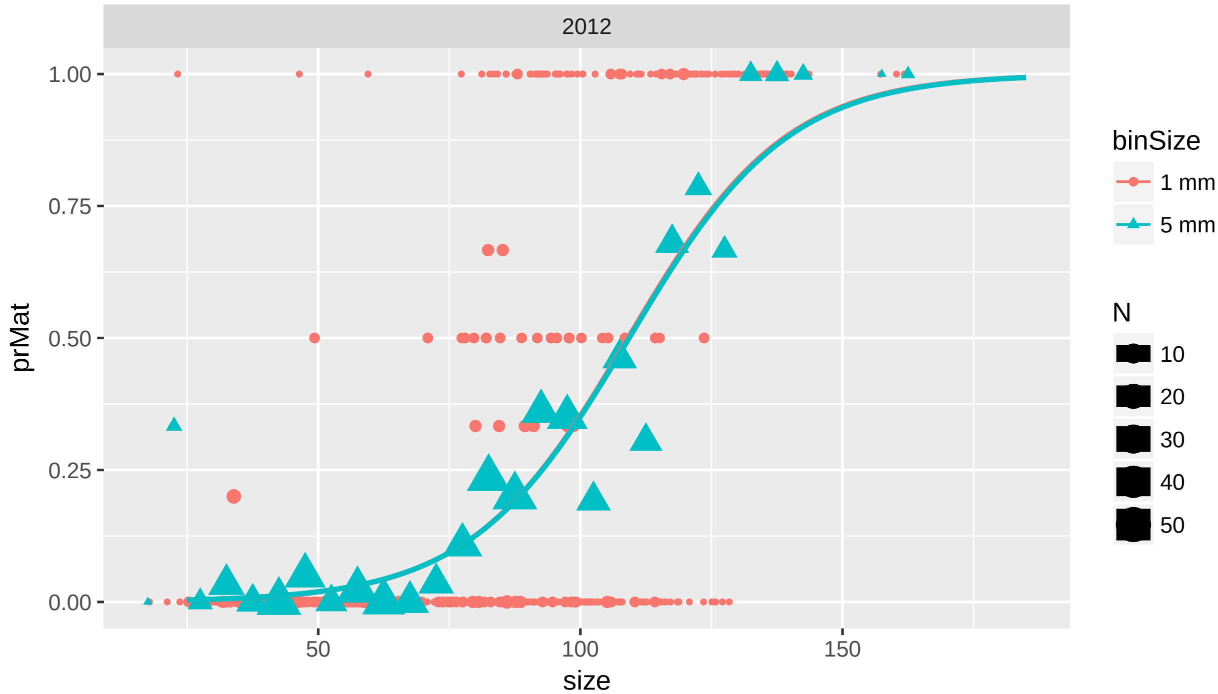

Figure 23: Figure 1. Estimated male maturity ogives for 2012.

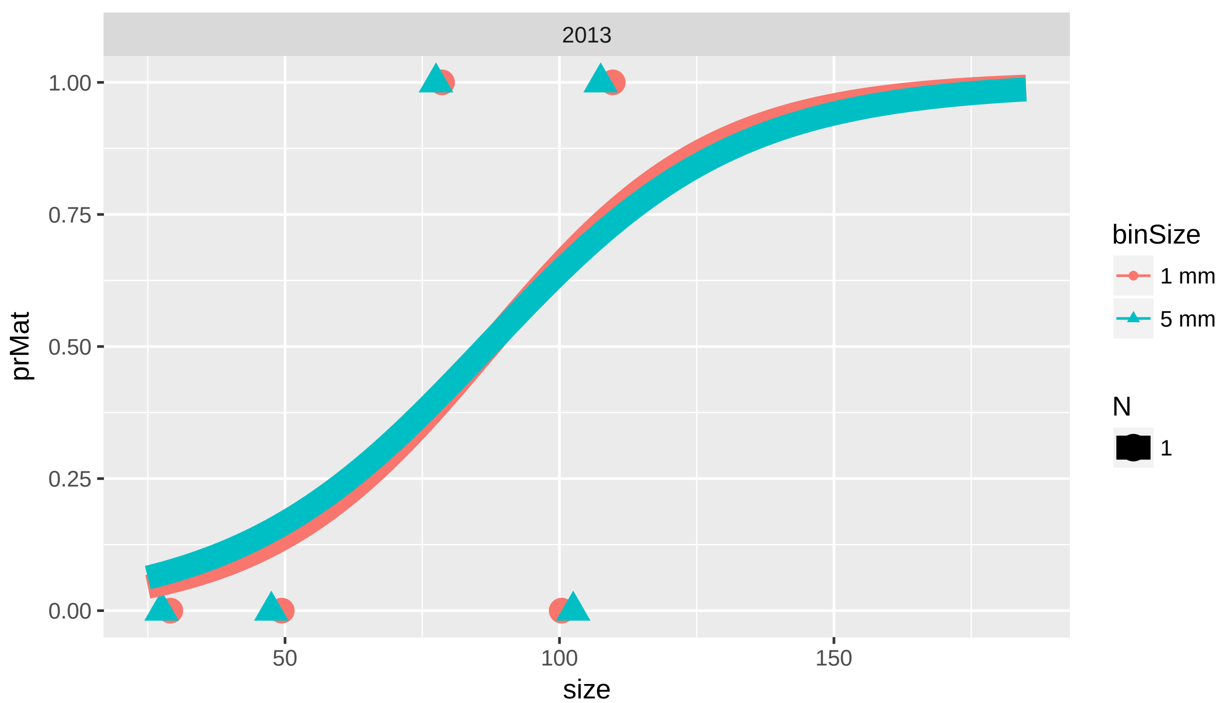

Figure 24: Figure 1. Estimated male maturity ogives for 2013.

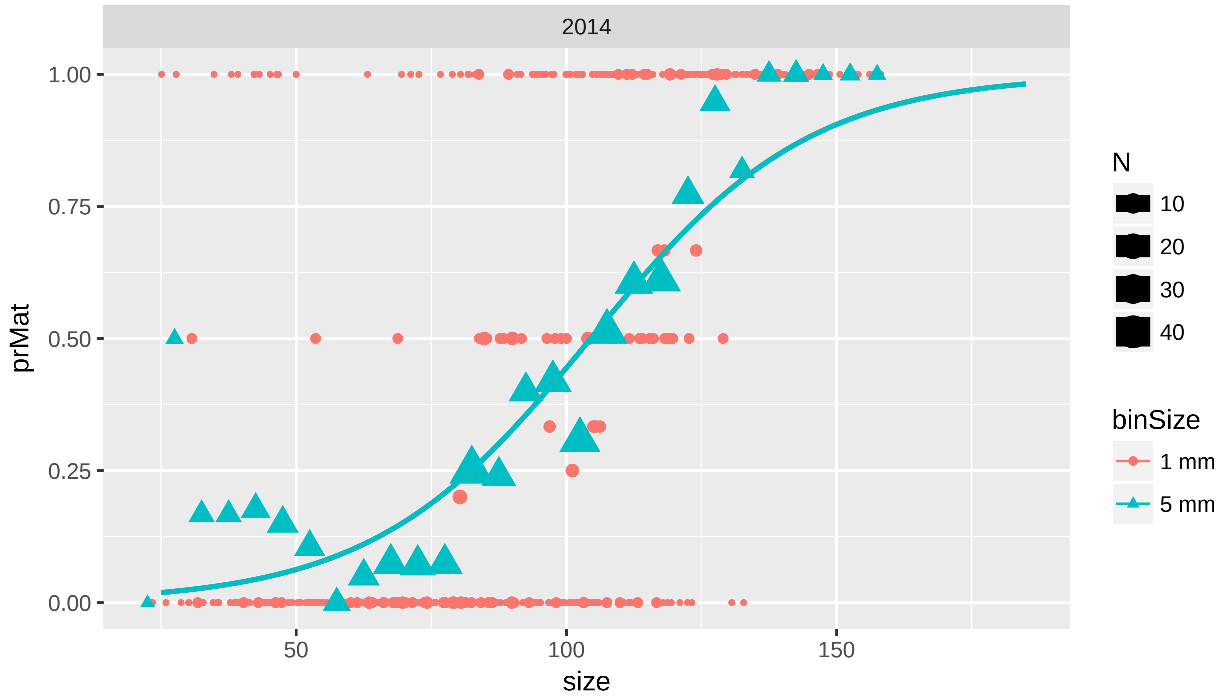

Figure 25: Figure 1. Estimated male maturity ogives for 2014.

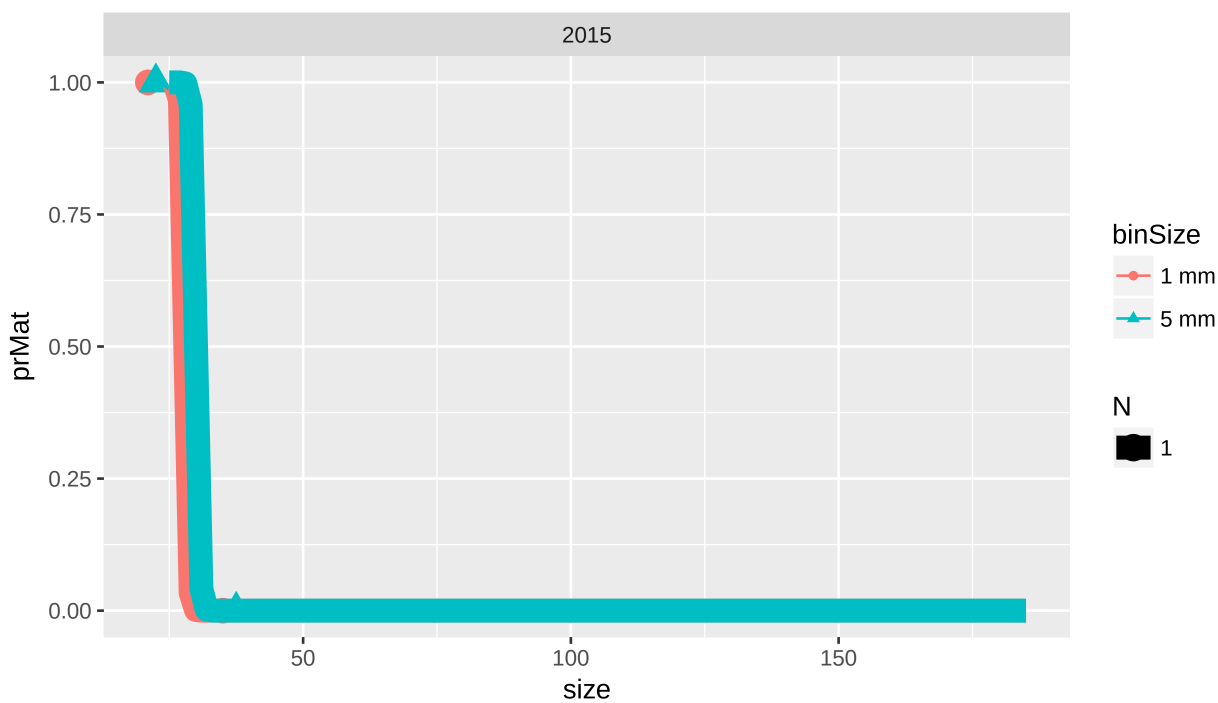

Figure 26: Figure 1. Estimated male maturity ogives for 2015.

Figure 27: Figure 1. Estimated male maturity ogives for 2016.

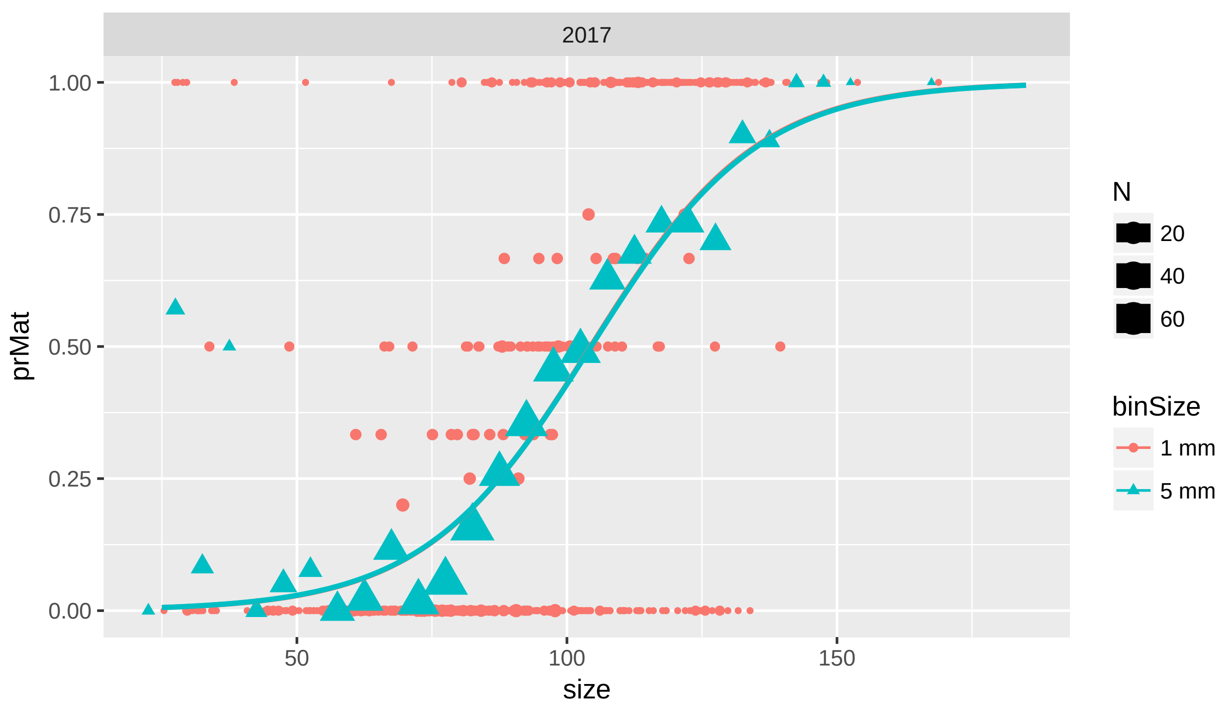

Figure 28: Figure 1. Estimated male maturity ogives for 2017.

Appendix H:
Tanner crab molt increment data

William T. Stockhausen

05 September, 2018

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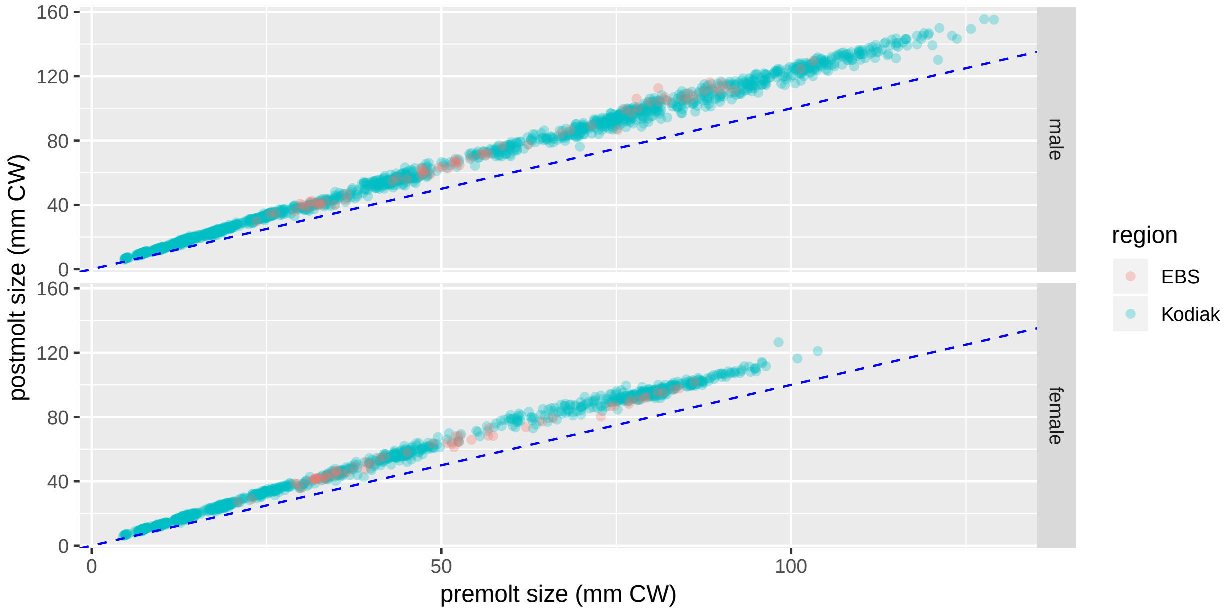

Figure 1: Tanner crab molt increment data, by region and sex.

Tanner crab growth data

Figure 1 shows molt increment data collected from crab near Kodiak Island in the Gulf of Alaska and in the eastern Bering Sea (EBS). THe Kodiak data was collected over a 20+ year period during opportunistic surveys and caged grow-out experiments. The EBS data was collected in 2014, 2015, and 2016 through cooperative research conducted by the AFSC/NMFS and the Bering Sea Research Foundation (BSFRF).

Mean growth

Sex-specific parameters for post-molt size as a power function of pre-molt size ($z_{post} = e^a \cdot {z_{pre}}^b$) were estimated in R using the glm function from the EBS data on the log-scale using the regression formula $ln[z_{post}] = a + b \cdot ln[z_{pre}]$. The resulting estimates

Table 1: Estimated growth parameters for the EBS molt increment data with post-molt size as a power lae of pre-molt size..

parameter	males	females
a	0.2708370	0.6106653
b	0.9922623	0.8975509

Sex-specific parameters from the 2016 assessment model reflecting estimated mean growth are listed in Table 2, where $z_{post} = e^a \cdot {z_{pre}}^b$.

Table 2: 2016 assessment model mean growth parameters.

parameter	males	females
a	0.4220295	0.6999999
b	0.9721004	0.8850577

Growth parameters estimated from the Kodiak data, used as prior mean values for parameters in the assessment model are listed in Table 3.

Table 3: Growth parameters based on Kodiak data, used as prior means for parameters in the assessment model.

parameter	males	females
a	0.437941	0.5656024
b	0.948700	0.9132661

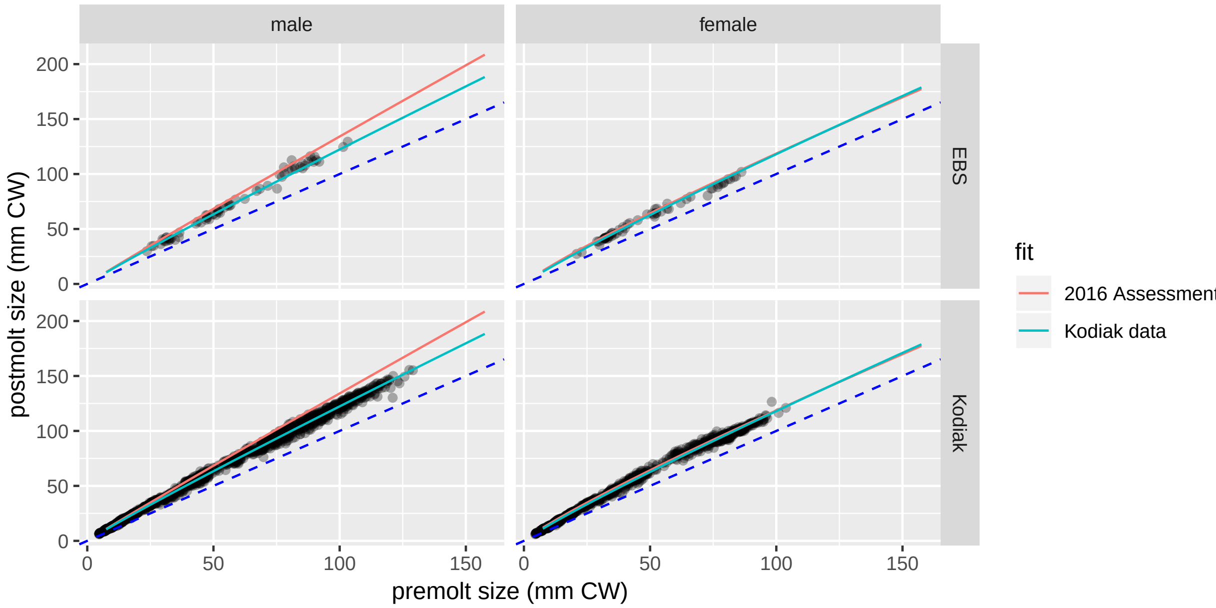

Figure 2: Tanner crab growth data, by region and sex. Colored lines indicate mean growth, by sex, as determined by the assessment model.

Comparison with the 2016 assessment model

The 2016 assessment model estimated mean growth parameters from size composition data. Priors were placed on the growth parameters based on a previous analysis by Rugolo and Turnock of molt increment data from Kodiak Island in the Gulf of Alaska. The estimated mean growth curves from the assessment over-predict post-molt size at larger pre-molt sizes for both males and females. The molt increment data from the EBS does not appear to be radically different from that collected at Kodiak. In the current assessment, only the EBS data will be included to fit.

Appendix I1:
Model Comparisons: Aggregated Catch Data
for the "18" Scenarios

William Stockhausen

31 August, 2018

Model fits to aggregated catch data

Fits to the aggregated catch data available to the model(s) are presented in this section. 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.

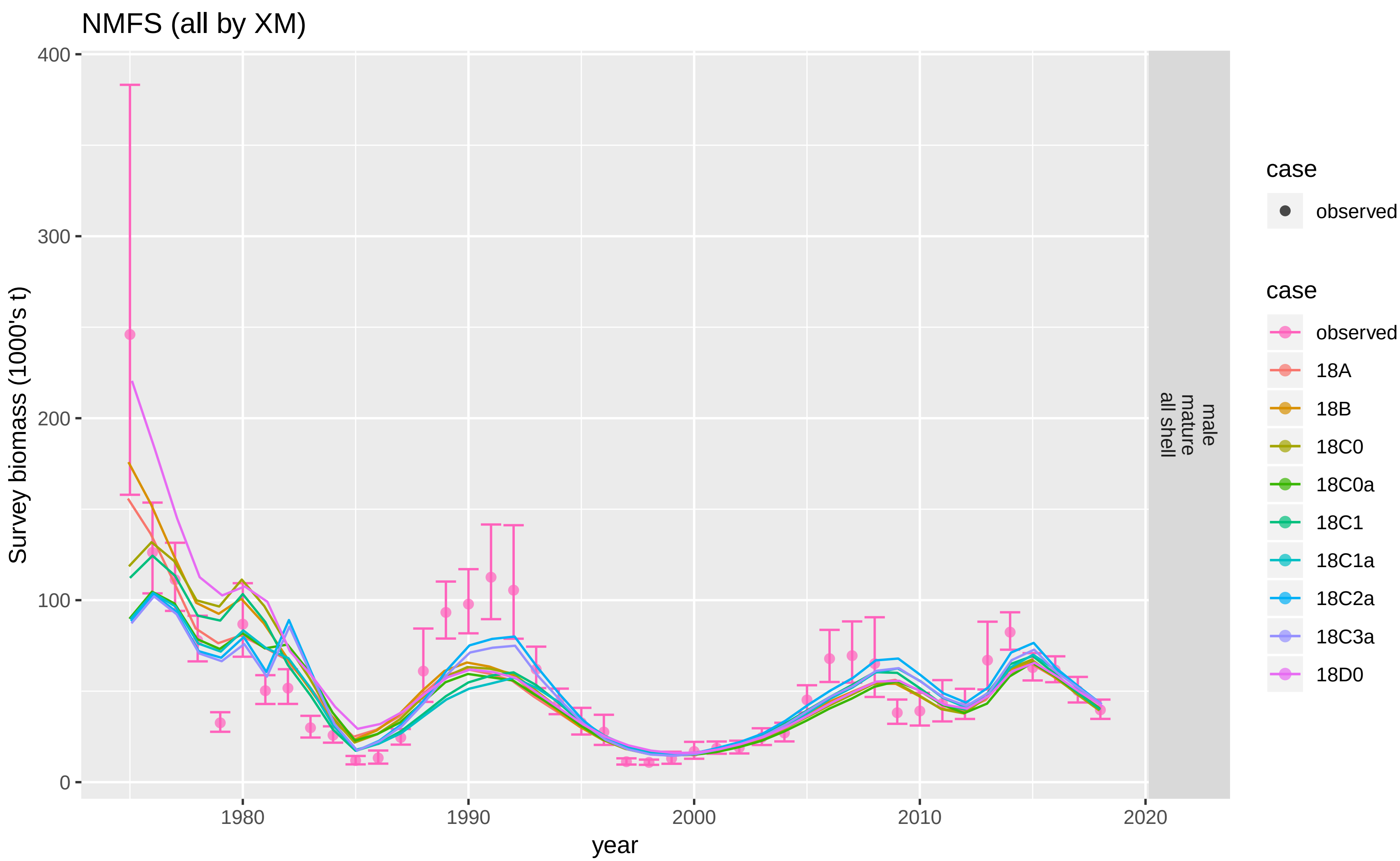

Figure 1: Comparison of observed and predicted male survey biomass for NMFS (all by XM). Observed time period.

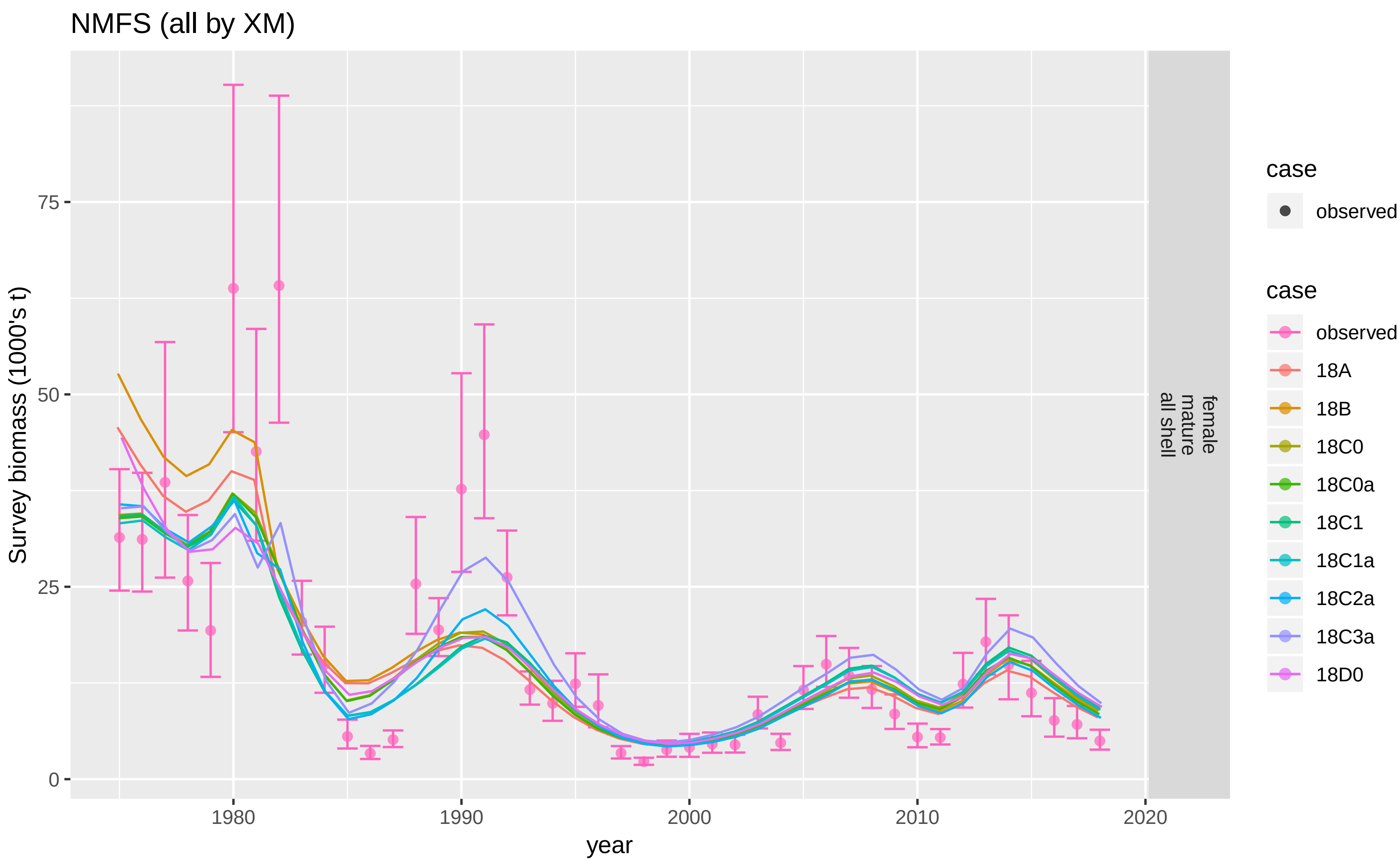

Figure 2: Comparison of observed and predicted female survey biomass for NMFS (all by XM). Observed time period.

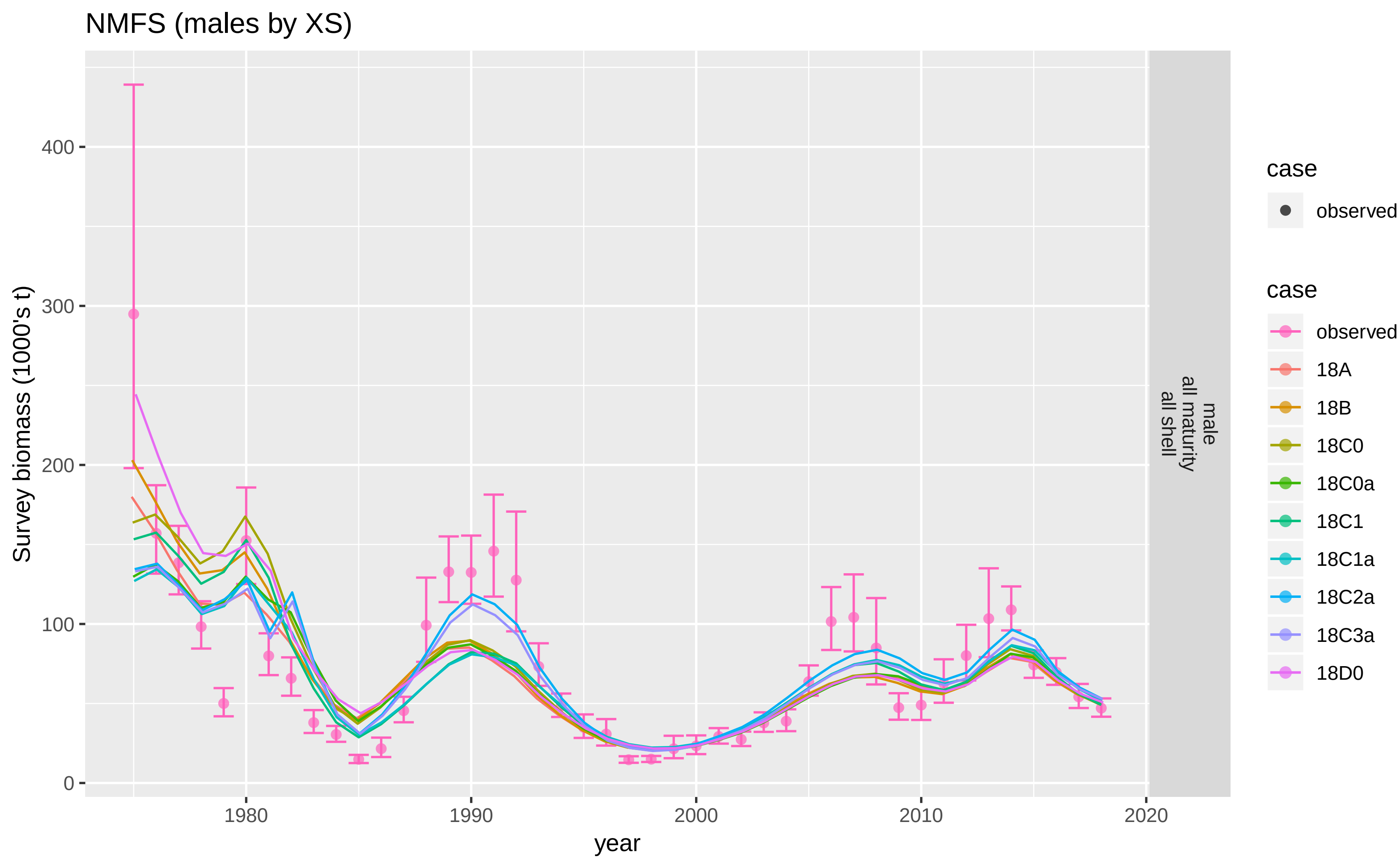

Figure 3: Comparison of observed and predicted male survey biomass for NMFS (males by XS). Observed time period.

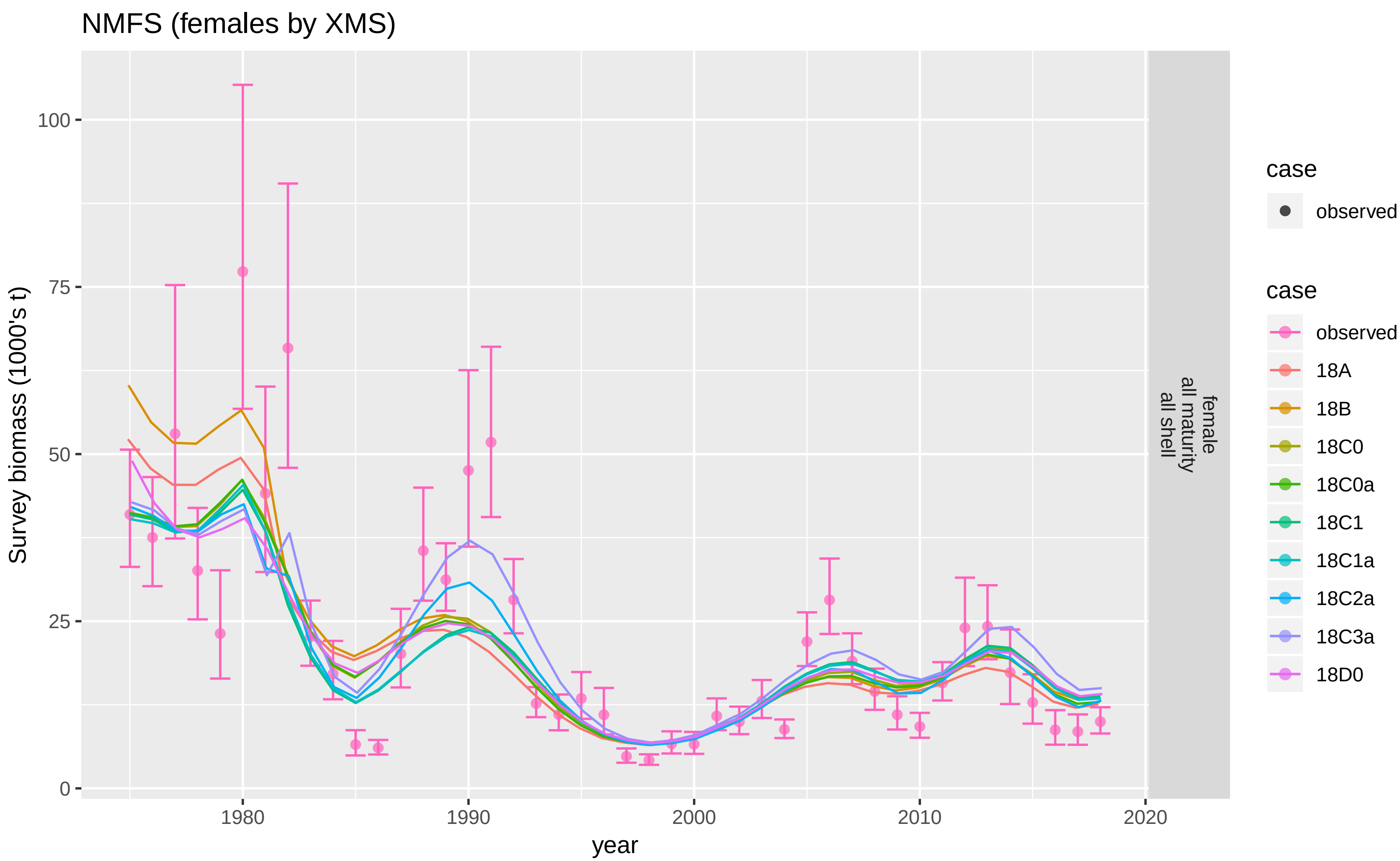

Figure 4: Comparison of observed and predicted female survey biomass for NMFS (females by XMS). Observed time period.

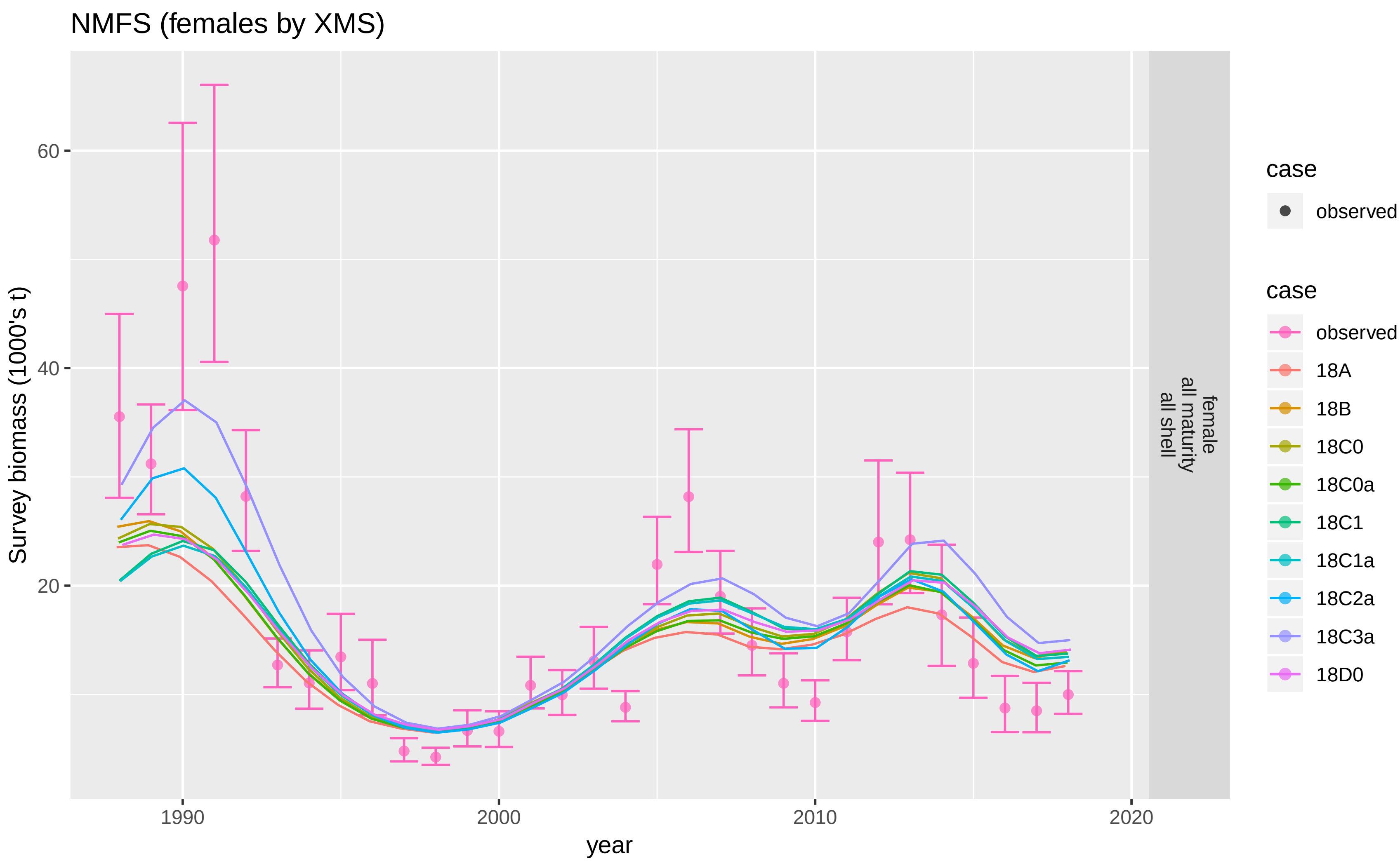

Figure 5: Comparison of observed and predicted female survey biomass for NMFS (females by XMS). Recent time period.

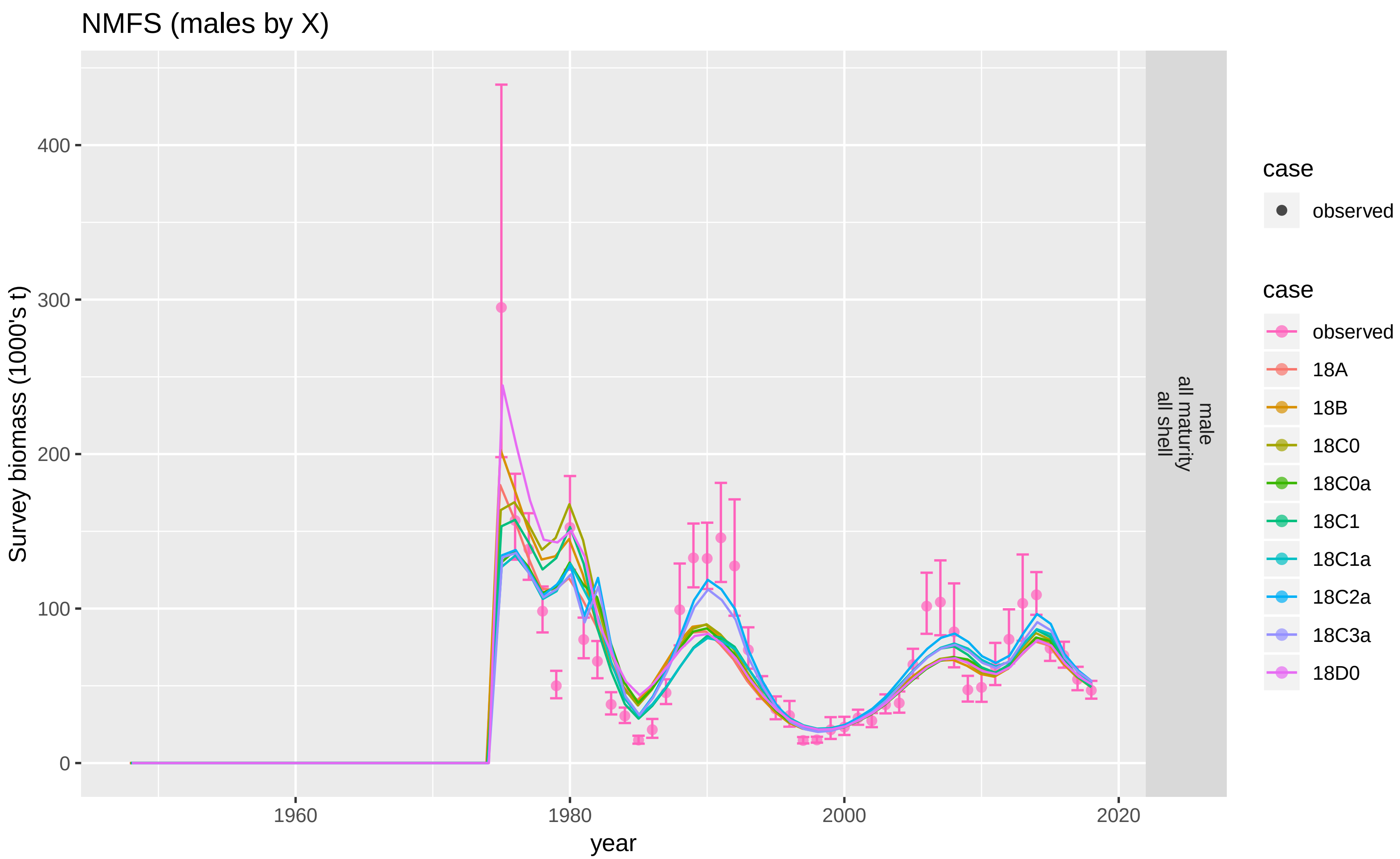

Figure 6: Comparison of observed and predicted male survey biomass for NMFS (males by X).

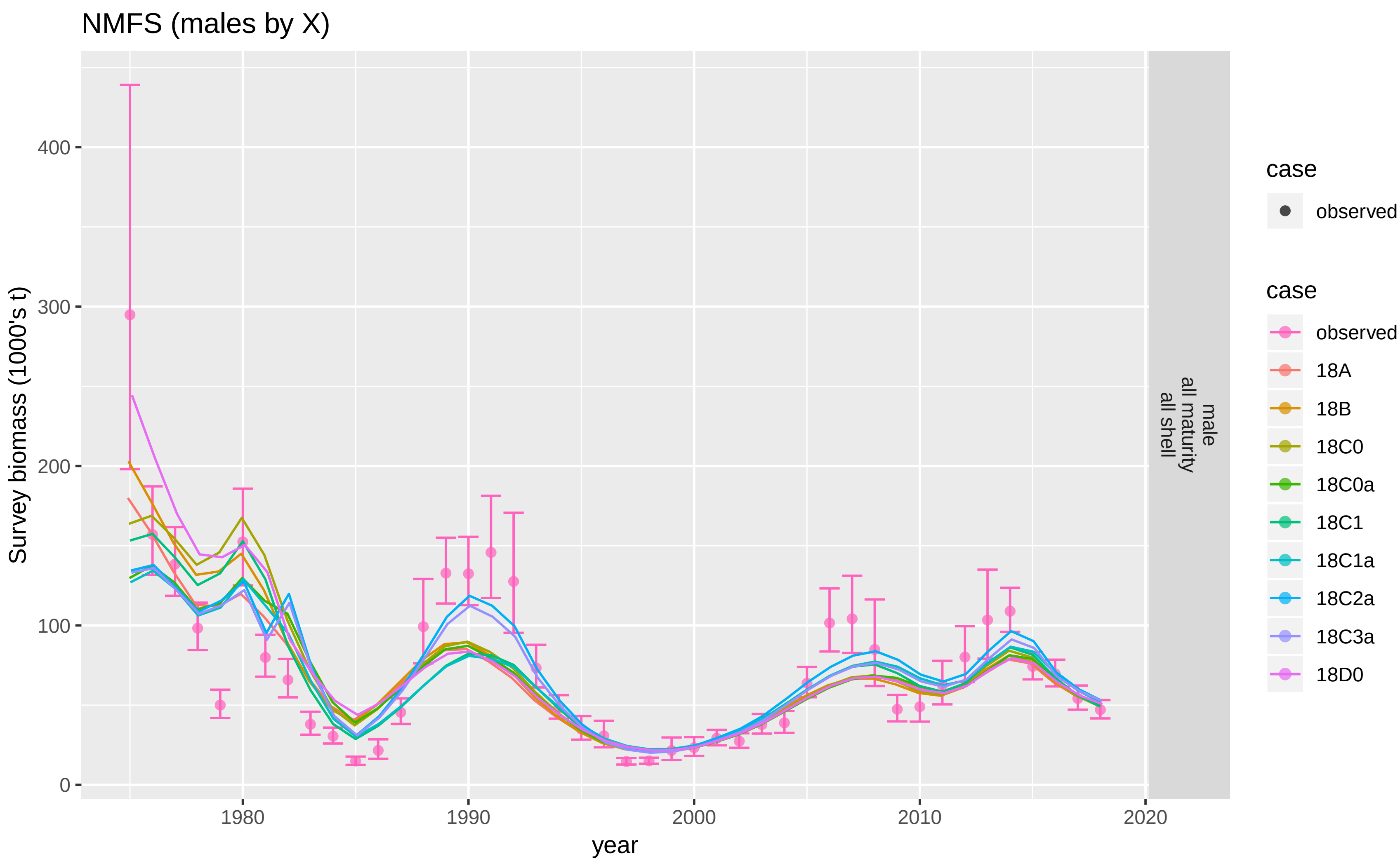

Figure 7: Comparison of observed and predicted male survey biomass for NMFS (males by X). Observed time period.

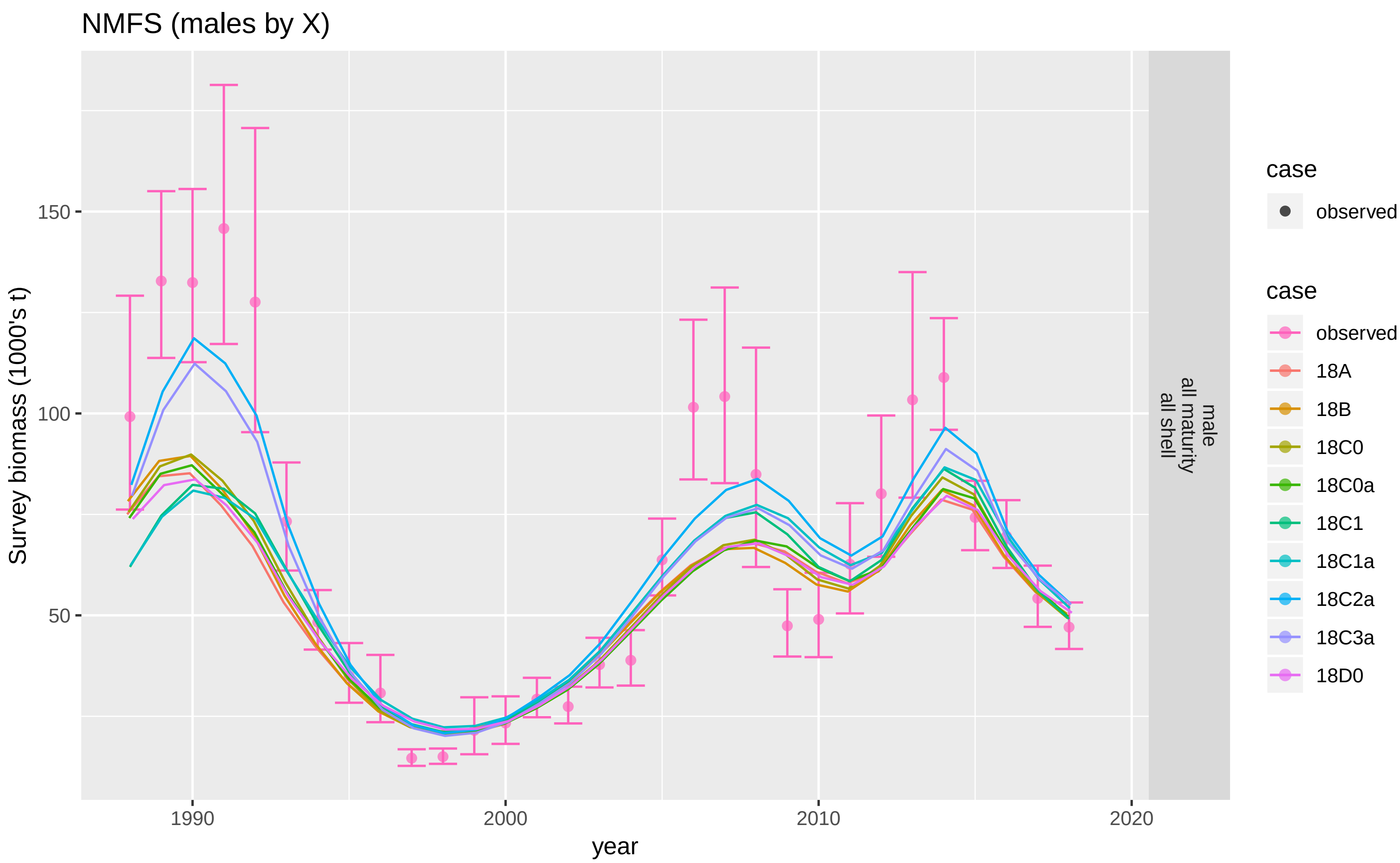

Figure 8: Comparison of observed and predicted male survey biomass for NMFS (males by X). Recent time period.

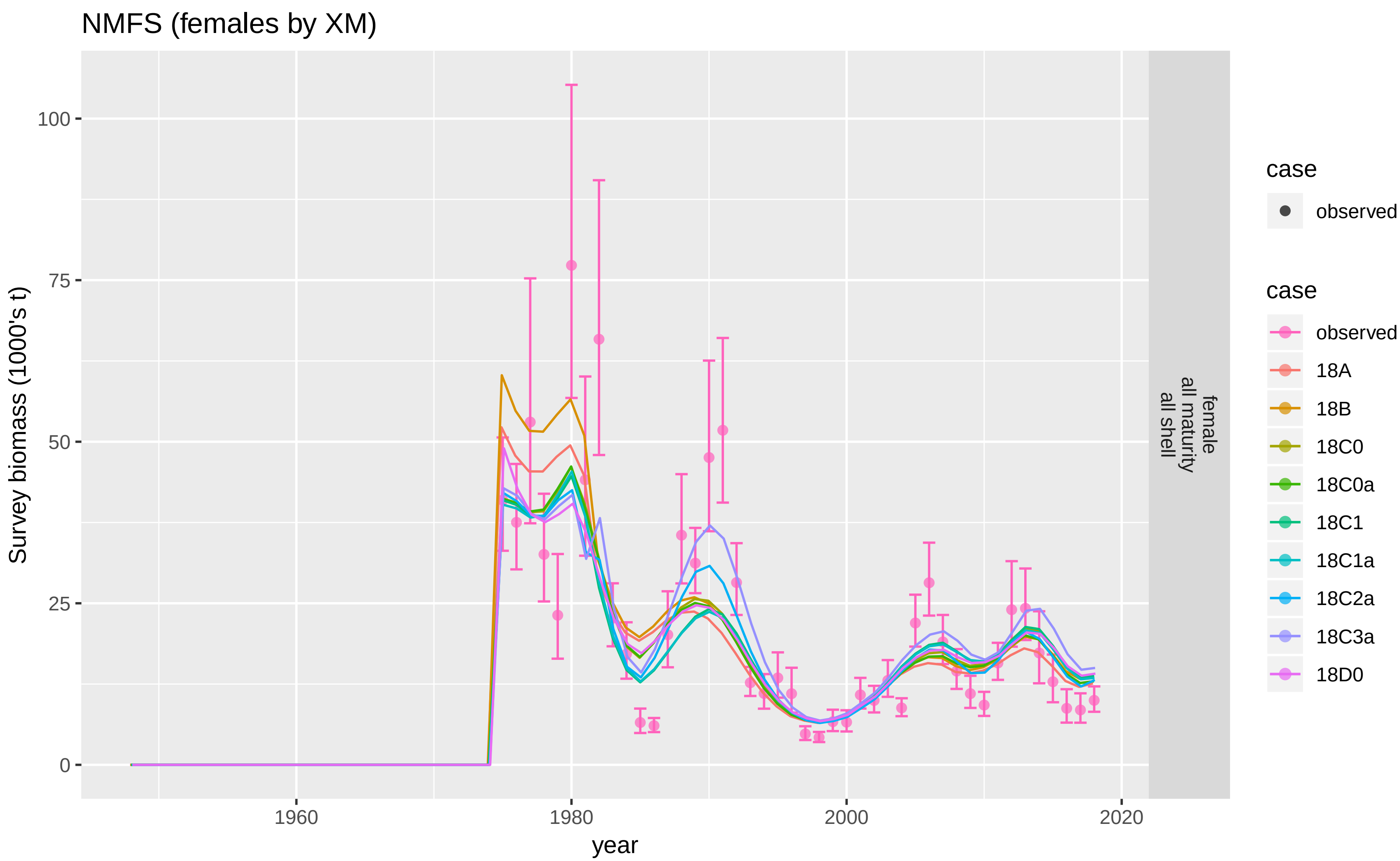

Figure 9: Comparison of observed and predicted female survey biomass for NMFS (females by XM).

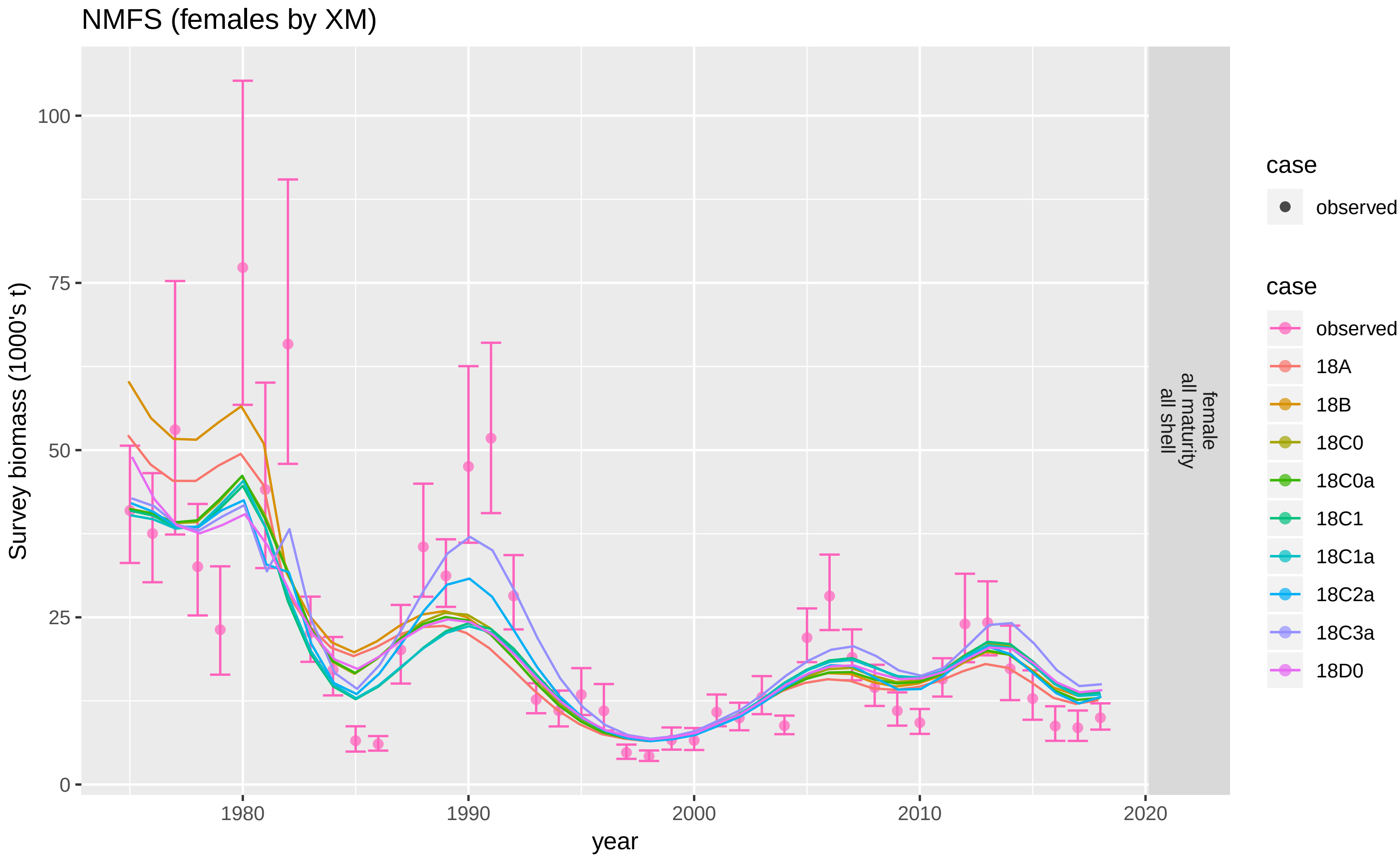

Figure 10: Comparison of observed and predicted female survey biomass for NMFS (females by XM). Observed time period.

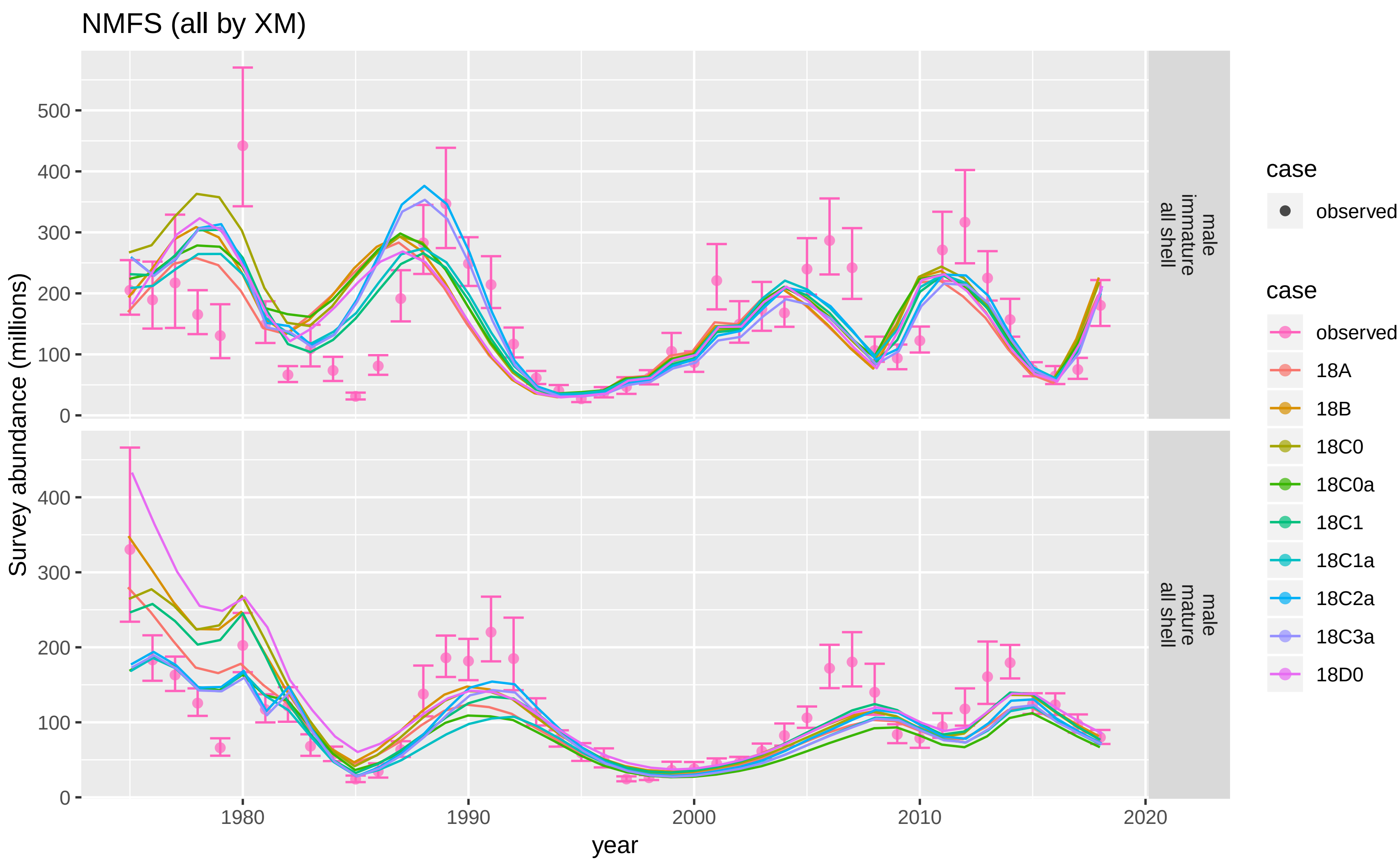

Figure 11: Comparison of observed and predicted male survey abundance for NMFS (all by XM). Observed time period.

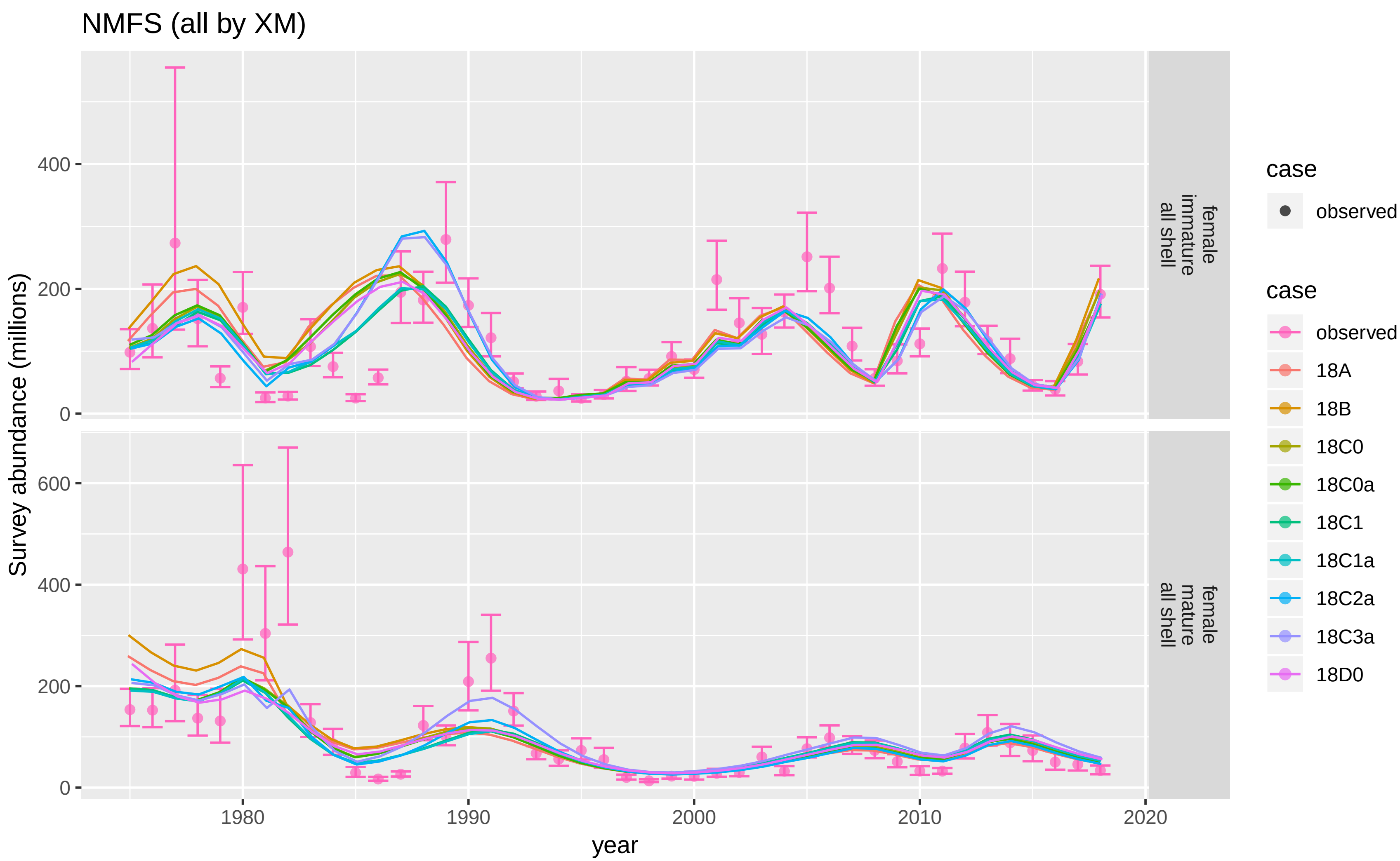

Figure 12: Comparison of observed and predicted female survey abundance for NMFS (all by XM). Observed time period.

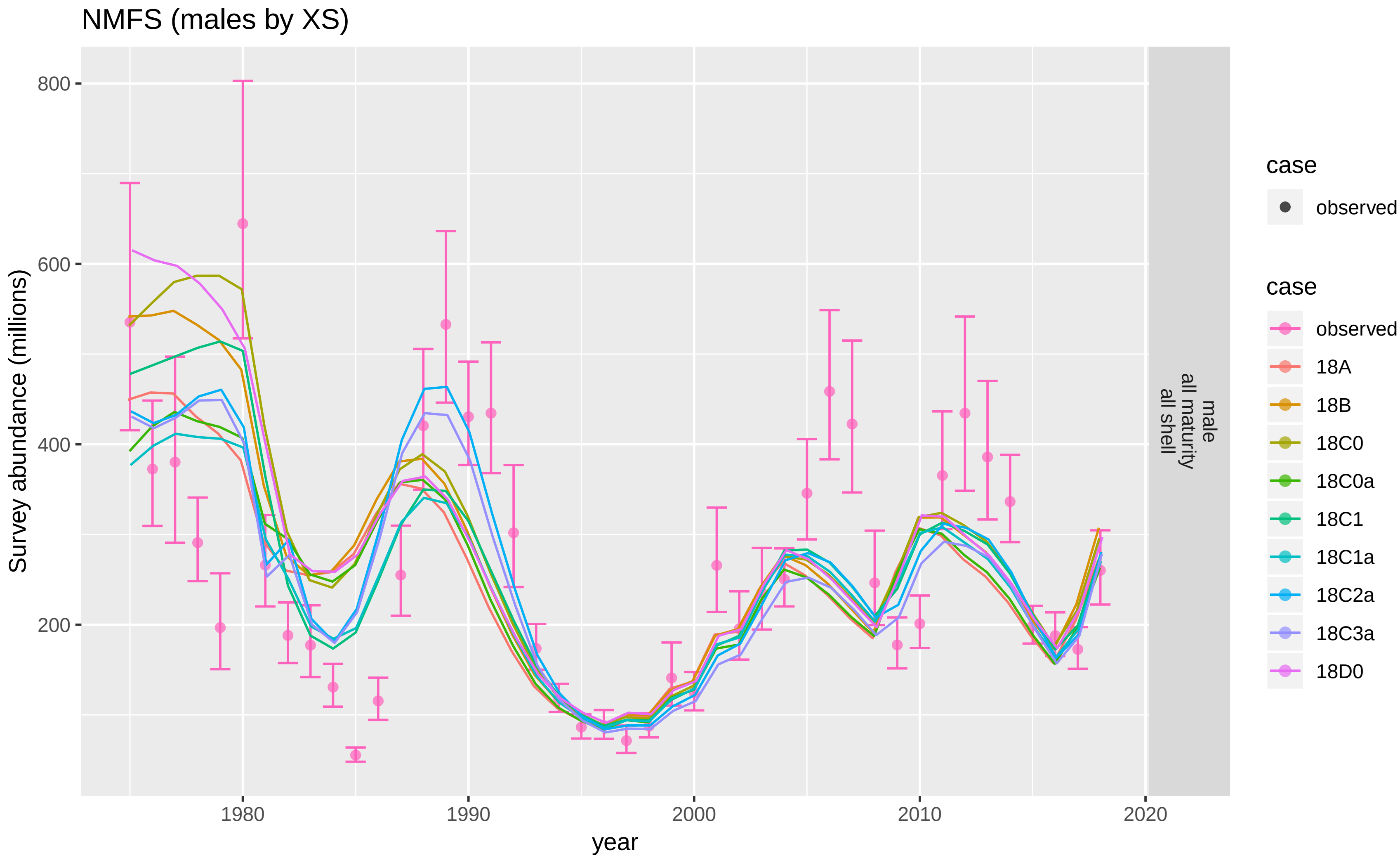

Figure 13: Comparison of observed and predicted male survey abundance for NMFS (males by XS). Observed time period.

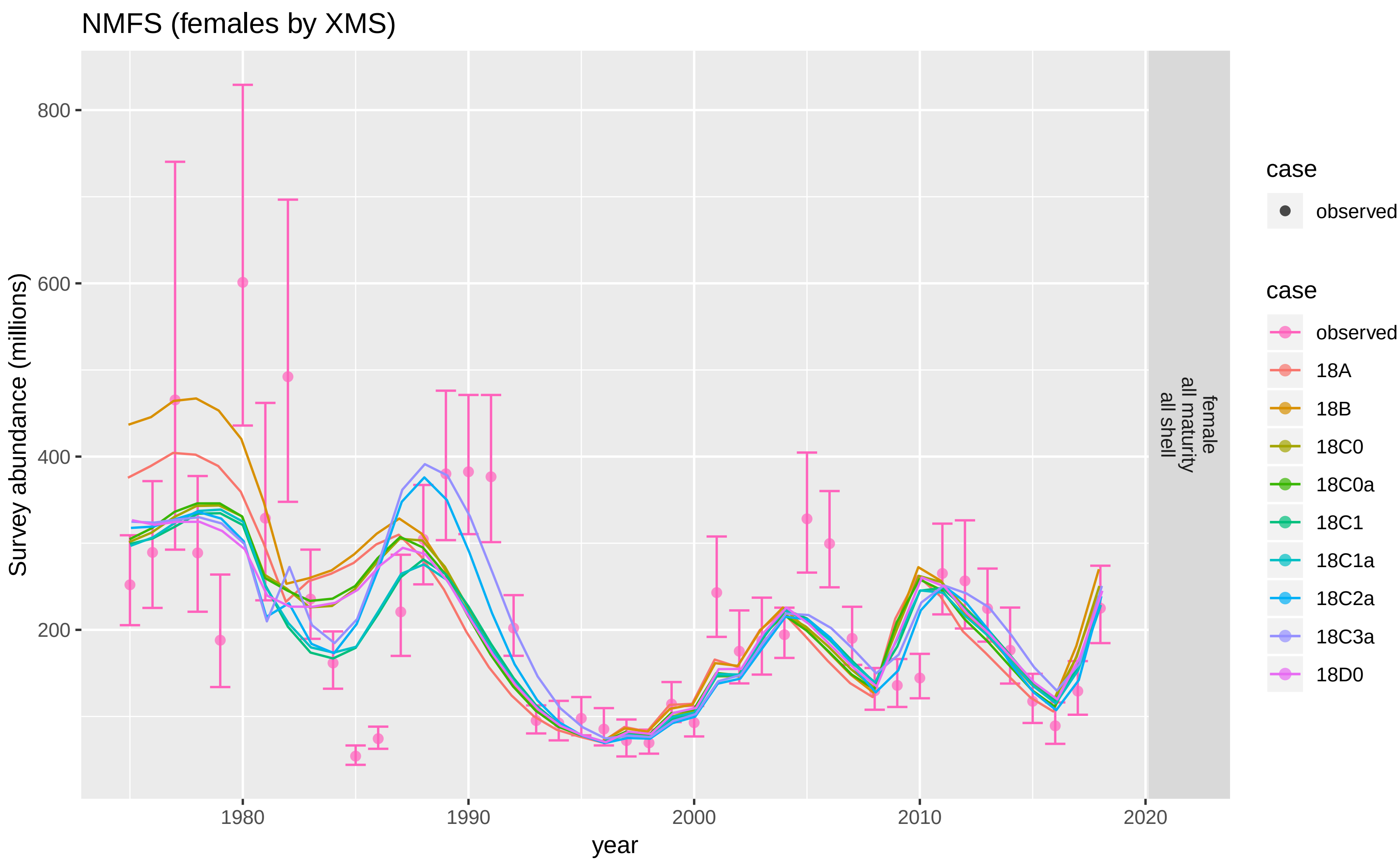

Figure 14: Comparison of observed and predicted female survey abundance for NMFS (females by XMS). Observed time period.

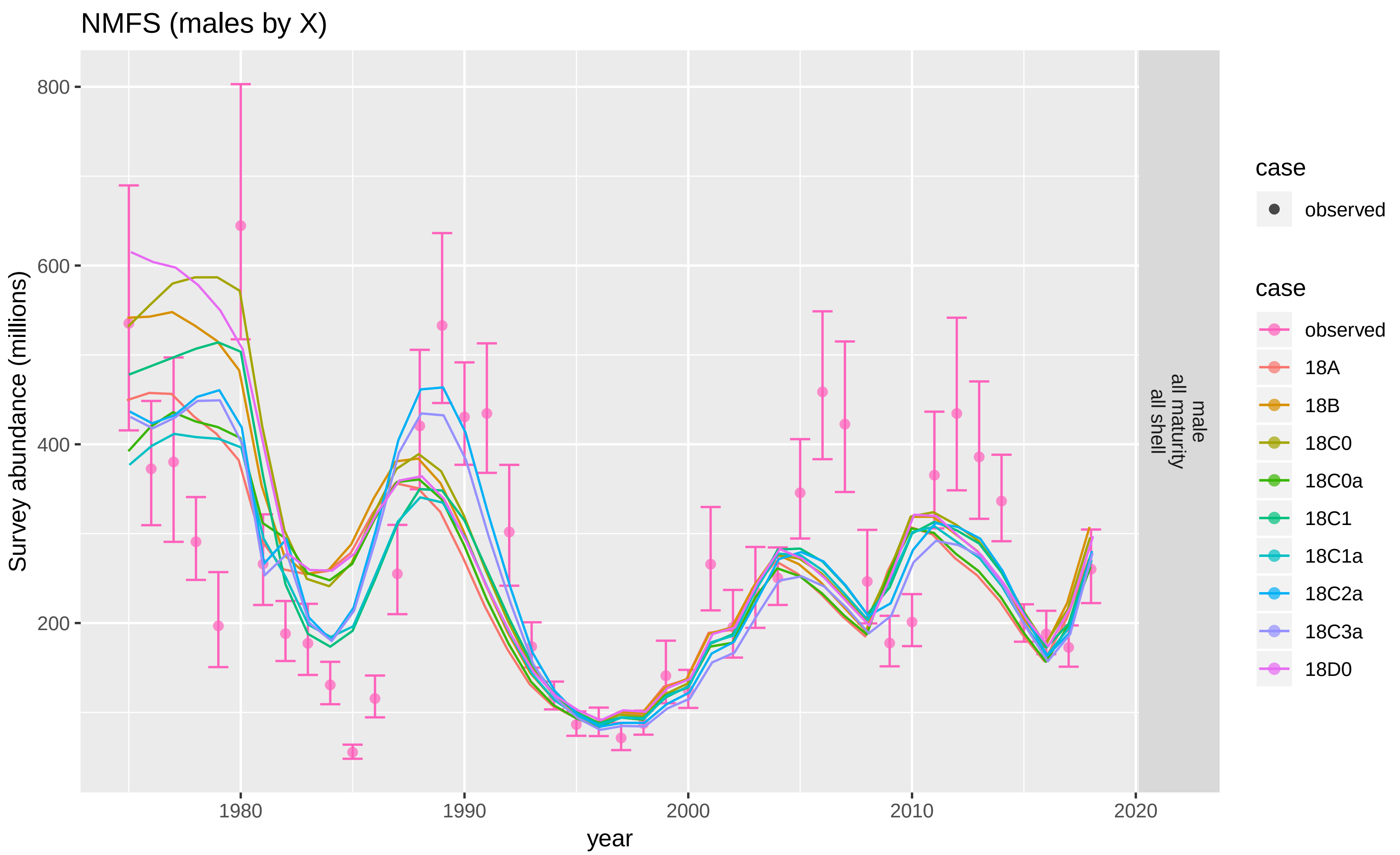

Figure 15: Comparison of observed and predicted male survey abundance for NMFS (males by X). Observed time period.

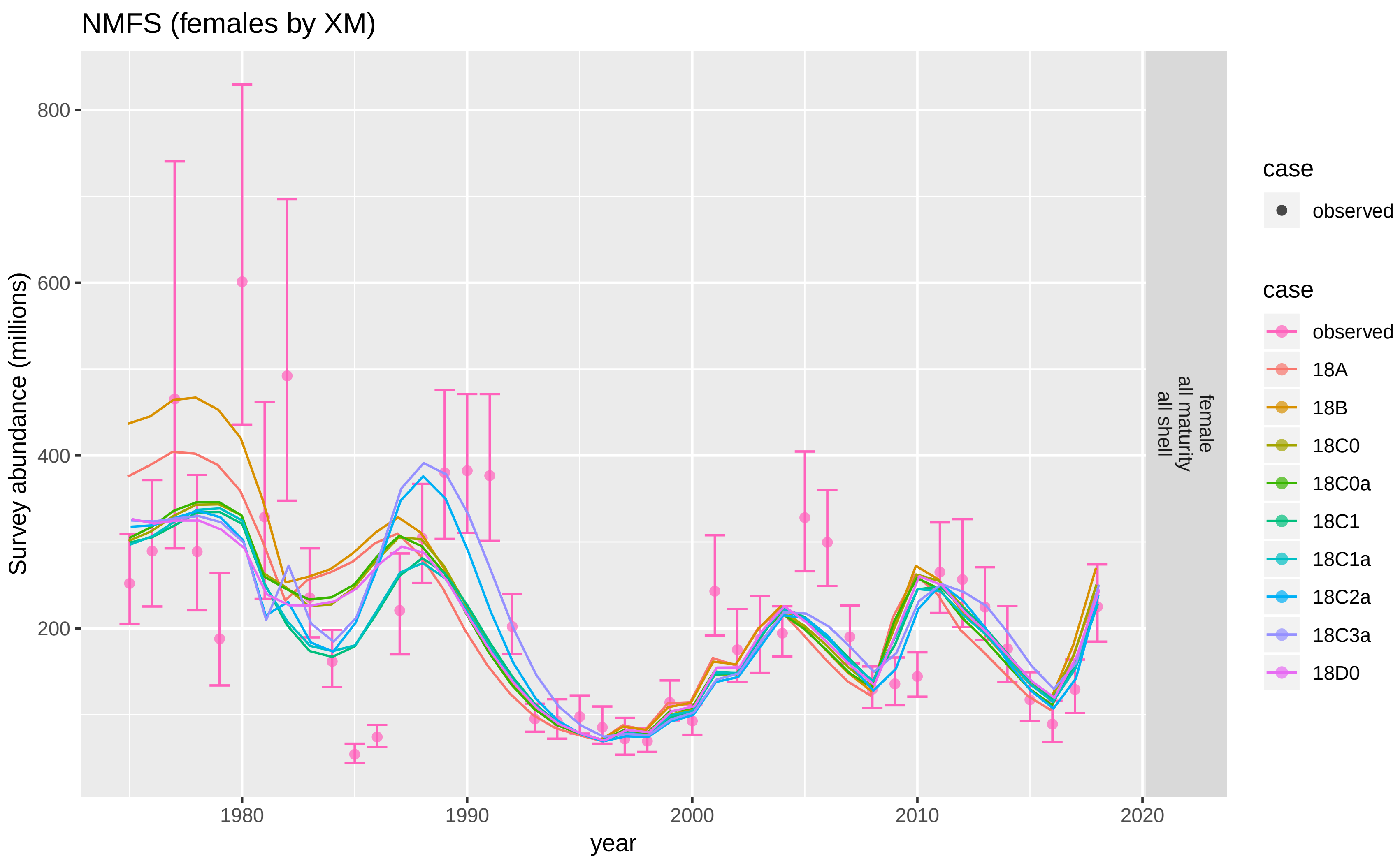

Figure 16: Comparison of observed and predicted female survey abundance for NMFS (females by XM). Observed time period.

Fishery retained catch biomass

Fits

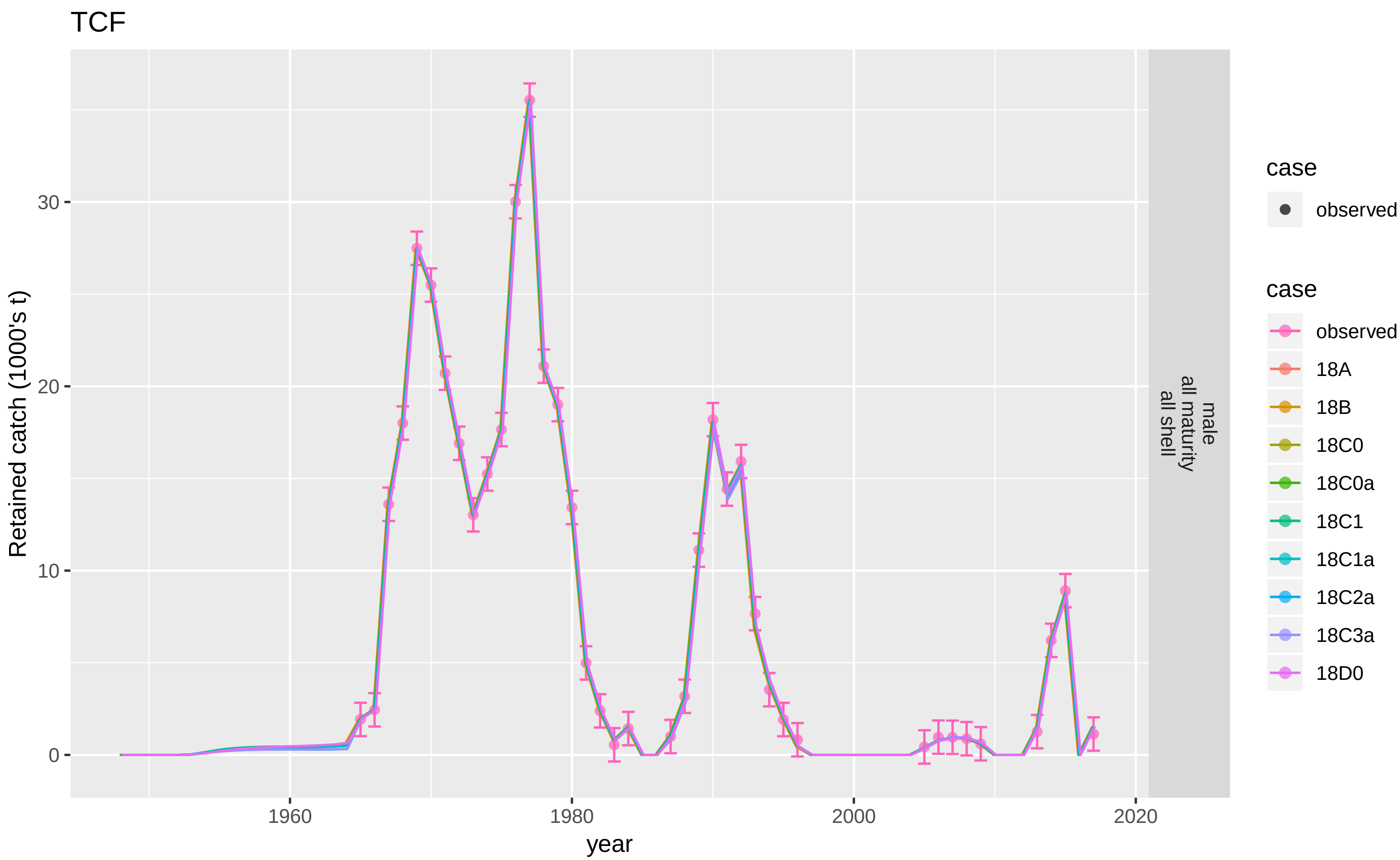

Figure 17: Comparison of observed and predicted male retained catch biomass for TCF.

Fishery retained catch abundance

Fits

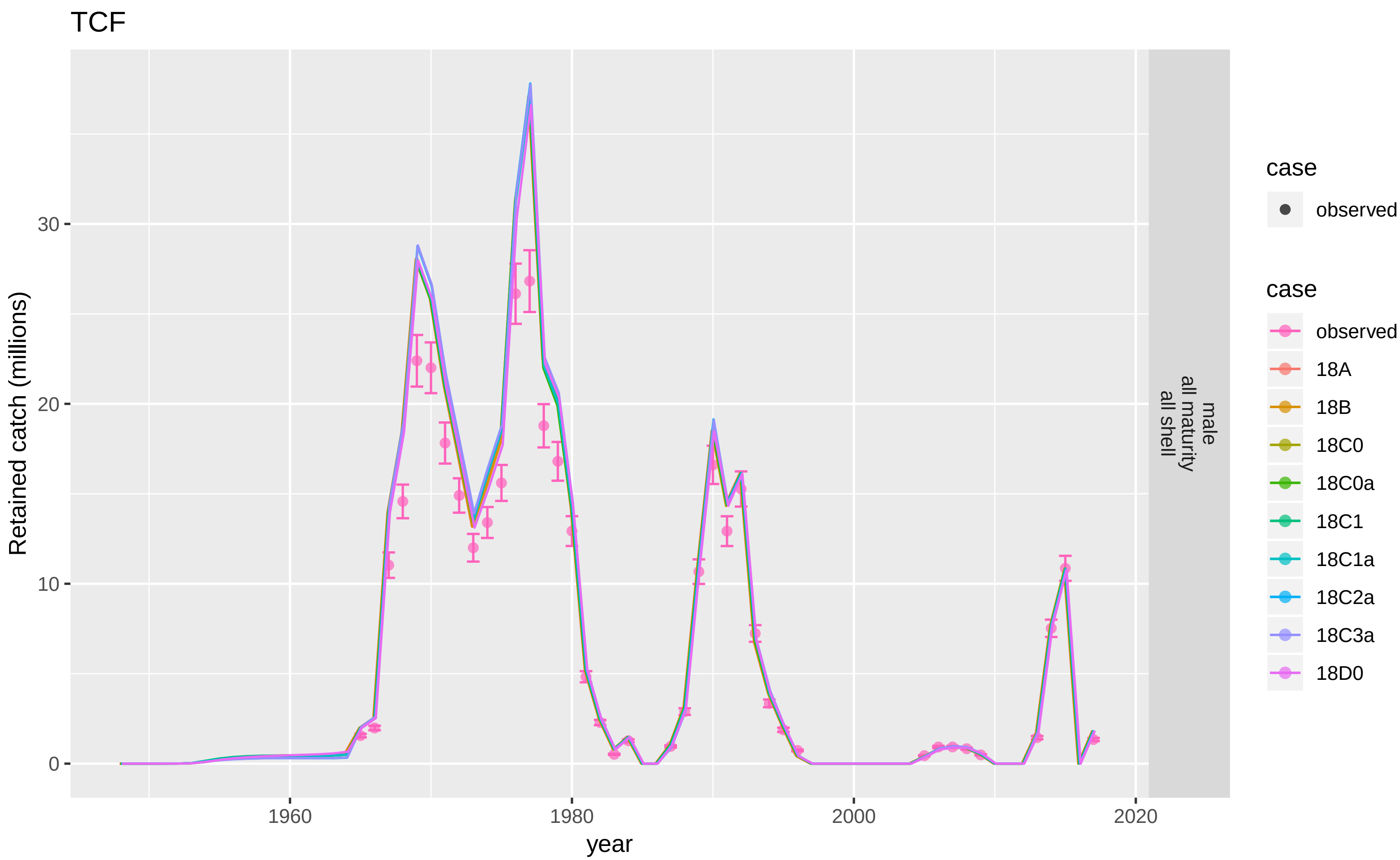

Figure 18: Comparison of observed and predicted male retained catch abundance for TCF.

Fishery total catch biomass

Fits

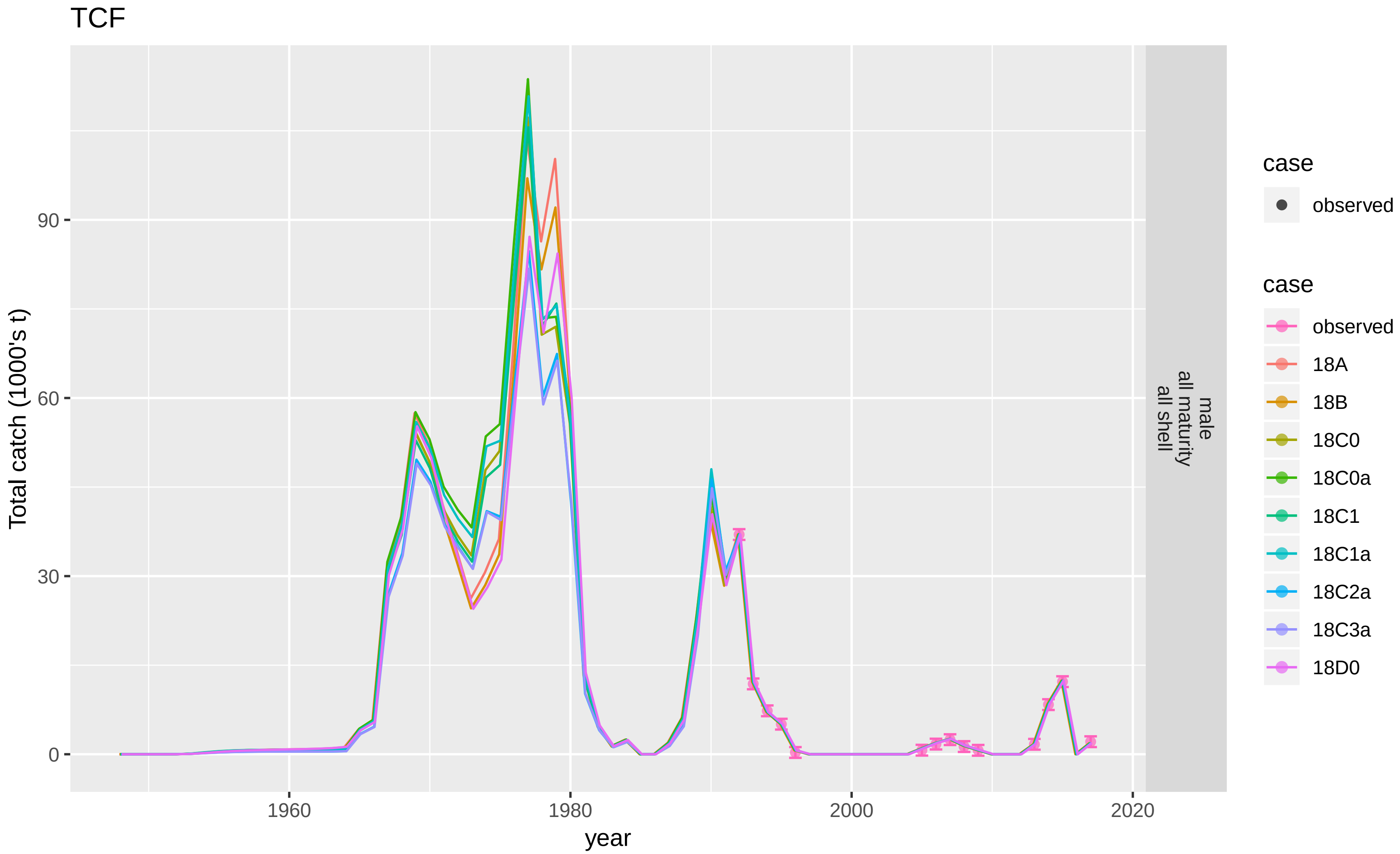

Figure 19: Comparison of observed and predicted total male catch biomass for TCF.

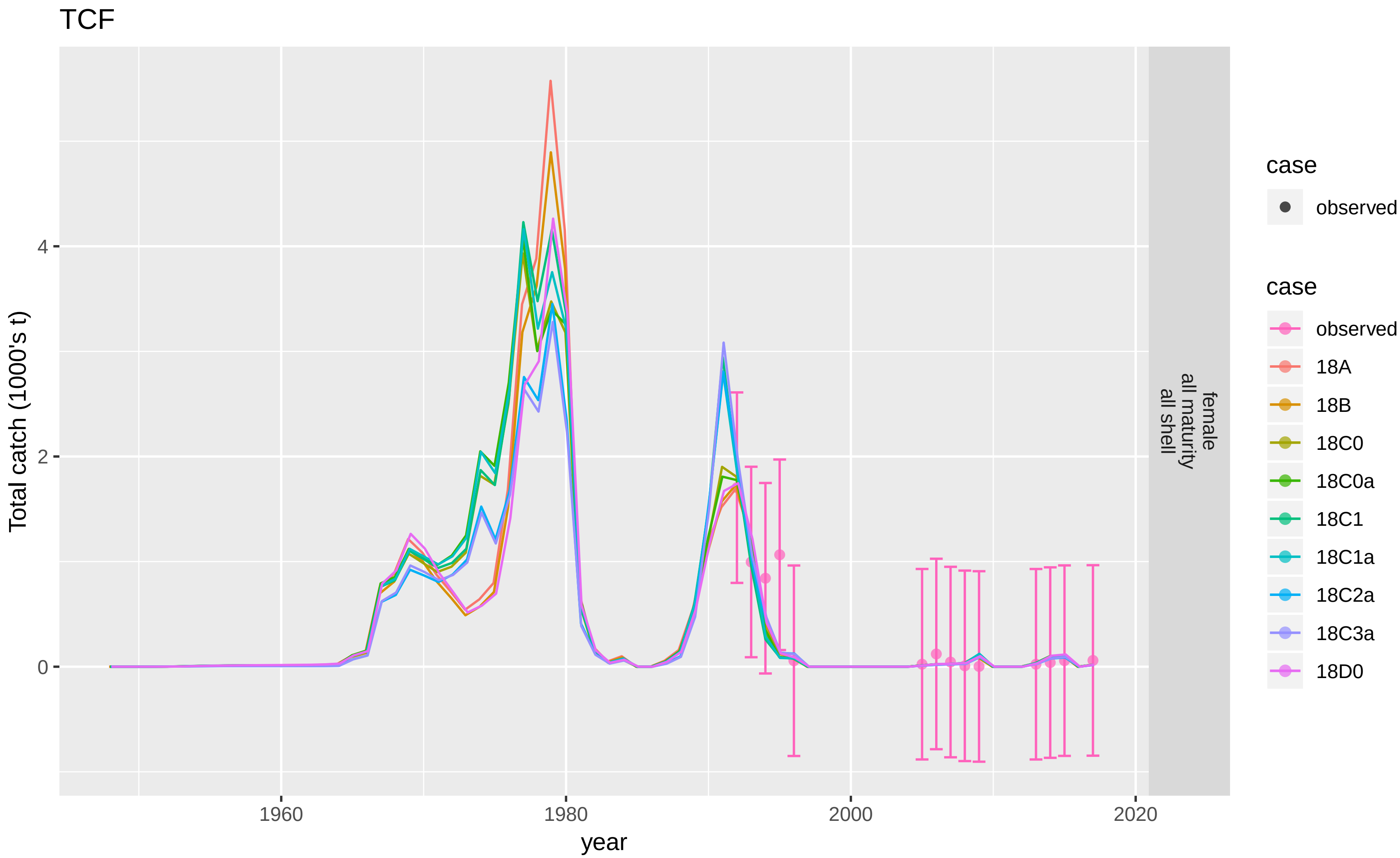

Figure 20: Comparison of observed and predicted total female catch biomass for TCF.

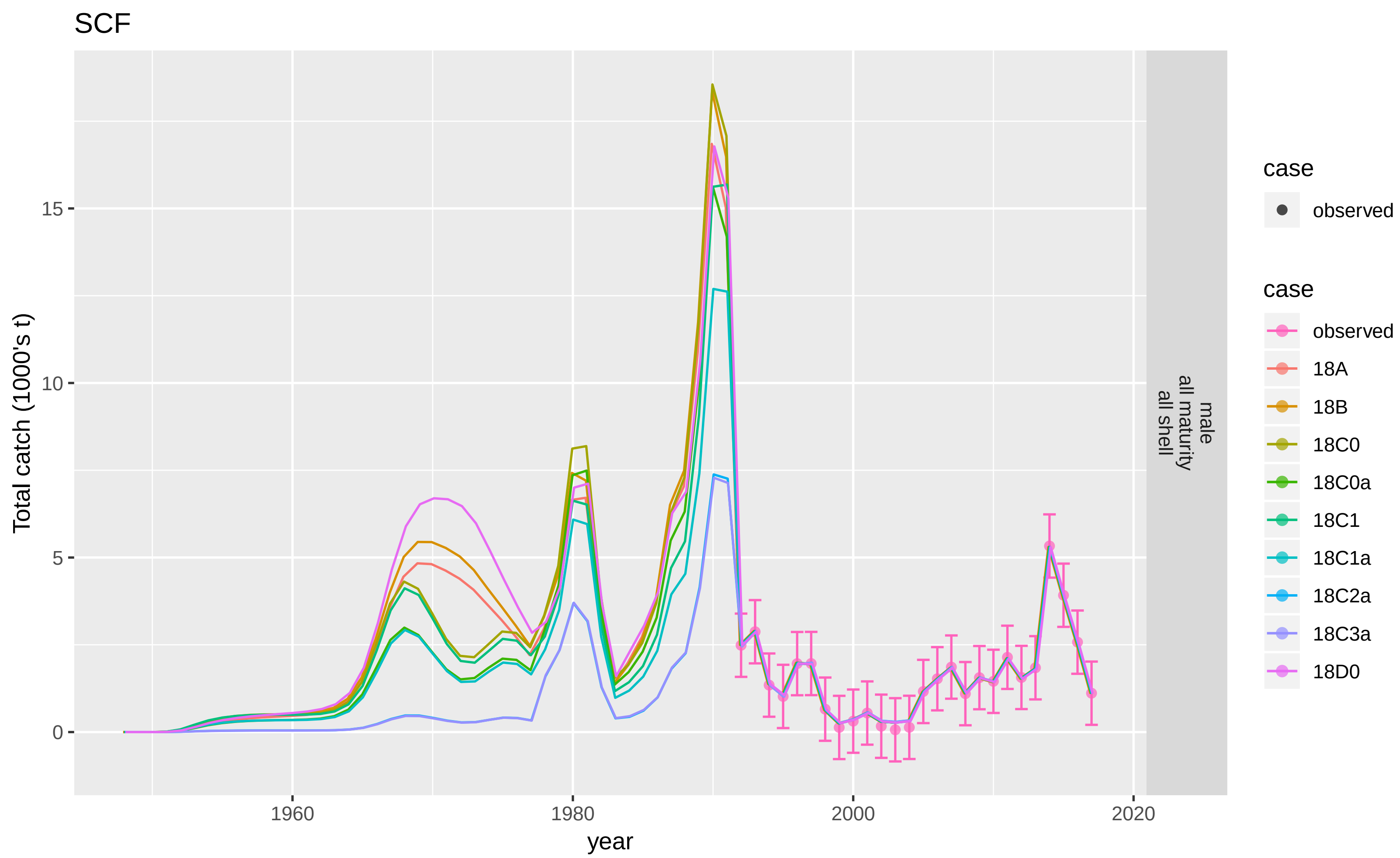

Figure 21: Comparison of observed and predicted total male catch biomass for SCF.

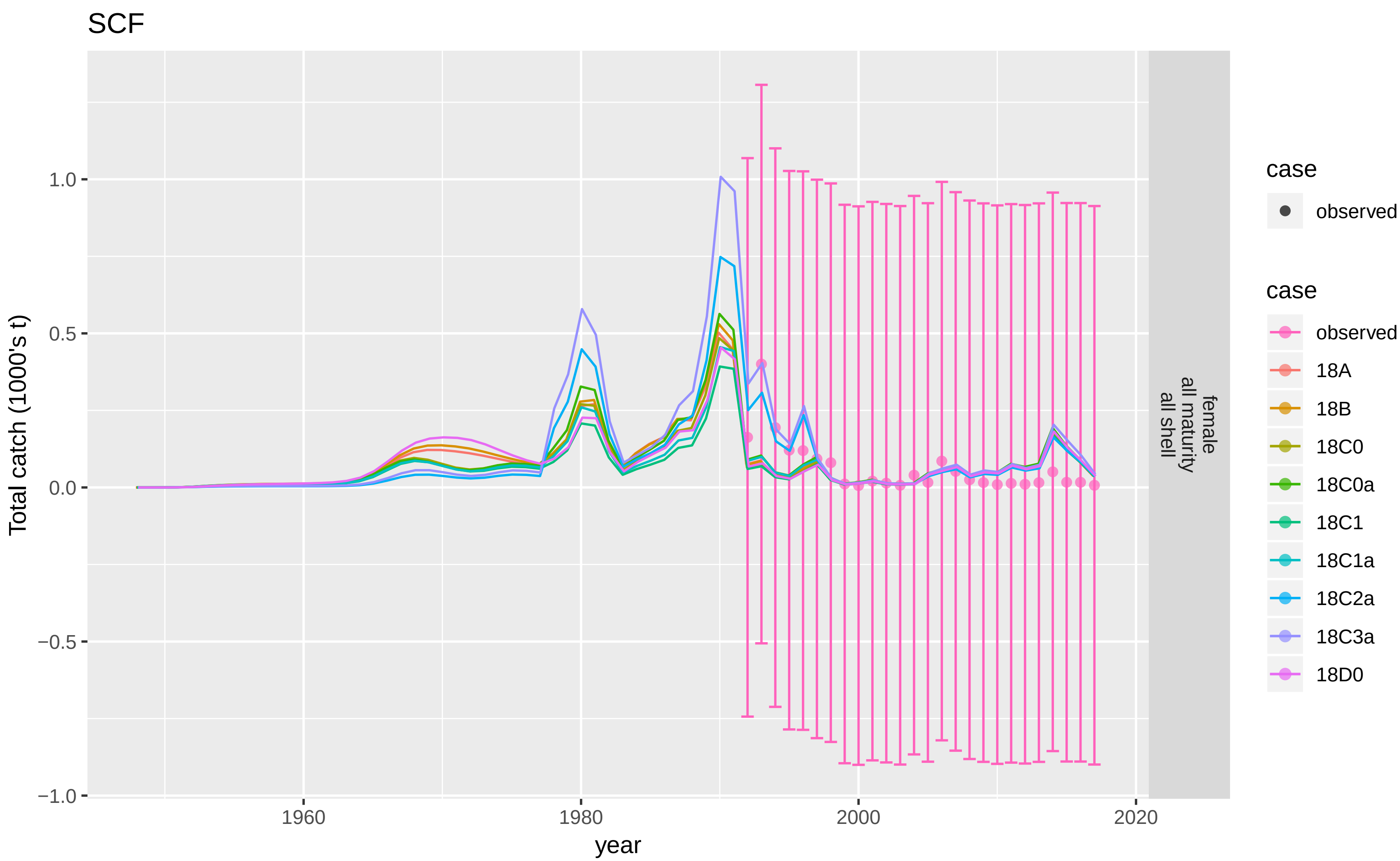

Figure 22: Comparison of observed and predicted total female catch biomass for SCF.

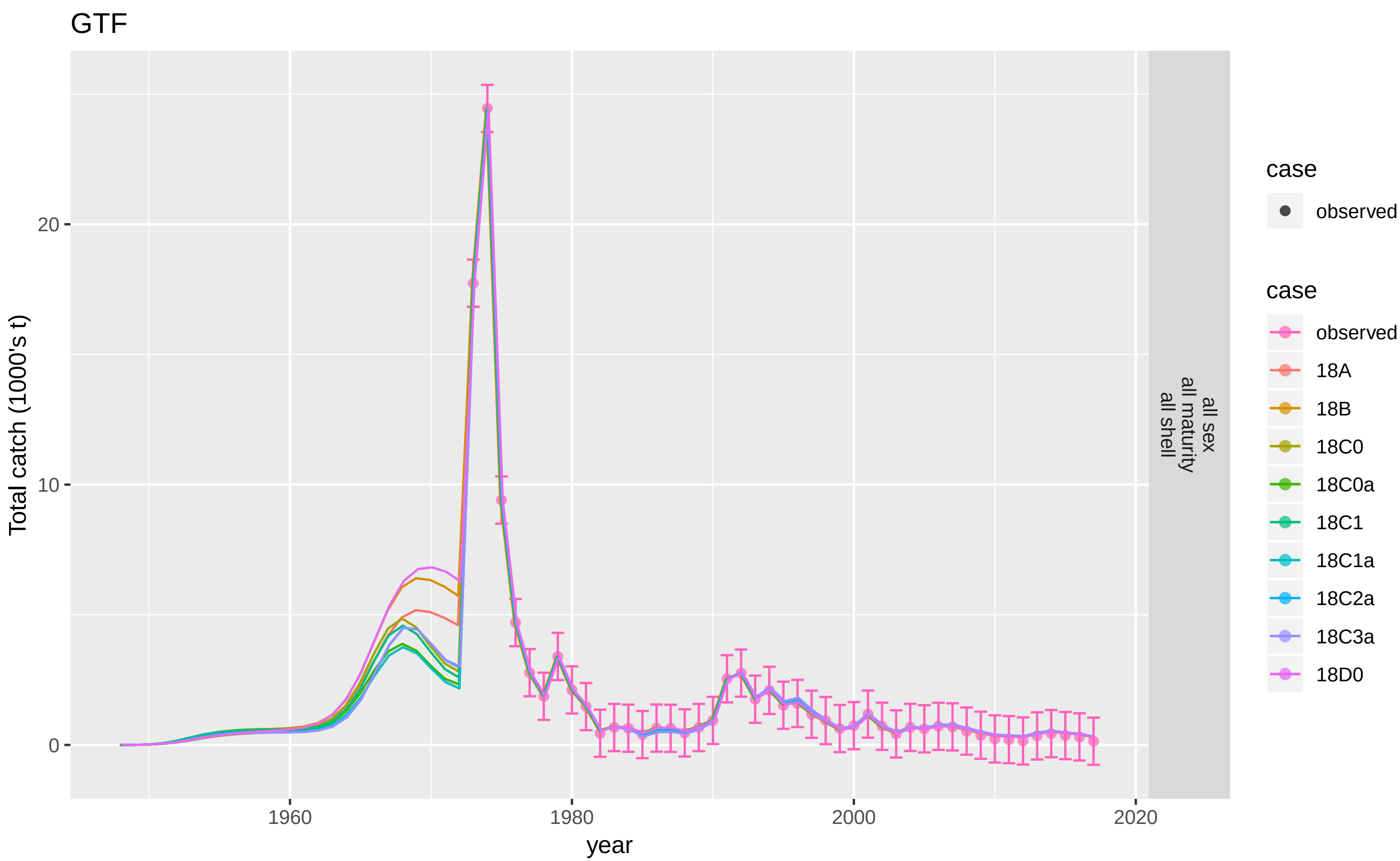

Figure 23: Comparison of observed and predicted total all sex catch biomass for GTF.

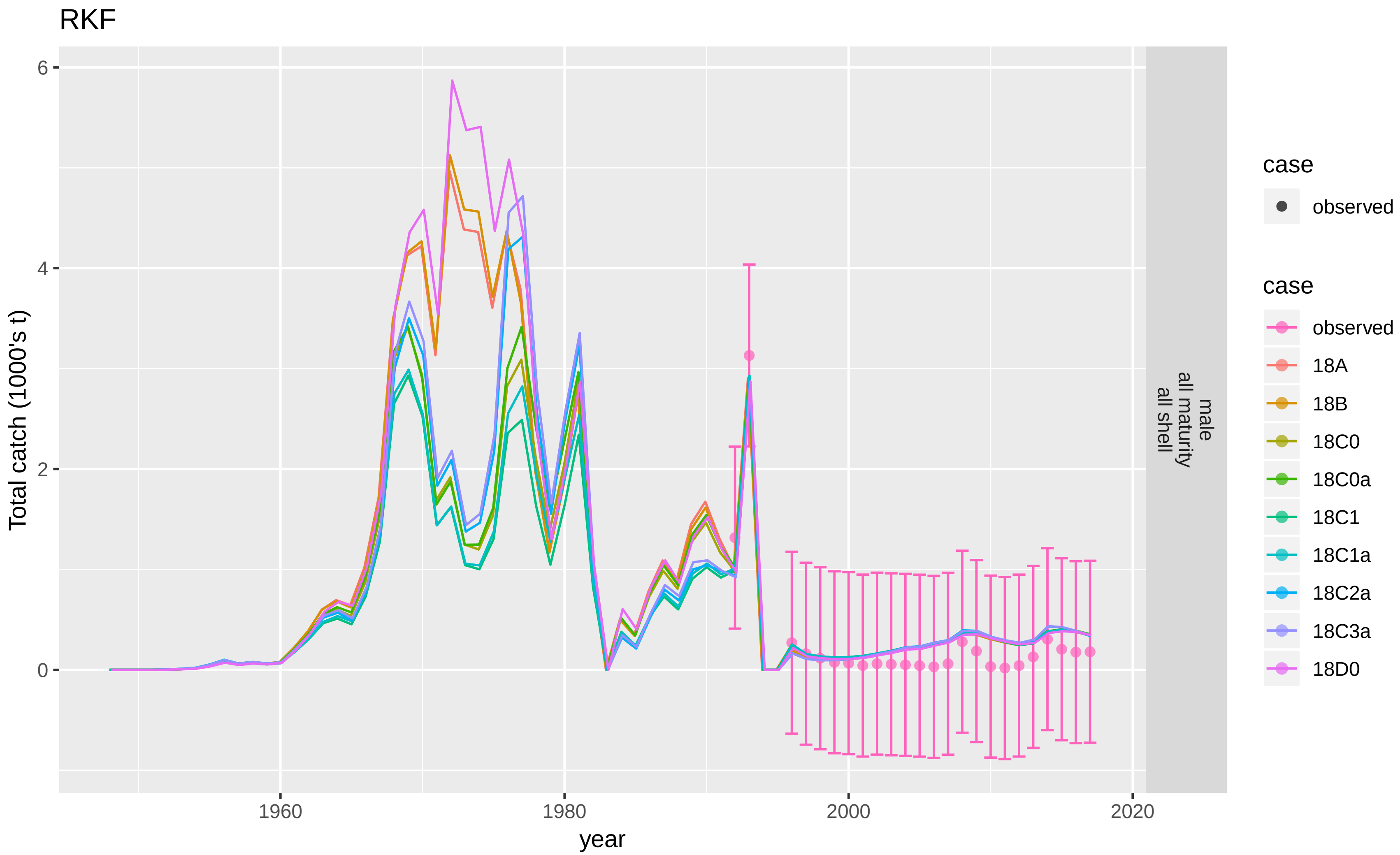

Figure 24: Comparison of observed and predicted total male catch biomass for RKF.

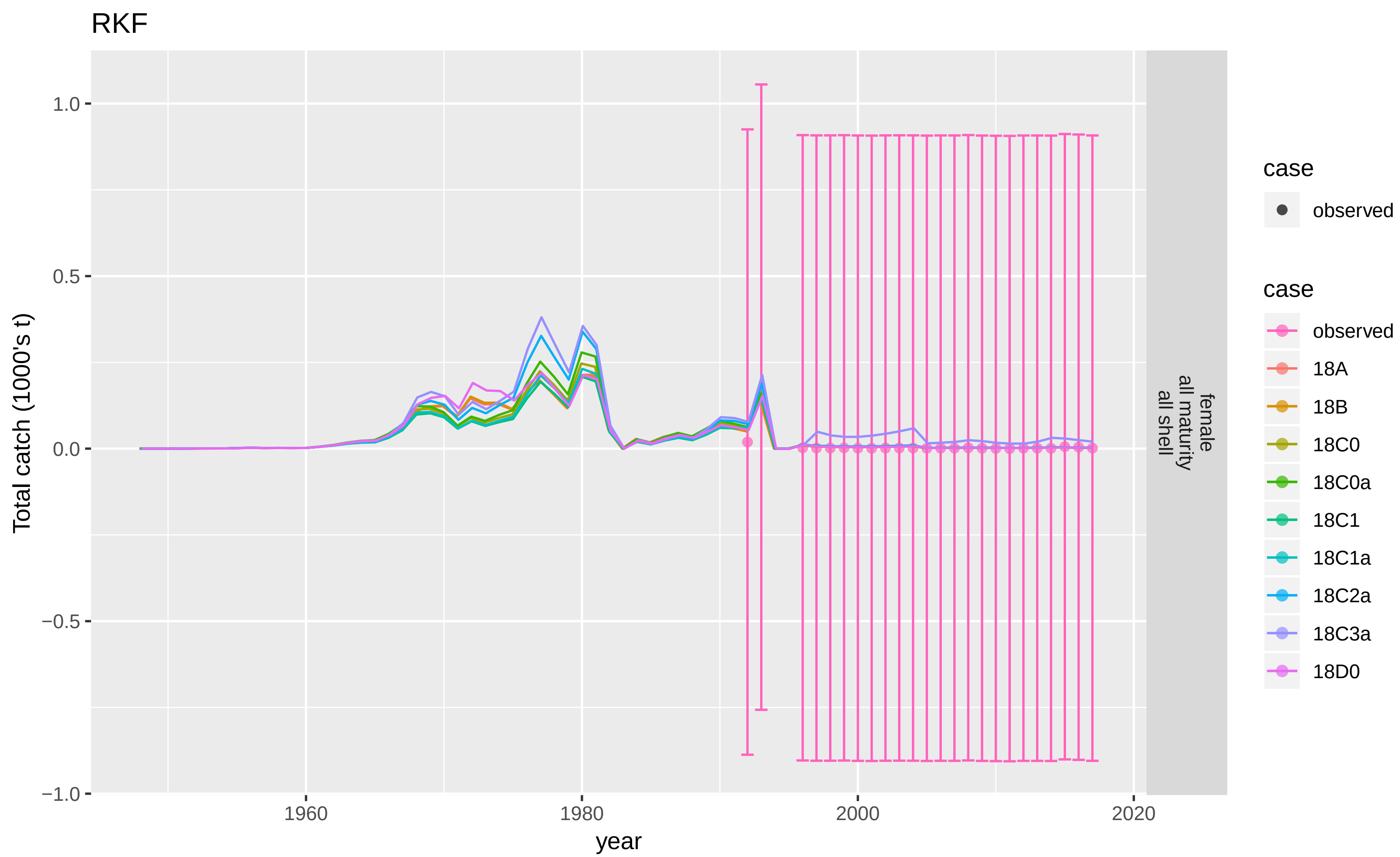

Figure 25: Comparison of observed and predicted total female catch biomass for RKF.

Appendix I2:
Model Comparisons of Fits to Survey Size Composition for "18" Scenarios

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.

Note: X, M, S = sex, maturity state, shell condition

Mean survey size compositions

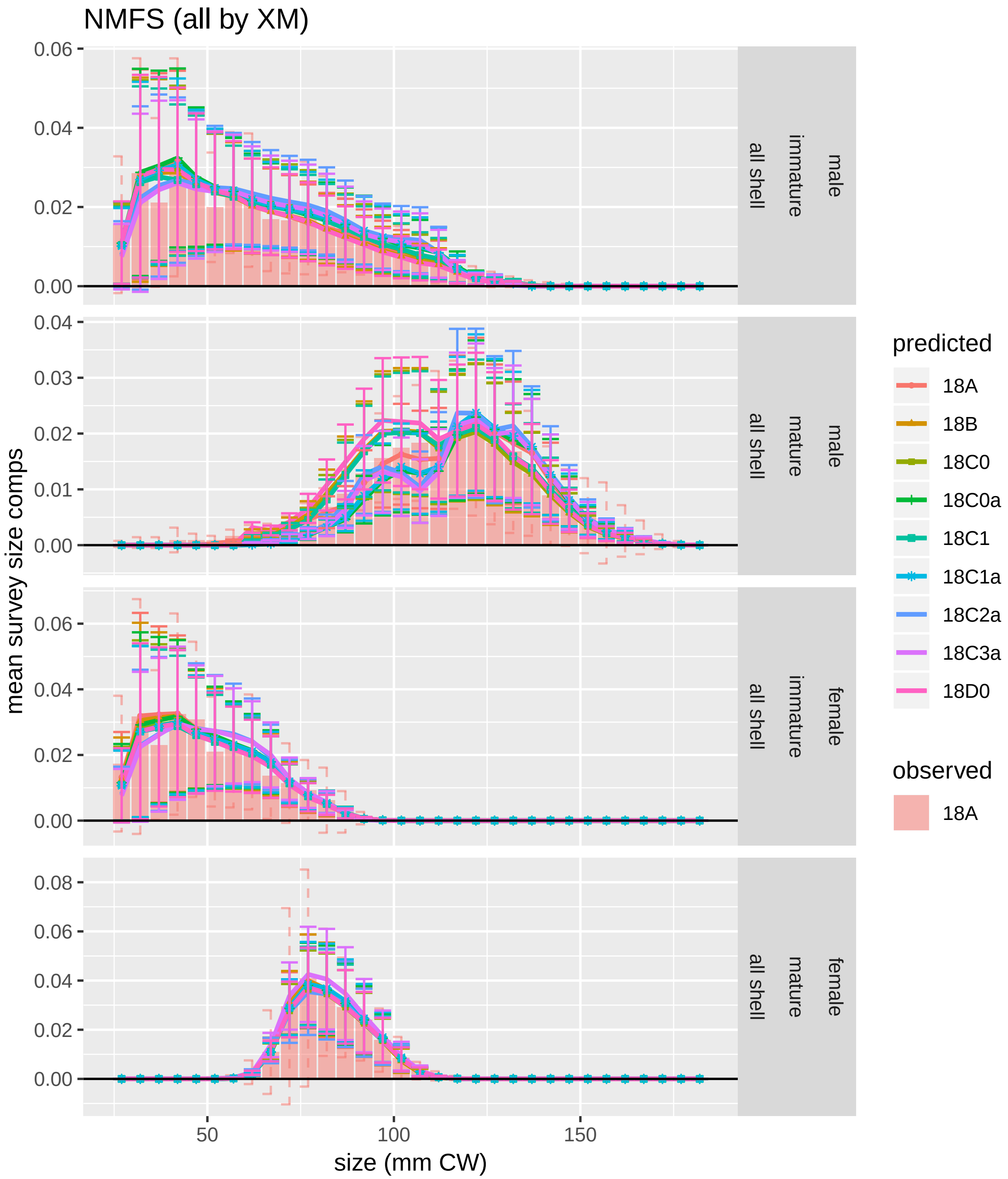

Figure 1: Comparison of observed and predicted mean survey size comps for NMFS (all by XM).

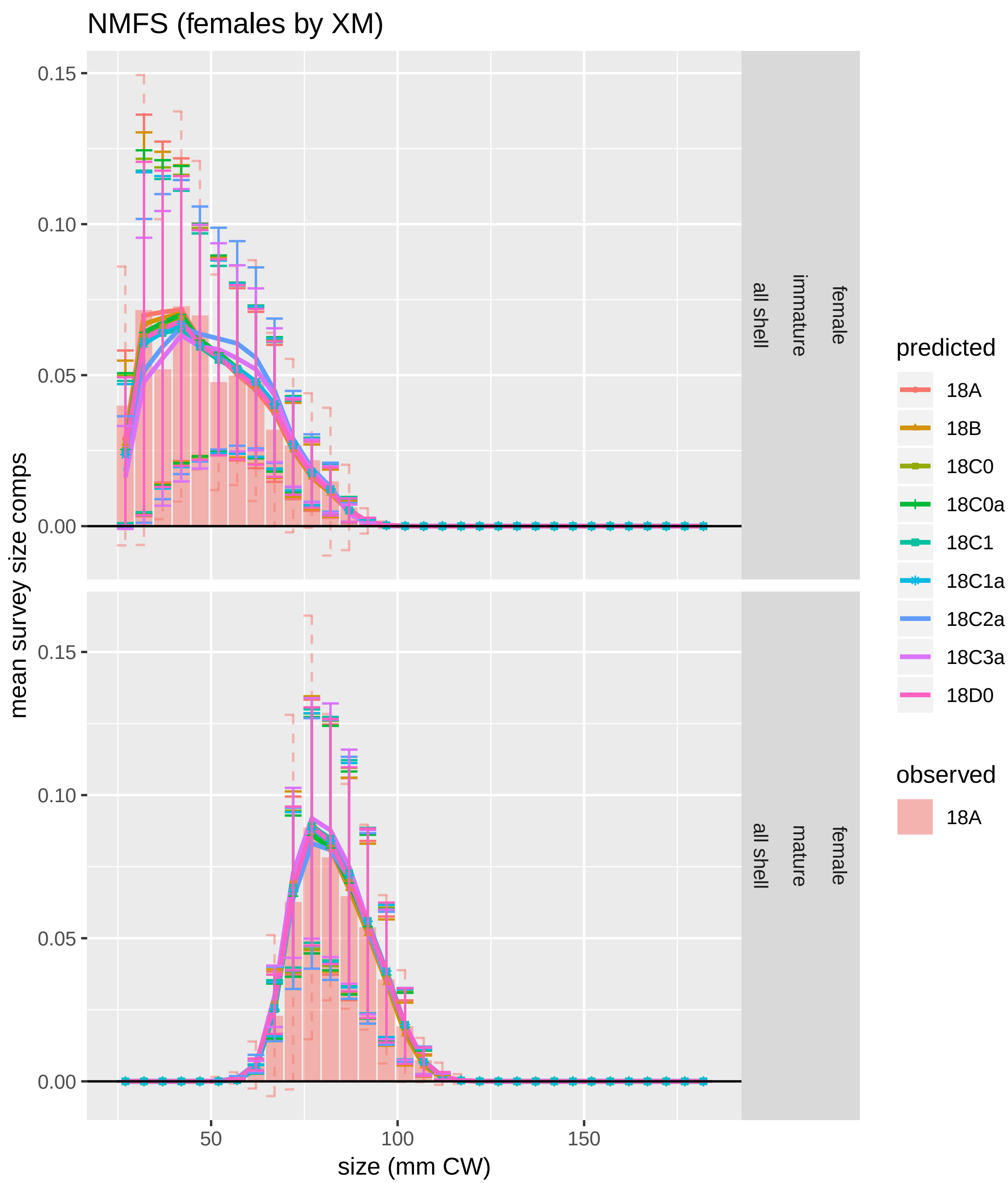

Figure 2: Comparison of observed and predicted mean survey size comps for NMFS (females by XM).

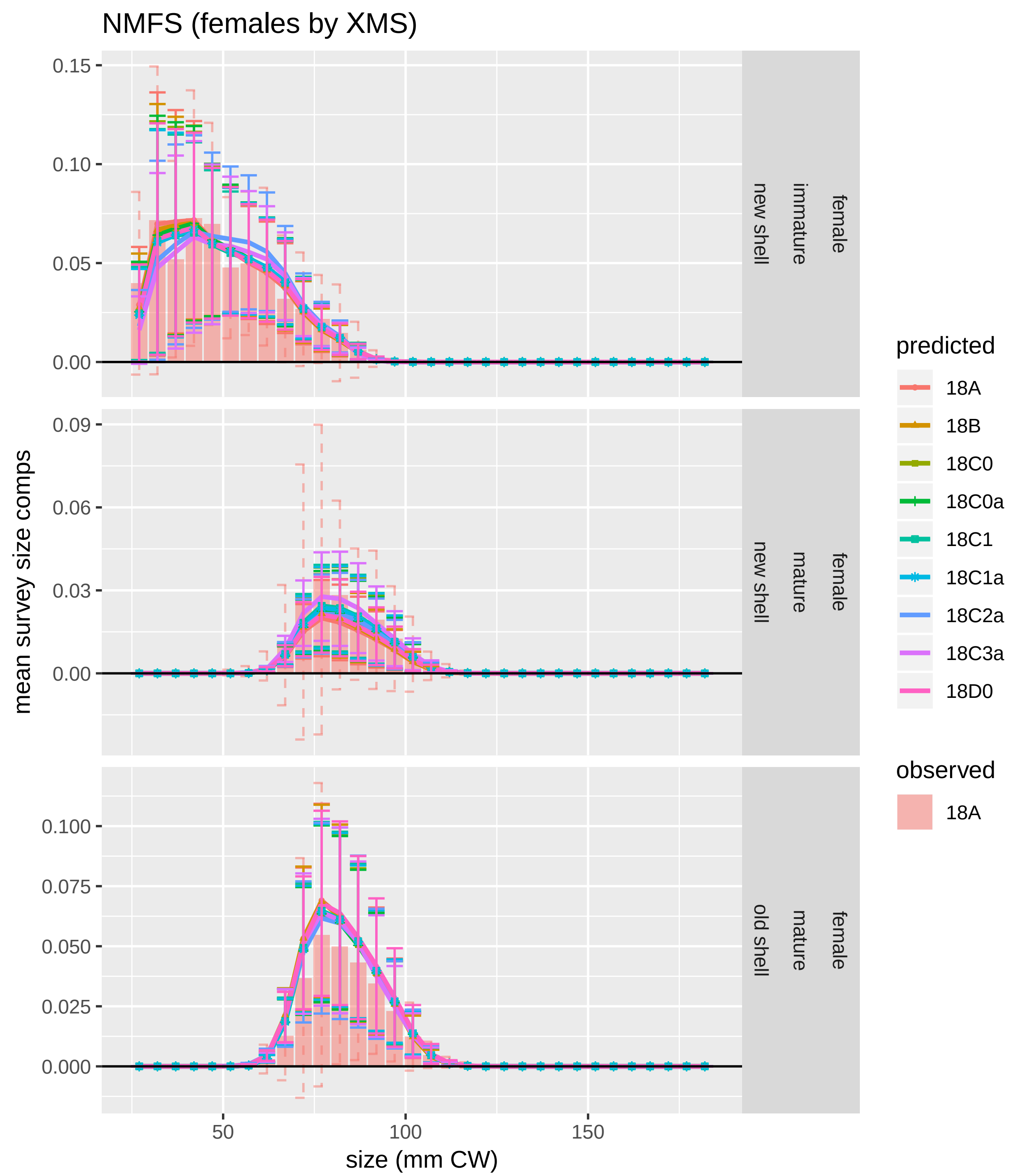

Figure 3: Comparison of observed and predicted mean survey size comps for NMFS (females by XMS).

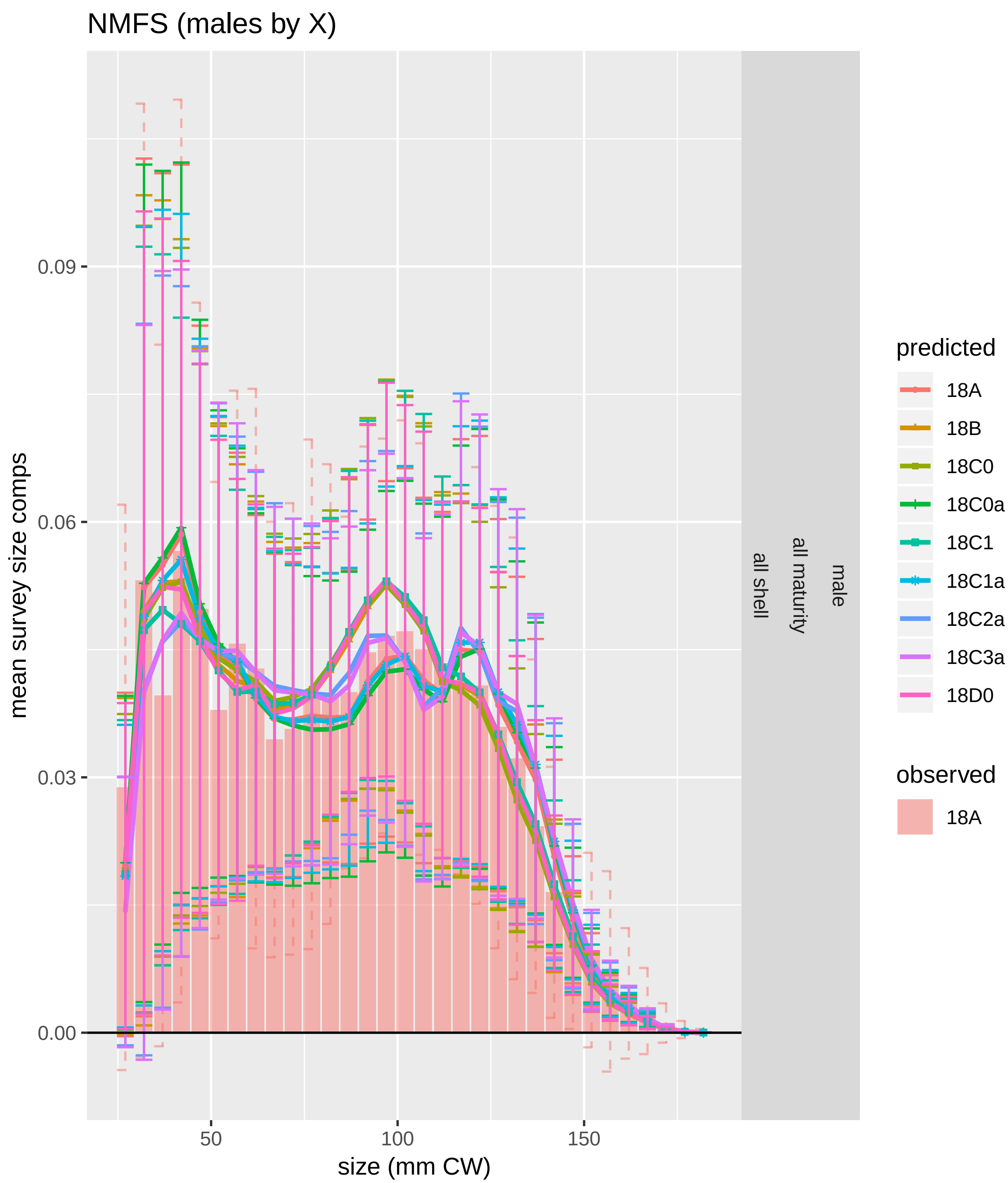

Figure 4: Comparison of observed and predicted mean survey size comps for NMFS (males by X).

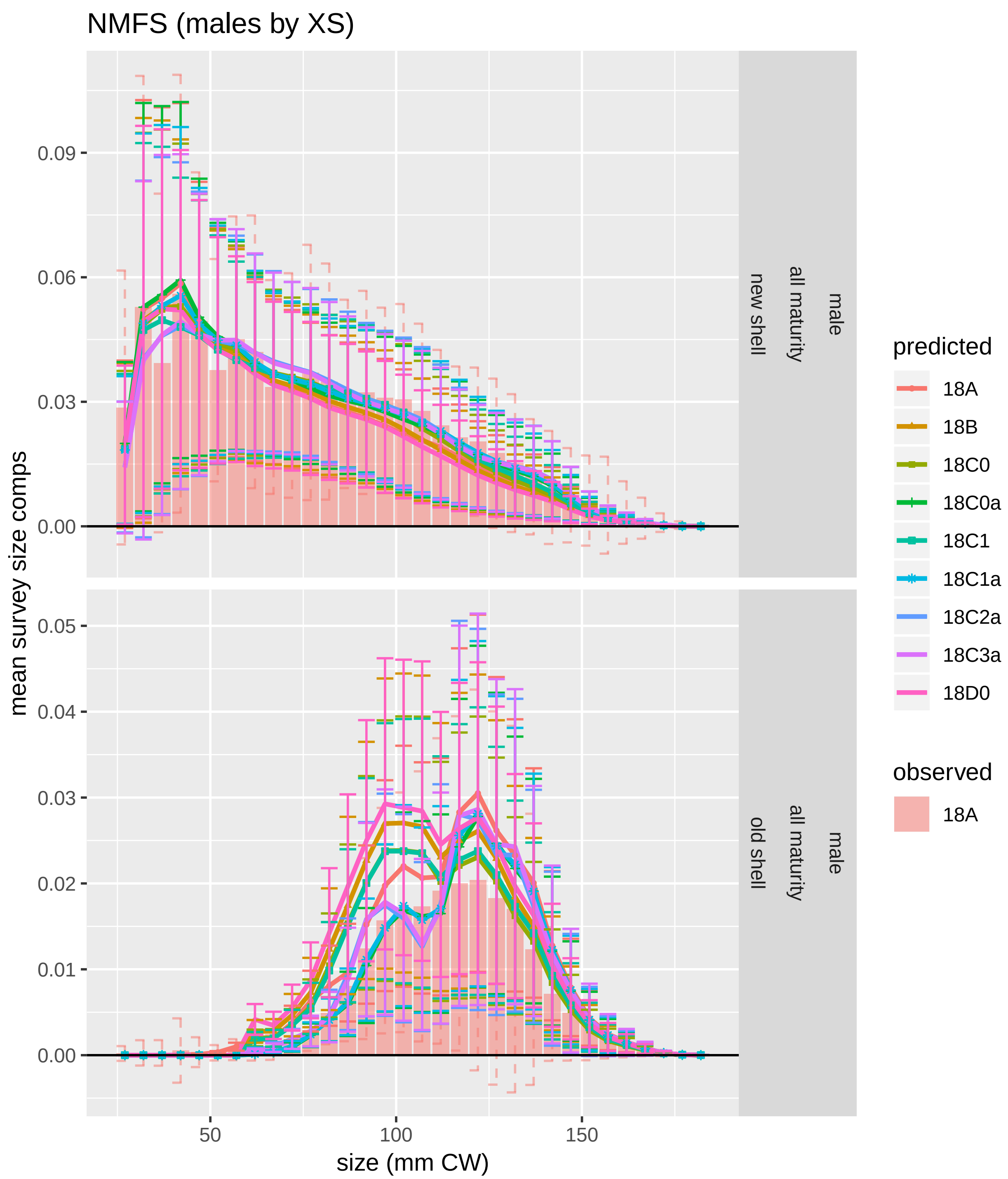

Figure 5: Comparison of observed and predicted mean survey size comps for NMFS (males by XS).

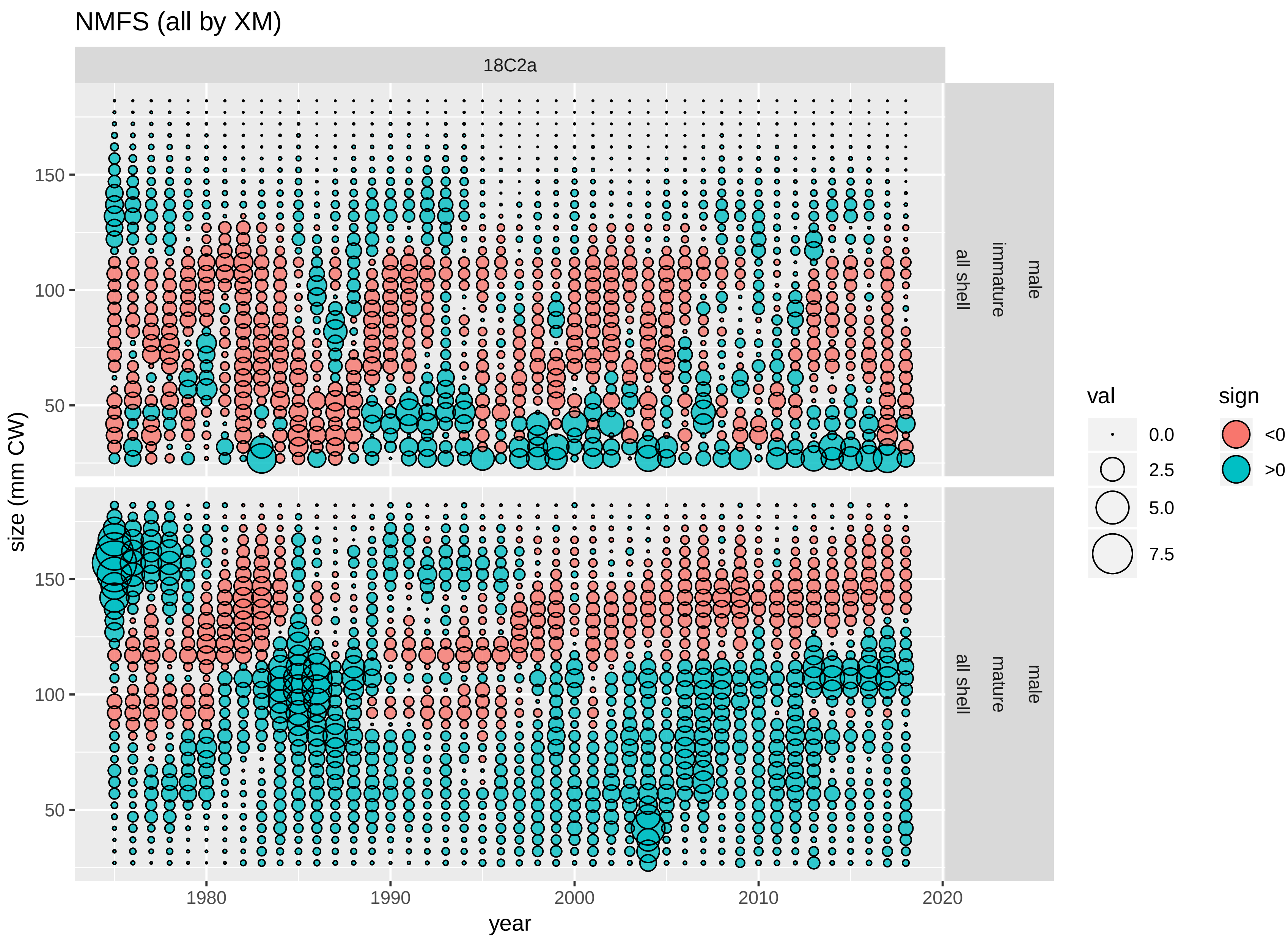

Figure 6: Pearson's residuals for proportions-at-size from the NMFS (all by XM) for scenario 18C2a.

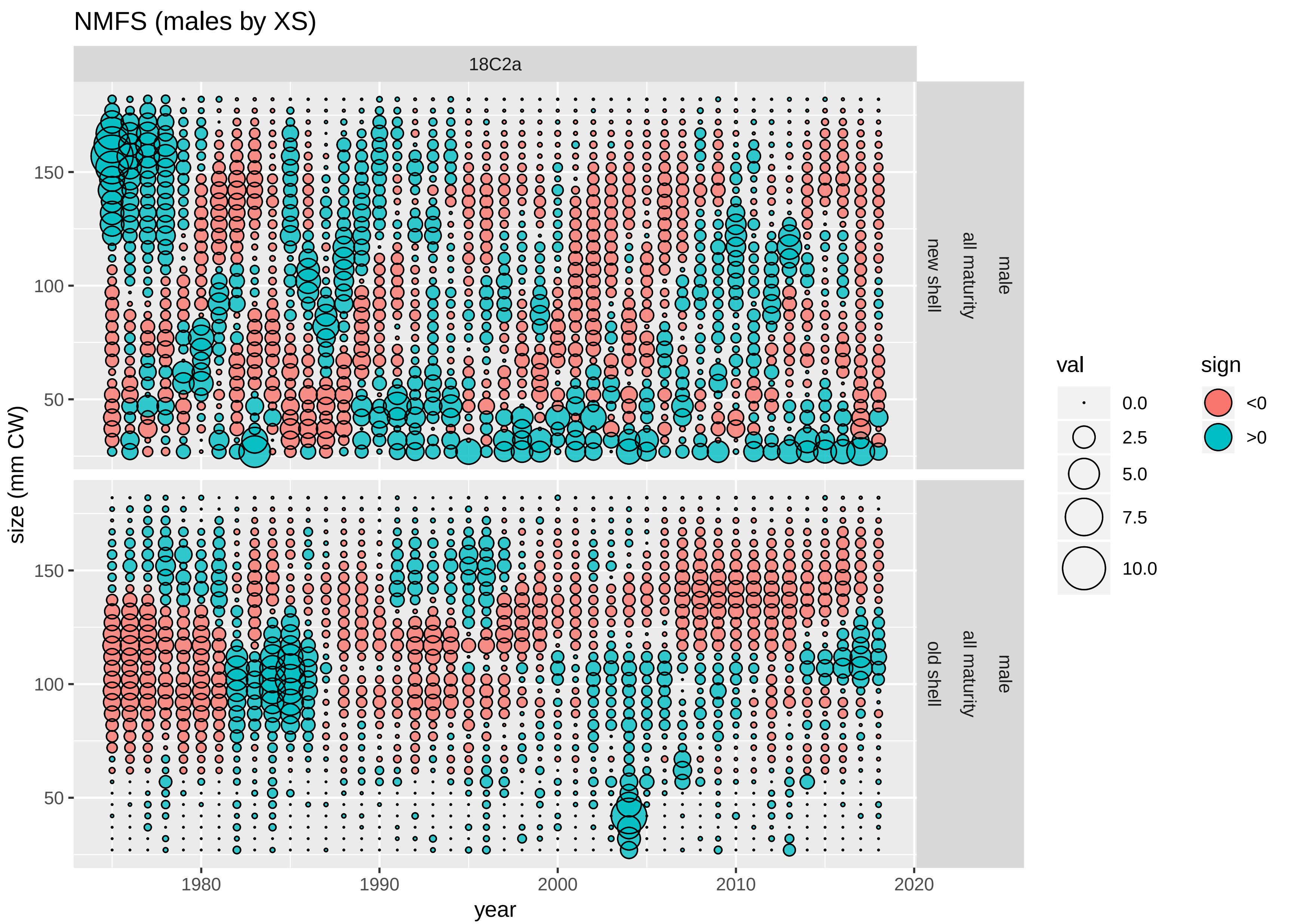

Figure 7: Pearson's residuals for proportions-at-size from the NMFS (males by XS) for scenario 18C2a.

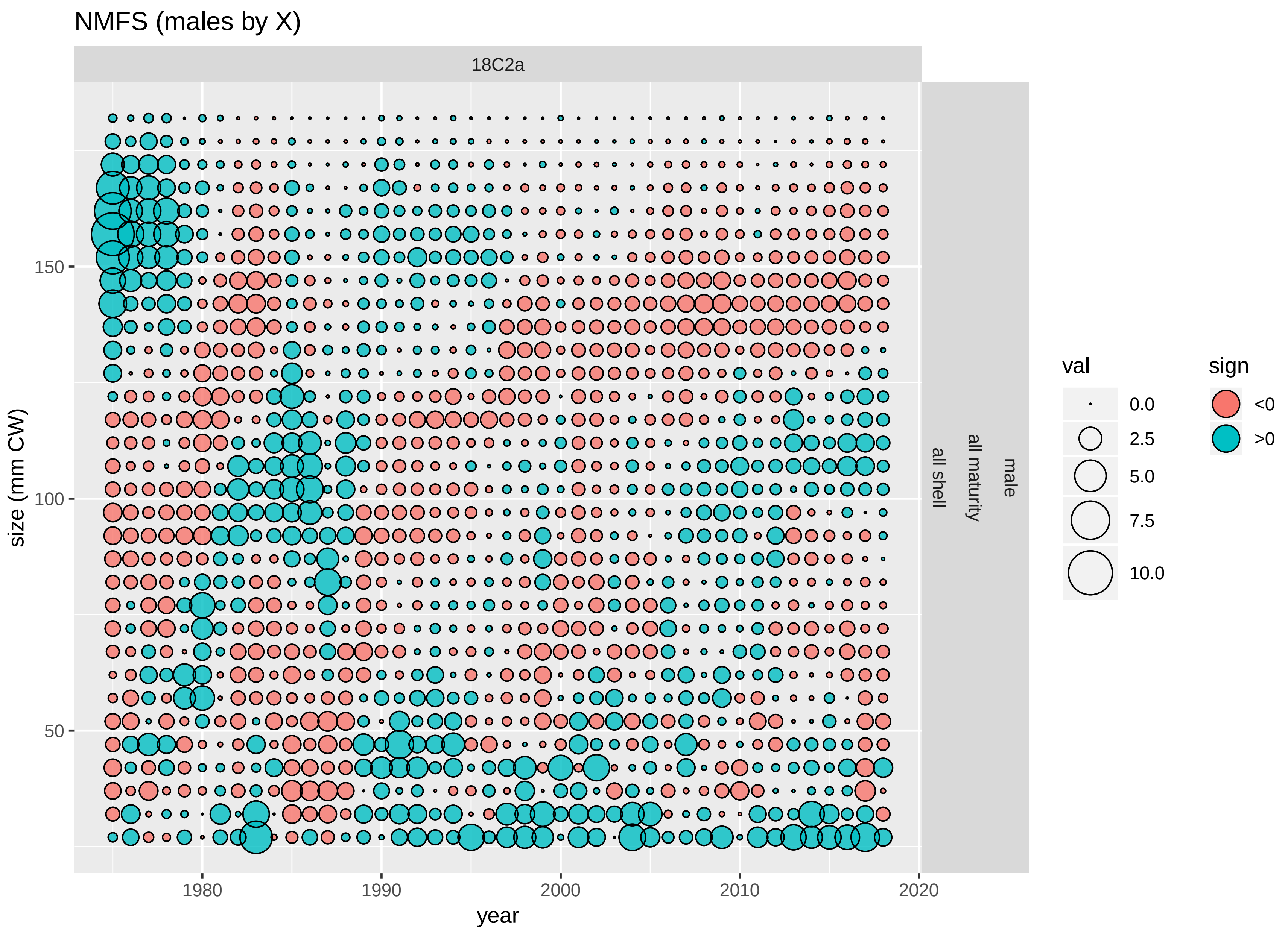

Figure 8: Pearson's residuals for proportions-at-size from the NMFS (males by X) for scenario 18C2a.

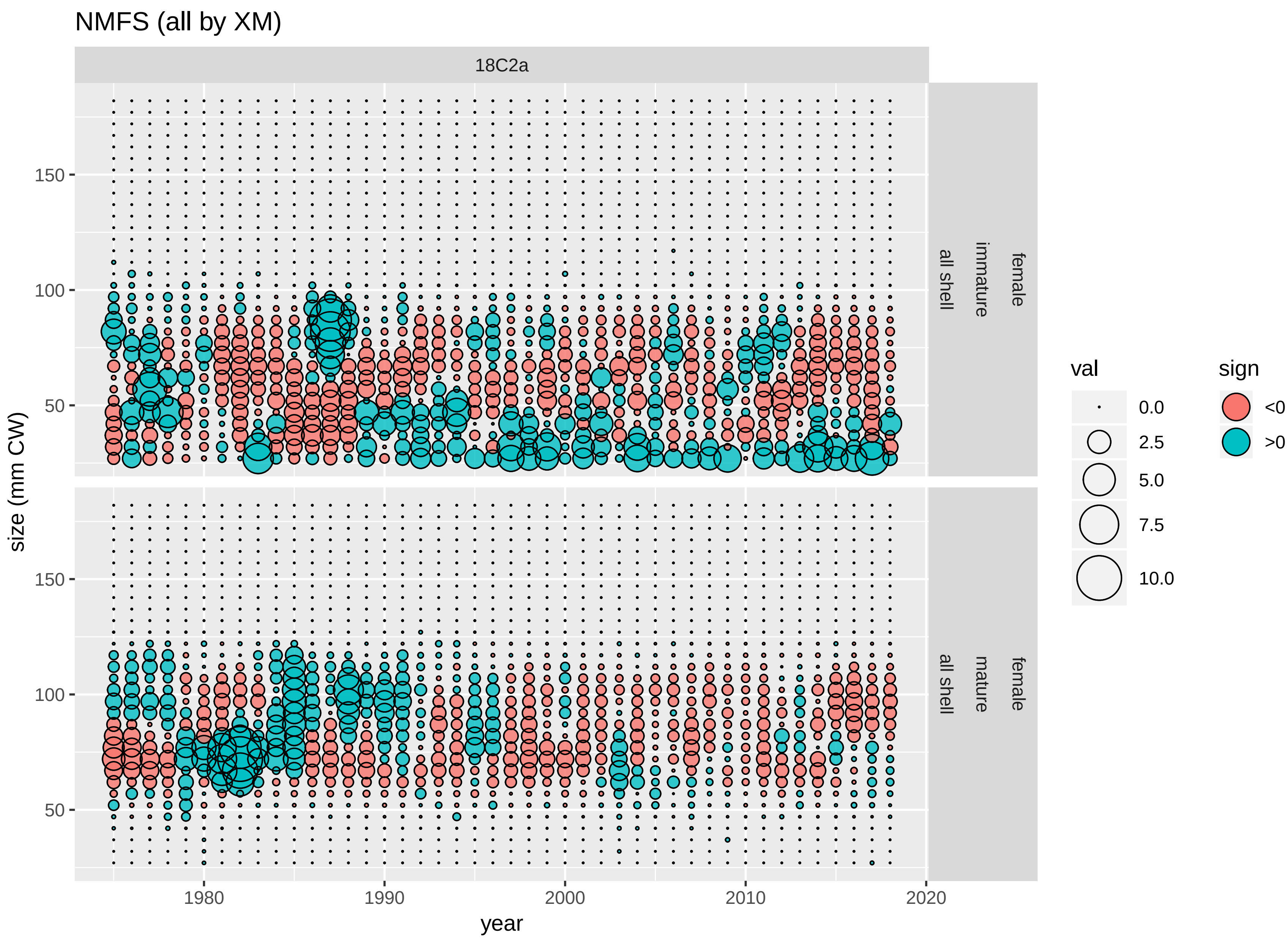

Figure 9: Pearson's residuals for proportions-at-size from the NMFS (all by XM) for scenario 18C2a.

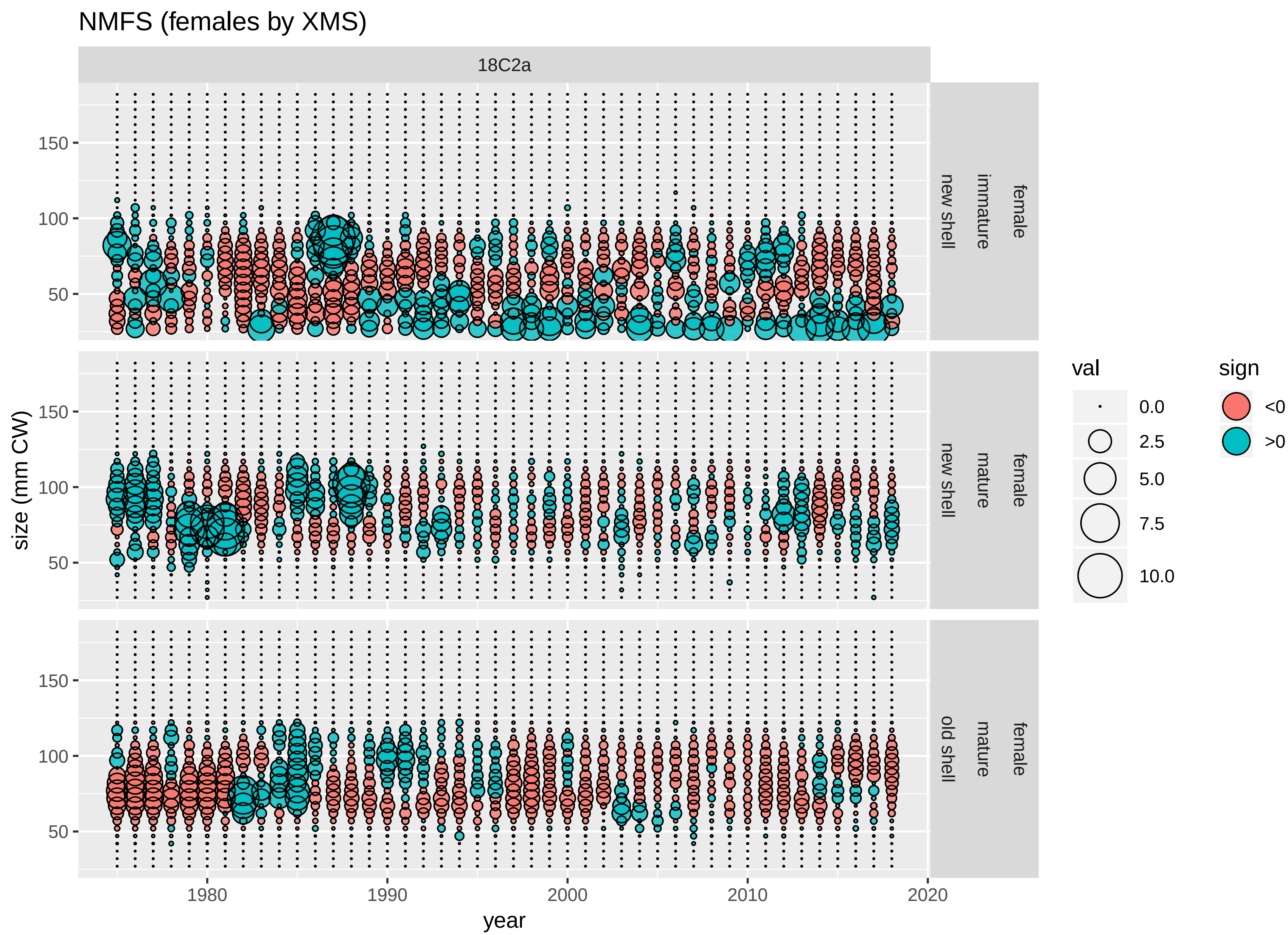

Figure 10: Pearson's residuals for proportions-at-size from the NMFS (females by XMS) for scenario 18C2a.

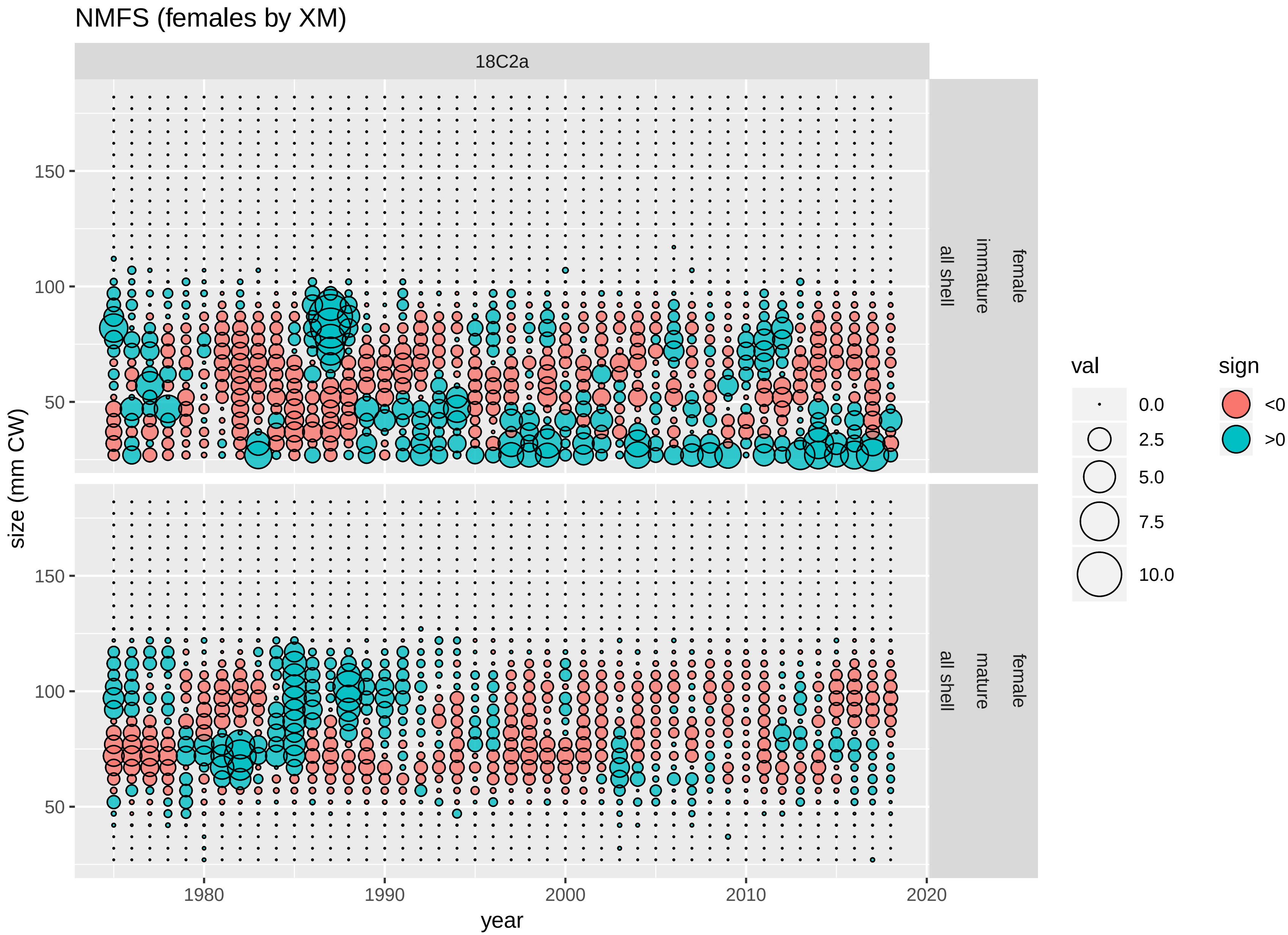

Figure 11: Pearson's residuals for proportions-at-size from the NMFS (females by XM) for scenario 18C2a.

Effective sample sizes for survey size compositions

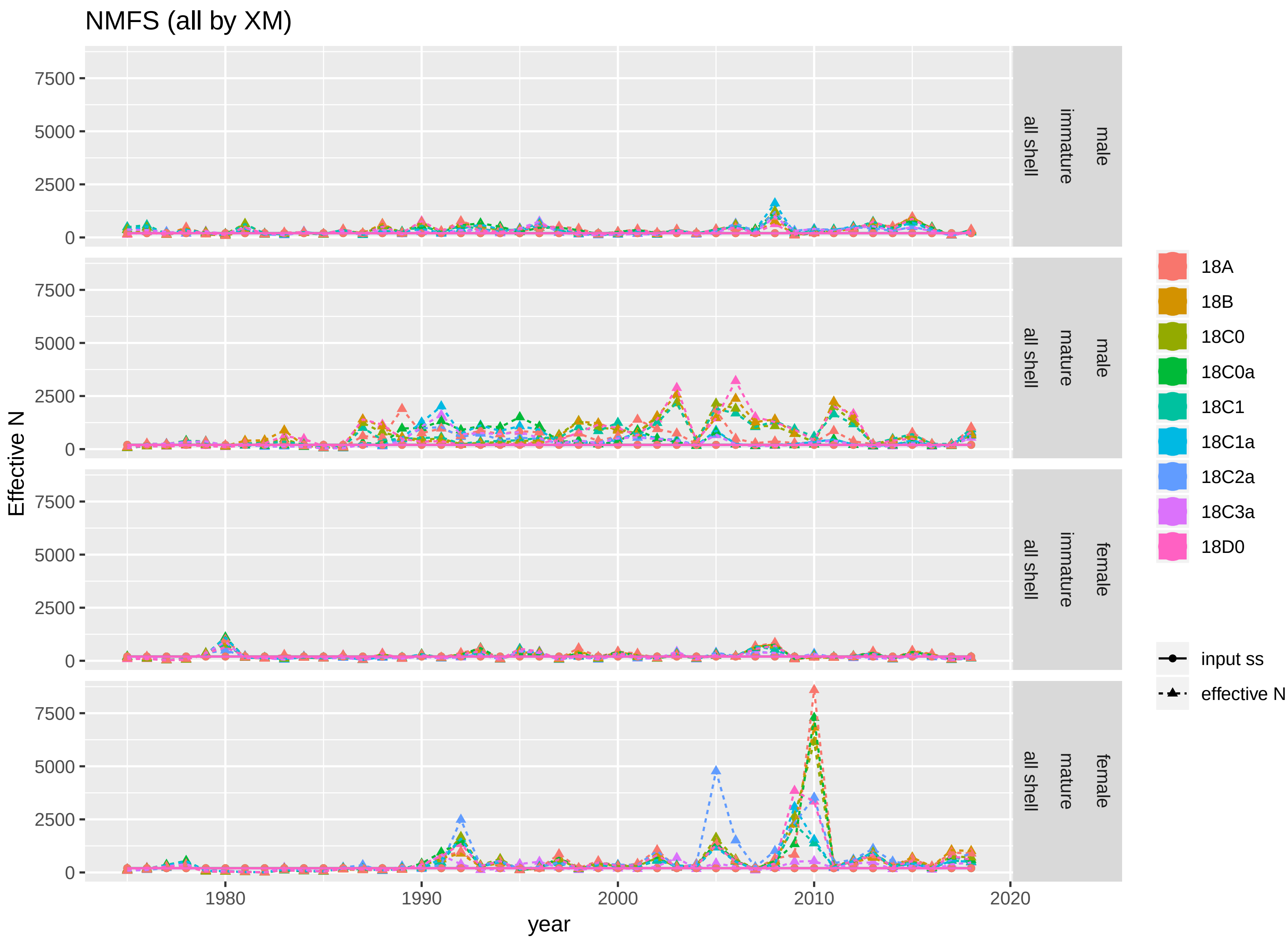

Figure 12: Input and effective sample sizes from retained catch size compositions from the NMFS (all by XM).

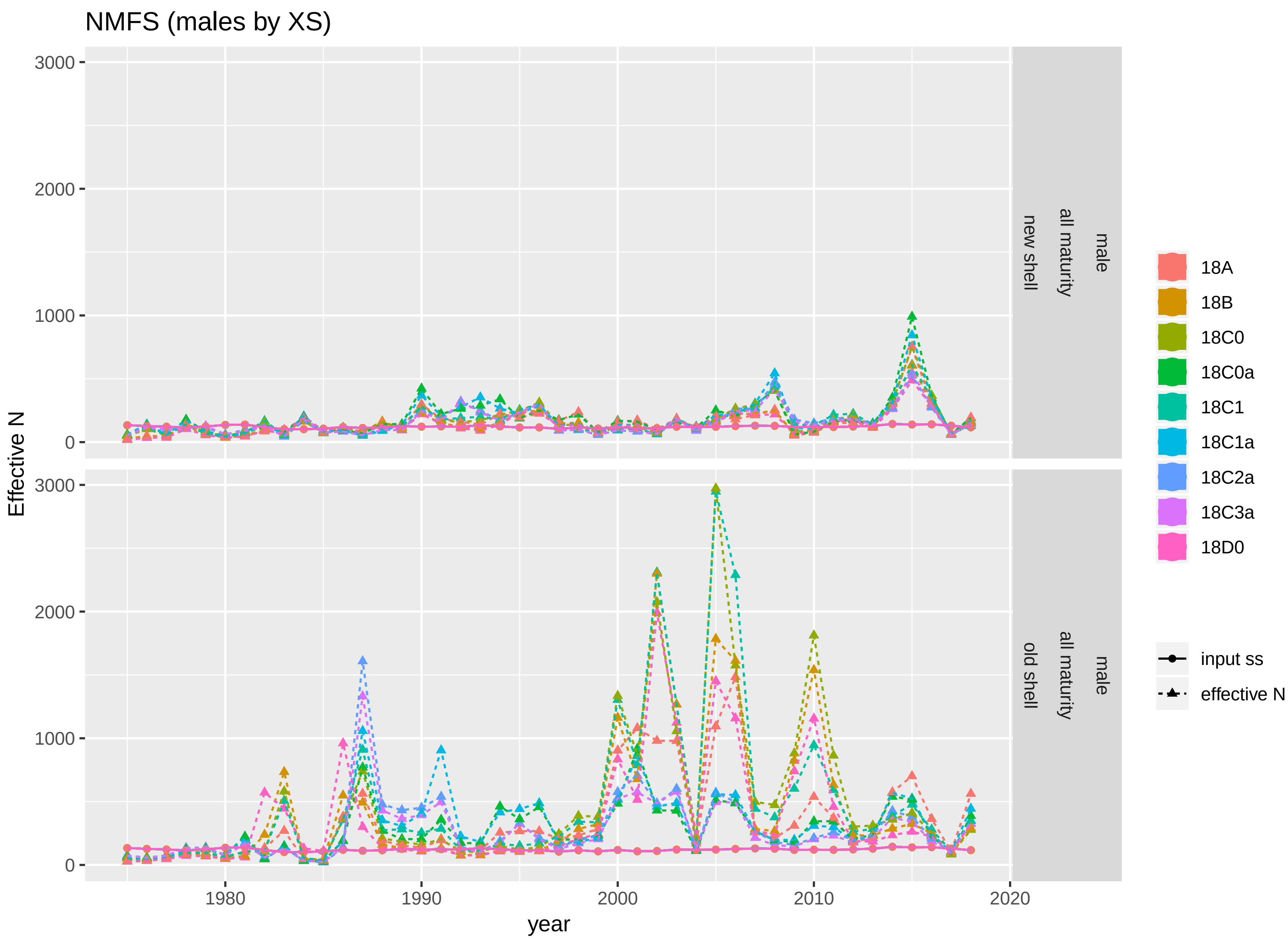

Figure 13: Input and effective sample sizes from retained catch size compositions from the NMFS (males by XS).

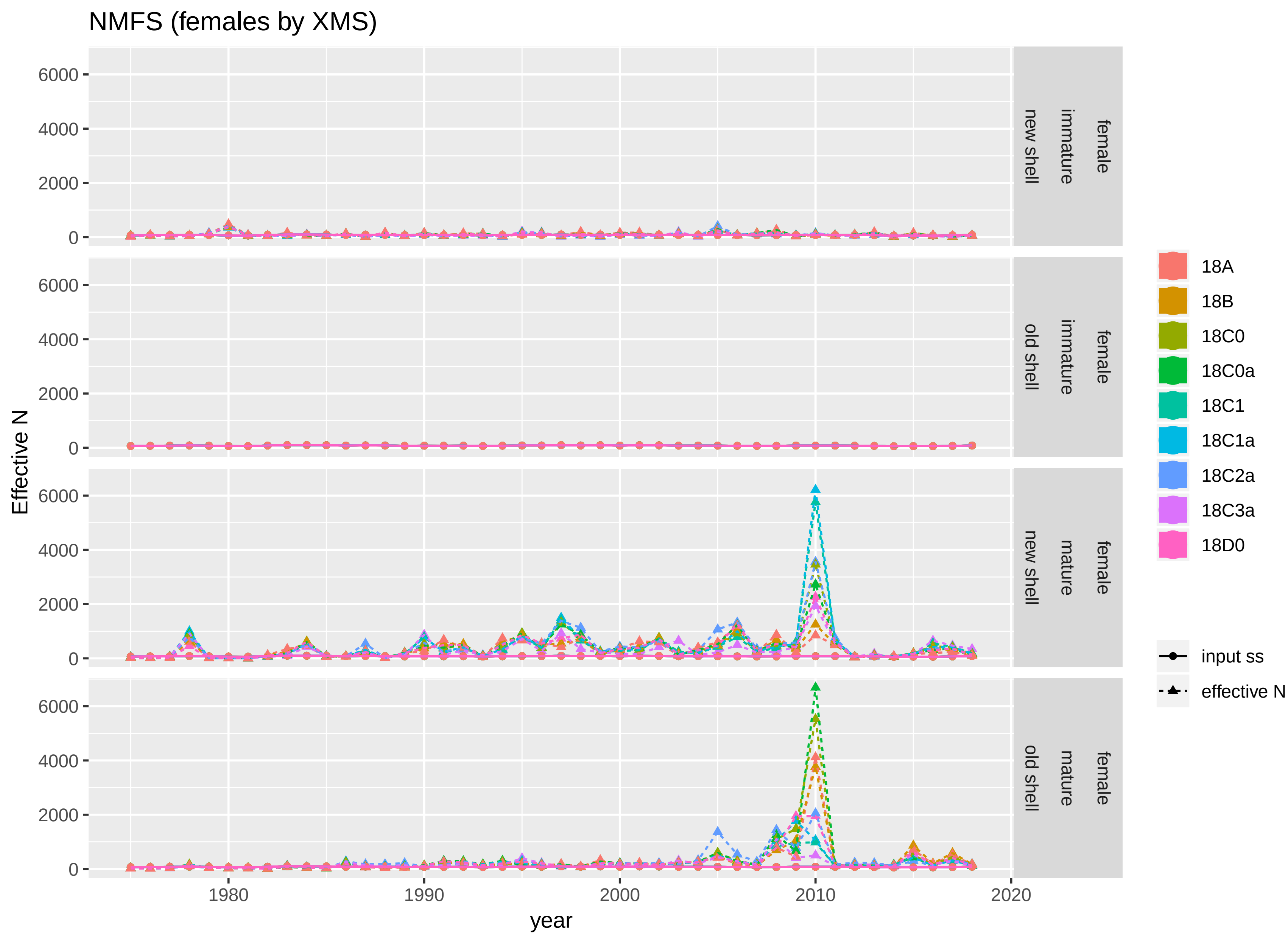

Figure 14: Input and effective sample sizes from retained catch size compositions from the NMFS (females by XMS).

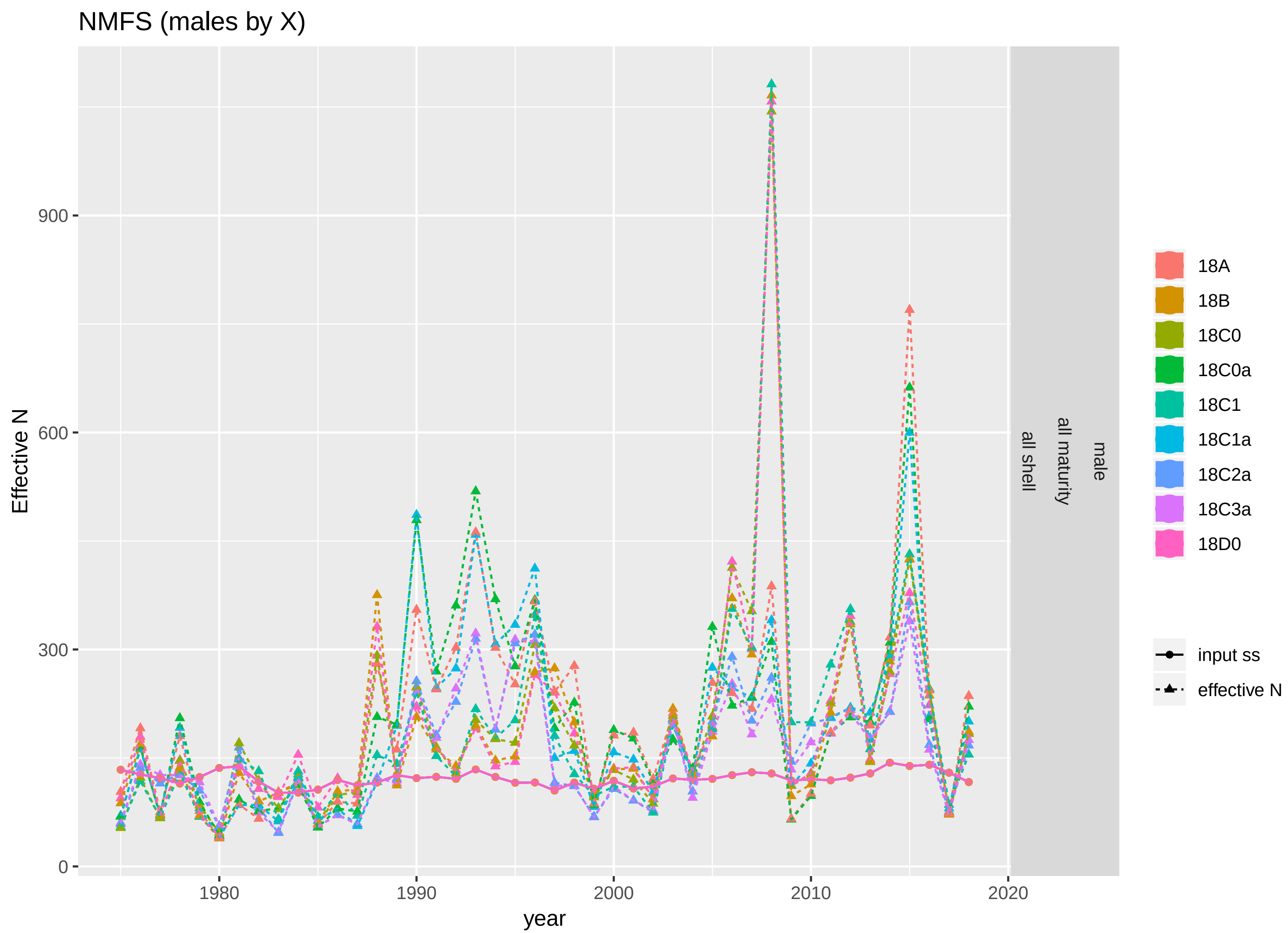

Figure 15: Input and effective sample sizes from retained catch size compositions from the NMFS (males by X).

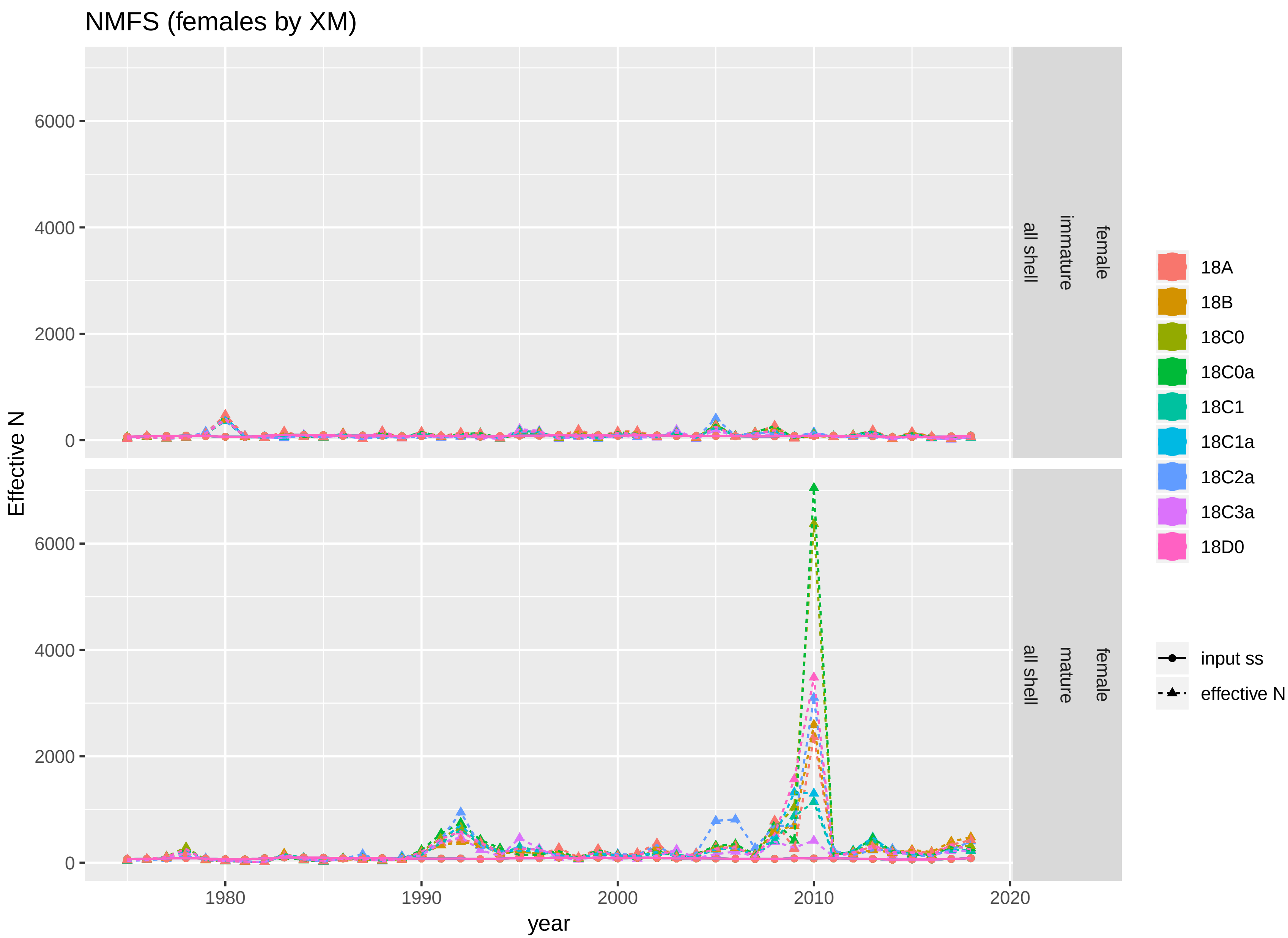

Figure 64: Input and effective sample sizes from retained catch size compositions from the NMFS (females by XM).

Appendix I3:
Fits to Fisheries Size Composition Data
for the "18" Scenarios

William Stockhausen

31 August, 2018

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

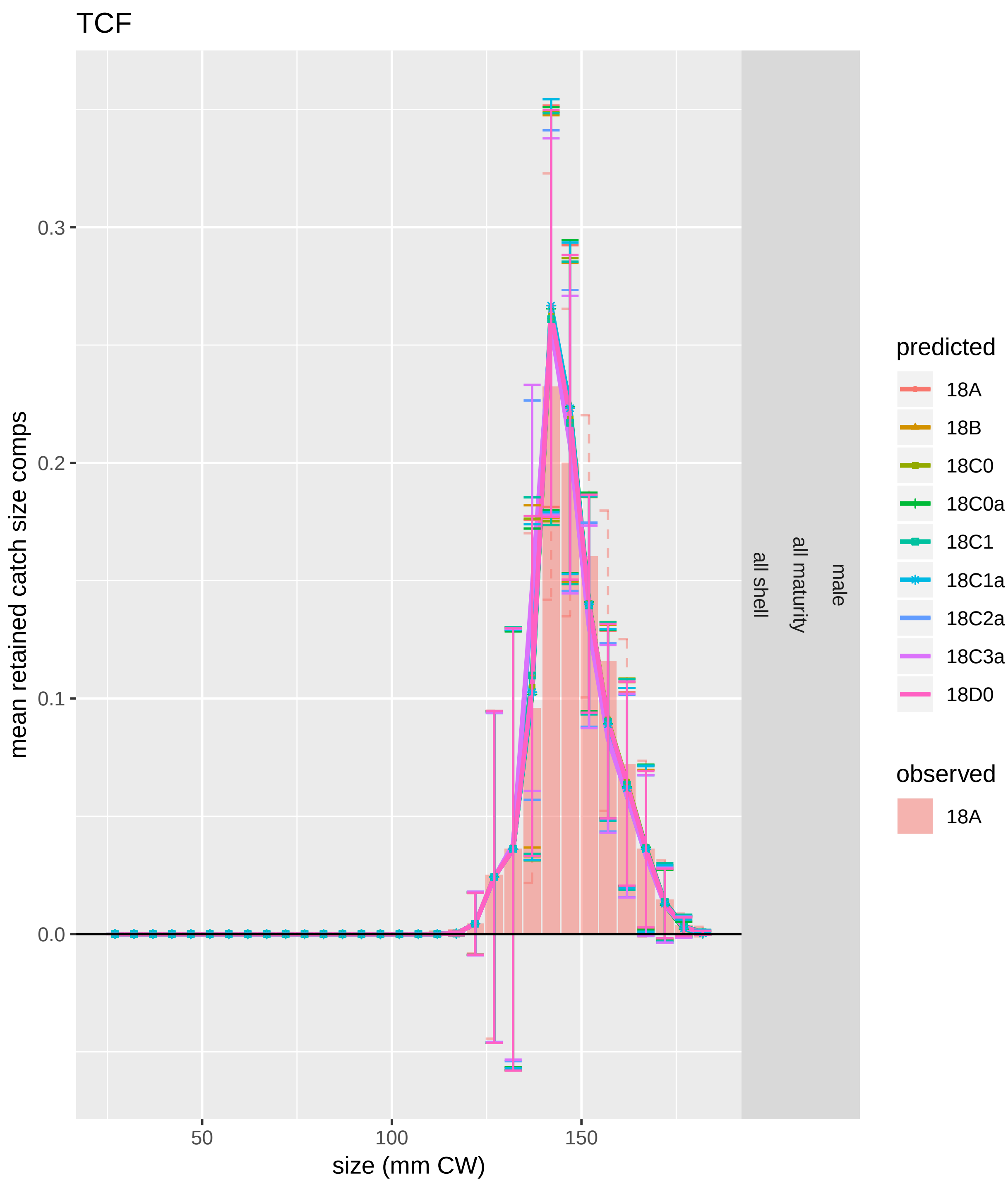

Figure 1: Comparison of observed and predicted mean retained catch size comps for TCF.

Total catch mean size compositions

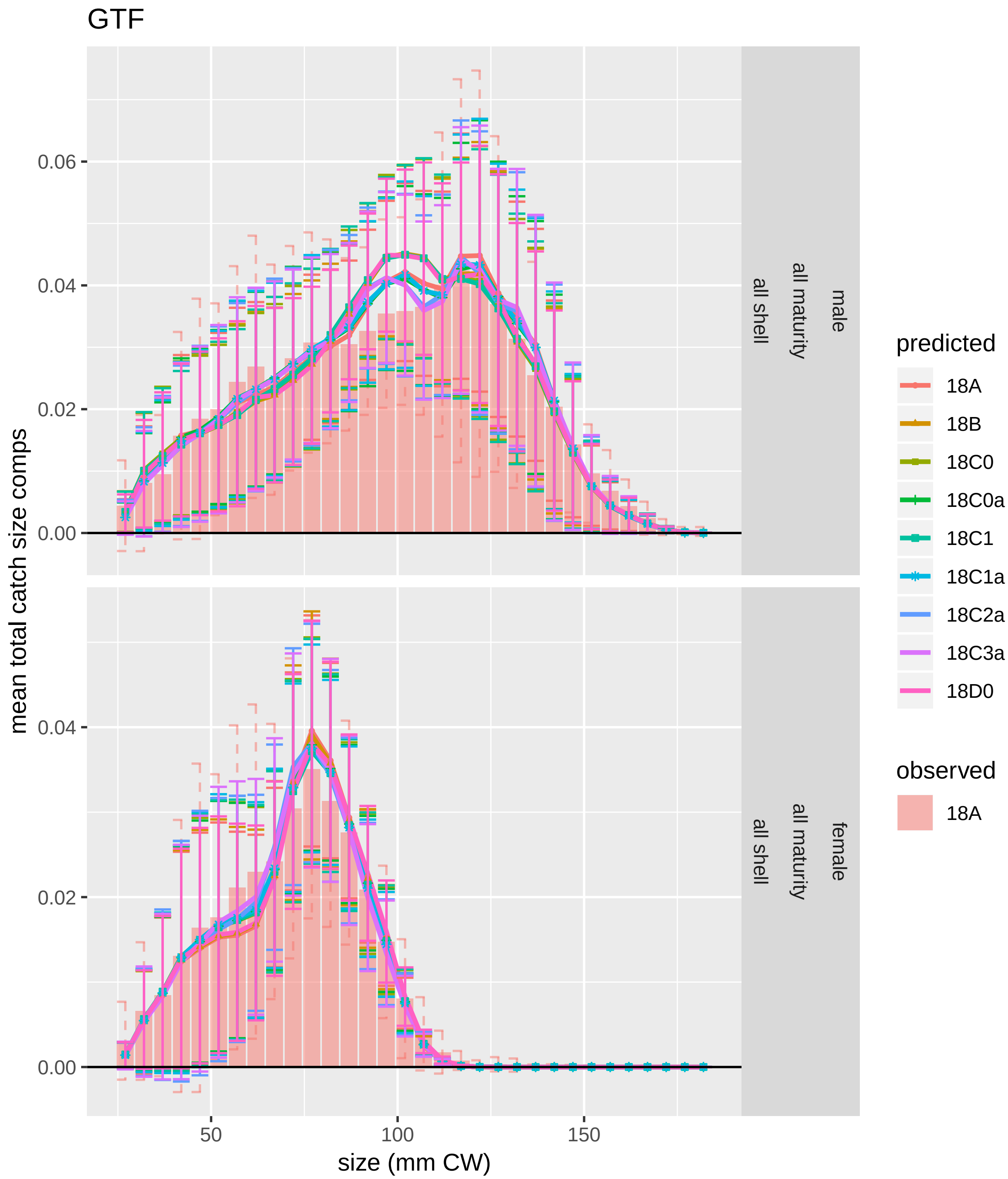

Figure 2: Comparison of observed and predicted mean total catch size comps for GTF.

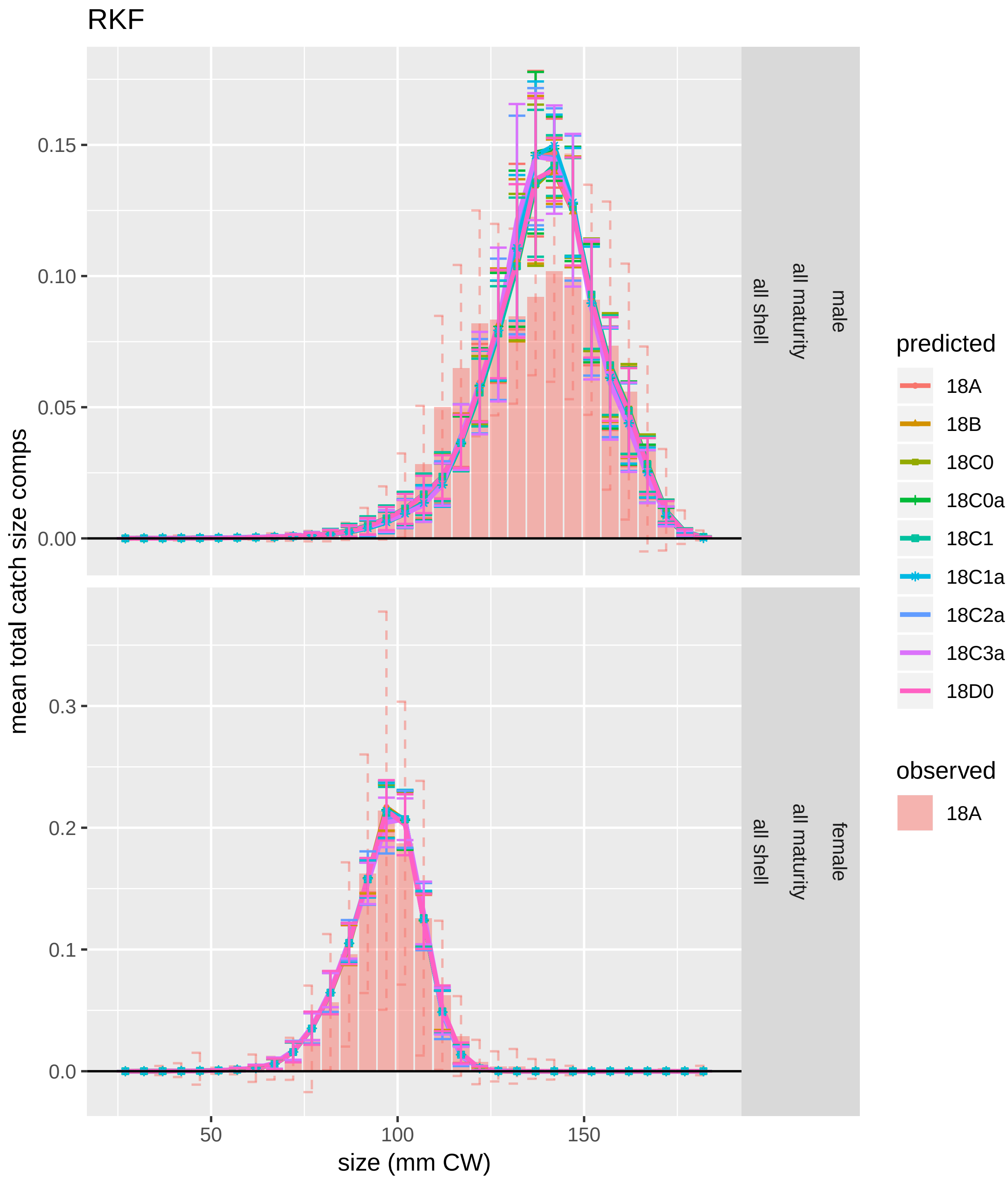

Figure 3: Comparison of observed and predicted mean total catch size comps for RKF.

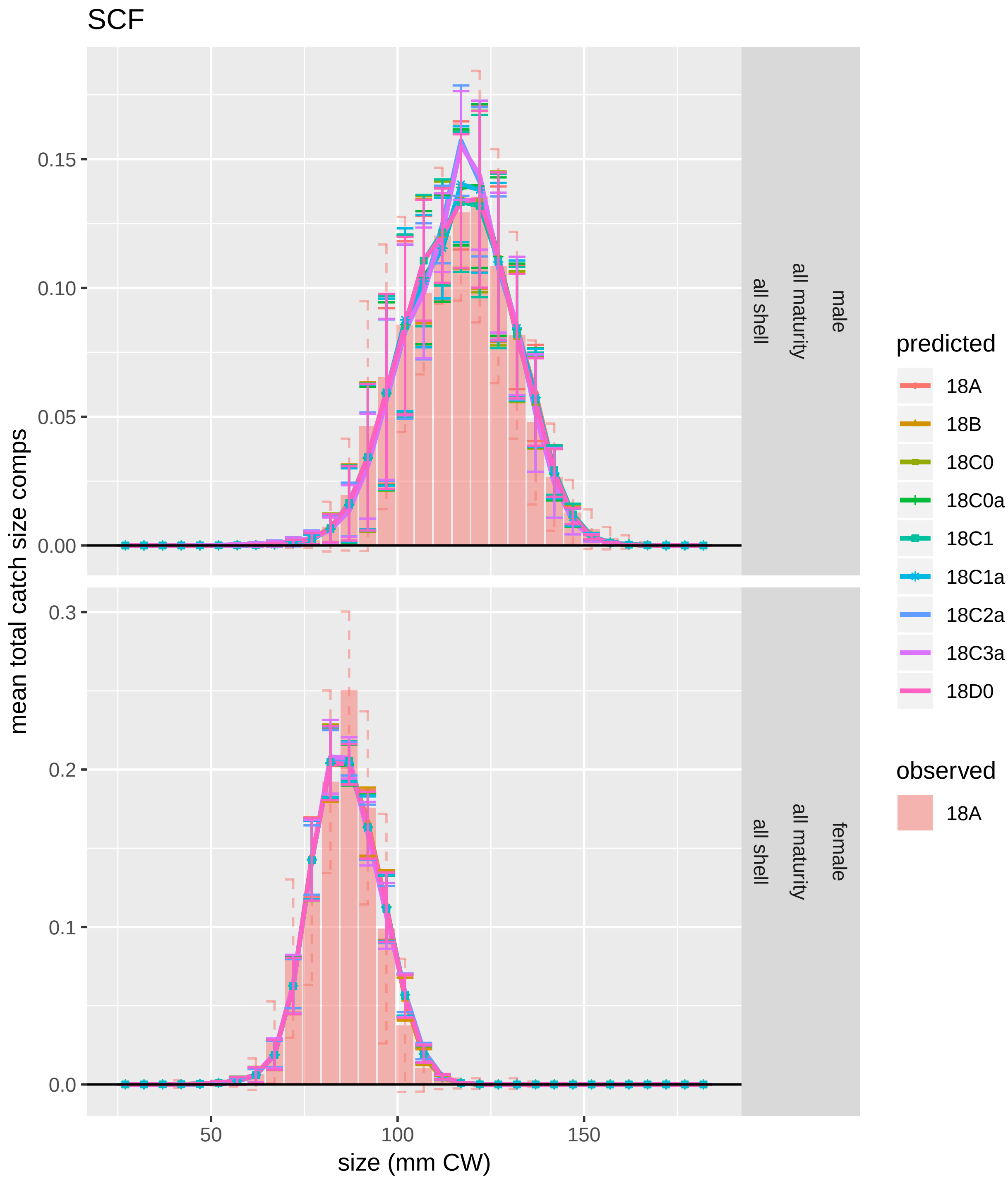

Figure 4: Comparison of observed and predicted mean total catch size comps for SCF.

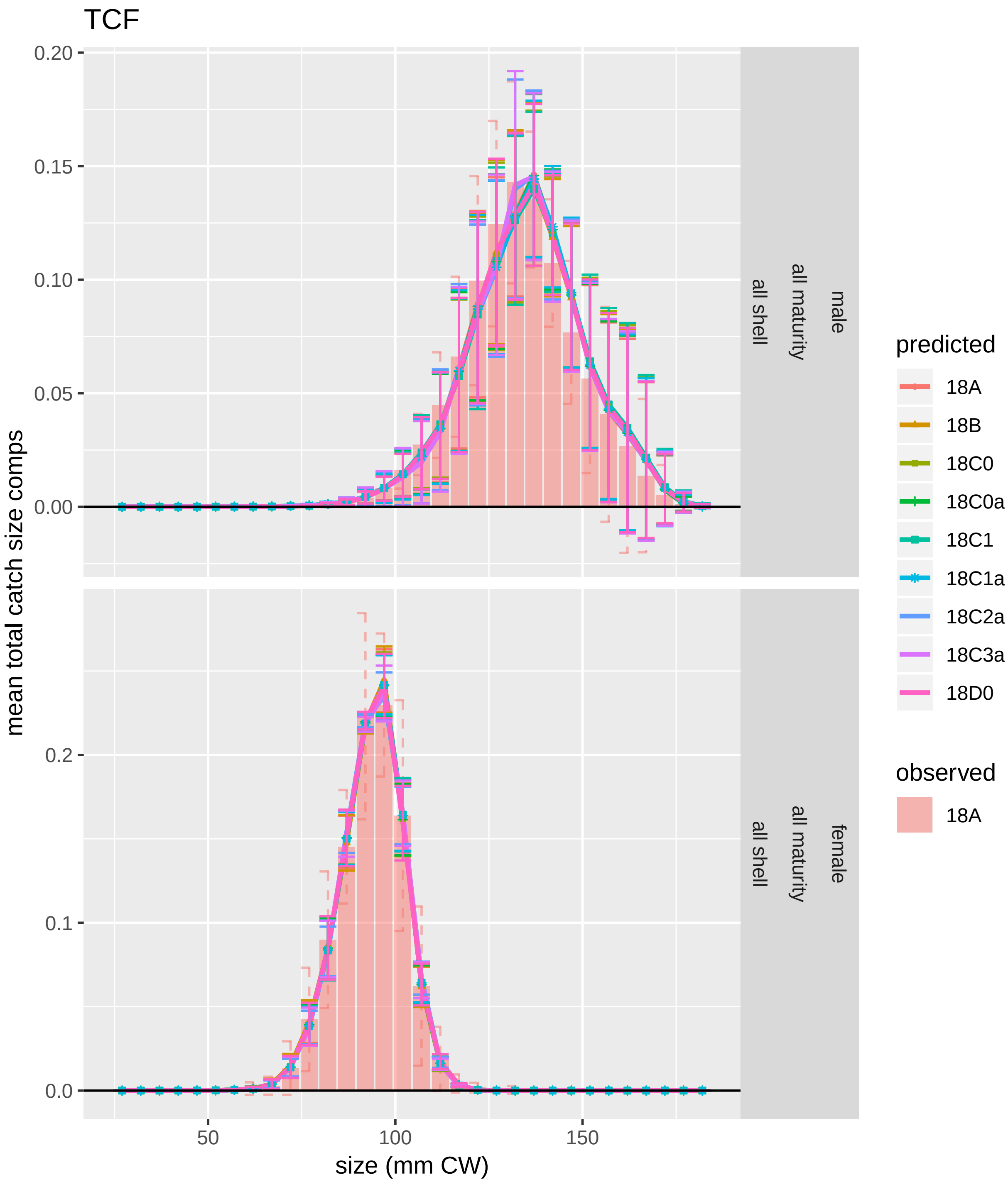

Figure 5: Comparison of observed and predicted mean total catch size comps for TCF.

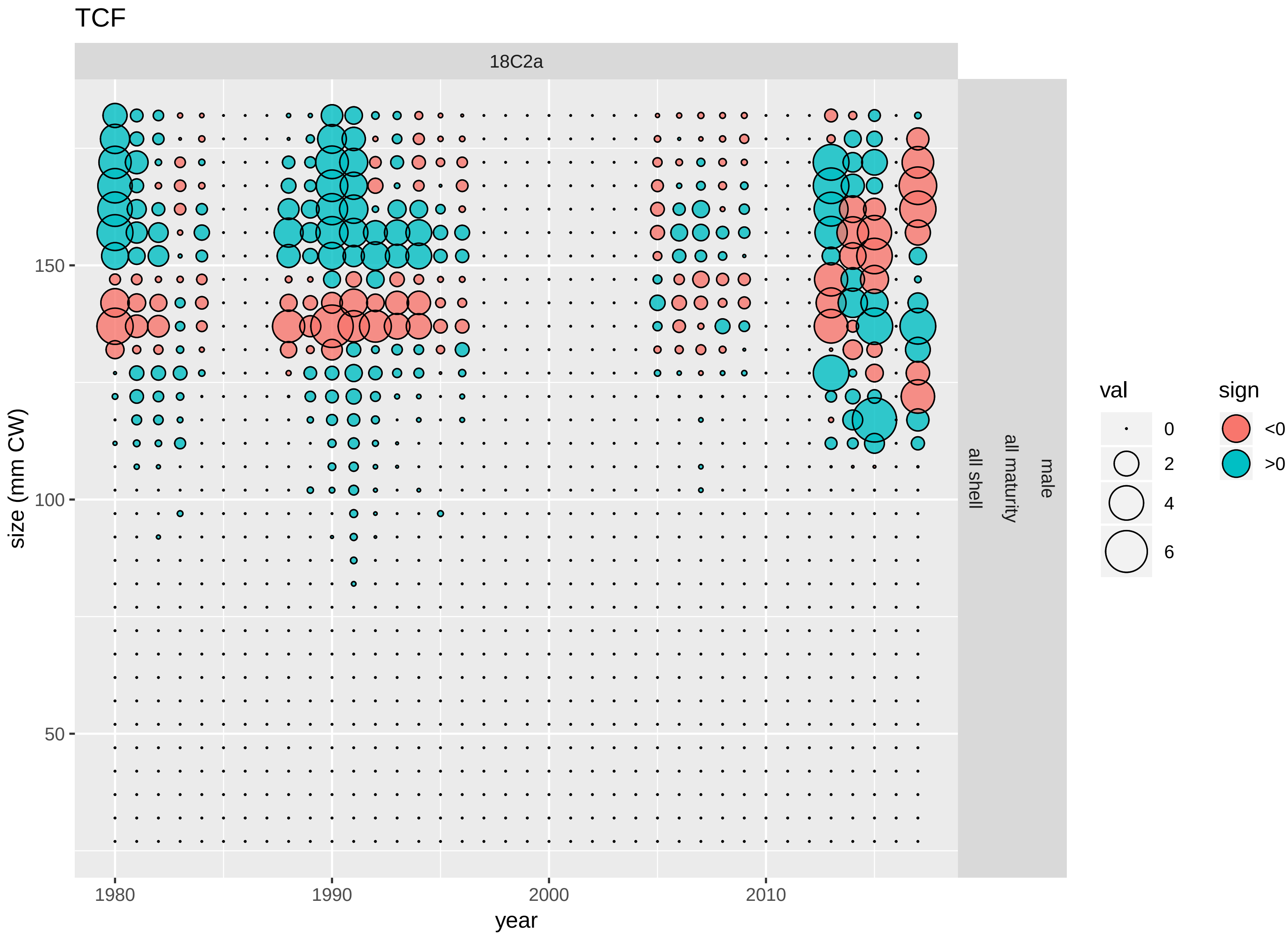

Figure 6: Pearson's residuals for proportions-at-size from the TCF for scenario 18C2a.

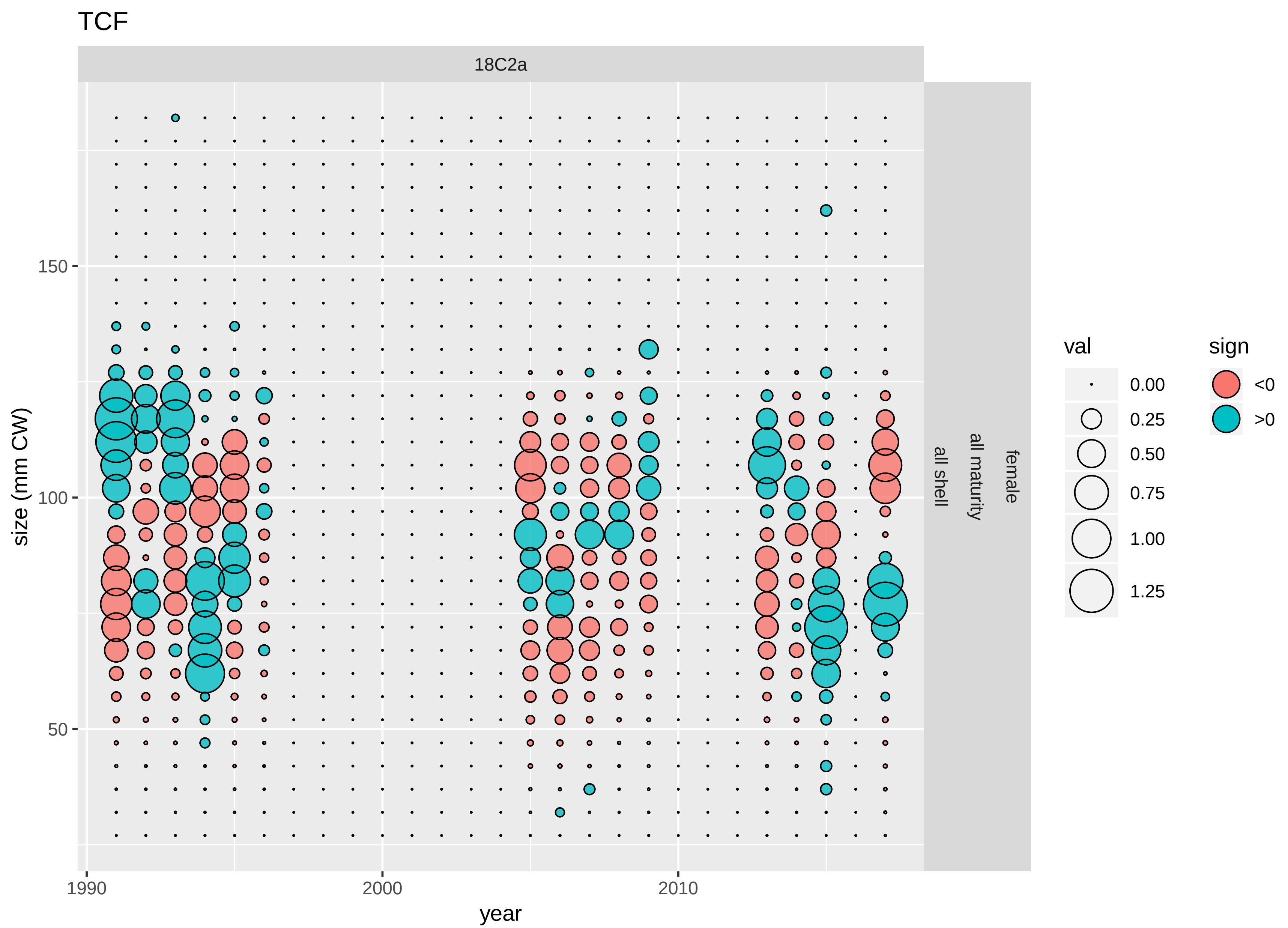

Figure 7: Pearson's residuals for proportions-at-size from the TCF for scenario 18C2a.

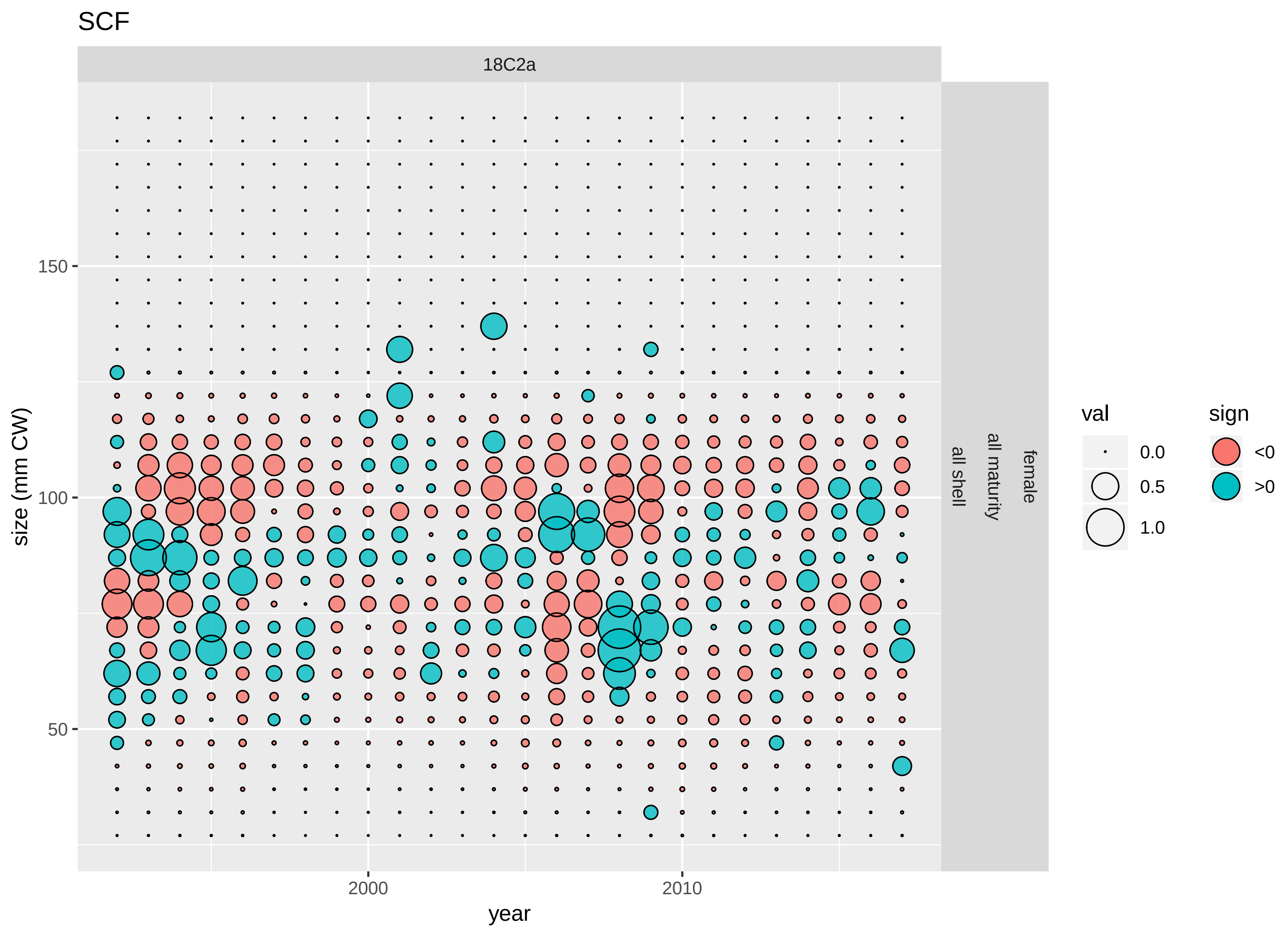

Figure 8: Pearson's residuals for proportions-at-size from the SCF for scenario 18C2a.

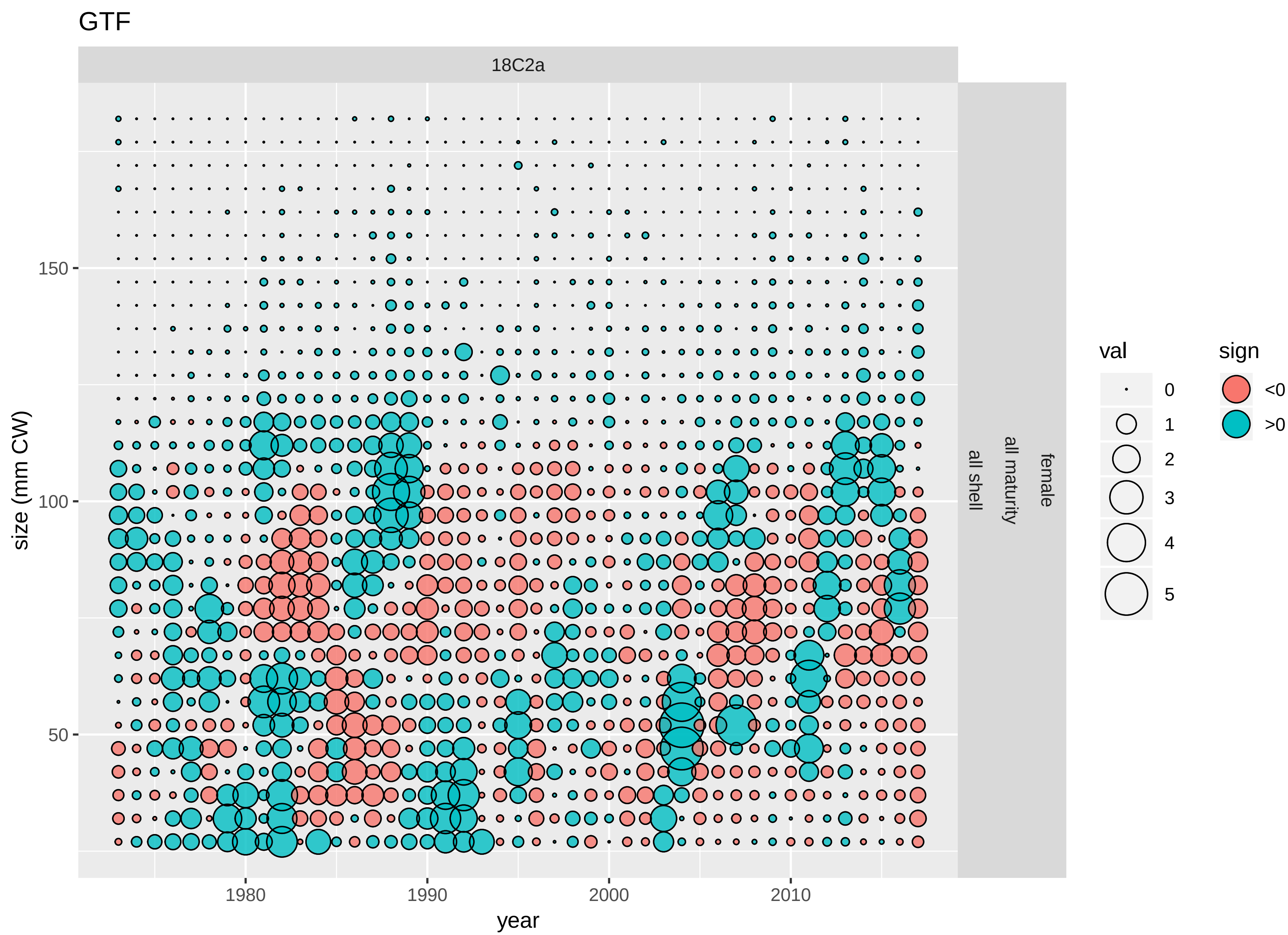

Figure 9: Pearson's residuals for proportions-at-size from the GTF for scenario 18C2a.

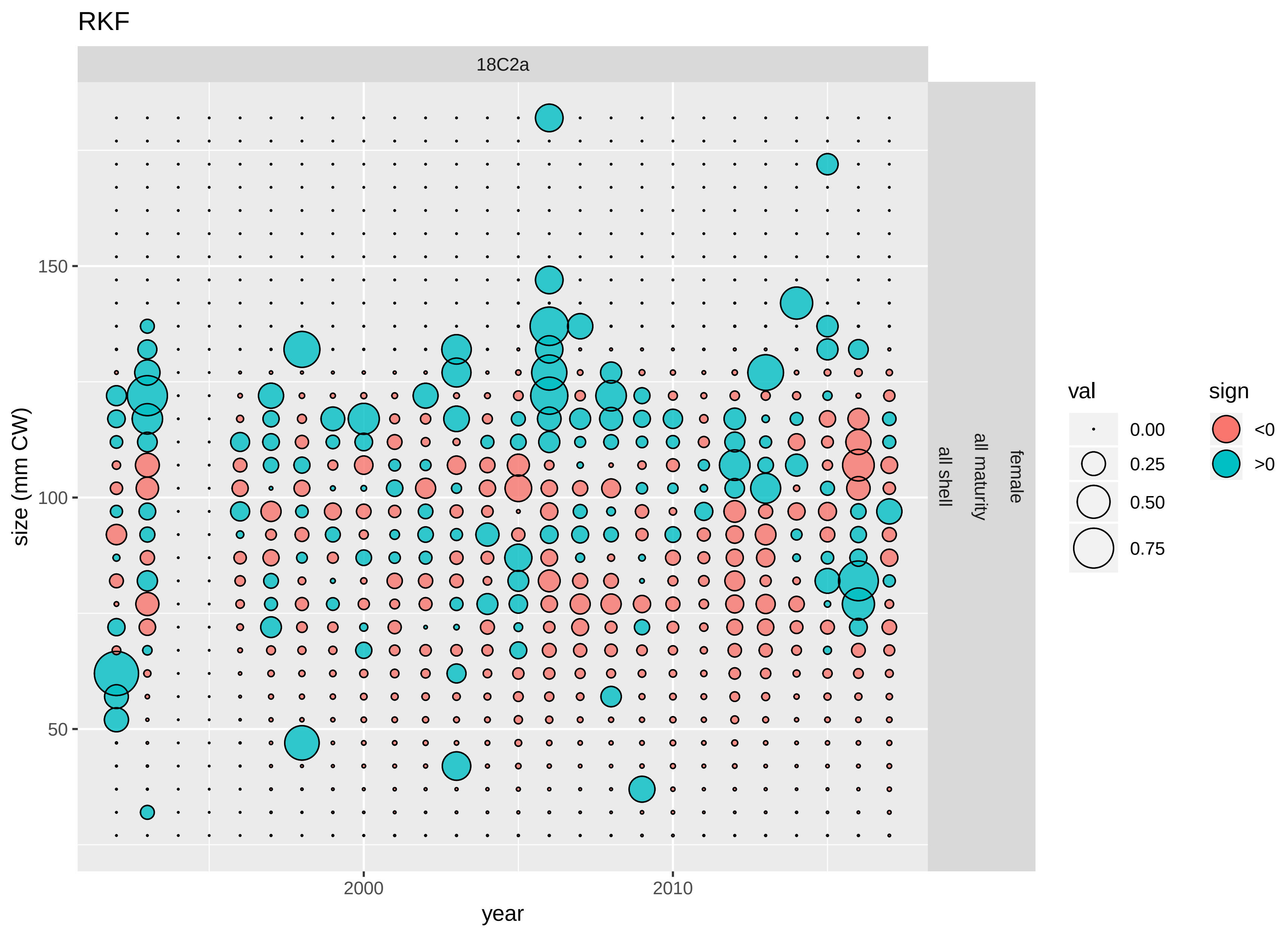

Figure 10: Pearson's residuals for proportions-at-size from the RKF for scenario 18C2a.

Effective Ns for total catch size compositions

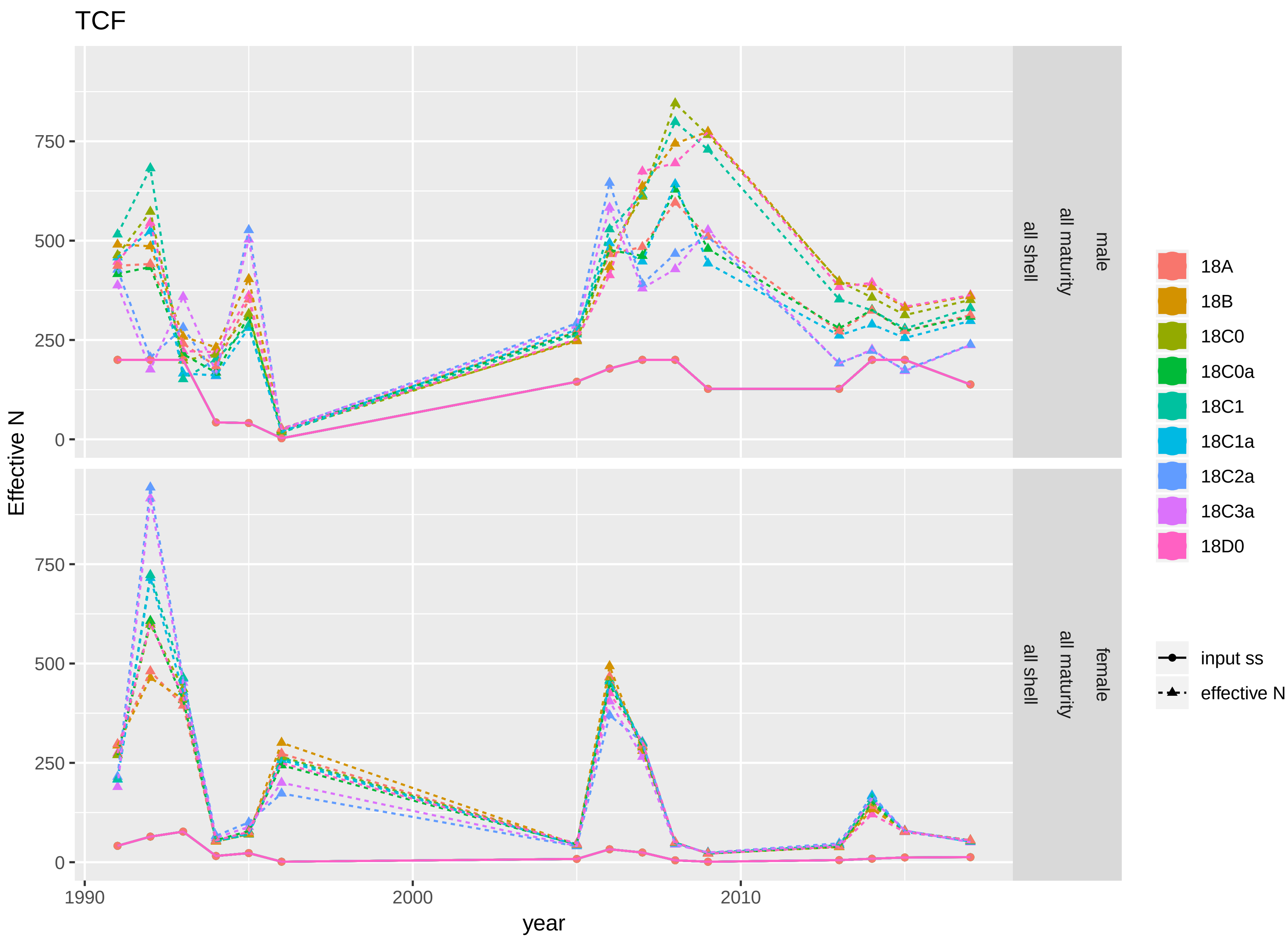

Figure 11: Input and effective sample sizes from total catch size compositions from the TCF fishery.

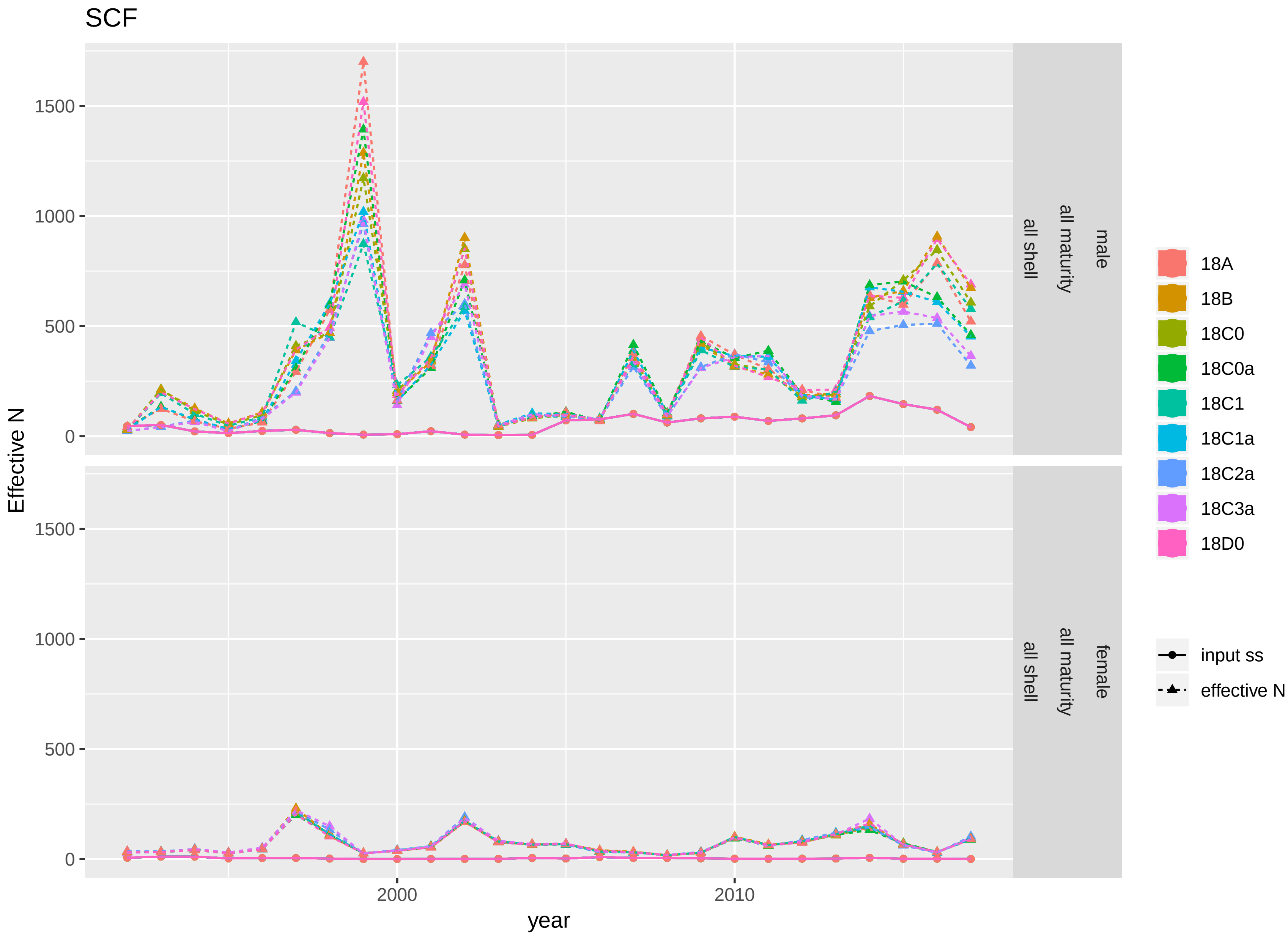

Figure 12: Input and effective sample sizes from total catch size compositions from the SCF fishery.

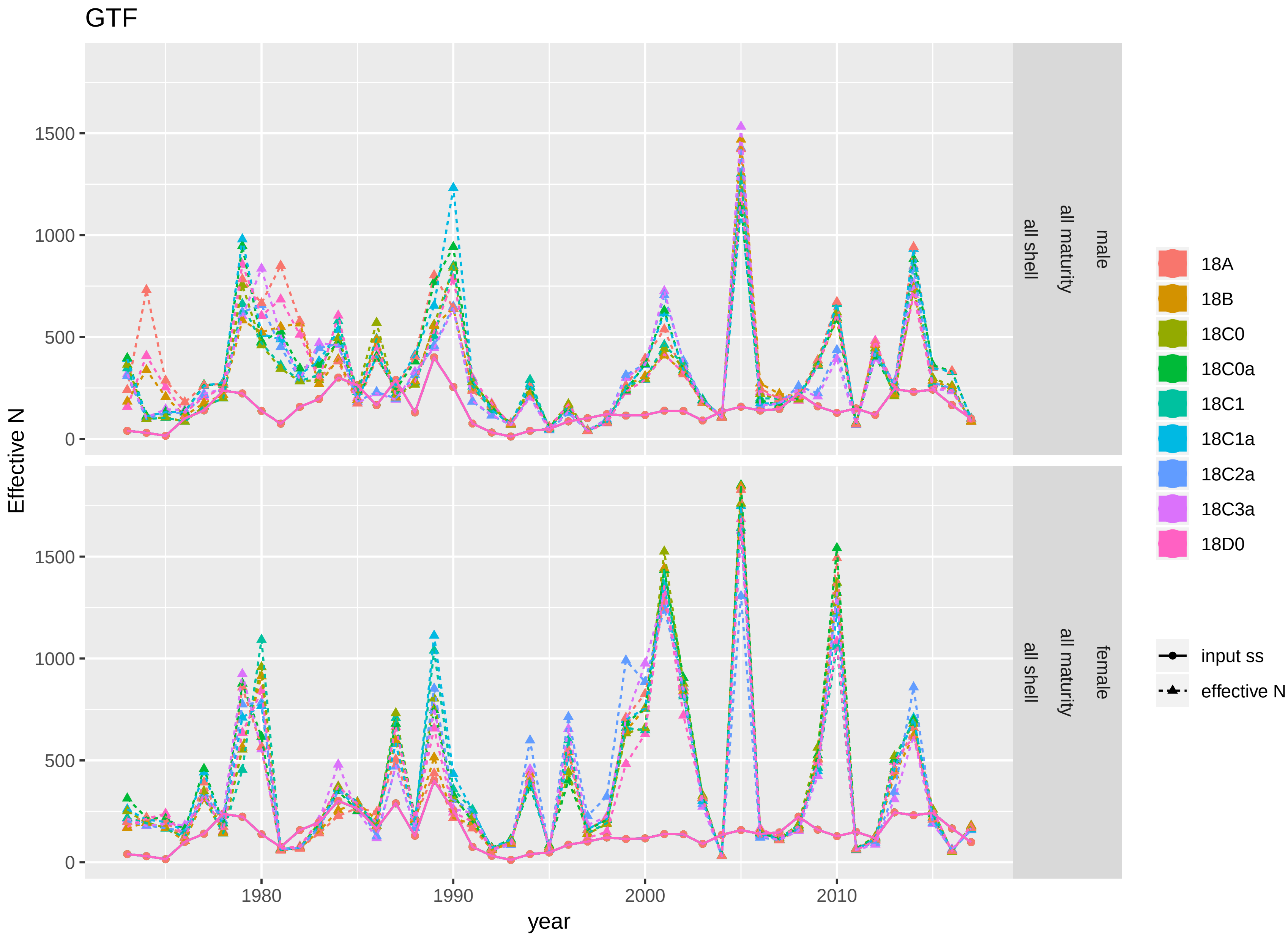

Figure 13: Input and effective sample sizes from total catch size compositions from the GTF fishery.

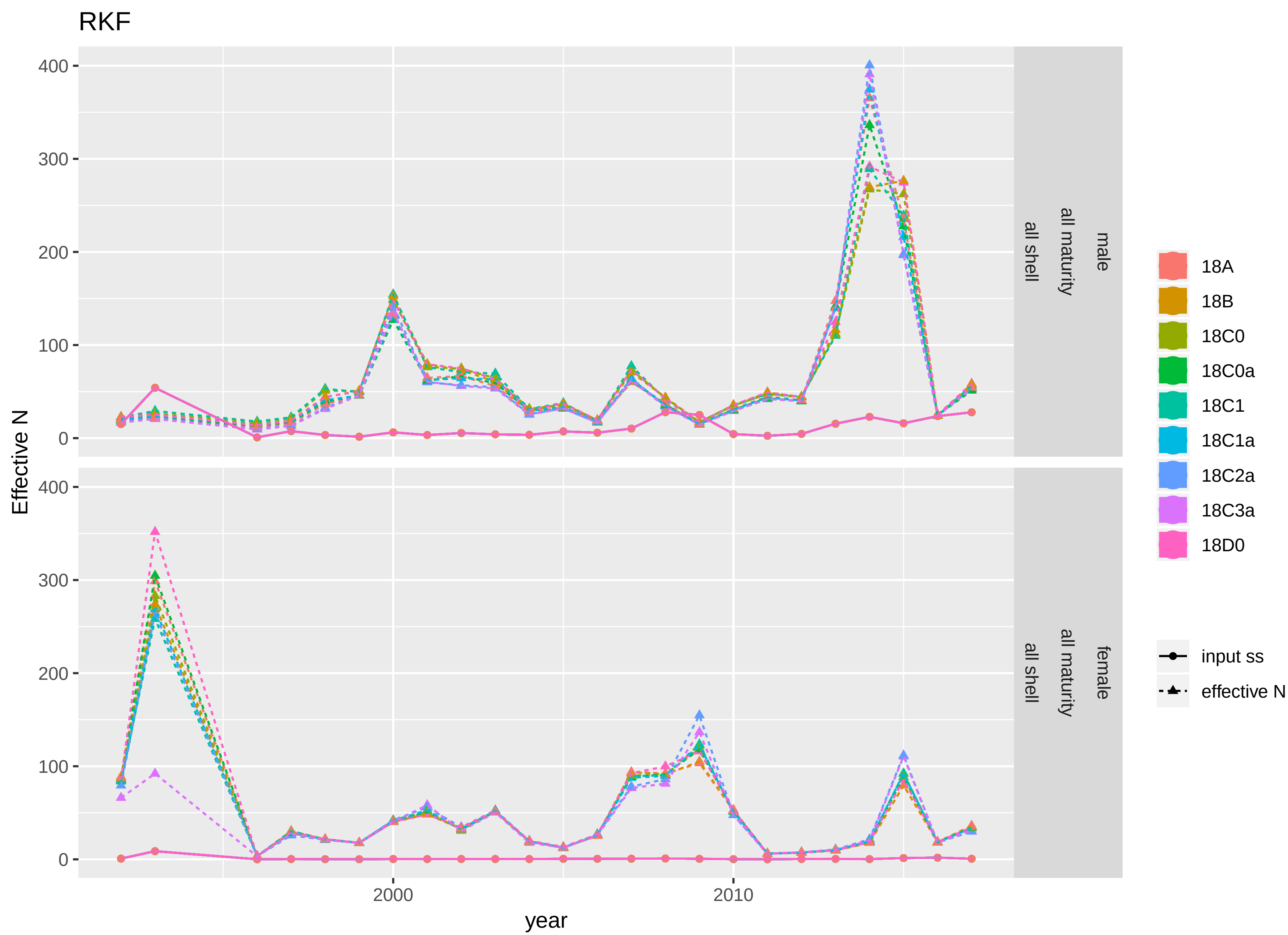

Figure 14: Input and effective sample sizes from total catch size compositions from the RKF fishery.

Appendix I4:
Fits to **Survey and Fishery** Size Composition Data from the "18" Scenarios

William Stockhausen

31 August, 2018

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

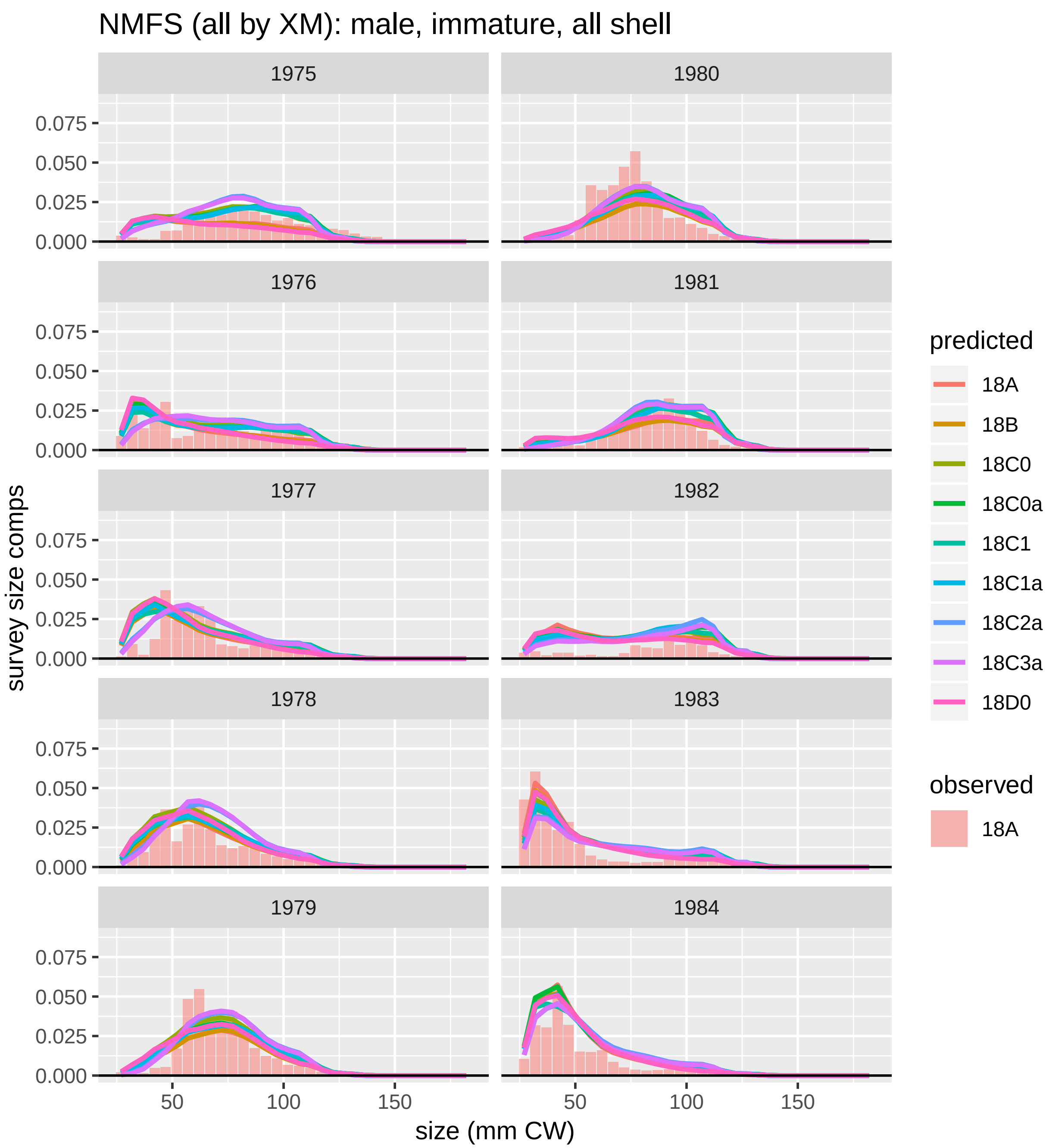

Figure 1: Comparison of observed and predicted male, immature, all shell survey size comps for NMFS (all by XM). Page 1 of 5.

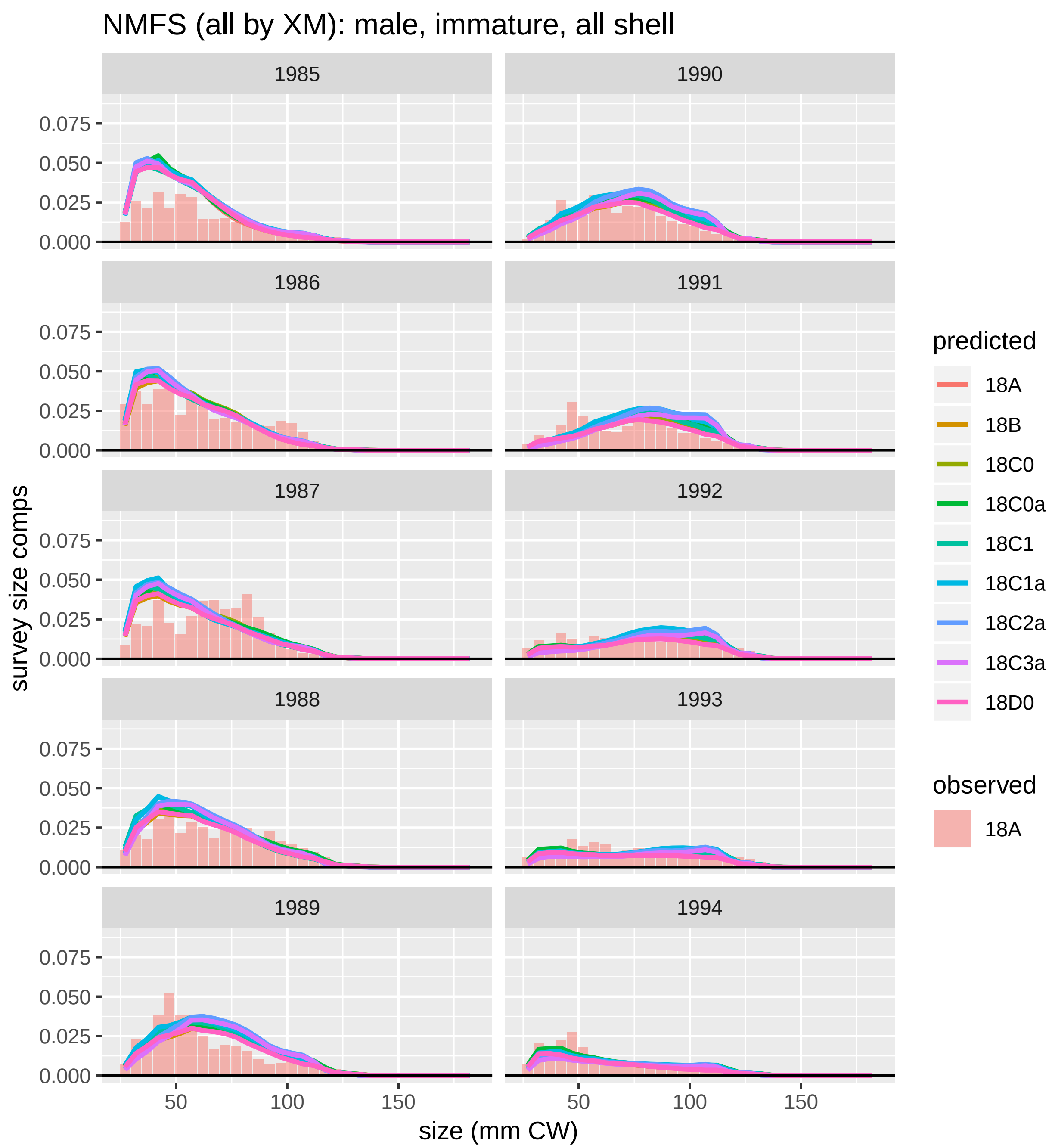

Figure 2: Comparison of observed and predicted male, immature, all shell survey size comps for NMFS (all by XM). Page 2 of 5.

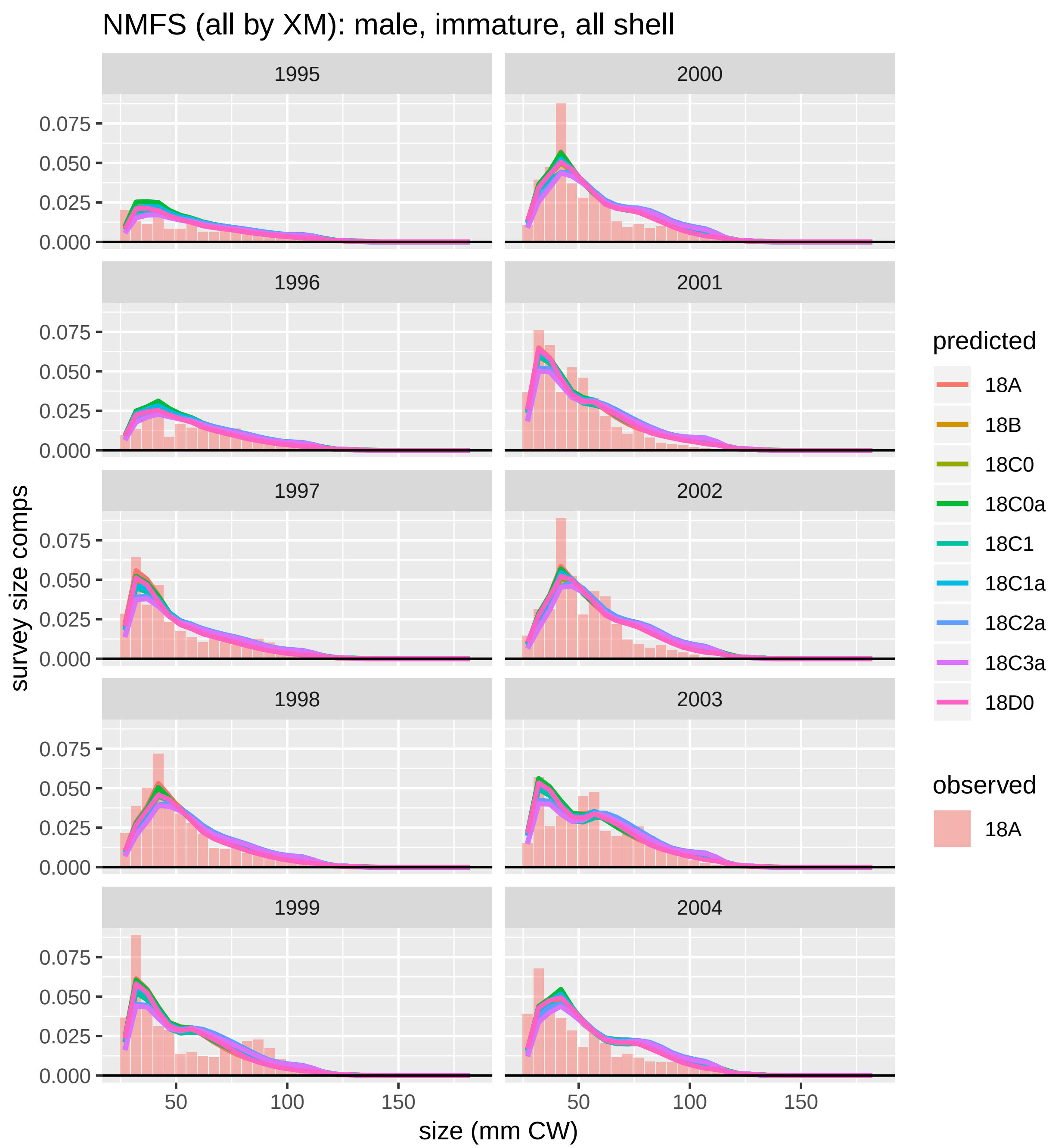

Figure 3: Comparison of observed and predicted male, immature, all shell survey size comps for NMFS (all by XM). Page 3 of 5.

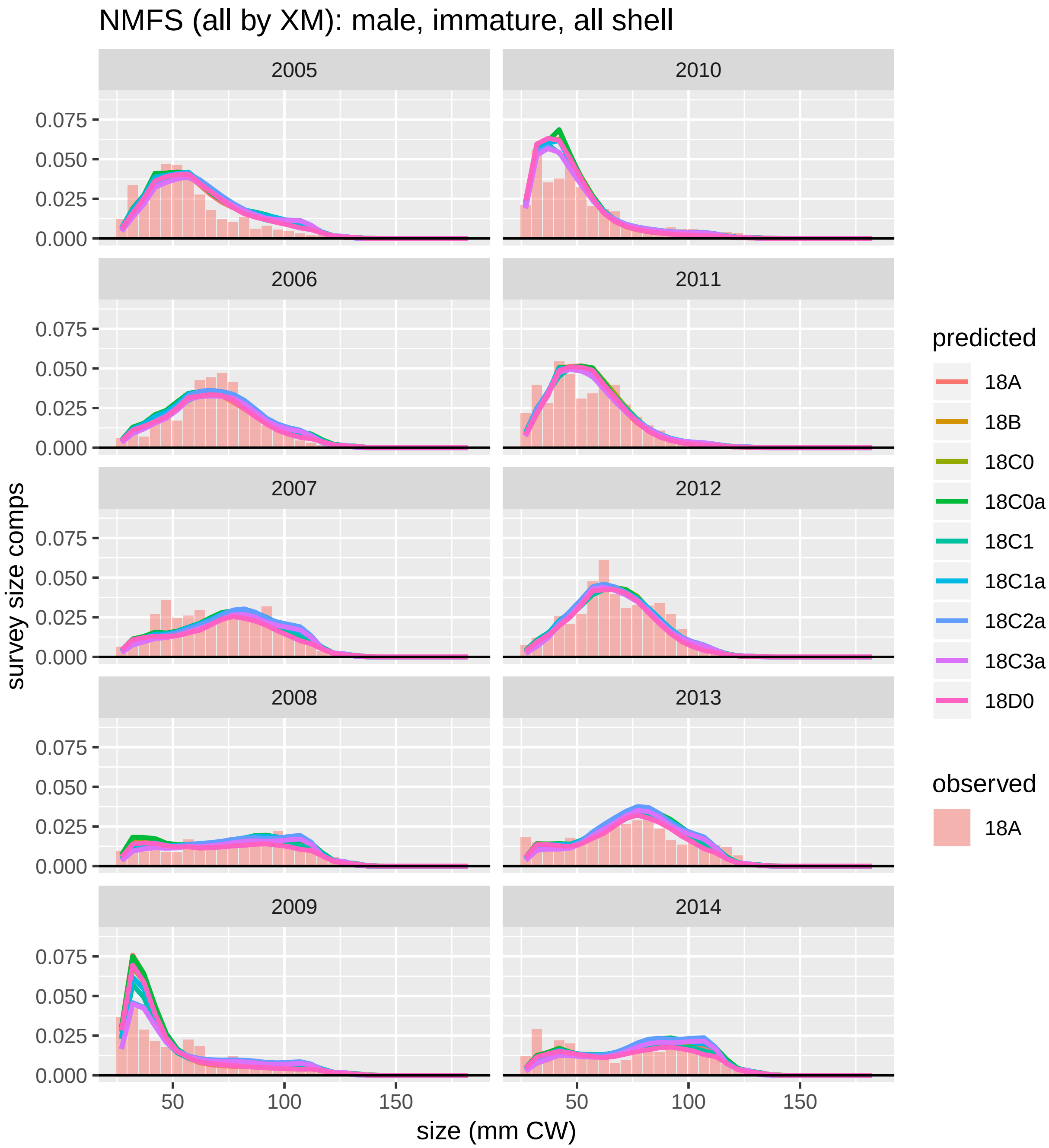

Figure 4: Comparison of observed and predicted male, immature, all shell survey size comps for NMFS (all by XM). Page 4 of 5.

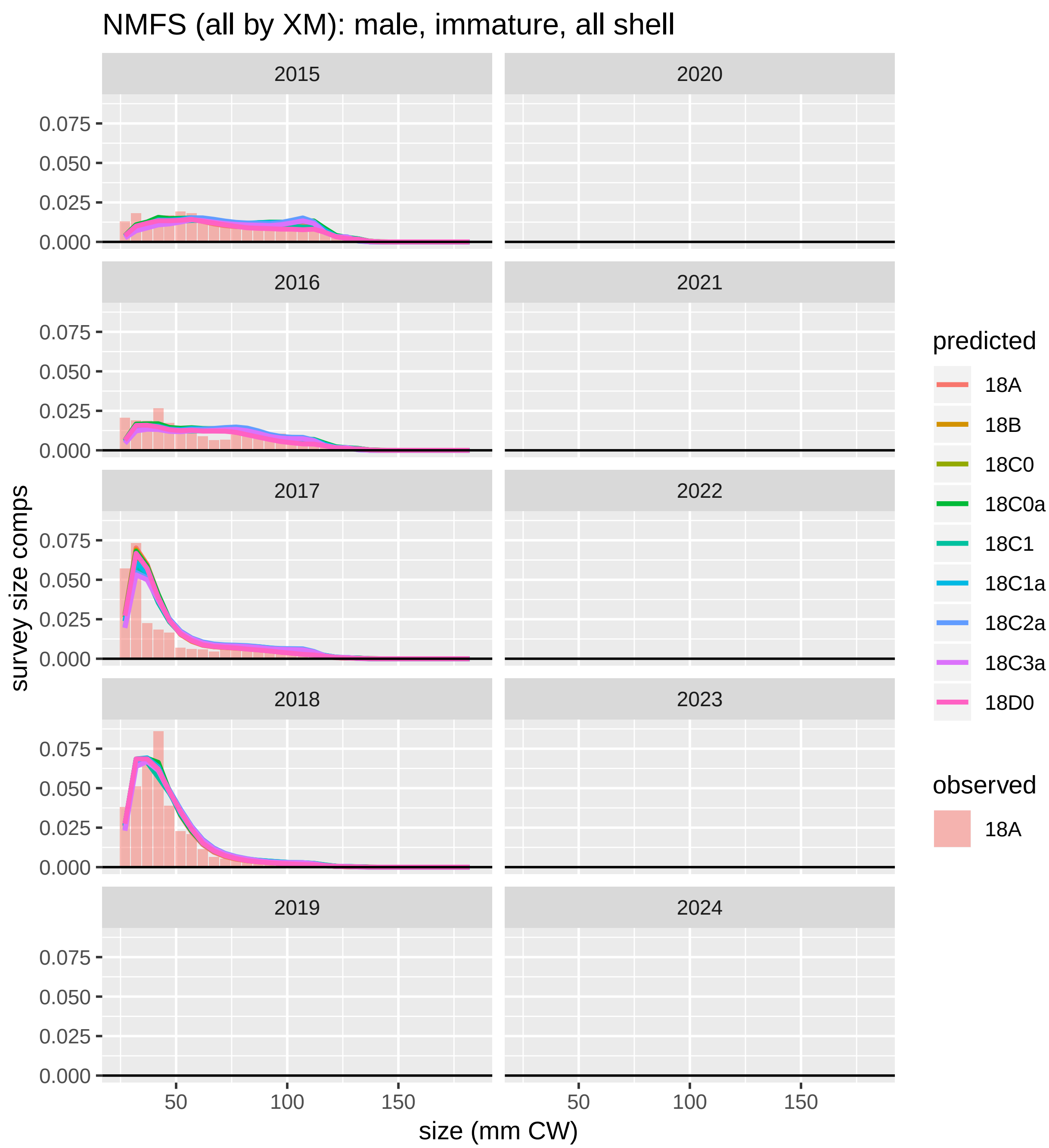

Figure 5: Comparison of observed and predicted male, immature, all shell survey size comps for NMFS (all by XM). Page 5 of 5.

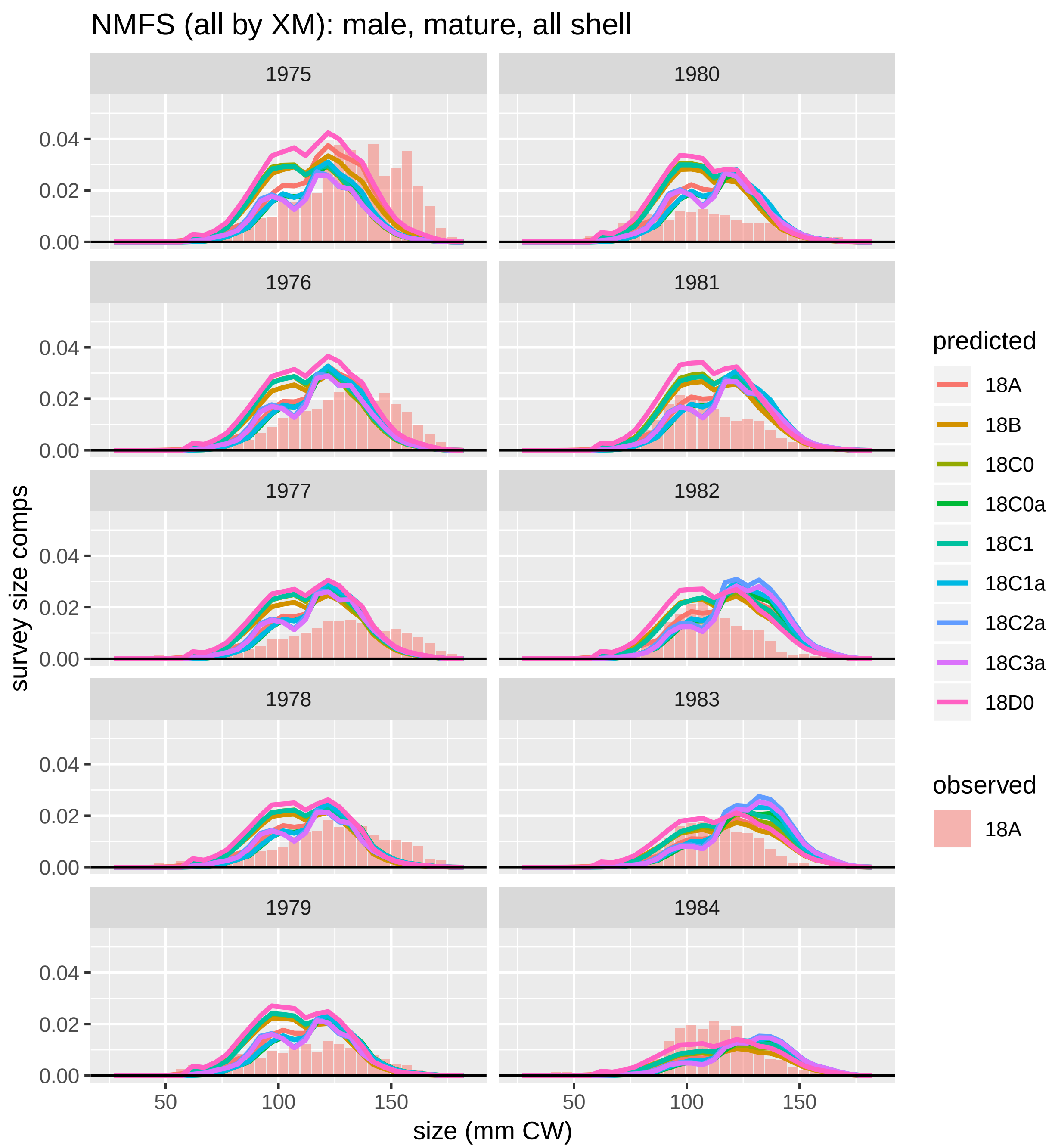

Figure 6: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS (all by XM). Page 1 of 5.

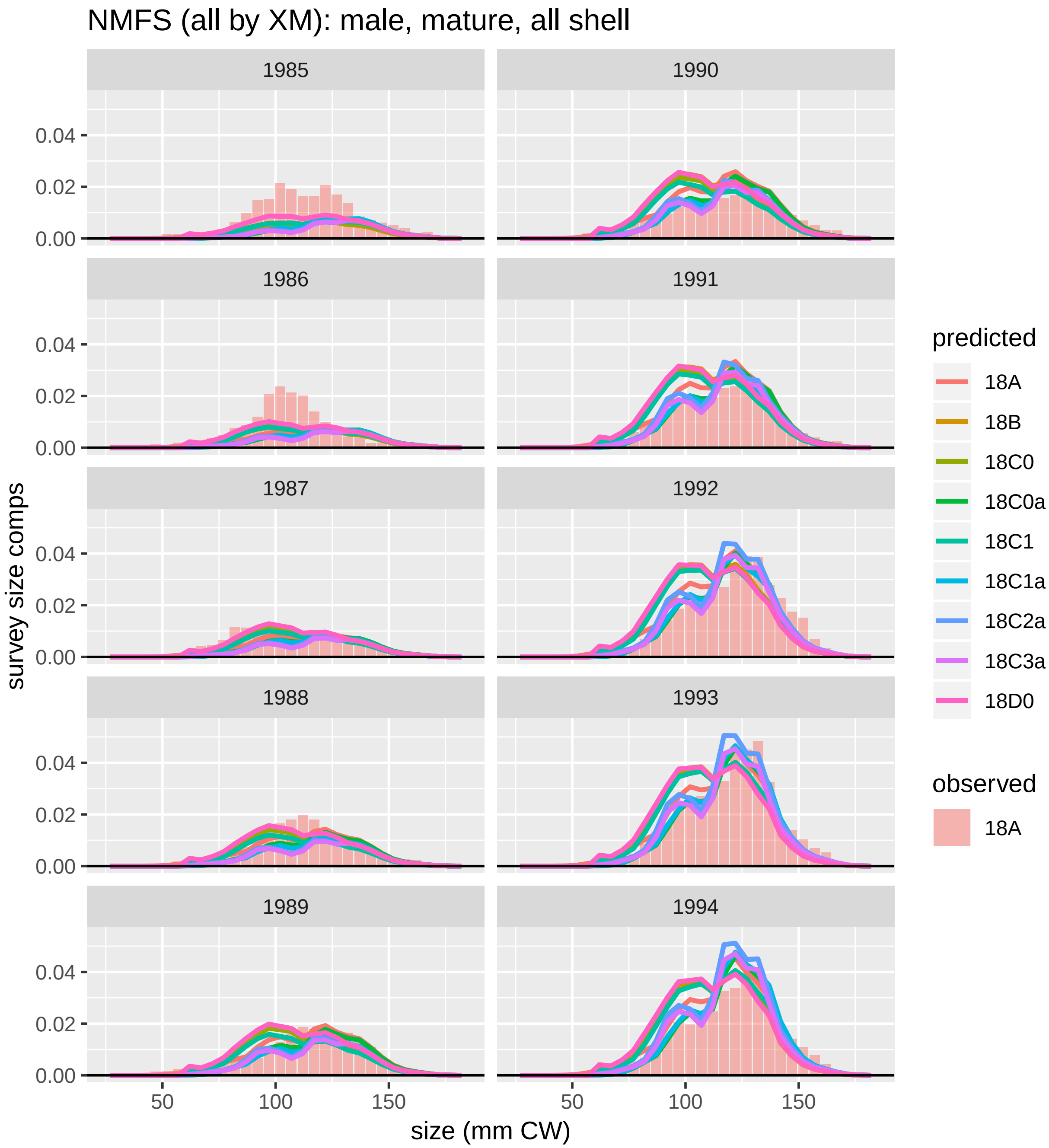

Figure 7: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS (all by XM). Page 2 of 5.

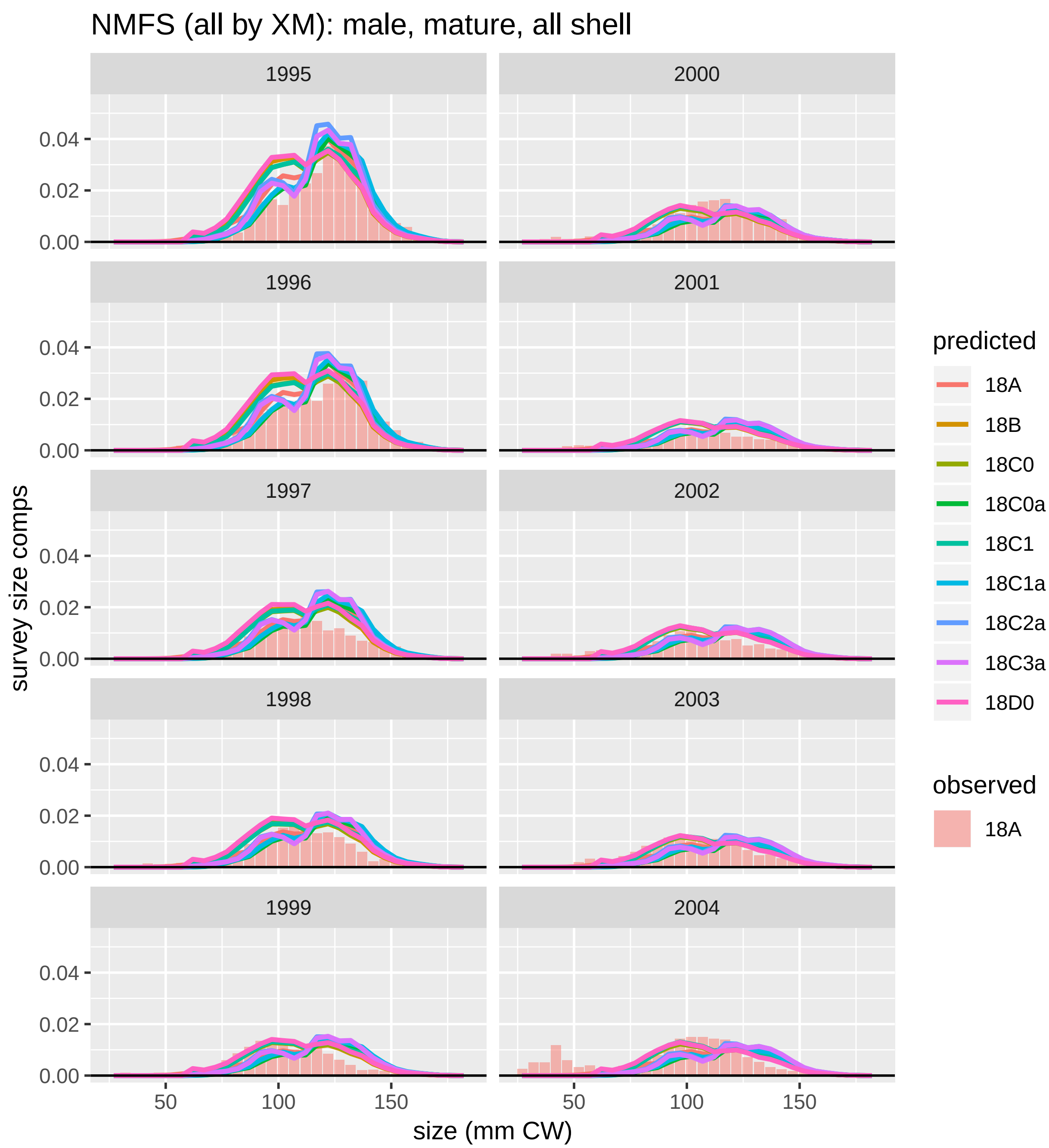

Figure 8: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS (all by XM). Page 3 of 5.

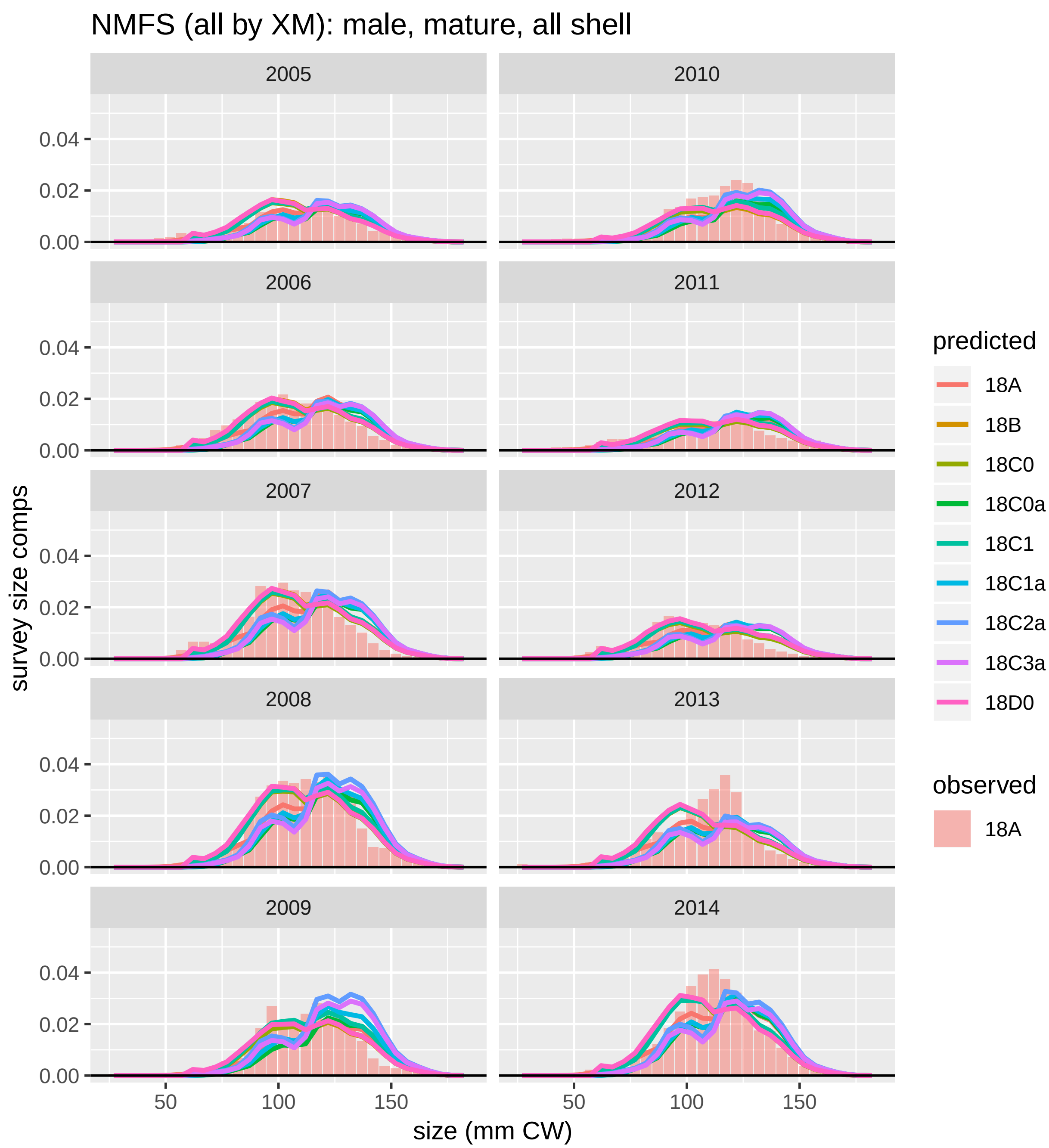

Figure 9: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS (all by XM). Page 4 of 5.

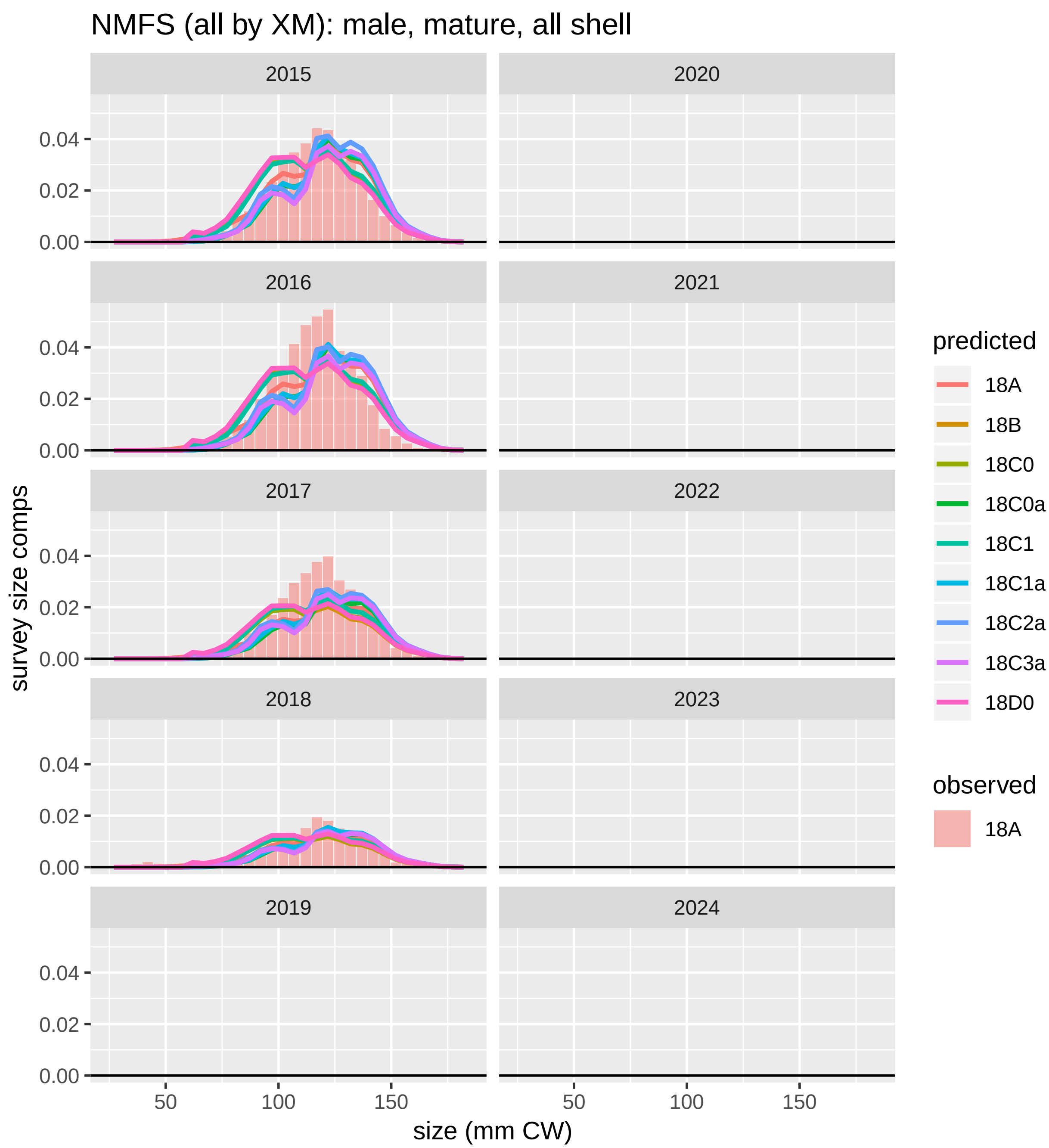

Figure 10: Comparison of observed and predicted male, mature, all shell survey size comps for NMFS (all by XM). Page 5 of 5.

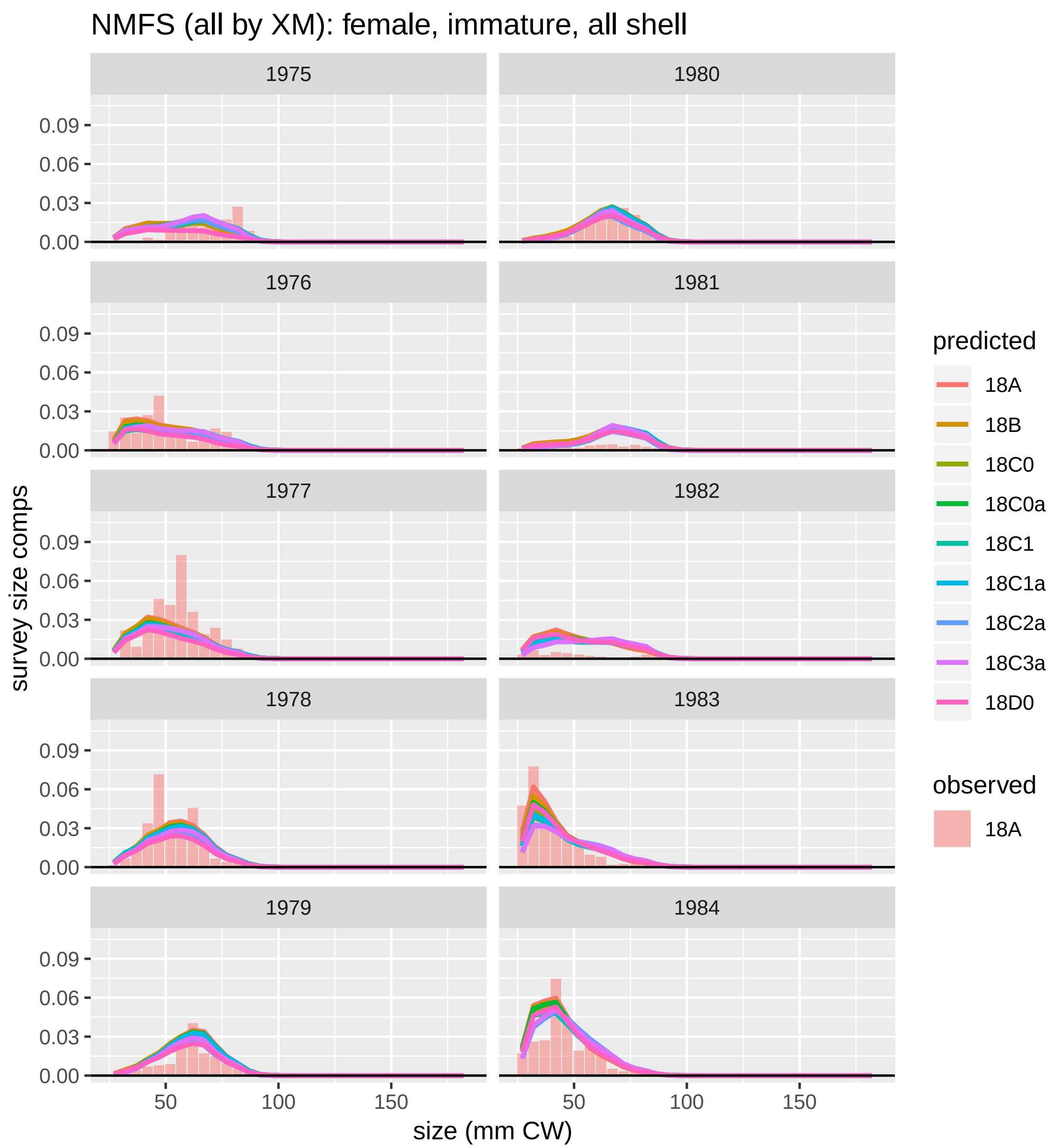

Figure 11: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS (all by XM). Page 1 of 5.

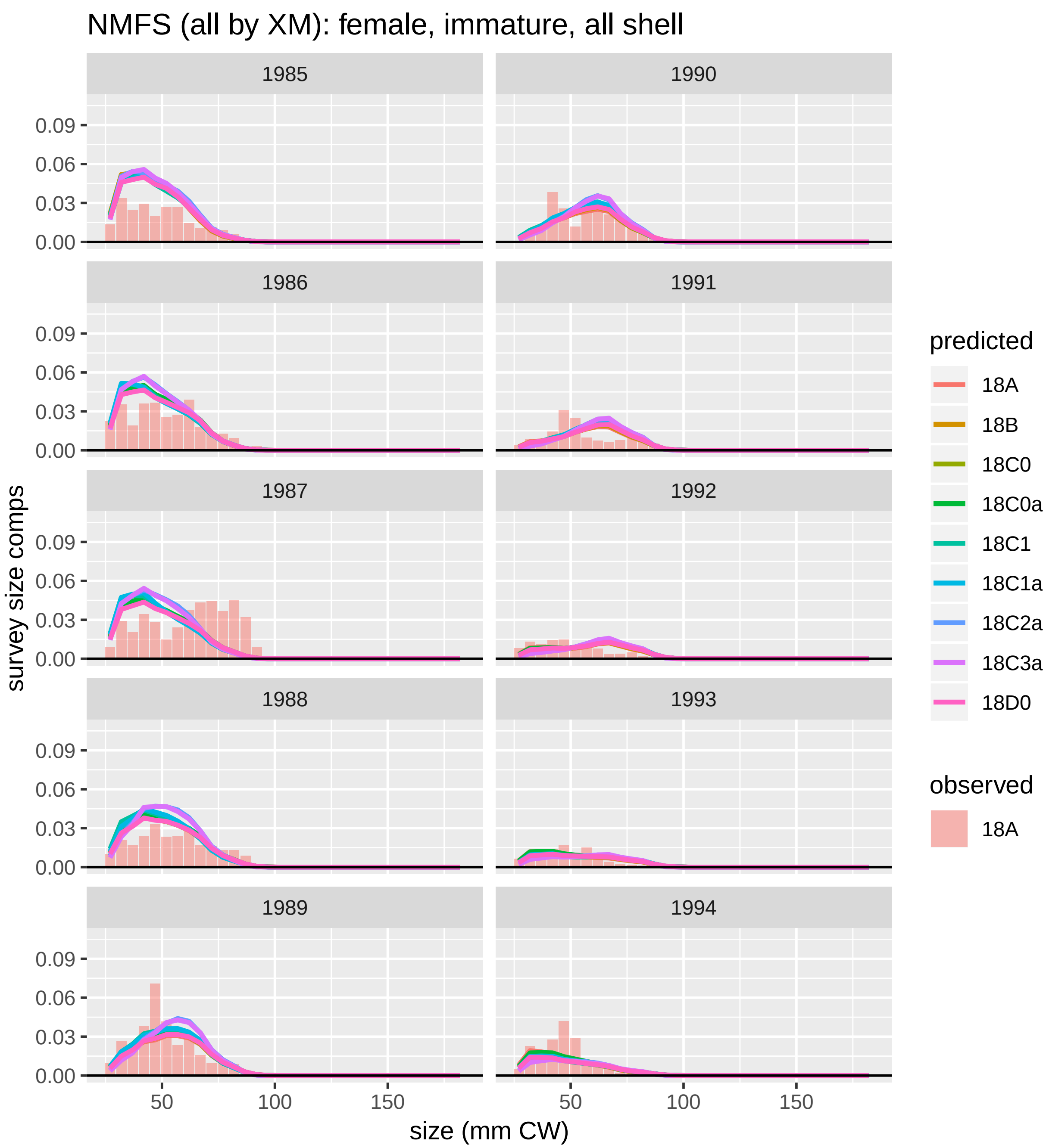

Figure 12: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS (all by XM). Page 2 of 5.

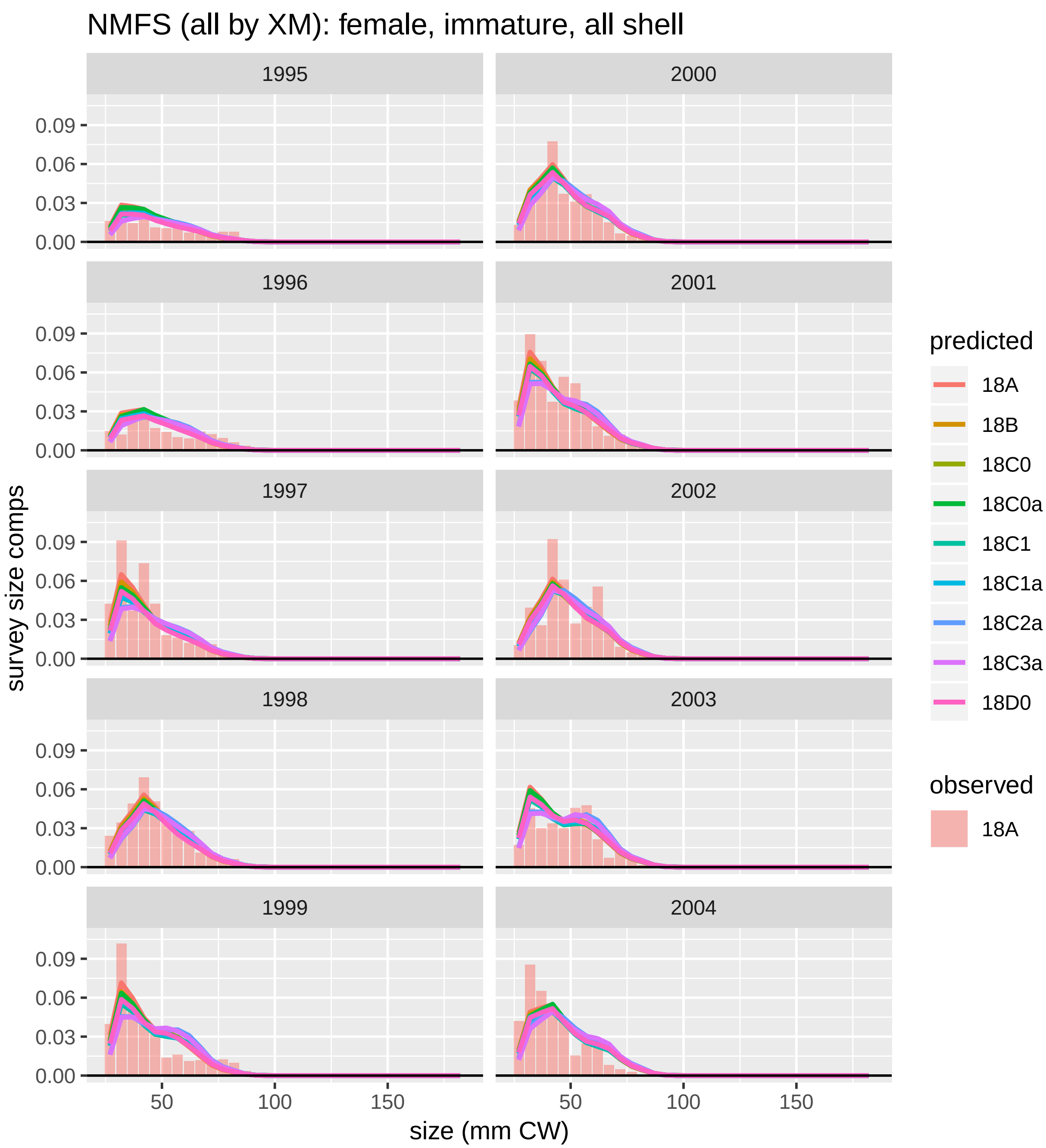

Figure 13: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS (all by XM). Page 3 of 5.

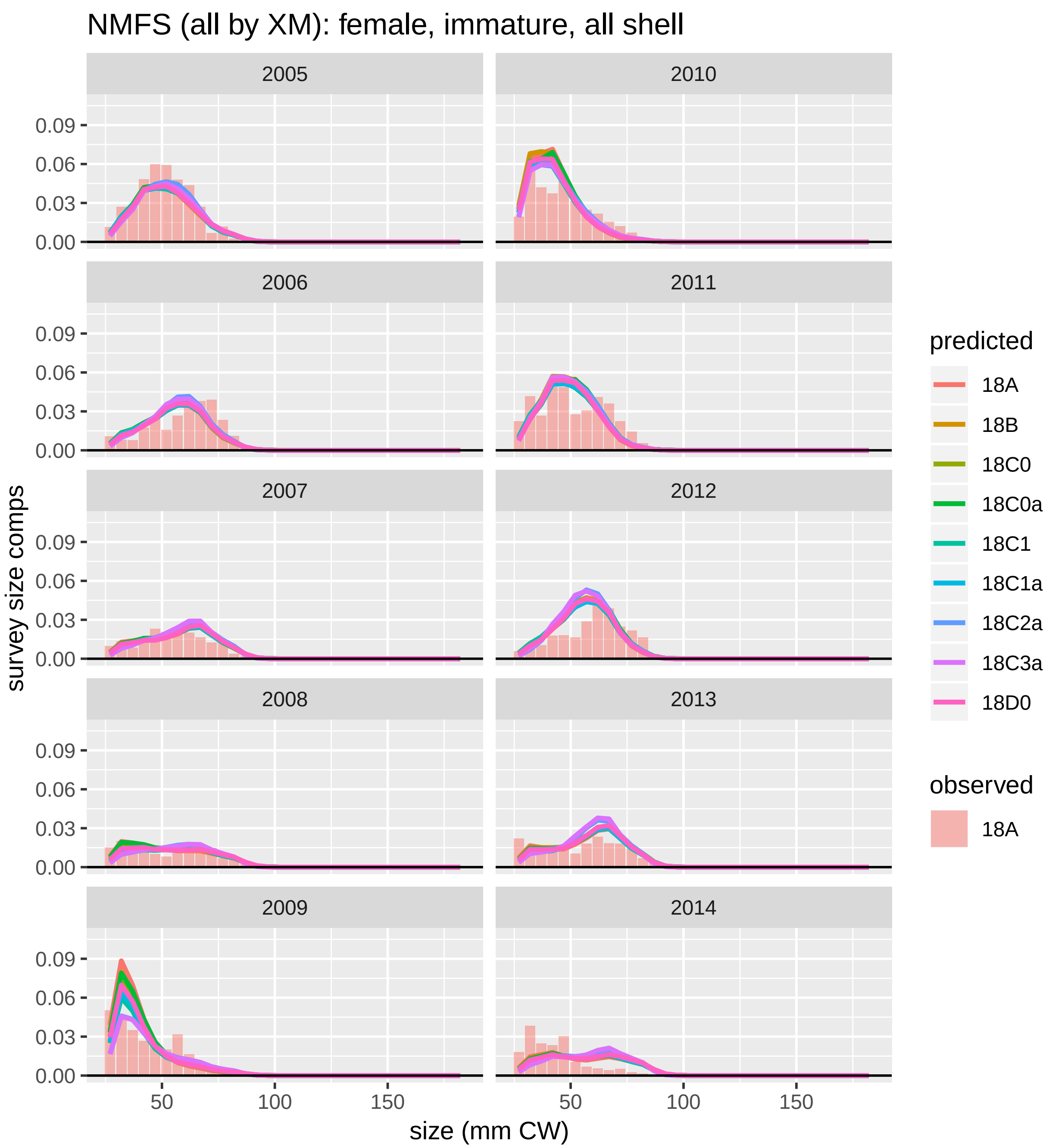

Figure 14: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS (all by XM). Page 4 of 5.

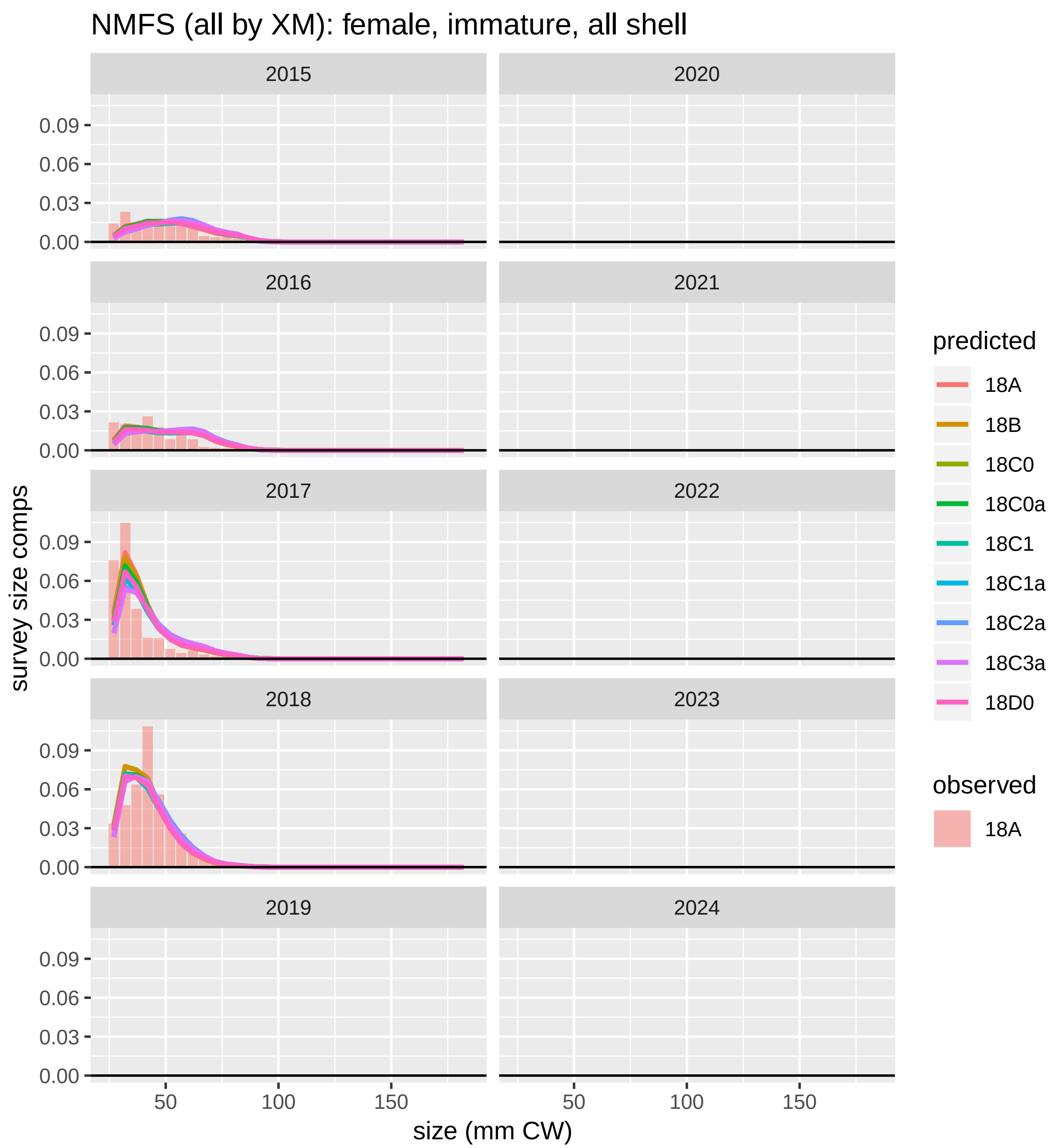

Figure 15: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS (all by XM). Page 5 of 5.

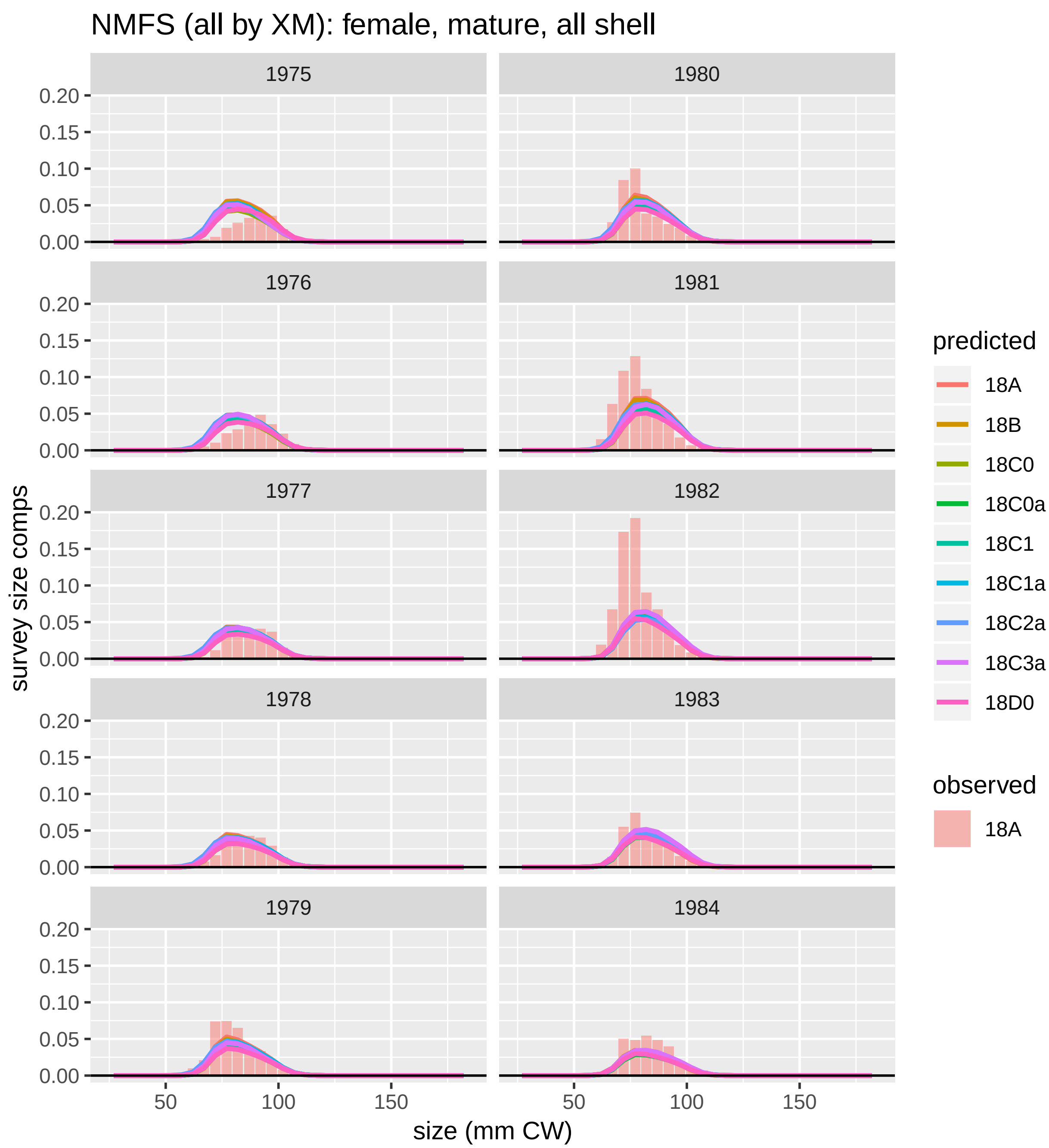

Figure 16: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS (all by XM). Page 1 of 5.

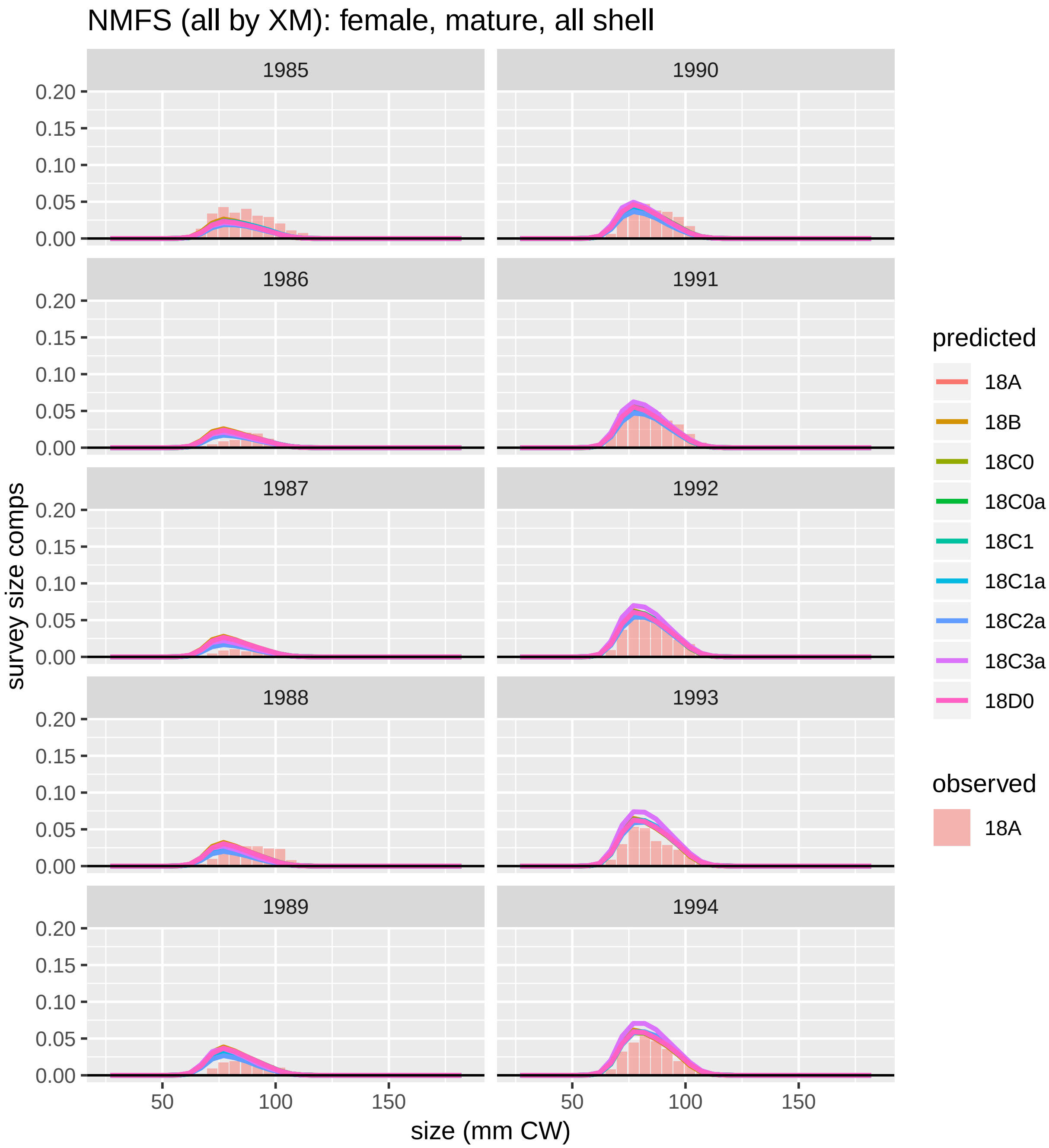

Figure 17: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS (all by XM). Page 2 of 5.

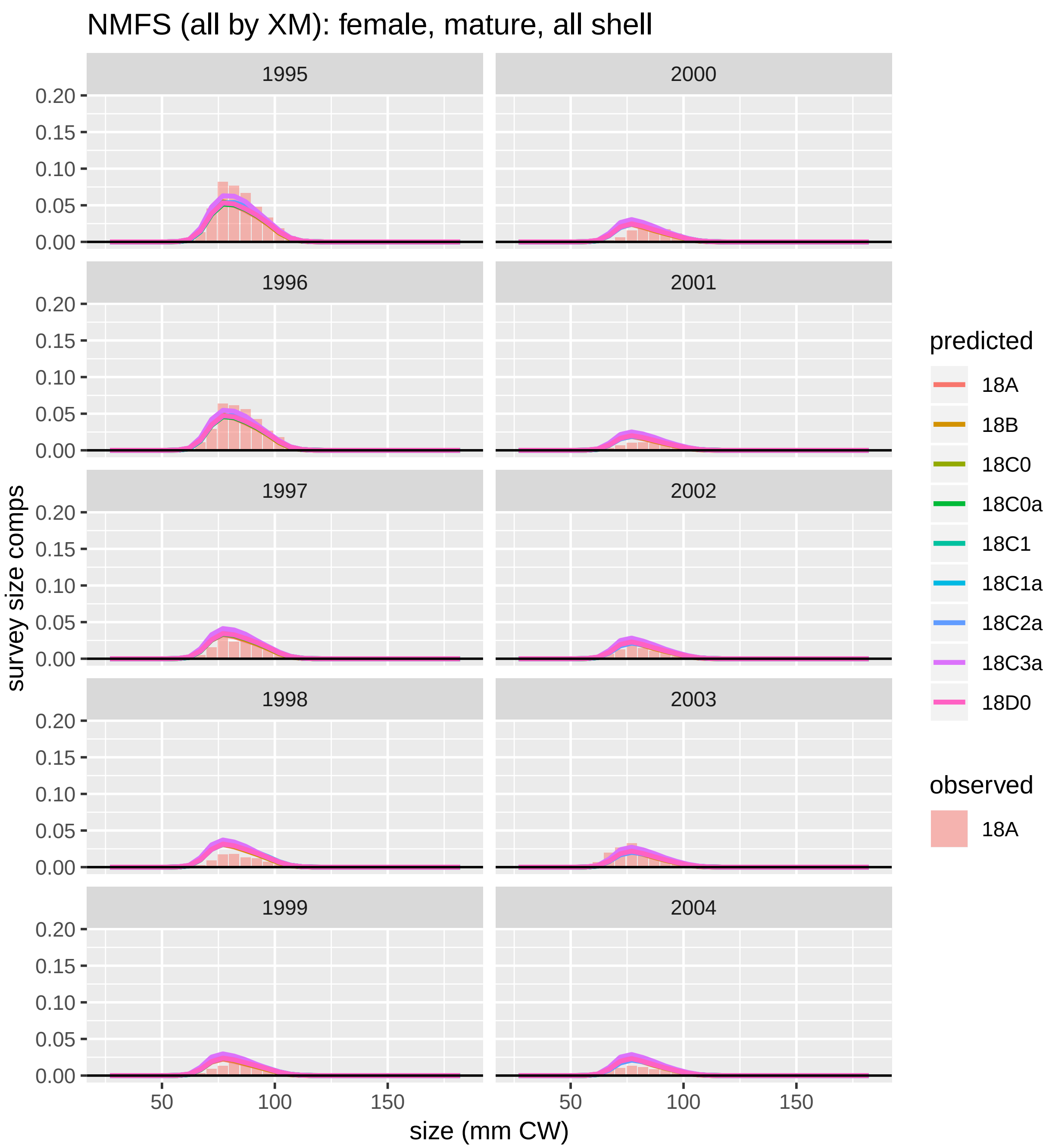

Figure 18: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS (all by XM). Page 3 of 5.

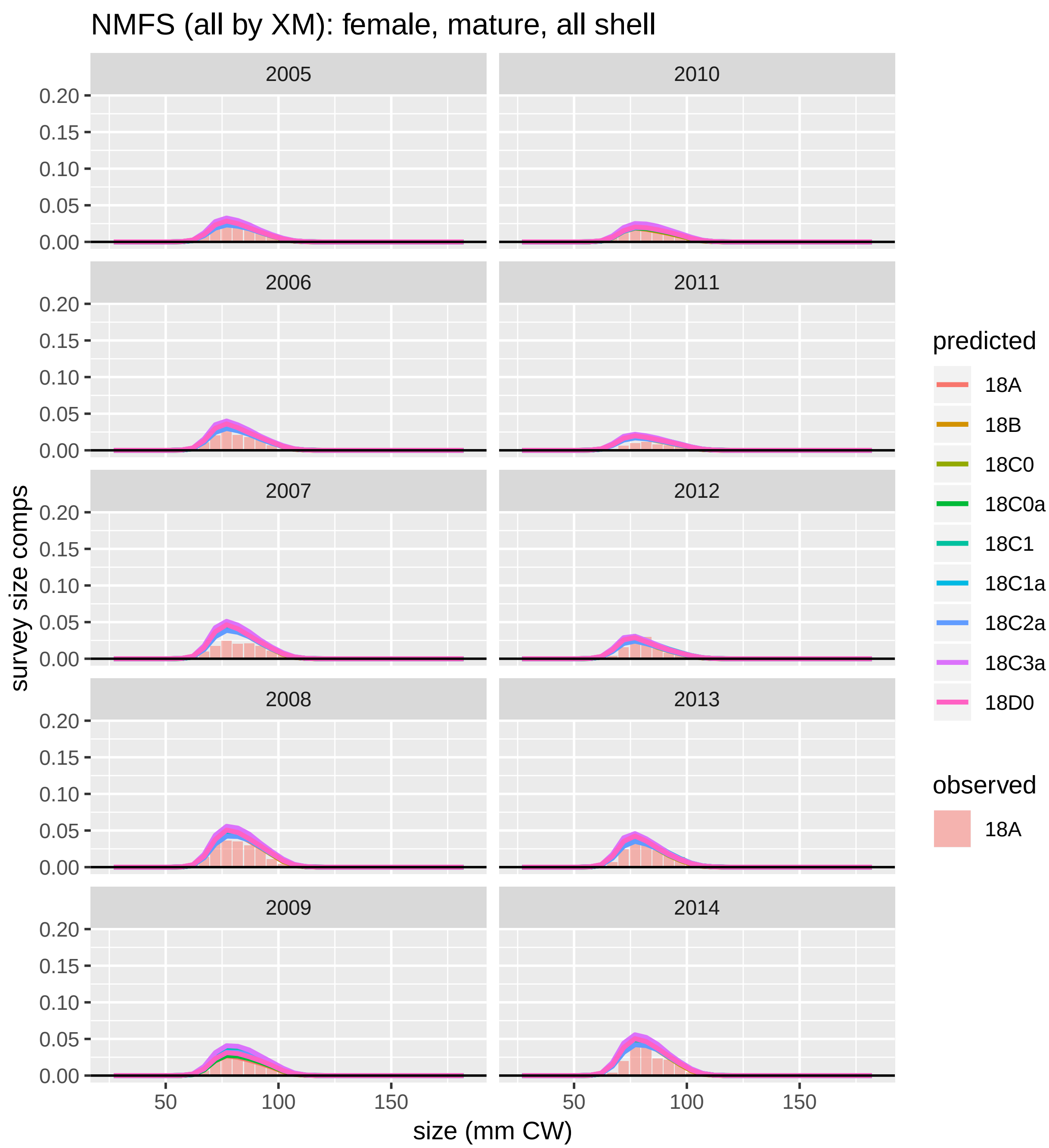

Figure 19: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS (all by XM). Page 4 of 5.

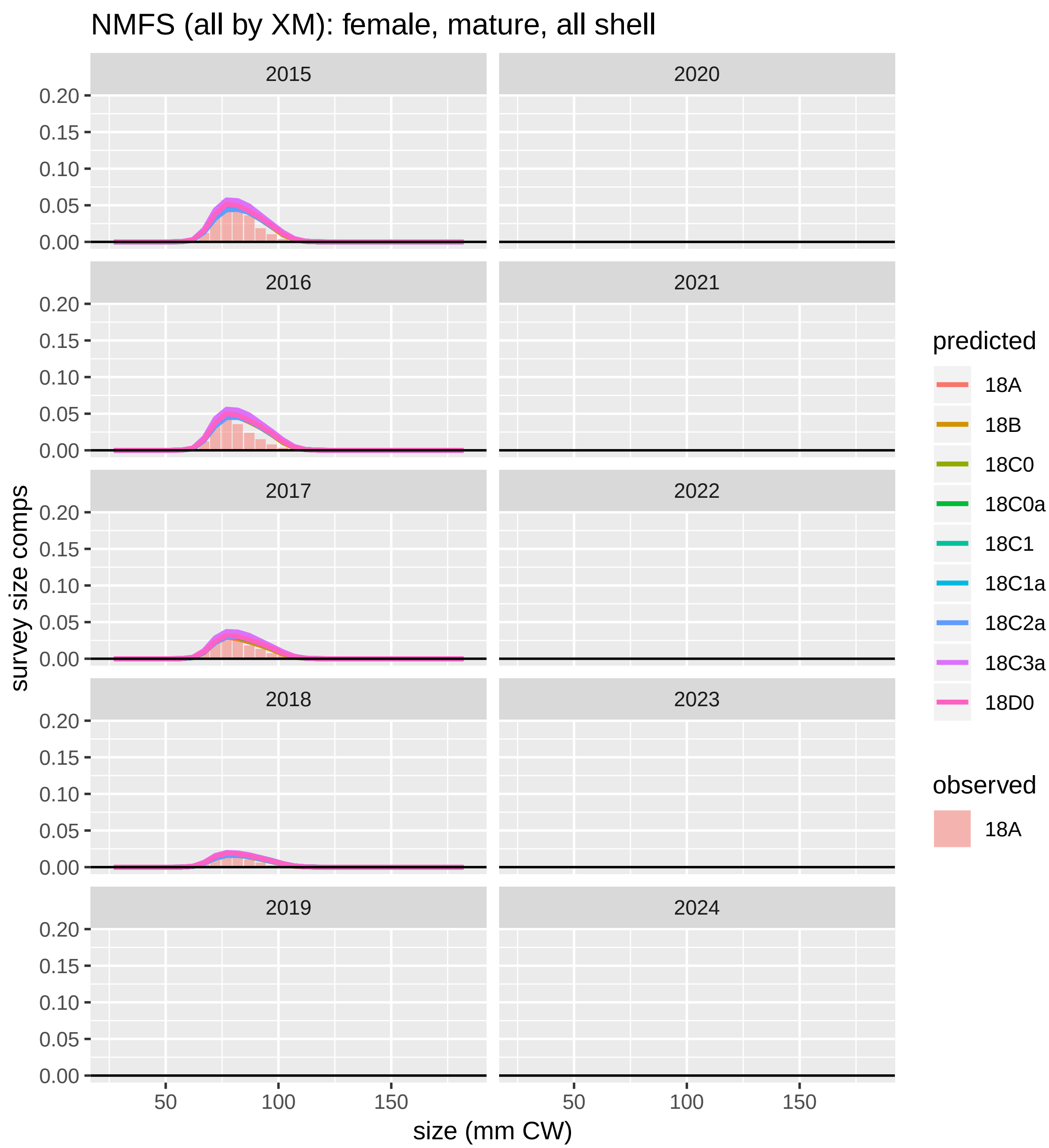

Figure 20: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS (all by XM). Page 5 of 5.

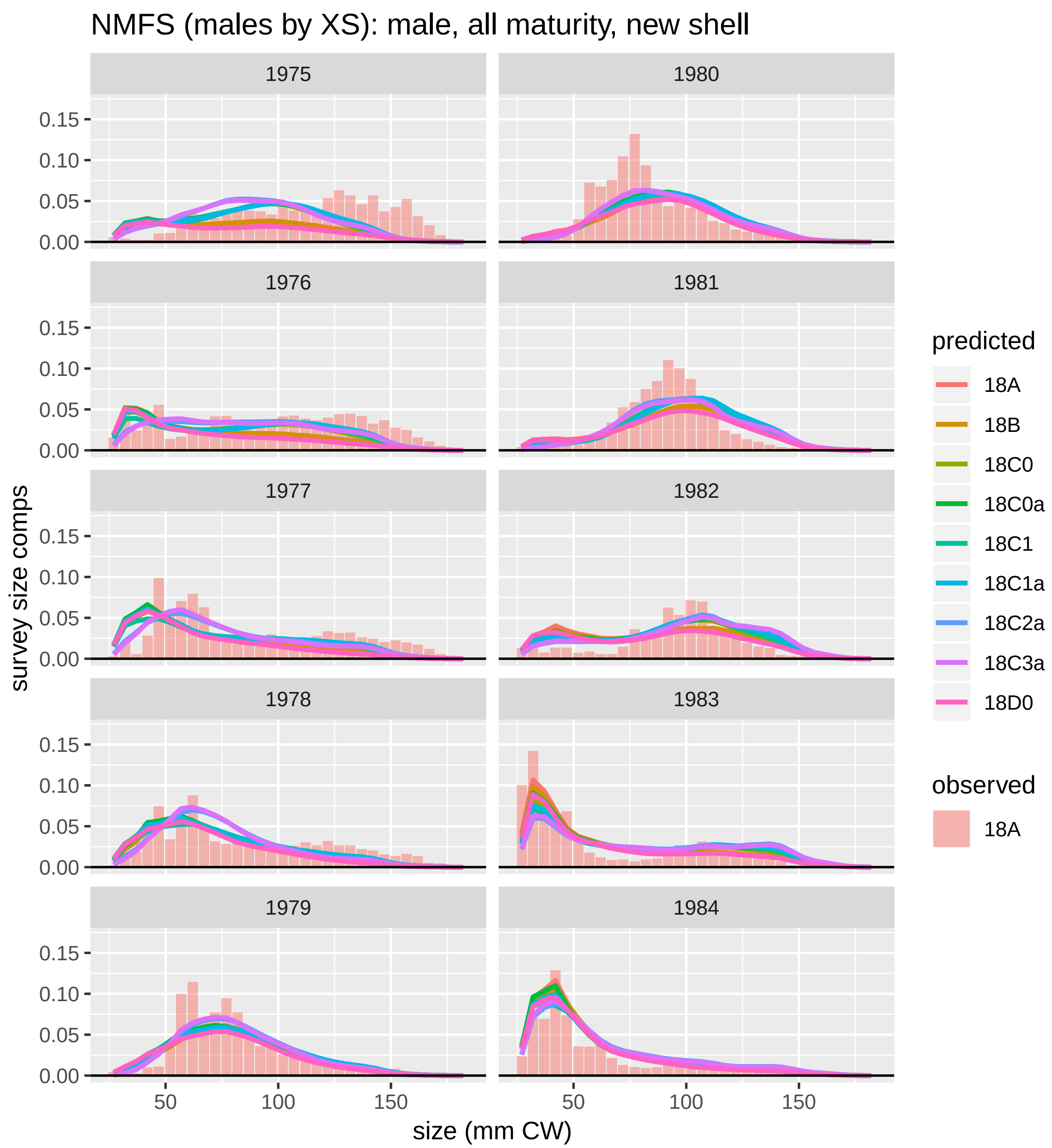

Figure 21: Comparison of observed and predicted male, all maturity, new shell survey size comps for NMFS (males by XS). Page 1 of 5.

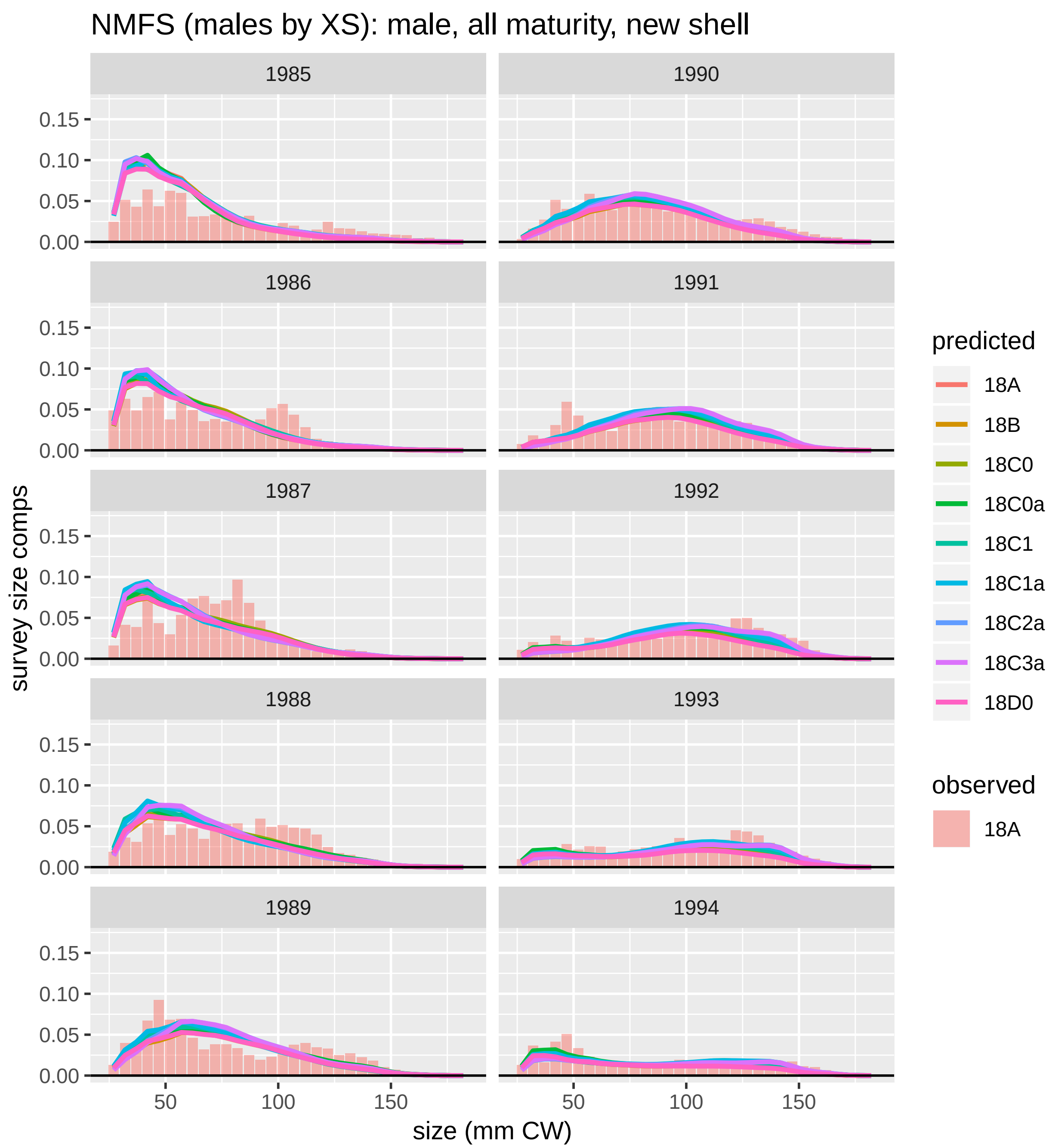

Figure 22: Comparison of observed and predicted male, all maturity, new shell survey size comps for NMFS (males by XS). Page 2 of 5.

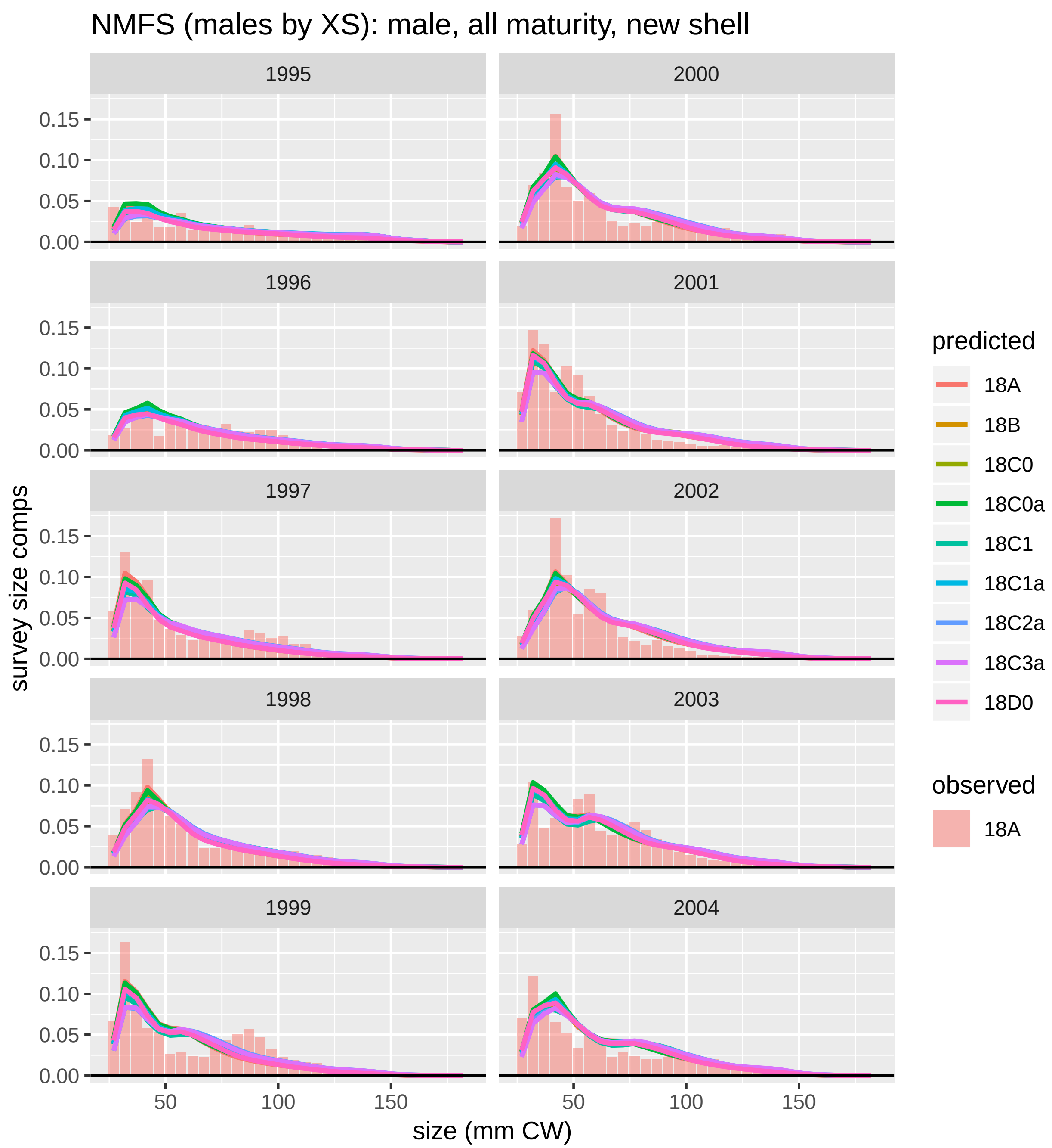

Figure 23: Comparison of observed and predicted male, all maturity, new shell survey size comps for NMFS (males by XS). Page 3 of 5.

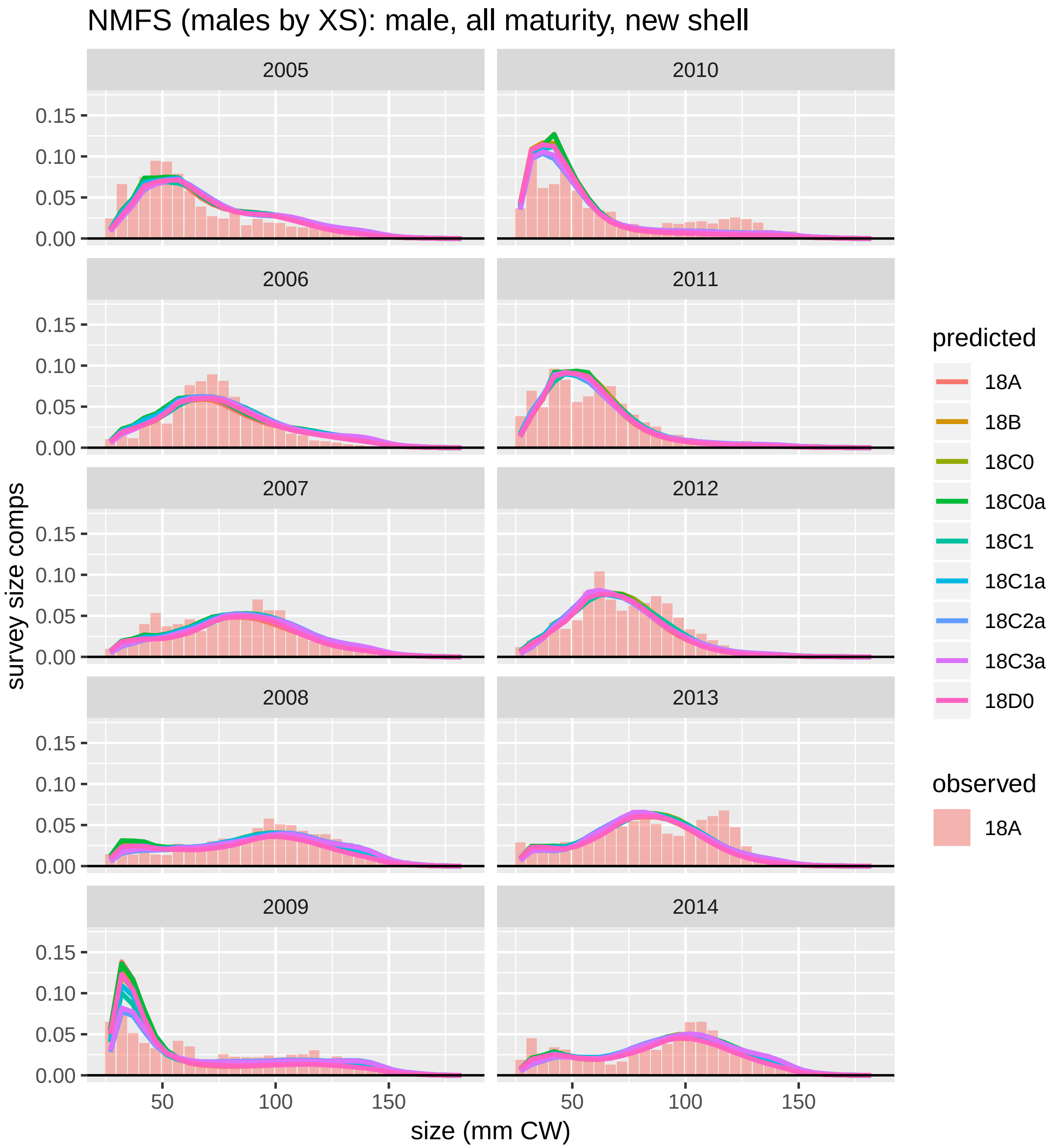

Figure 24: Comparison of observed and predicted male, all maturity, new shell survey size comps for NMFS (males by XS). Page 4 of 5.

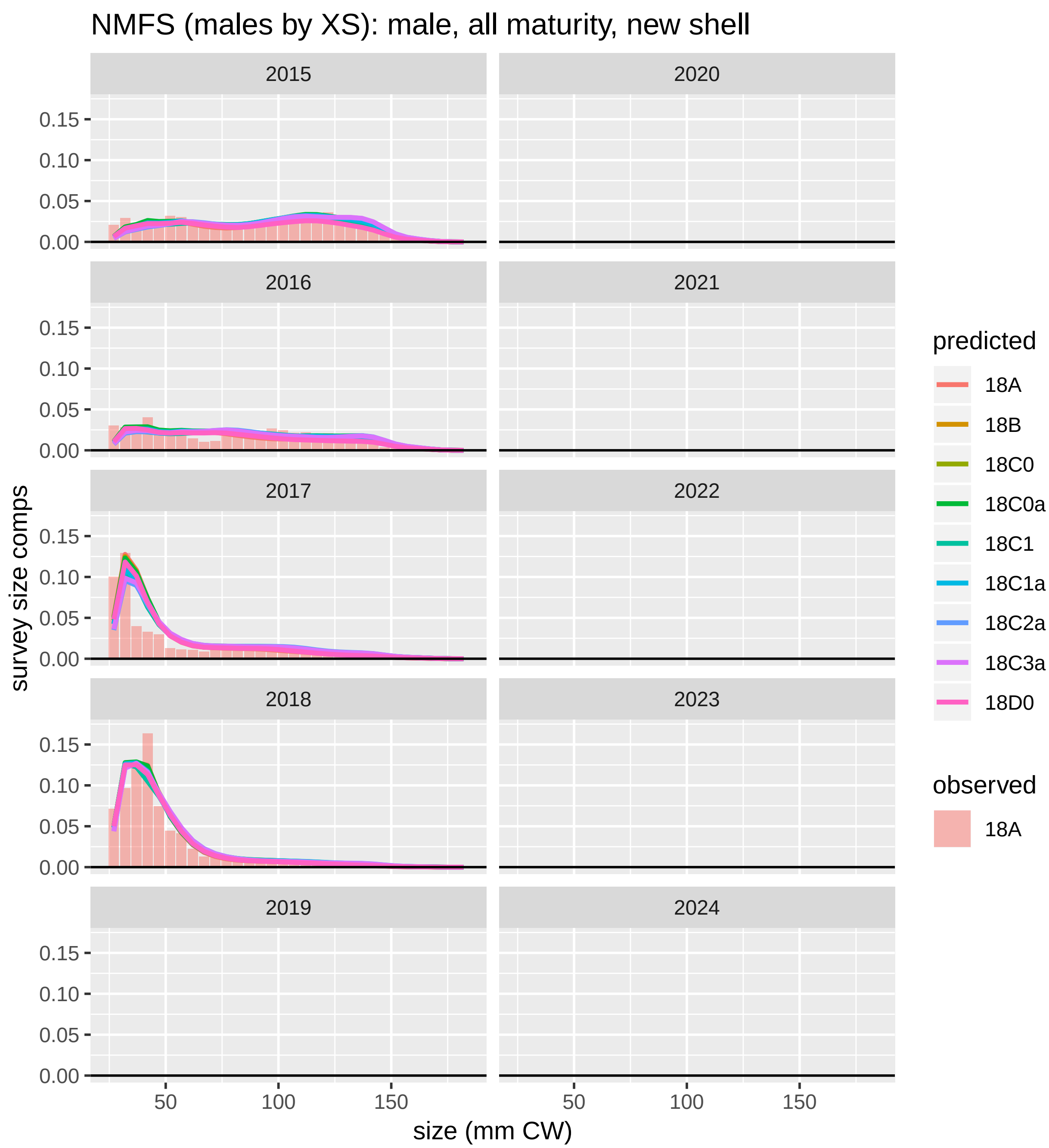

Figure 25: Comparison of observed and predicted male, all maturity, new shell survey size comps for NMFS (males by XS). Page 5 of 5.

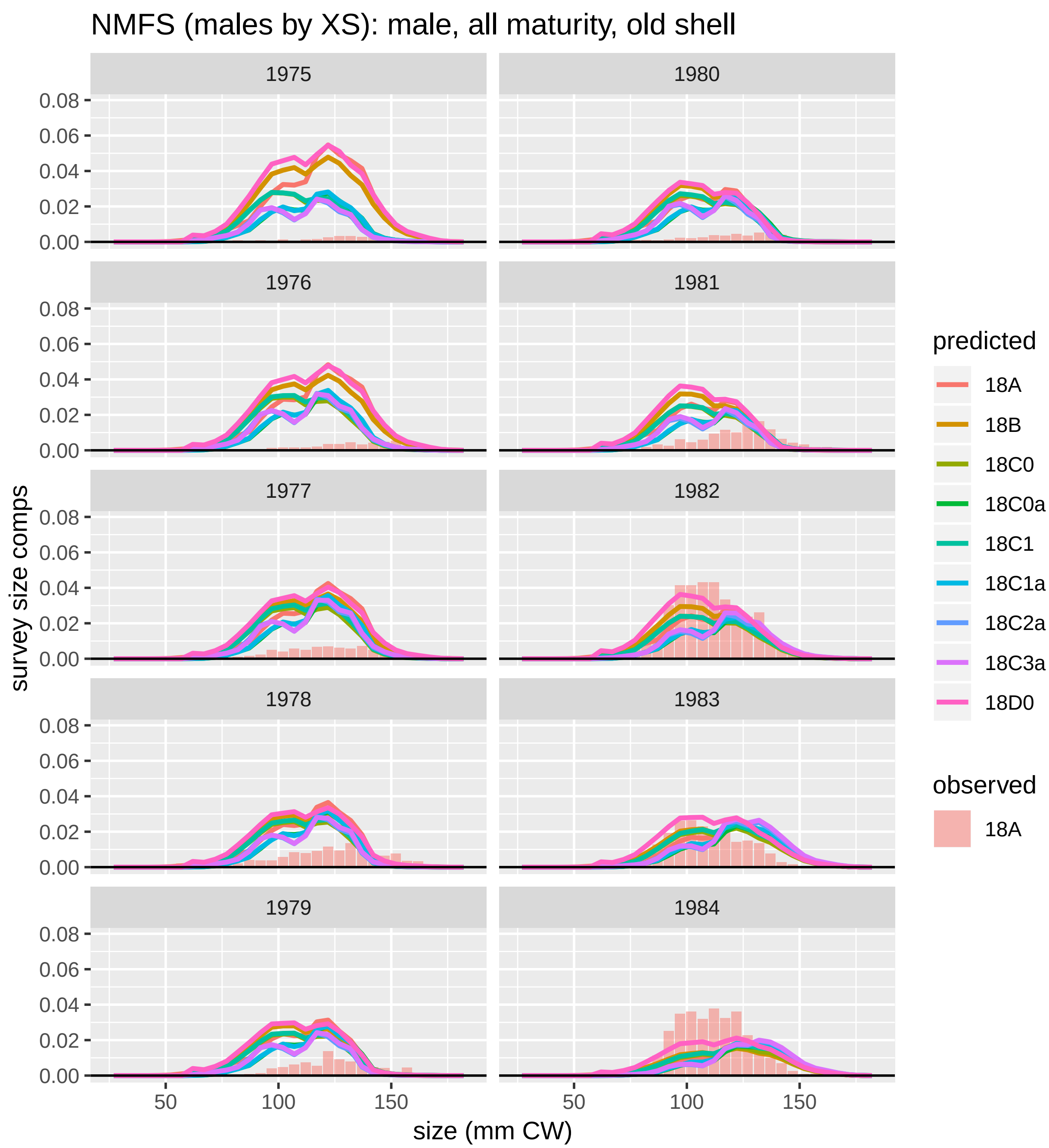

Figure 26: Comparison of observed and predicted male, all maturity, old shell survey size comps for NMFS (males by XS). Page 1 of 5.

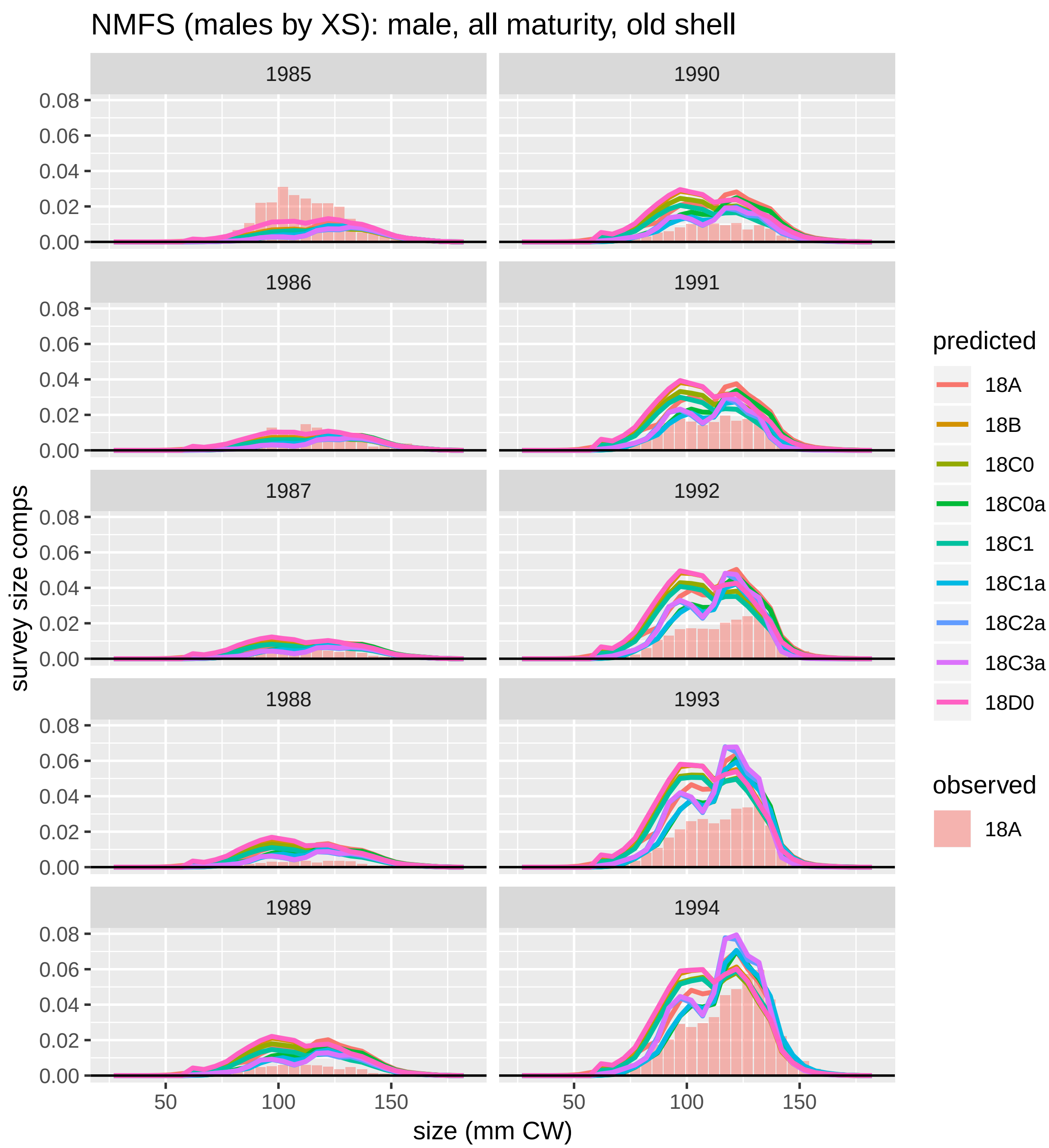

Figure 27: Comparison of observed and predicted male, all maturity, old shell survey size comps for NMFS (males by XS). Page 2 of 5.

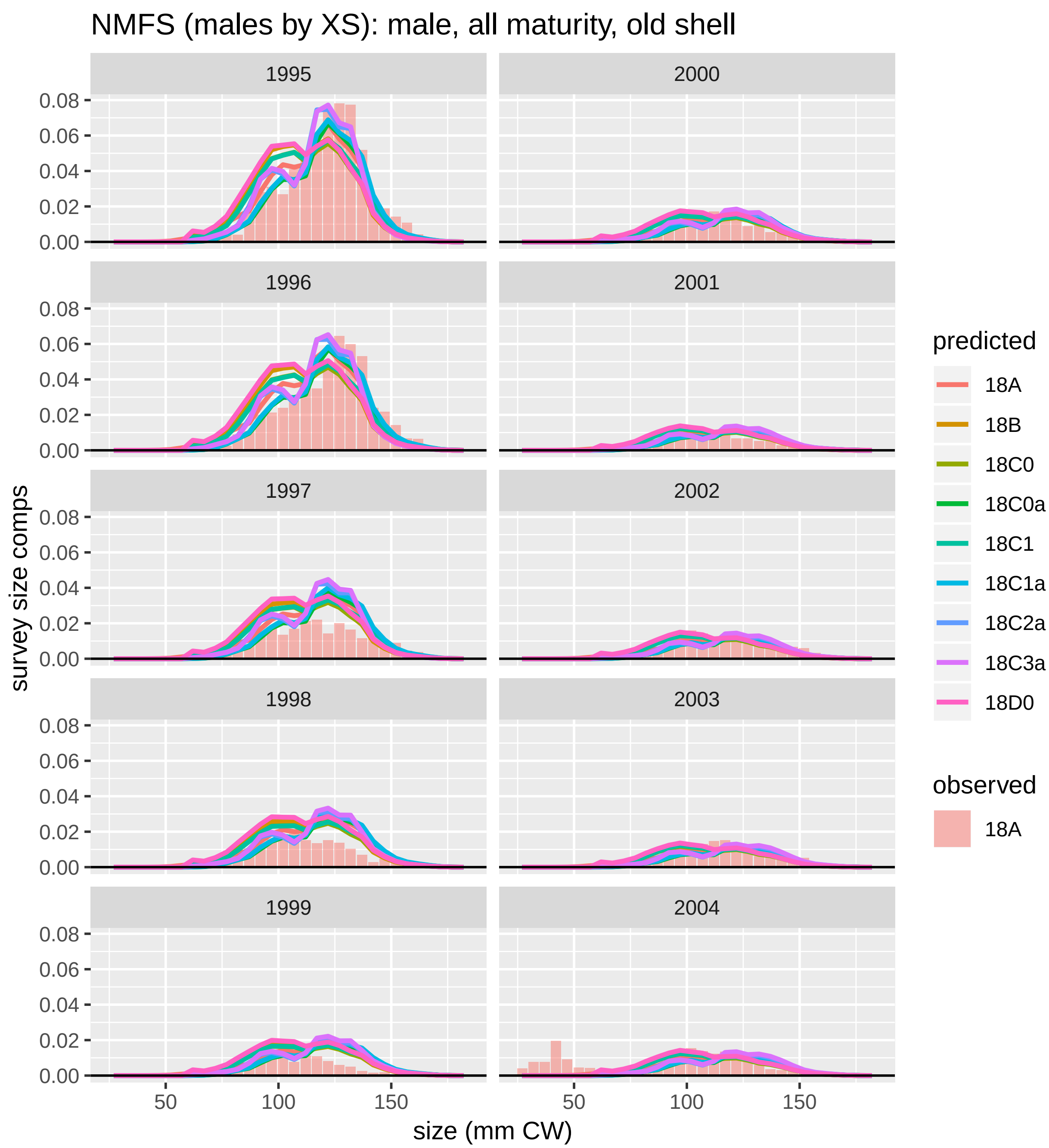

Figure 28: Comparison of observed and predicted male, all maturity, old shell survey size comps for NMFS (males by XS). Page 3 of 5.

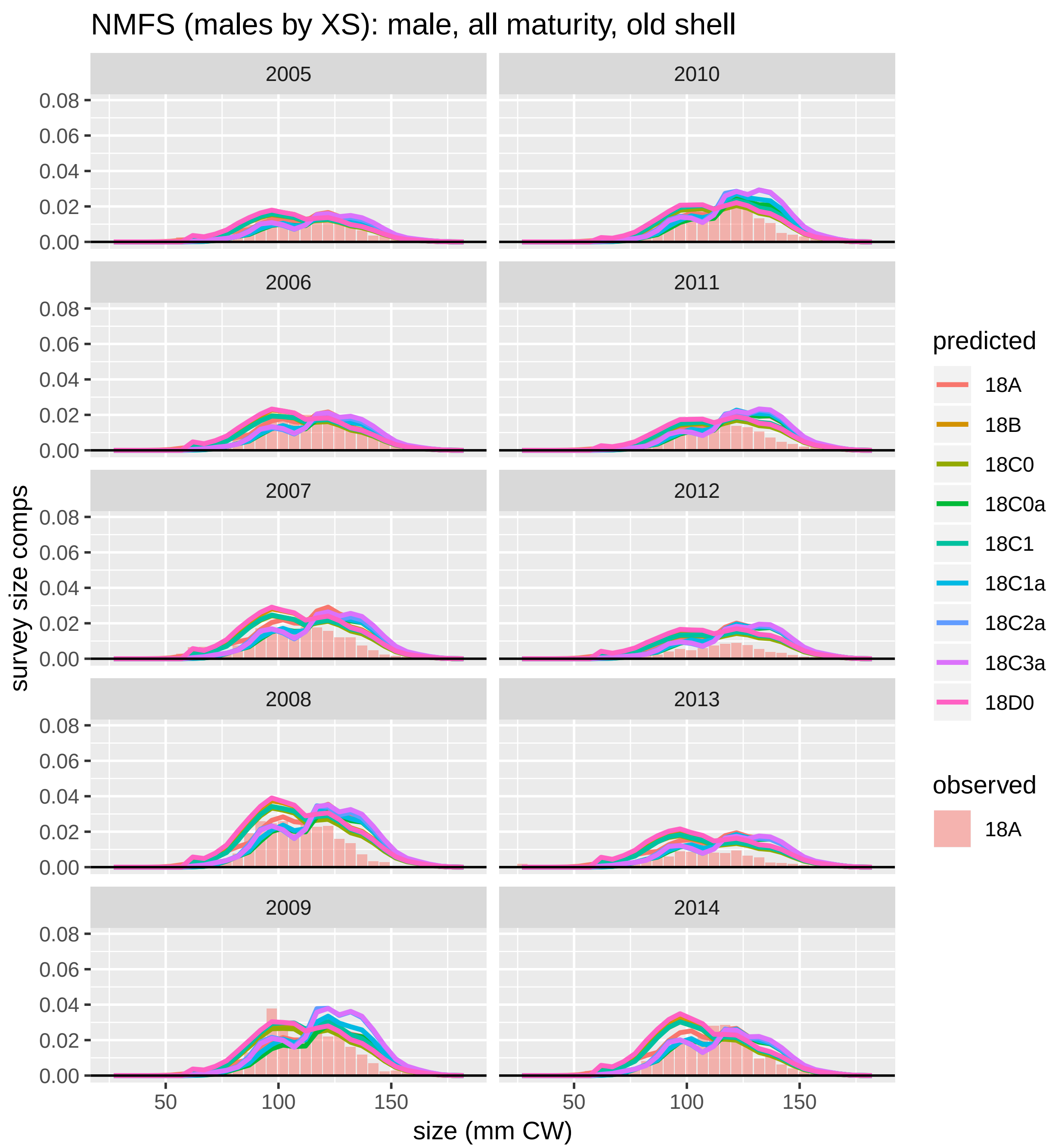

Figure 29: Comparison of observed and predicted male, all maturity, old shell survey size comps for NMFS (males by XS). Page 4 of 5.

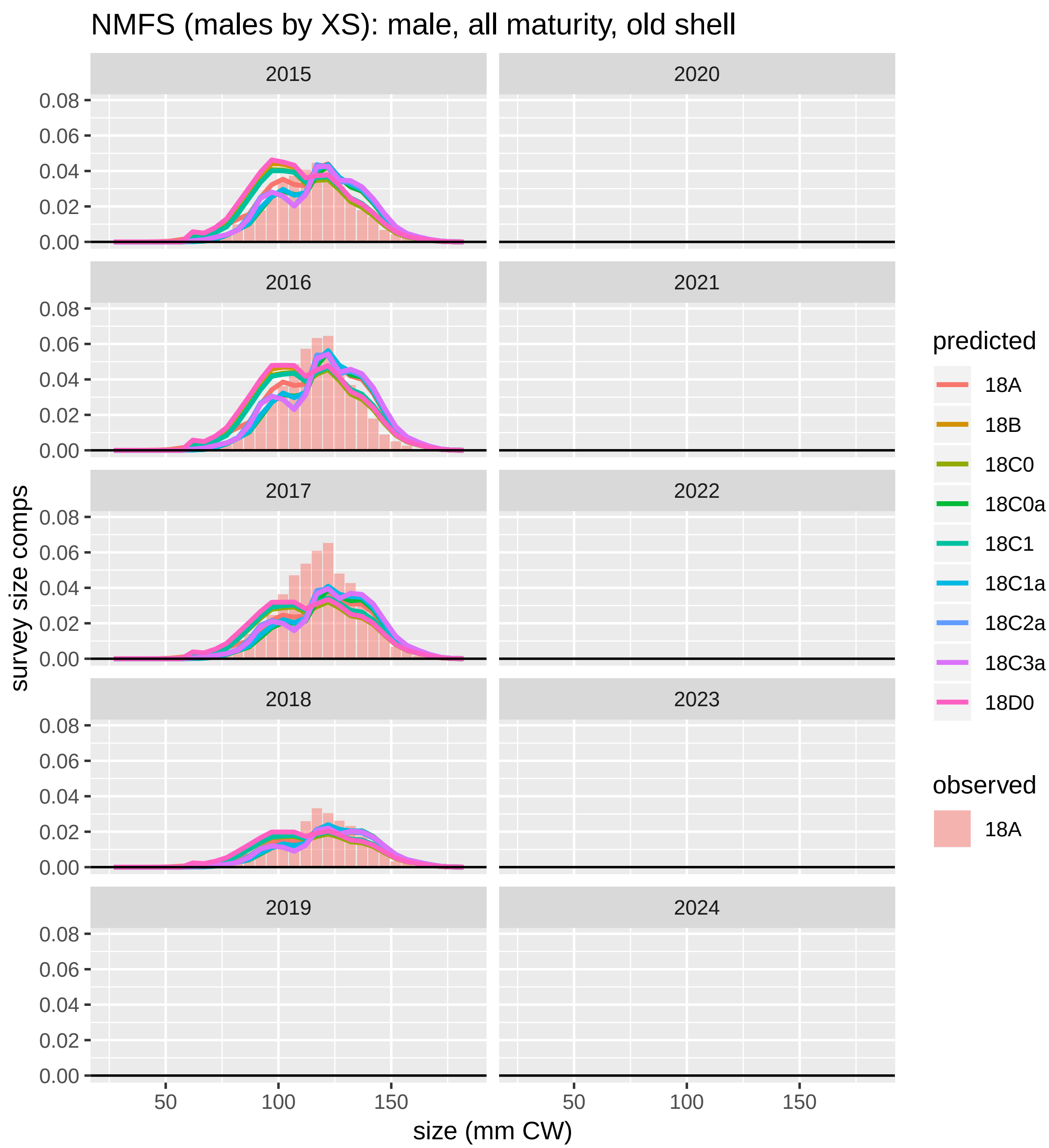

Figure 30: Comparison of observed and predicted male, all maturity, old shell survey size comps for NMFS (males by XS). Page 5 of 5.

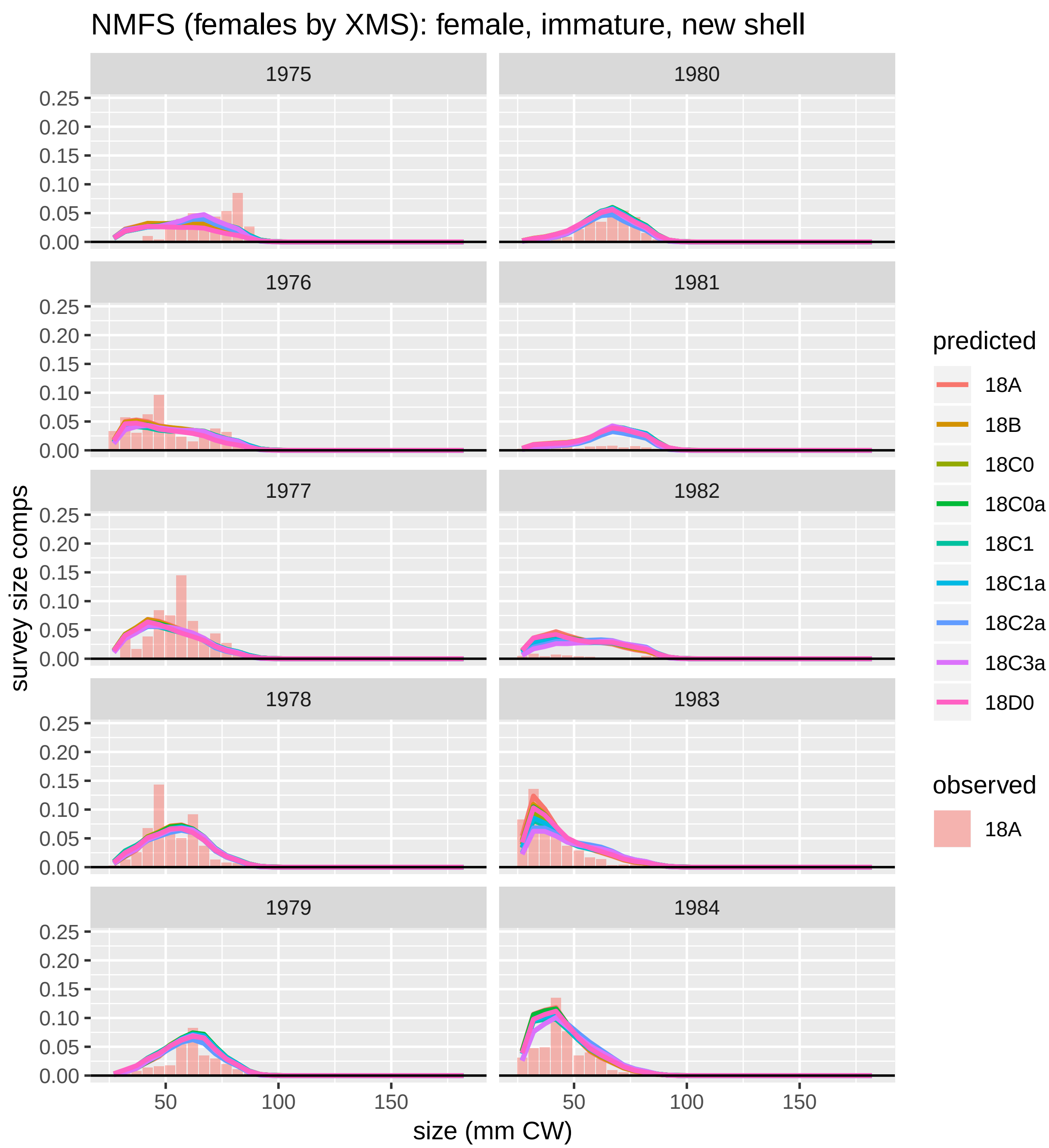

Figure 31: Comparison of observed and predicted female, immature, new shell survey size comps for NMFS (females by XMS). Page 1 of 5.

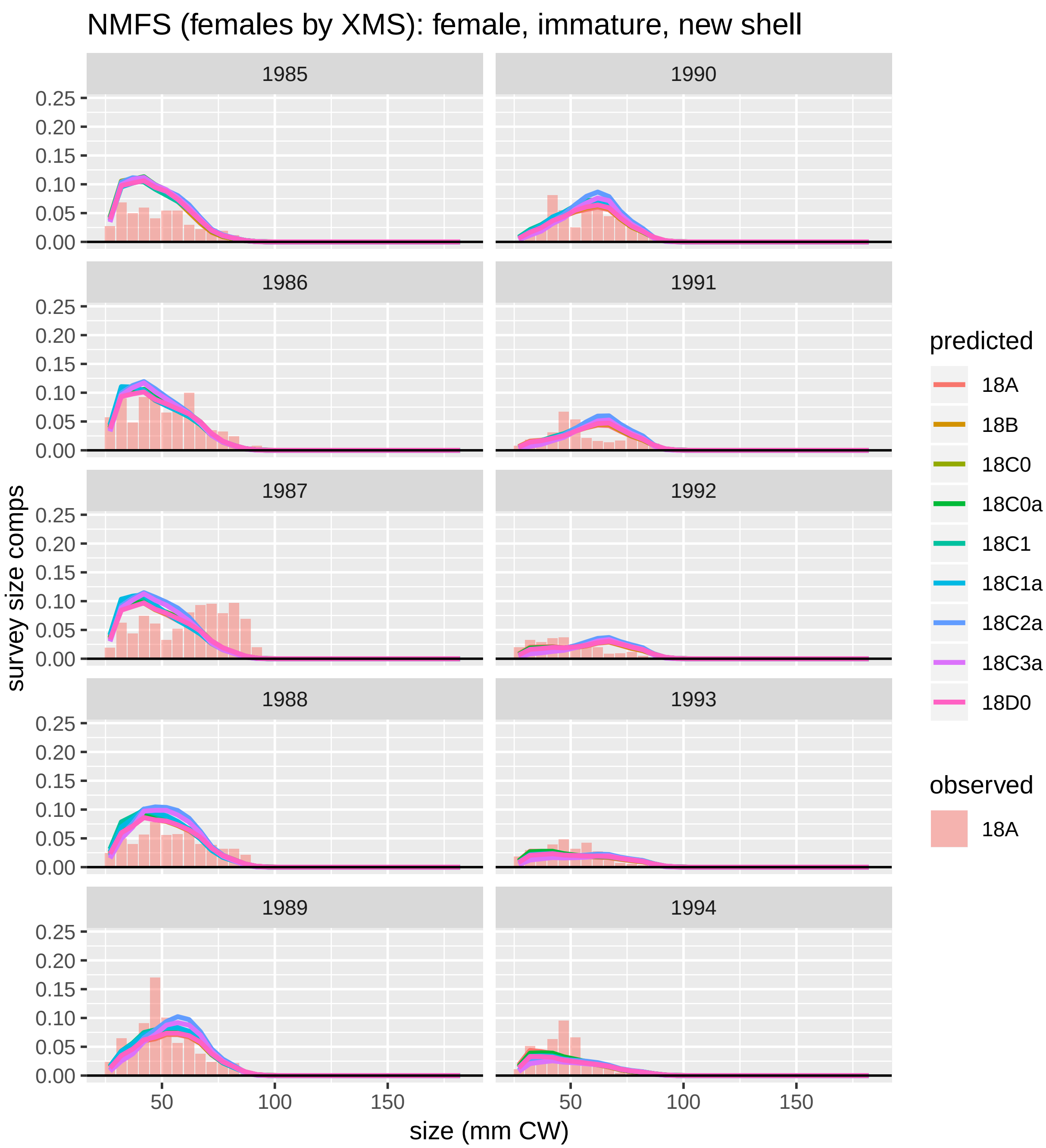

Figure 32: Comparison of observed and predicted female, immature, new shell survey size comps for NMFS (females by XMS). Page 2 of 5.

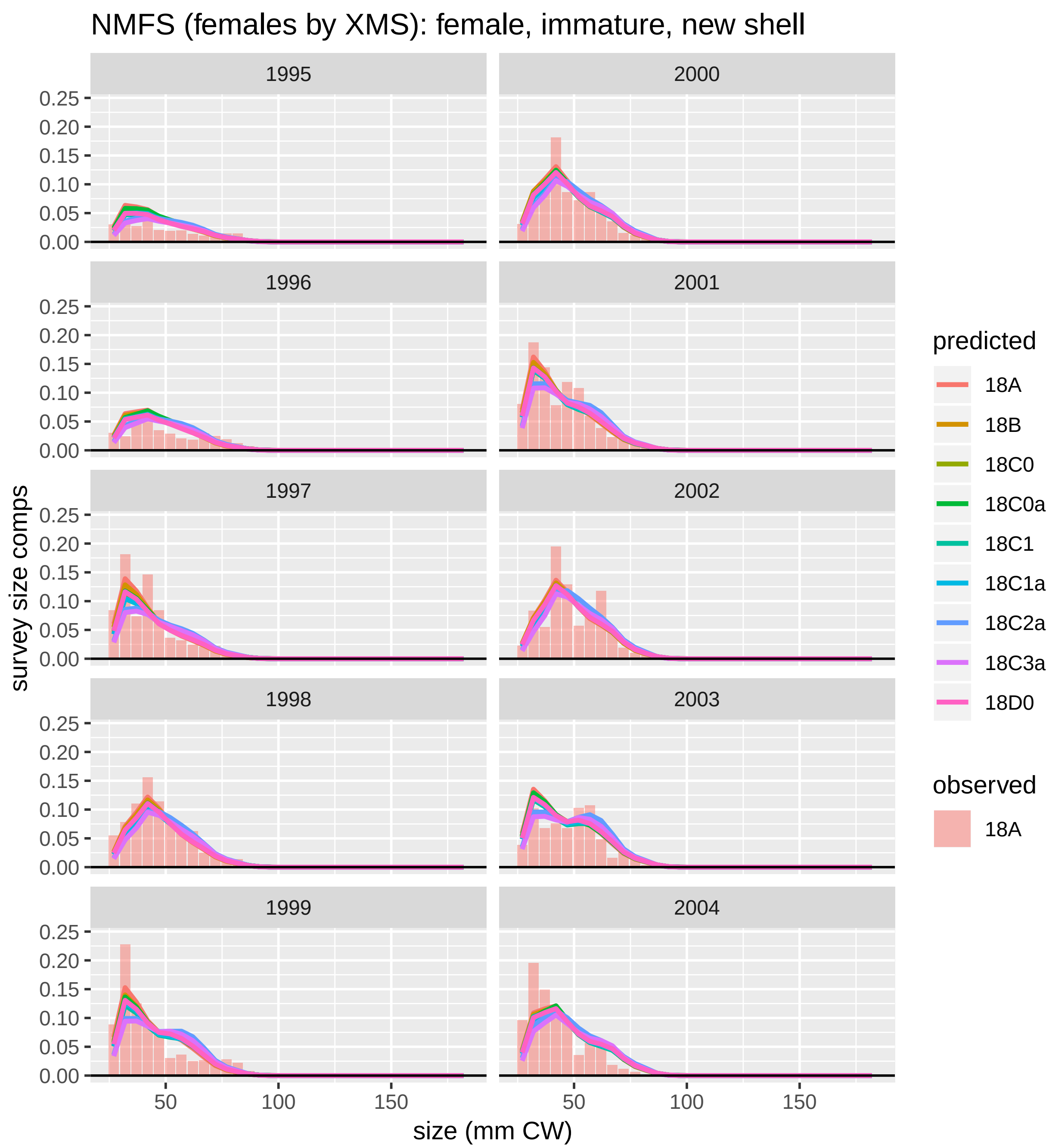

Figure 33: Comparison of observed and predicted female, immature, new shell survey size comps for NMFS (females by XMS). Page 3 of 5.

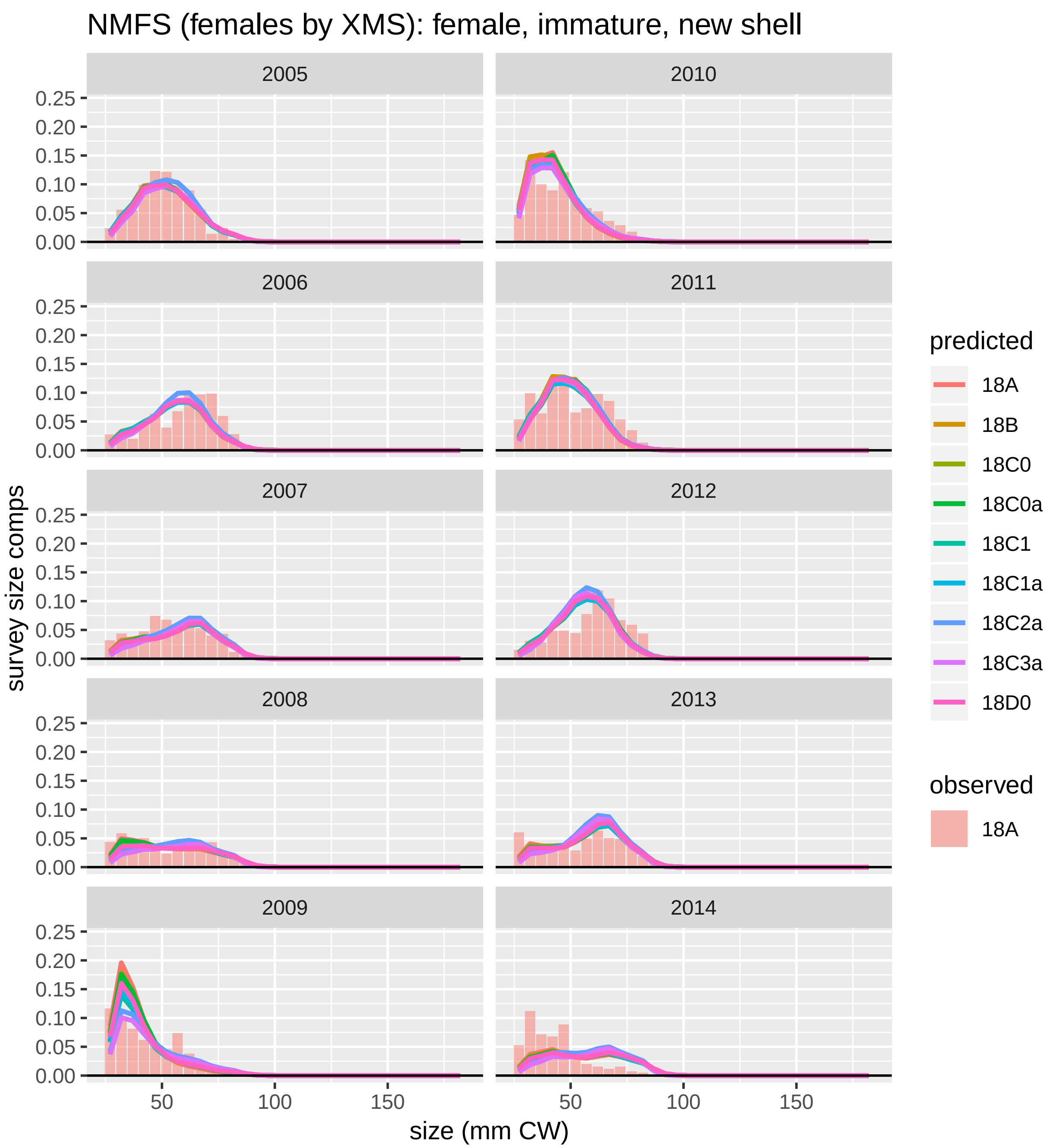

Figure 34: Comparison of observed and predicted female, immature, new shell survey size comps for NMFS (females by XMS). Page 4 of 5.

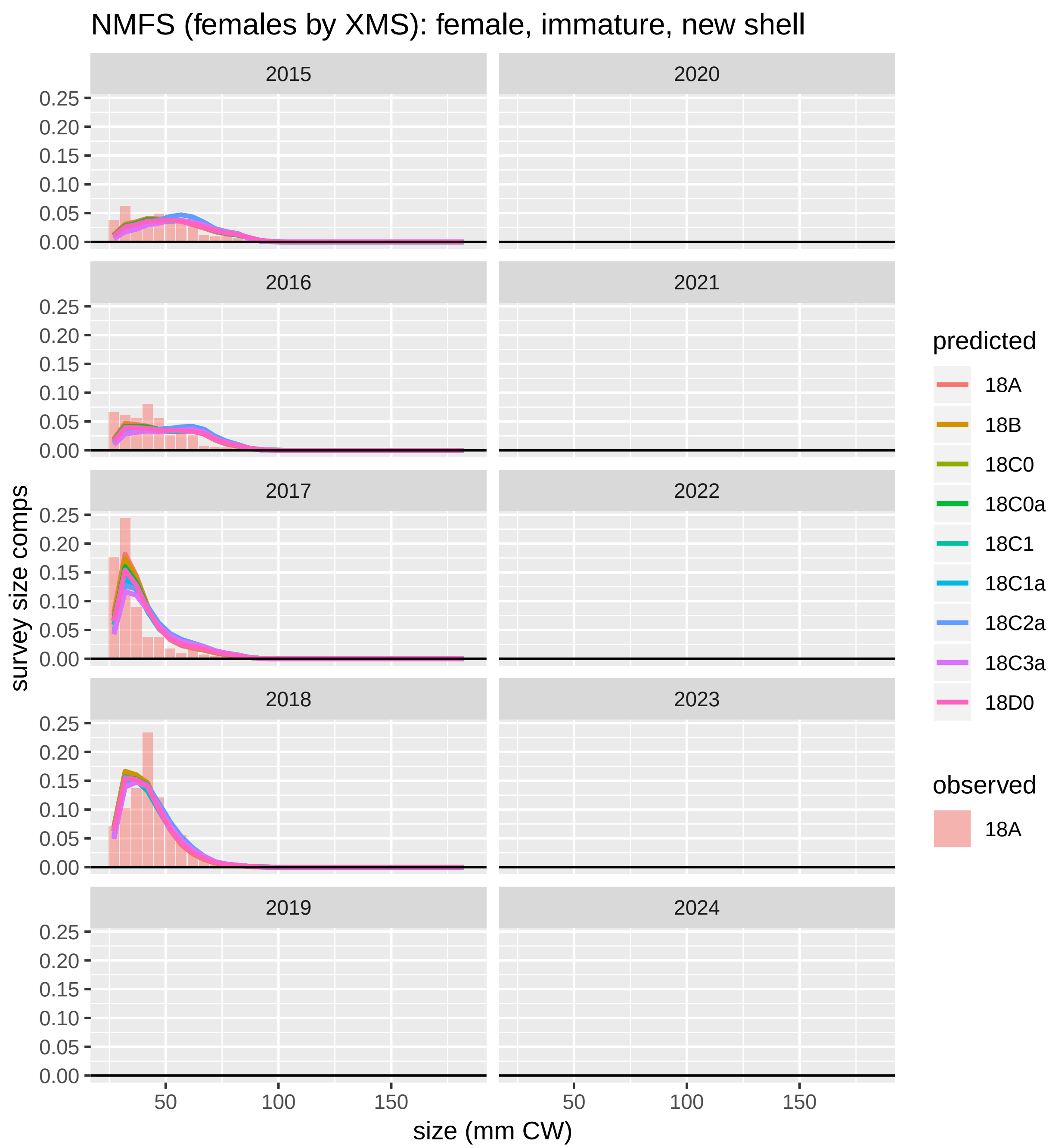

Figure 35: Comparison of observed and predicted female, immature, new shell survey size comps for NMFS (females by XMS). Page 5 of 5.

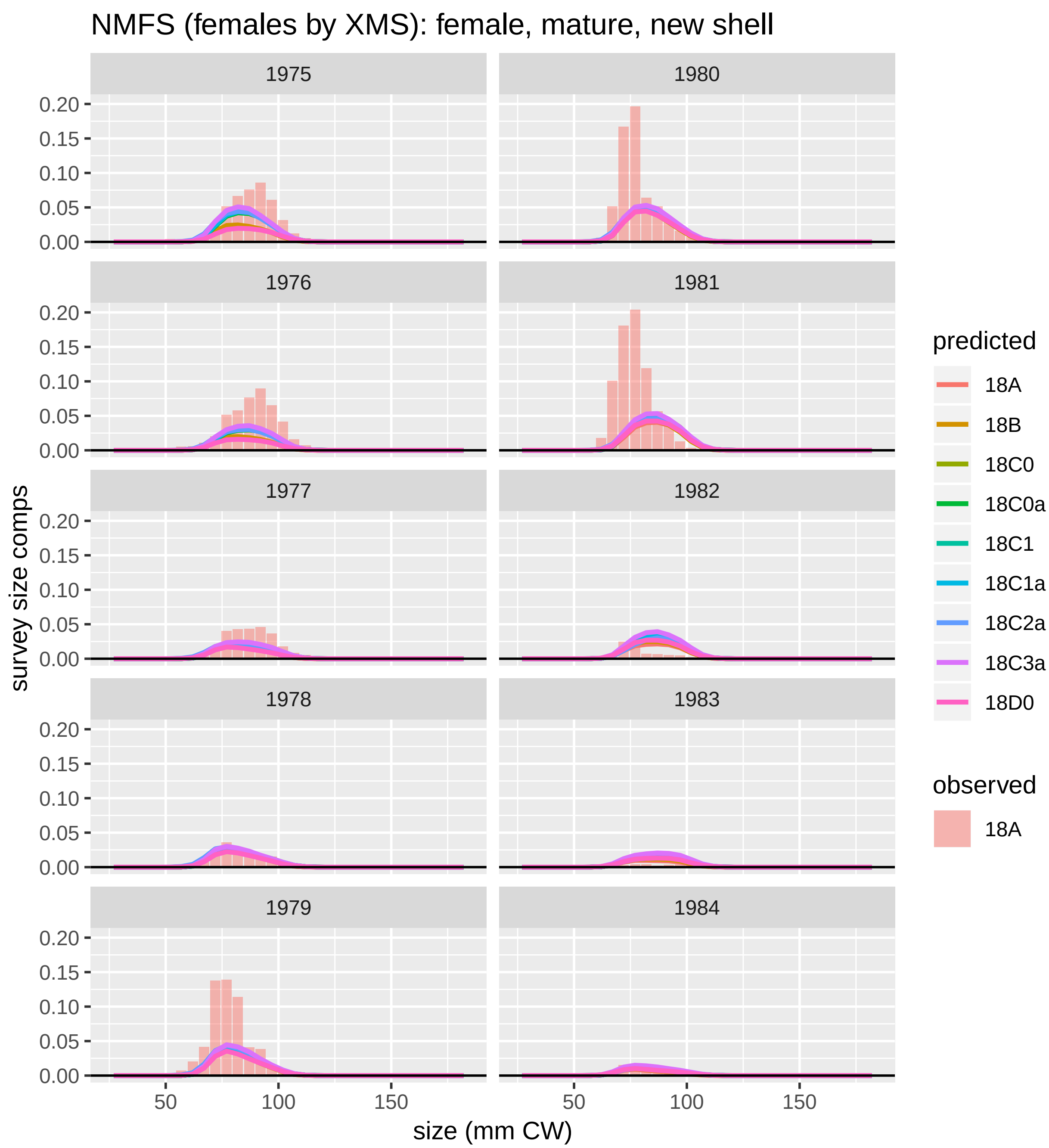

Figure 36: Comparison of observed and predicted female, mature, new shell survey size comps for NMFS (females by XMS). Page 1 of 5.

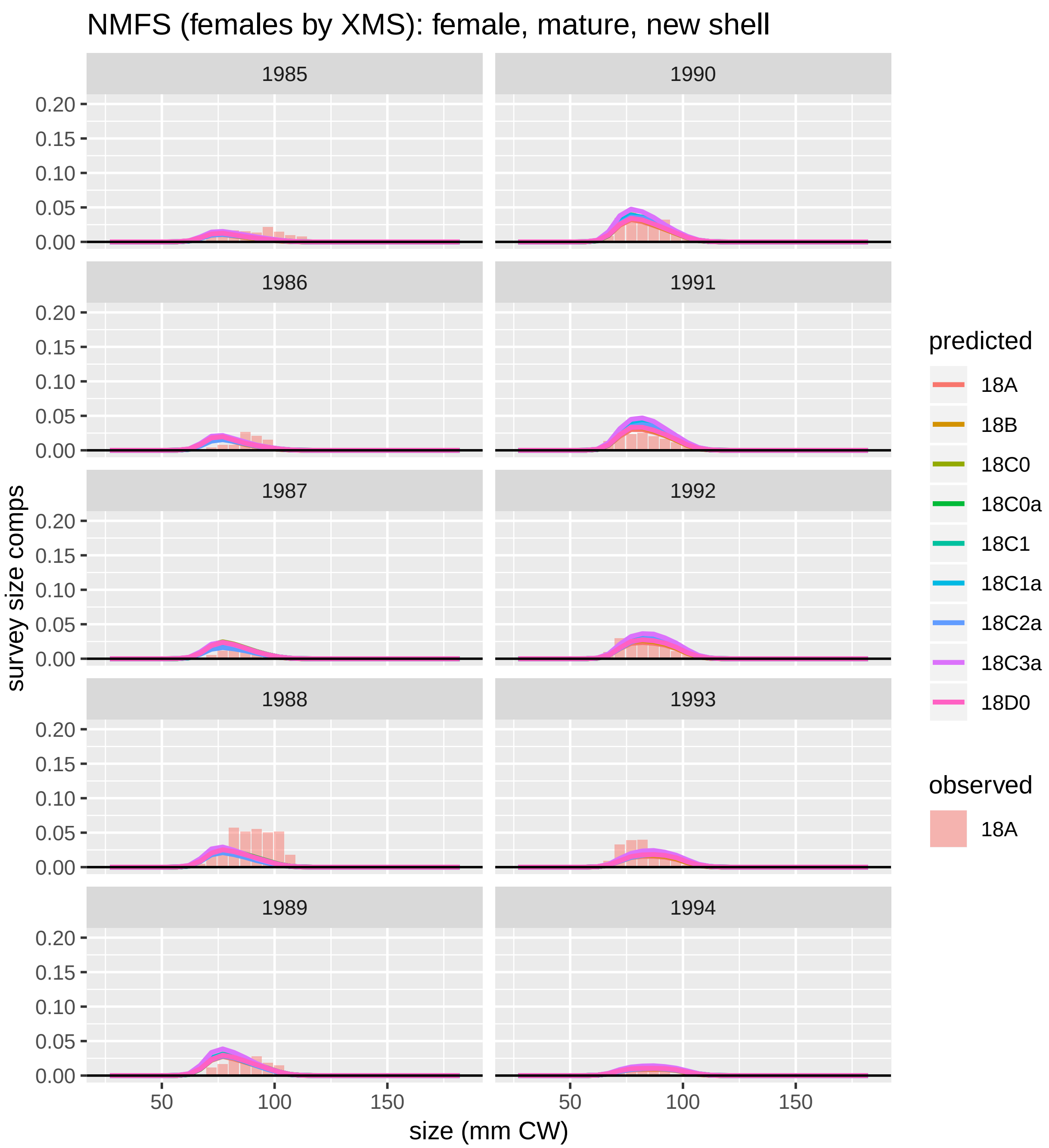

Figure 37: Comparison of observed and predicted female, mature, new shell survey size comps for NMFS (females by XMS). Page 2 of 5.

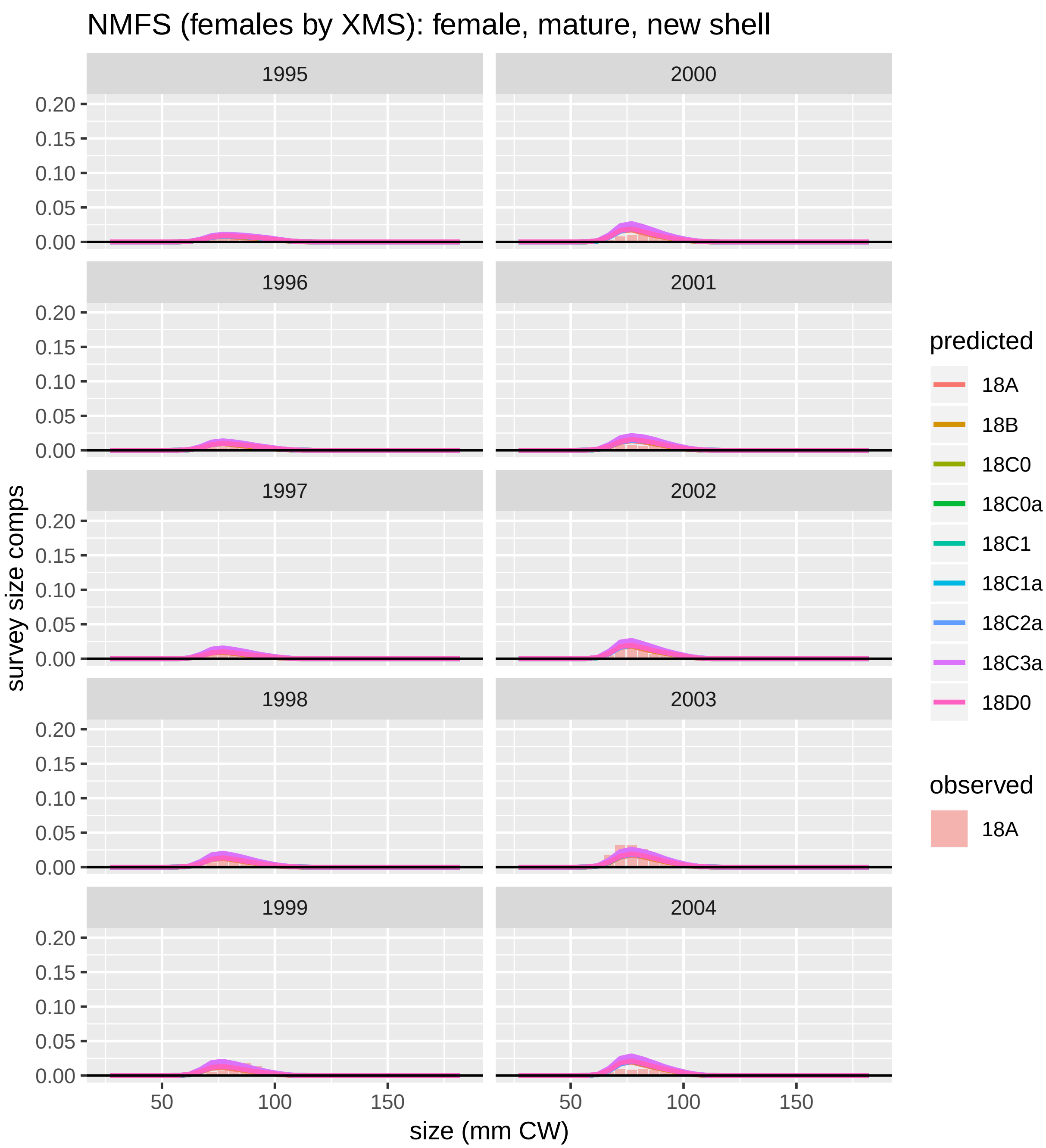

Figure 38: Comparison of observed and predicted female, mature, new shell survey size comps for NMFS (females by XMS). Page 3 of 5.

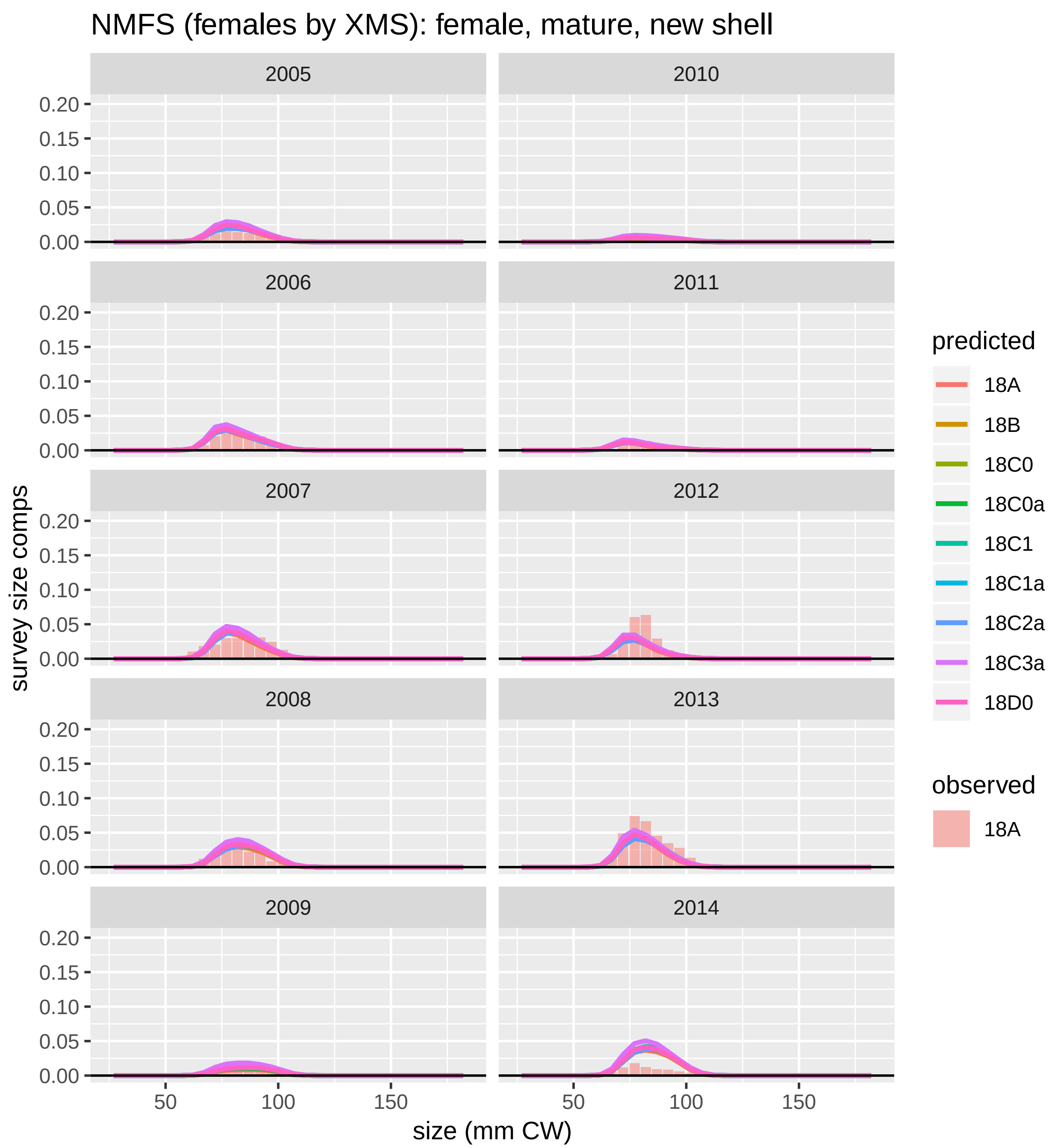

Figure 39: Comparison of observed and predicted female, mature, new shell survey size comps for NMFS (females by XMS). Page 4 of 5.

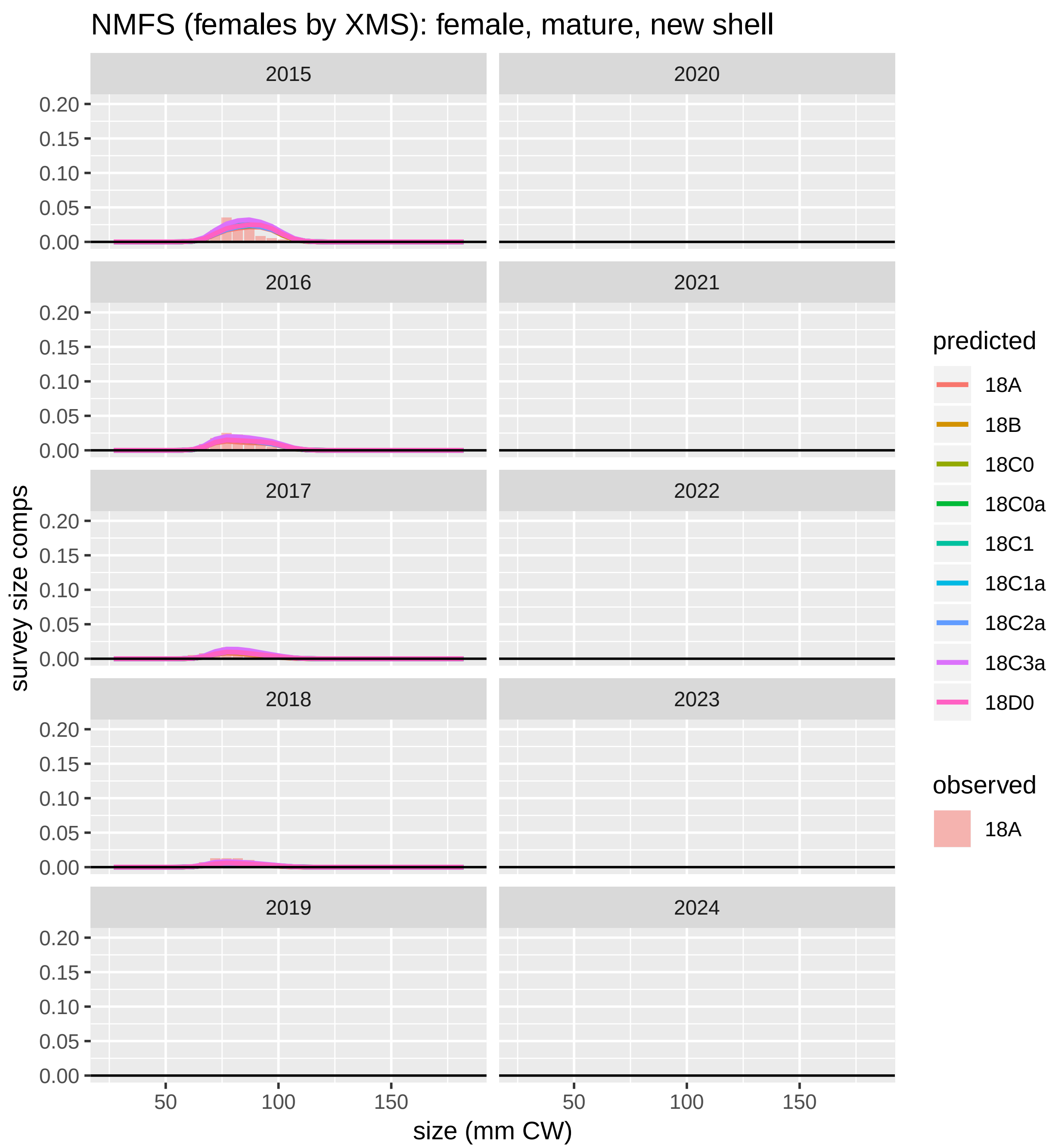

Figure 40: Comparison of observed and predicted female, mature, new shell survey size comps for NMFS (females by XMS). Page 5 of 5.

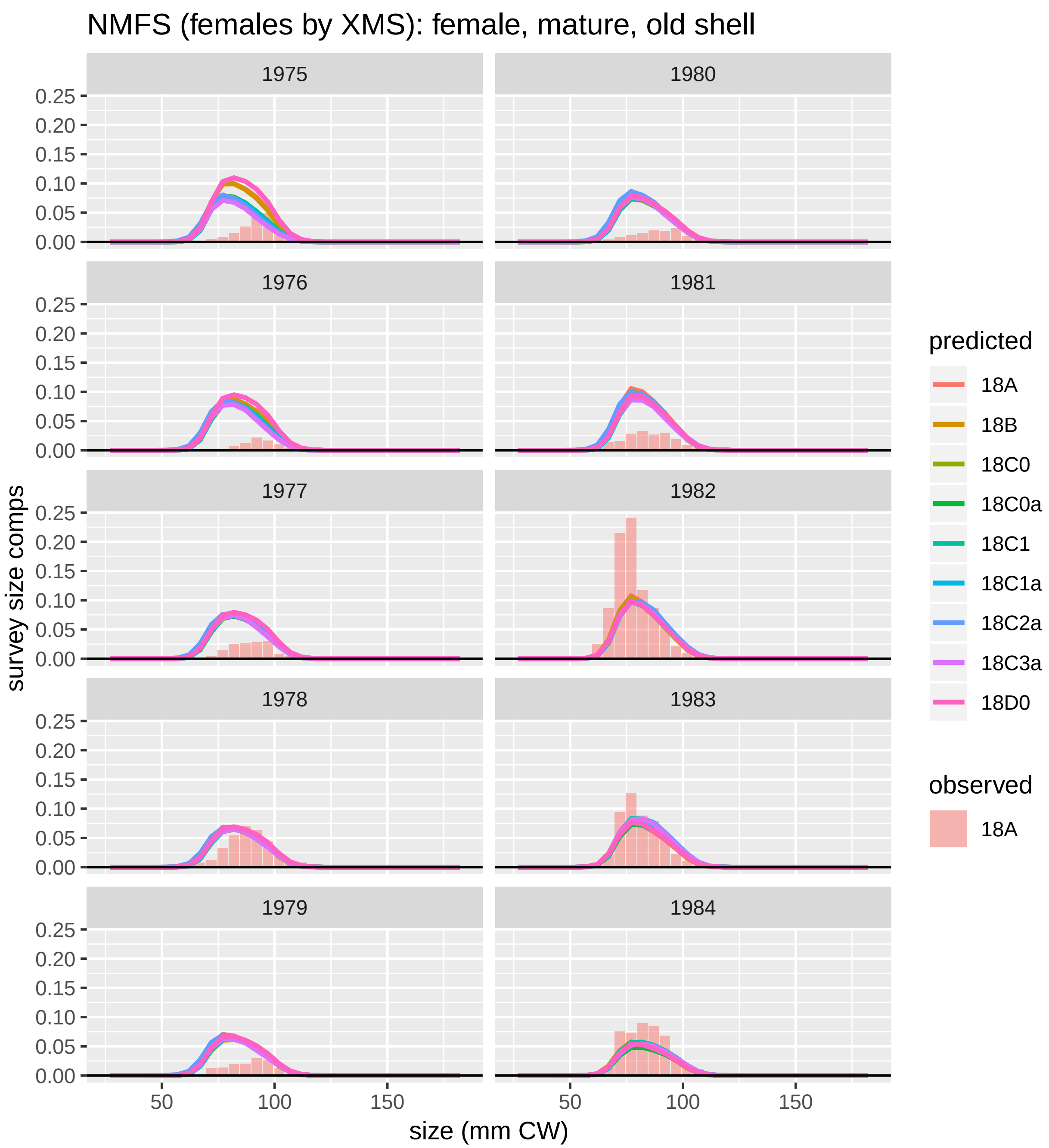

Figure 41: Comparison of observed and predicted female, mature, old shell survey size comps for NMFS (females by XMS). Page 1 of 5.

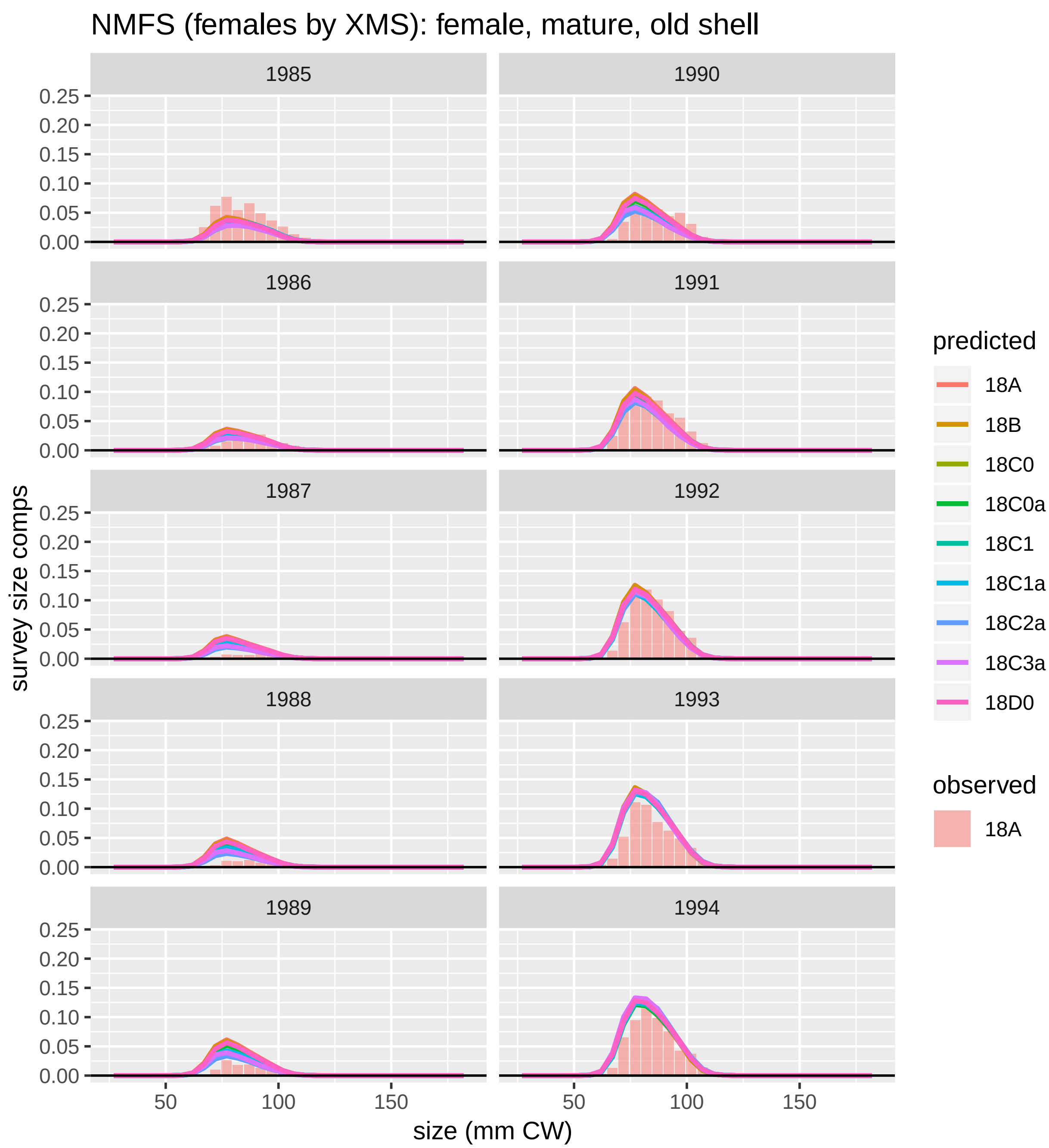

Figure 42: Comparison of observed and predicted female, mature, old shell survey size comps for NMFS (females by XMS). Page 2 of 5.

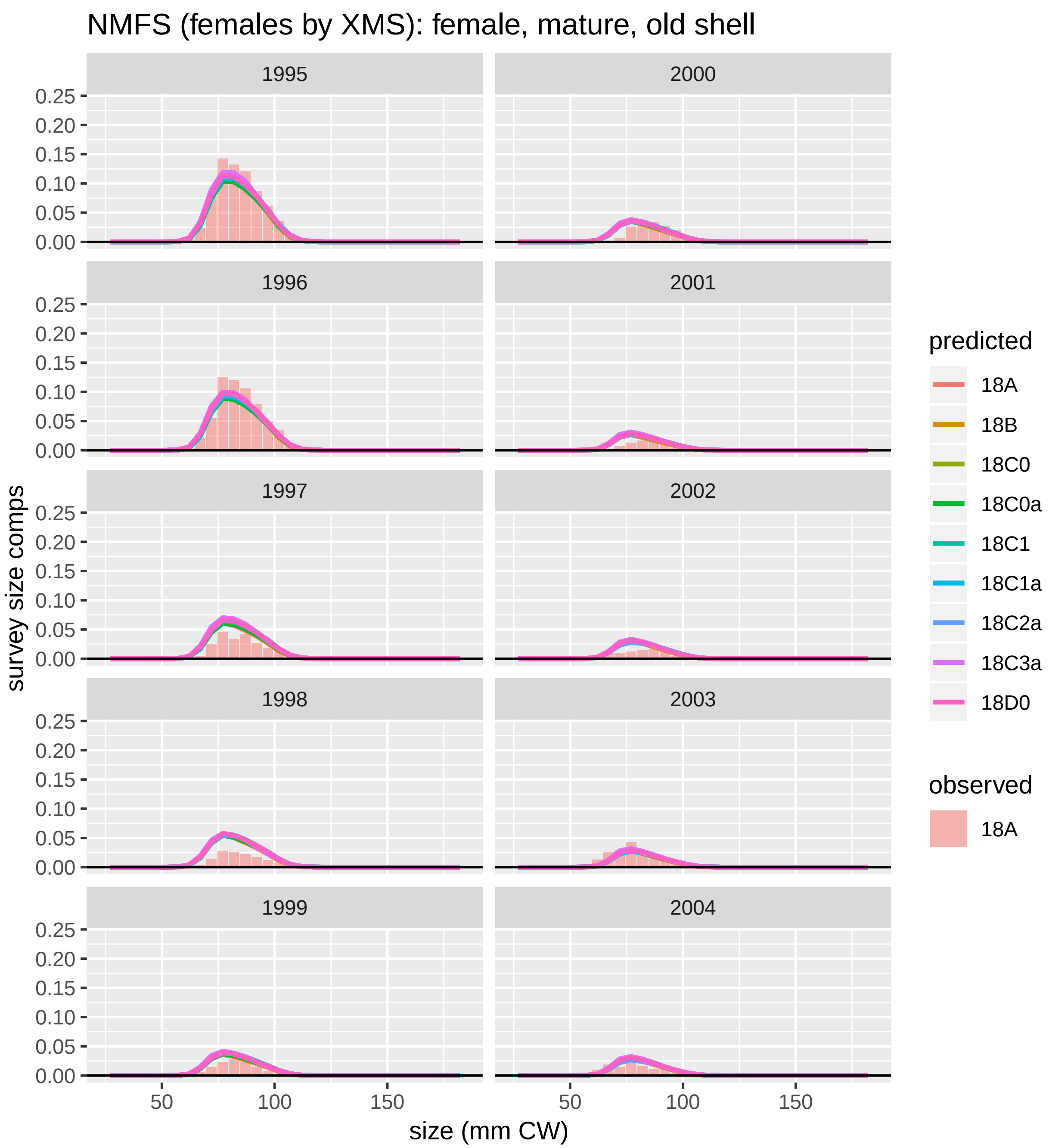

Figure 43: Comparison of observed and predicted female, mature, old shell survey size comps for NMFS (females by XMS). Page 3 of 5.

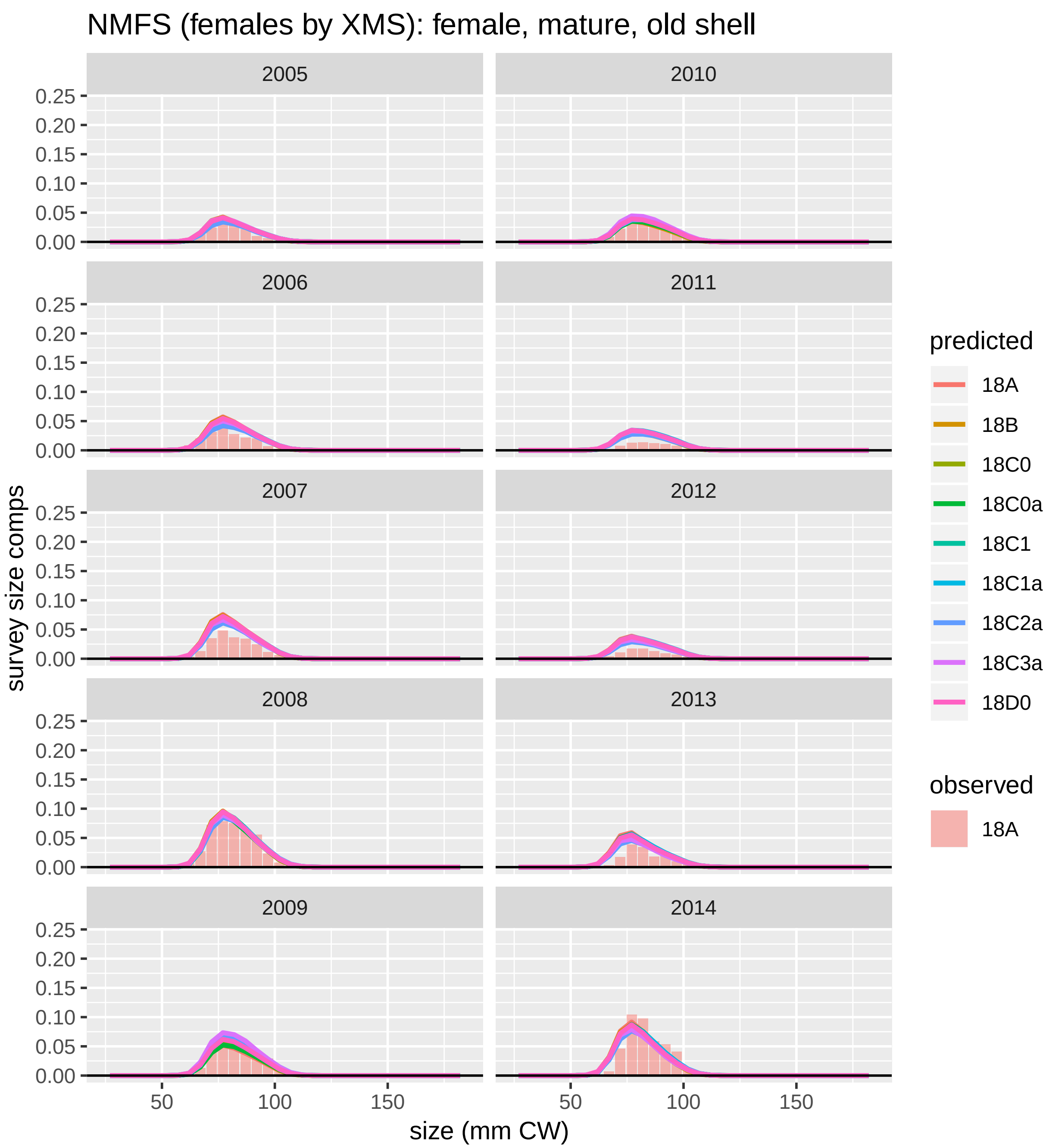

Figure 44: Comparison of observed and predicted female, mature, old shell survey size comps for NMFS (females by XMS). Page 4 of 5.

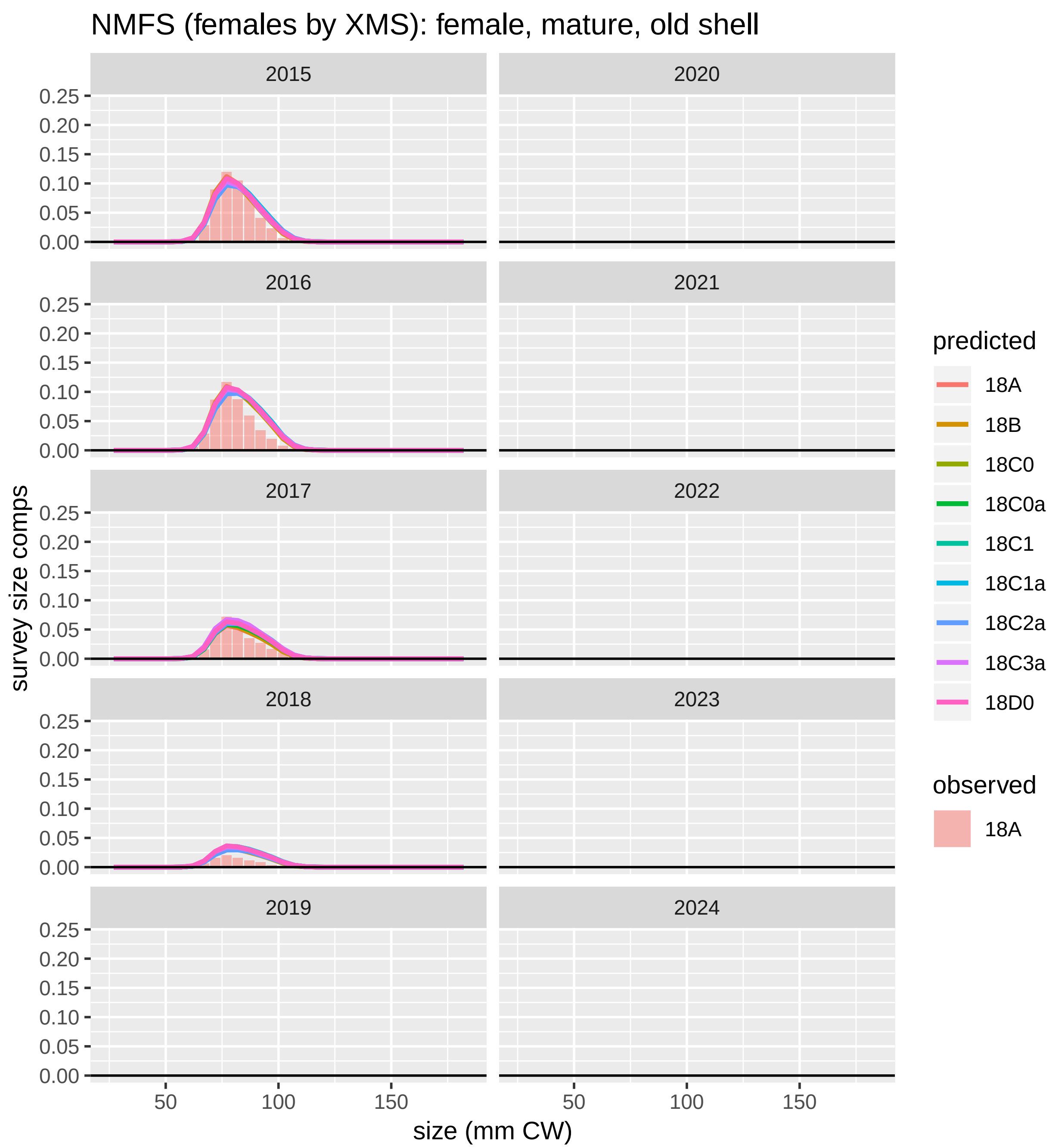

Figure 45: Comparison of observed and predicted female, mature, old shell survey size comps for NMFS (females by XMS). Page 5 of 5.

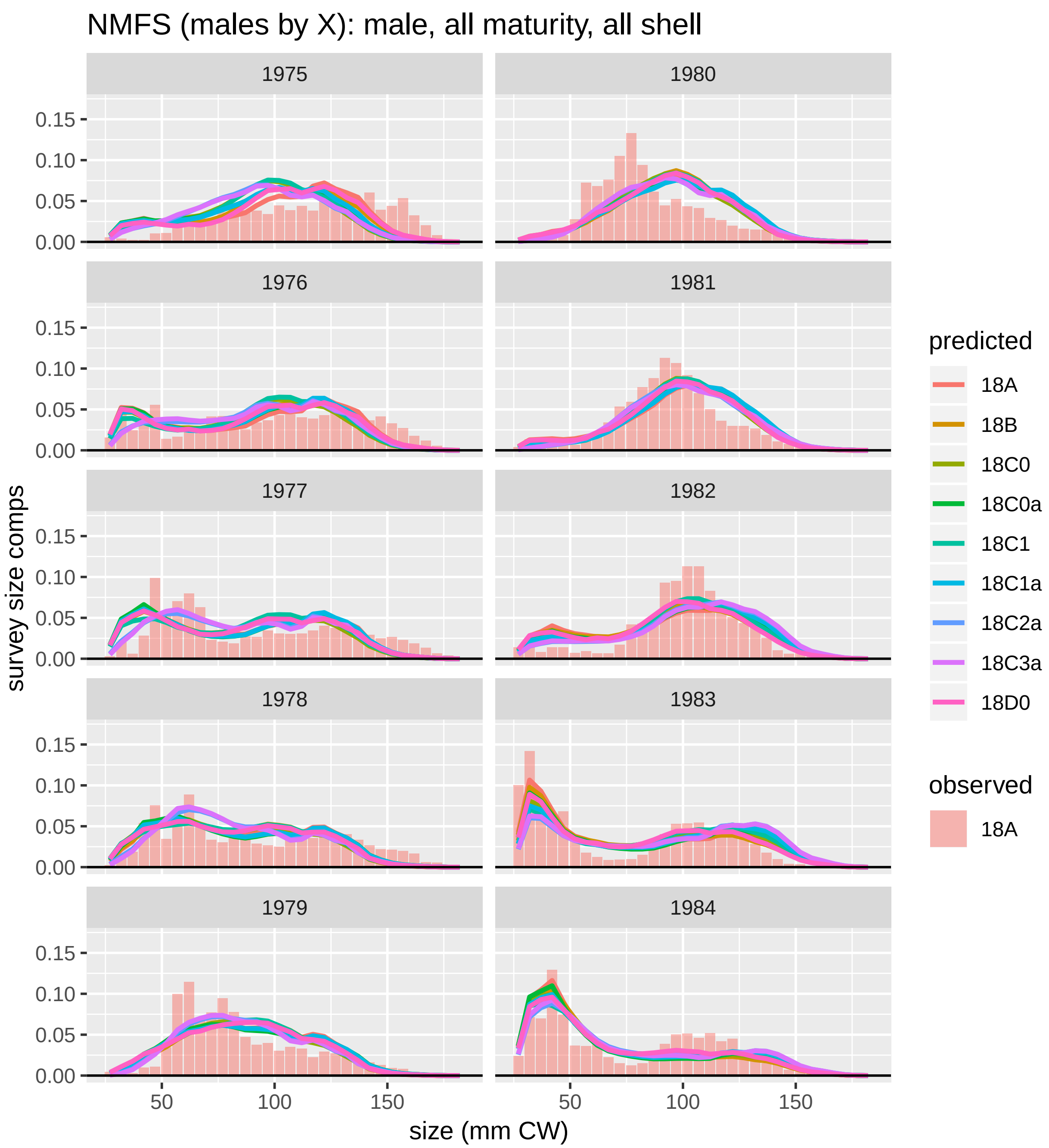

Figure 46: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS (males by X). Page 1 of 5.

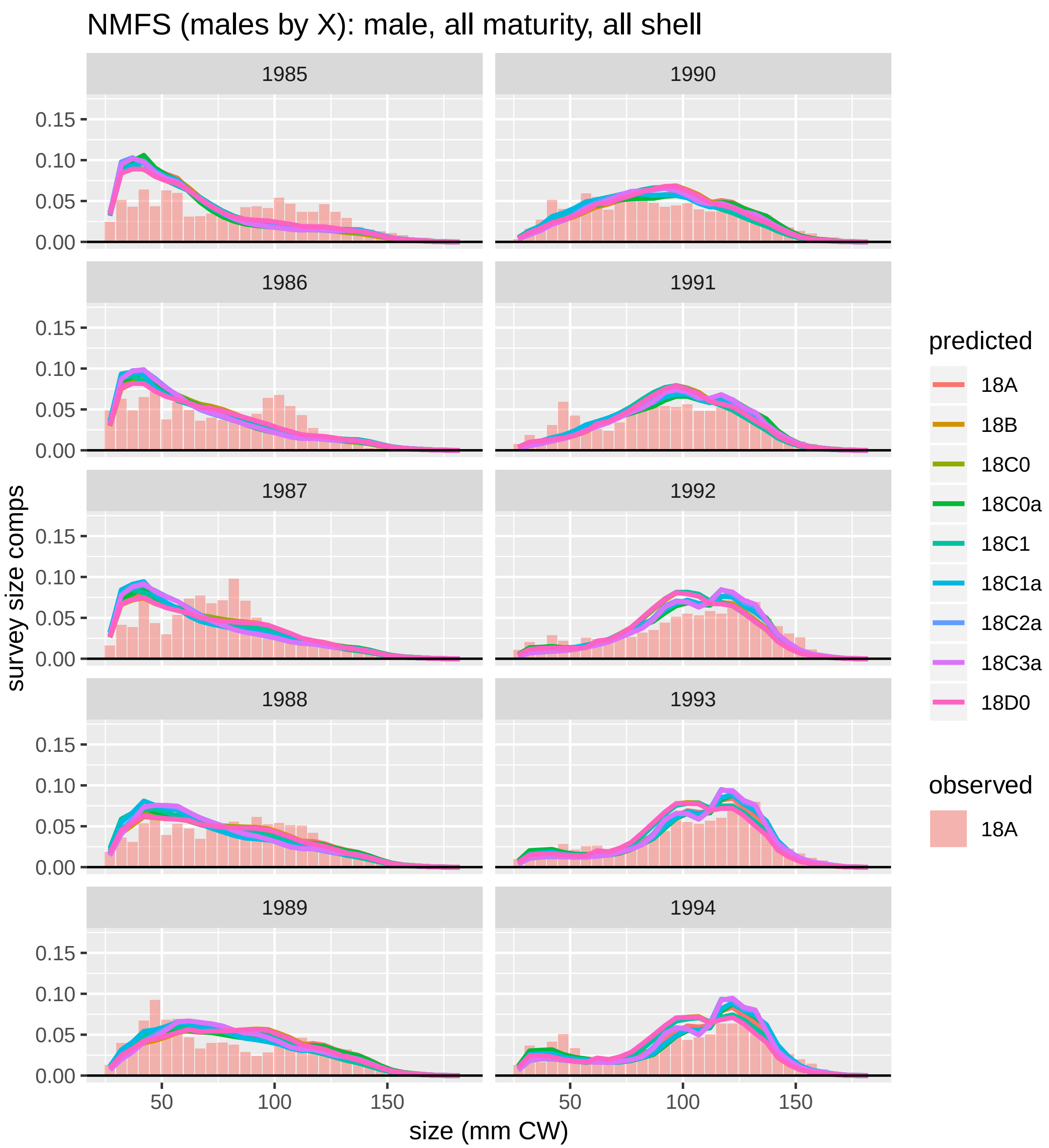

Figure 47: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS (males by X). Page 2 of 5.

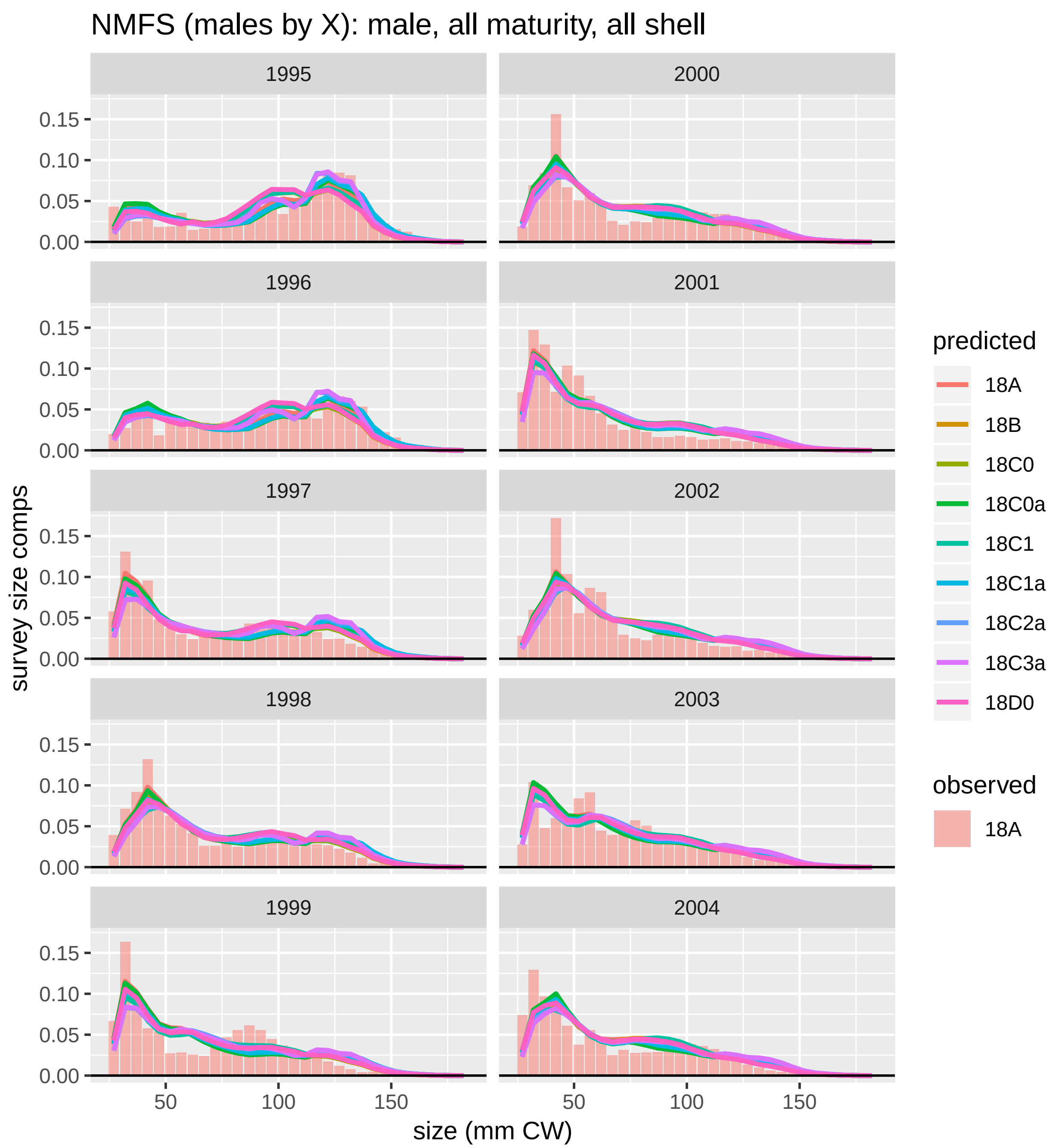

Figure 48: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS (males by X). Page 3 of 5.

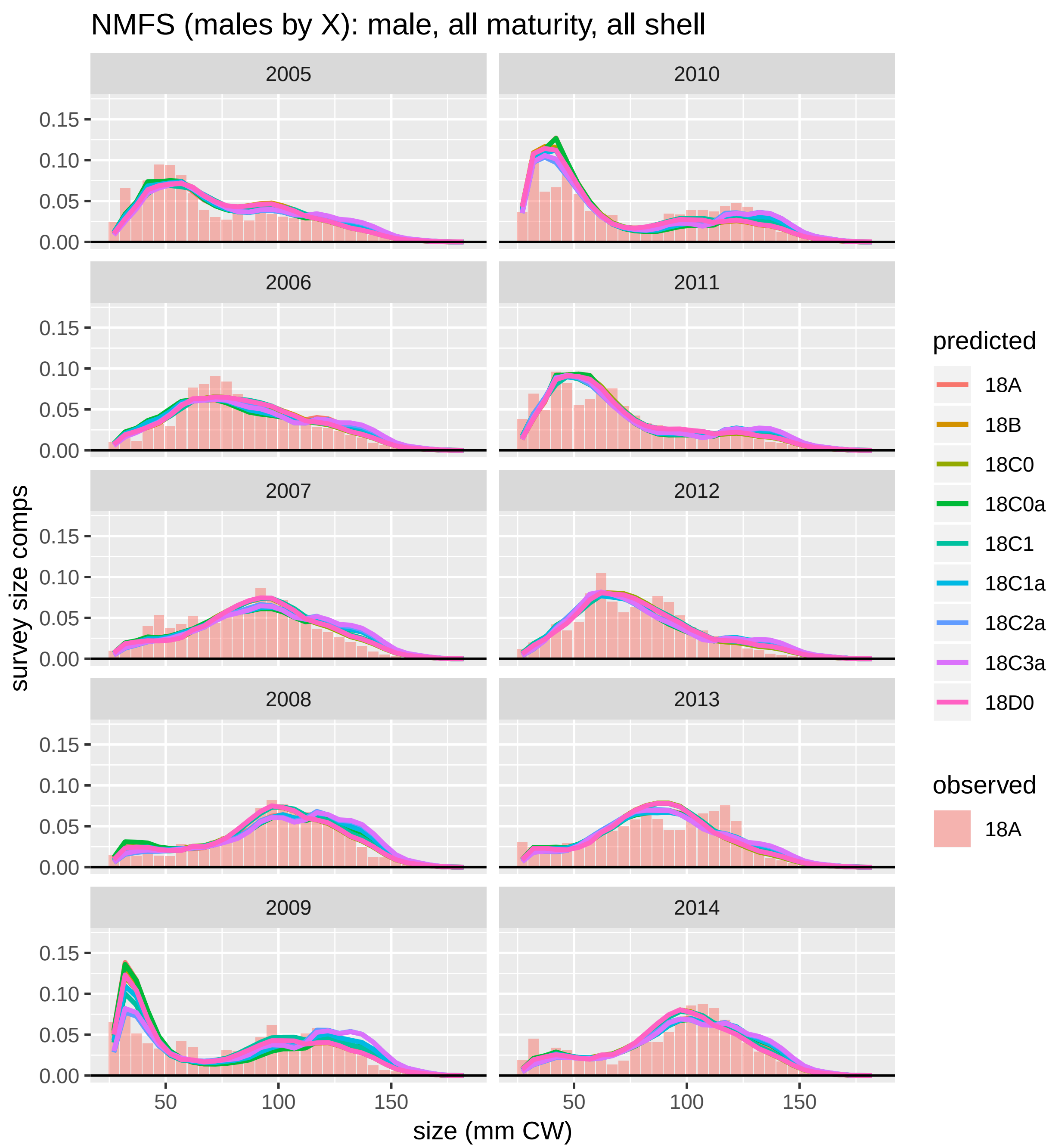

Figure 49: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS (males by X). Page 4 of 5.

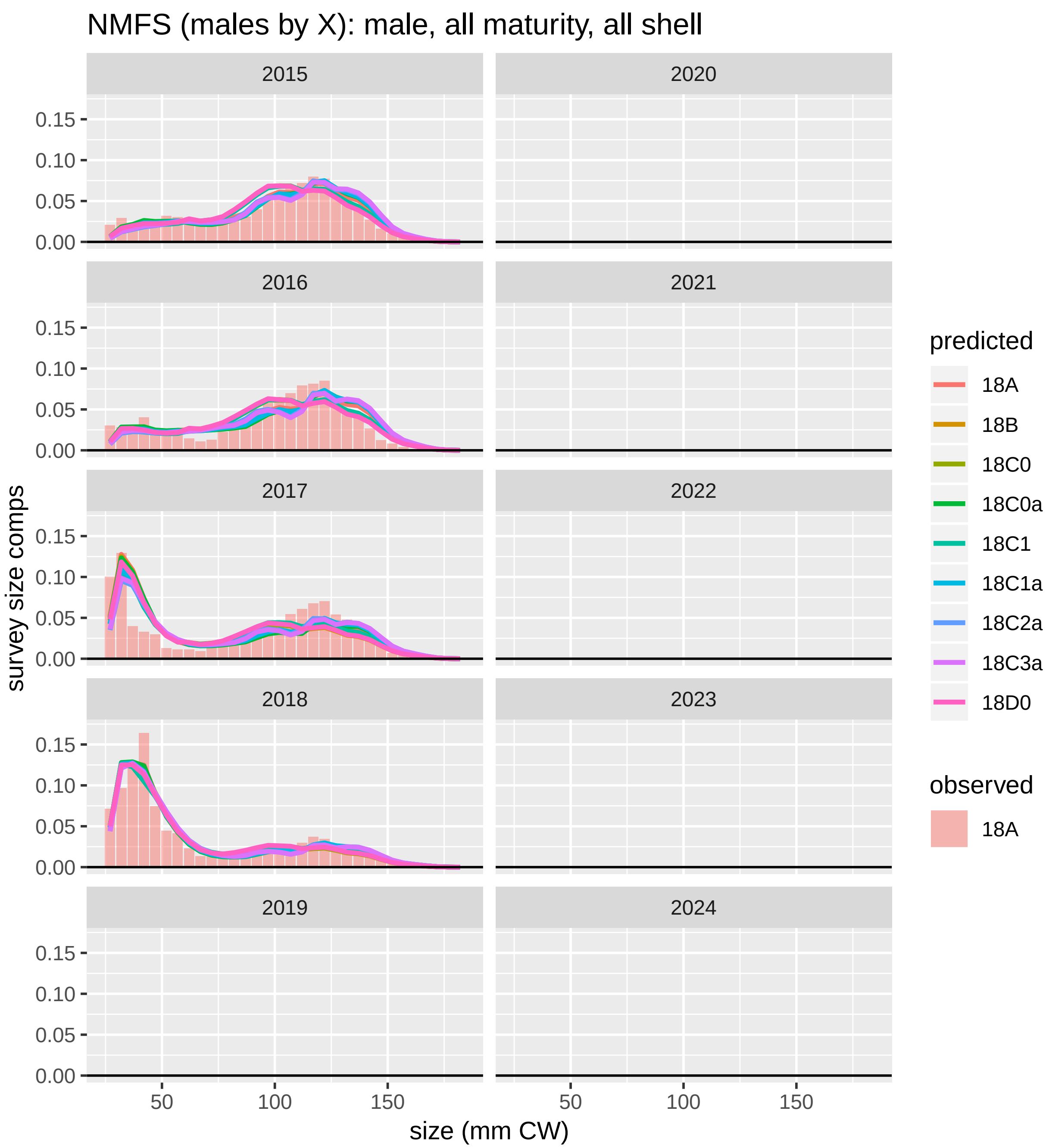

Figure 50: Comparison of observed and predicted male, all maturity, all shell survey size comps for NMFS (males by X). Page 5 of 5.

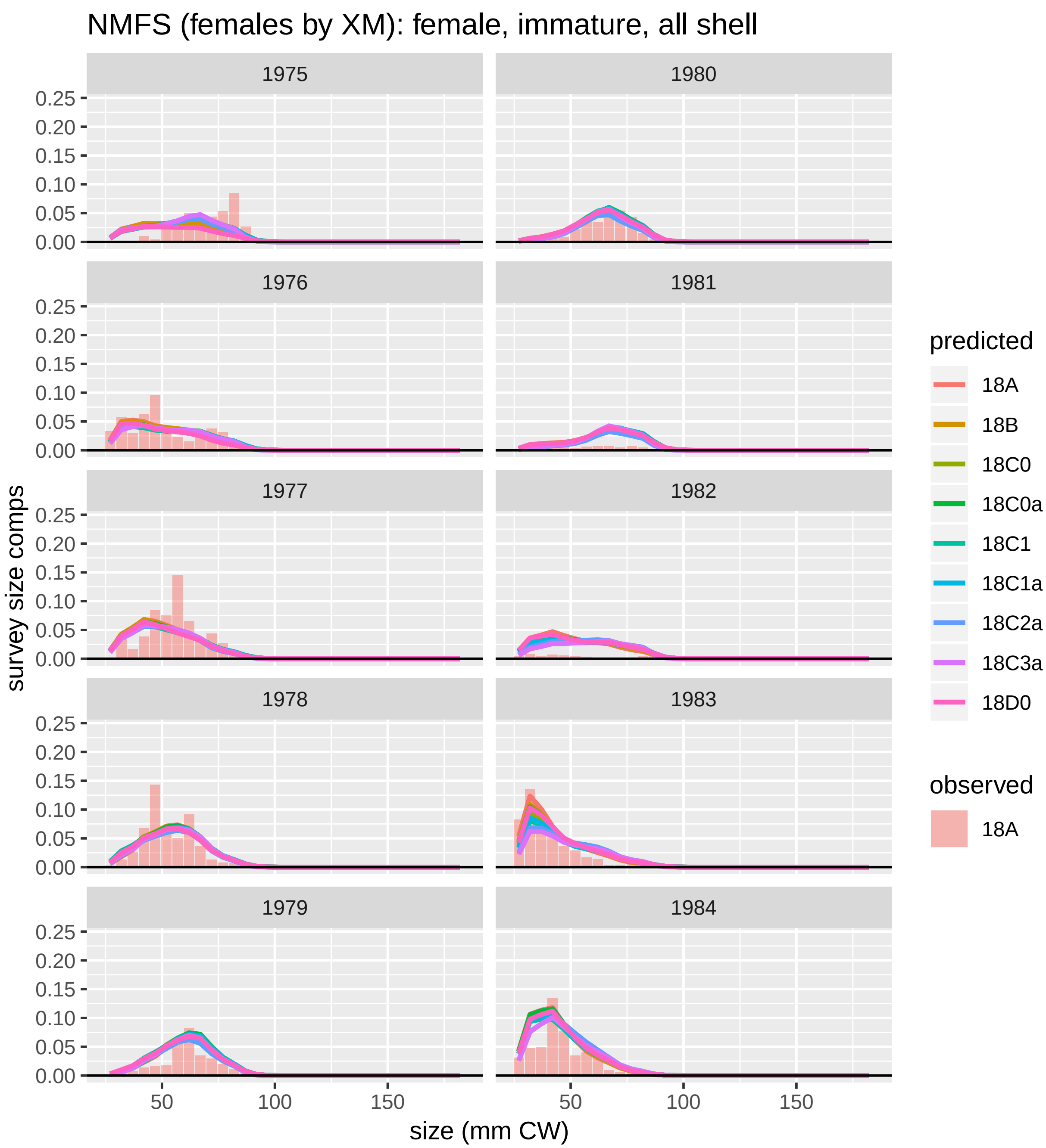

Figure 51: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS (females by XM). Page 1 of 5.

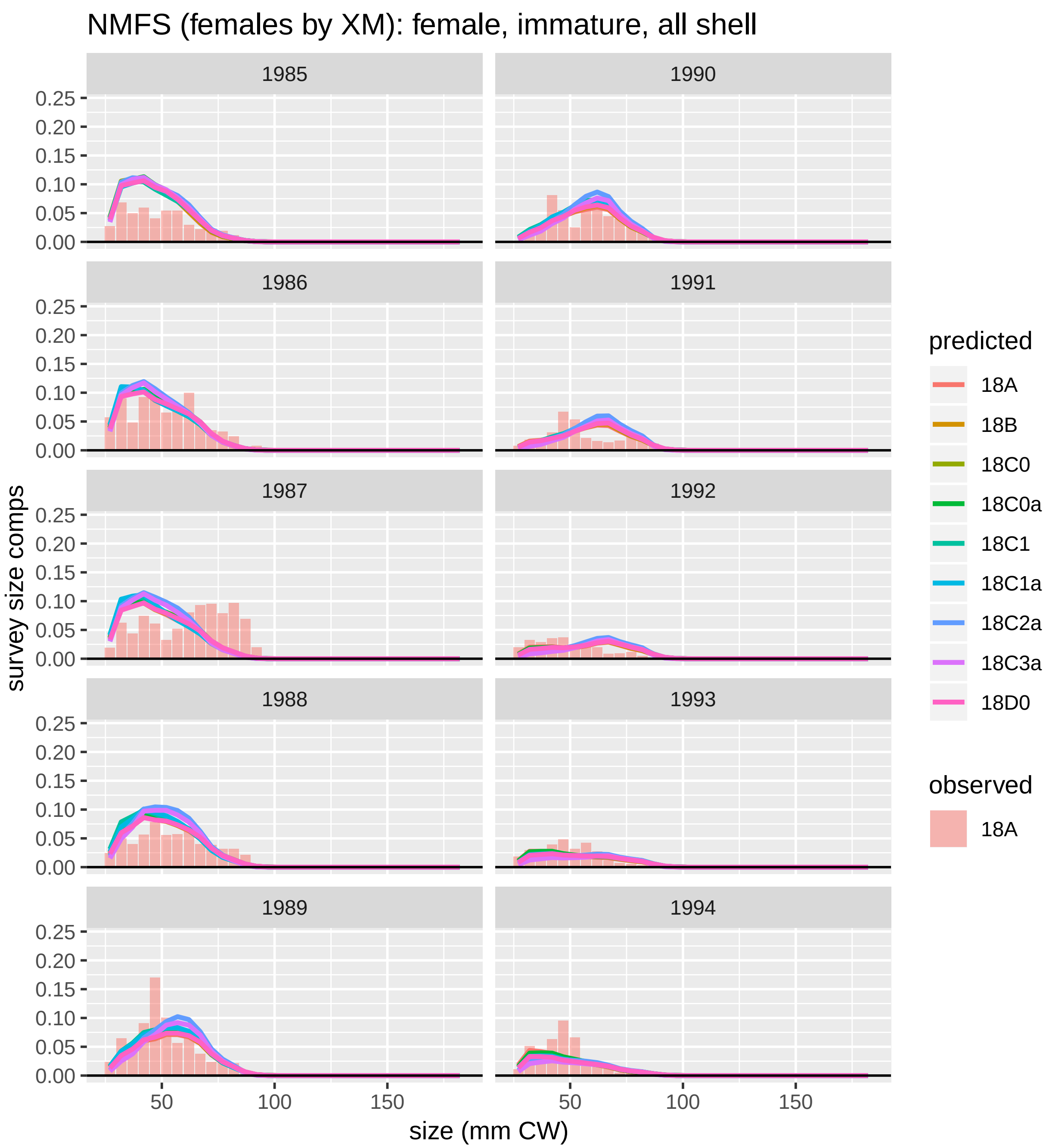

Figure 52: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS (females by XM). Page 2 of 5.

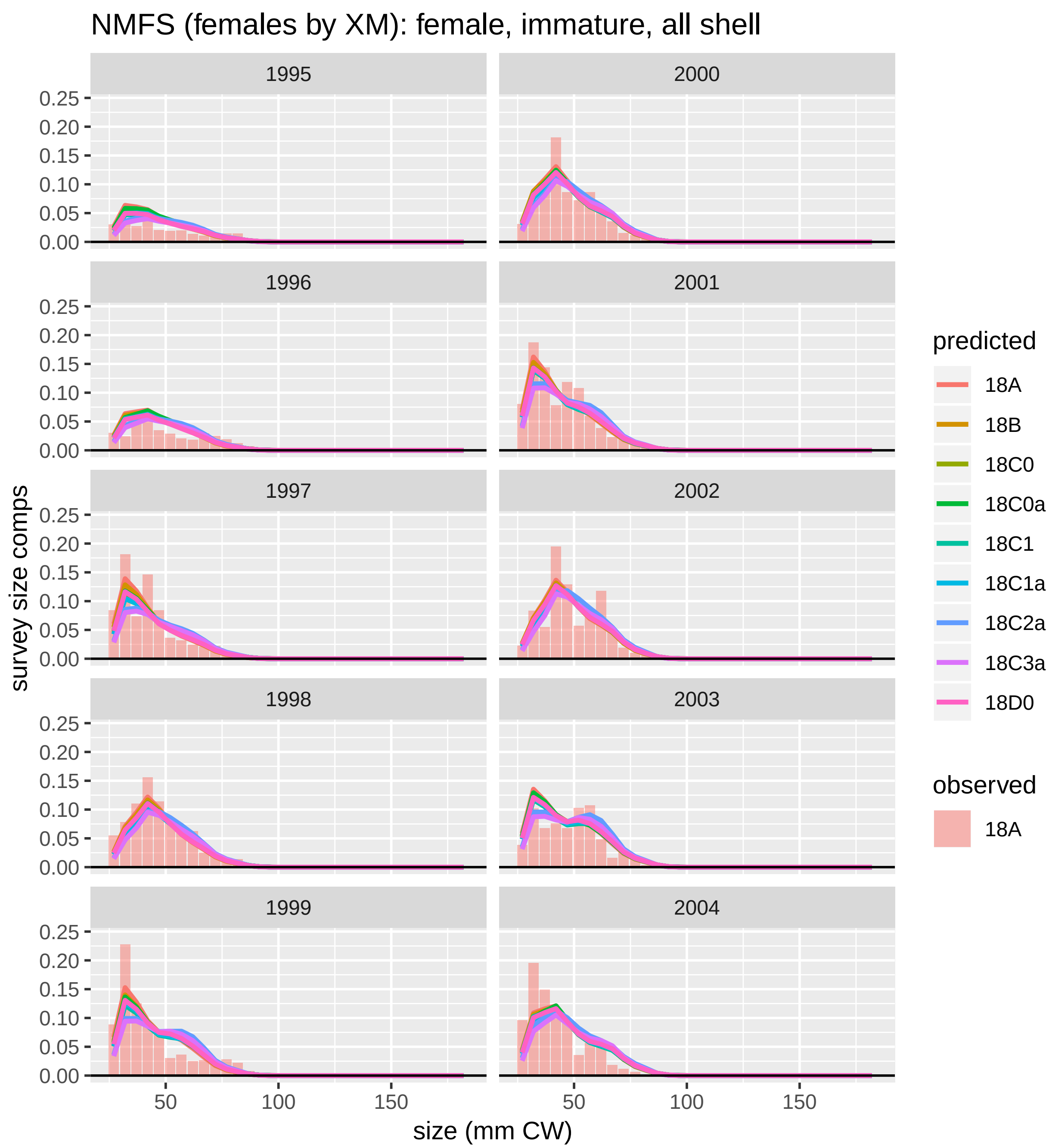

Figure 53: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS (females by XM). Page 3 of 5.

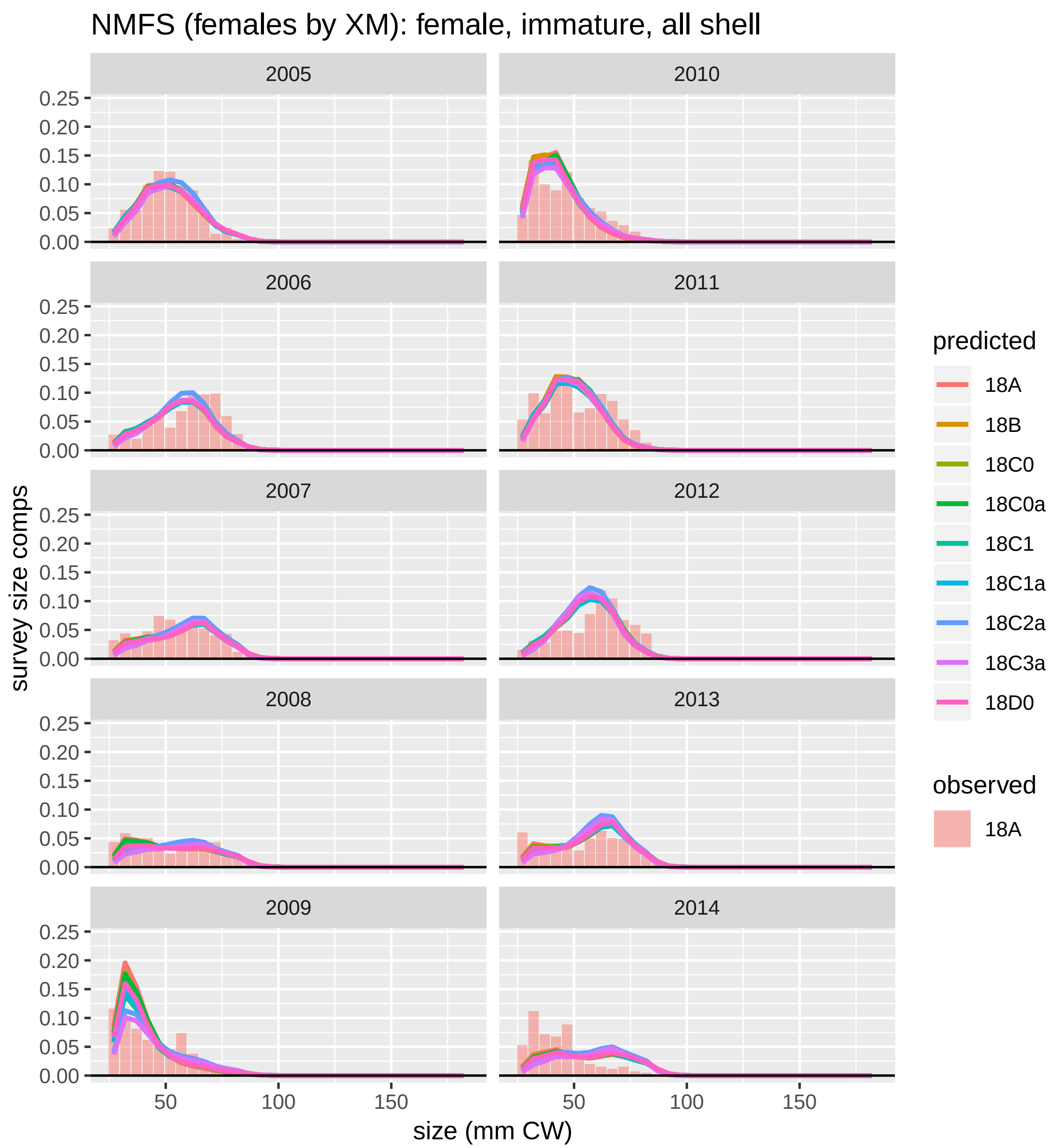

Figure 54: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS (females by XM). Page 4 of 5.

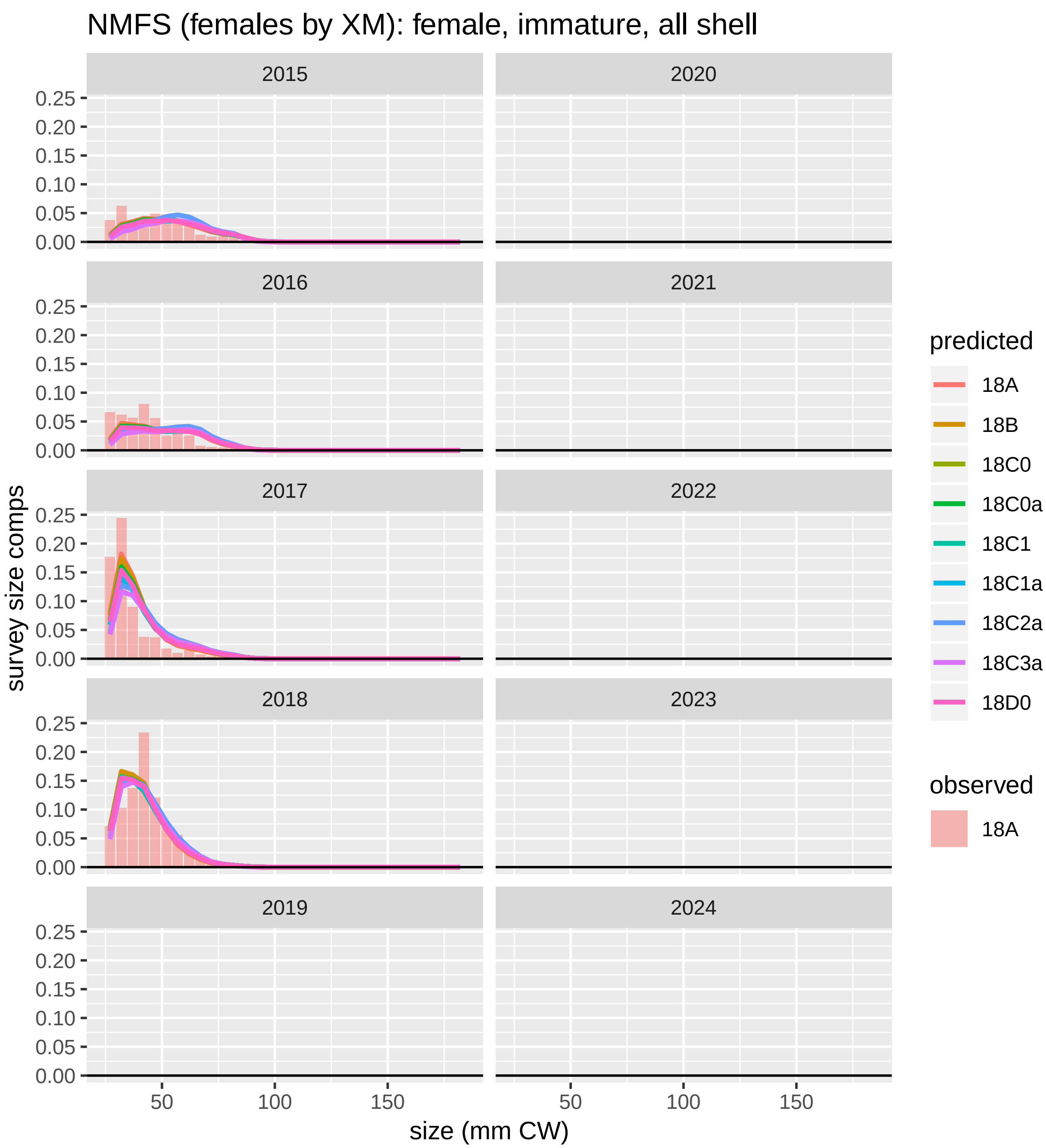

Figure 55: Comparison of observed and predicted female, immature, all shell survey size comps for NMFS (females by XM). Page 5 of 5.

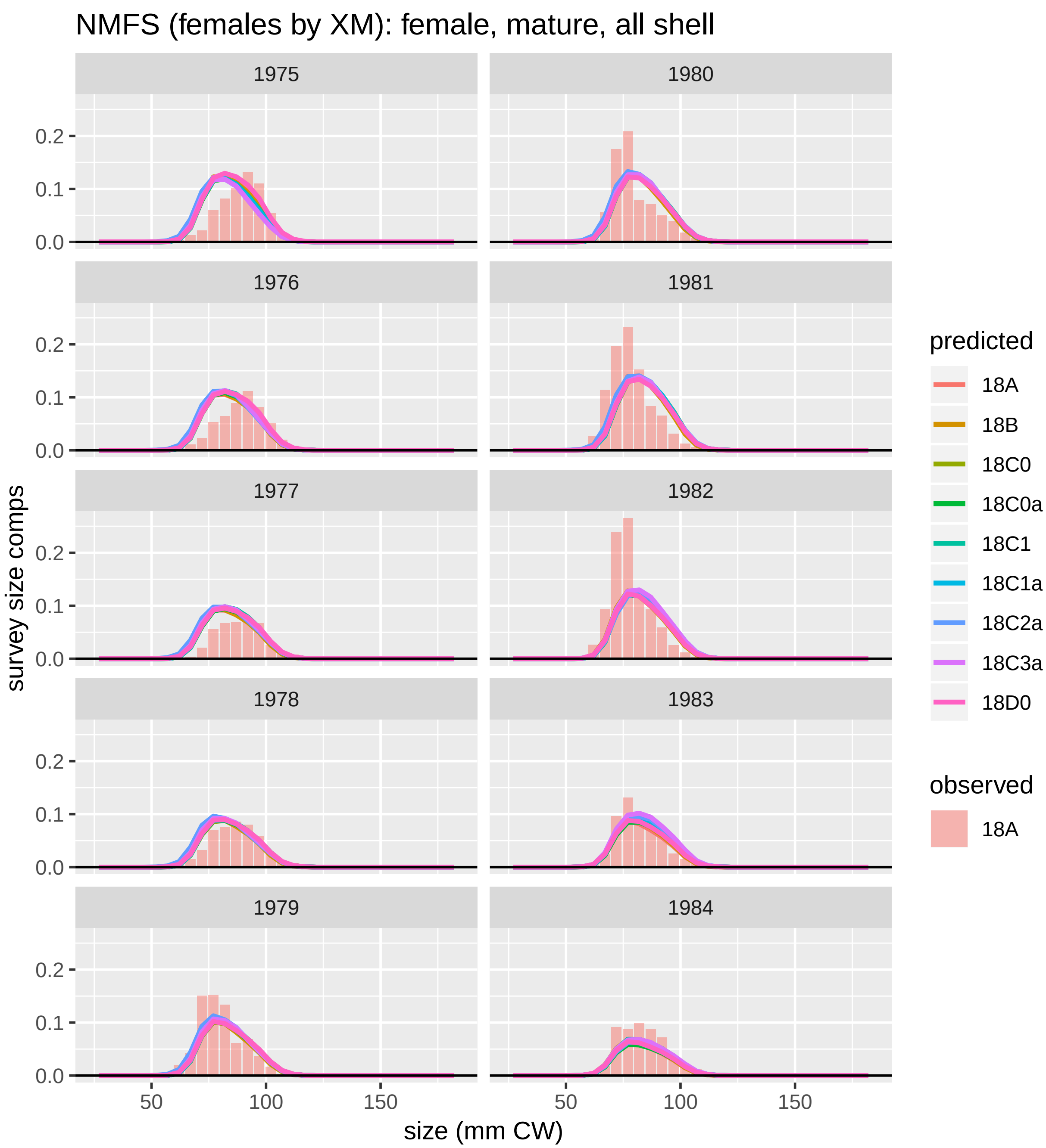

Figure 56: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS (females by XM). Page 1 of 5.

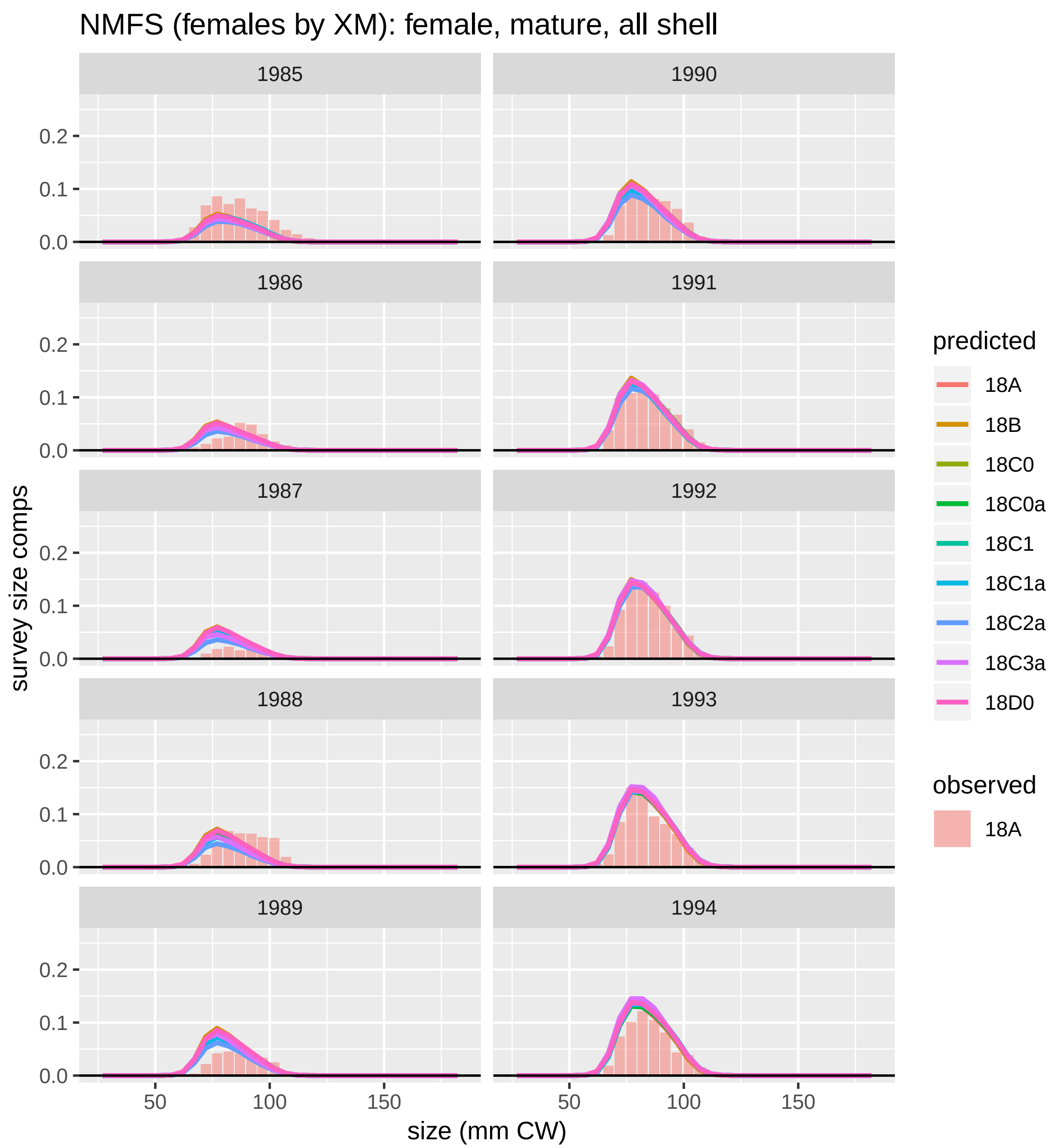

Figure 57: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS (females by XM). Page 2 of 5.

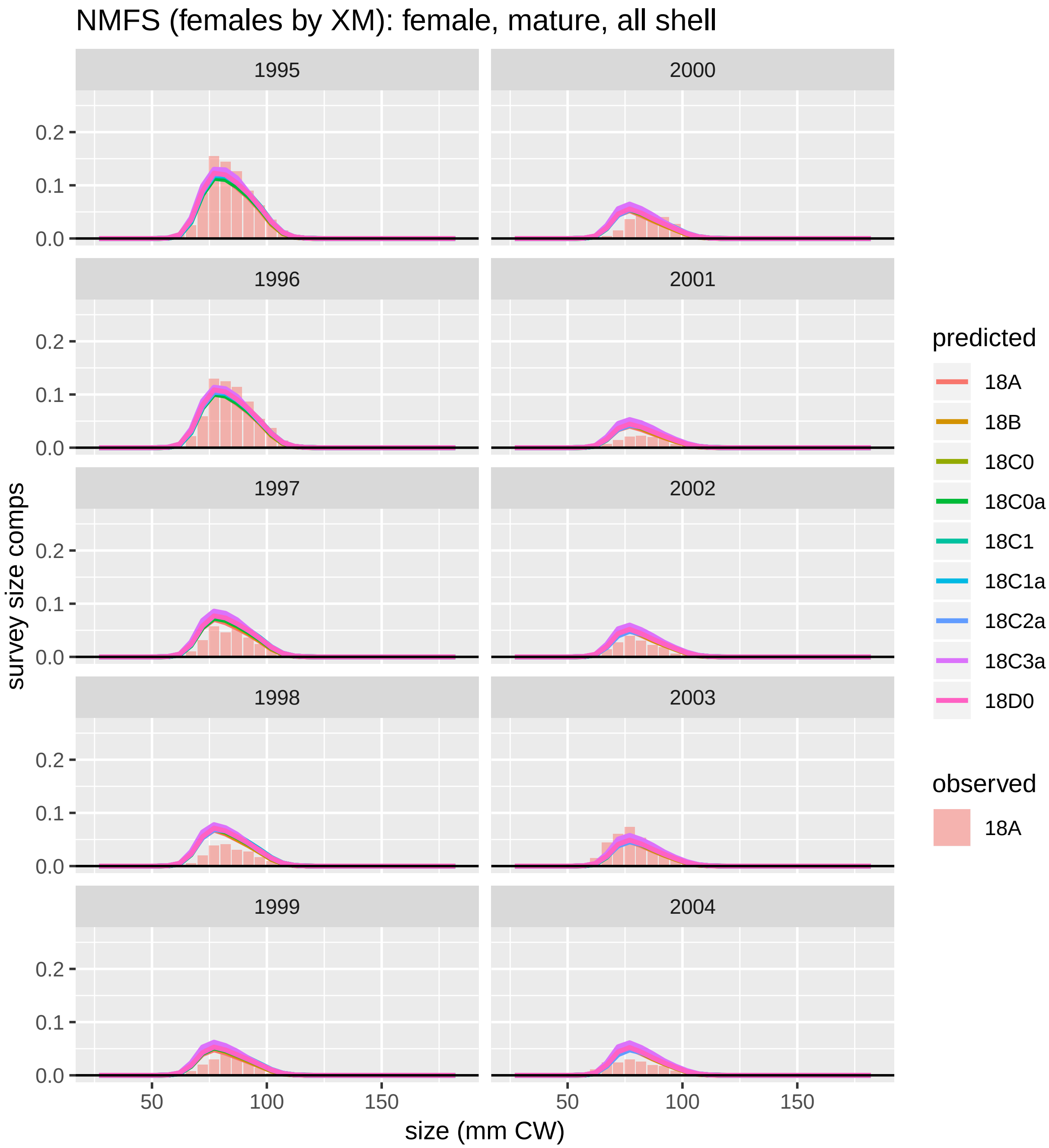

Figure 58: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS (females by XM). Page 3 of 5.

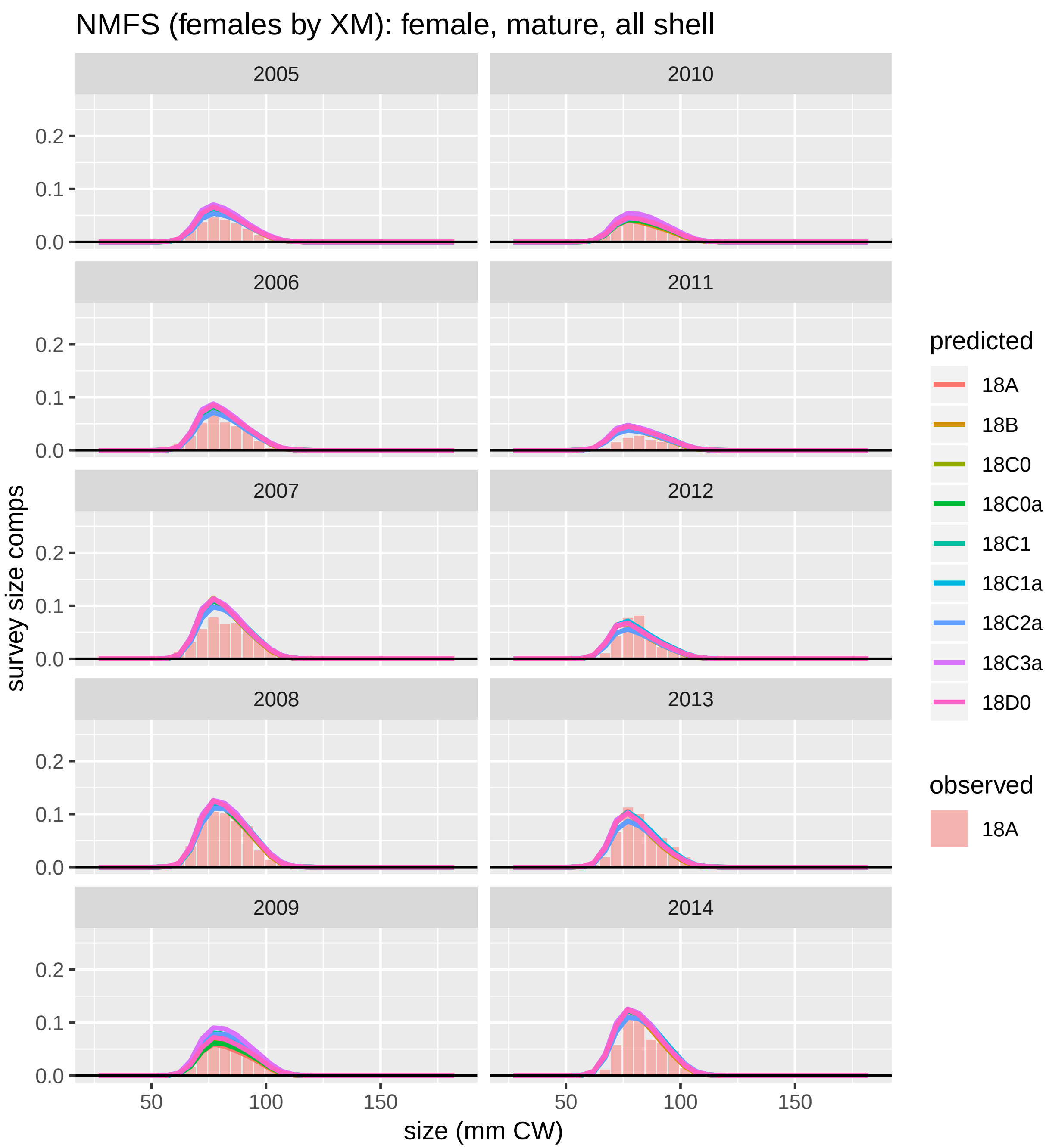

Figure 59: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS (females by XM). Page 4 of 5.

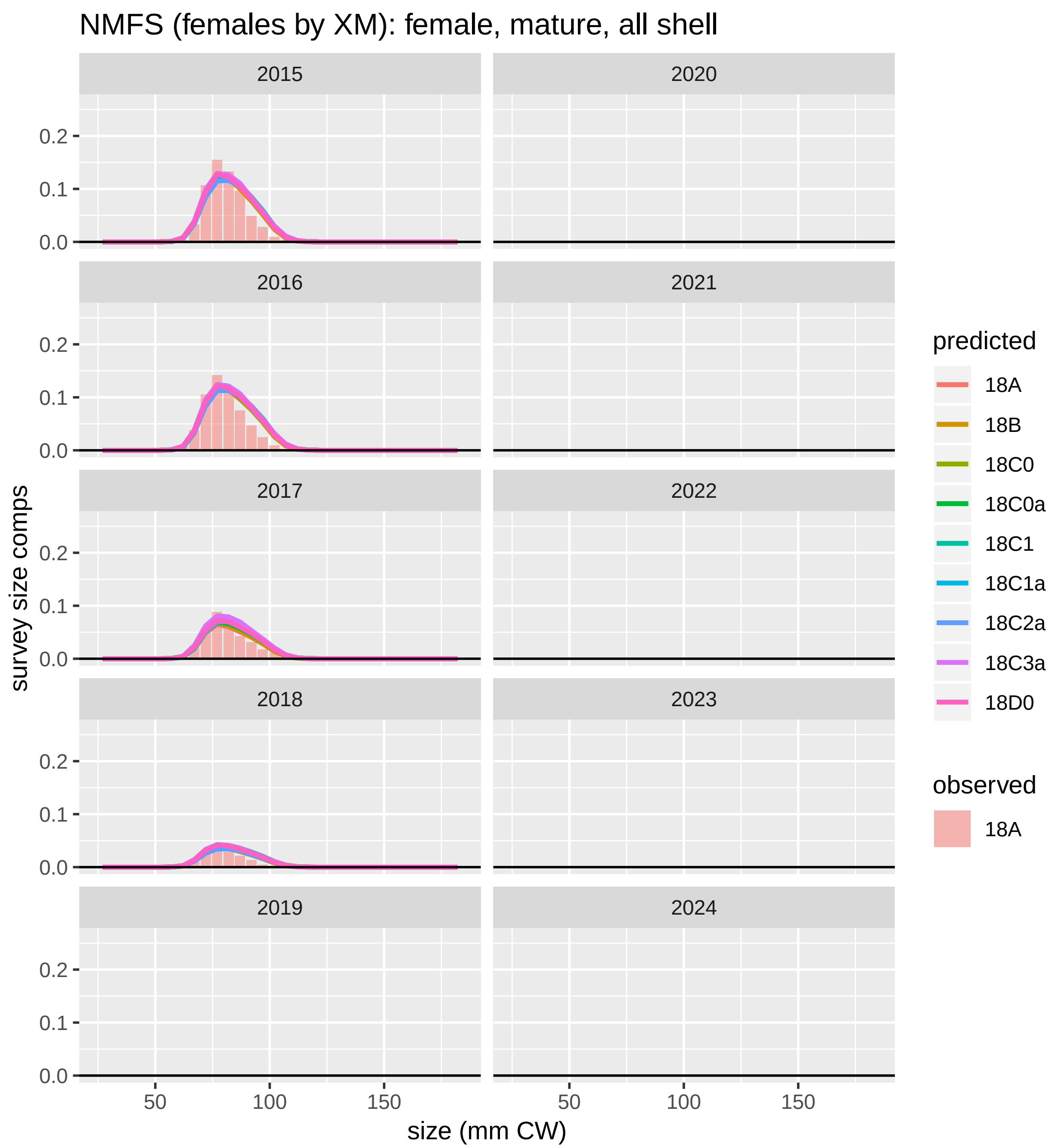

Figure 60: Comparison of observed and predicted female, mature, all shell survey size comps for NMFS (females by XM). Page 5 of 5.

Fishery retained catch size compositions

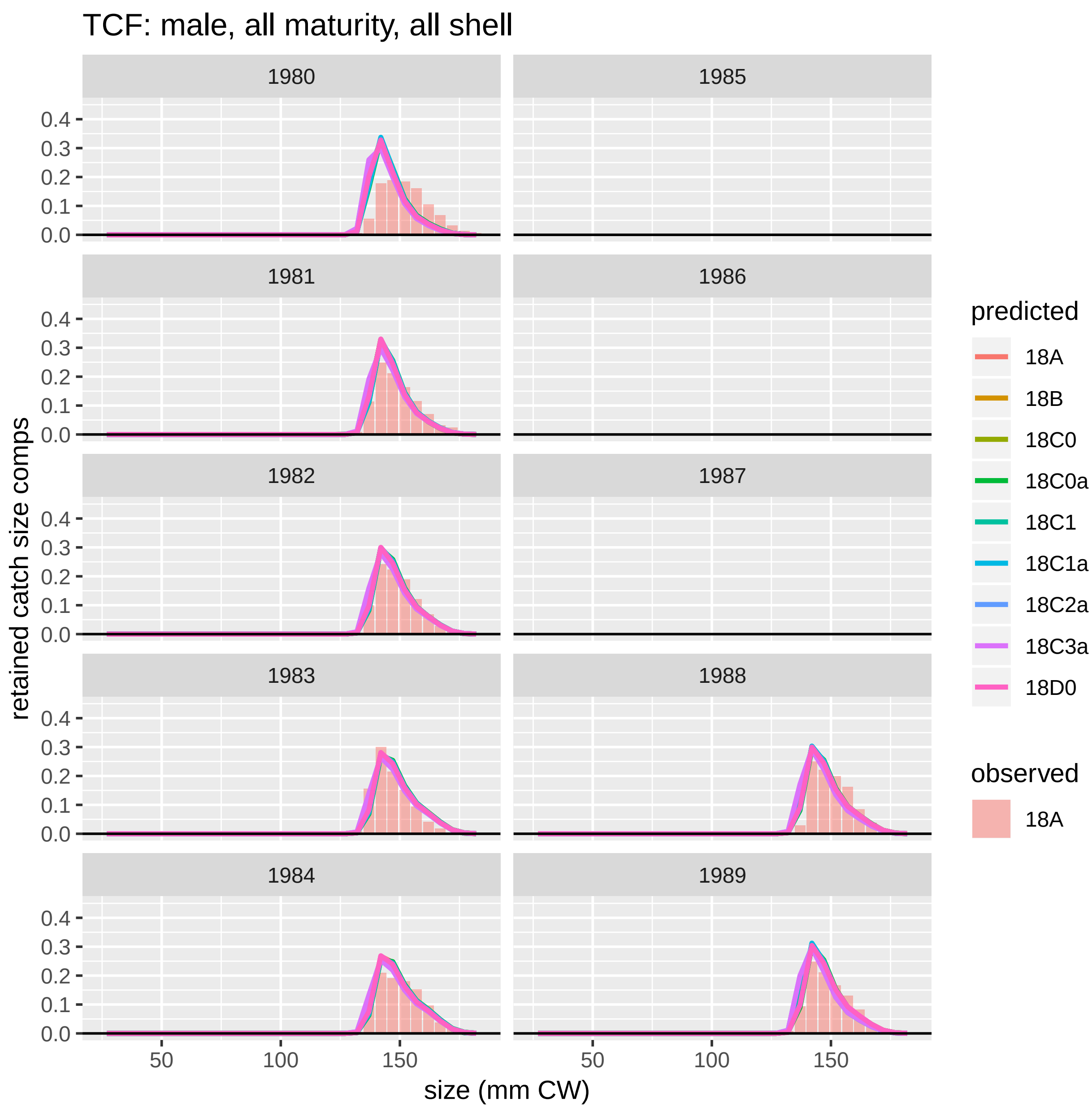

Figure 61: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 1 of 4.

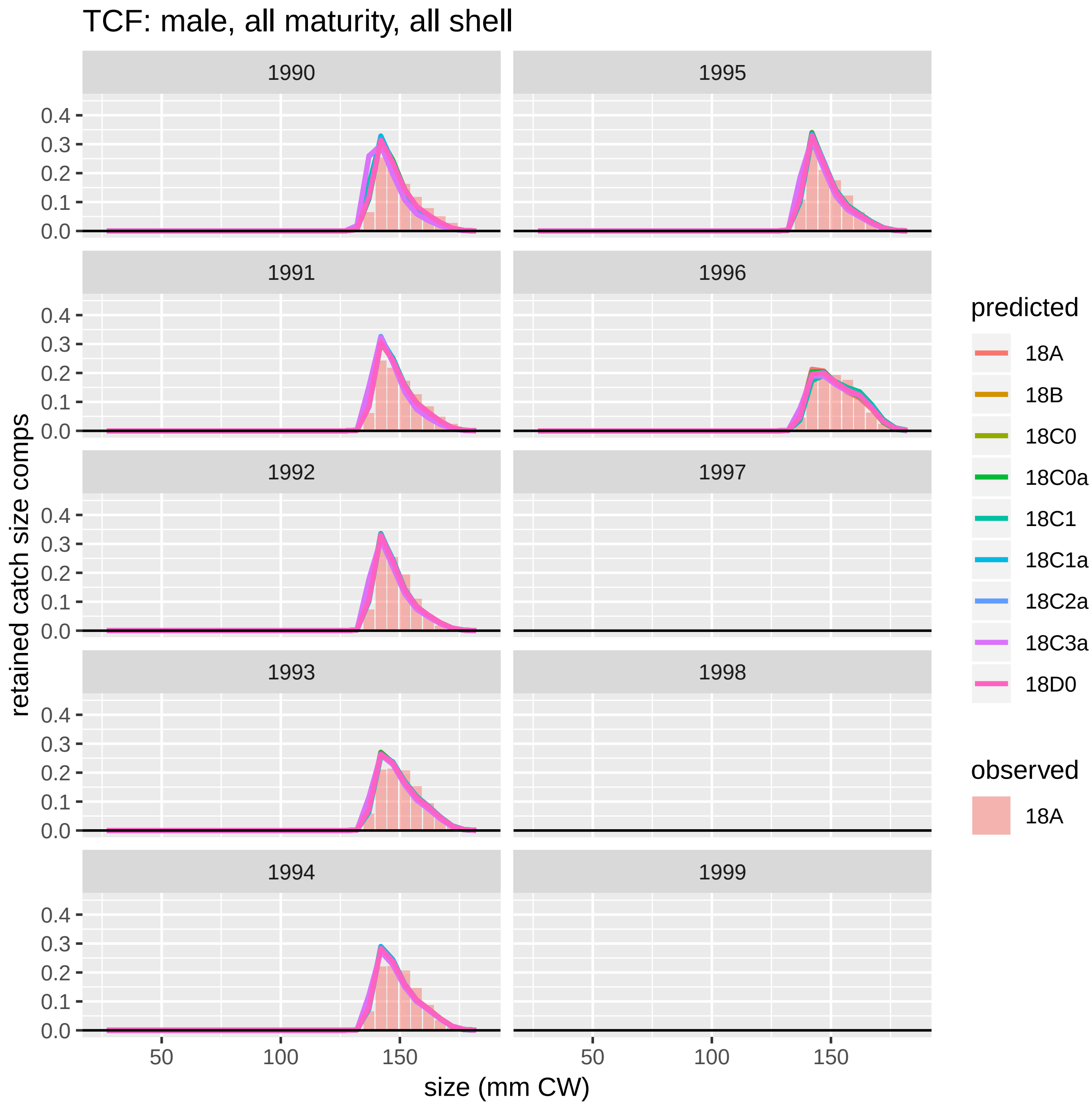

Figure 62: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 2 of 4.

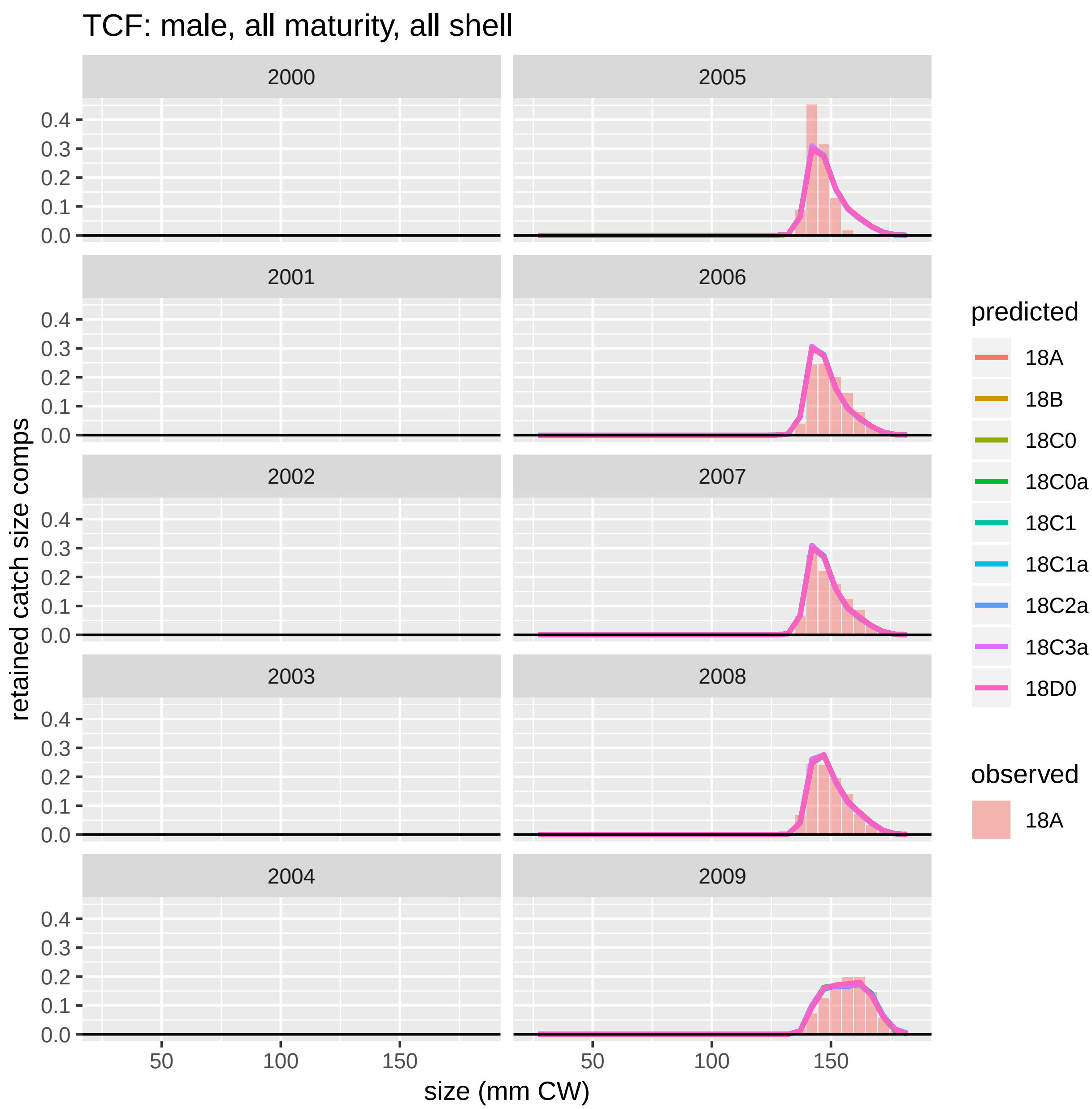

Figure 63: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 3 of 4.

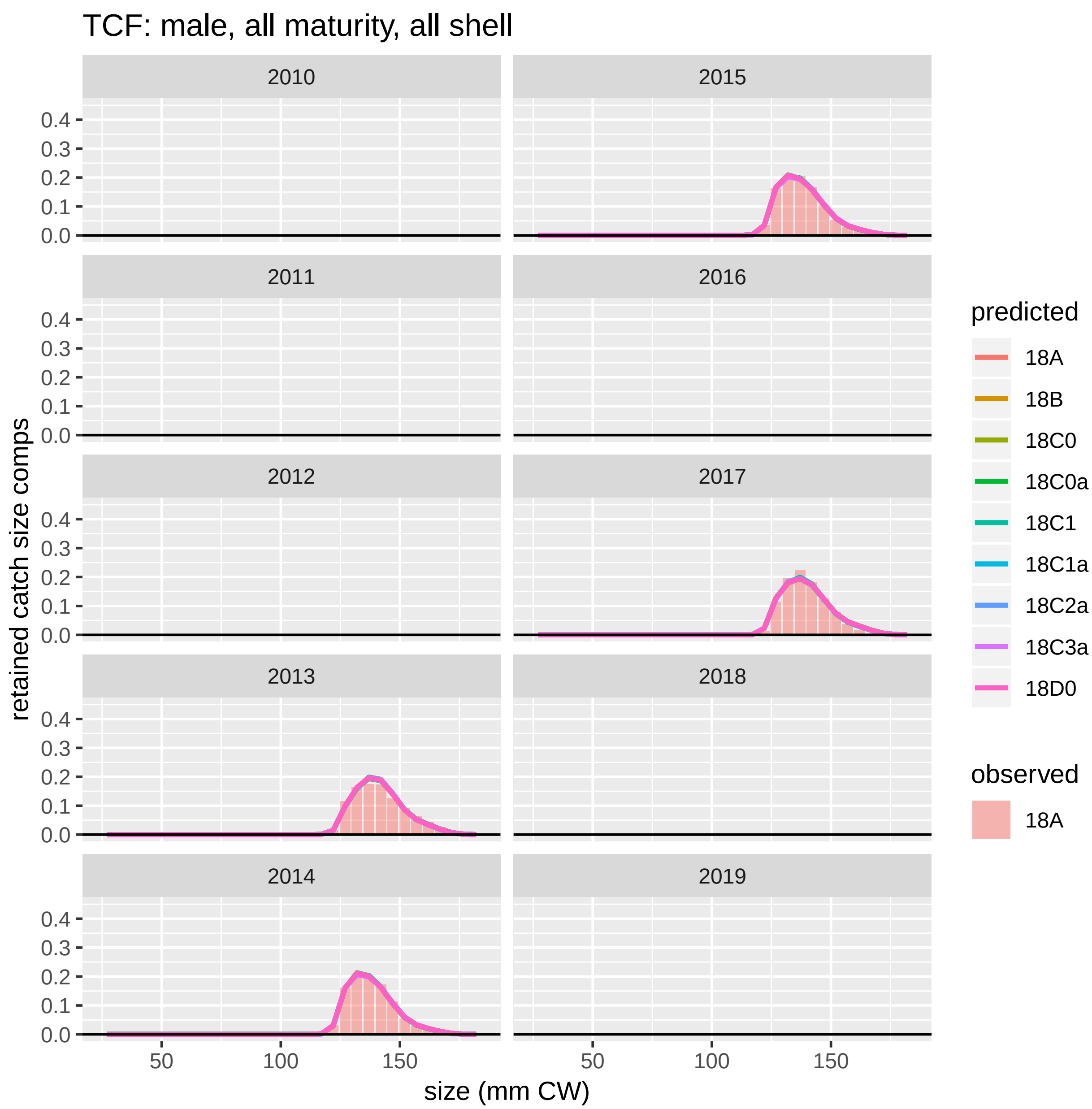

Figure 64: Comparison of observed and predicted male, all maturity, all shell retained catch size comps for TCF. Page 4 of 4.

Fishery total catch size compositions

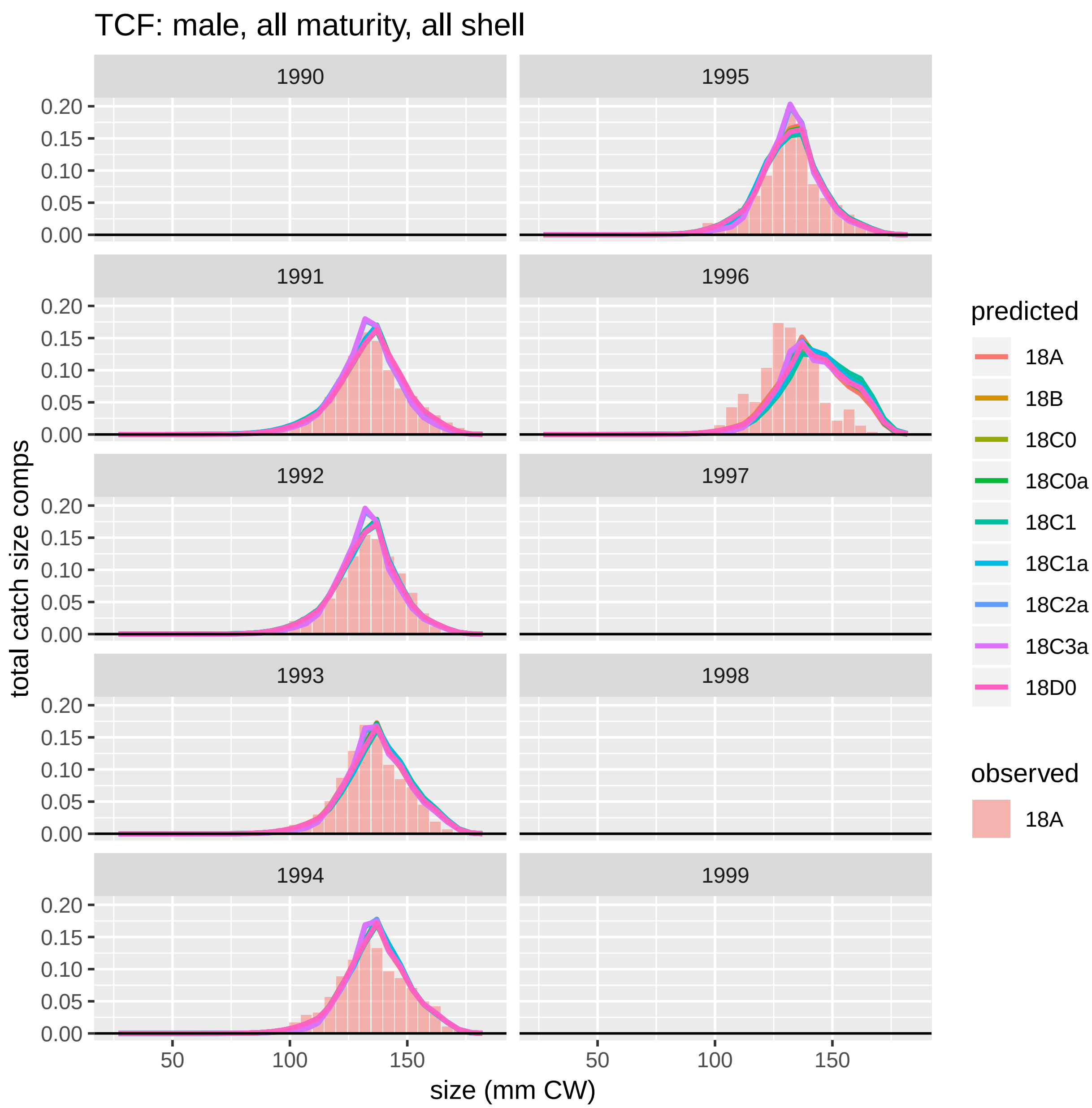

Figure 65: Comparison of observed and predicted male, all maturity, all shell total catch size comps for TCF. Page 1 of 3.

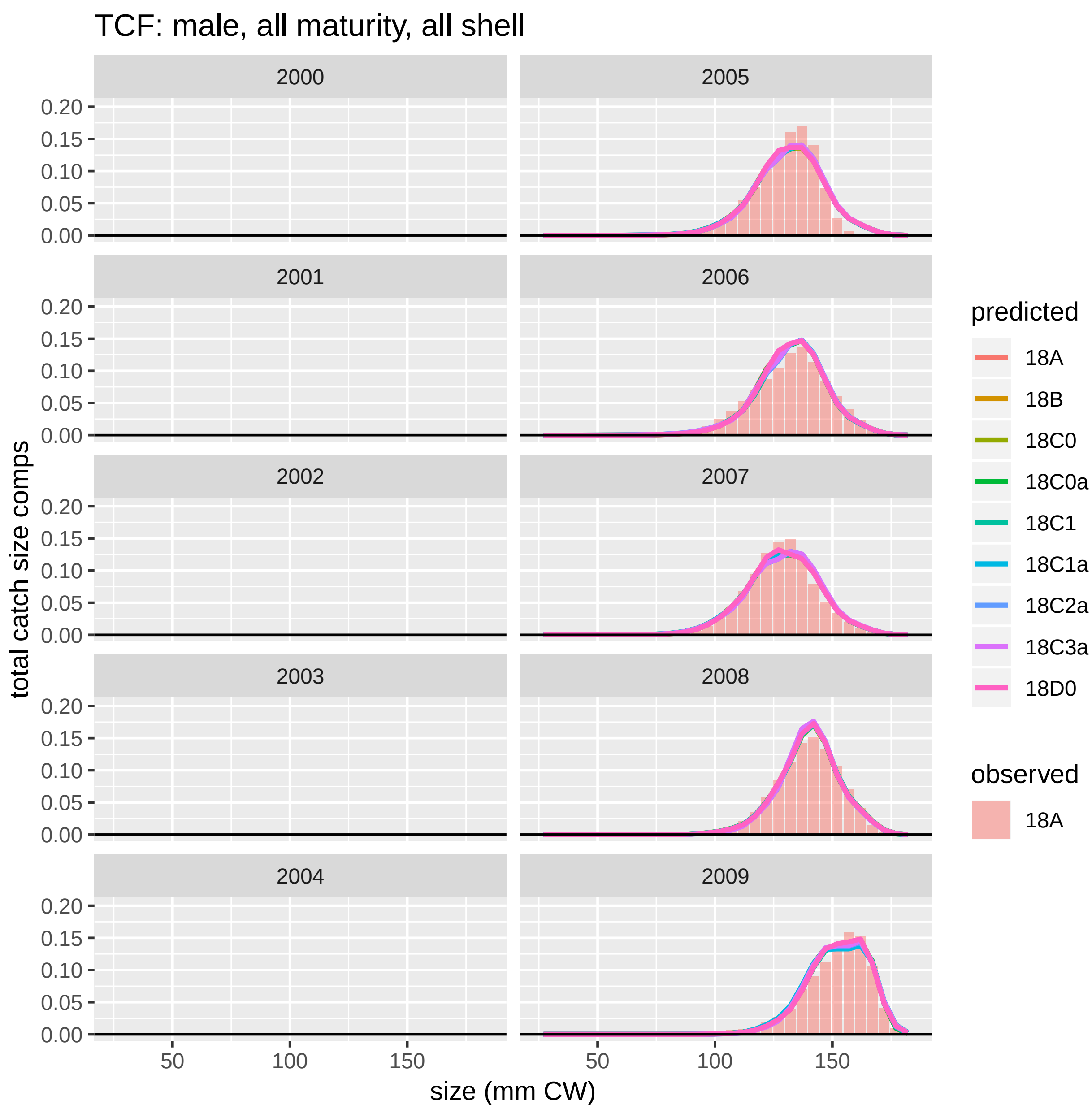

Figure 66: Comparison of observed and predicted male, all maturity, all shell total catch size comps for TCF. Page 2 of 3.

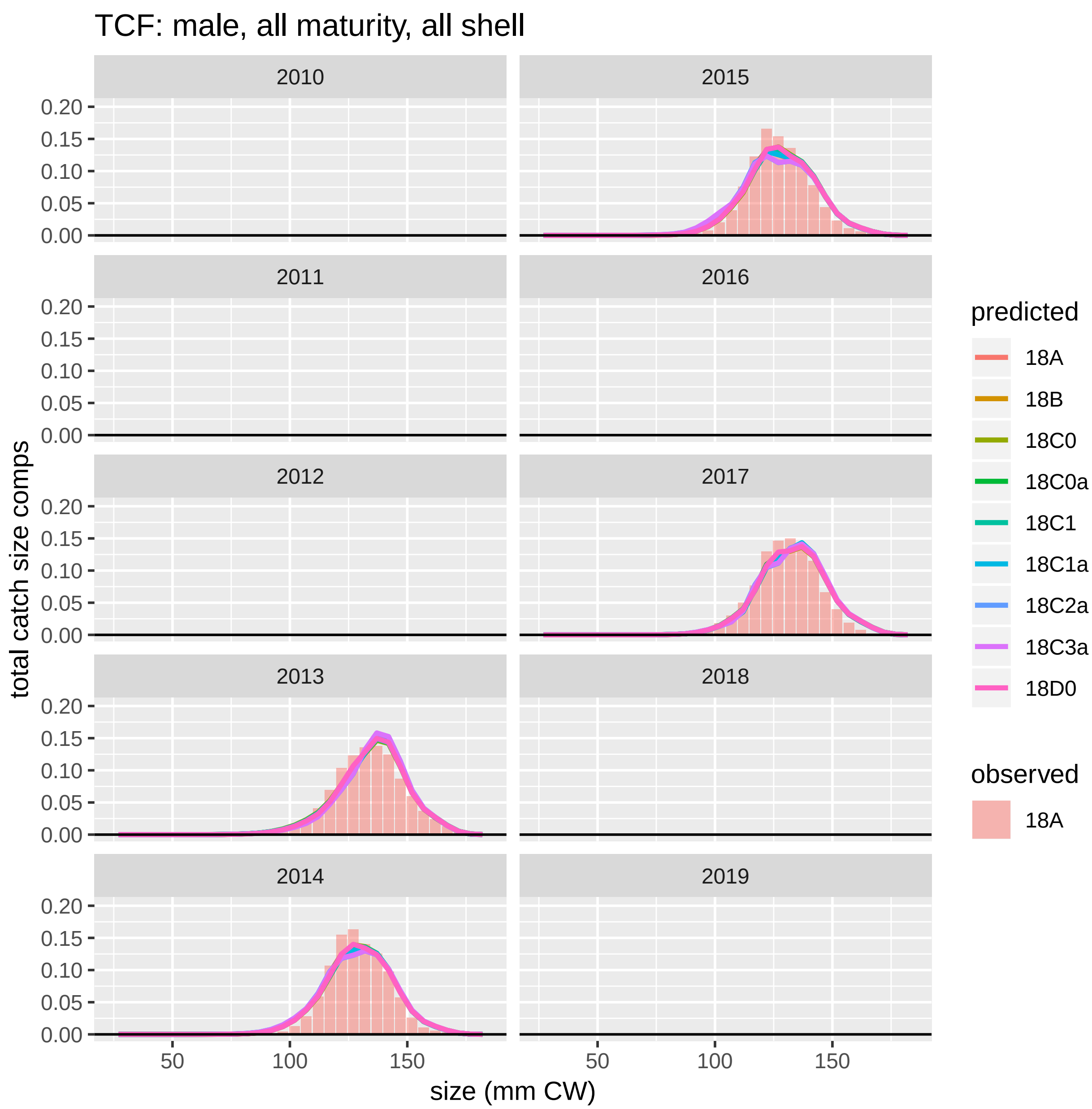

Figure 67: Comparison of observed and predicted male, all maturity, all shell total catch size comps for TCF. Page 3 of 3.

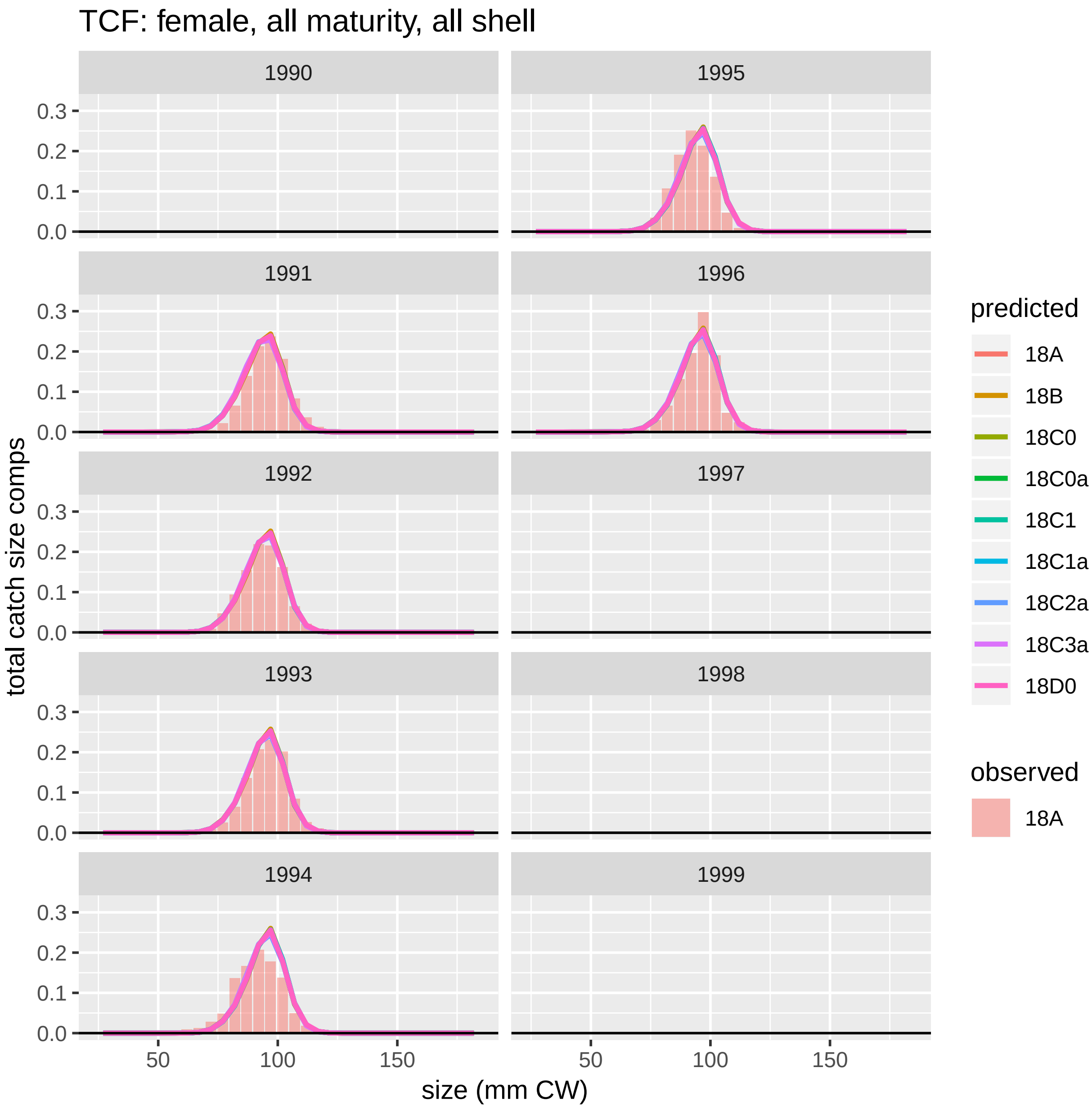

Figure 68: Comparison of observed and predicted female, all maturity, all shell total catch size comps for TCF. Page 1 of 3.

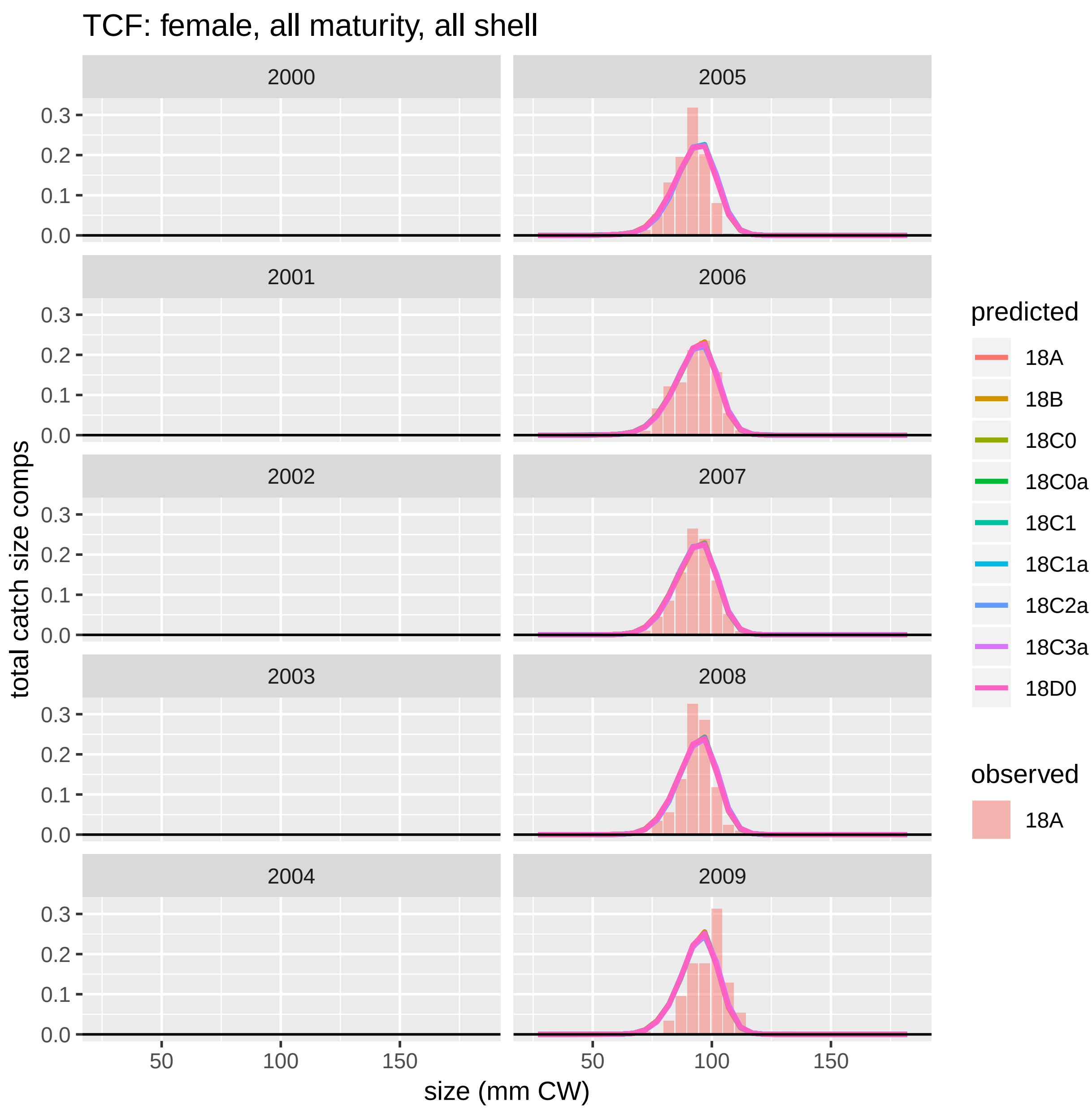

Figure 69: Comparison of observed and predicted female, all maturity, all shell total catch size comps for TCF. Page 2 of 3.

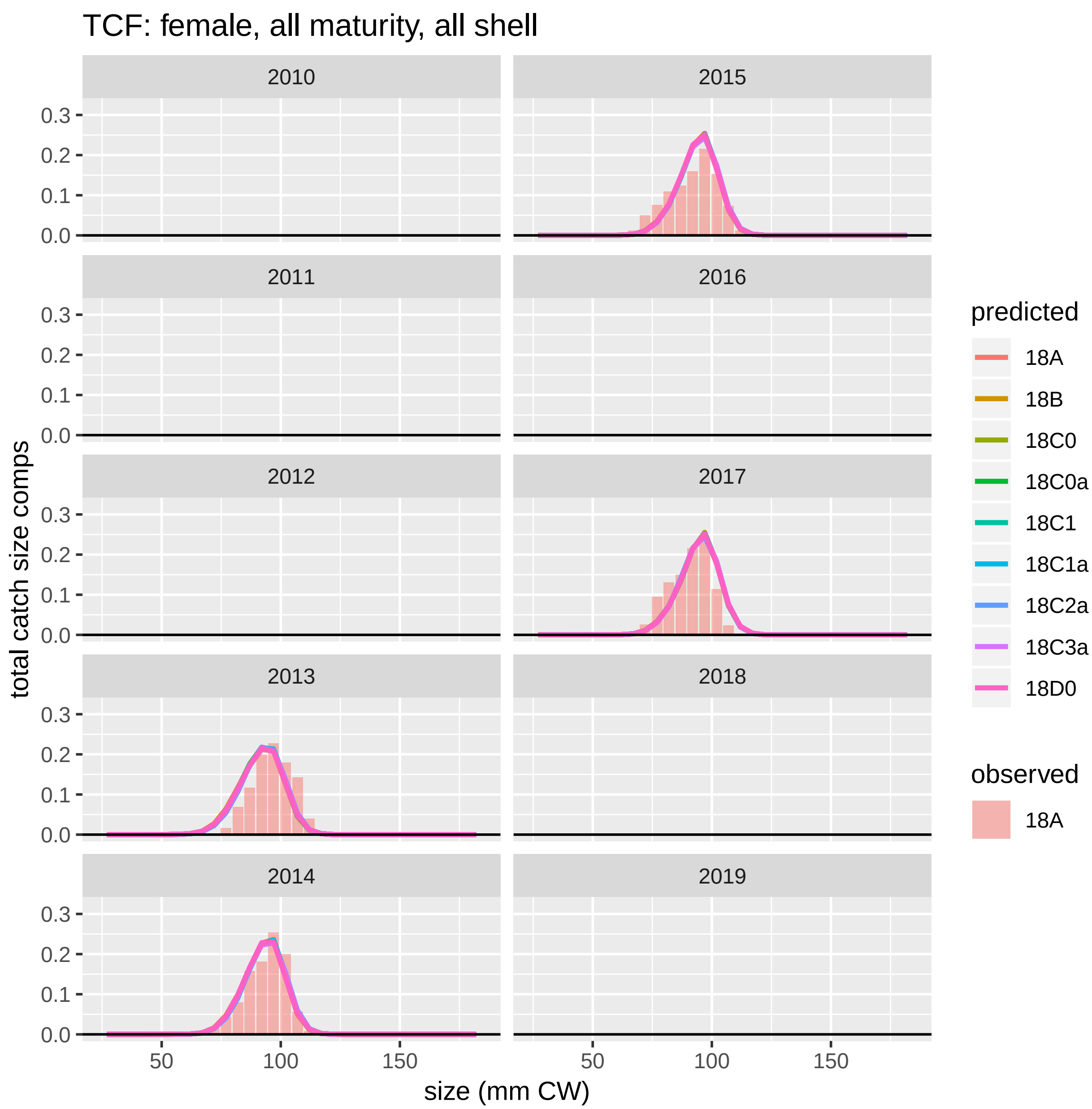

Figure 70: Comparison of observed and predicted female, all maturity, all shell total catch size comps for TCF. Page 3 of 3.

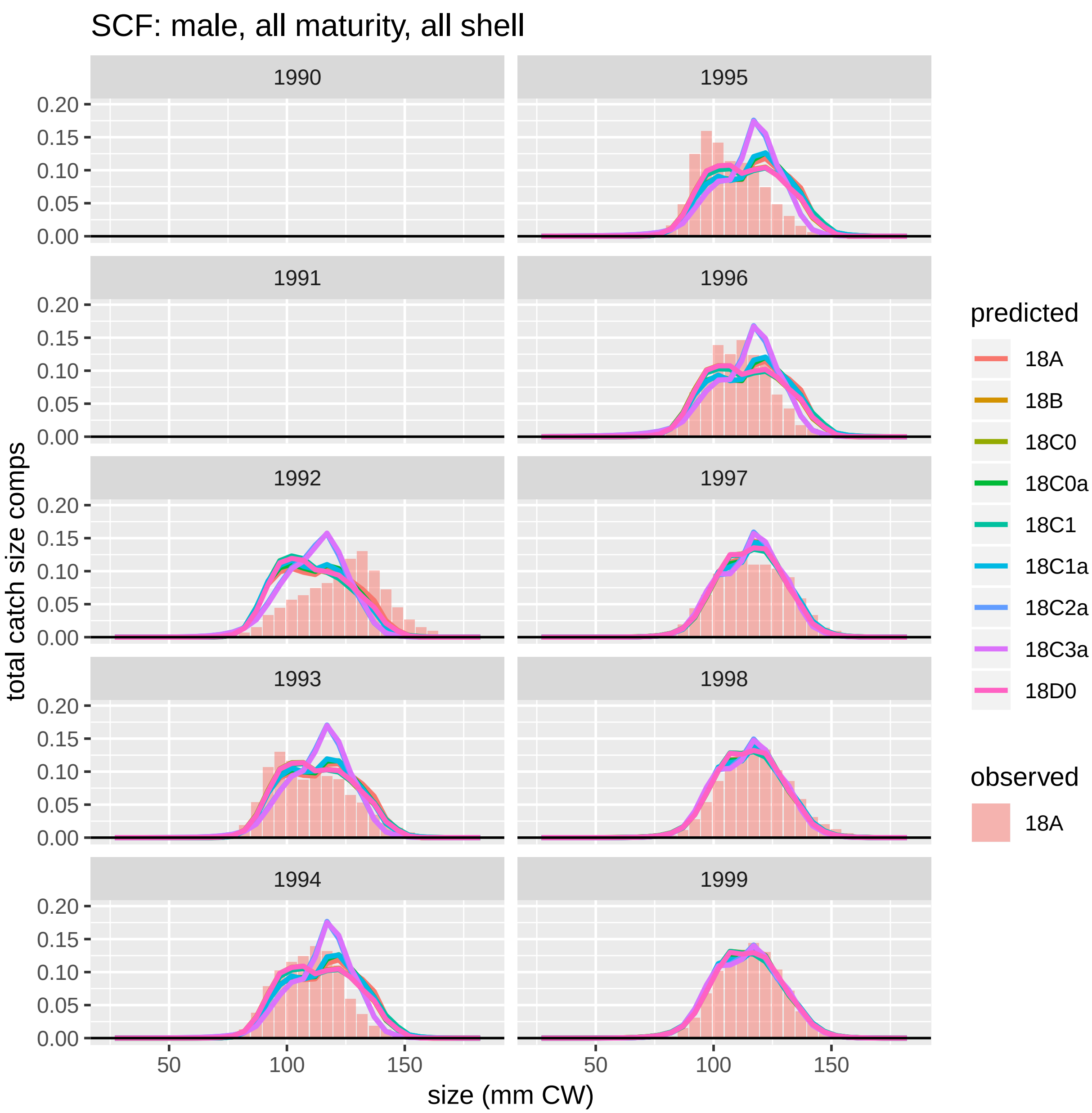

Figure 71: Comparison of observed and predicted male, all maturity, all shell total catch size comps for SCF. Page 1 of 3.

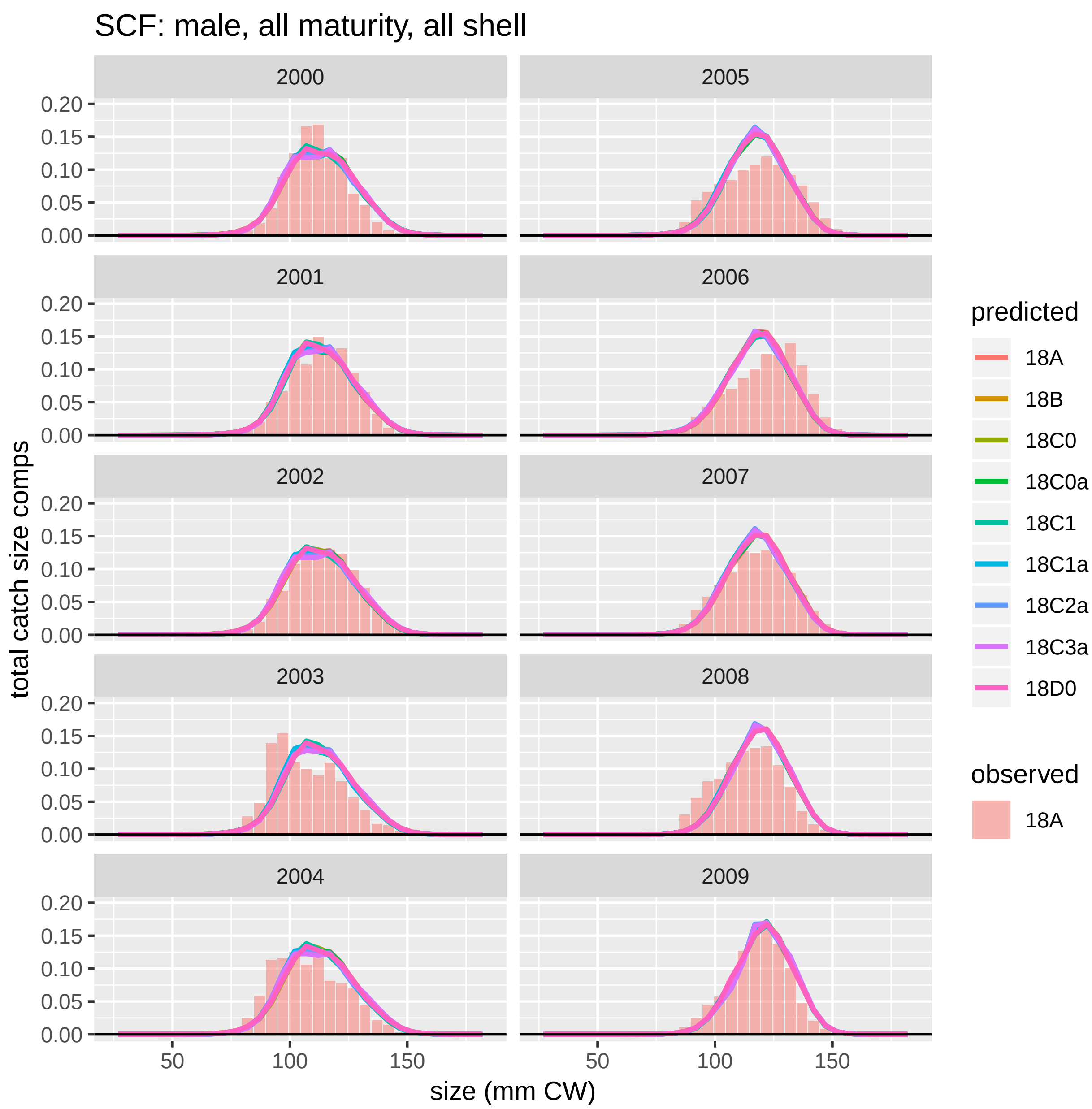

Figure 72: Comparison of observed and predicted male, all maturity, all shell total catch size comps for SCF. Page 2 of 3.

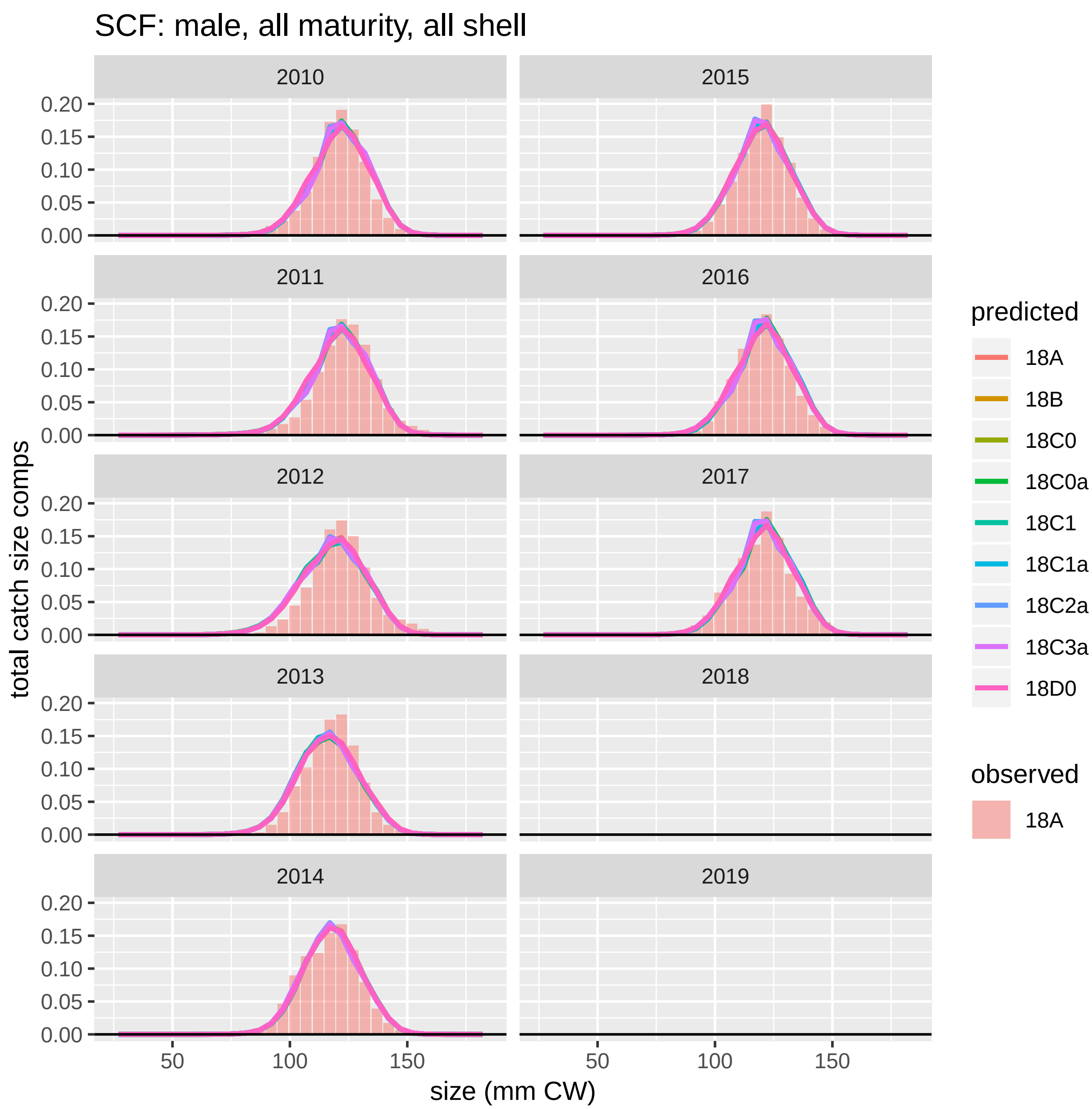

Figure 73: Comparison of observed and predicted male, all maturity, all shell total catch size comps for SCF. Page 3 of 3.

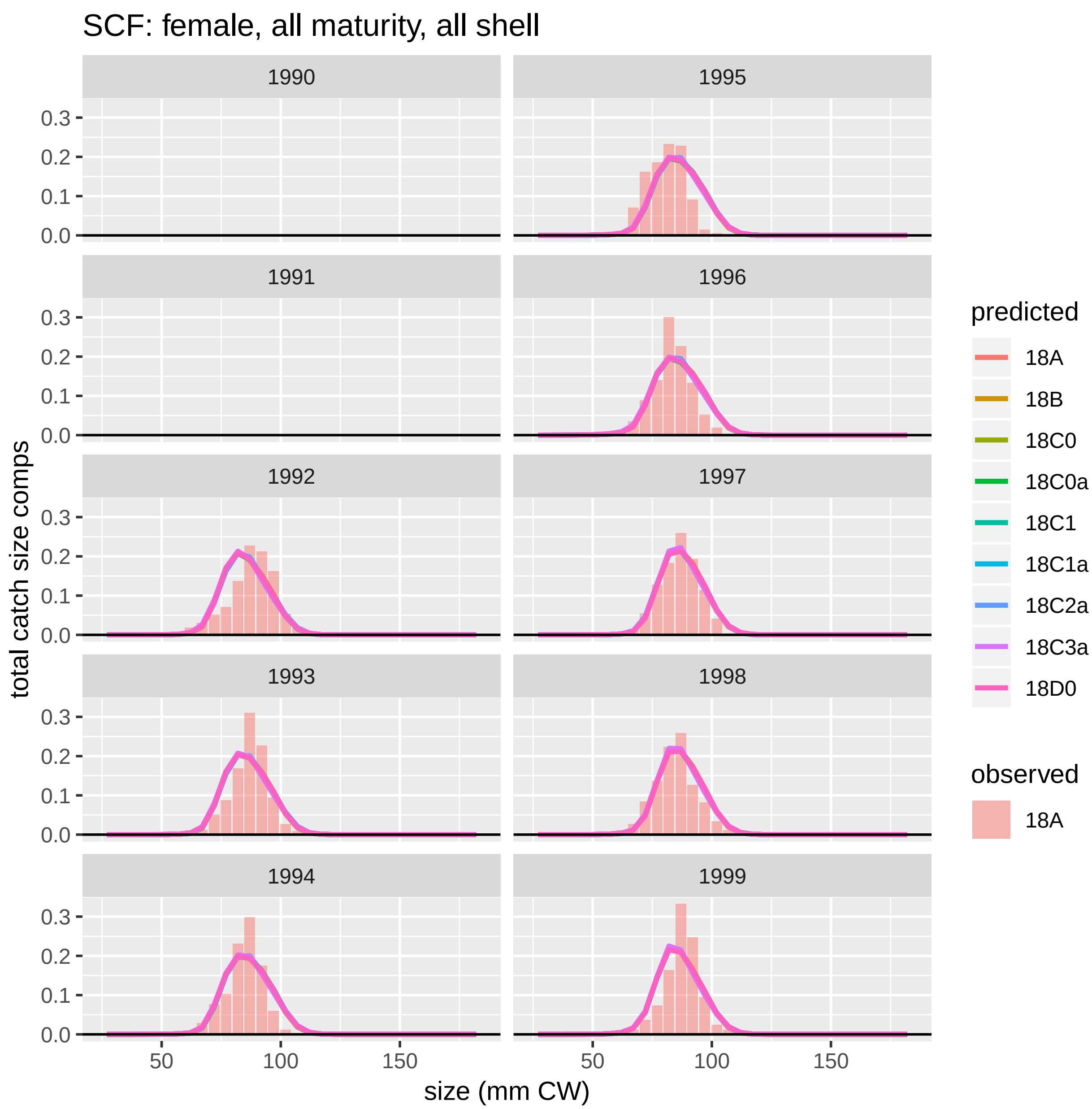

Figure 74: Comparison of observed and predicted female, all maturity, all shell total catch size comps for SCF. Page 1 of 3.

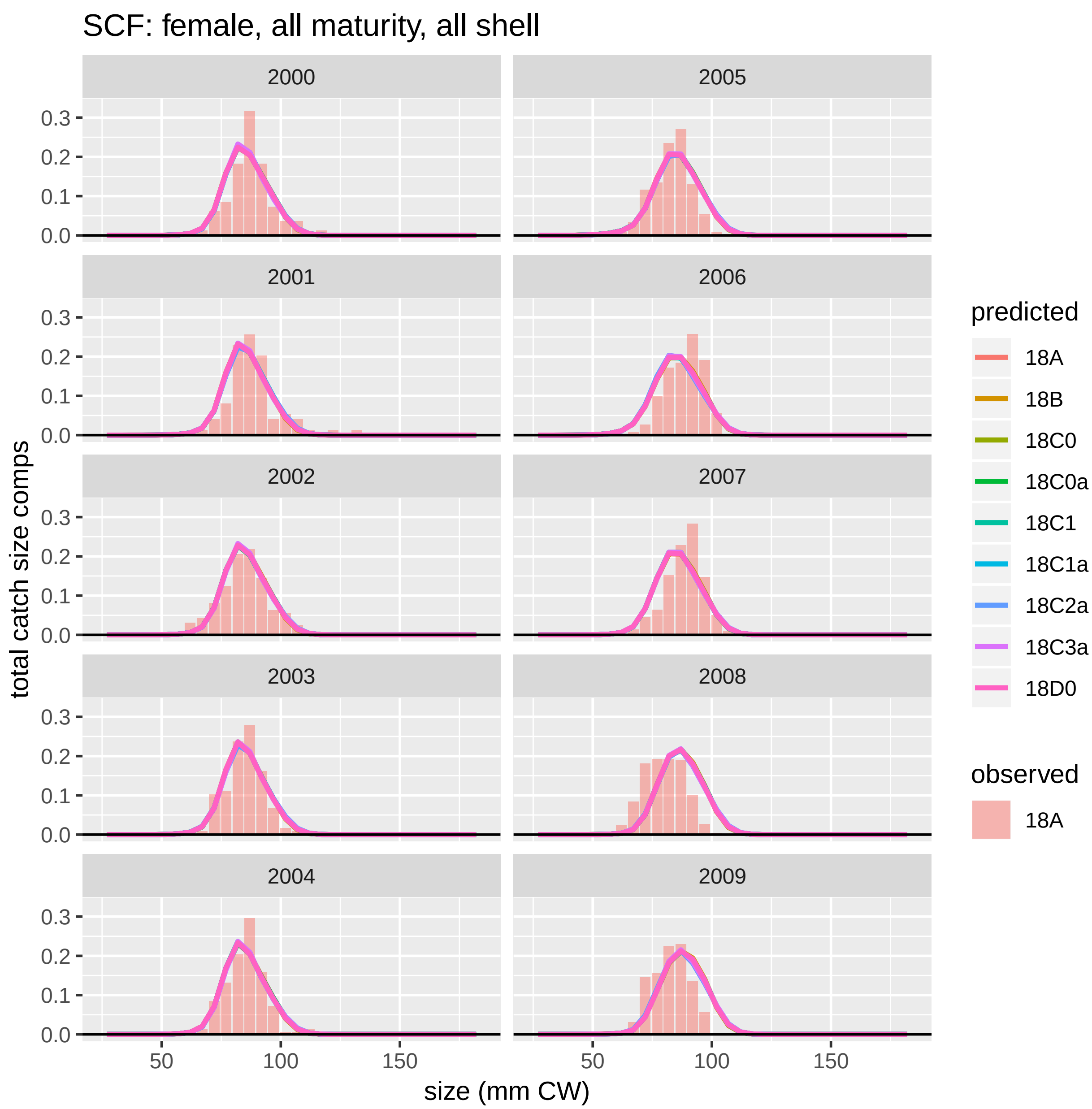

Figure 75: Comparison of observed and predicted female, all maturity, all shell total catch size comps for SCF. Page 2 of 3.

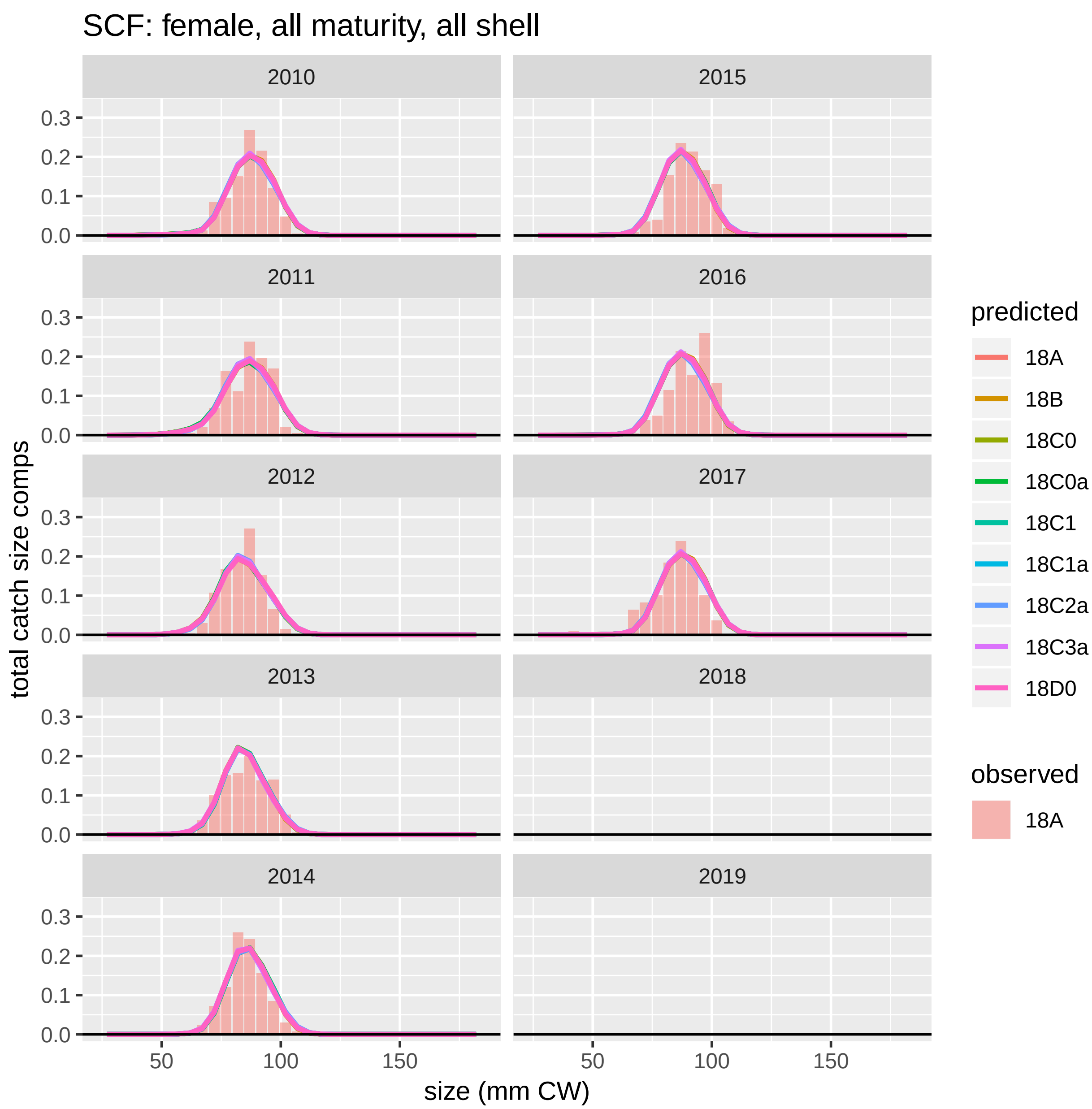

Figure 76: Comparison of observed and predicted female, all maturity, all shell total catch size comps for SCF. Page 3 of 3.

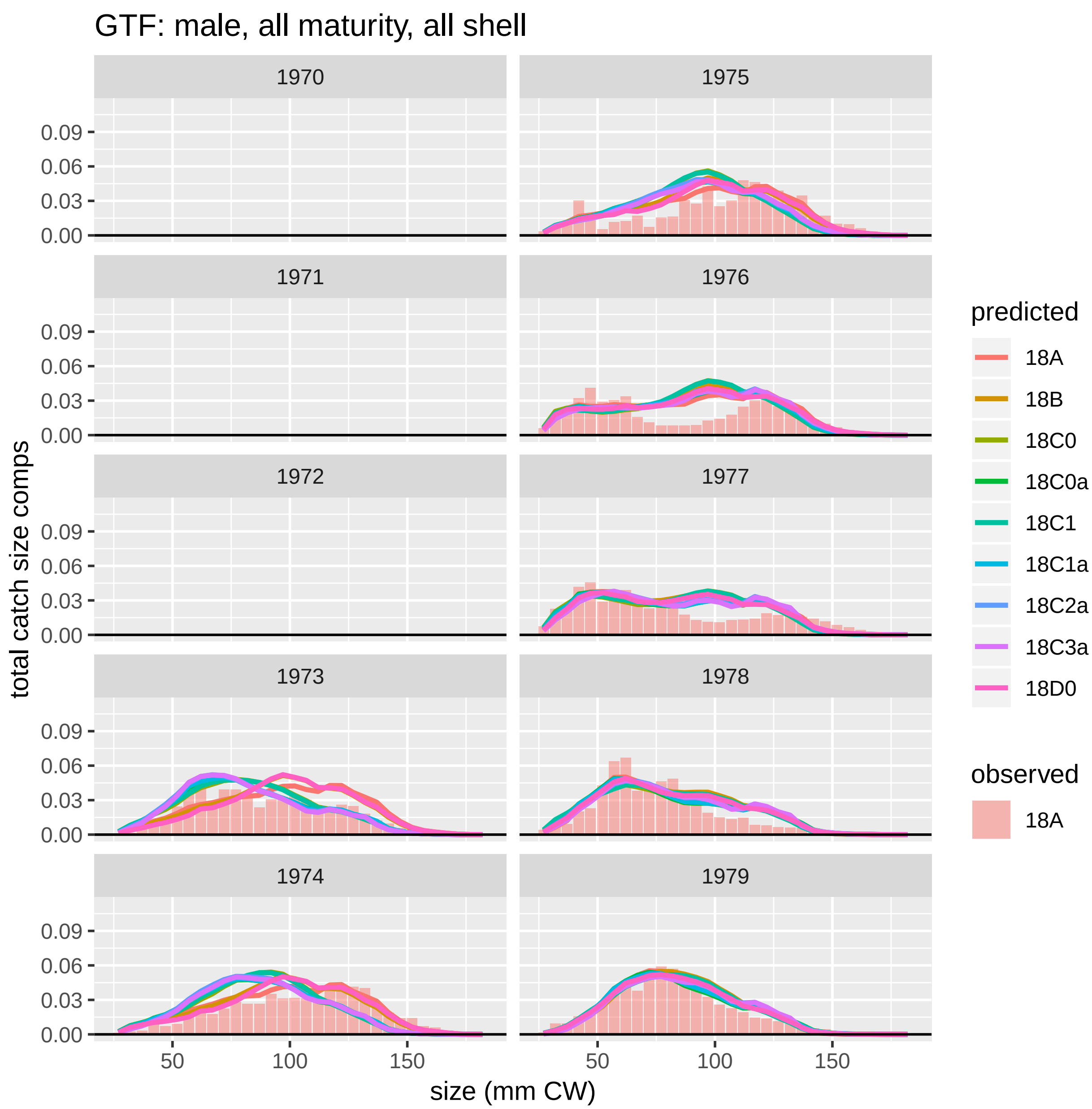

Figure 77: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 1 of 5.

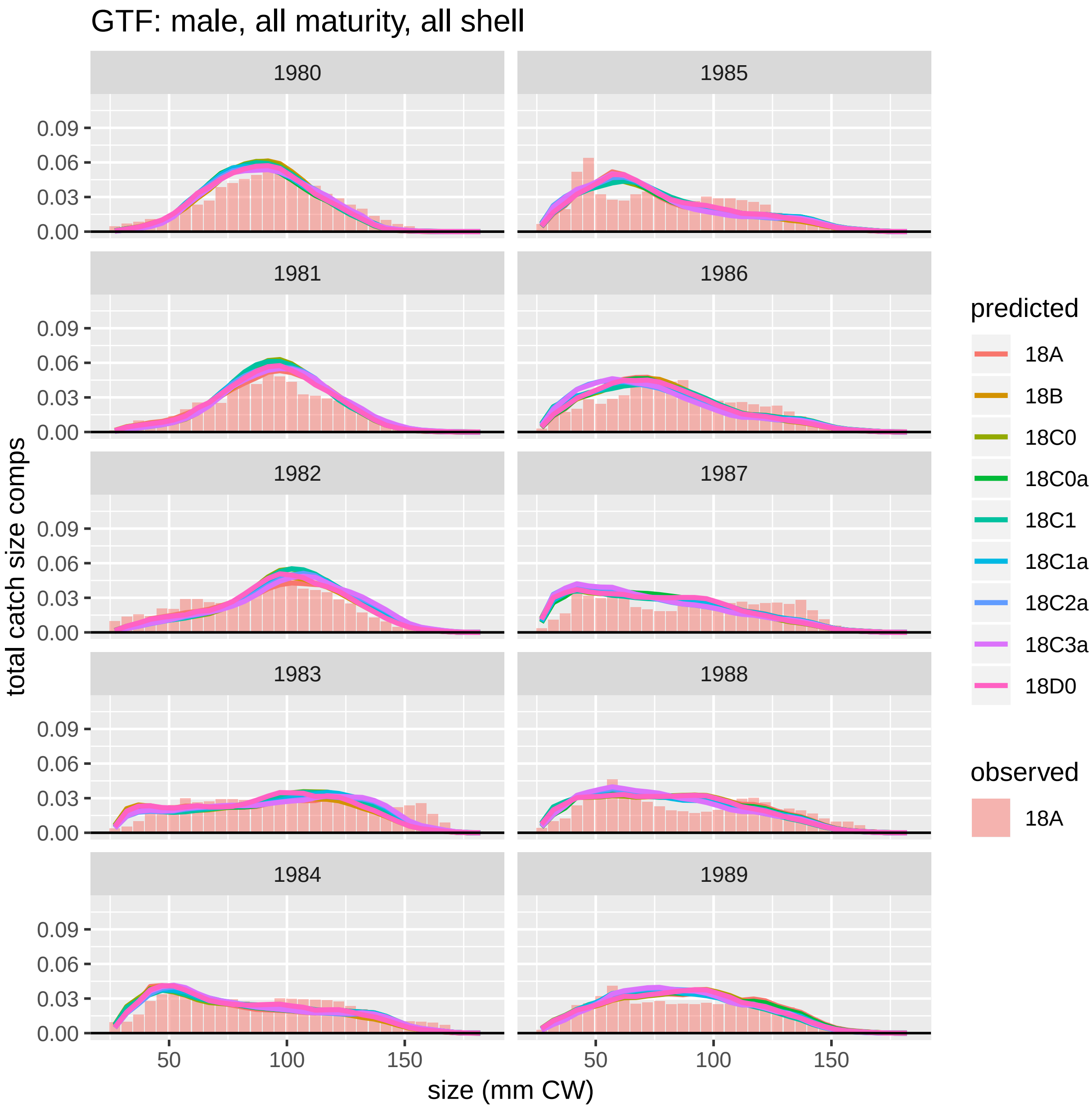

Figure 78: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 2 of 5.

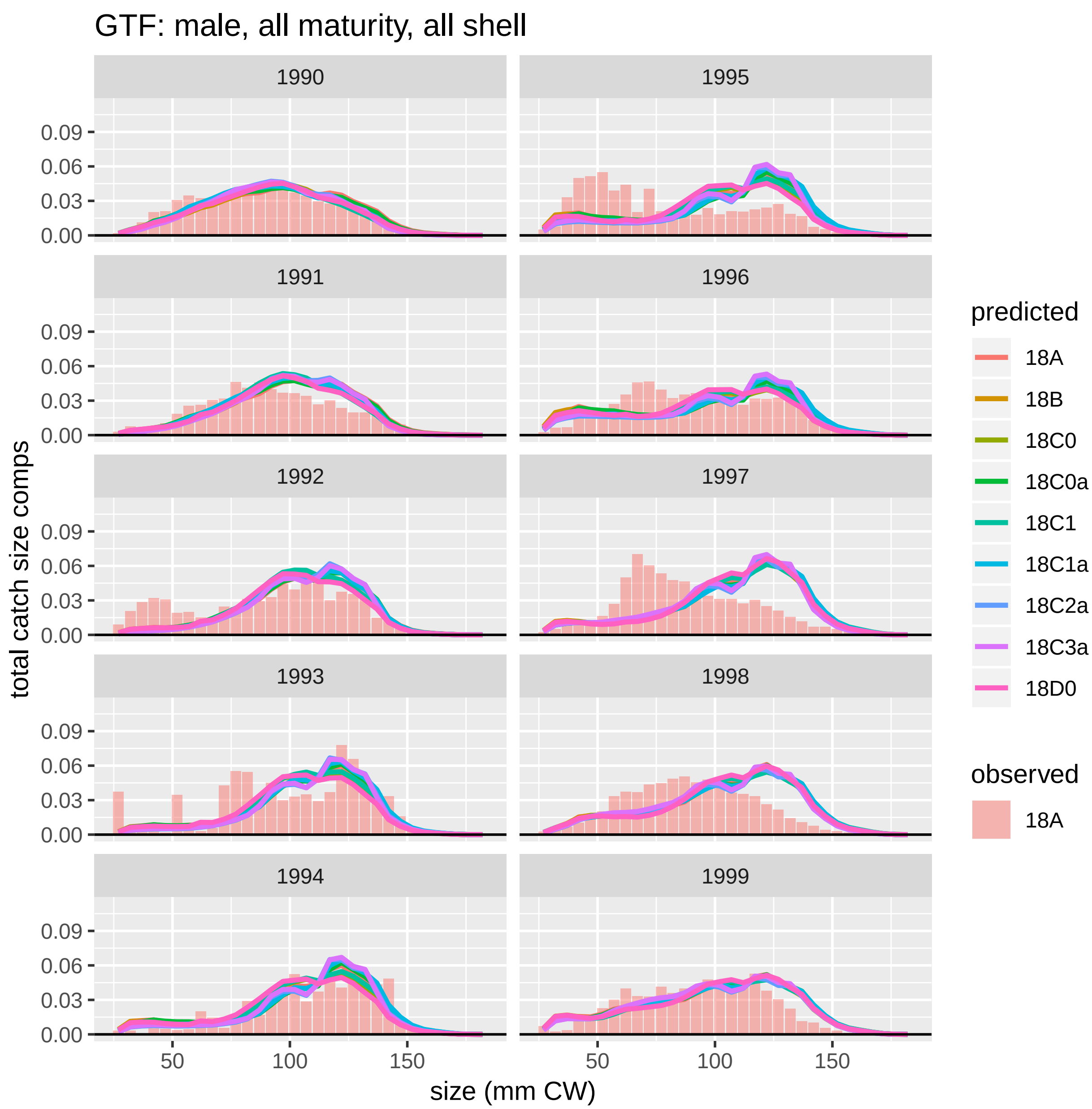

Figure 79: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 3 of 5.

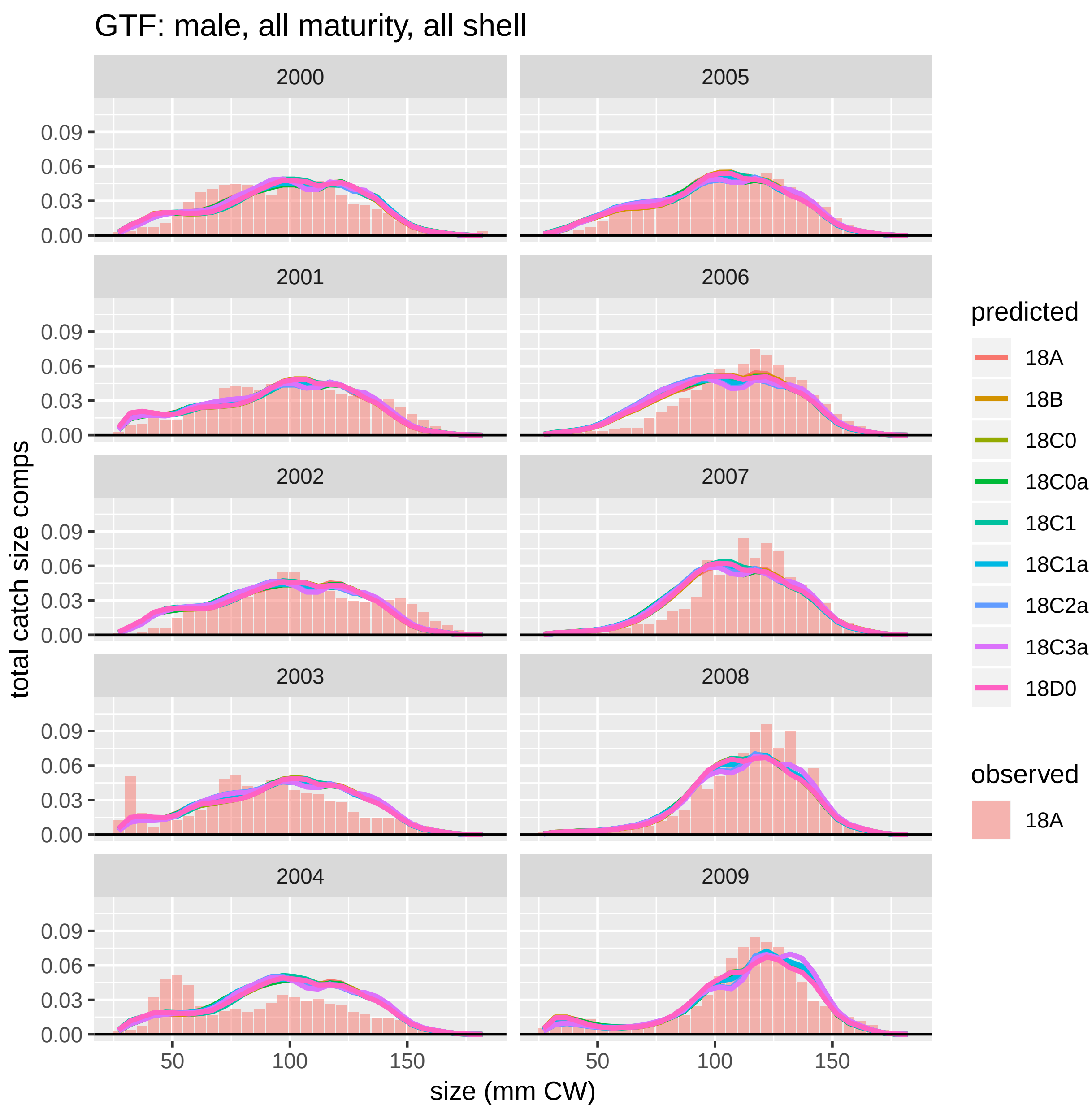

Figure 80: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 4 of 5.

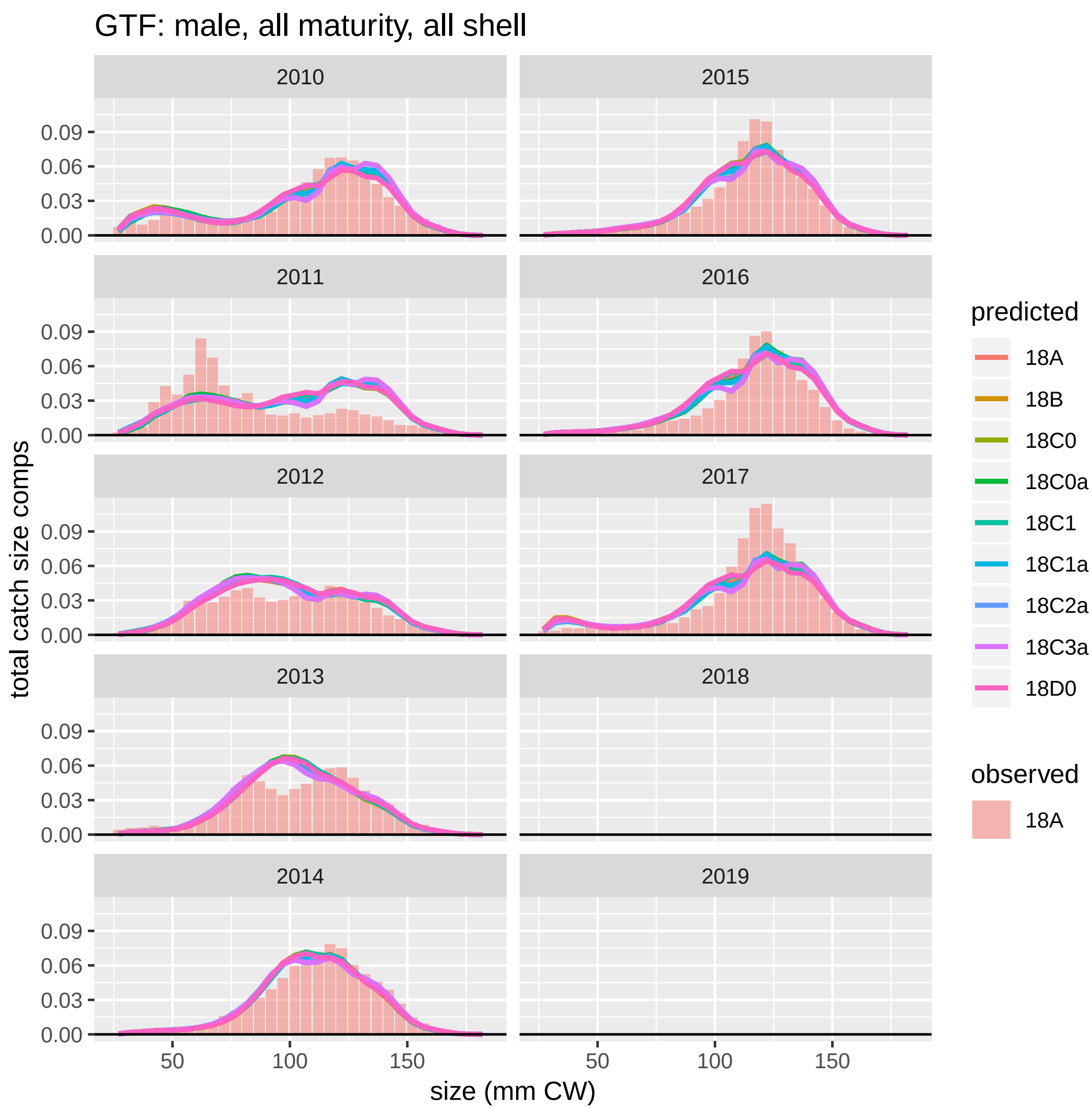

Figure 81: Comparison of observed and predicted male, all maturity, all shell total catch size comps for GTF. Page 5 of 5.

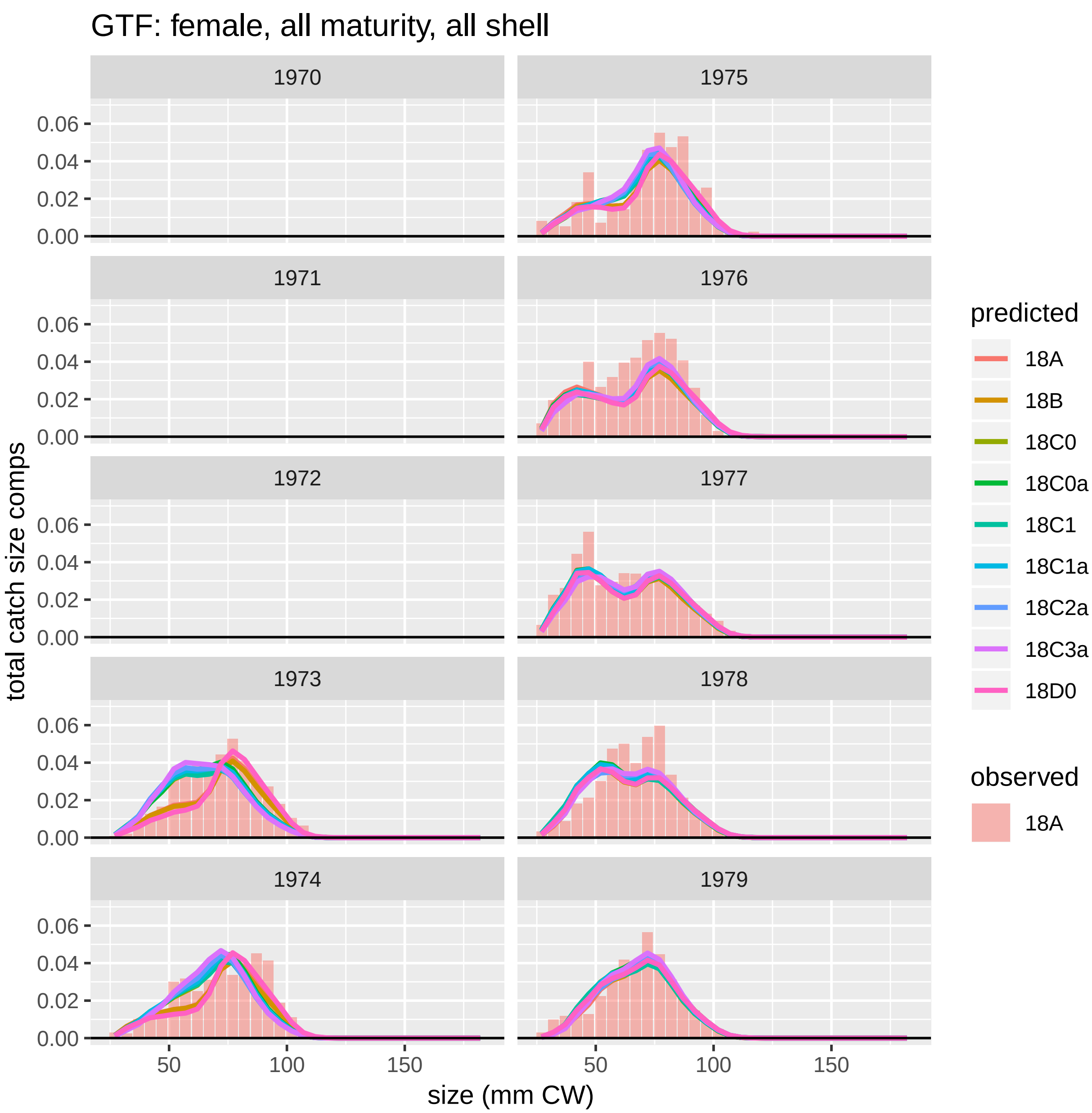

Figure 82: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 1 of 5.

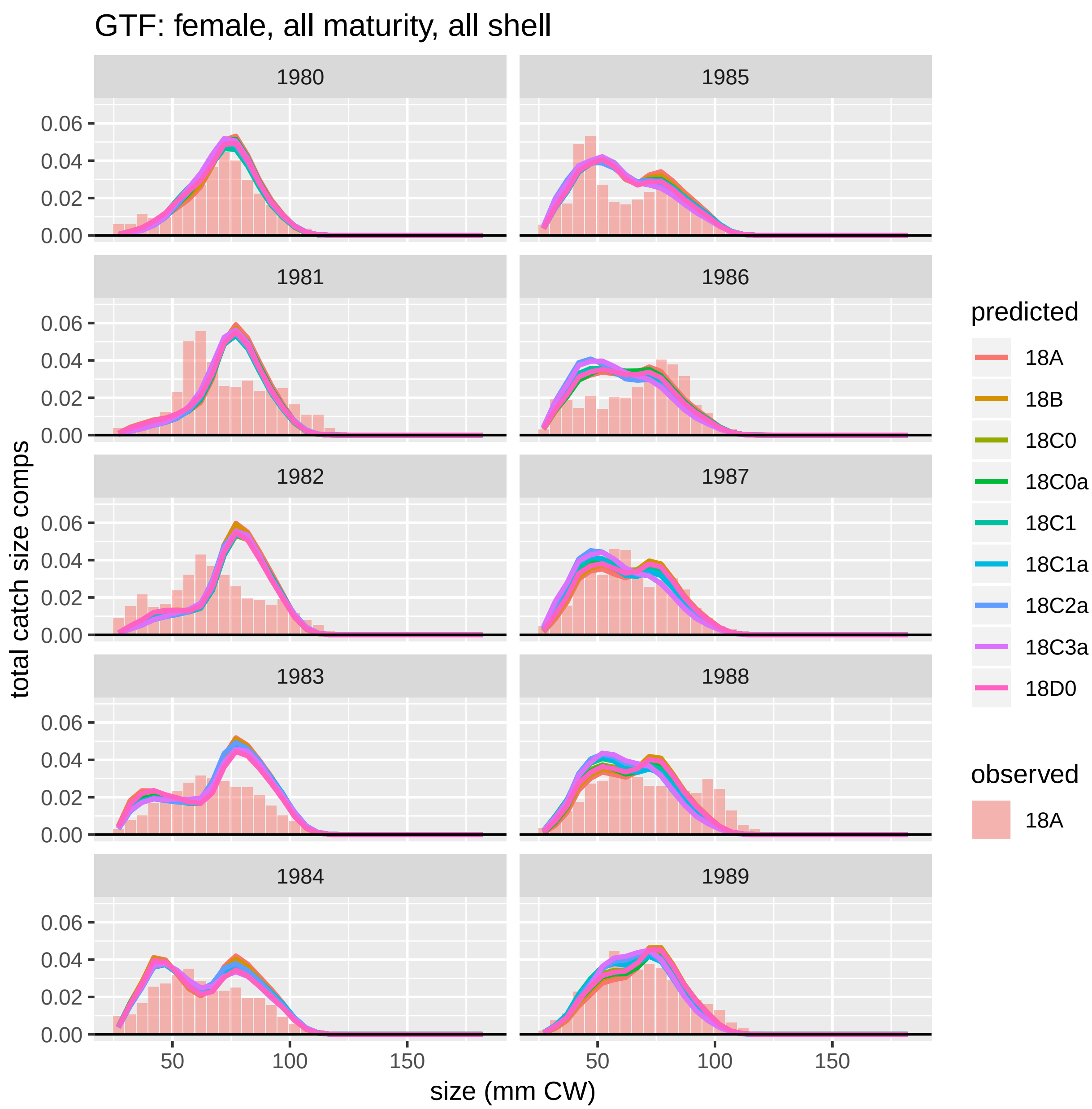

Figure 83: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 2 of 5.

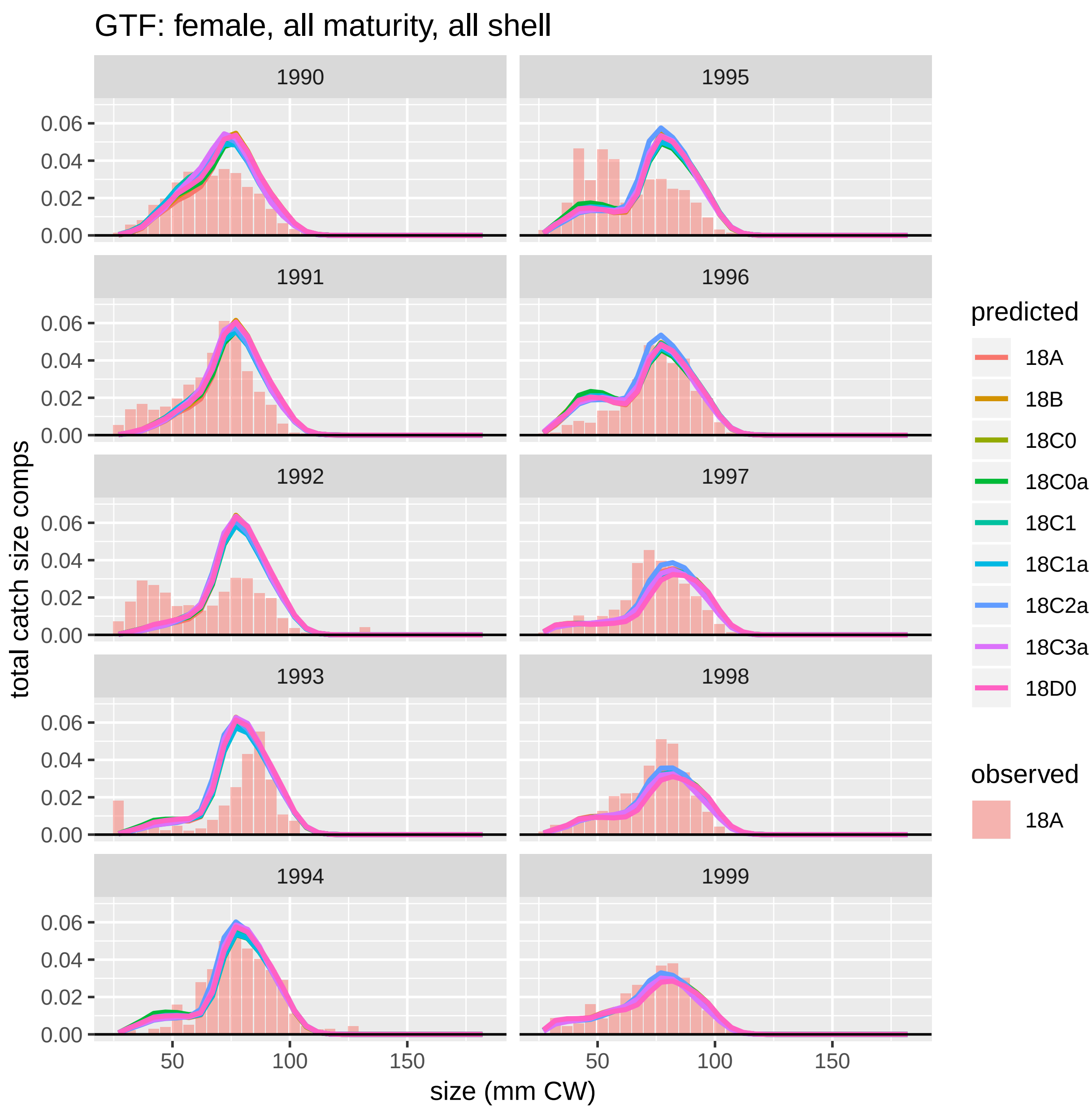

Figure 84: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 3 of 5.

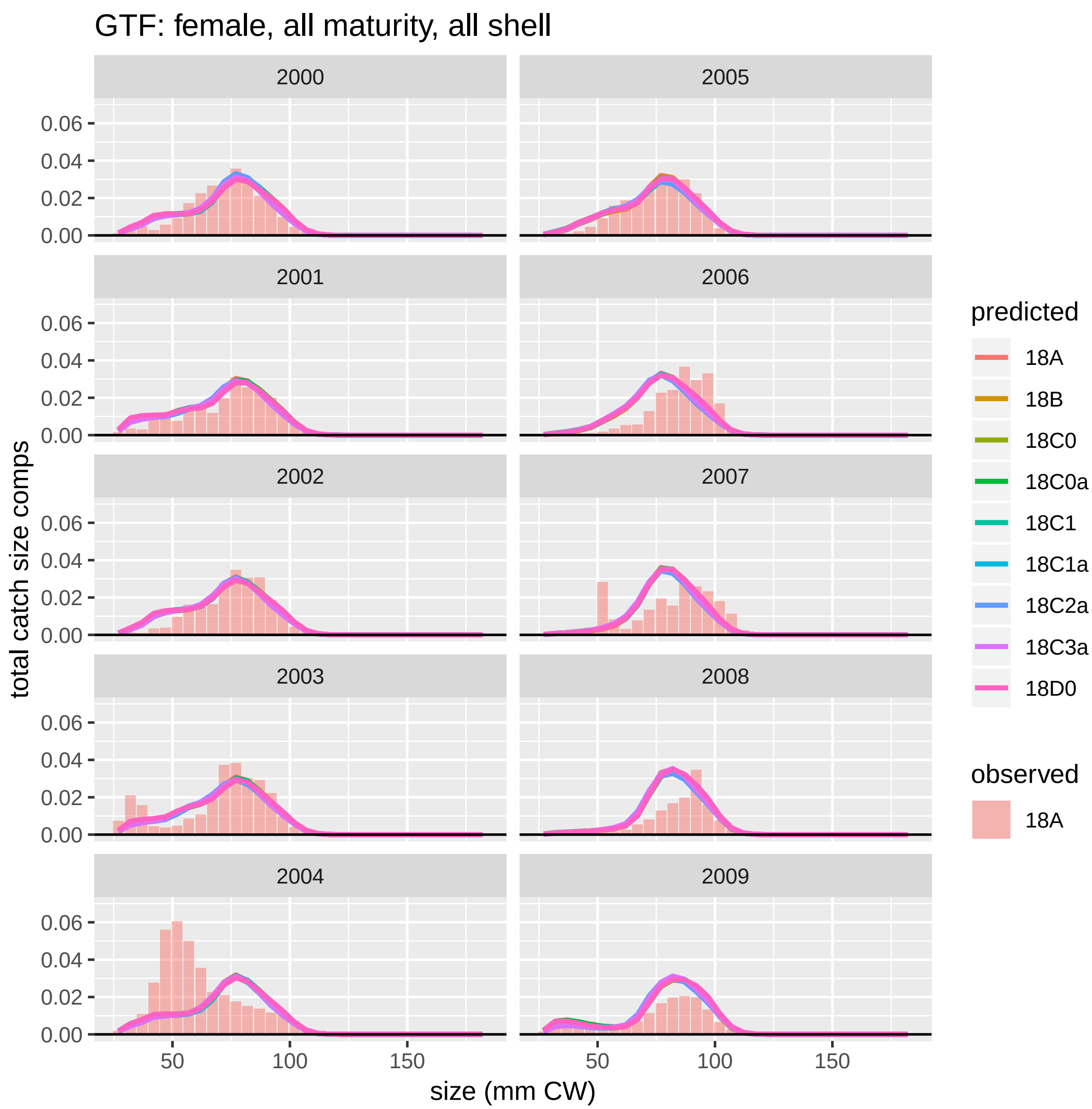

Figure 85: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 4 of 5.

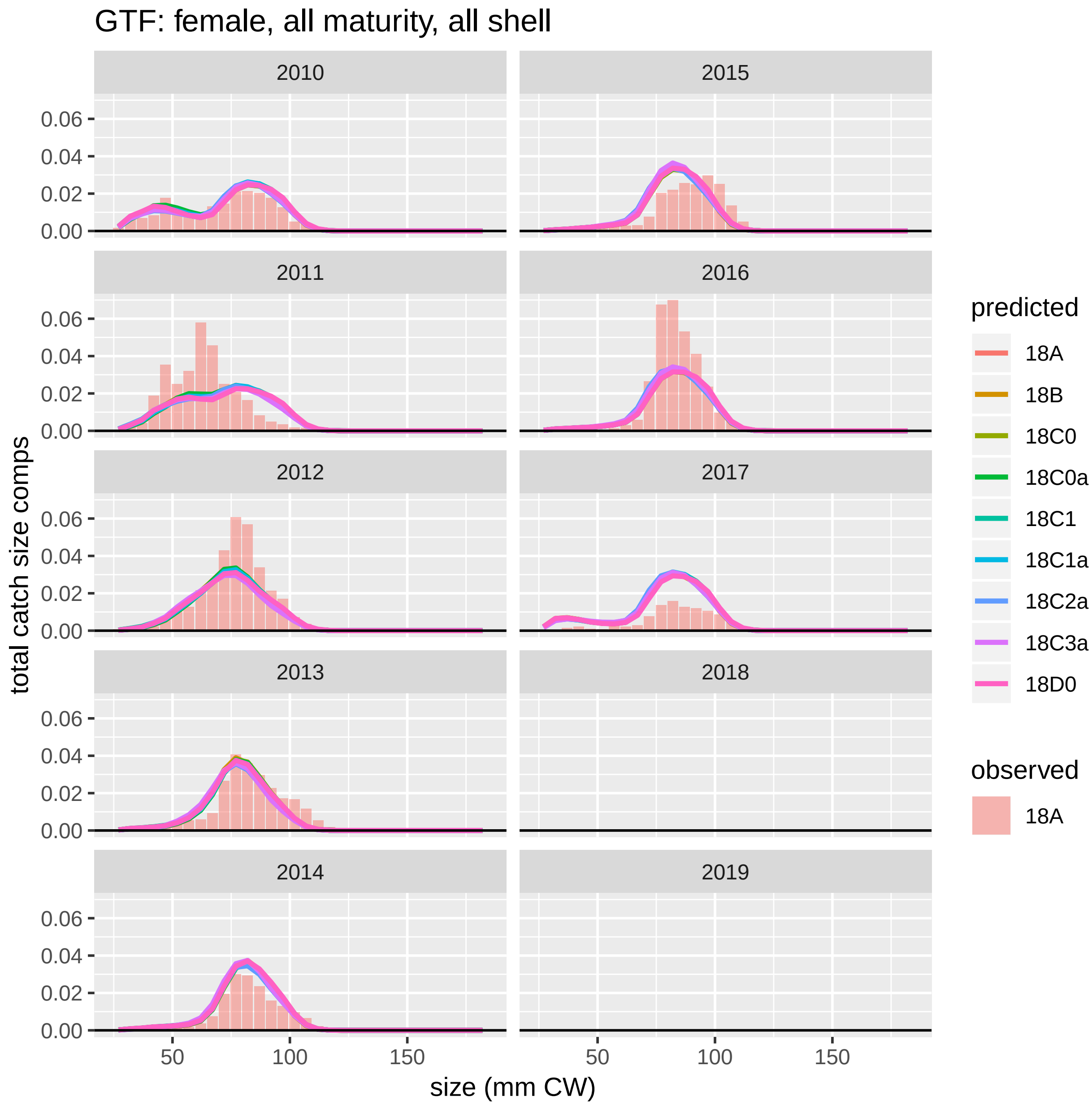

Figure 86: Comparison of observed and predicted female, all maturity, all shell total catch size comps for GTF. Page 5 of 5.

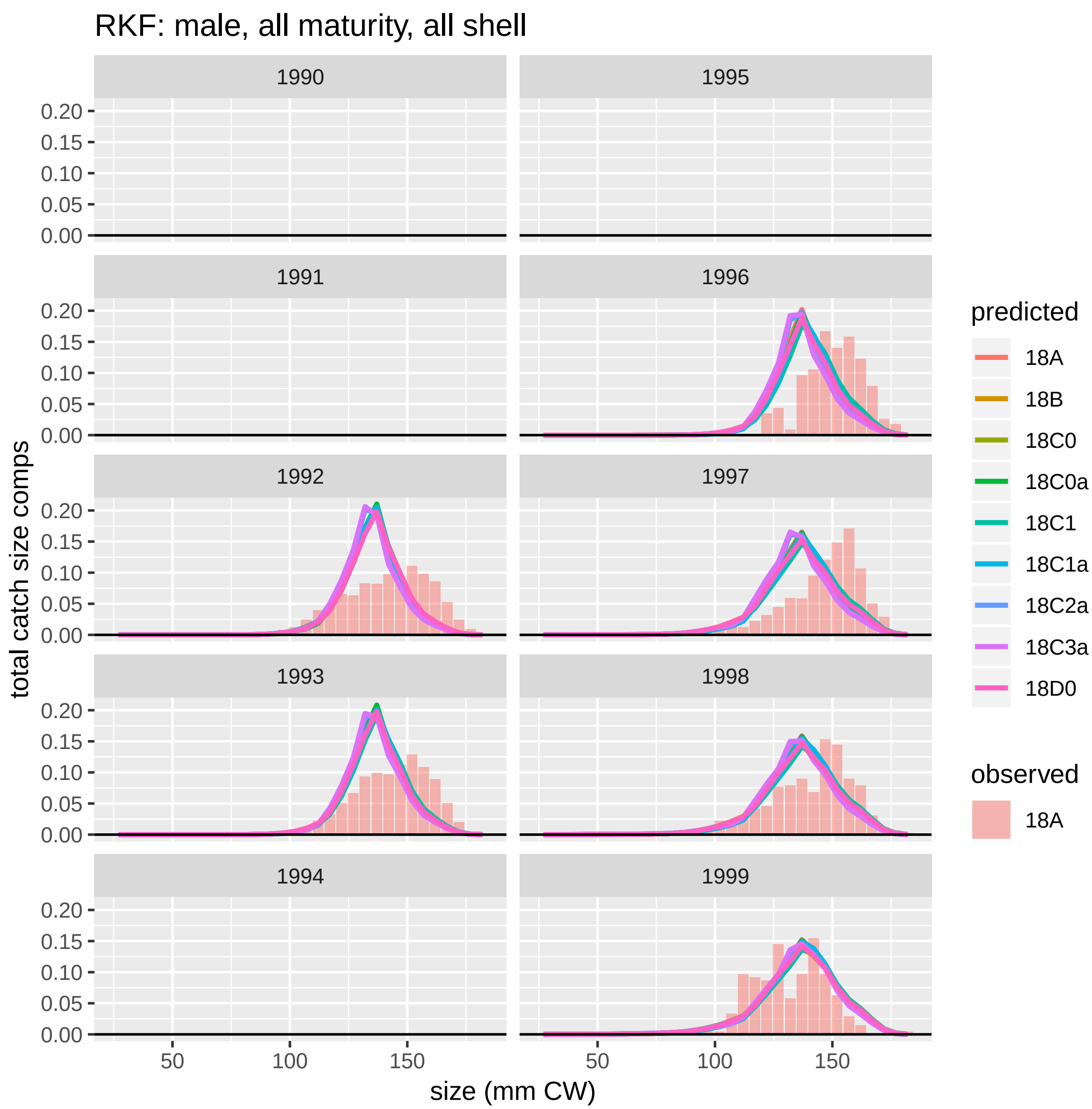

Figure 87: Comparison of observed and predicted male, all maturity, all shell total catch size comps for RKF. Page 1 of 3.

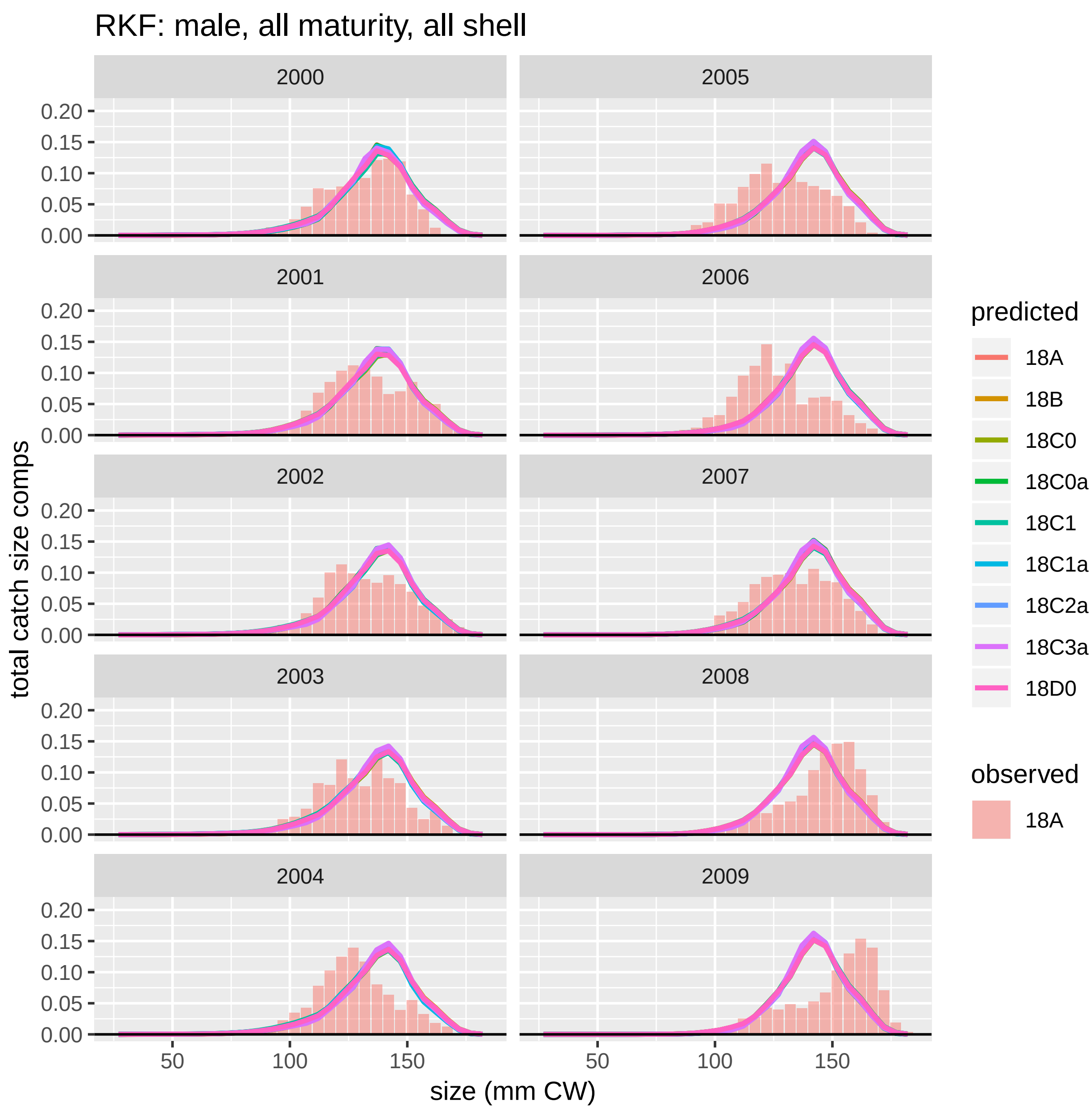

Figure 88: Comparison of observed and predicted male, all maturity, all shell total catch size comps for RKF. Page 2 of 3.

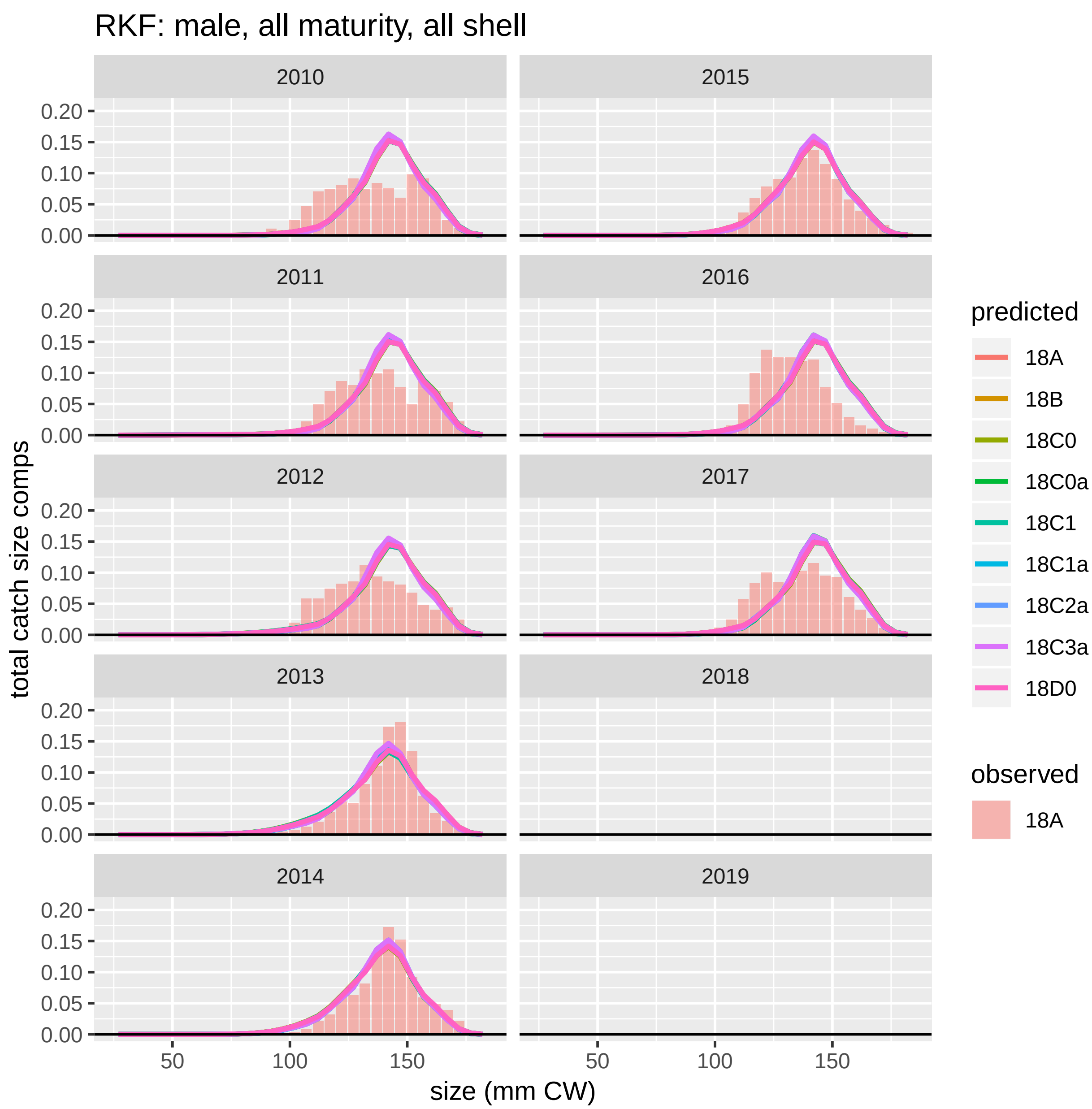

Figure 89: Comparison of observed and predicted male, all maturity, all shell total catch size comps for RKF. Page 3 of 3.

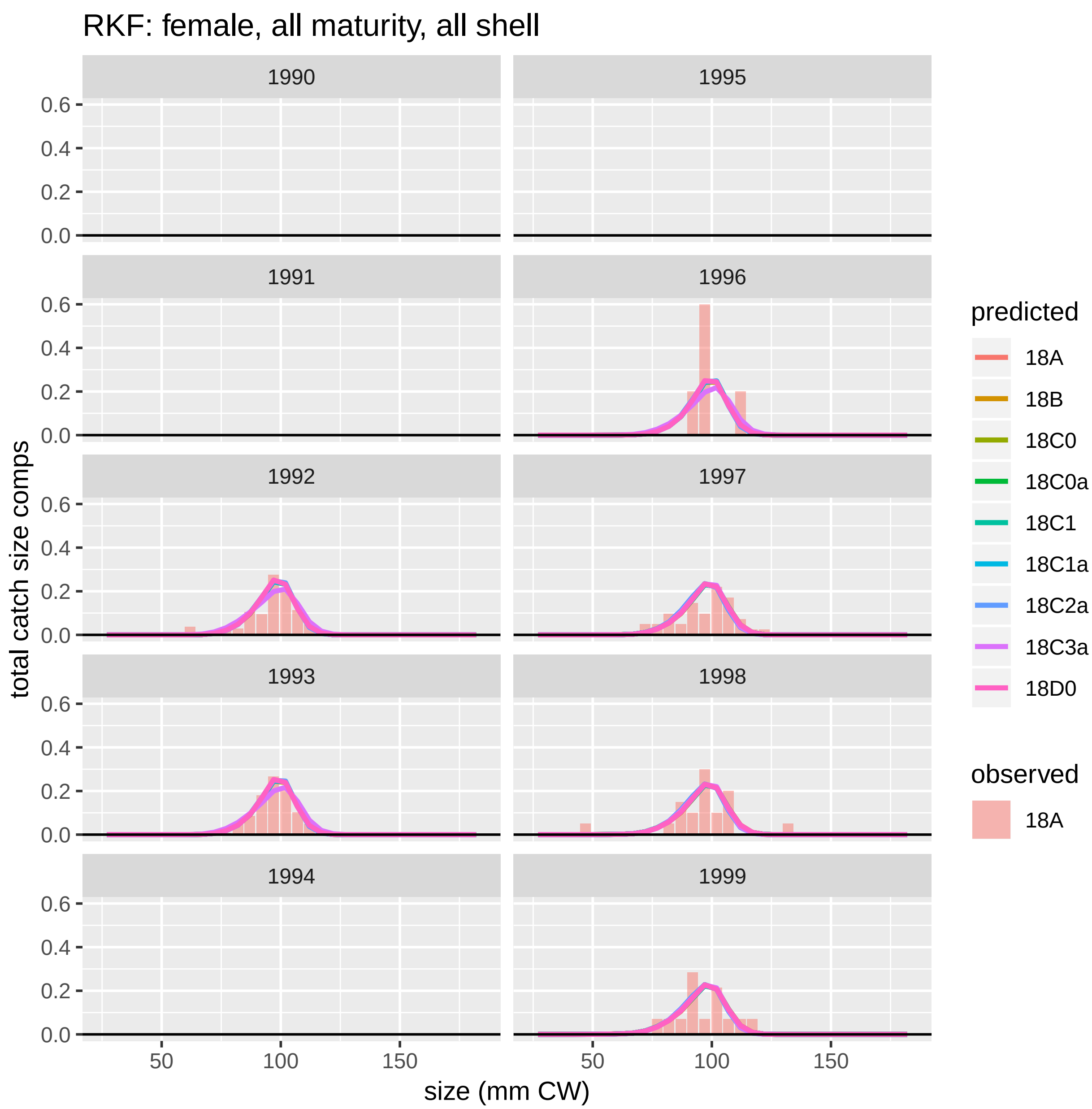

Figure 90: Comparison of observed and predicted female, all maturity, all shell total catch size comps for RKF. Page 1 of 3.

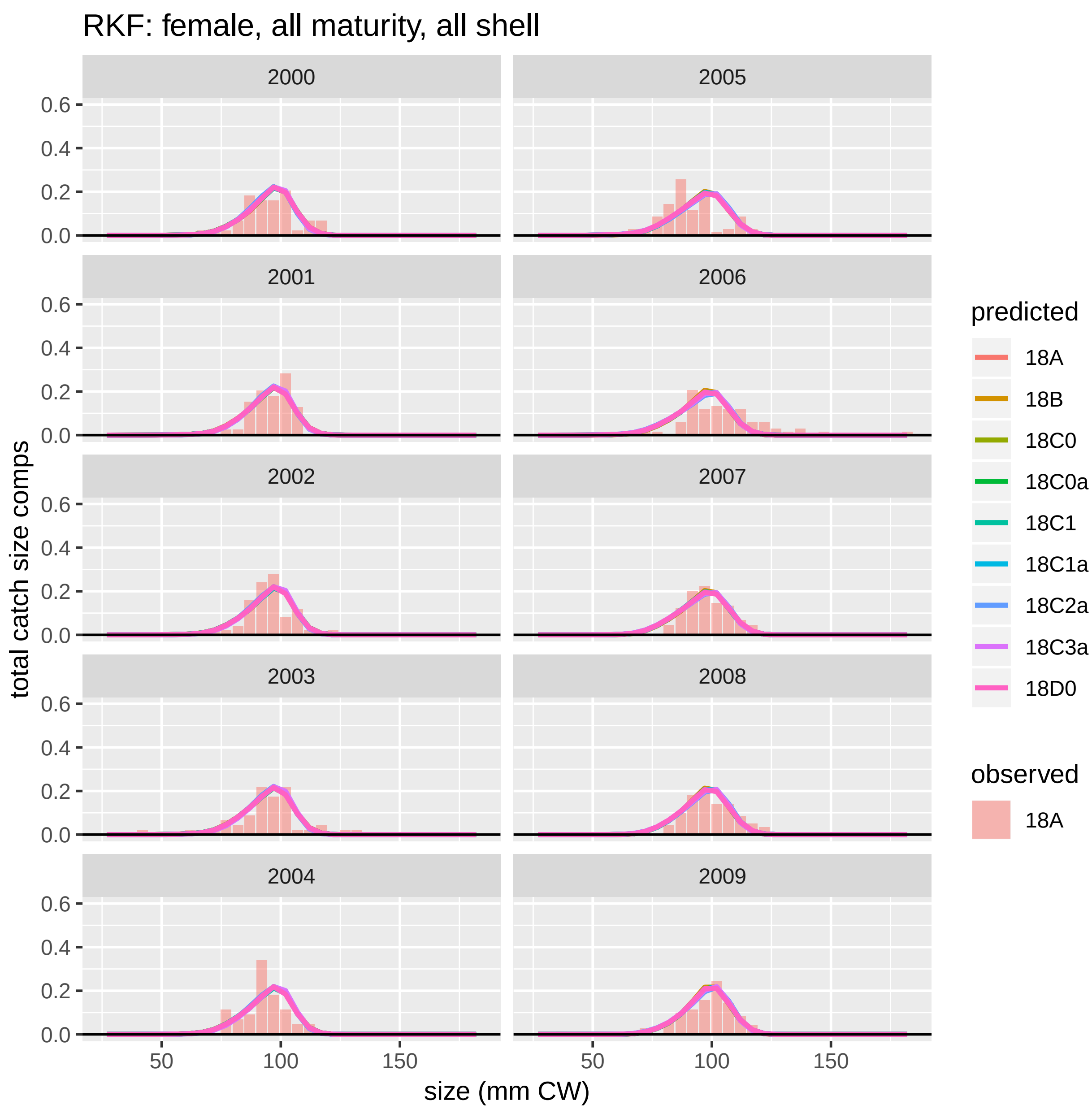

Figure 91: Comparison of observed and predicted female, all maturity, all shell total catch size comps for RKF. Page 2 of 3.

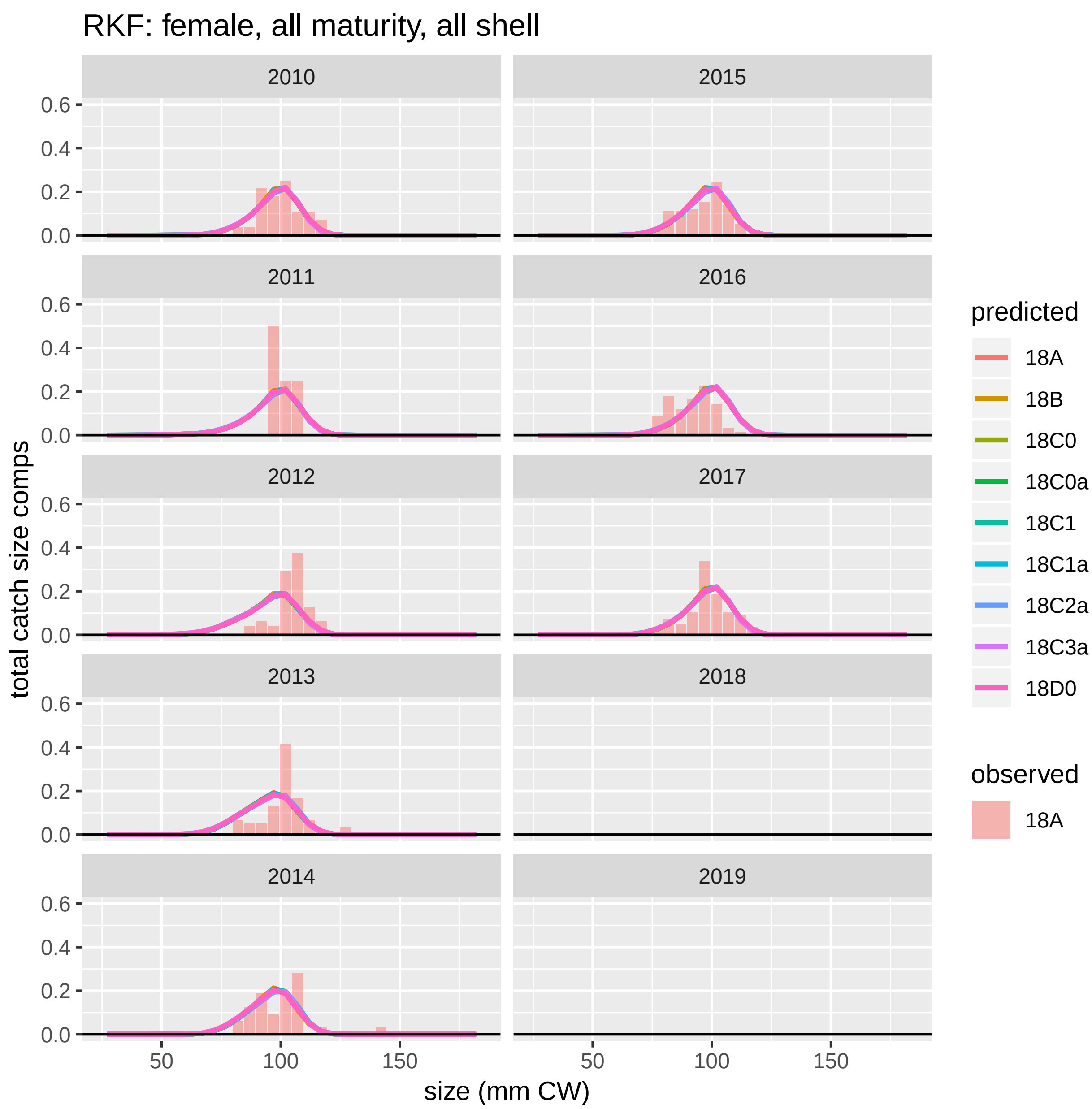

Figure 92: Comparison of observed and predicted female, all maturity, all shell total catch size comps for RKF. Page 3 of 3.

Appendix I5:
Fits to Maturity and Growth Data

William Stockhausen

31 August, 2018

Contents

Model fits to "other" data

Fits to growth data and male maturity datasets by the model(s) are presented in this section. Not all of the fits presented are necessarily included in the parameter optimization for each model; some fits 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.

Growth data

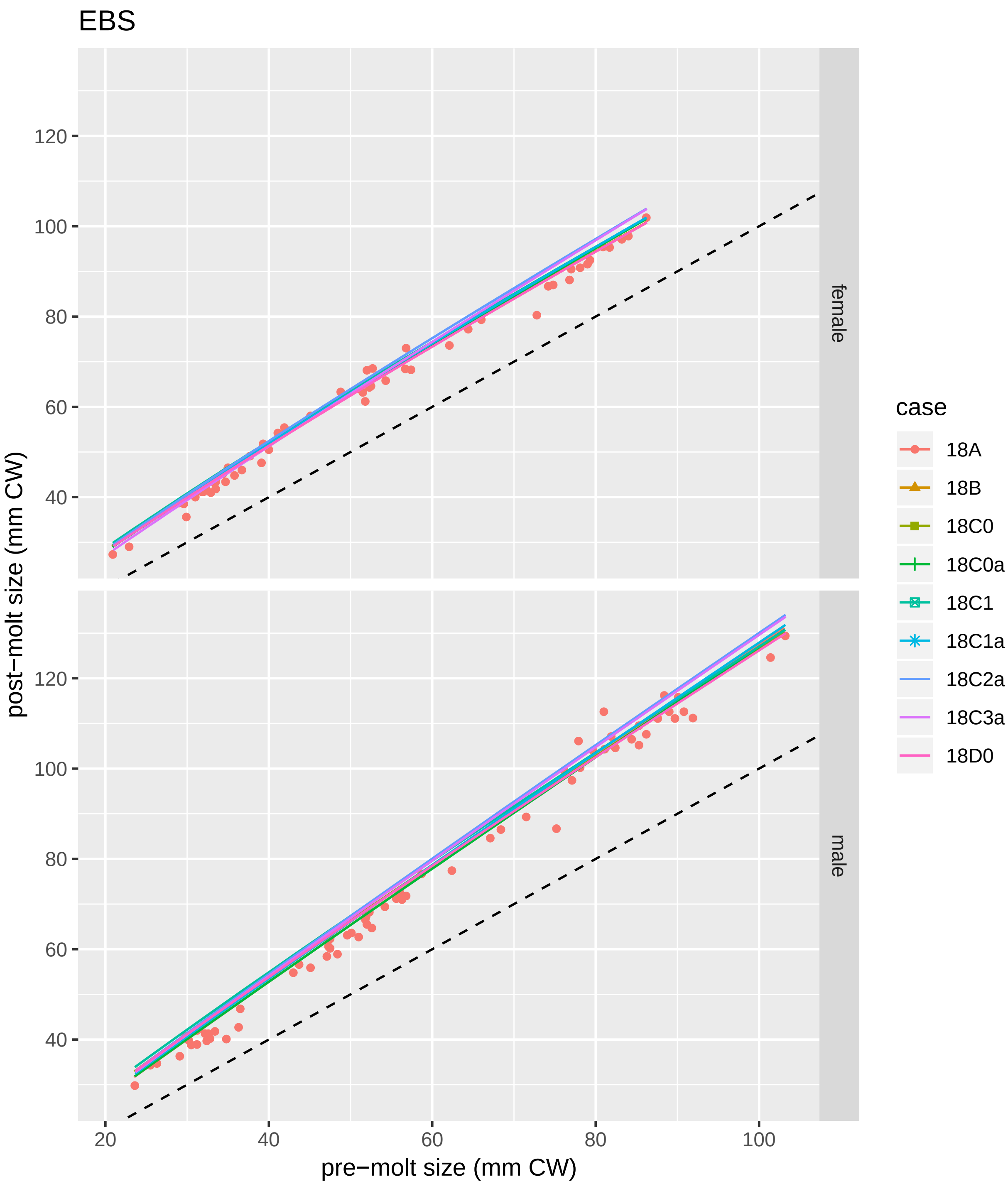

Figure 1: Model fits to EBS.

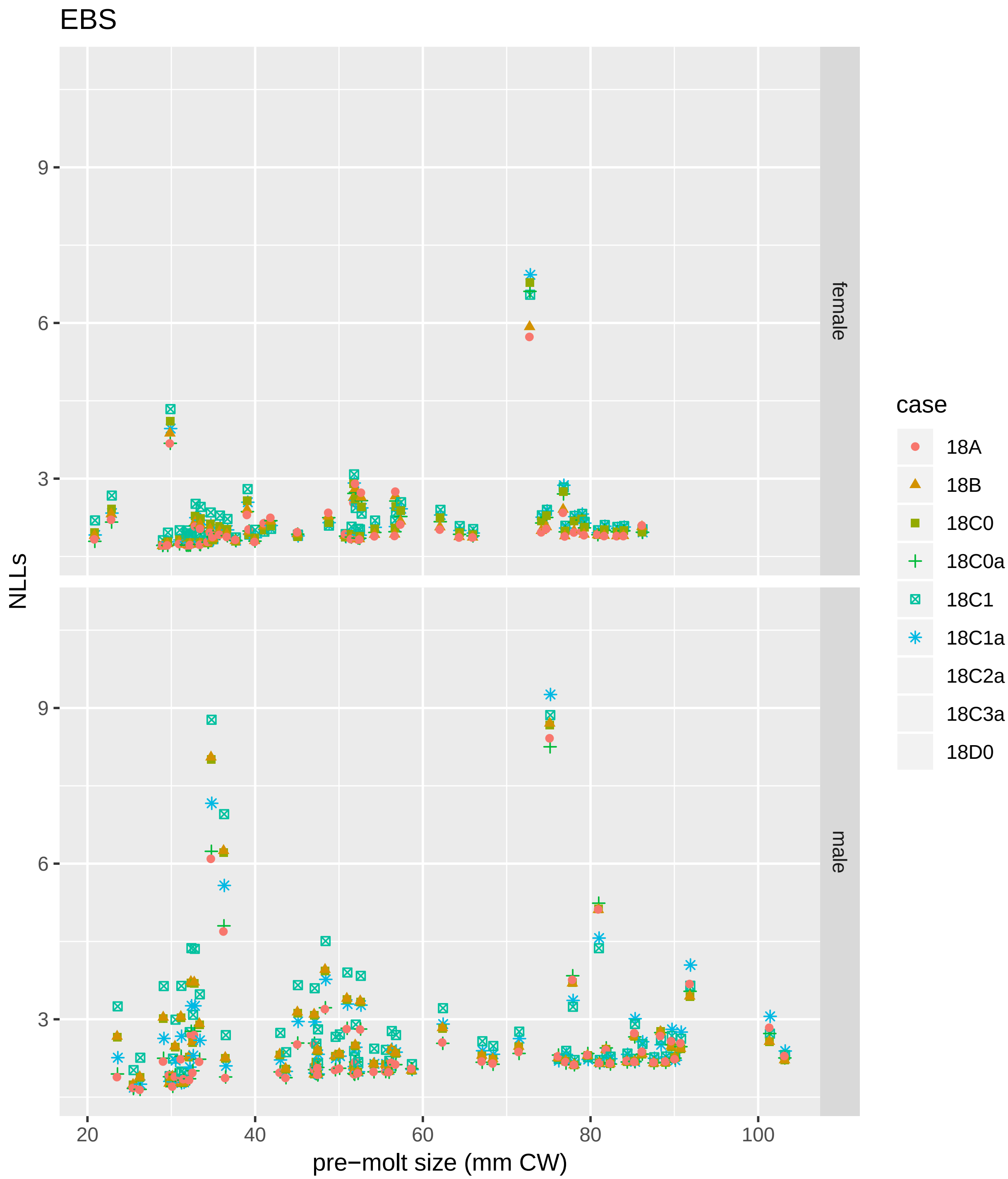

Figure 2: Negative log-likelihood values for fits to EBS.

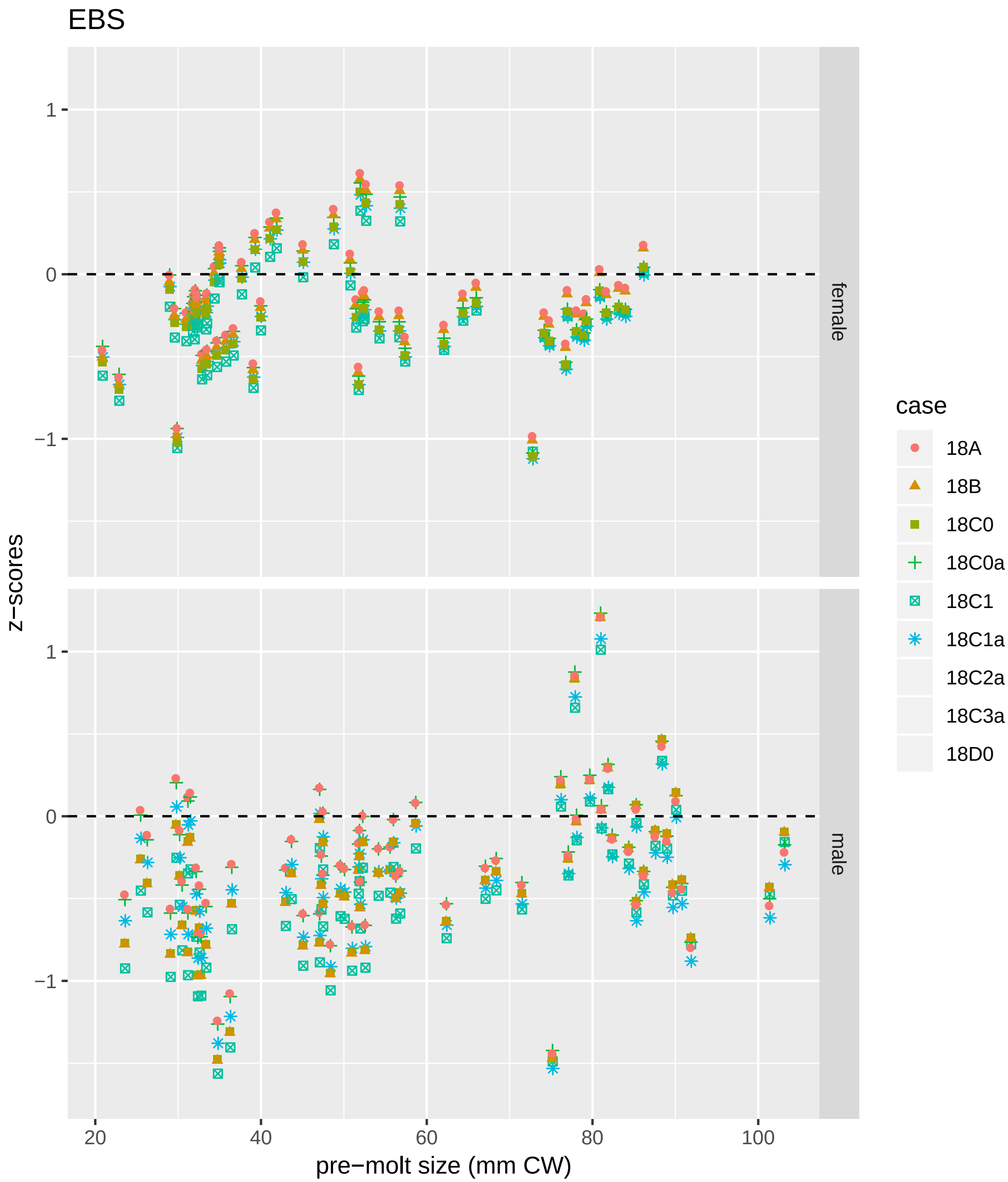

Figure 3: Z-scores for fits to EBS.

Maturity data

In the male maturity dataset used in this assessment, a number of male crab less than 60 mm CW were classified as mature based on their chela height-to-carapace width ratios. For the purposes of fitting the data, these crab were assumed to be misclassified and to actually be immature. Consequently, data from size bins less than 60 mm CW, although shown in the following plots comparing model predictions to observations, were not included in the likelihood used for model optimization and are not shown in the NLL and z-score plots.

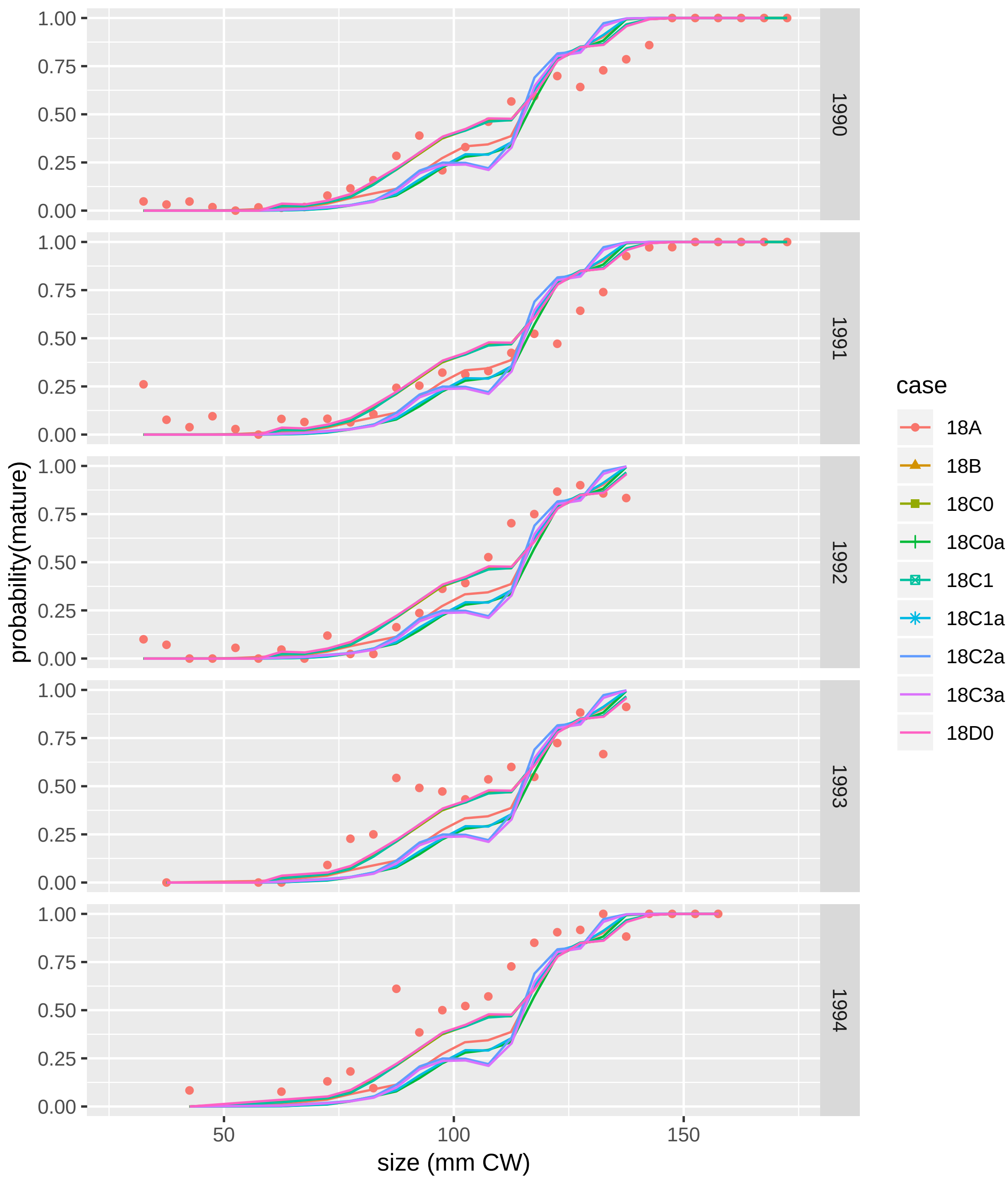

Figure 4: Model fits to MATURITY OGIVES for 1990 to 1994.

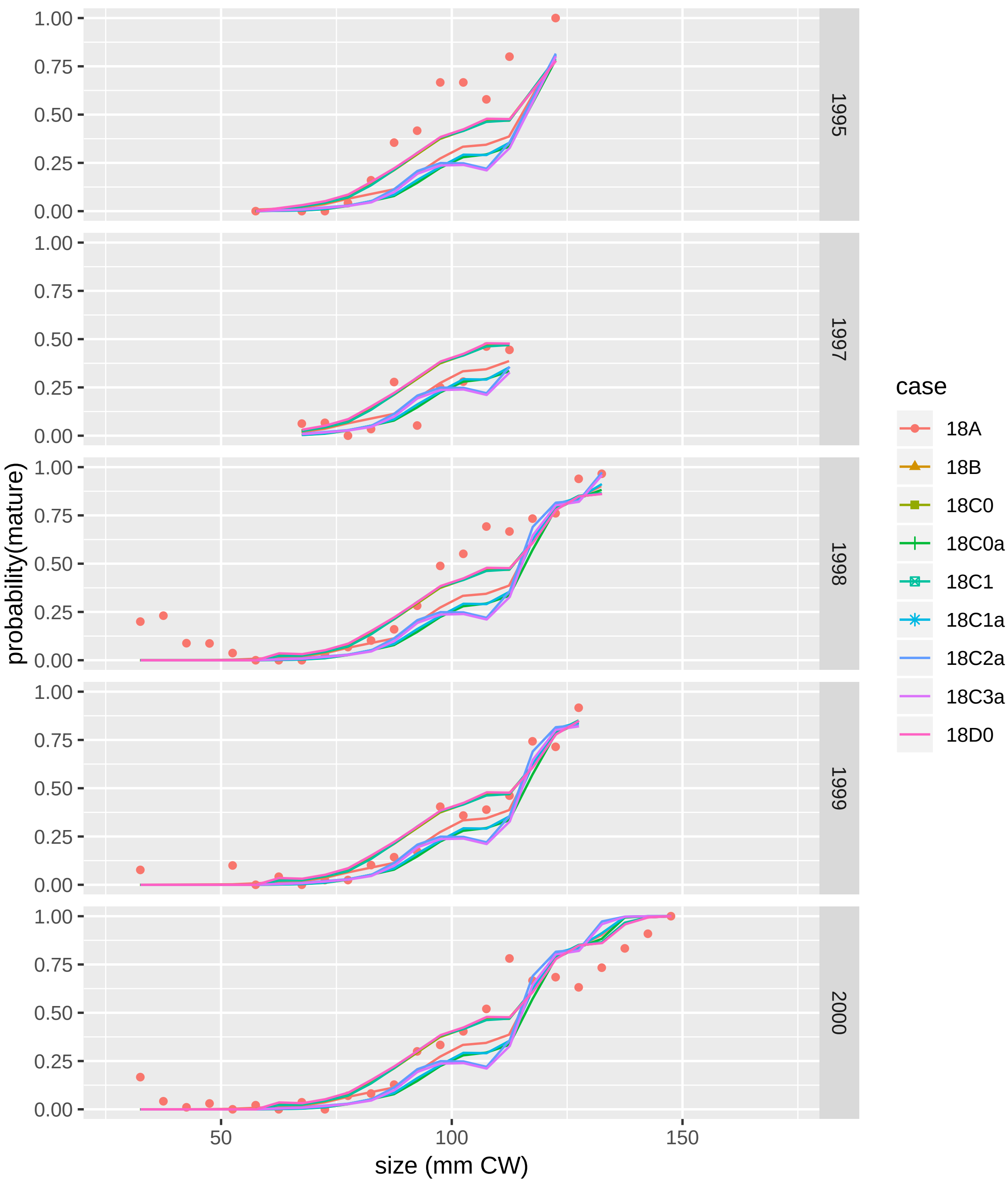

Figure 5: Model fits to MATURITY OGIVES for 1995 to 2000.

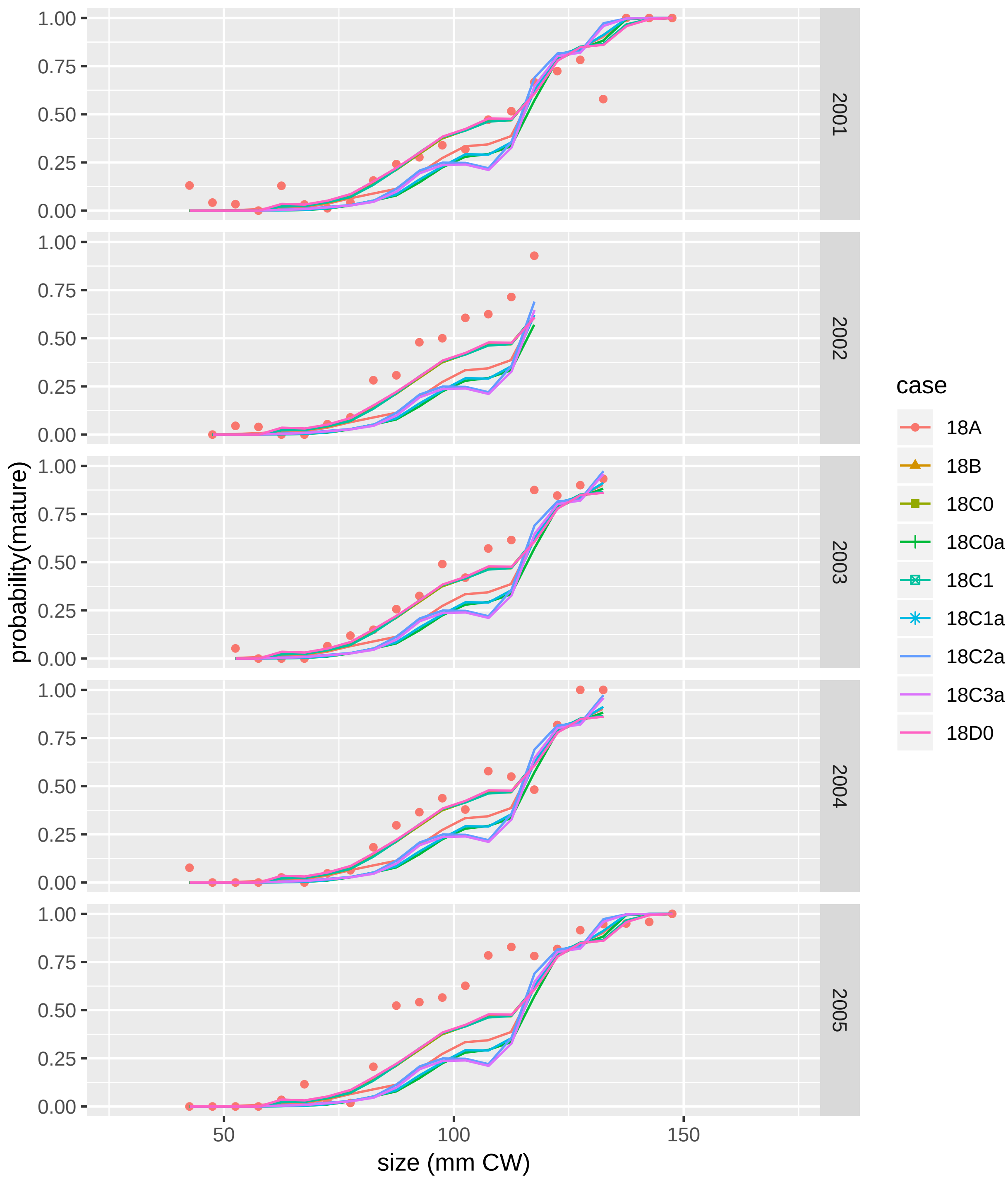

Figure 6: Model fits to MATURITY OGIVES for 2001 to 2005.

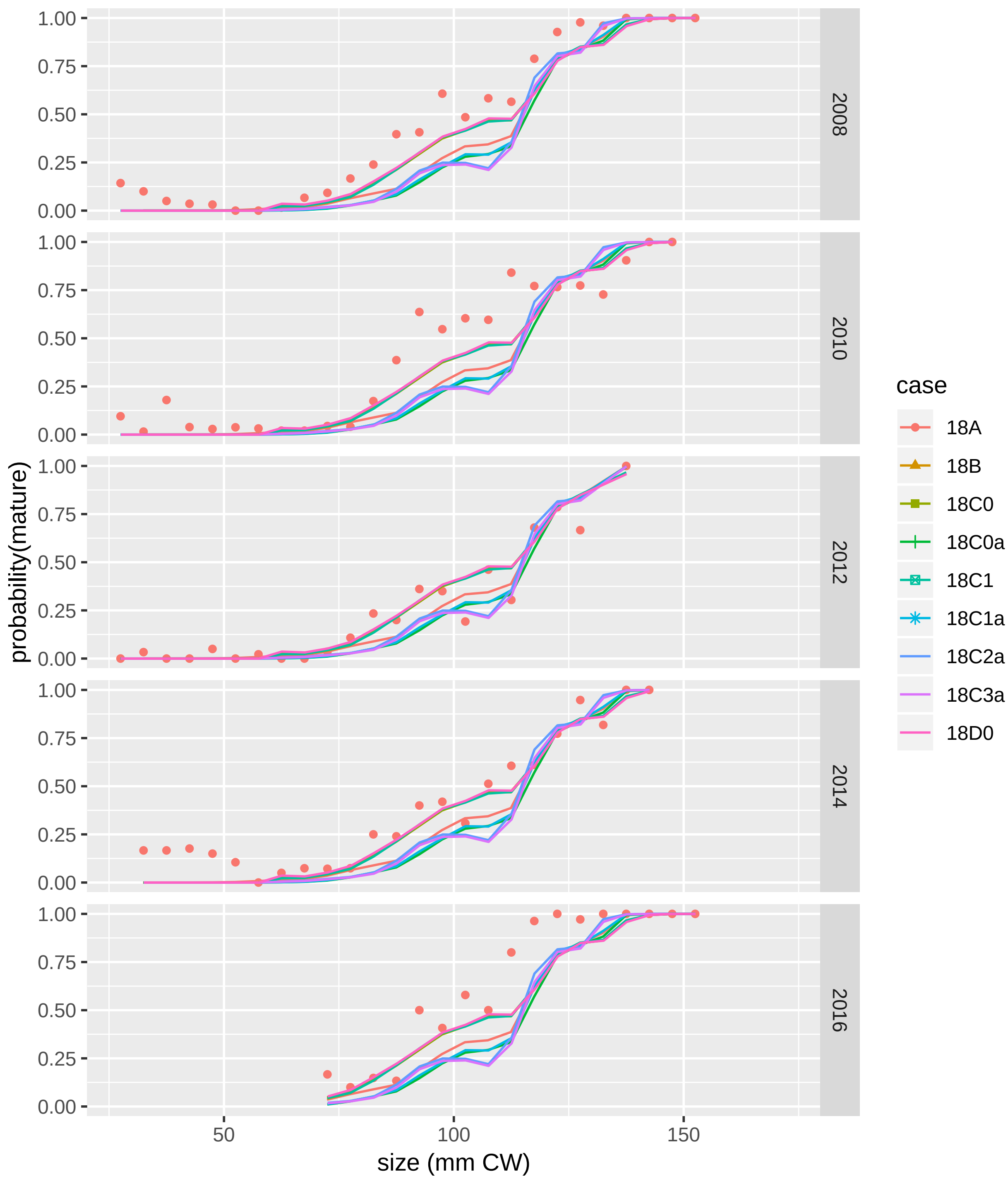

Figure 7: Model fits to MATURITY OGIVES for 2008 to 2016.

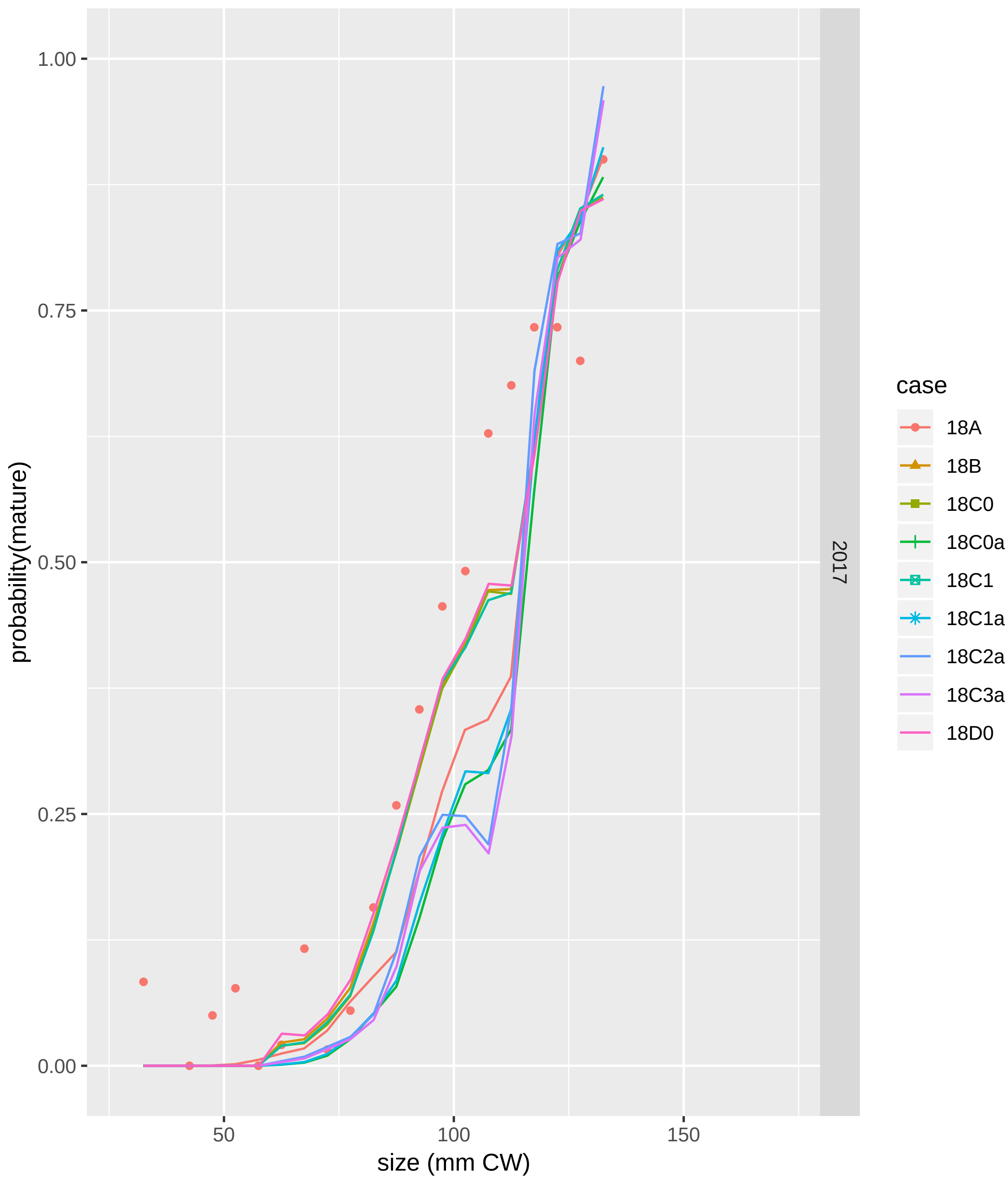

Figure 8: Model fits to MATURITY OGIVES for 2017 to 2017.

Appendix I6:
Population Processes from "18" Scenarios

William Stockhausen

31 August, 2018

Contents

Introduction

Figures and tables in this section present comparisons between alternative model scenarios for estimated rates (e.g., natural mortality) or other attributes (e.g., molt increments) describing inferred Tanner crab population processes.

Natural mortality

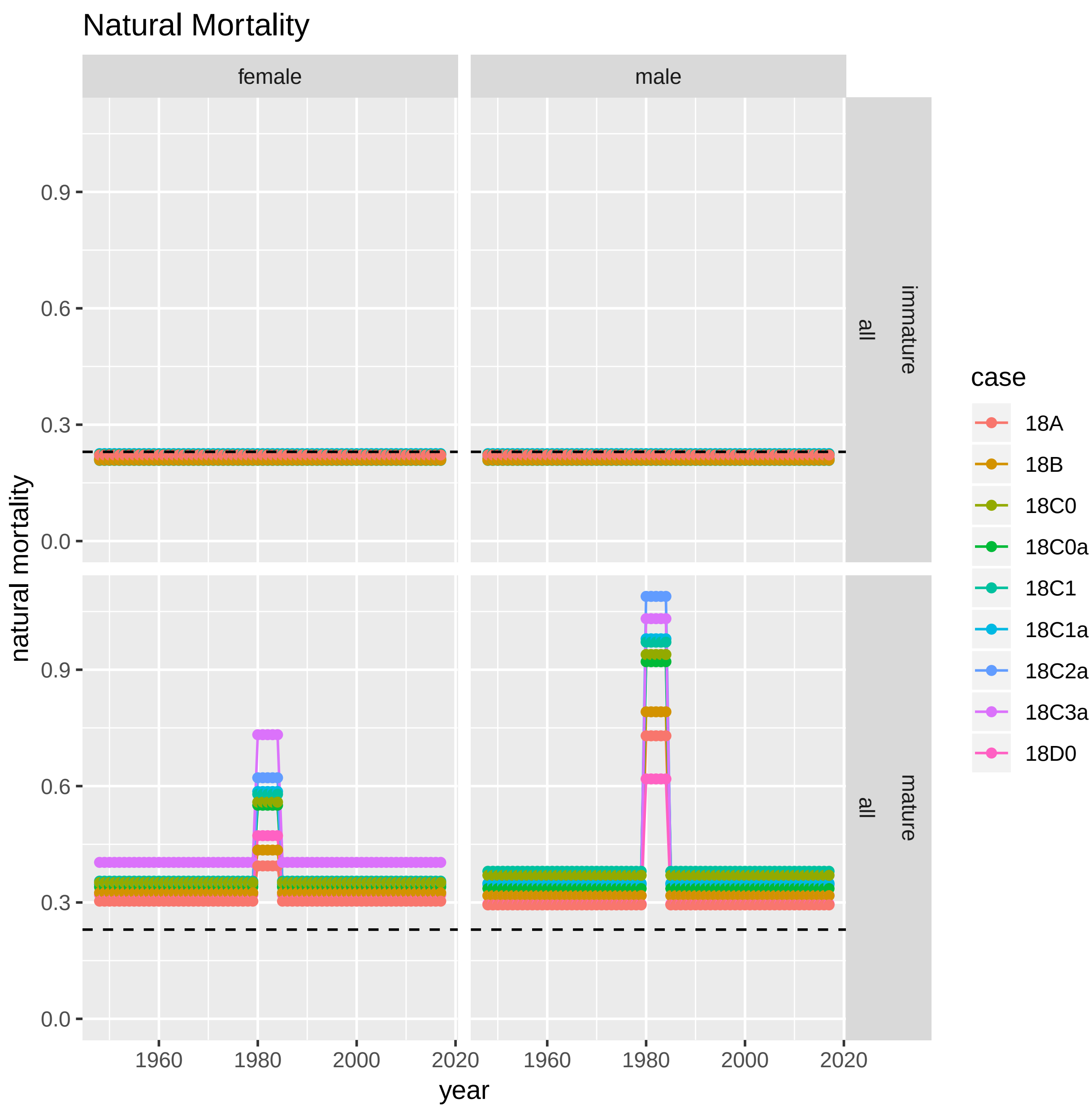

Figure 1: Estimated natural mortality rates, by year.

Probability of terminal molt

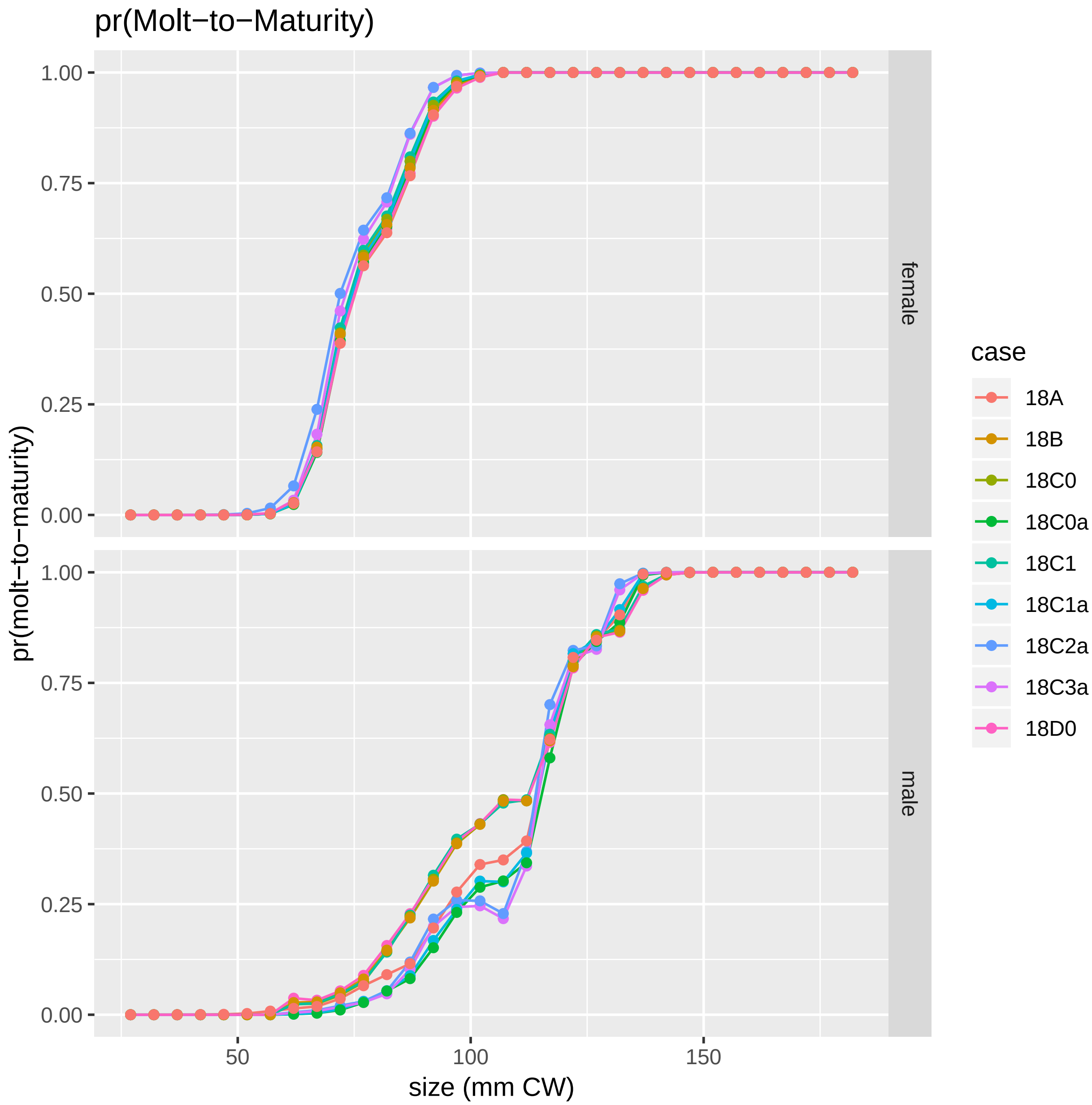

Figure 2: Probability of terminal molt.

Mean growth

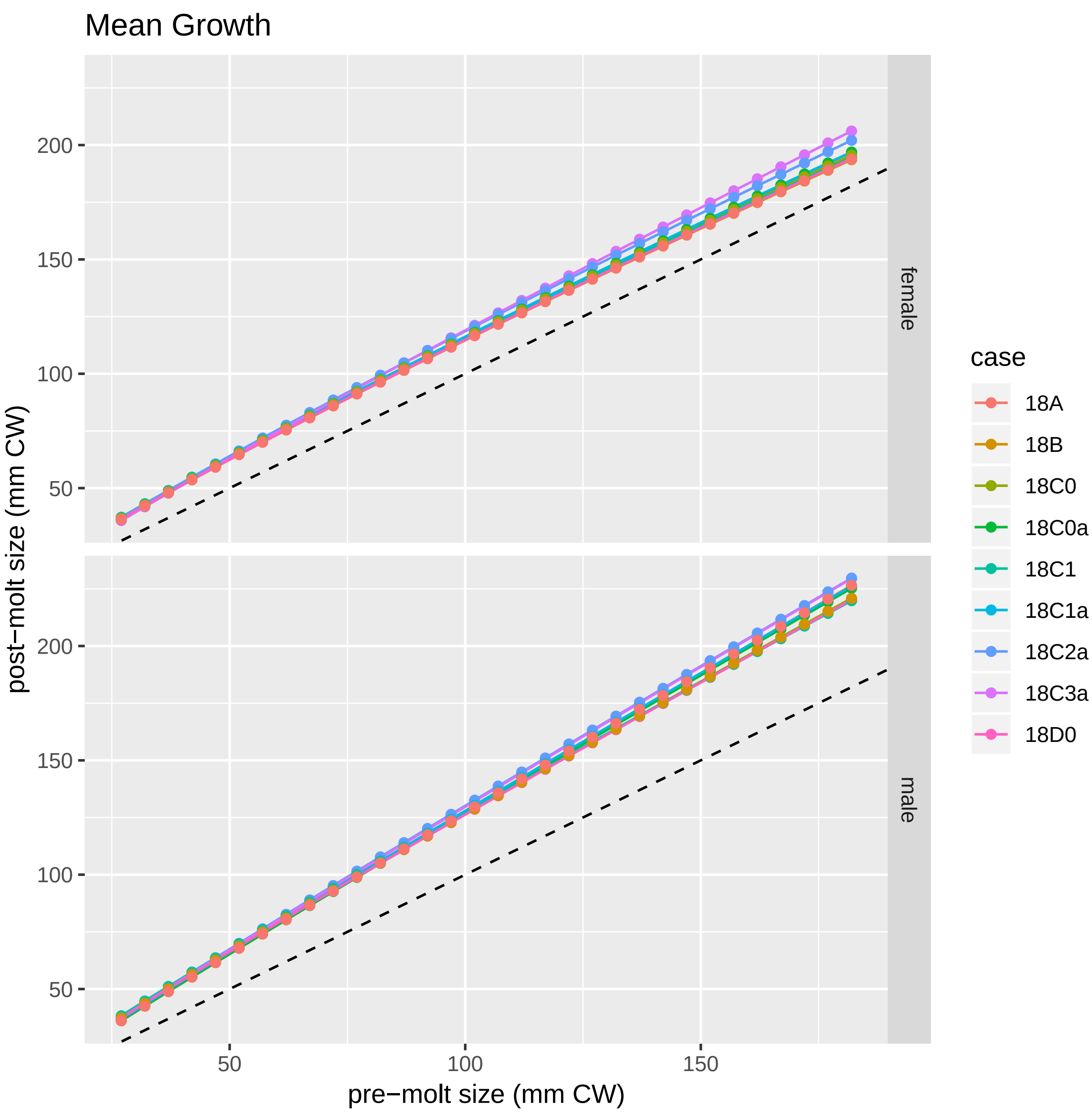

Figure 3: Mean growth.

The same growth matrices are compared in the following figure(s) as line plots for each pre-molt size bin, by sex.

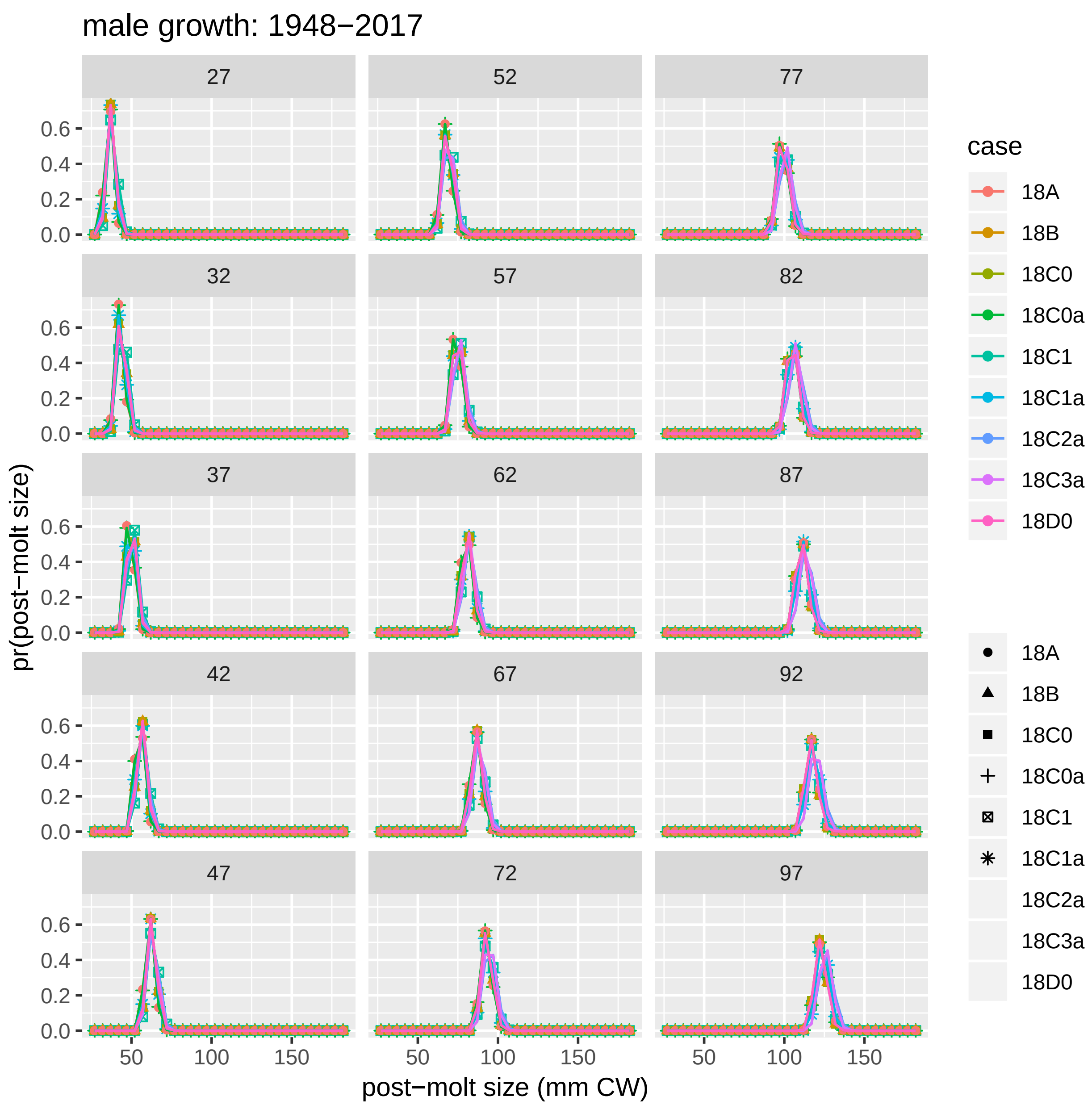

Figure 4: Growth matrices for males during 1948-2017, page 1.

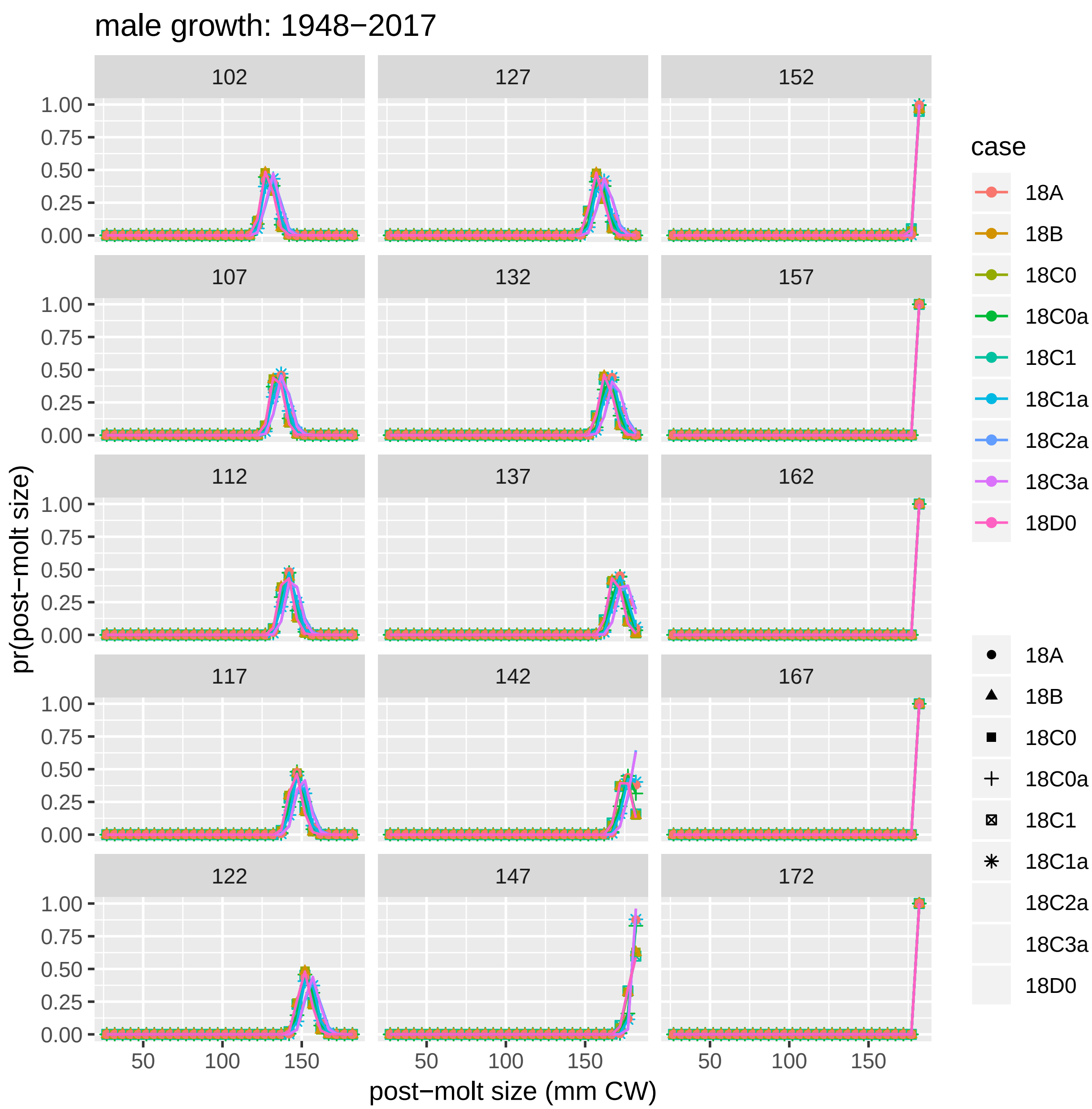

Figure 5: Growth matrices for males during 1948-2017, page 2.

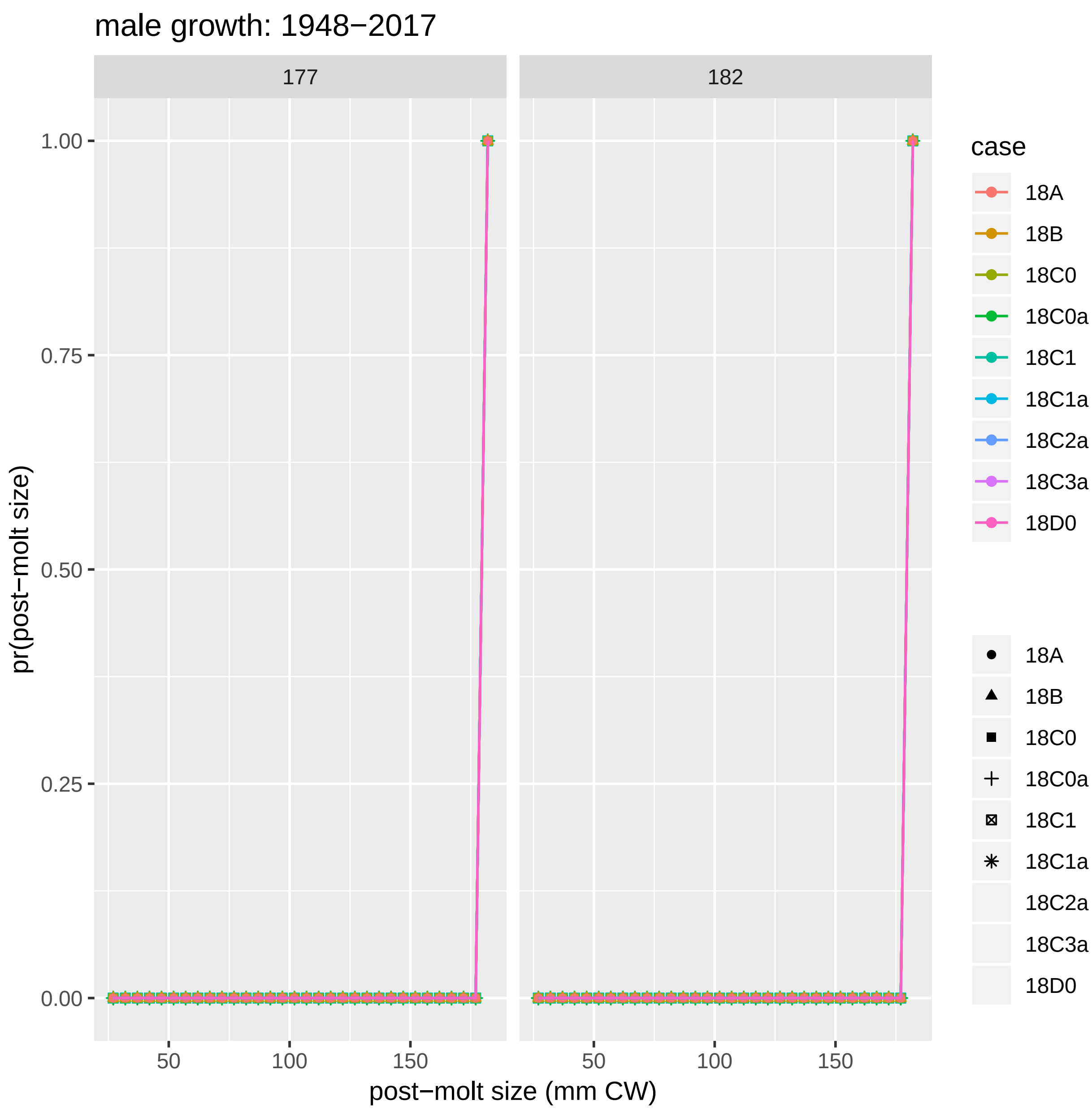

Figure 6: Growth matrices for males during 1948-2017, page 3.

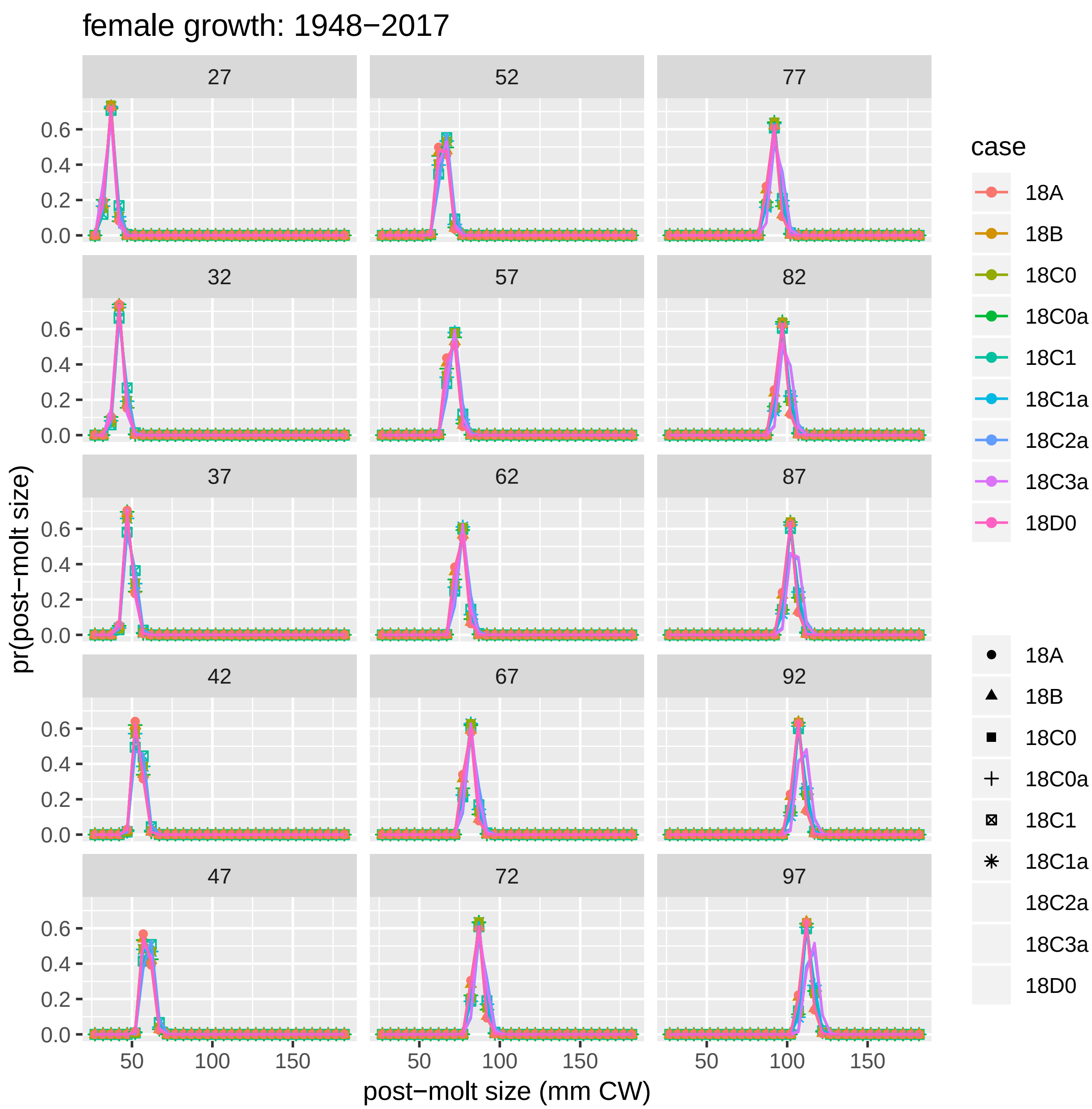

Figure 7: Growth matrices for females during 1948-2017, page 1.

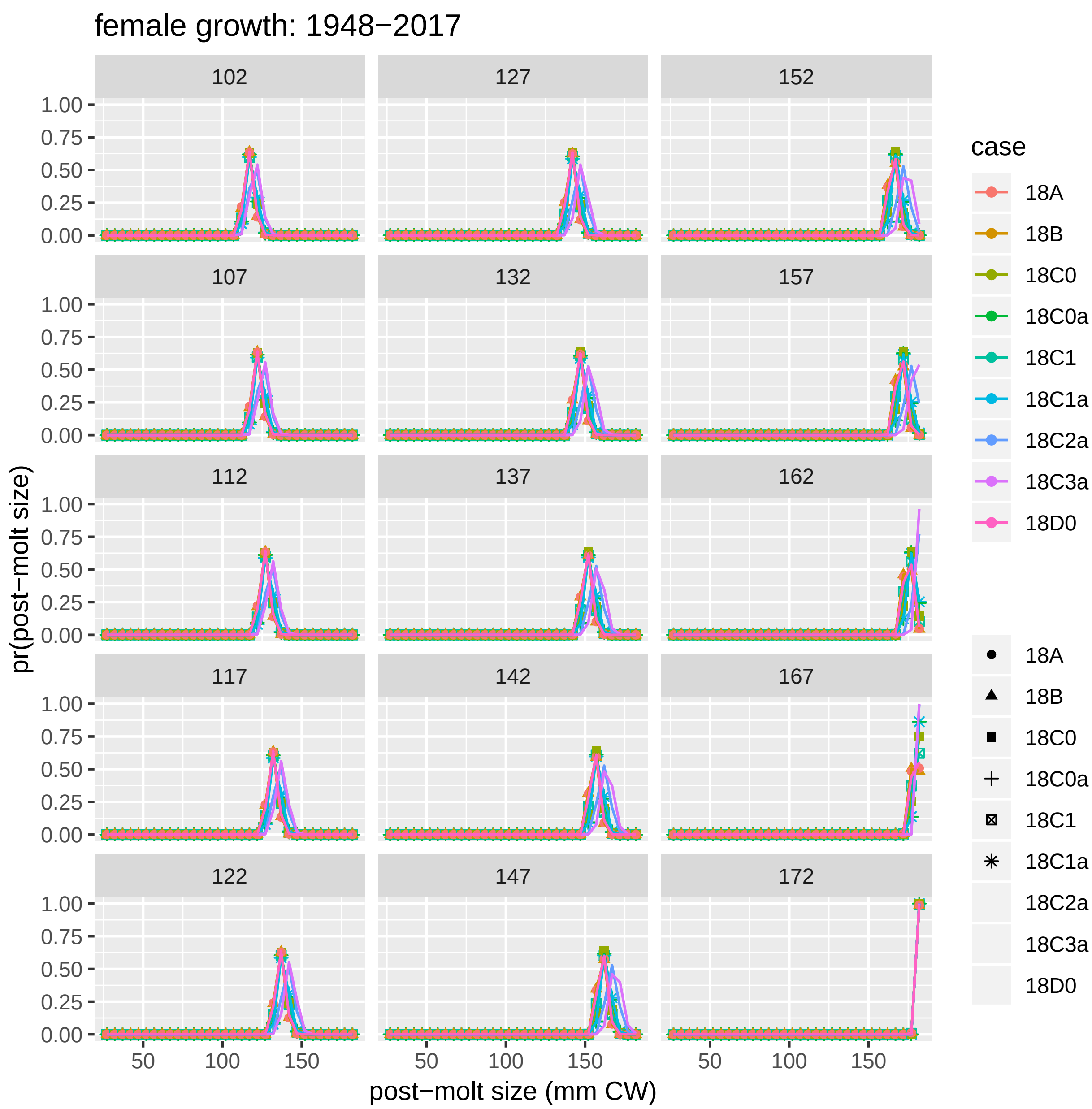

Figure 8: Growth matrices for females during 1948-2017, page 2.

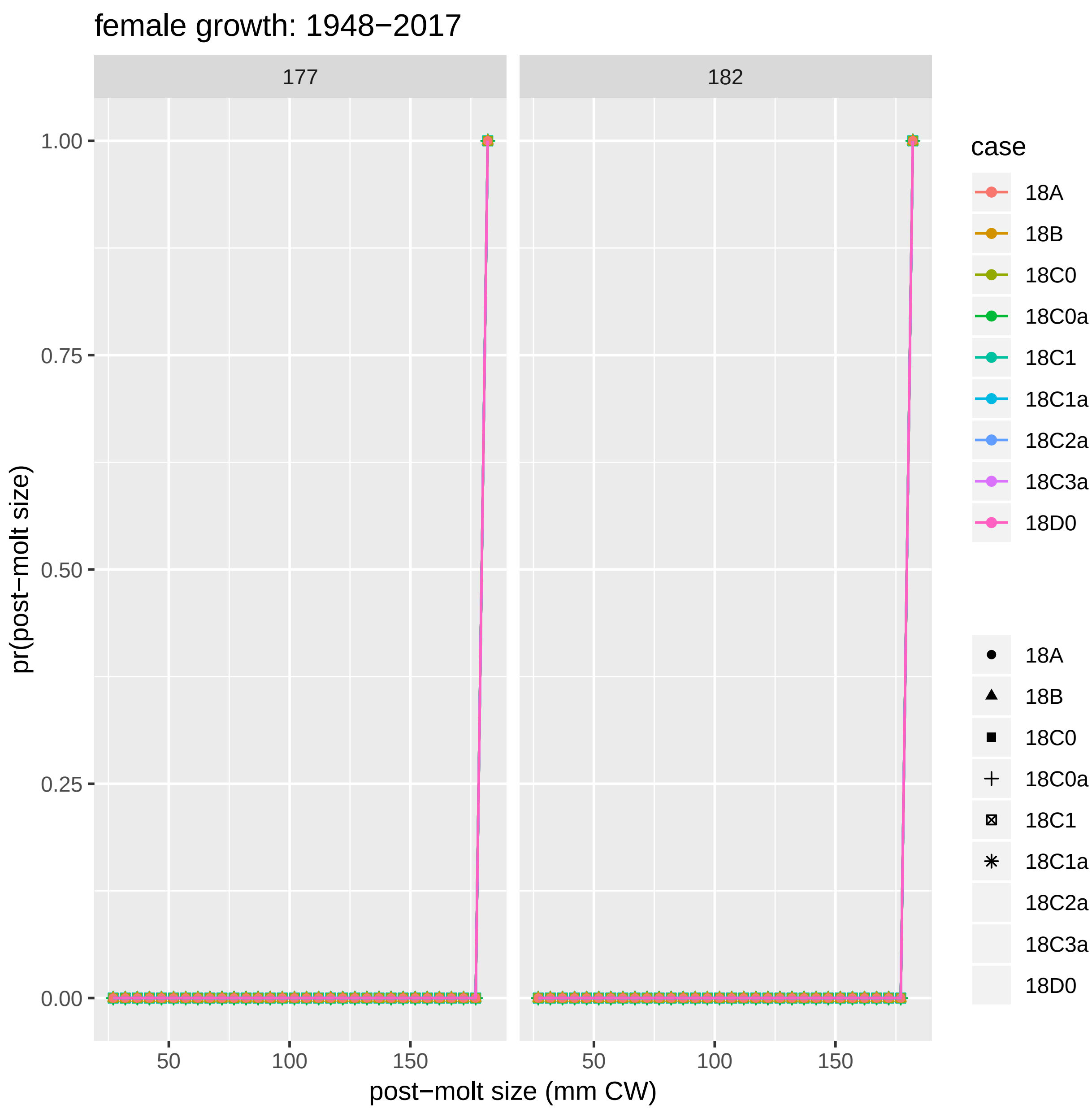

Figure 9: Growth matrices for females during 1948-2017, page 3.

Size distribution for recruits

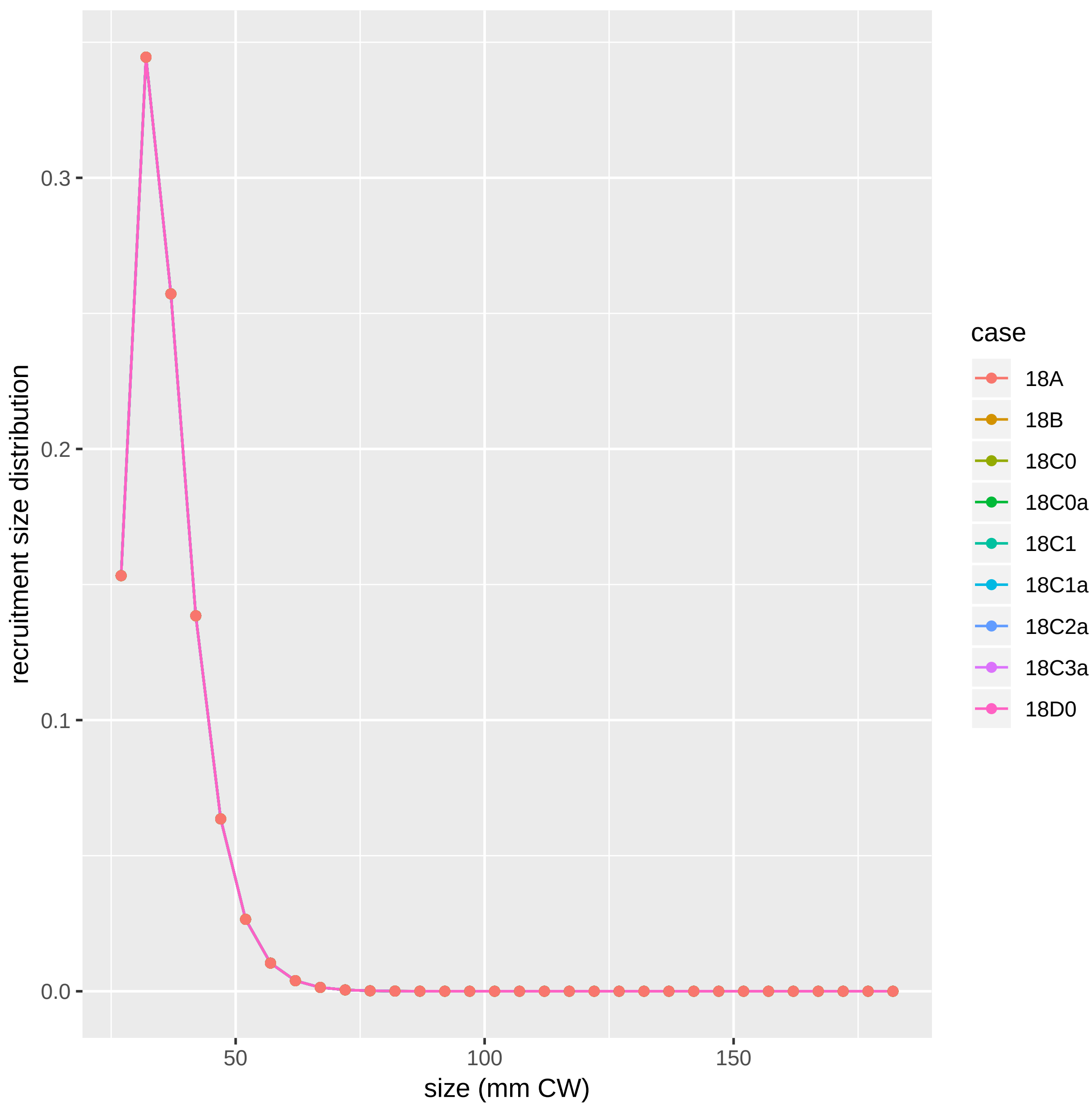

Figure 10: Size distribution for recruits.

Appendix I7:
Population Quantities from the "18" Scenarios

William Stockhausen

31 August, 2018

Figures and tables in this section present comparisons between alternative model scenarios for estimated quantities (e.g., recruitment, abundance time series) describing the inferred Tanner crab population.

Recruitment

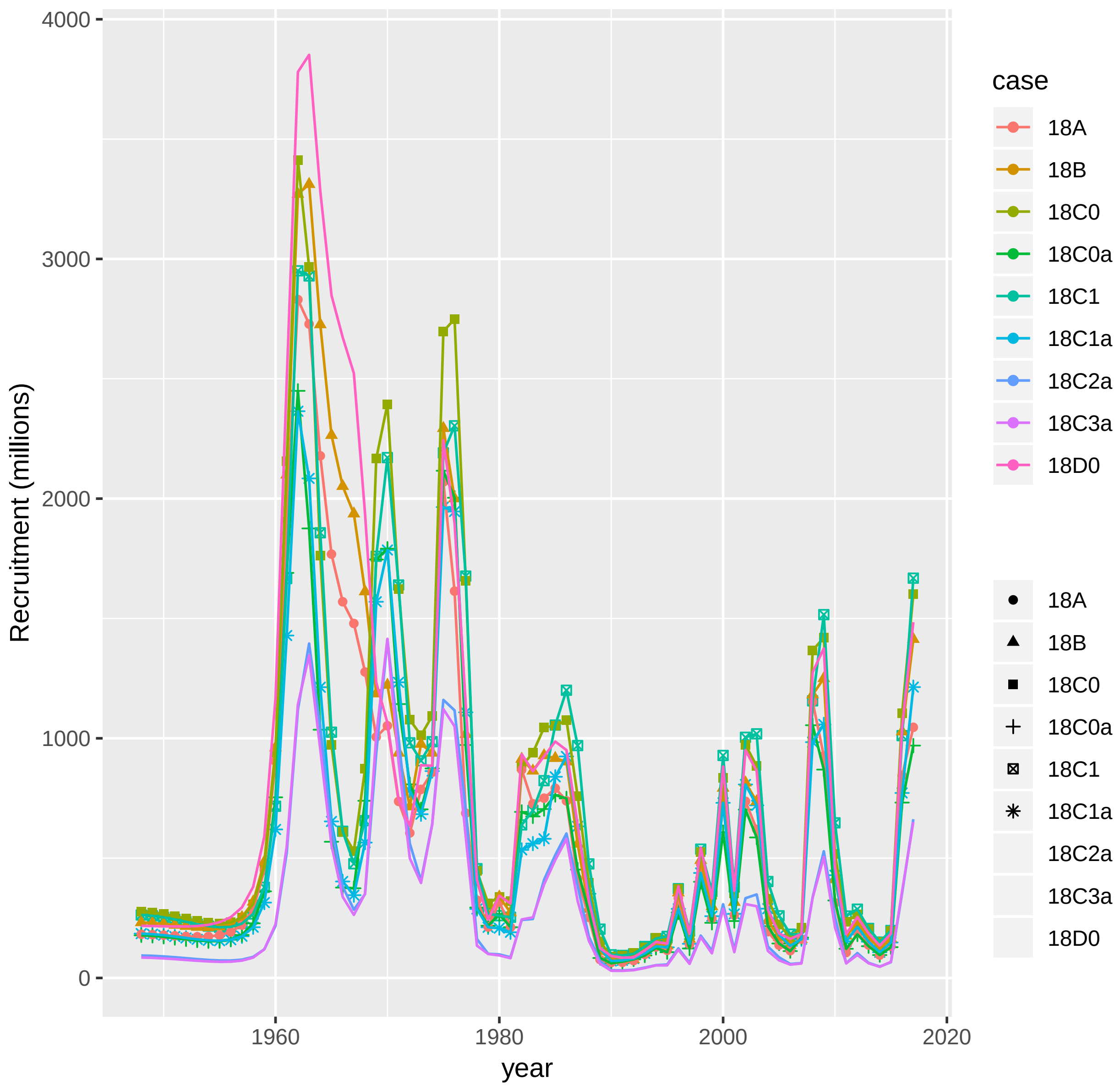

Figure 1: Estimated annual recruitment.

Population abundance

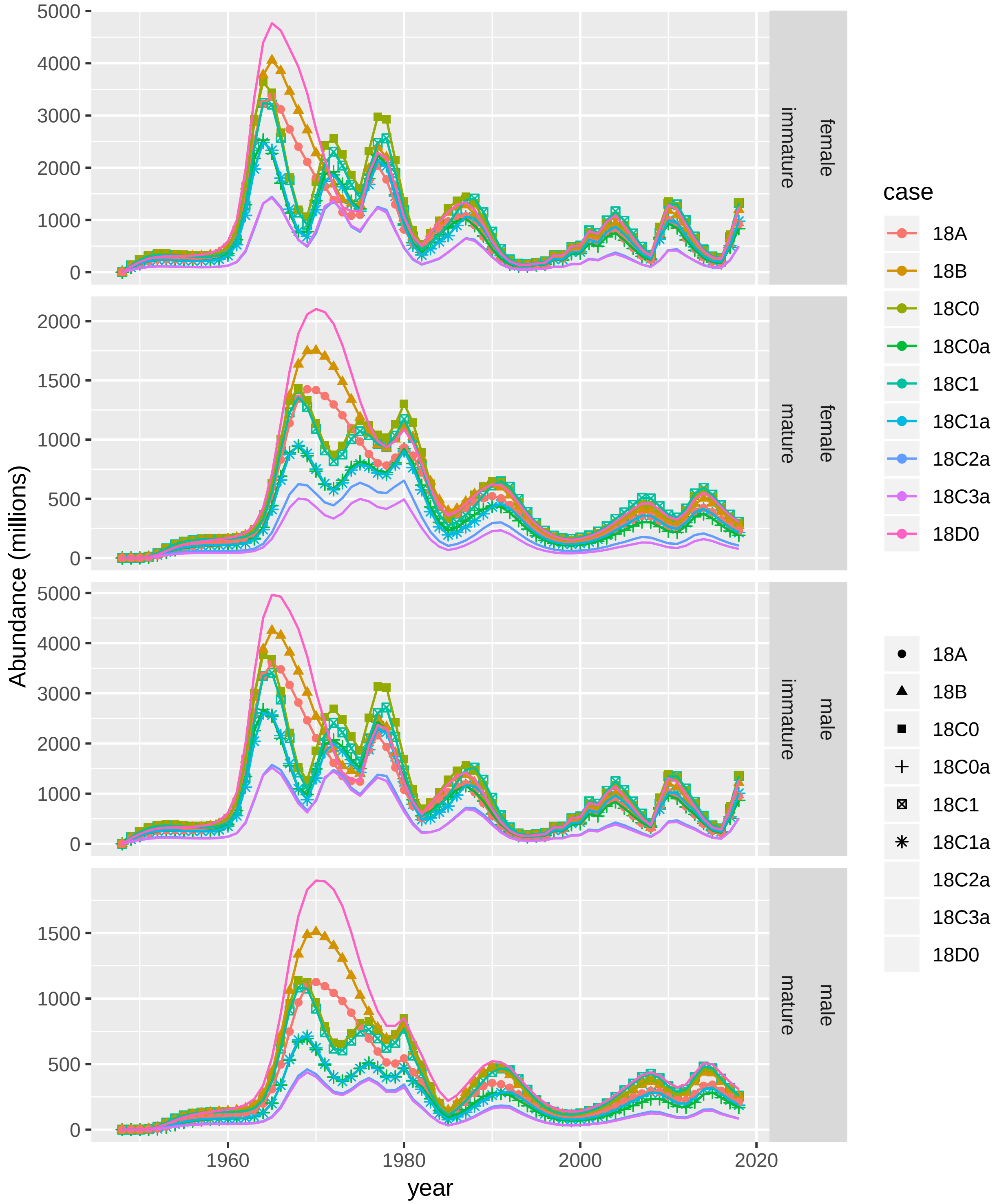

Figure 2: Population abundance trends.

Population biomass

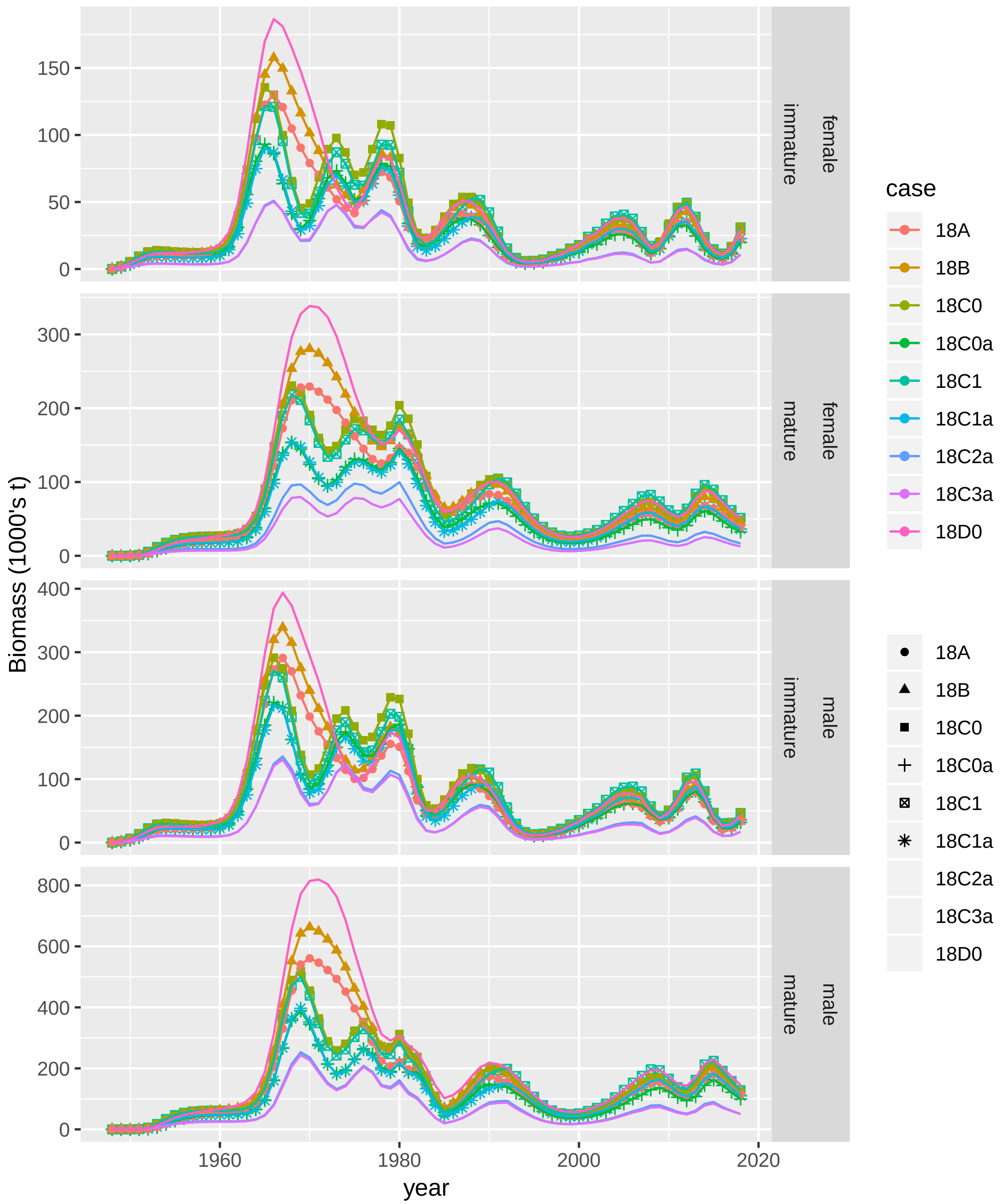

Figure 3: Population biomass trends.

Appendix I8:
Survey Characteristics from the "18" Scenarios

William Stockhausen

31 August, 2018

Model-estimated survey characteristics such as catchability, selectivity functions, and capture probability are presented in this section.

Survey catchability

"Catchability" here refers to the catchability of crab in a "fully-selected" size bin.

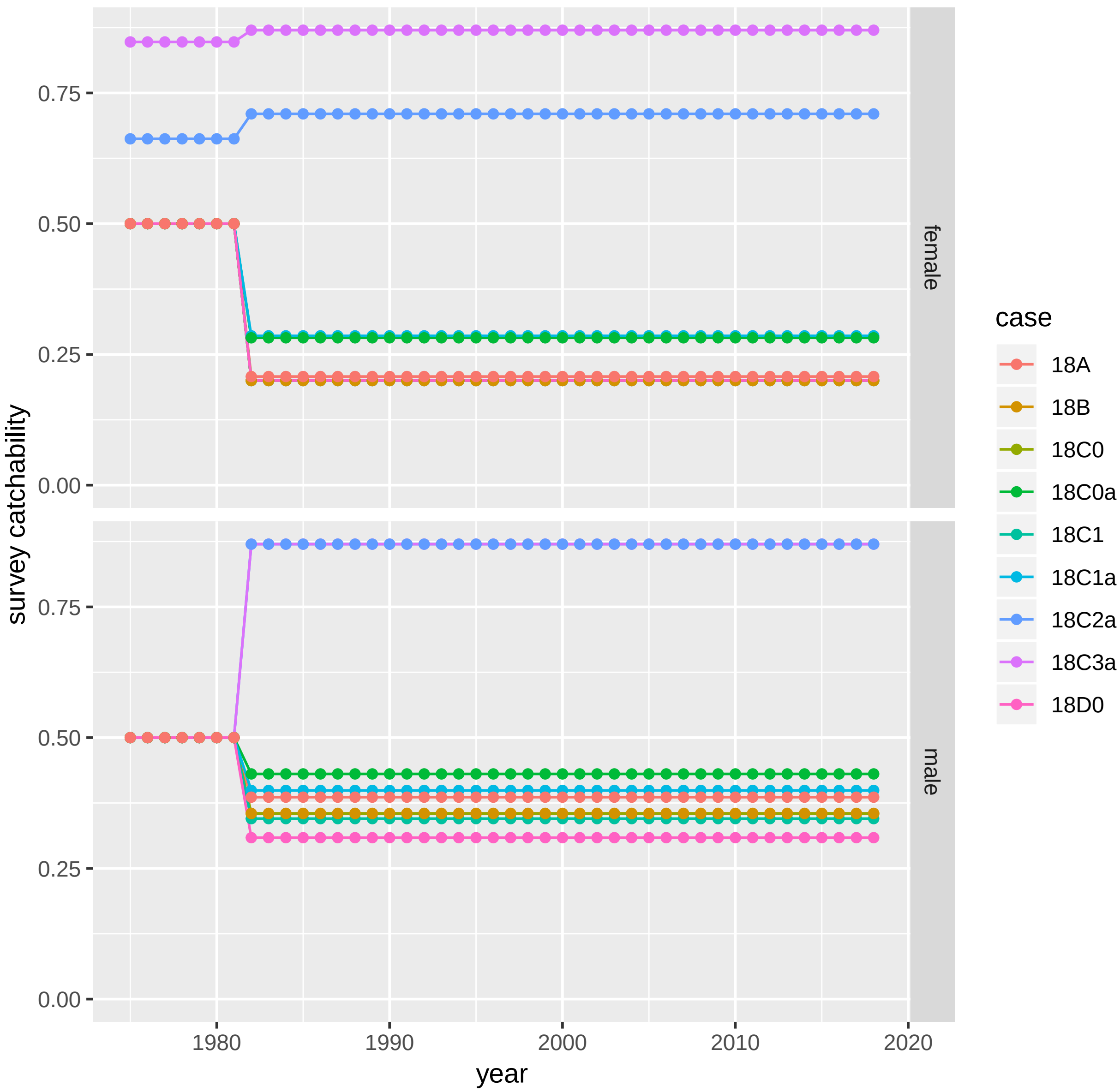

Figure 1: Survey catchabilities for NMFS.

Survey selectivity functions

Survey selectivity functions reflect size-specific catchability relative to a "fully-selected" size class.

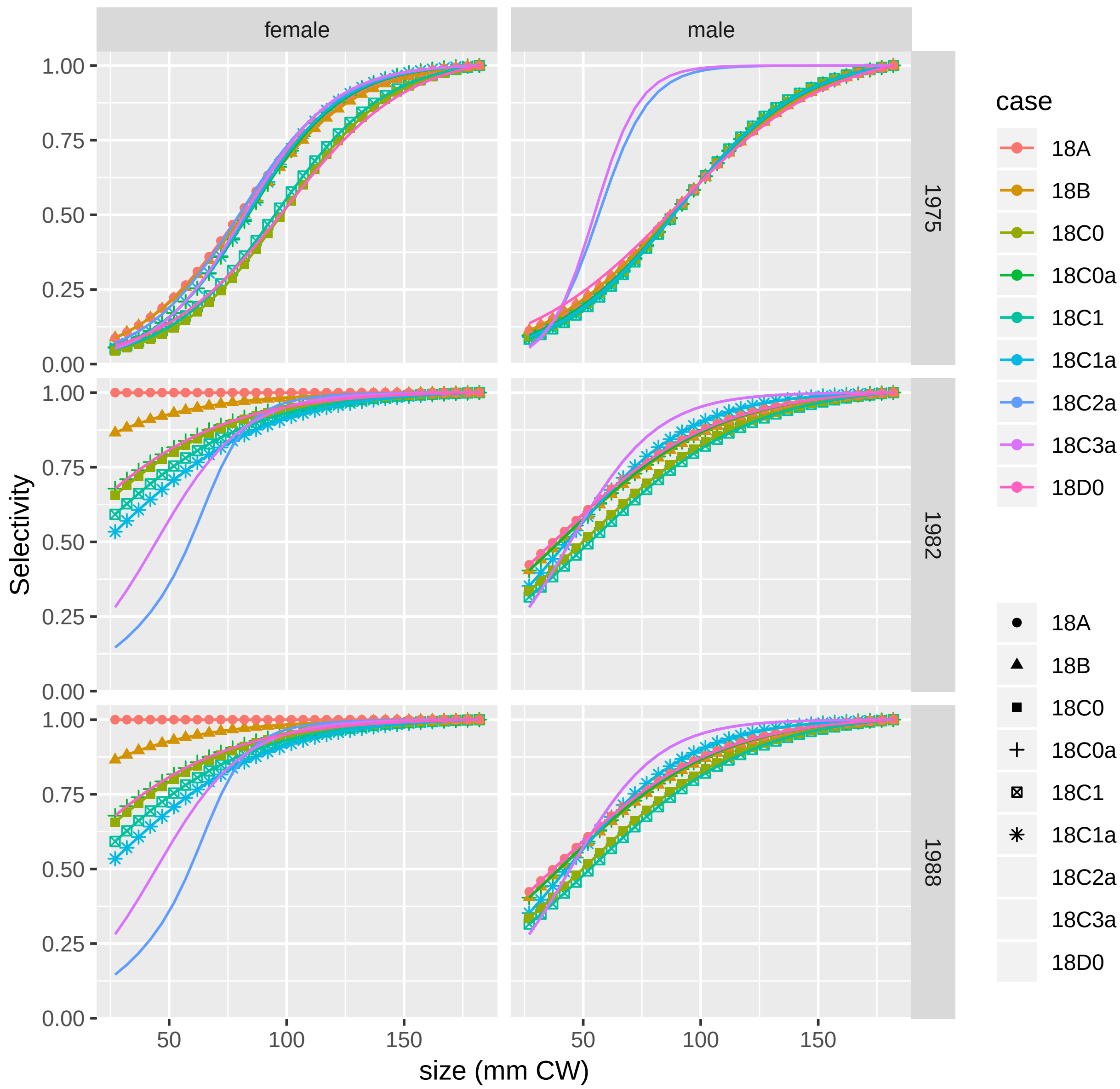

Figure 2: NMFS survey selectivities.

Survey capture probability functions

Survey capture probability functions incorporate both catchability and size-specific selectivity.

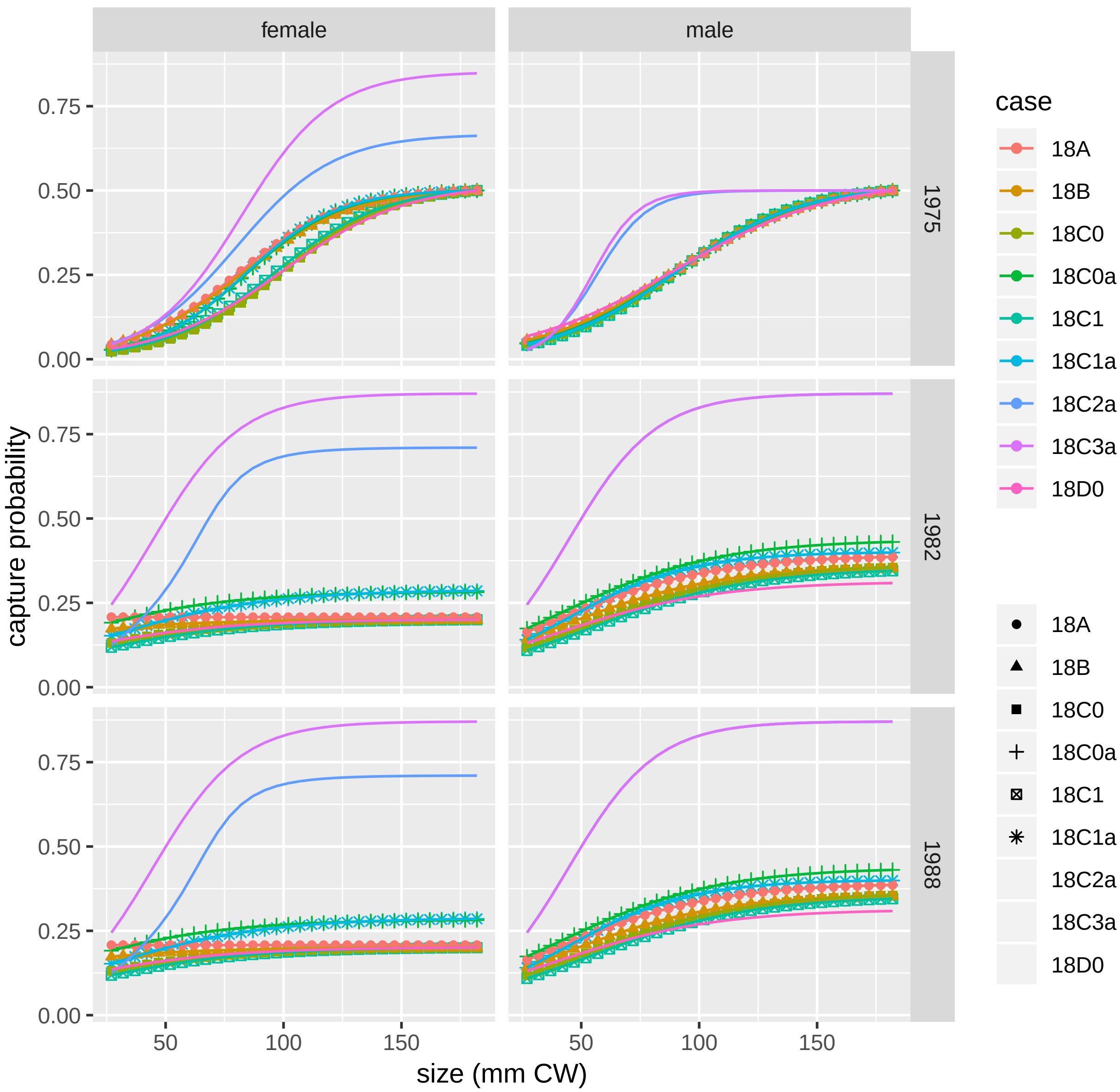

Figure 13 Capture probabilities for NMFS surveys.

Appendix I9:
Fishery Characteristics from the "18" Scenarios

William Stockhausen

31 August, 2018

Contents

Introduction

Model-estimated fishery characteristics such as catchability and selectivity and retention functions are presented in this section.

Fishery catchability

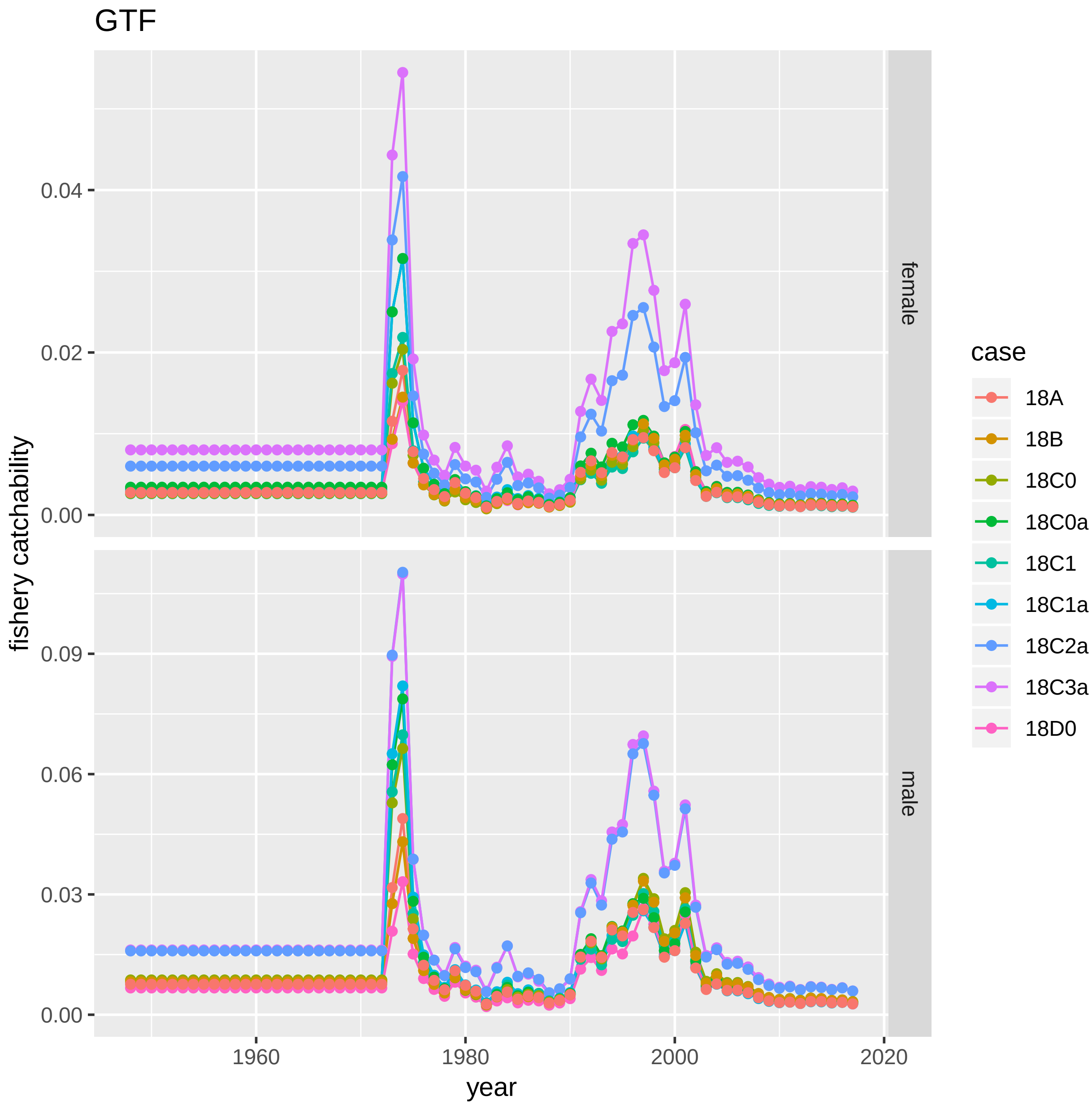

Figure 1: Fishery catchabilities for GTF.

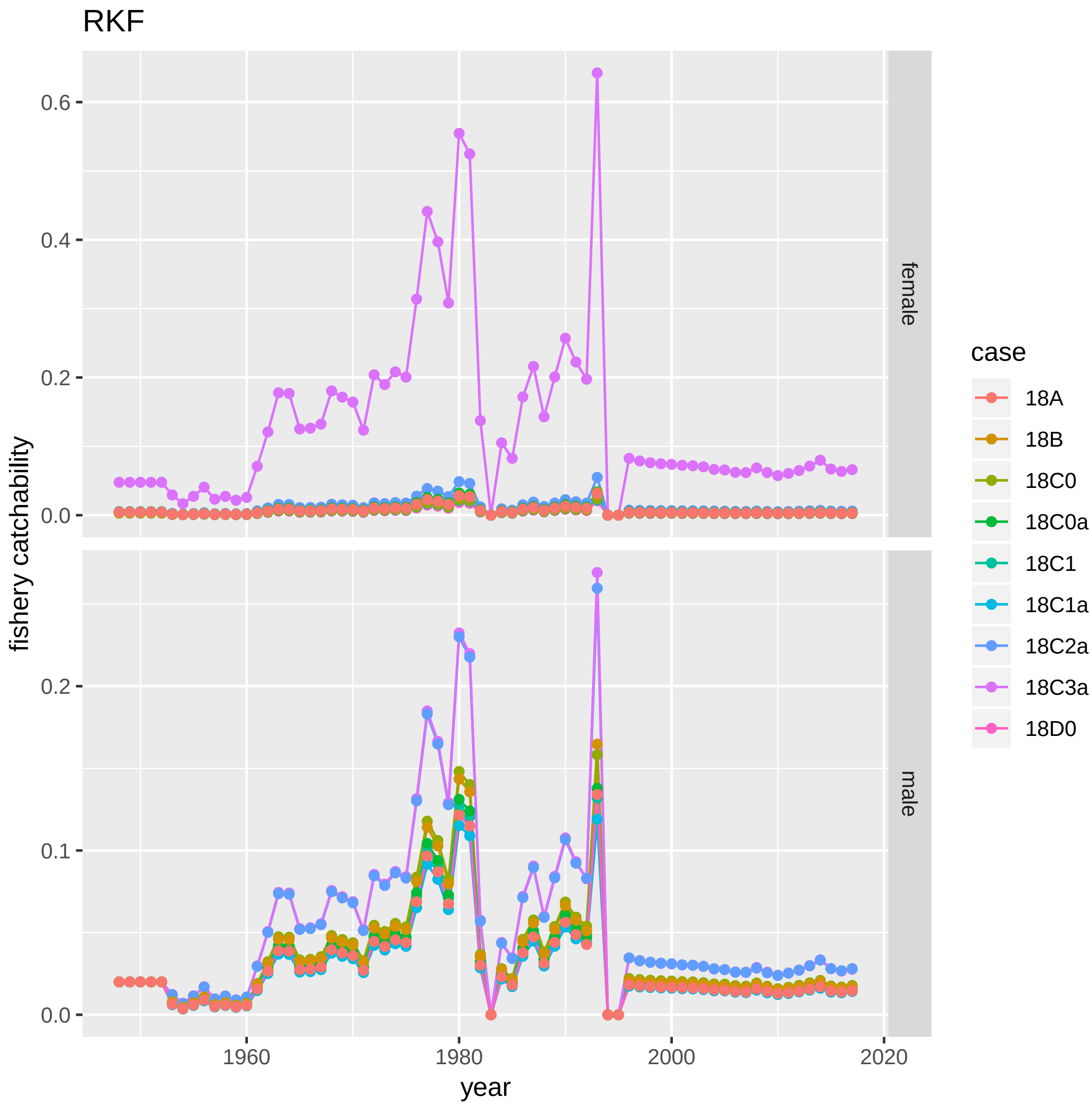

Figure 2: Fishery catchabilities for RKF.

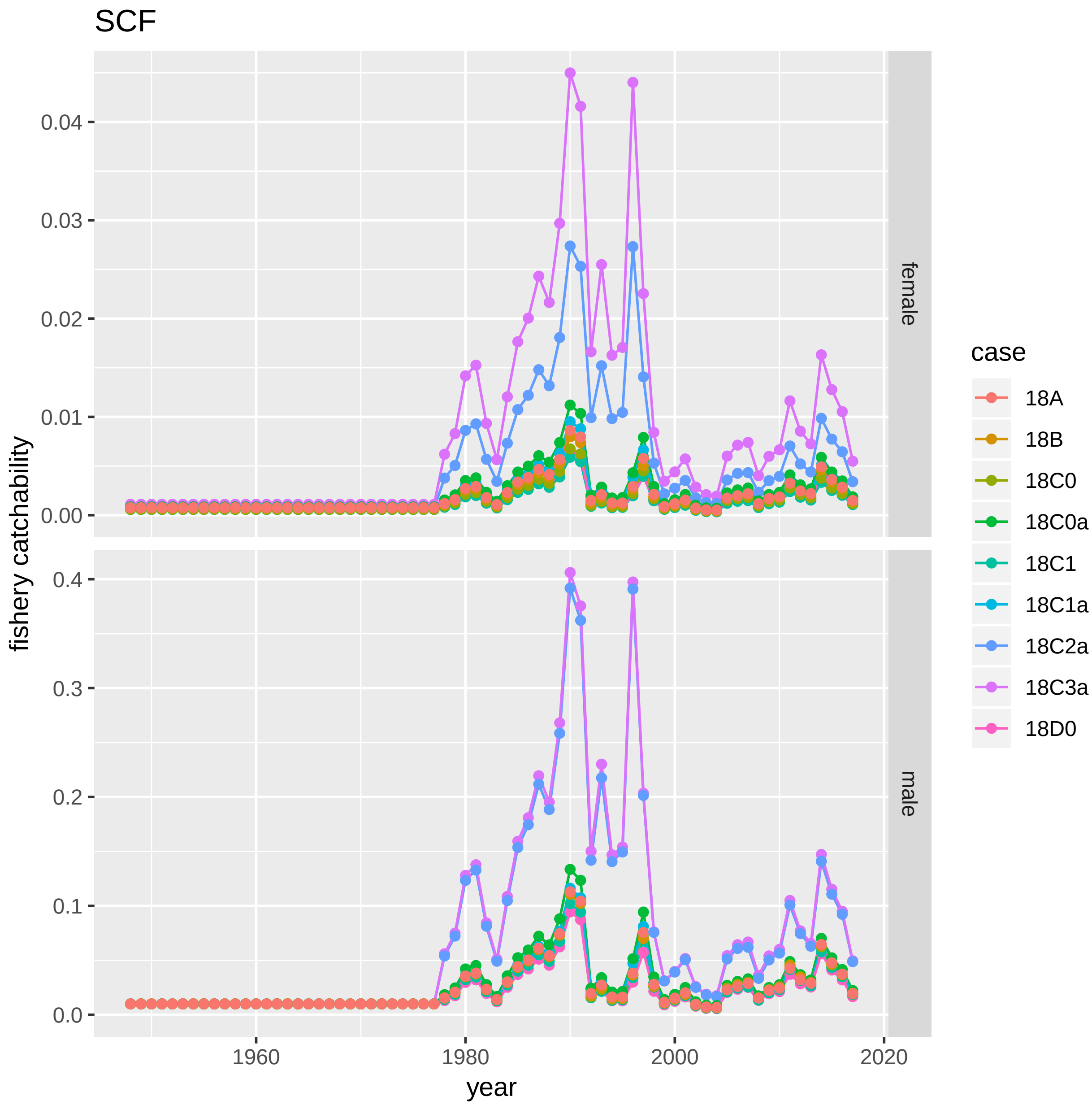

Figure 3: Fishery catchabilities for SCF.

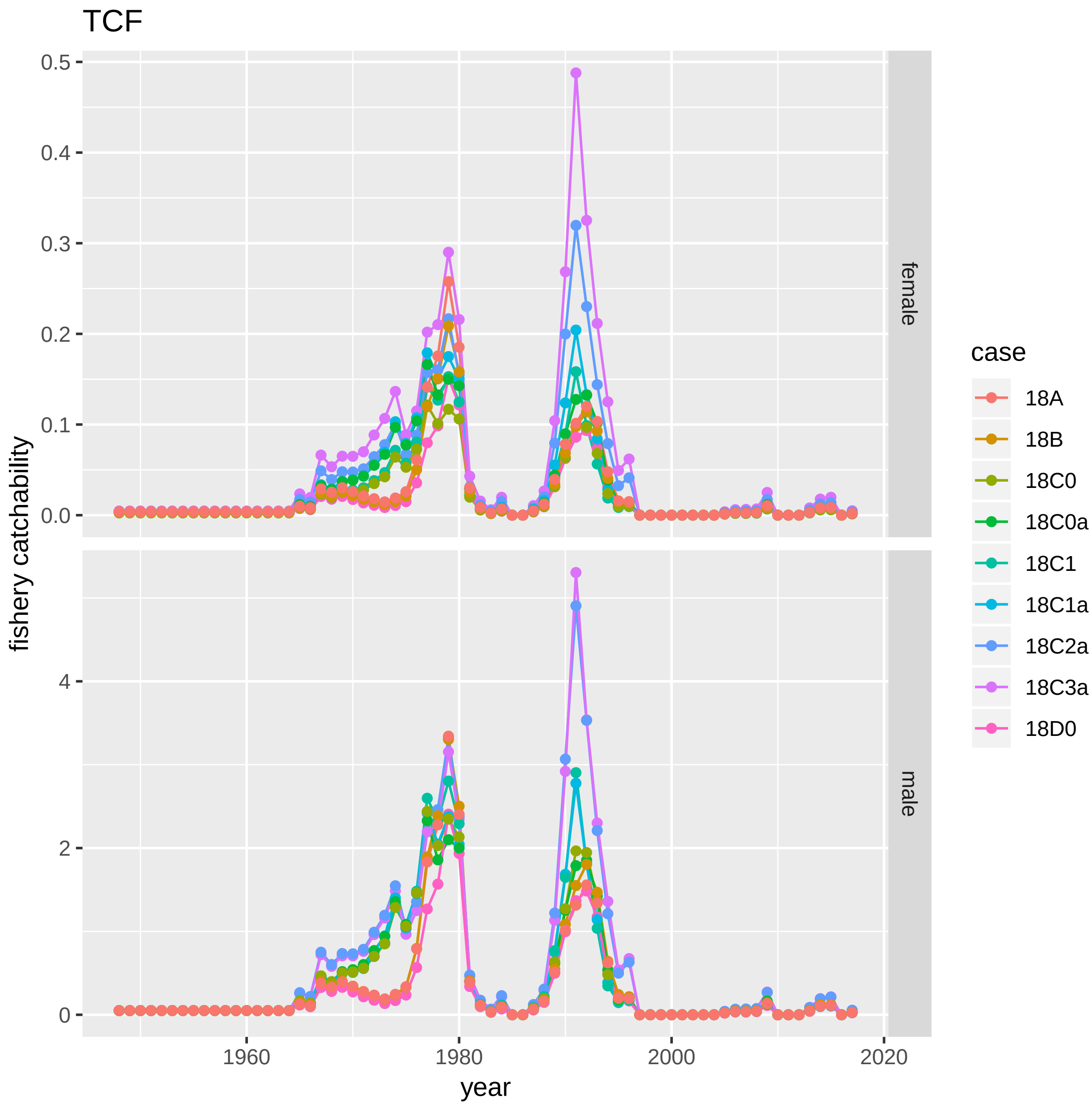

Figure 4: Fishery catchabilities for TCF.

Total selectivity functions

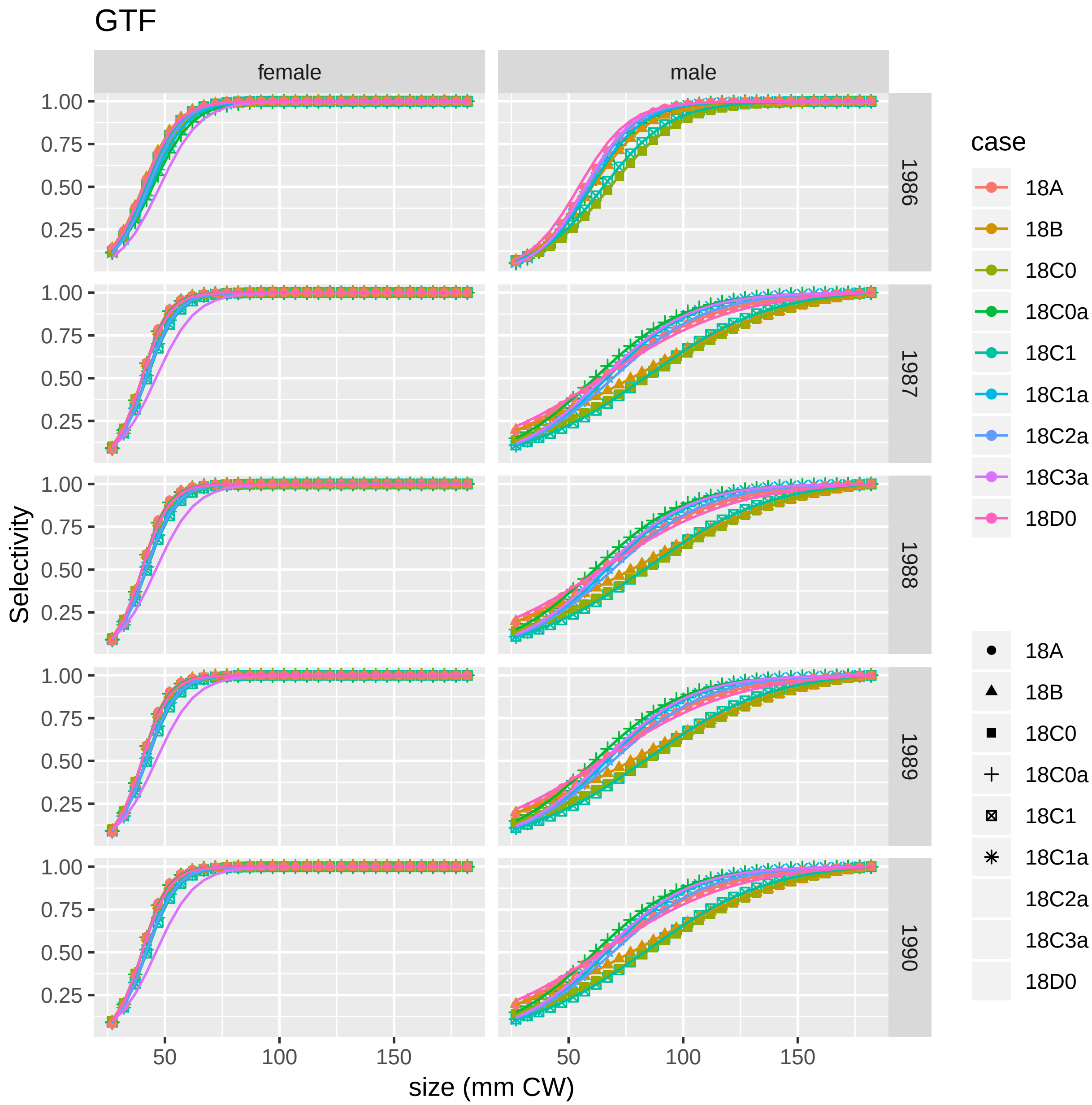

Figure 5: Selectivity functions for GTF(1 of 6).

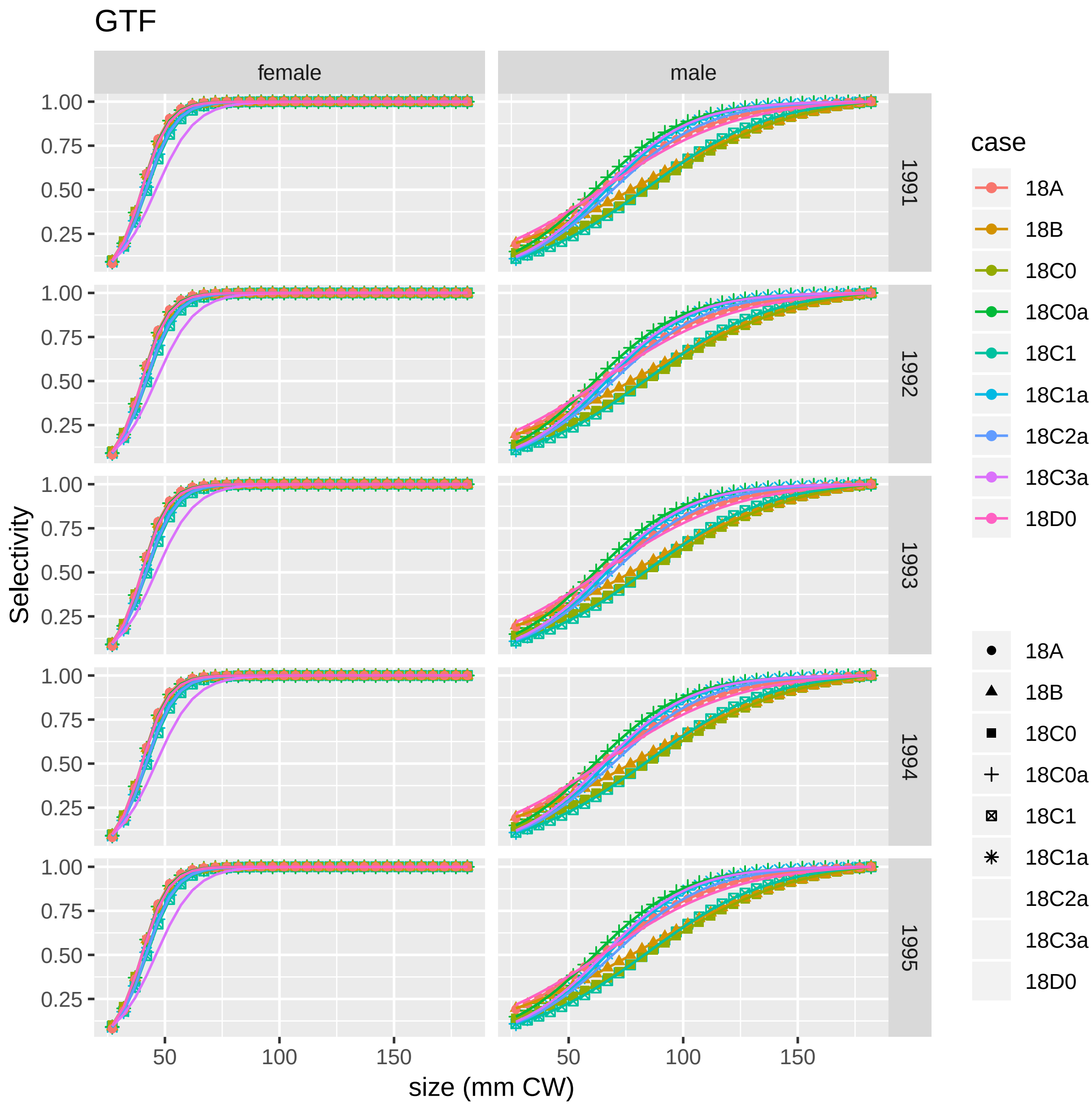

Figure 6: Selectivity functions for GTF(2 of 6).

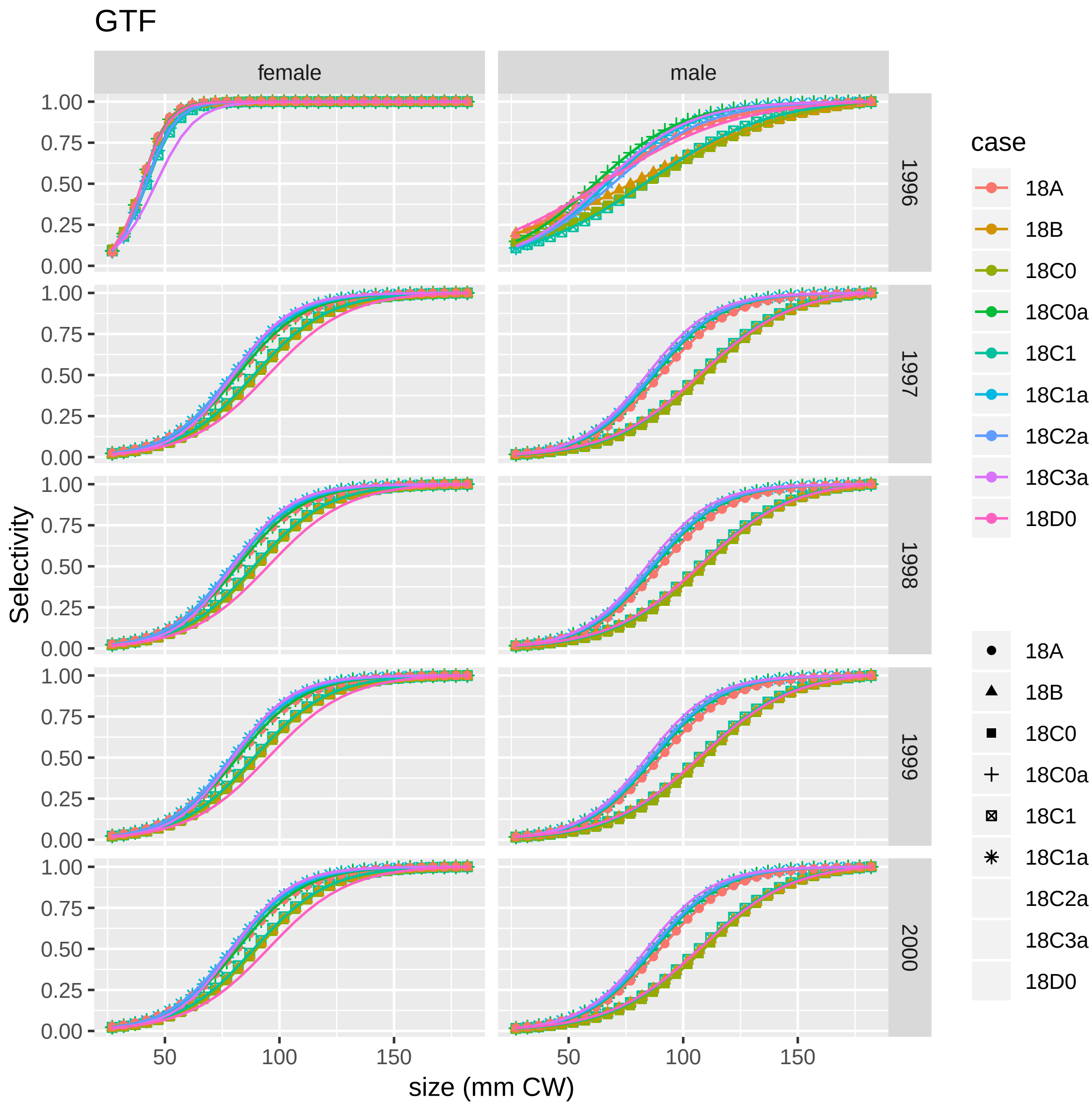

Figure 7: Selectivity functions for GTF(3 of 6).

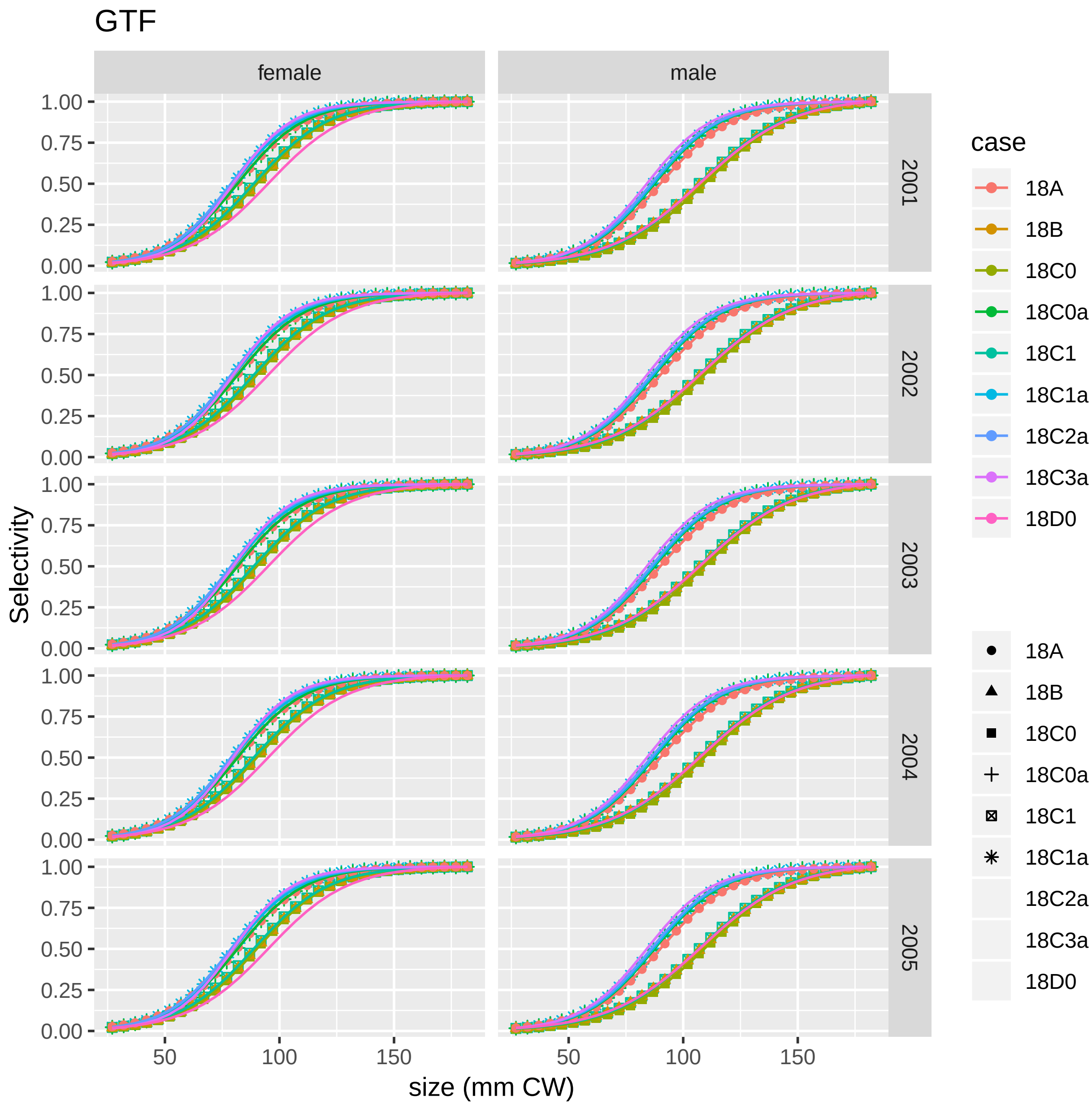

Figure 8: Selectivity functions for GTF(4 of 6).

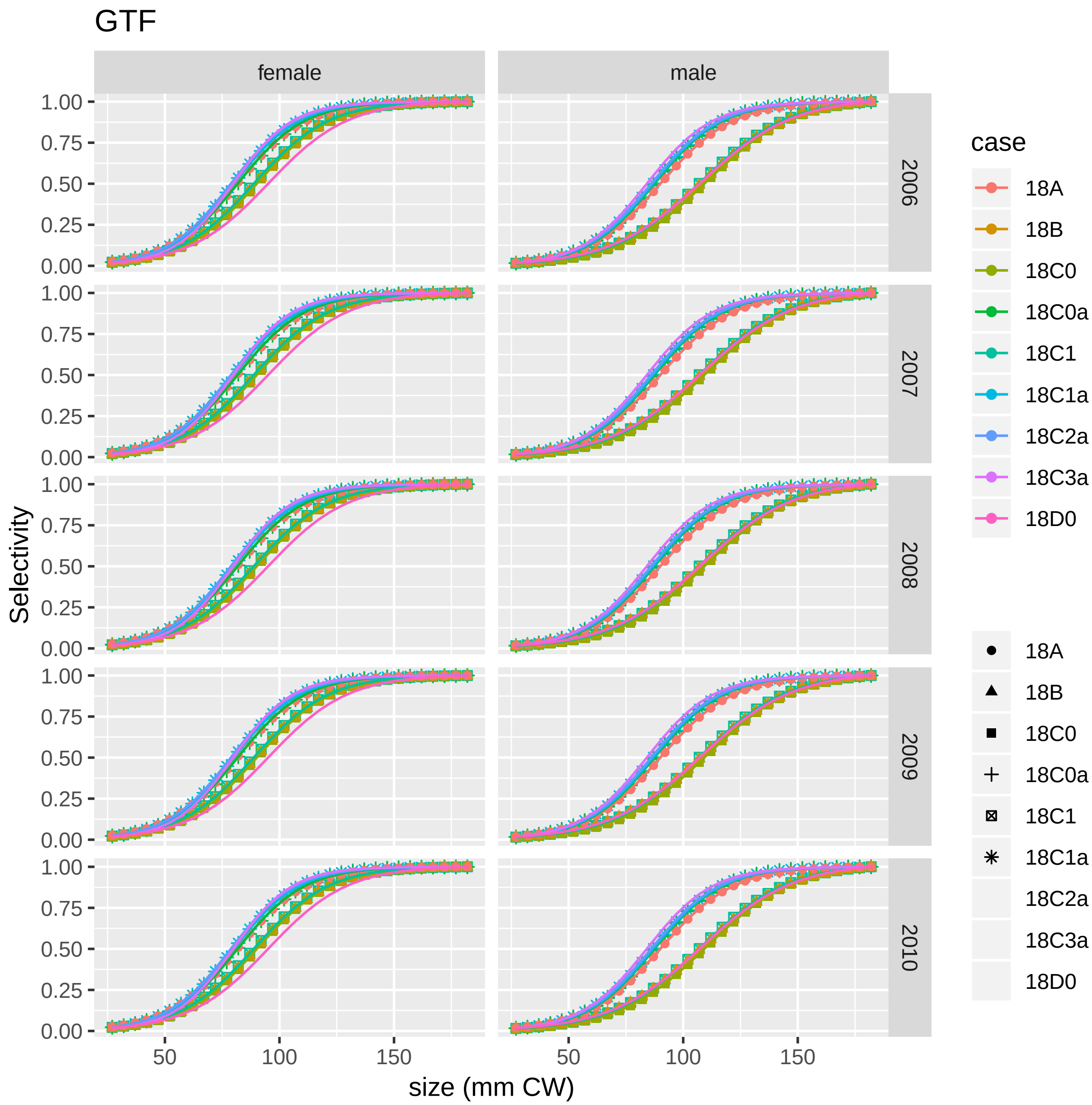

Figure 9: Selectivity functions for GTF(5 of 6).

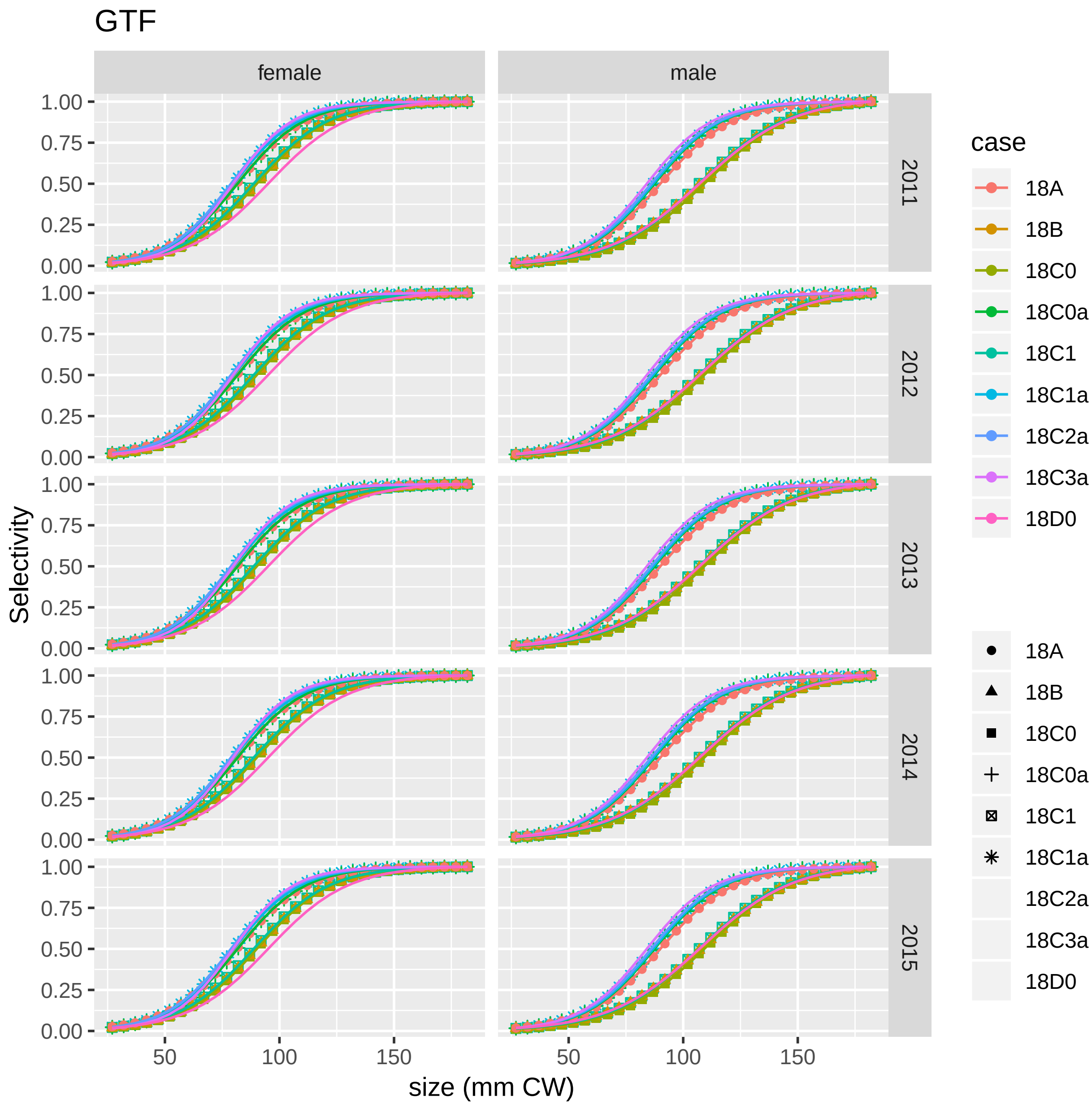

Figure 10: Selectivity functions for GTF(6 of 6).

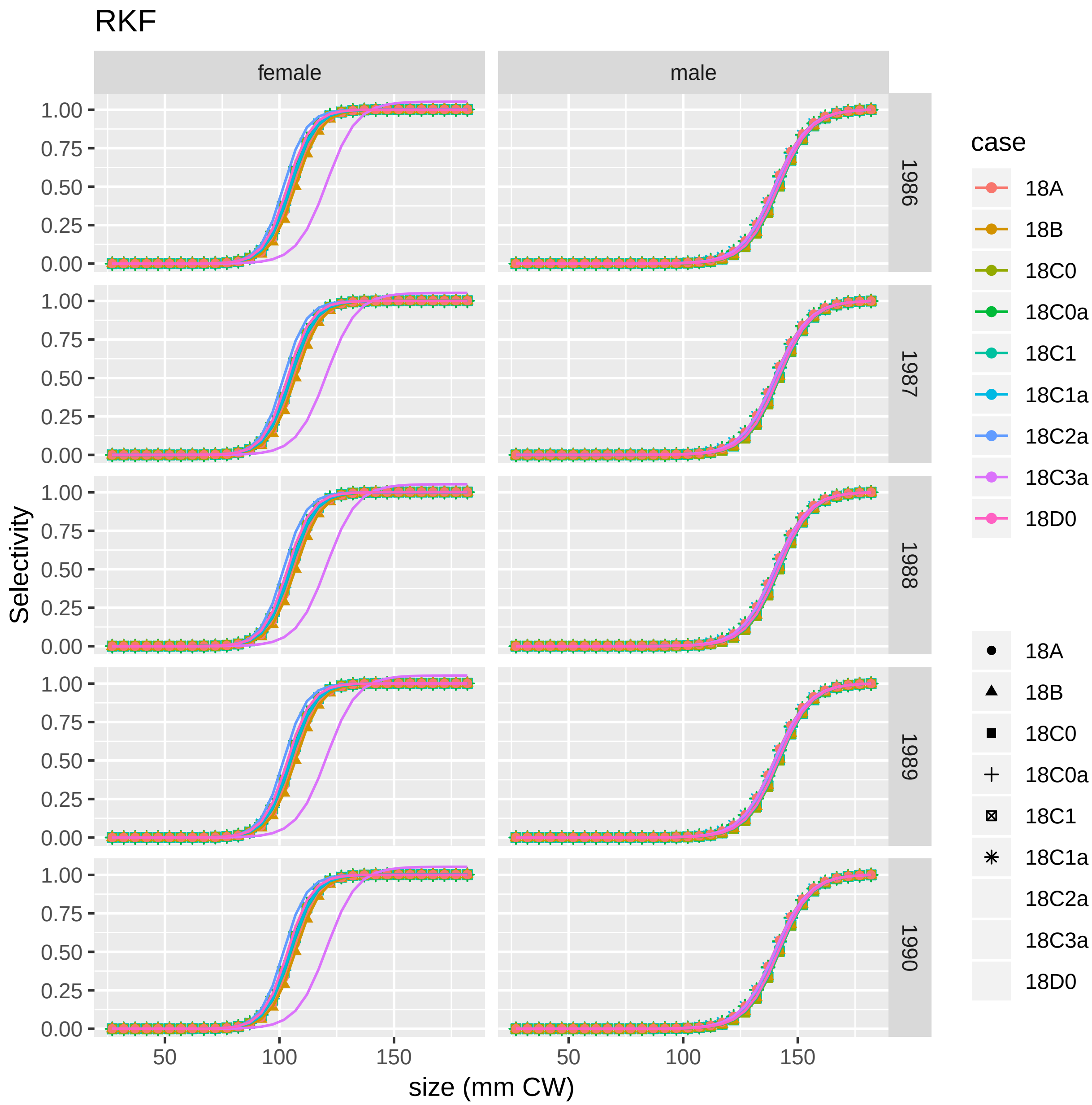

Figure 11: Selectivity functions for RKF(1 of 6).

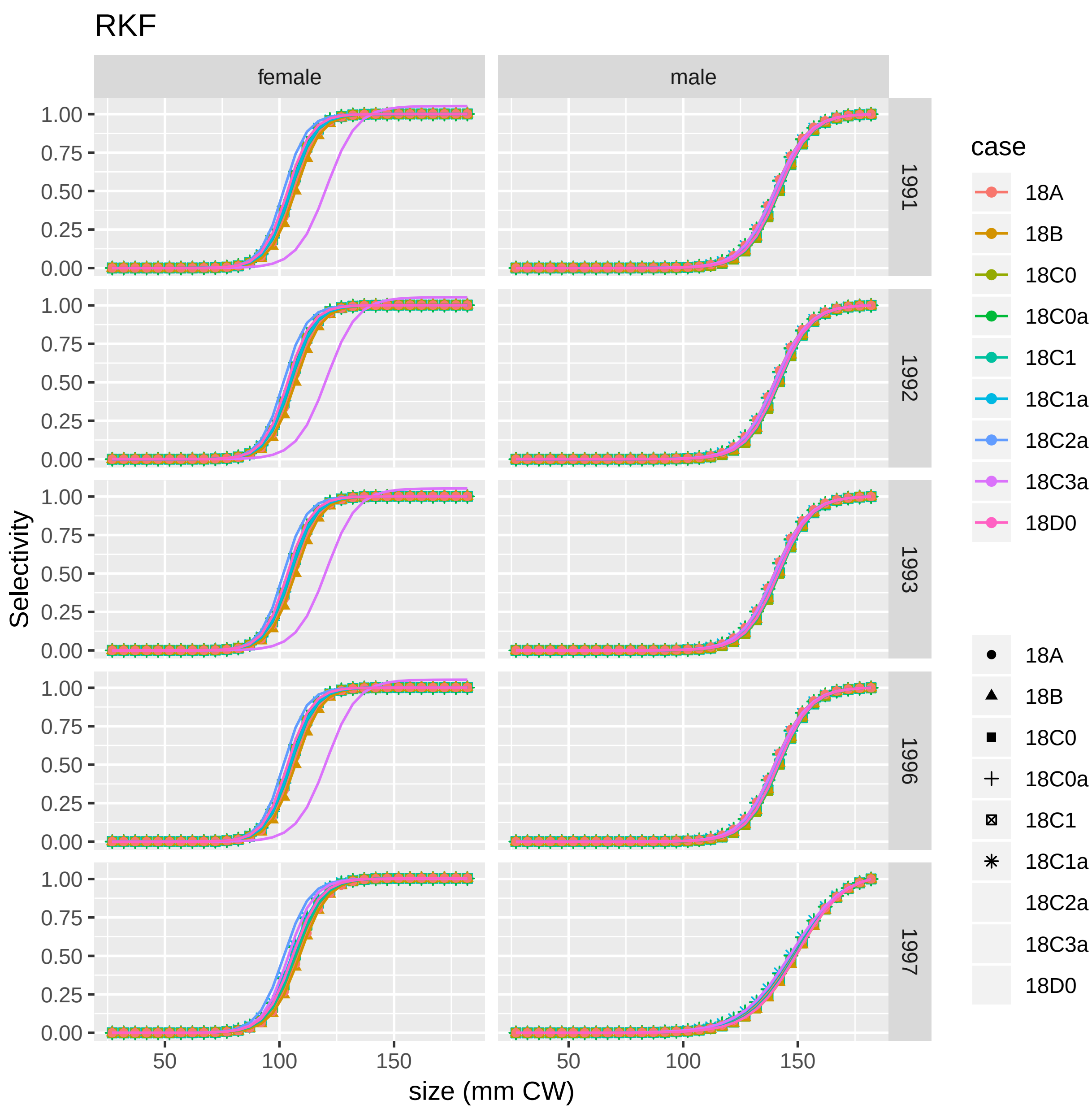

Figure 12: Selectivity functions for RKF(2 of 6).

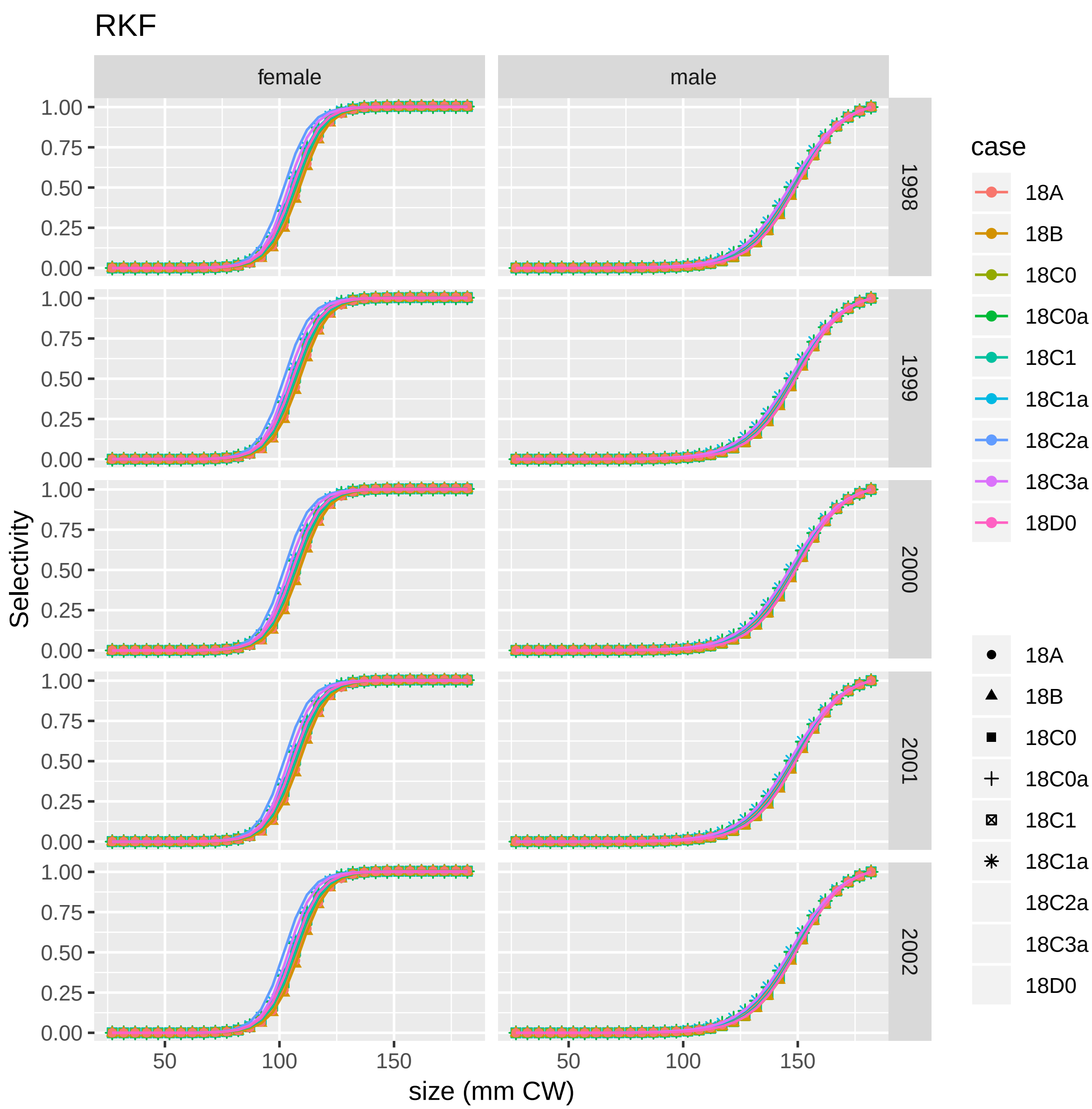

Figure 13: Selectivity functions for RKF(3 of 6).

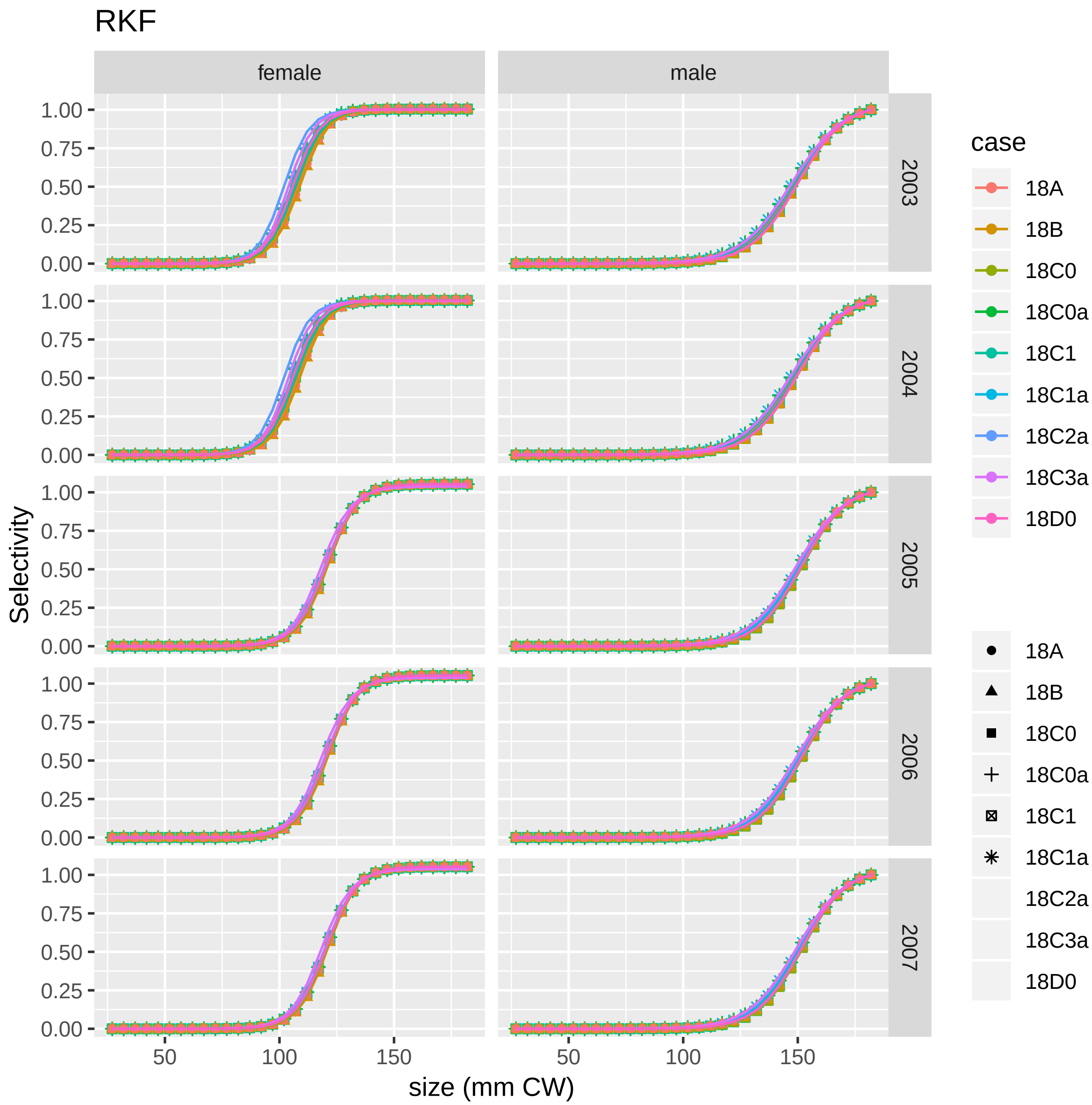

Figure 14: Selectivity functions for RKF(4 of 6).

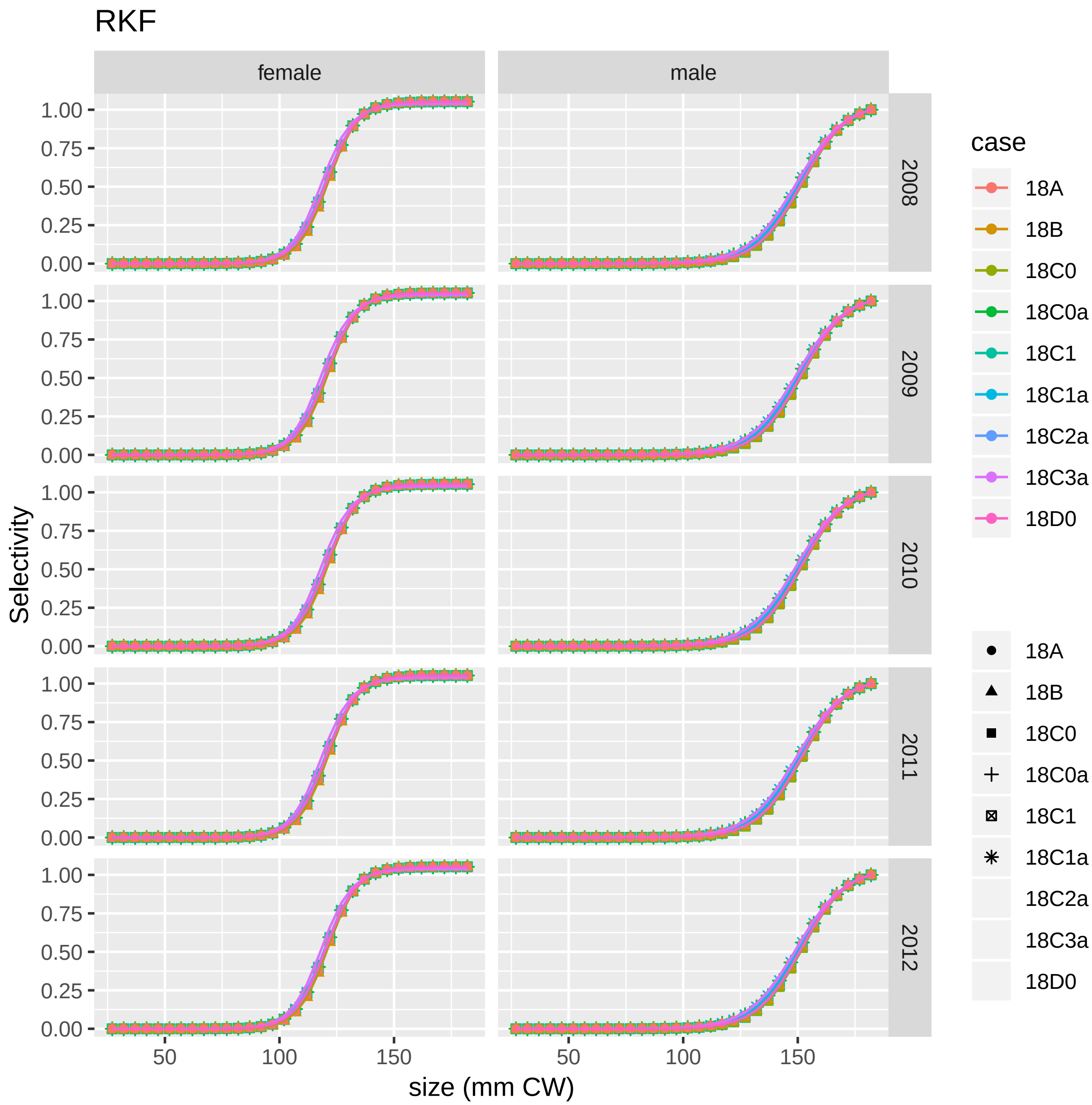

Figure 15: Selectivity functions for RKF(5 of 6).

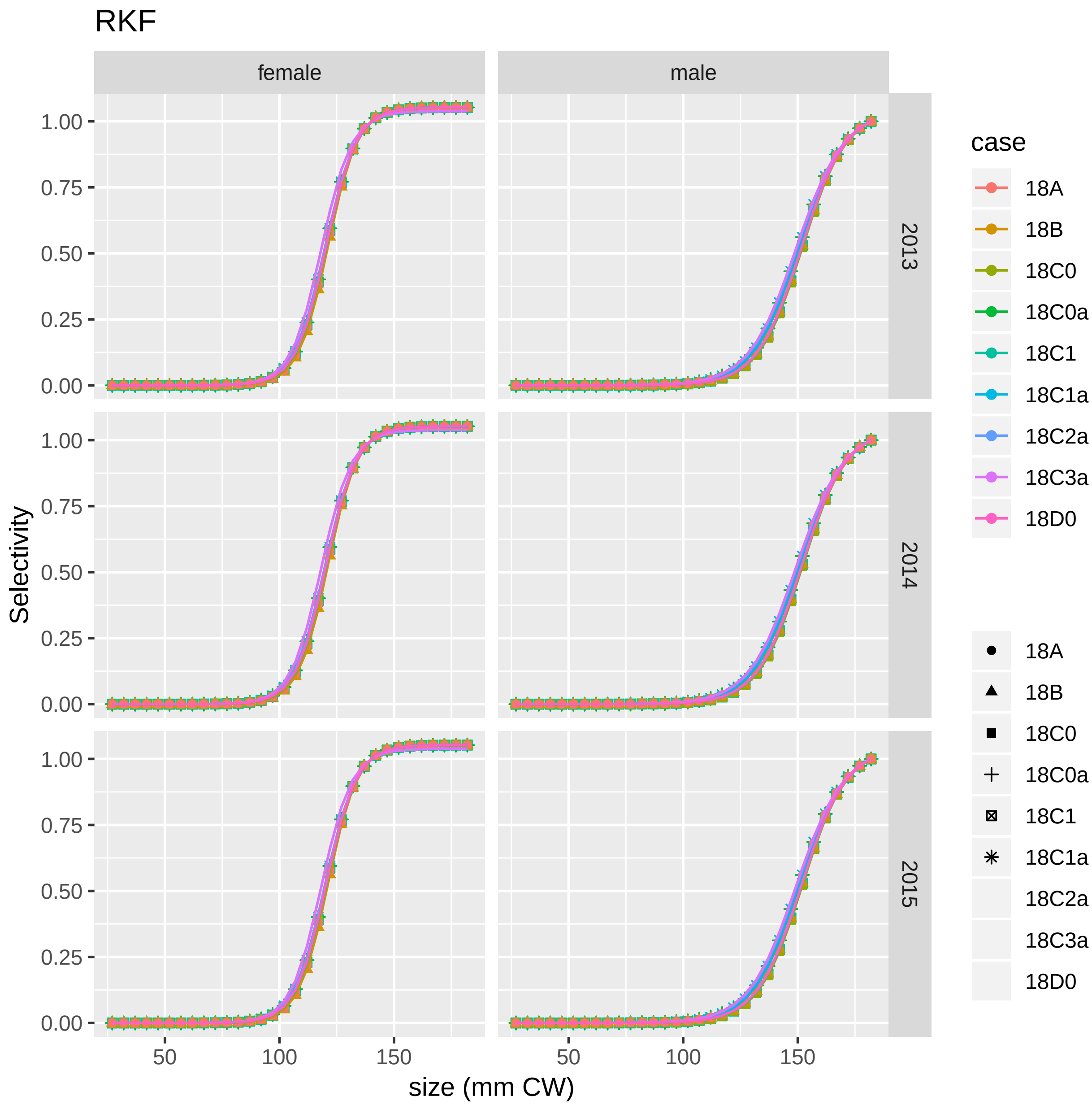

Figure 16: Selectivity functions for RKF(6 of 6).

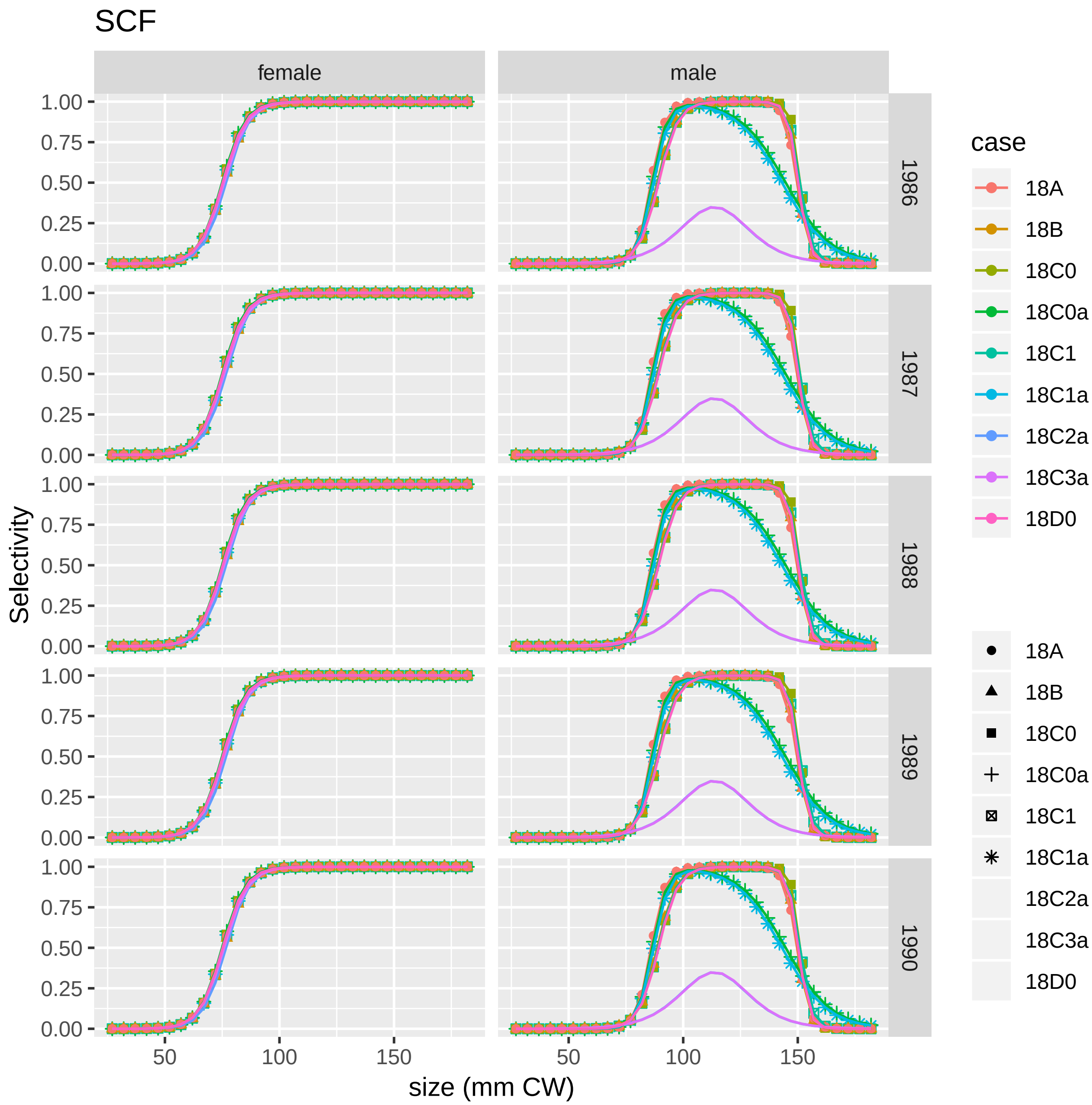

Figure 17: Selectivity functions for SCF(1 of 6).

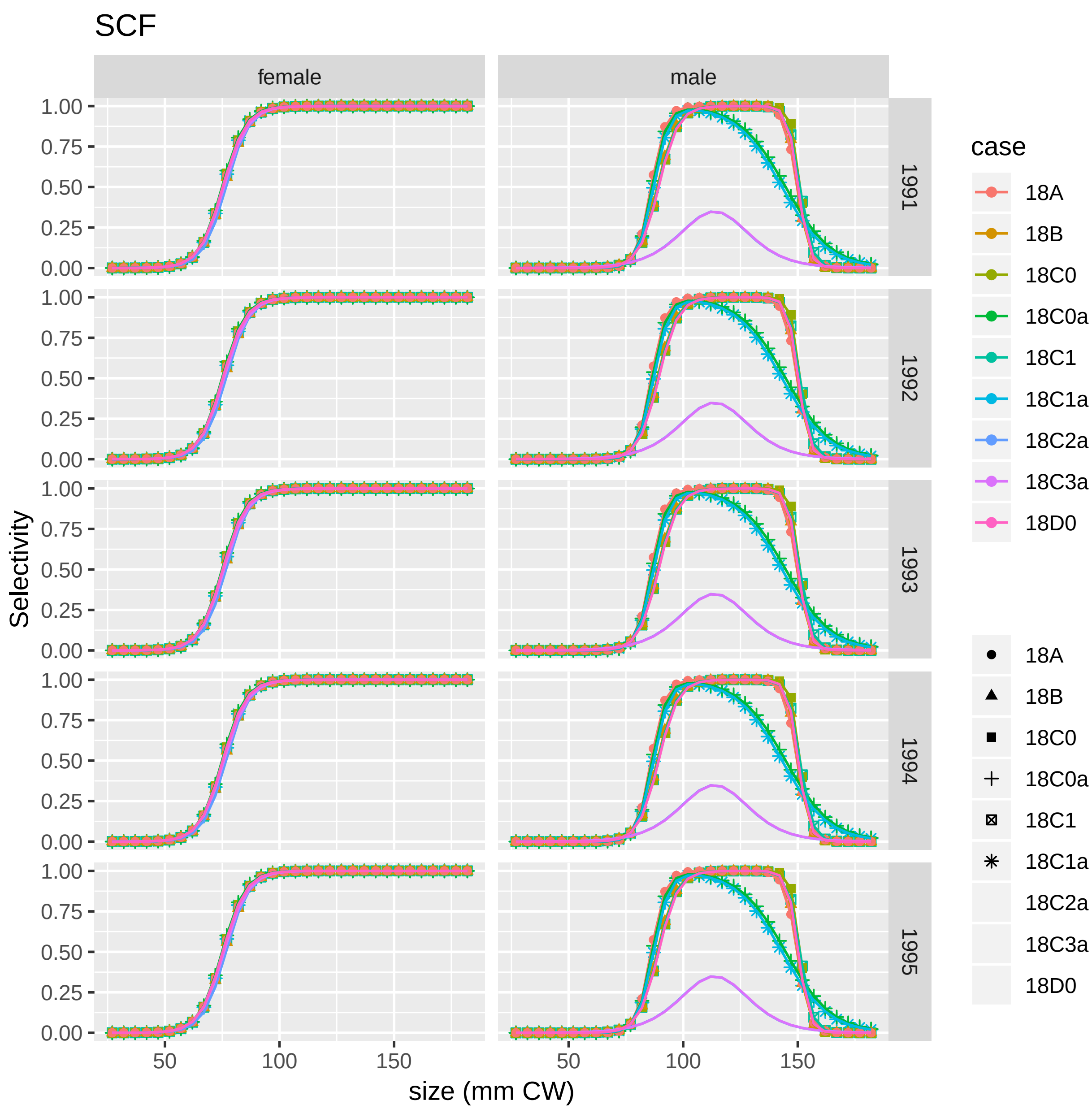

Figure 18: Selectivity functions for SCF(2 of 6).

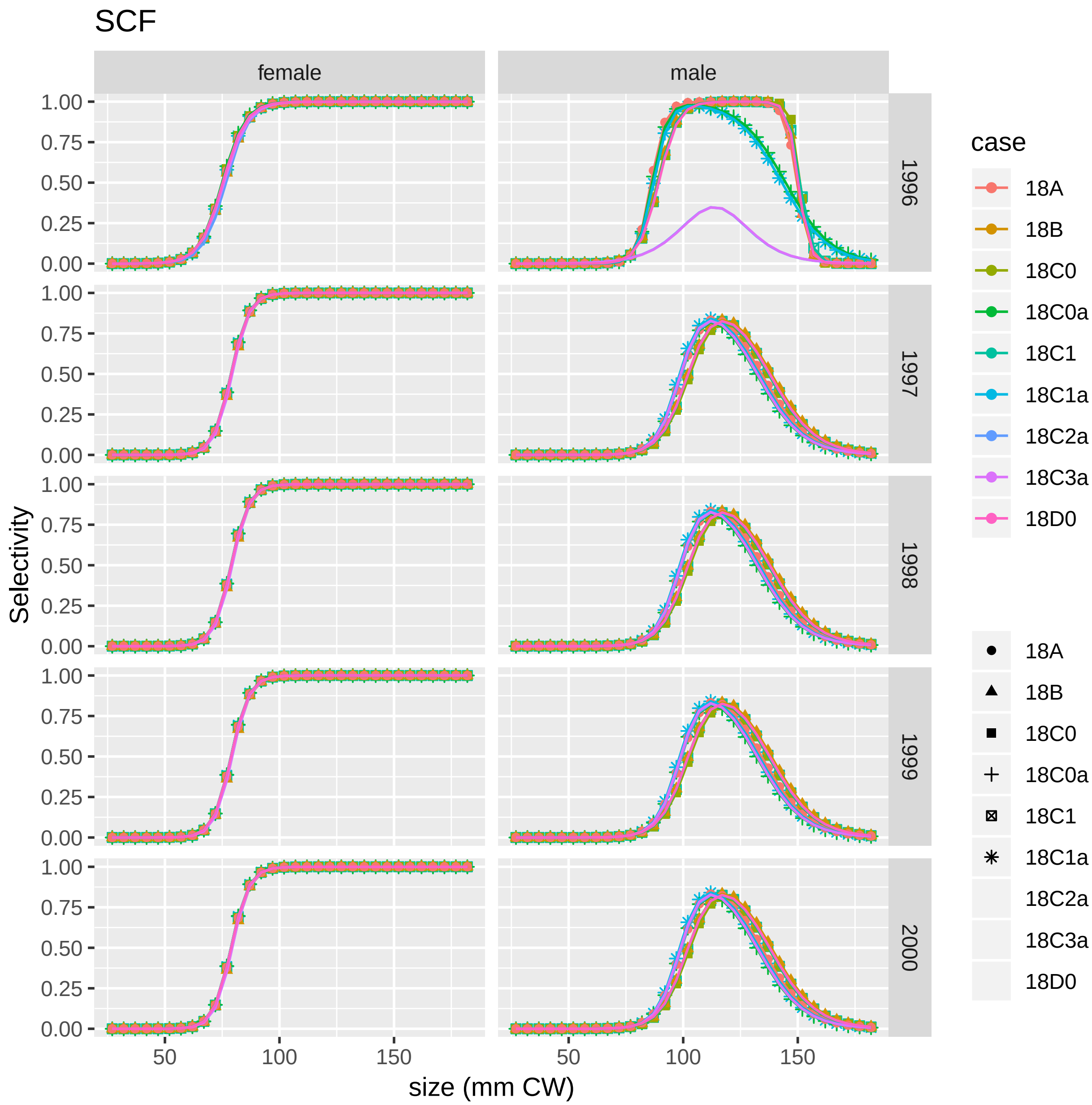

Figure 19: Selectivity functions for SCF(3 of 6).

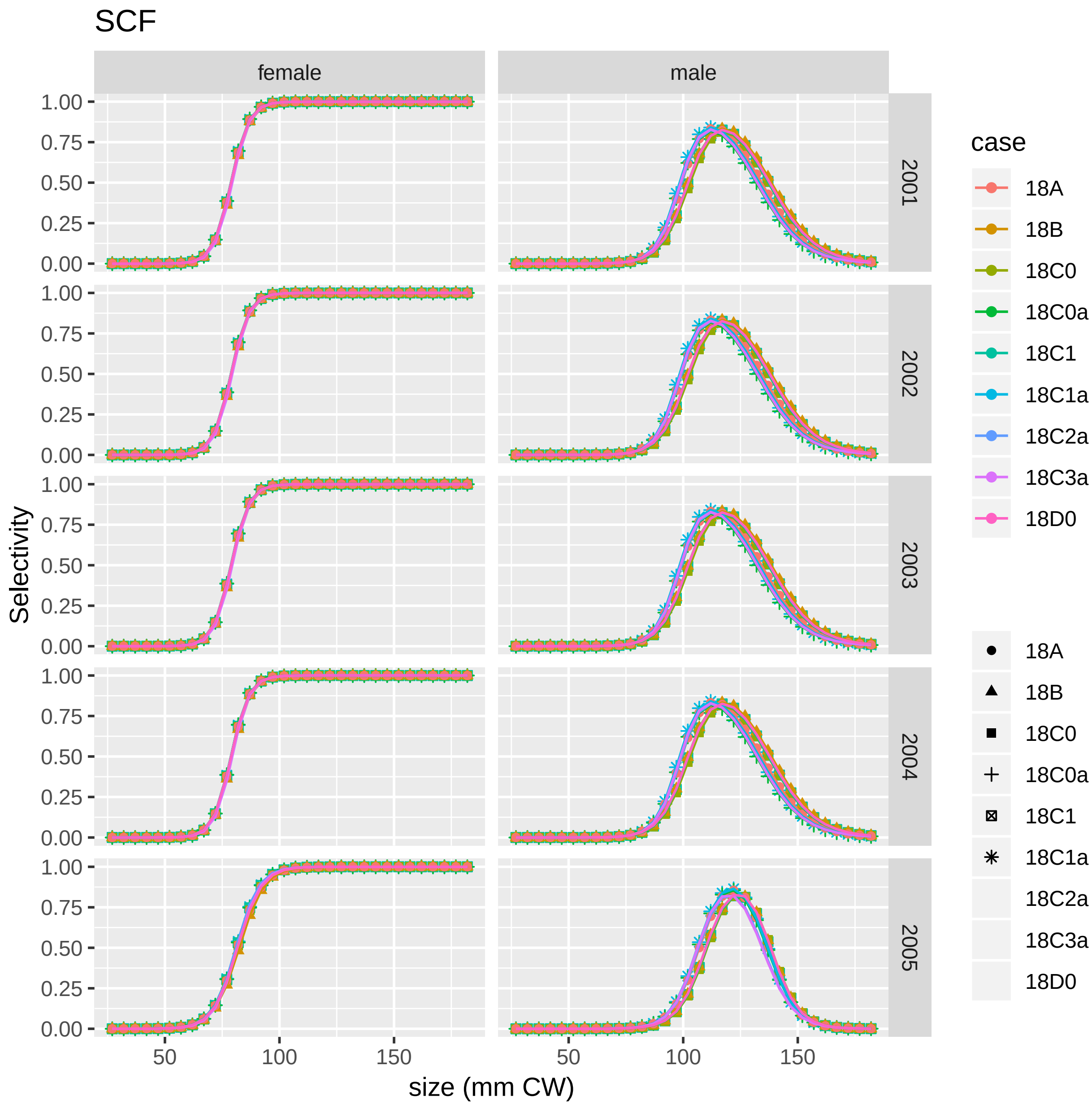

Figure 20: Selectivity functions for SCF(4 of 6).

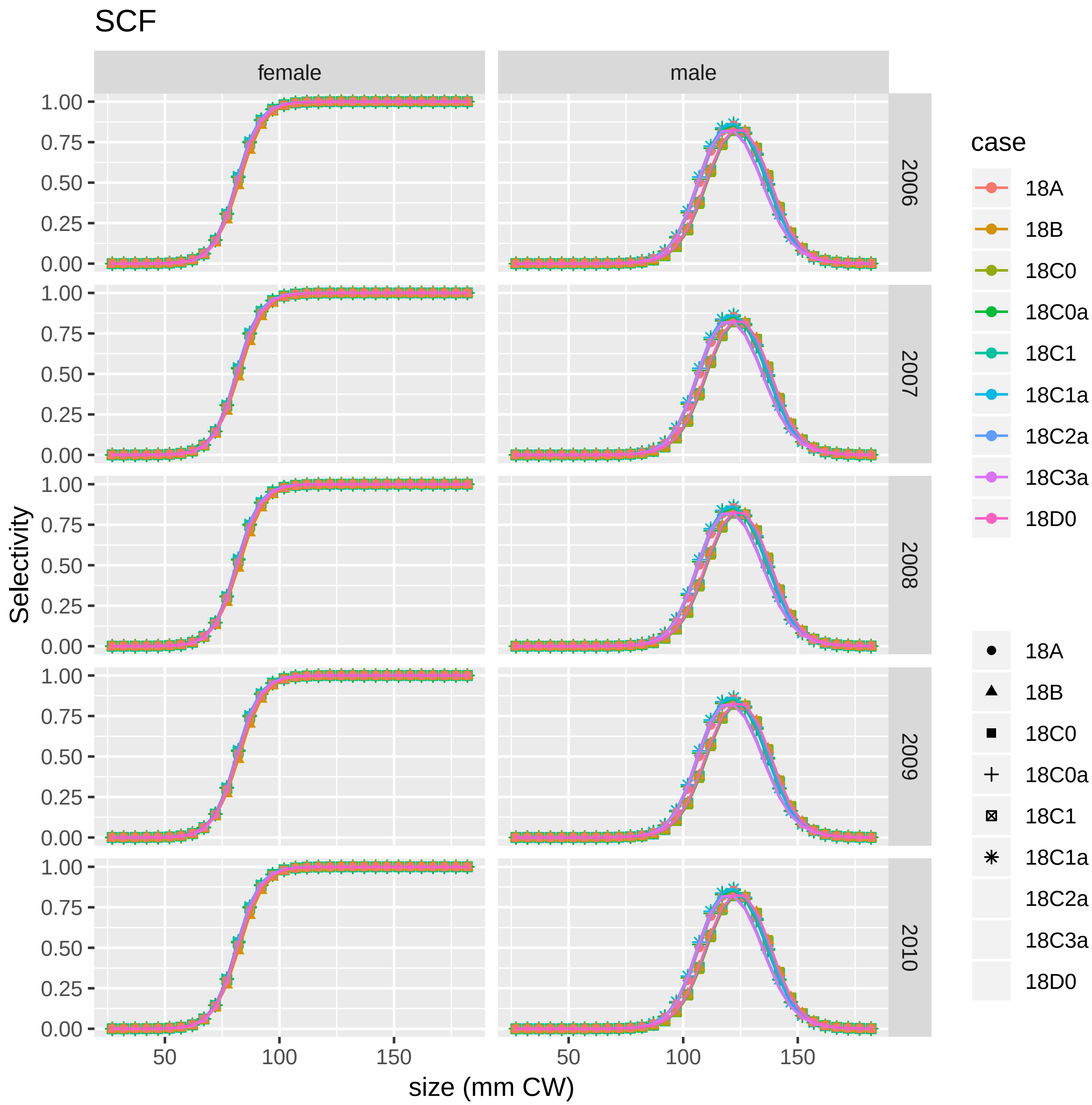

Figure 21: Selectivity functions for SCF(5 of 6).

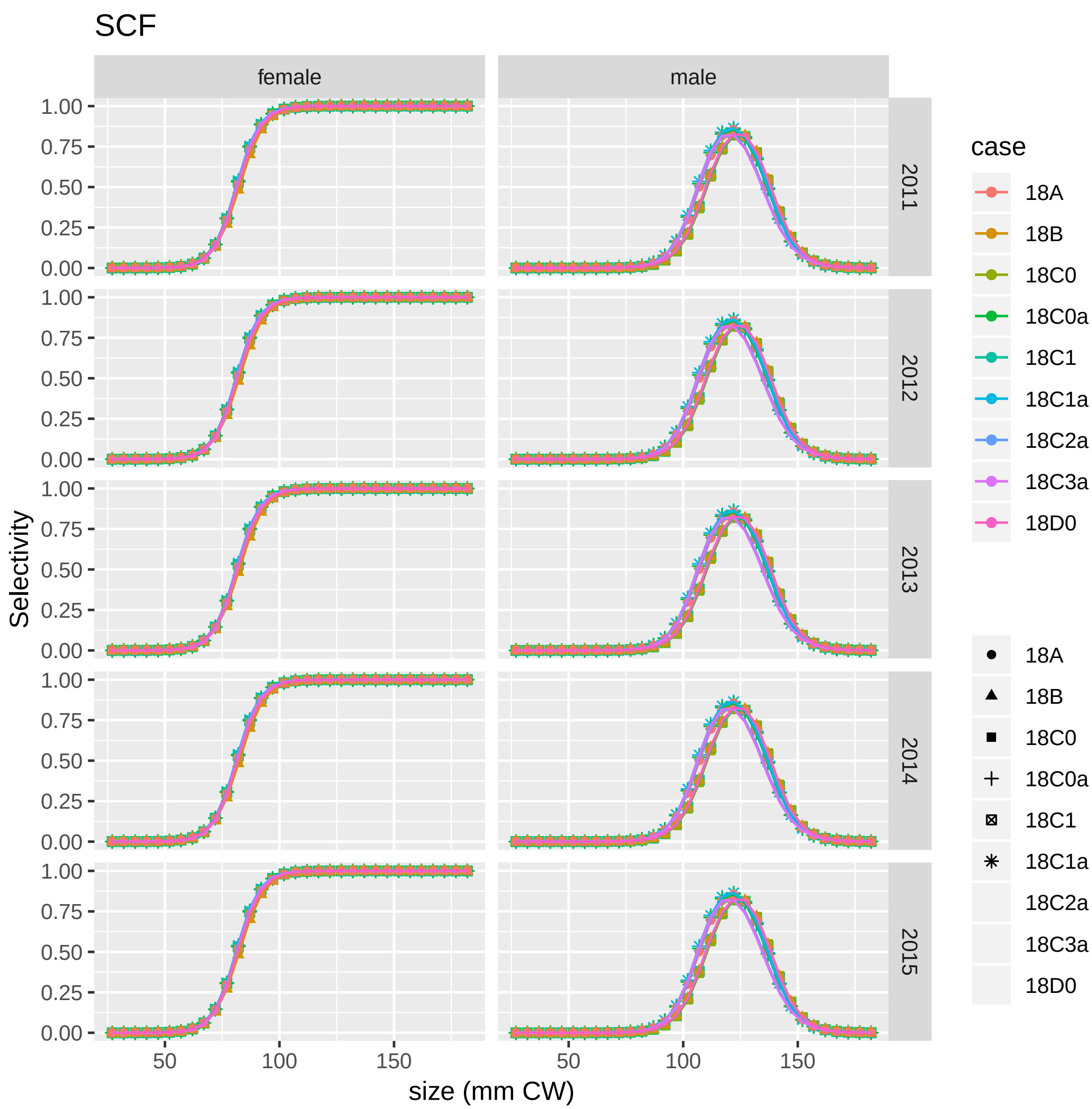

Figure 22: Selectivity functions for SCF(6 of 6).

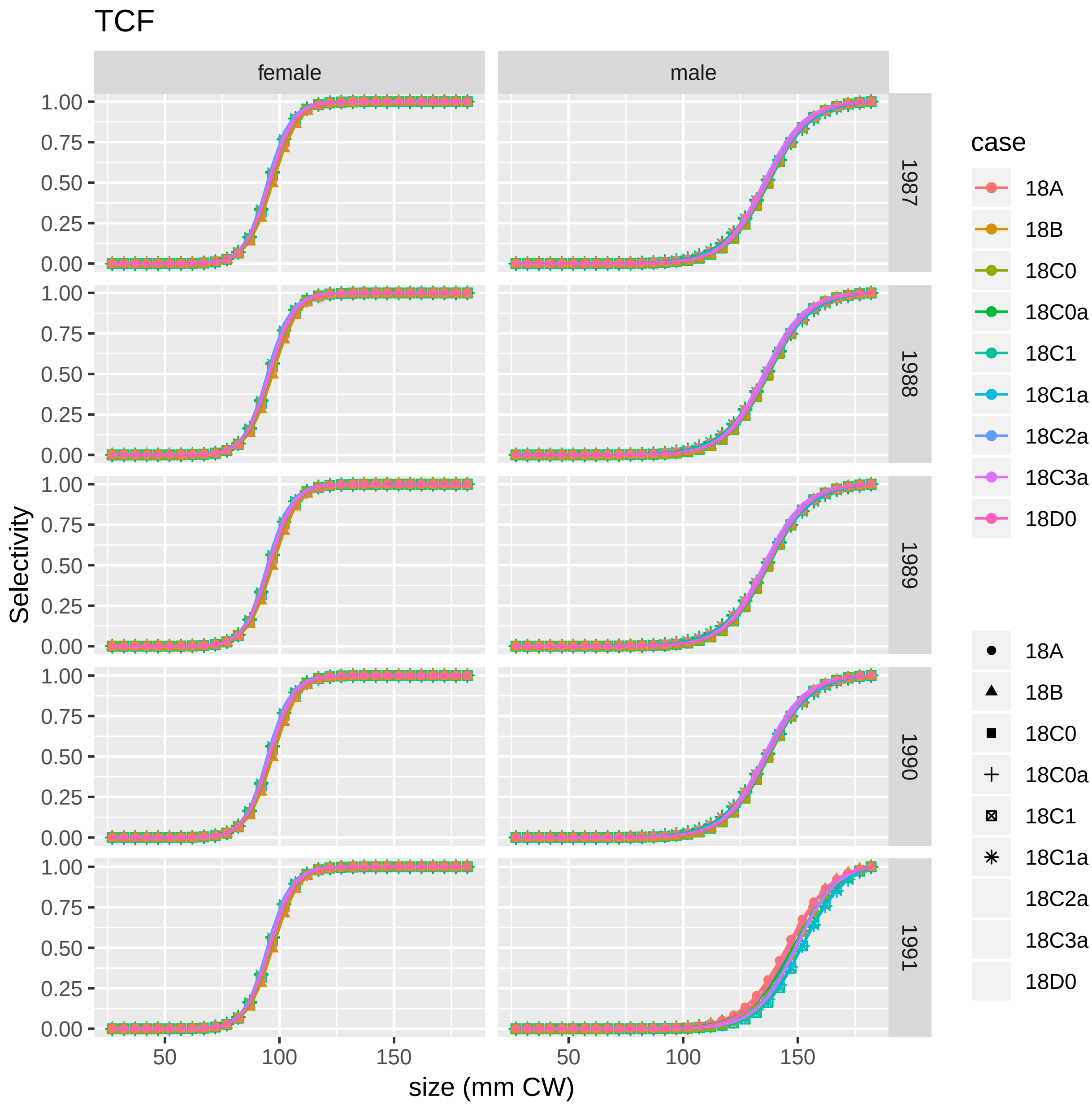

Figure 23: Selectivity functions for TCF(1 of 4).

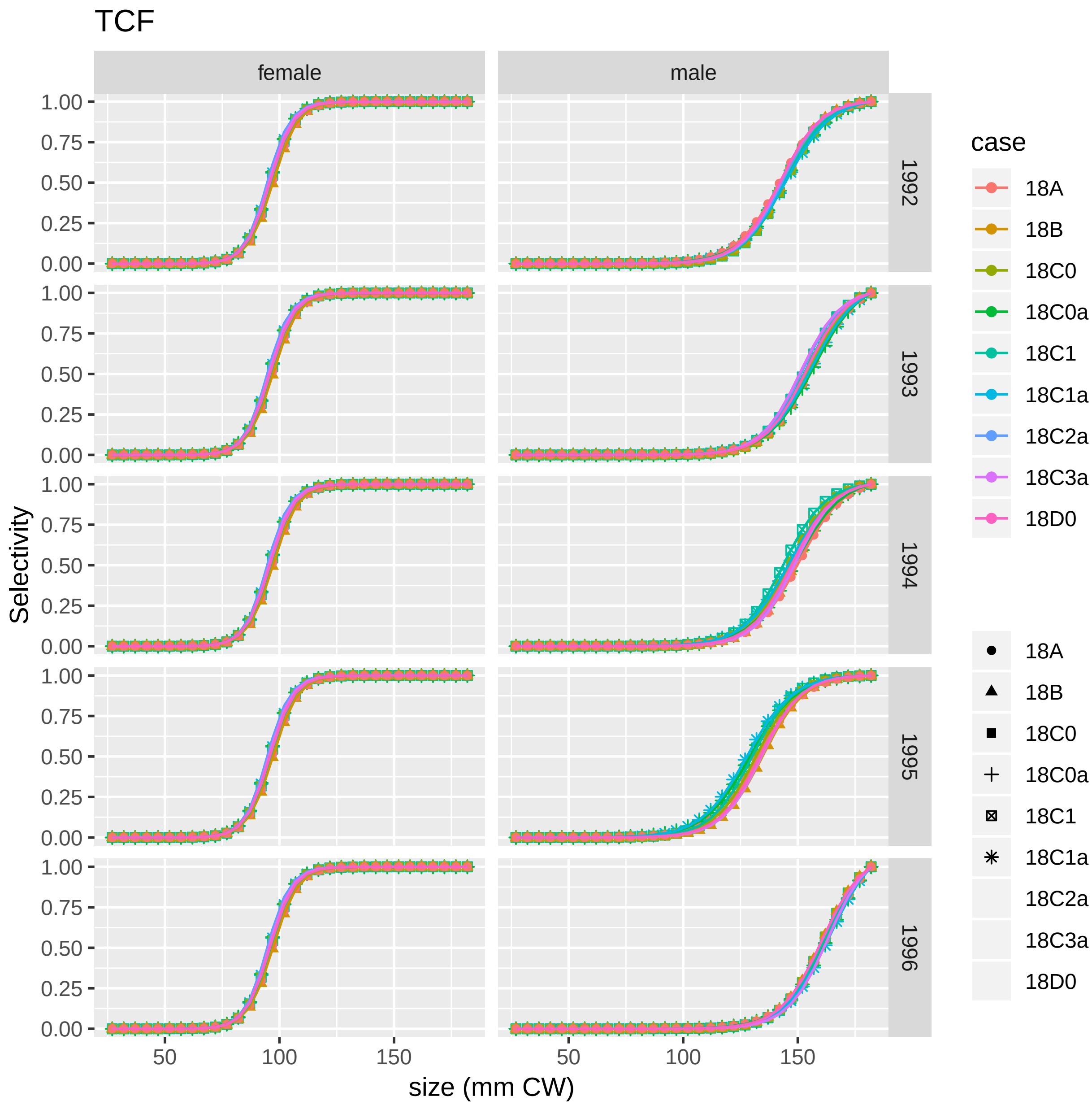

Figure 24: Selectivity functions for TCF(2 of 4).

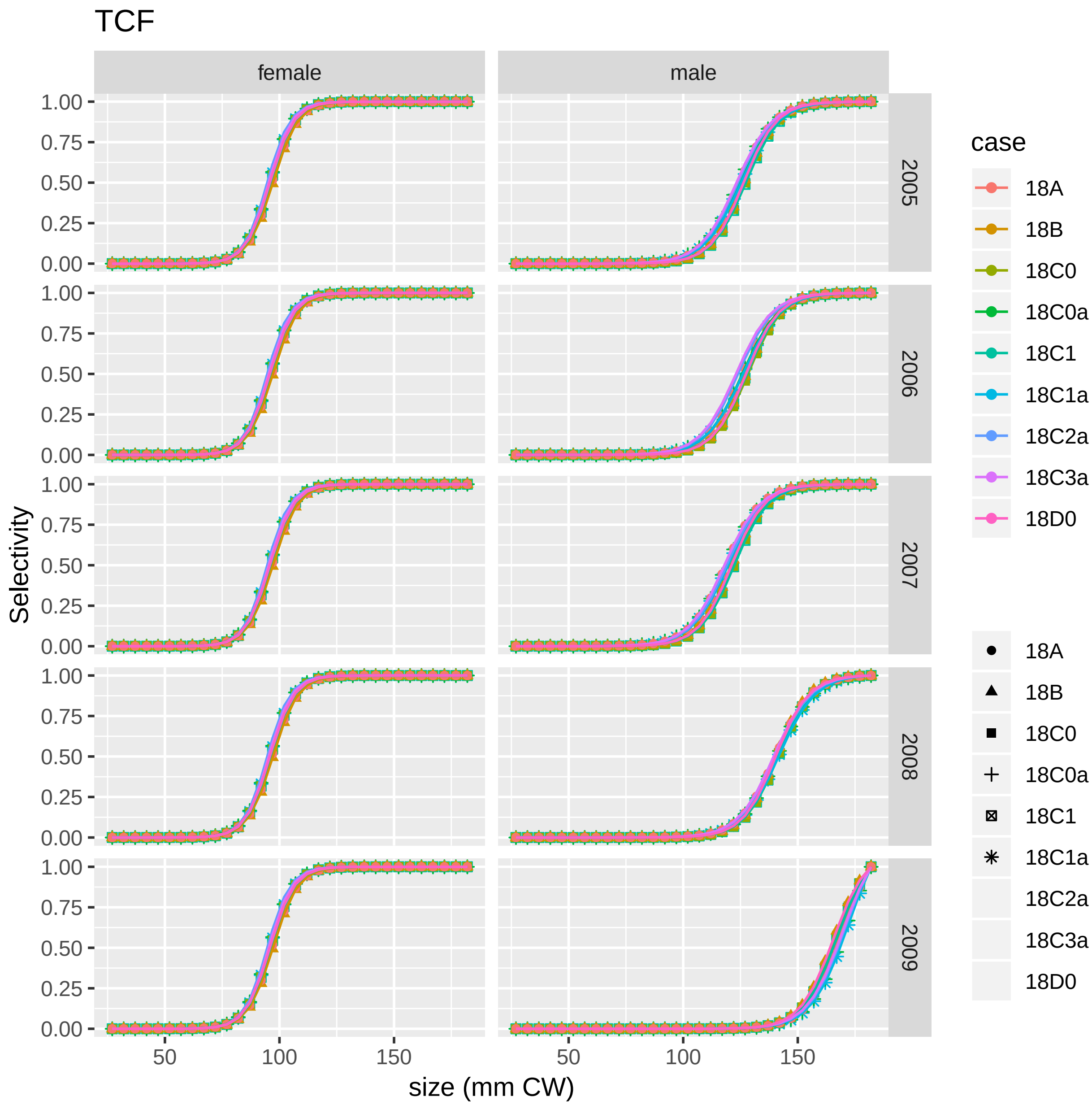

Figure 25: Selectivity functions for TCF(3 of 4).

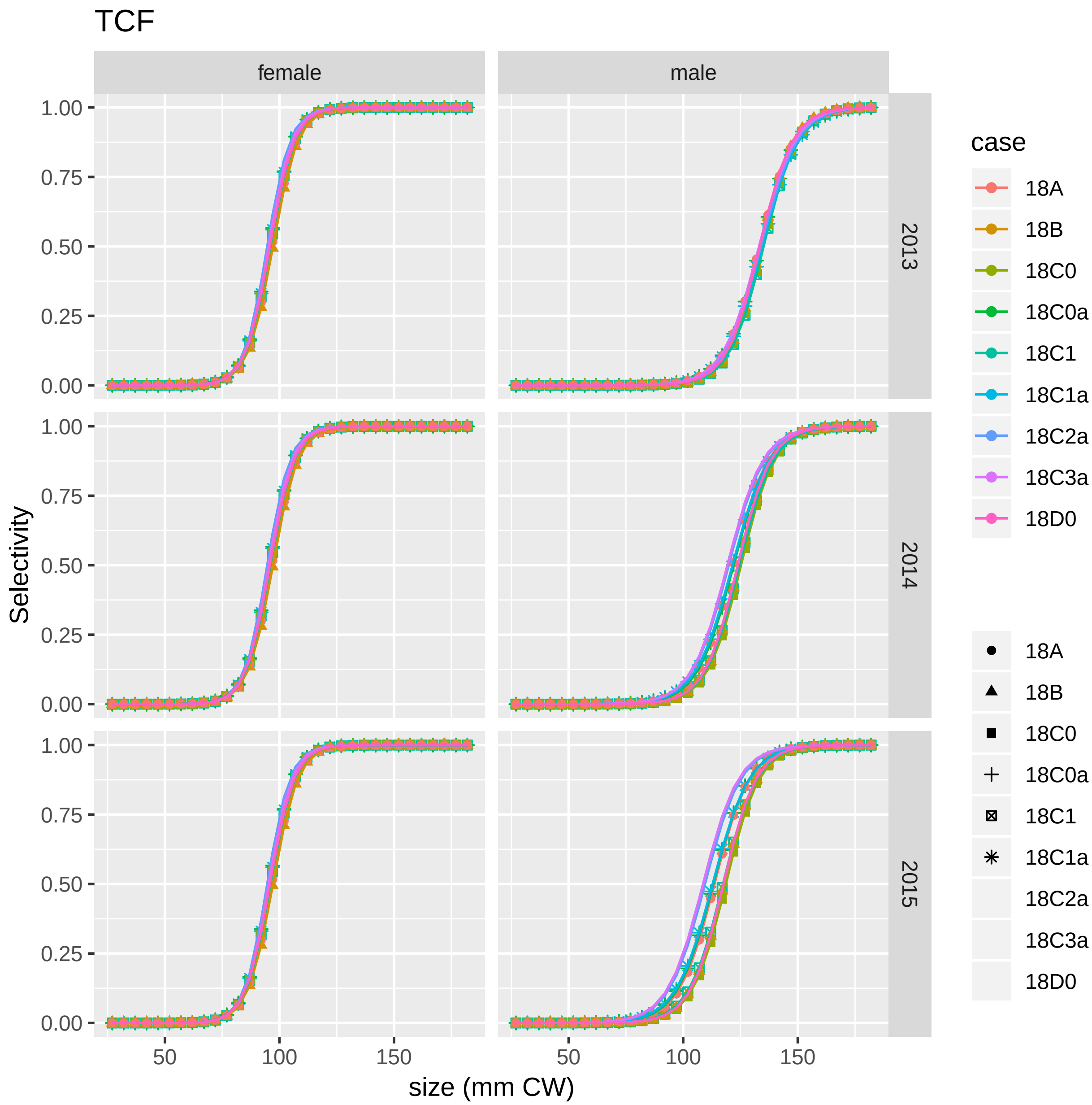

Figure 26: Selectivity functions for TCF(4 of 4).

Retention functions

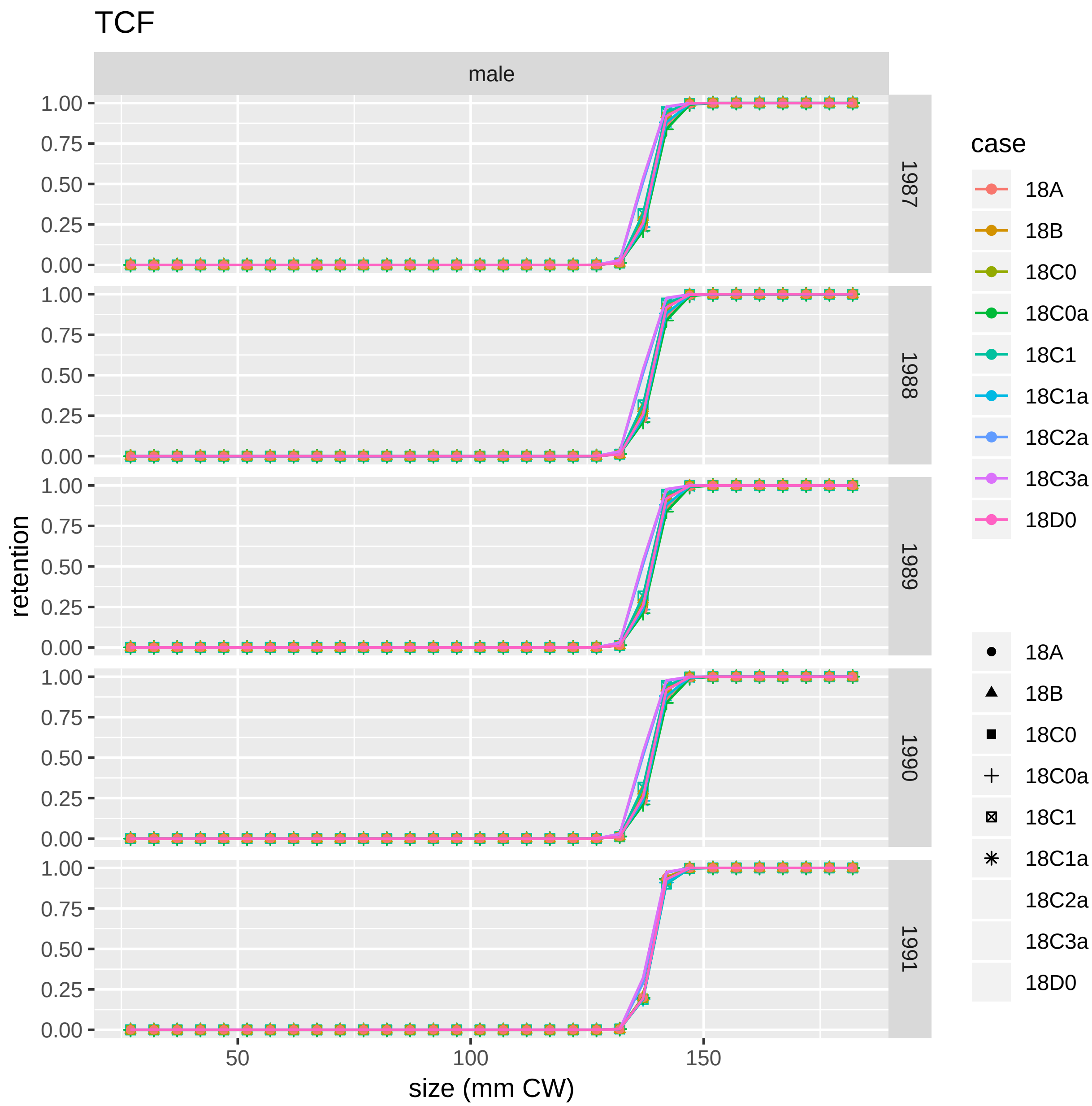

Figure 27: Retention functions for TCF(1 of 4).

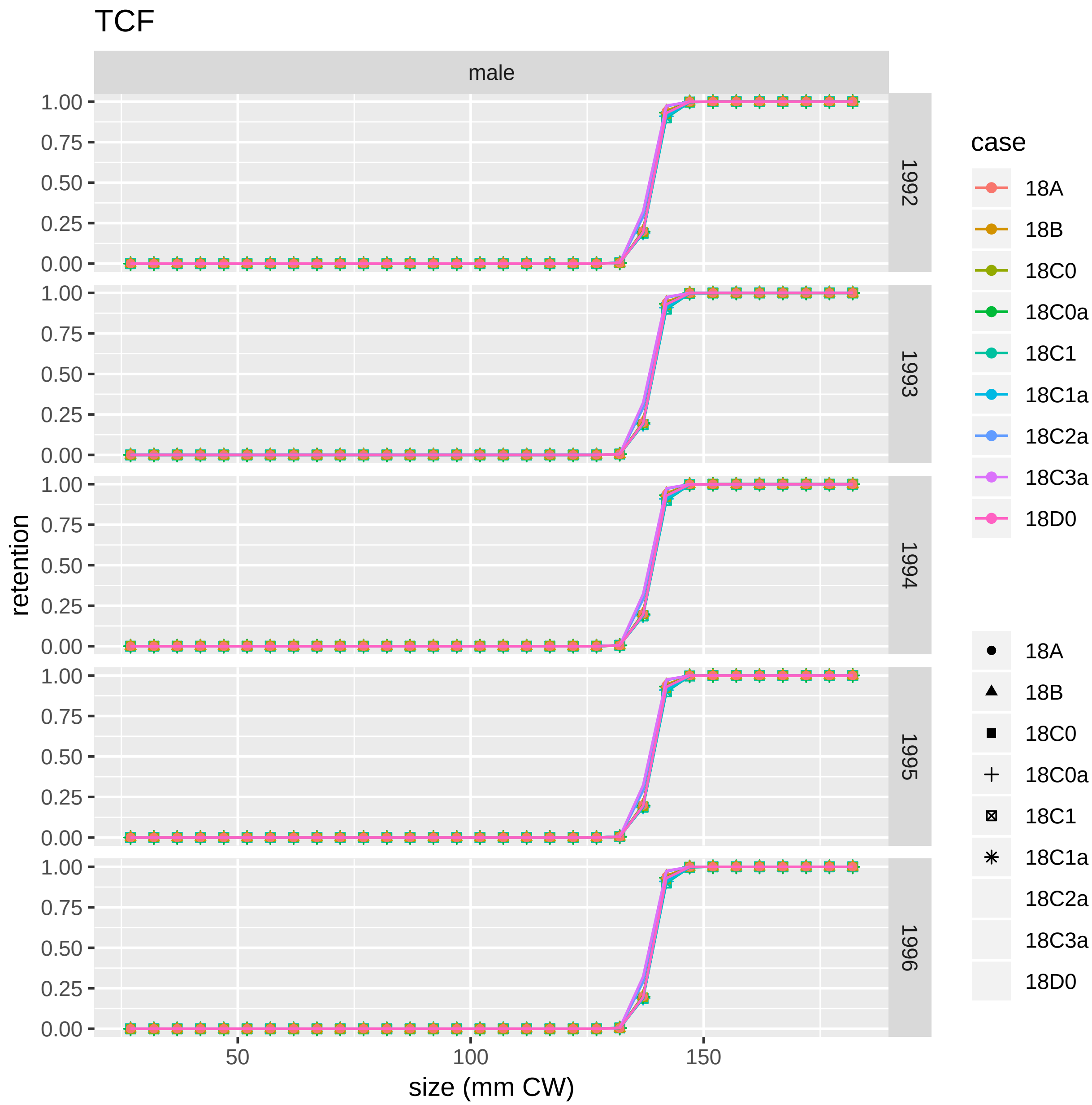

Figure 28: Retention functions for TCF(2 of 4).

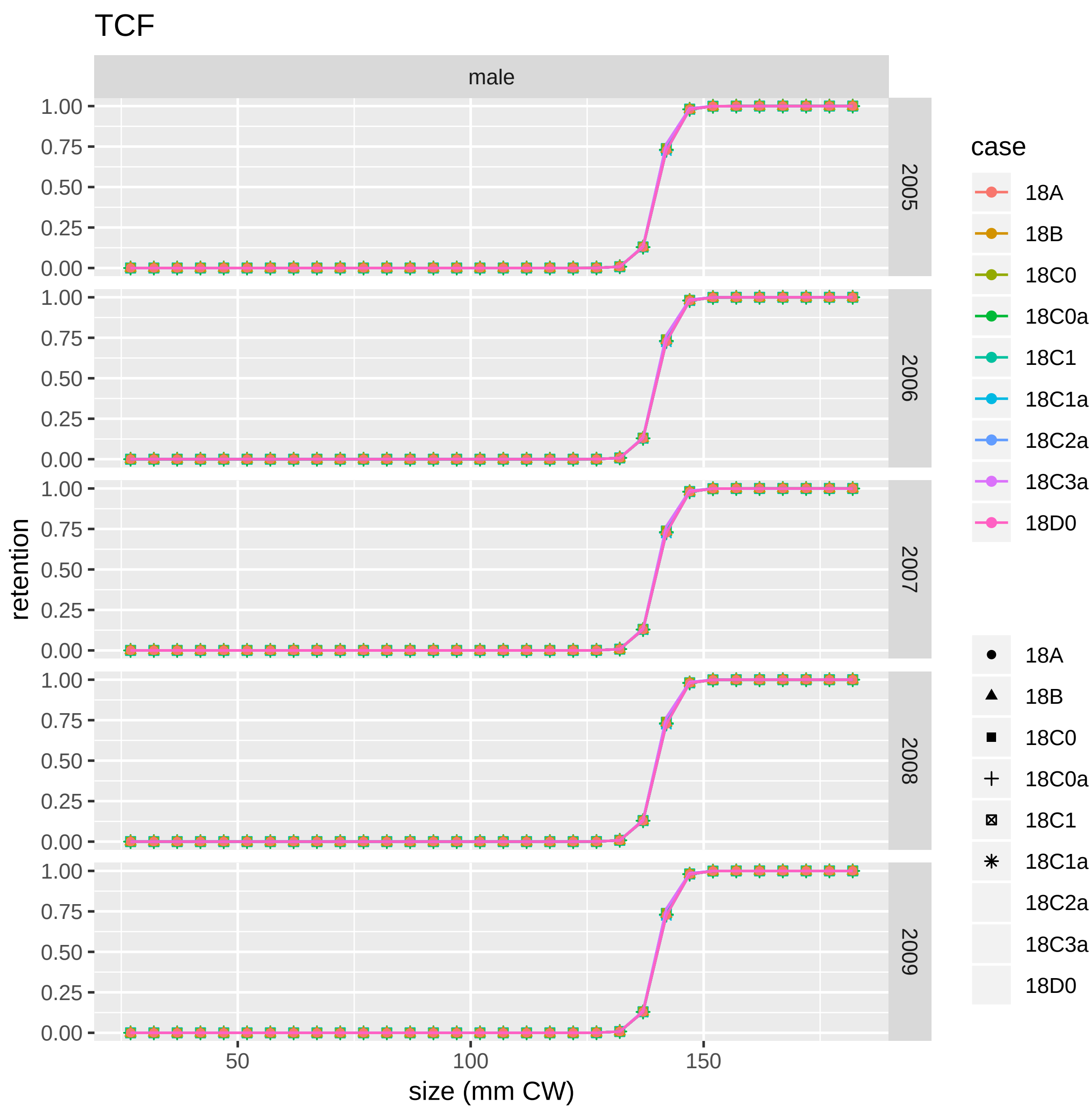

Figure 29: Retention functions for TCF(3 of 4).

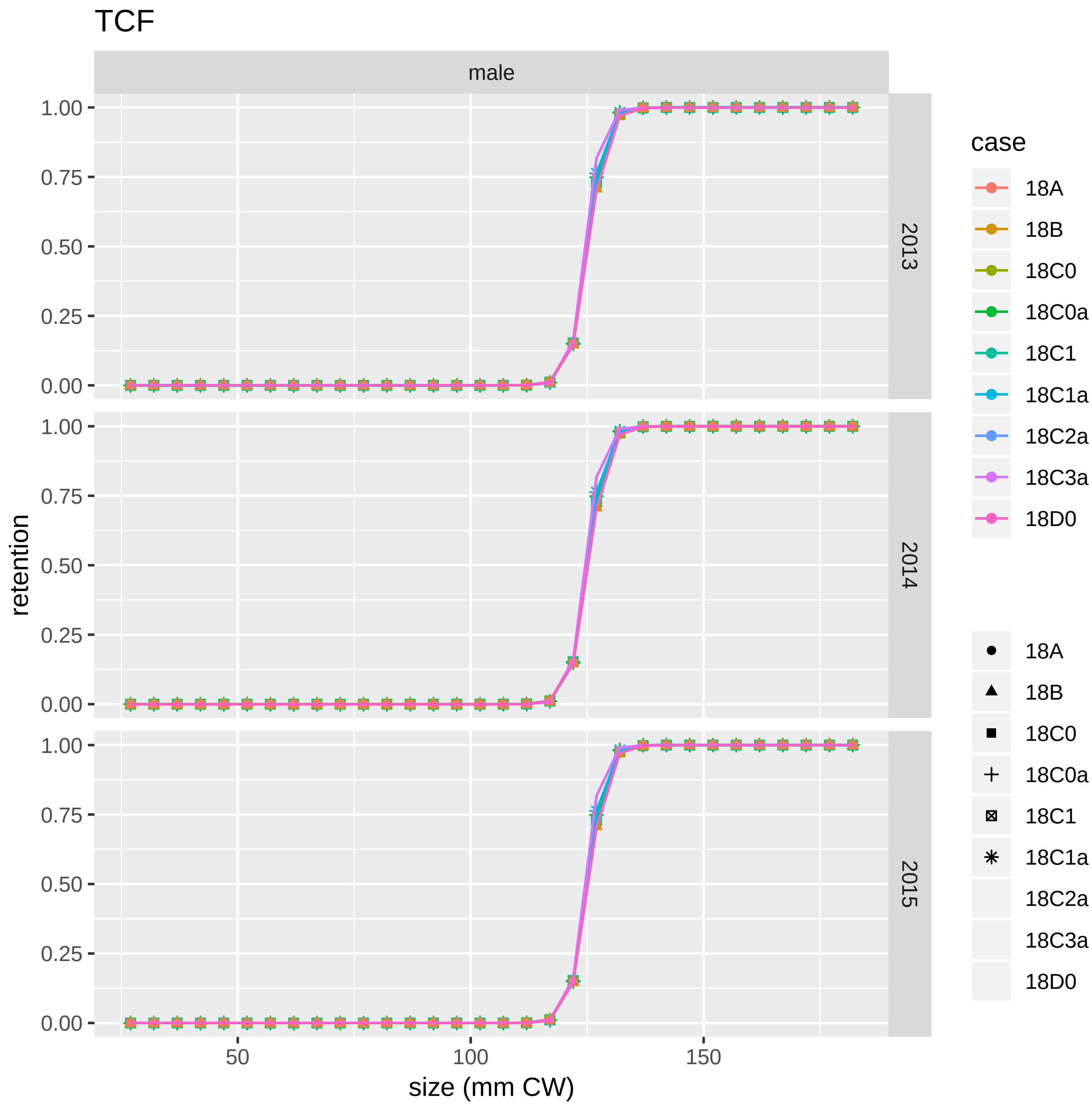

Figure 30: Retention functions for TCF(4 of 4).

Appendix J:
Population Quantities **from** 17AM **and** 18C2a

William Stockhausen

04 September, 2018

Contents

Population quantities

Figures and tables in this section present comparisons between alternative model scenarios for estimated quantities (e.g., recruitment, abundance time series) describing the inferred Tanner crab population.

Recruitment

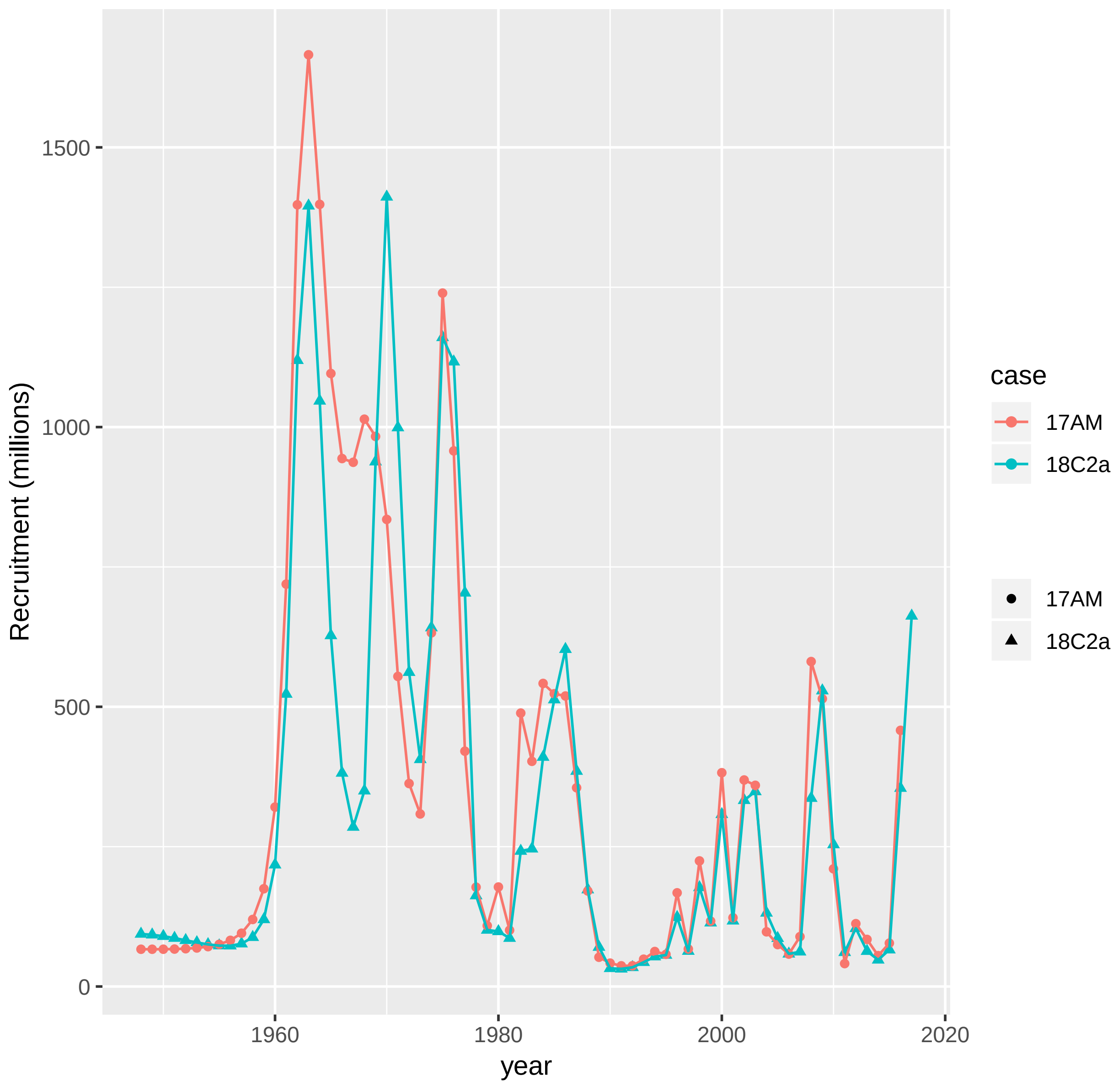

Figure 1: Estimated annual recruitment.

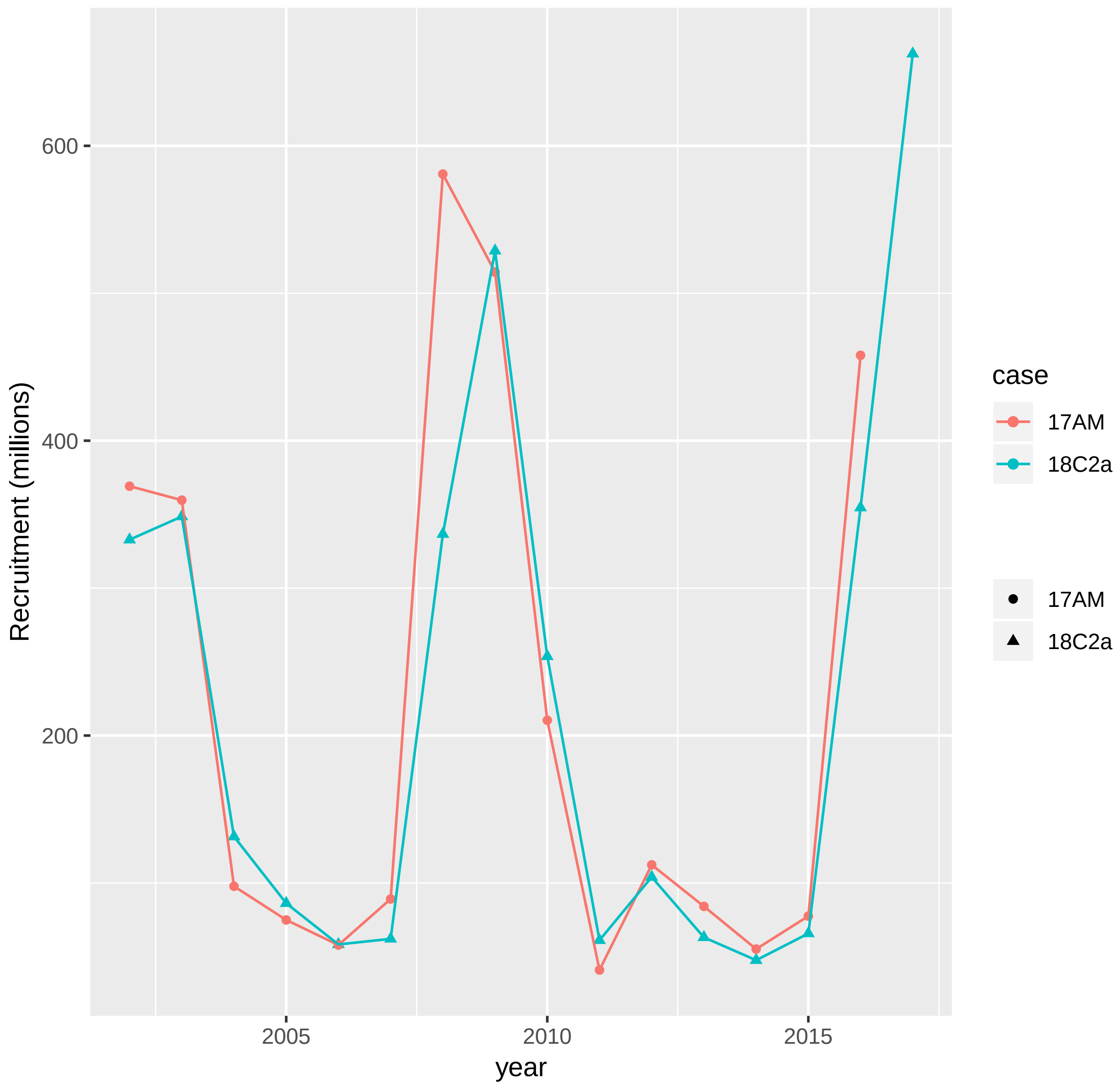

Figure 2: Estimated recent recruitment.

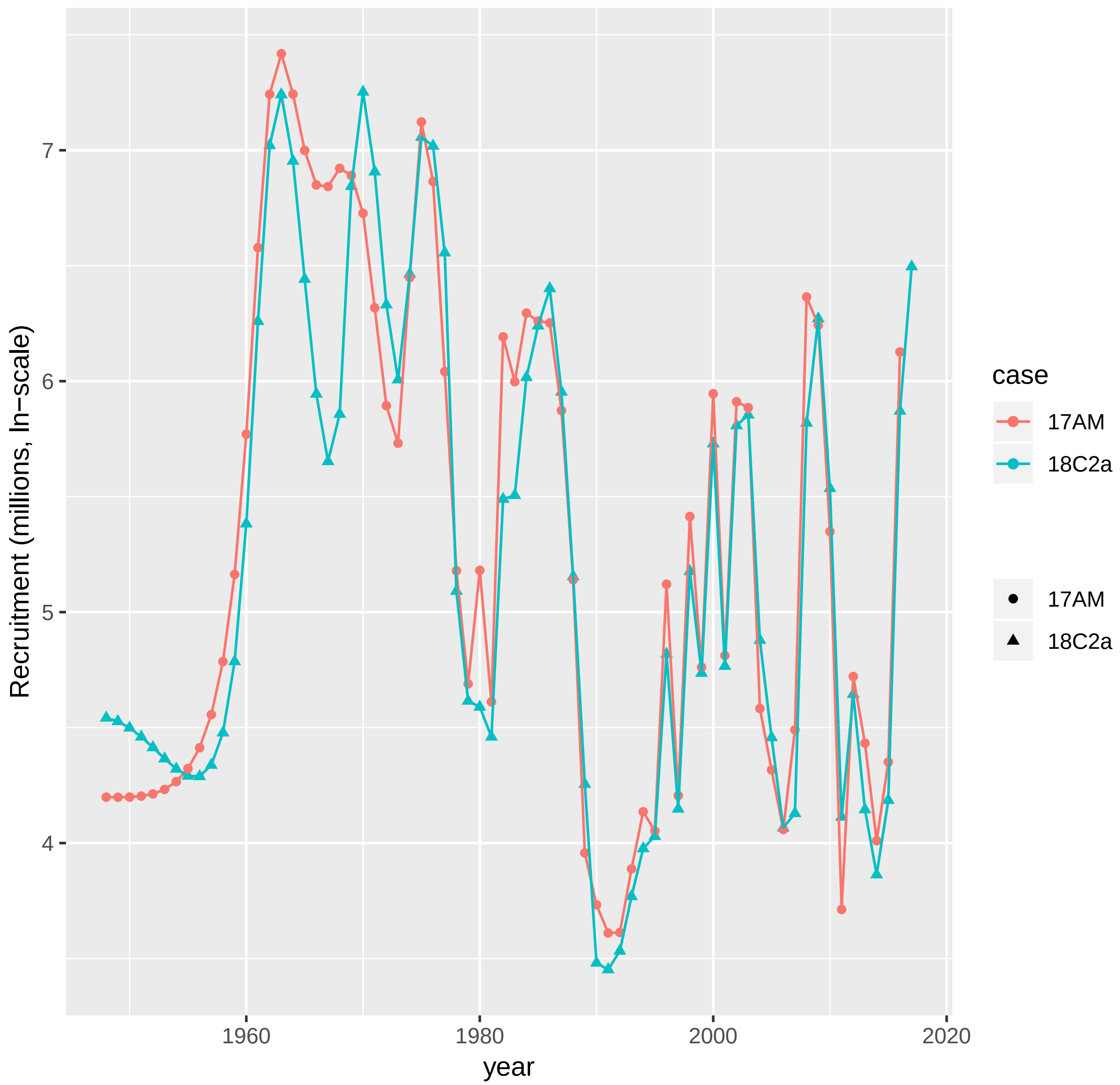

Figure 3: Estimated annual recruitment, on ln-scale.

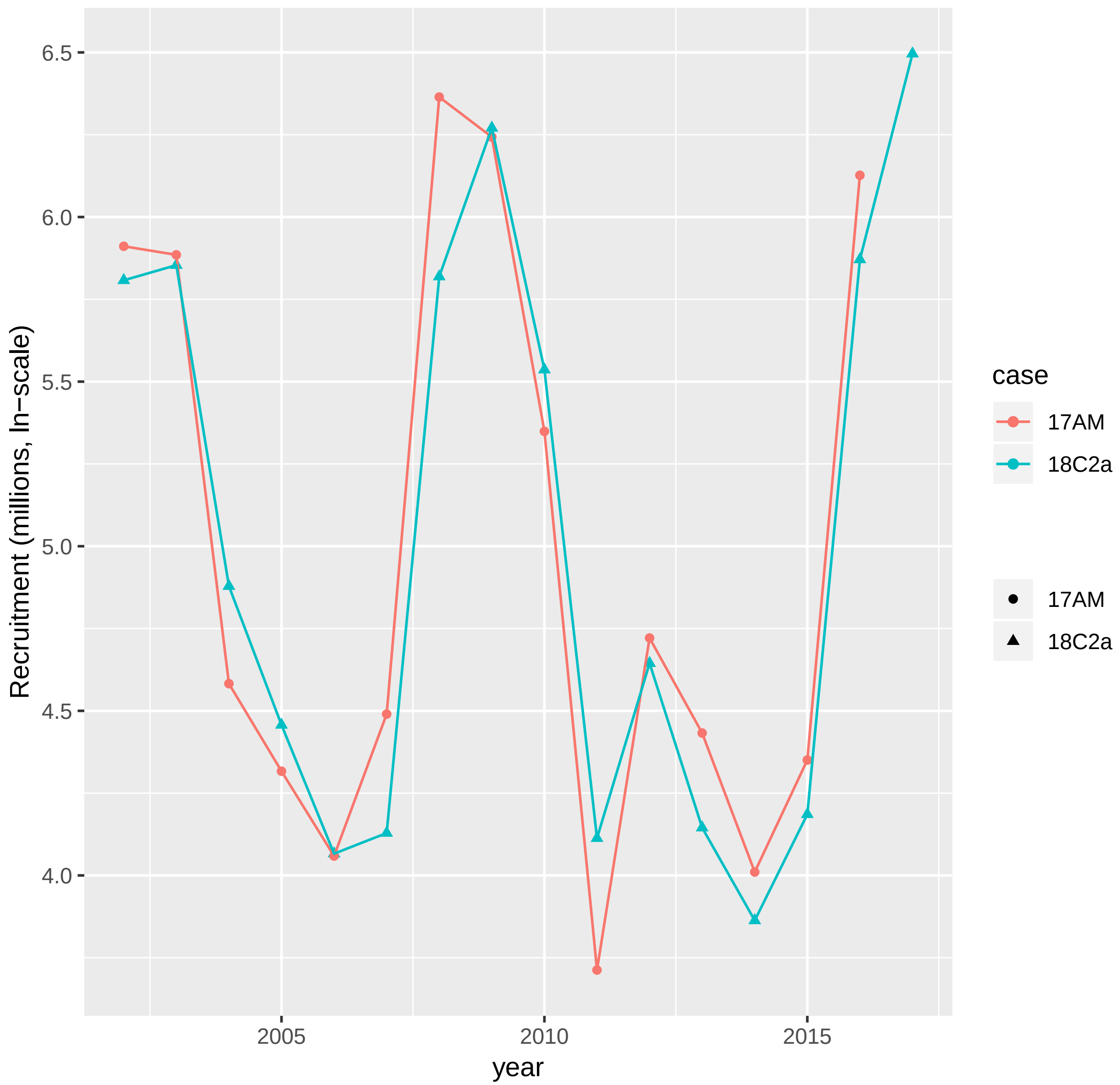

Figure 4: Estimated recent recruitment, on ln-scale.

Mature biomass

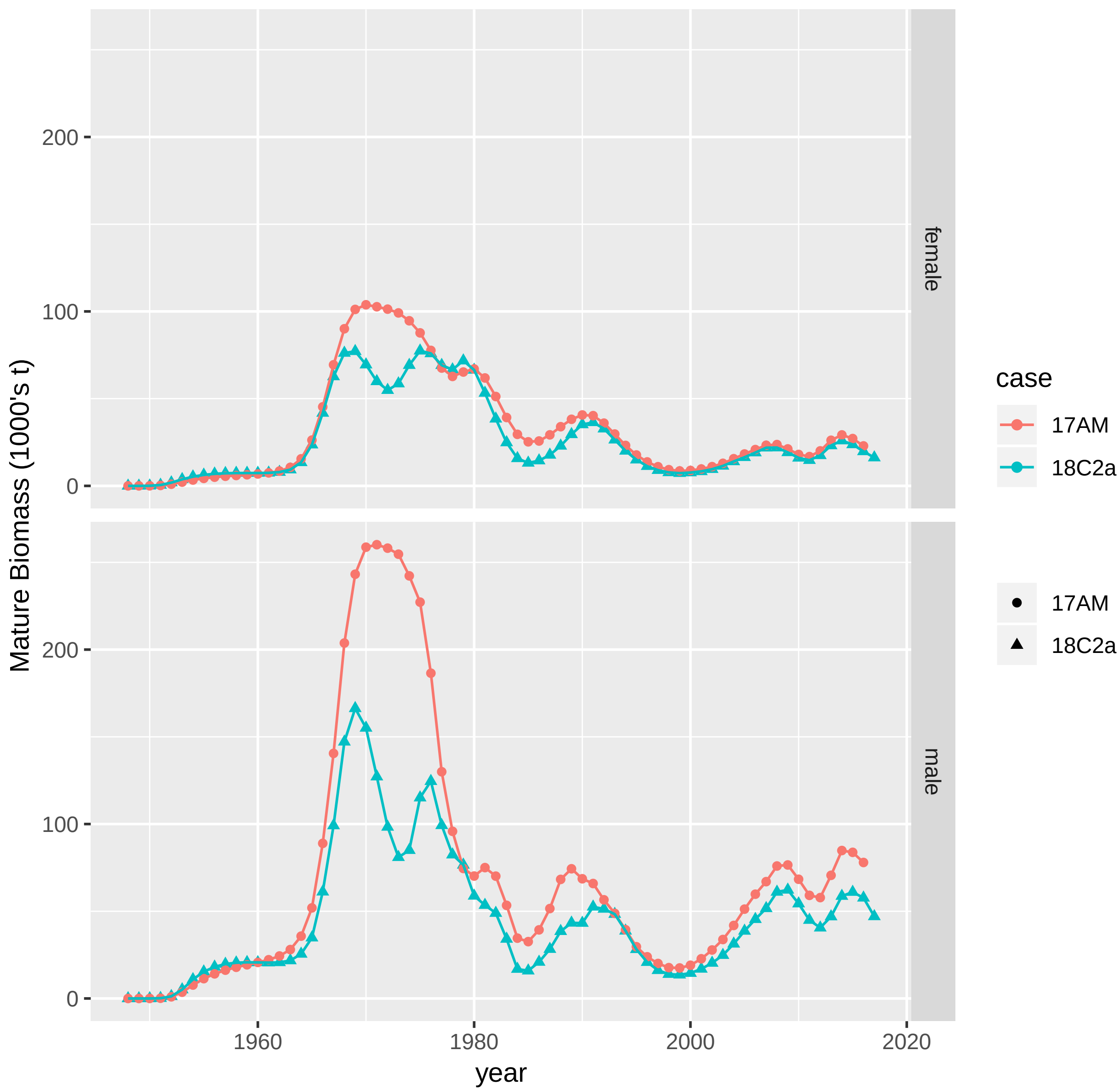

Figure 5: Estimated annual mature biomass.

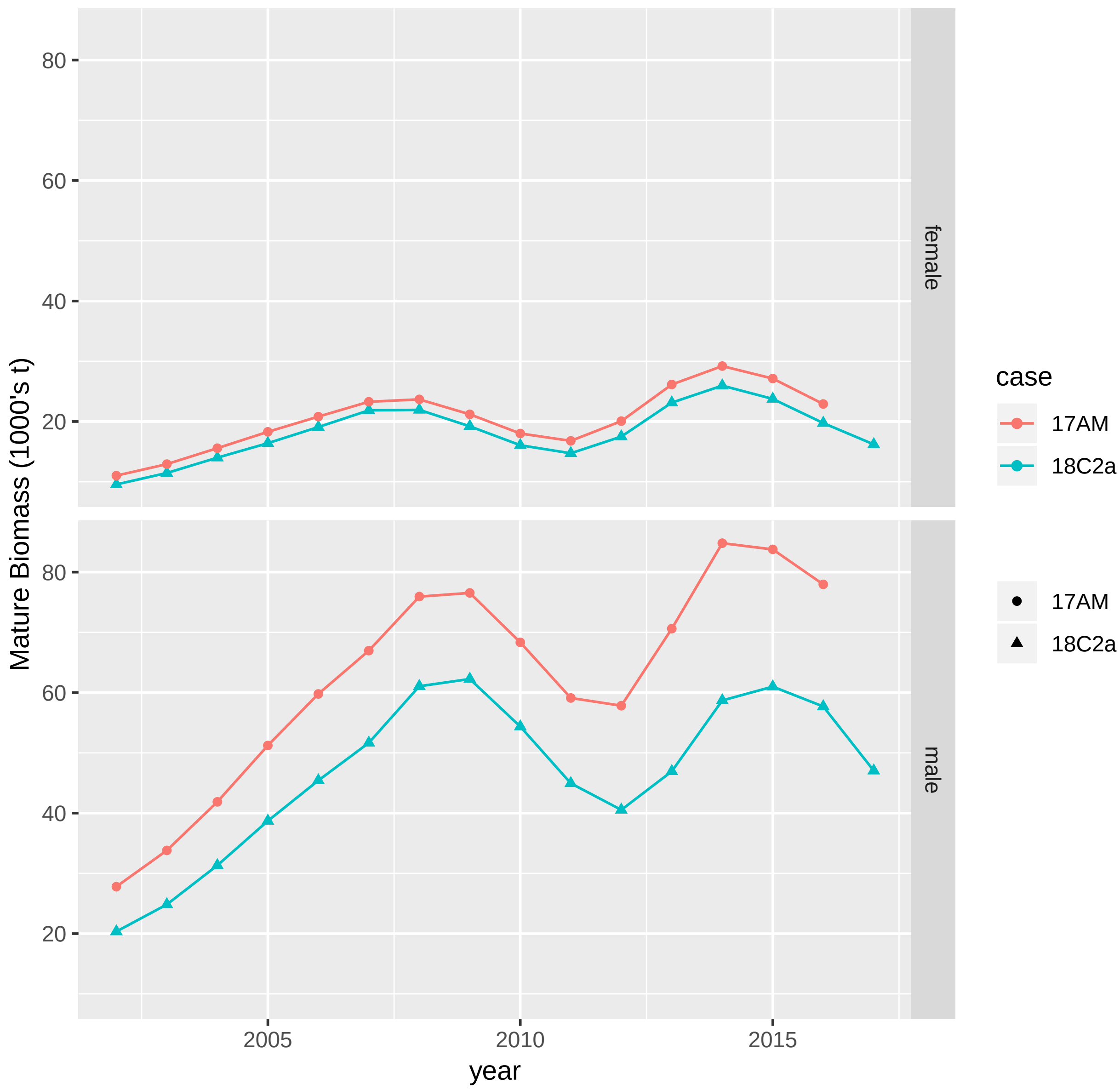

Figure 6: Estimated recent mature biomass.

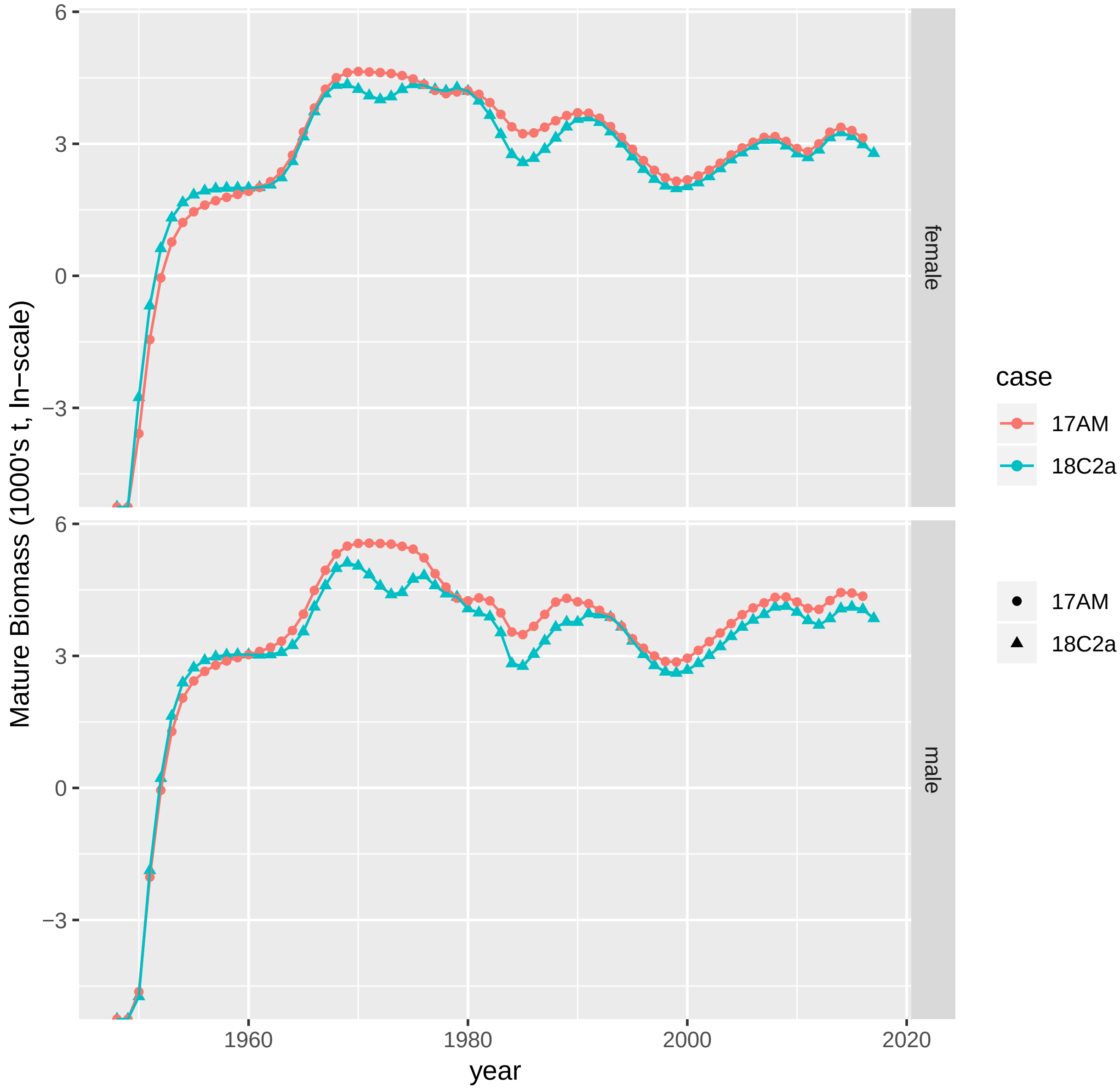

Figure 7: Estimated annual mature biomass, on ln-scale.

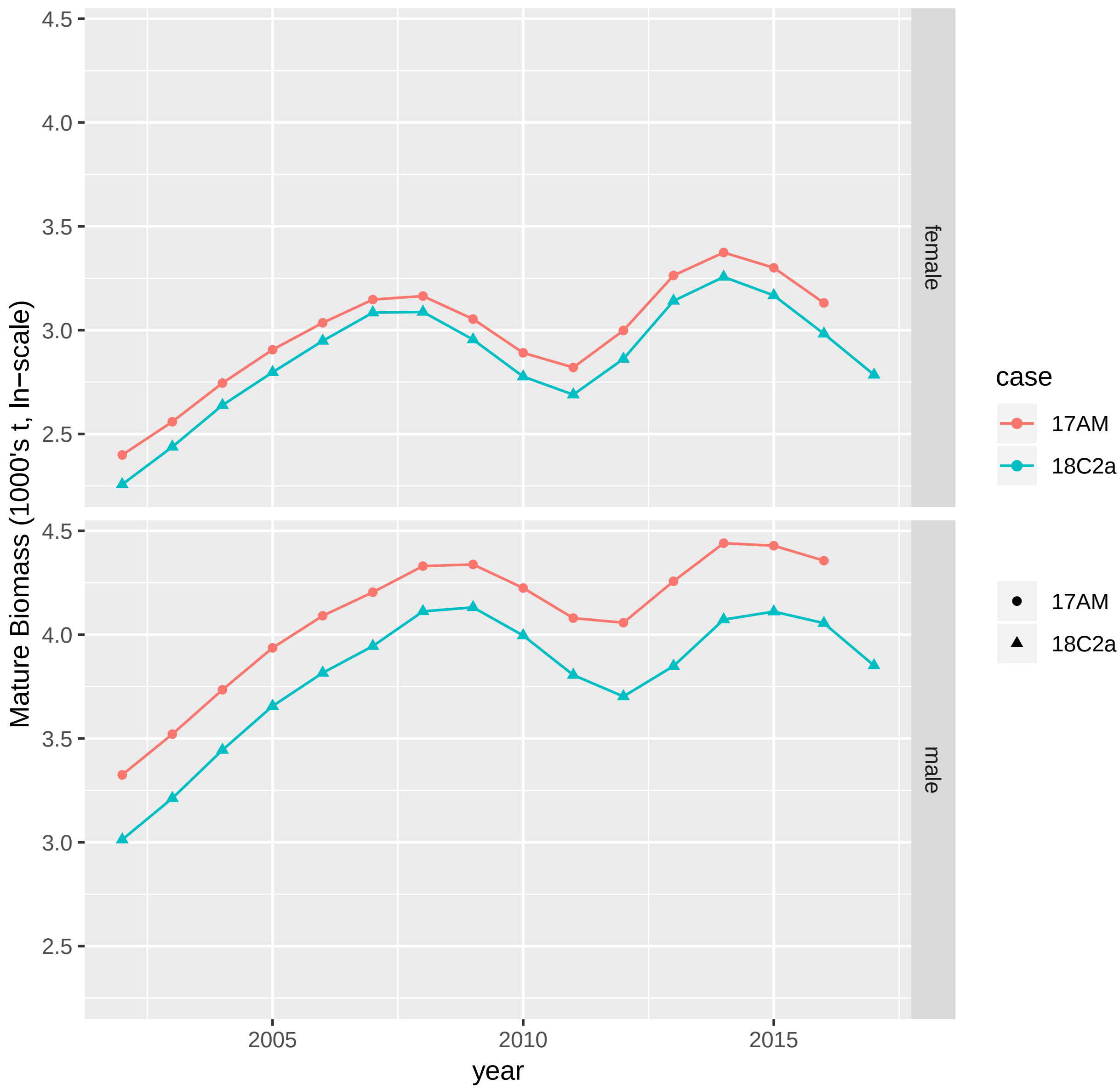

Figure 8: Estimated recent mature biomass, on ln-scale.

Population abundance

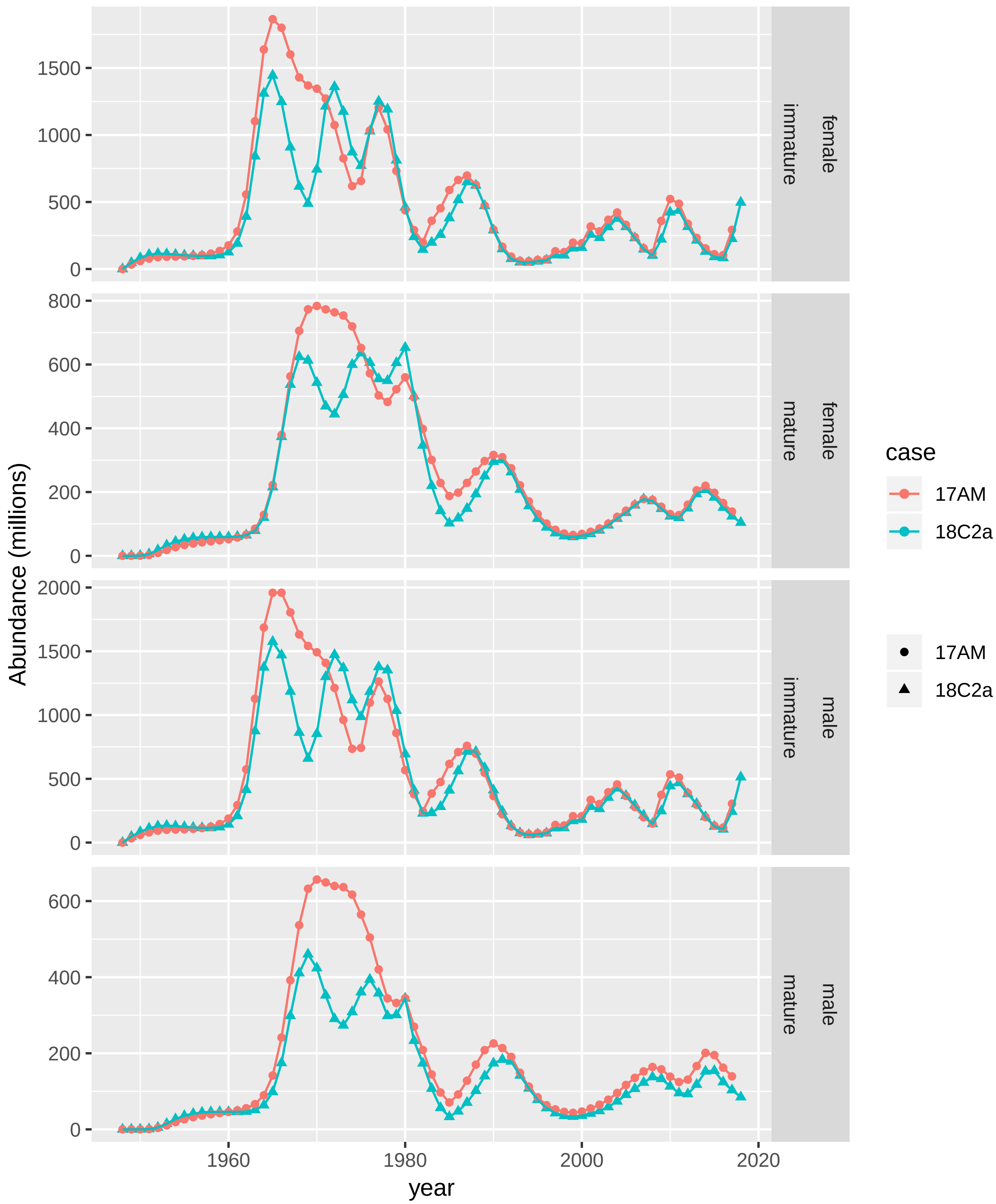

Figure 9: Population abundance trends.

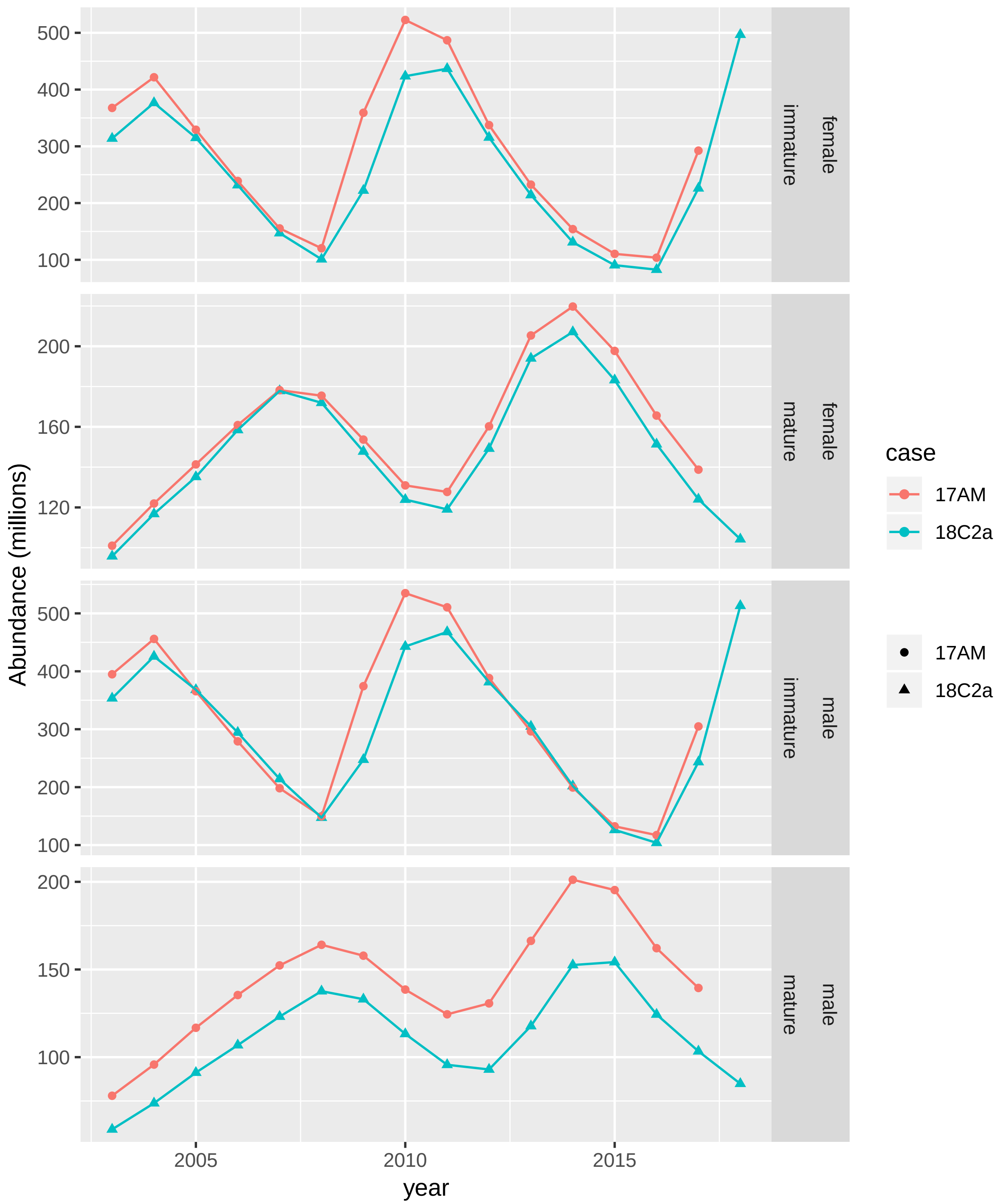

Figure 10: Recent population abundance trends.

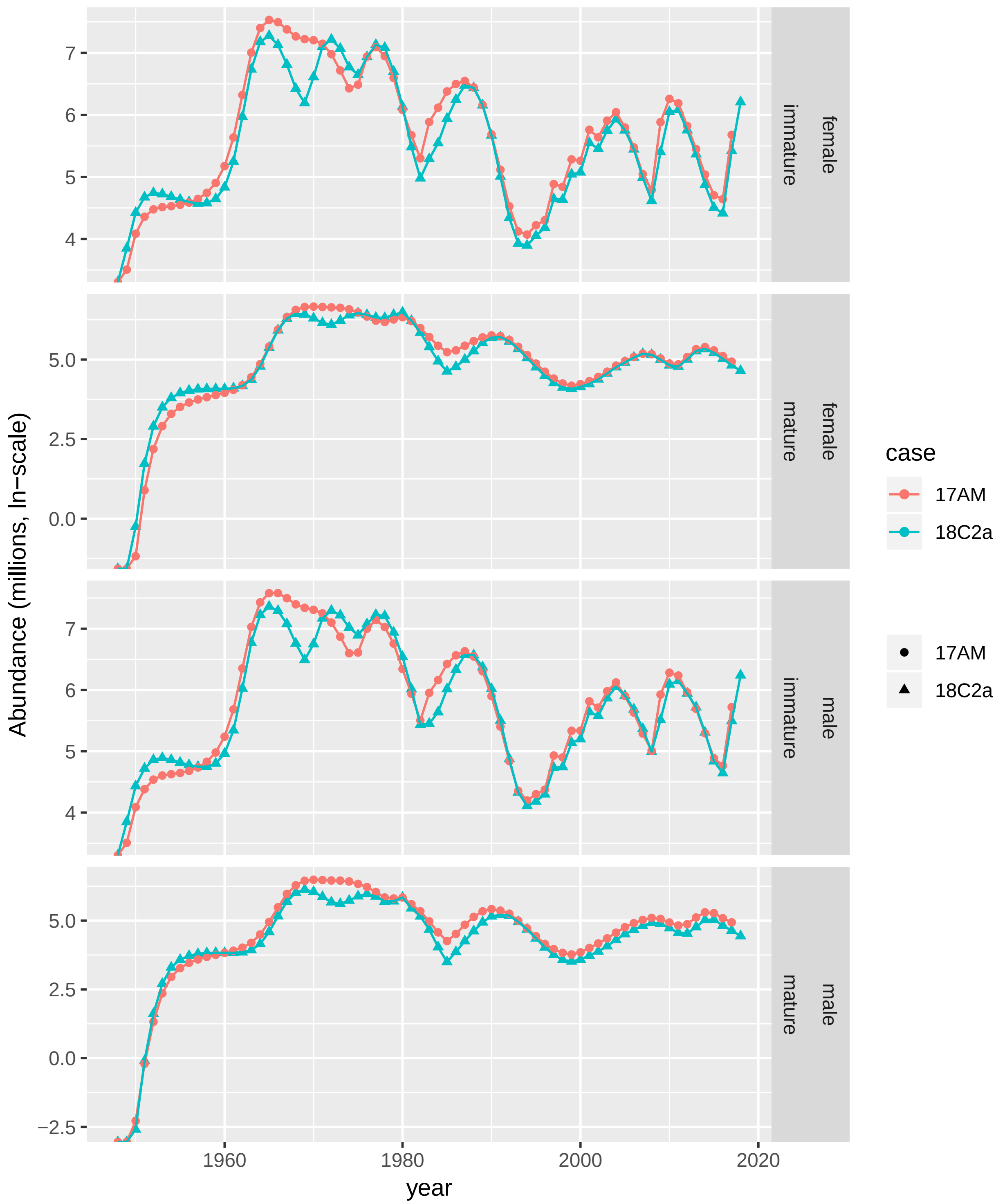

Figure 11: Ln-scale population abundance trends.

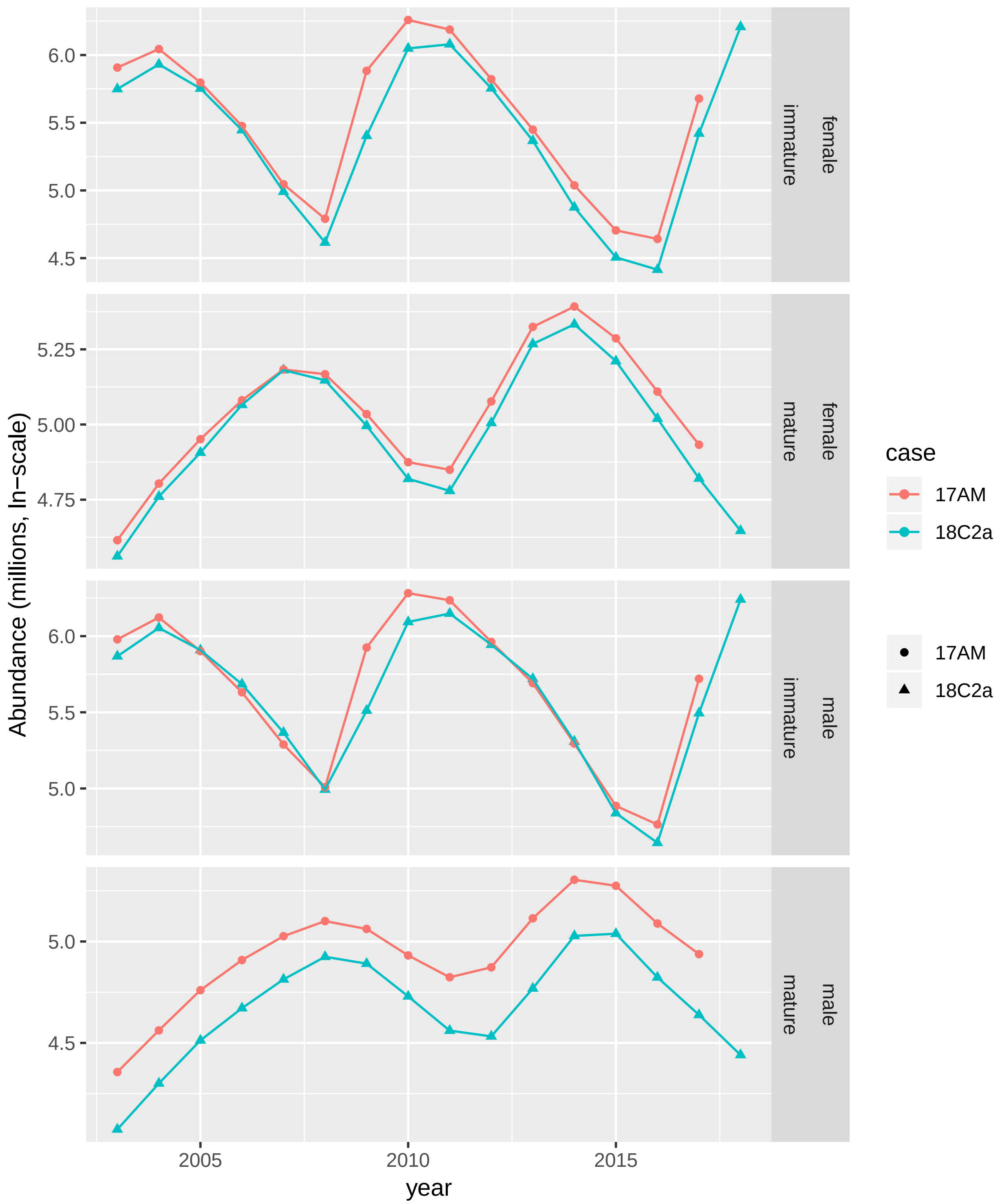

Figure 12: Recent ln-scale population abundance trends.

Population biomass

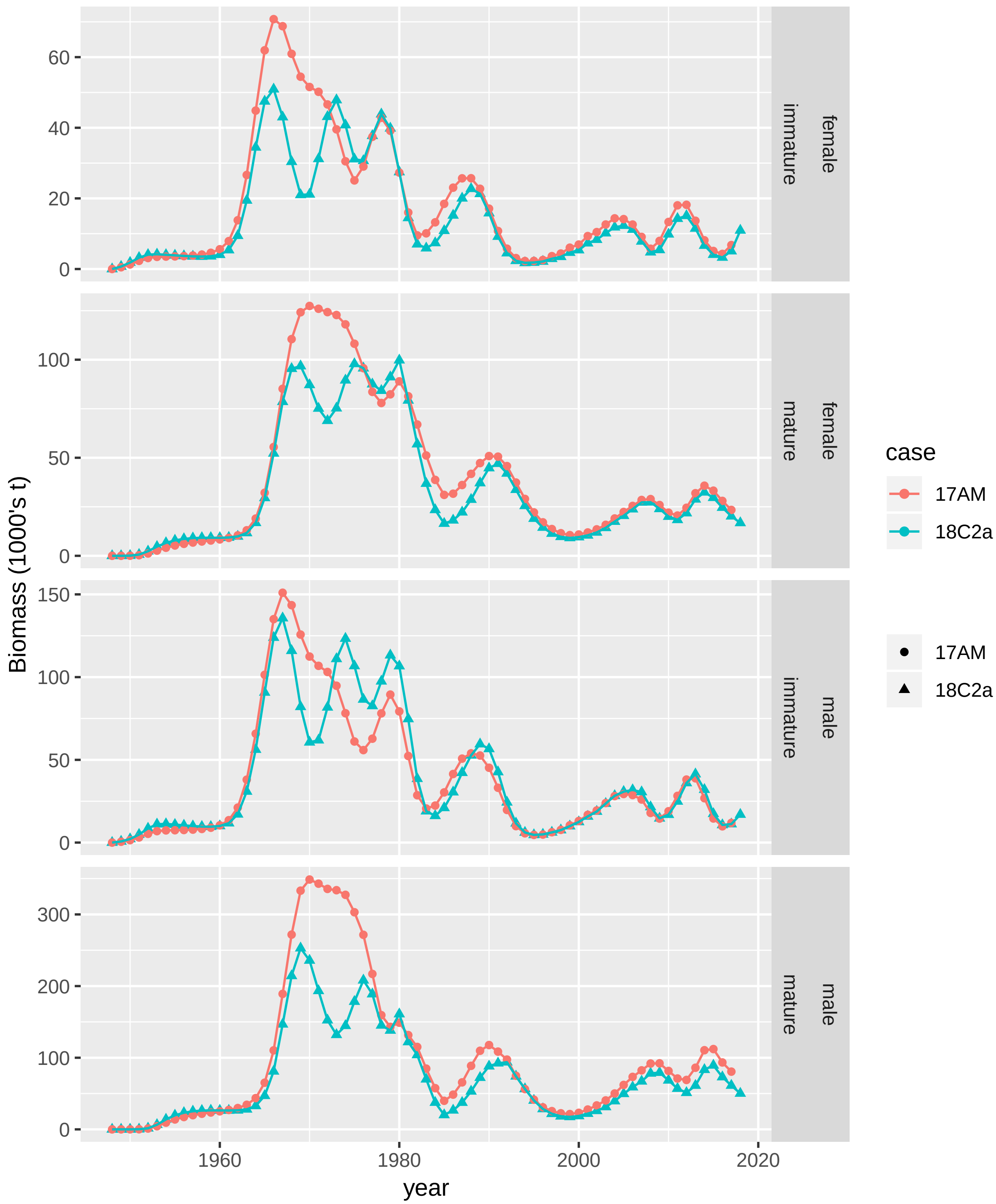

Figure 13: Population biomass trends.

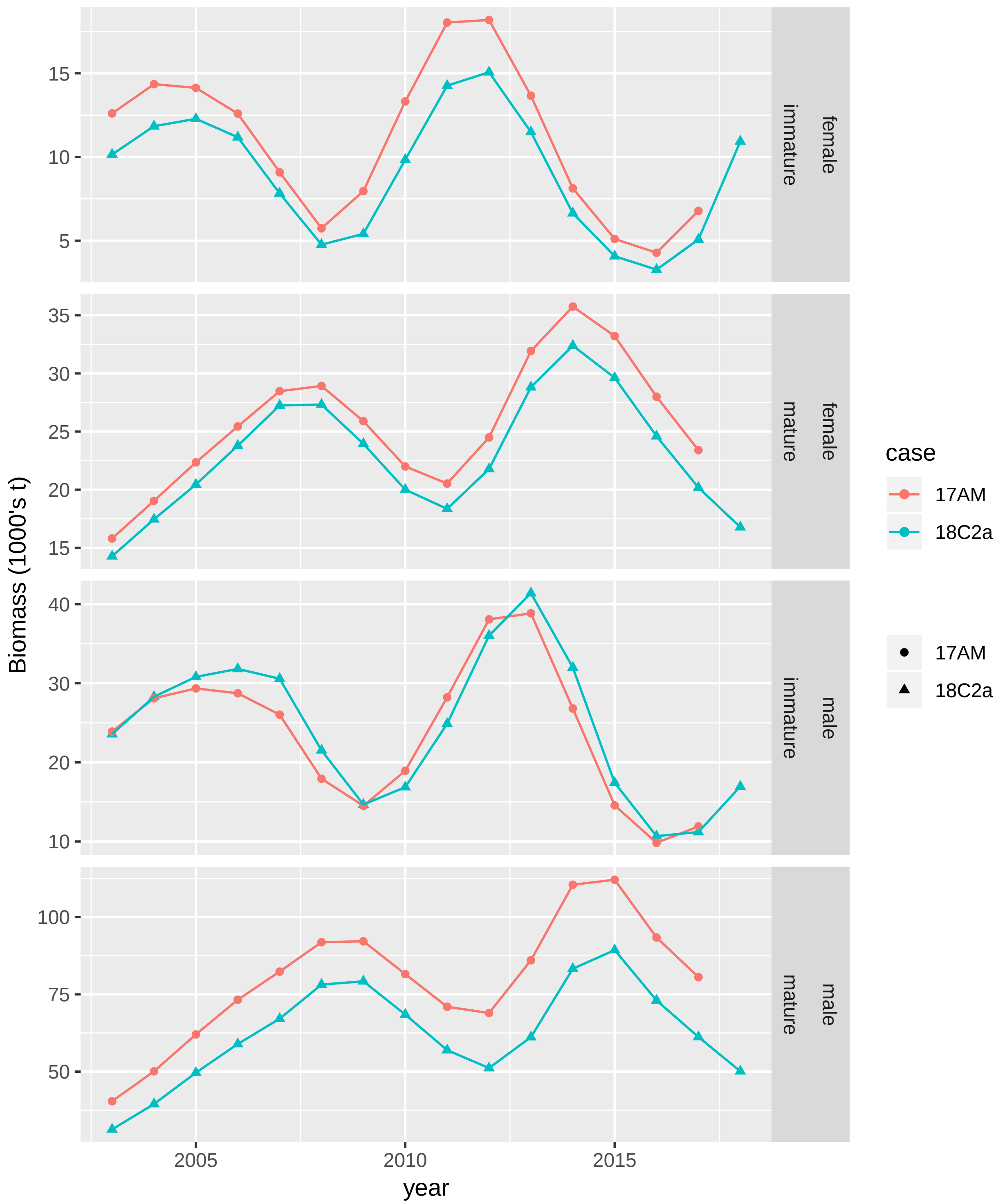

Figure 14: Recent population biomass trends.

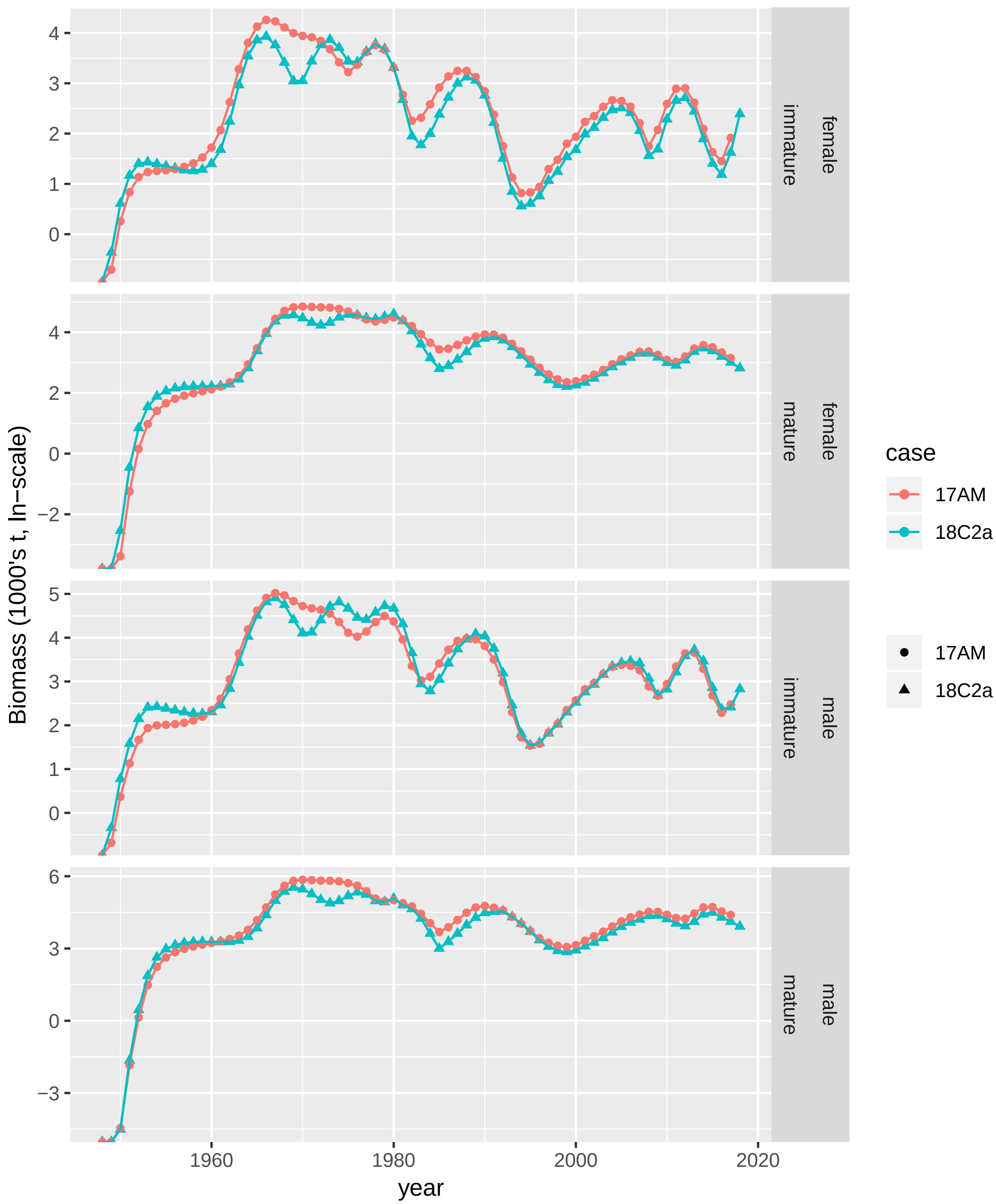

Figure 15: Ln-scale population biomass trends.

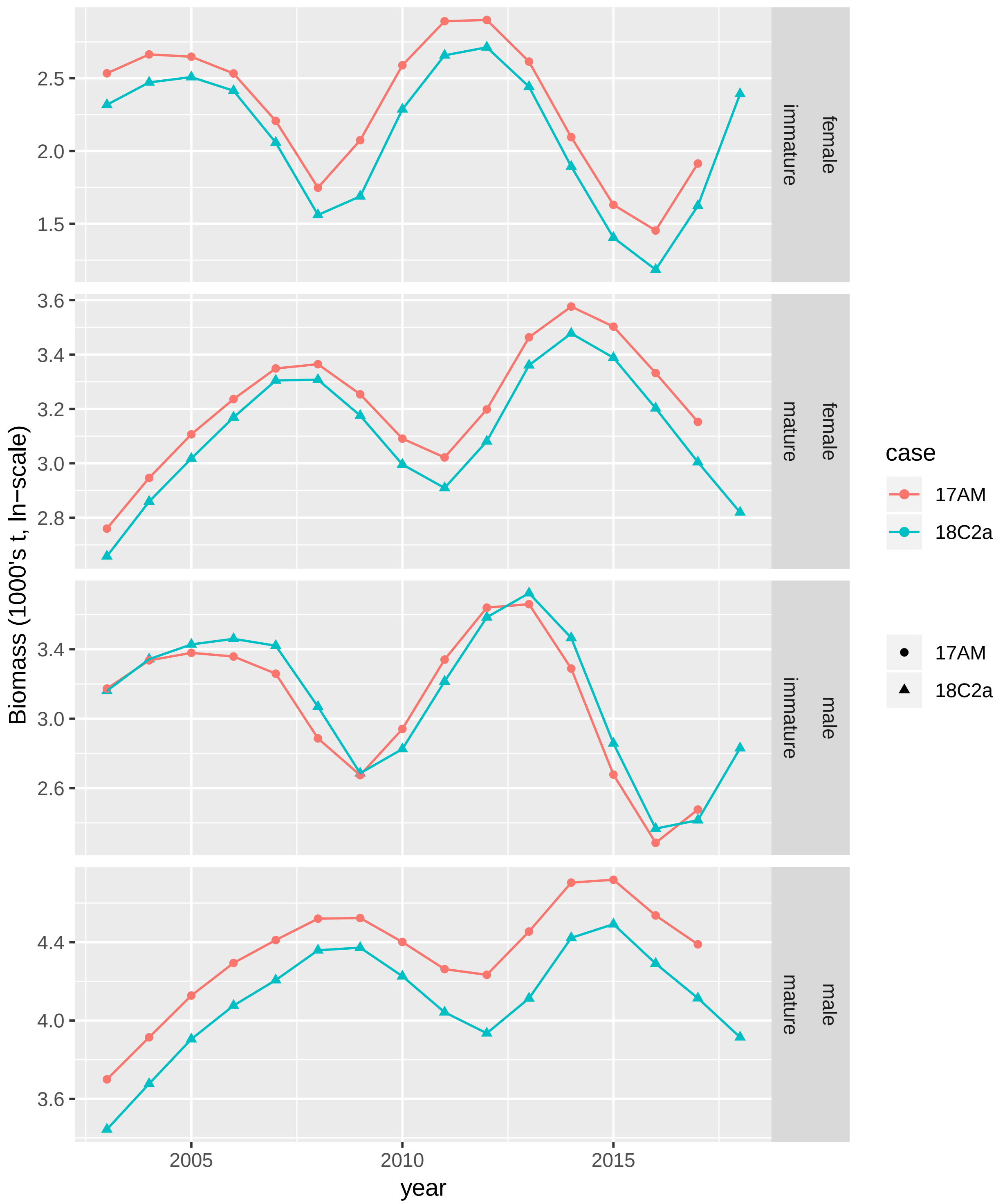

Figure 16: Recent ln-scale population biomass trends.

Appendix K:
Description of the Tanner Crab Stock Assessment Model (ver. 2)

Introduction

The computer code used in the 2016 Tanner crab stock assessment (Stockhausen, 2016), referred to here as "TCSAM2013" (i.e., an acronym for Tanner Crab Stock Assessment Model, 2013), evolved directly from the assessment model code developed by Rugolo and Turnock (2011, 2012a) used in the 2012 stock assessment (Rugolo and Turnock, 2012b), as rewritten and revised by Stockhausen for the 2013 and subsequent stock assessments (Stockhausen et al., 2013; Stockhausen, 2014; Stockhausen, 2015; Stockhausen, 2016). TCSAM2013, no longer used for assessments, was an integrated assessment model that estimated model parameters in a maximum likelihood framework using AD Model Builder C++ libraries (Fournier et al., 2012) for automatic differentiation to fit to time series of survey (fishery-independent) biomass and size compositions, retained catch biomass and size compositions in the directed fishery, and catch biomass and size compositions in several fisheries that take Tanner crab as bycatch. The computer code for the TCSAM2013 is available on GitHub (the 2016 assessment model version is on the "2016AssessmentModel" branch). While a number of model options could be configured "on-the-fly" using a control file, assessment models developed using the TCSAM2013 computer code were constrained in a number of ways, including the number of directed fisheries (1) and bycatch fisheries (3) that can be accommodated, the type of surveys that can accommodated (1), and the number and type of time blocks that are defined for model parameters (most are hard-wired in the code). Additionally, status determination and overfishing limit (OFL) calculations required a separate "projection model" code to be run separately using a results file from a successful TCSAM2013 model run.

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. 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 current development branch is "After201705CPT"). 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.

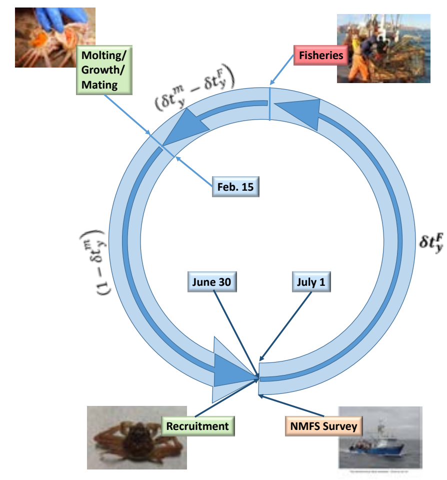

Fig. 1. Timing of annual events in TCSAM02 when fisheries occur before molting/growth/mating.

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 ($\delta t_y^F \le \delta t_y^m$) 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 $\boldsymbol{\delta t_y^F \le \delta t_y^m}$

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:

$$n_{y,x,m,s,z}^1 = e^{-M_{y,x,m,s,z} \cdot \delta t_y^F} \cdot n_{y,x,m,s,z} \qquad \text{A1.1}$$

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:

$$n_{y,x,m,s,z}^2 = e^{-F_{y,x,m,s,z}^T} \cdot n_{y,x,m,s,z}^1 \qquad \text{A1.2}$$

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:

$$n_{y,x,m,s,z}^3 = e^{-M_{y,x,m,s,z} \cdot (\delta t_y^m - \delta t_y^F)} \cdot n_{y,x,m,s,z}^2 \qquad \text{A1.3}$$

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
$M_{y,x,m=MAT,s,z} = \begin{cases} M^{base} \cdot \delta M_{x,MAT} & otherwise \\ M^{base} \cdot \delta M_{x,MAT} \cdot \delta M^T_{x,MAT} & 1980 \le y \le 1984 \end{cases}$	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:

$\Theta_{t,x,z,z'} = c_{t,x,z'} \cdot \int_{z-bin/2}^{z+bin/2} \Gamma\left(\frac{z''-\bar{z}_{t,x,z'}}{\beta_{t,x}}\right) dz''$	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
$\alpha_{t,x,z'} = \left[\bar{z}_{t,x,z'} - z'\right]/\beta_{t,x}$	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:

$n^{+}_{y,x,IMM,NS,z} = \left(1 - \phi_{t,x,z}\right) \cdot n_{y,x,IMM,NS,z}$ $n^{+}_{y,x,MAT,NS,z} = \phi_{t,x,z} \cdot n_{y,x,IMM,NS,z}$	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:

$S_z = \left\{1 + e^{-\beta\cdot(z - z_{50})}\right\}^{-1}$	standard logistic	G.1
$S_z = \left\{1 + e^{-\beta\cdot(z - \exp(lnZ_{50}))}\right\}^{-1}$	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

$\rho_{f,y,x,m,s,z} = \dfrac{1}{1 + e^{\rho_{f,t,x,m,s}}} \cdot R_{f,y,x,m,s,z}$	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

$c_{f,y,x,m,s,z} = \dfrac{\phi_{f,y,x,m,s,z}}{F^T_{y,x,m,s,z}} \cdot \left[1 - e^{-F^T_{y,x,m,s,z}}\right] \cdot n_{y,x,m,s,z}$	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

$r_{f,y,x,m,s,z} = \dfrac{\rho_{f,y,x,m,s,z} \cdot \phi_{f,y,x,m,s,z}}{F^T_{y,x,m,s,z}} \cdot \left[1 - e^{-F^T_{y,x,m,s,z}}\right] \cdot n_{y,x,m,s,z}$	number of retained crab	H.4

while the number of discarded crab, $d_{f,y,x,m,s,z}$, is given by

$d_{f,y,x,m,s,z} = \frac{\left(1-\rho_{f,y,x,m,s,z}\right) \cdot \phi_{f,y,x,m,s,z}}{F^T_{y,x,m,s,z}} \cdot \left[1-e^{-F^T_{y,x,m,s,z}}\right] \cdot n_{y,x,m,s,z}$	number of discarded crab	H.5

and the discard mortality, $dm_{f,y,x,m,s,z}$, is

$dm_{f,y,x,m,s,z} = \frac{h_{f,y} \cdot \left(1-\rho_{f,y,x,m,s,z}\right) \cdot \phi_{f,y,x,m,s,z}}{F^T_{y,x,m,s,z}} \cdot \left[1-e^{-F^T_{y,x,m,s,z}}\right] \cdot n_{y,x,m,s,z}$	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:

$\phi_{f,y,x,m,s} = \exp\left(\overline{lnC}_{f,t,x,m,s} + pDevsC_{f,y,x,m,s}\right)$	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 $\overline{lnC}_{f,t,x,m,s}$. The latter is expressed in terms of model parameters as

$\overline{lnC}_{f,t,x,m,s} = pLnC_{f,t,x,m,s} + \sum_{i=1}^{4} \delta C^i_{f,t,x,m,s}$	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

$a_{v,y,x,m,s,z} = q_{v,y,x,m,s,z} \cdot n_{y,x,m,s,z}$	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*:

$q_{v,y,x,m,s,z} = q_{v,t,x,m,s} \cdot S_{v,t,x,m,s,z}$	survey catchability	I.2

where $q_{v,t,x,m,s}$ is the fully-selected catchability in time block *t* and $S_{v,t,x,m,s,z}$ is the size-specific survey selectivity.

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:

$q_{v,t,x,m,s} = \exp\left(pLnQ_{v,t,x,m,s} + \sum_{i=1}^{4} \delta Q_{v,t,x,m,s}^{i}\right)$	I.3

where the $pLnQ_{v,t,x,m,s}$ is the mean ln-scale catchability (e.g., for mature males) and the $\delta Q_{v,t,x,m,s}^{i}$ 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 *p*th prior probability function, $\mathcal{L}_l$ represents the *l*th likelihood function, and the λ's represent user-adjustable weights for each component.

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:

$\ln(\mathcal{L}) = \sum_{y} n_{y,c} \cdot \sum_{z} \{p_{y,c,z}^{obs} \cdot \ln(p_{y,c,z}^{mod} + \delta) - p_{y,c,z}^{obs} \cdot \ln(p_{y,c,z}^{obs} + \delta)\}$	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, $p_{y,c,z}^{obs}$ is the observed size composition in size bin *z* (i.e., the size frequency normalized to sum to 1 across size bins for each year), $p_{y,c,z}^{mod}$ 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 tin 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 by	Size Conpositions 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	λ	none	exponential pdf
gamma	r, μ	none	gamma pdf
invchisquare	υ	none	inverse χ^2 pdf

invgamma	r, μ	none	inverse gamma pdf
invgaussian	μ, λ	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**	$\boldsymbol{a_{x,m}}$	$\boldsymbol{b_{x,m}}$
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

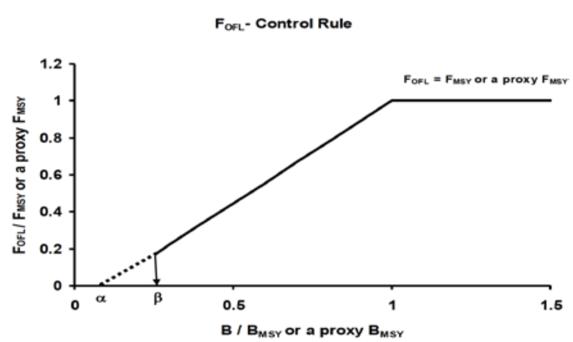

Fig. 2. The F_{OFL} harvest control rule.

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 $0.5xB_{MSY}$: 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:

$$in^{+} = R + S_{2in} \cdot \{(1 - \Theta_{in}) \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \cdot in + T_{io} \cdot (1 - \Theta_{io}) \cdot \Phi_{io} \cdot S_{1io} \cdot io\} \tag{N.1}$$
$$io^{+} = S_{2io} \cdot \{(1 - \Phi_{in}) \cdot S_{1in} \cdot in + (1 - \Phi_{io}) \cdot S_{1io} \cdot io\} \tag{N.2}$$
$$mn^{+} = S_{2mn} \cdot \{\Theta_{in} \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \cdot in + \Theta_{io} \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \cdot io\} \tag{N.3}$$
$$mo^{+} = S_{2mo} \cdot \{S_{1mn} \cdot mn + S_{1mo} \cdot mo\} \tag{N.4}$$

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:

$$in = R + S_{2in} \cdot \{(1 - \Theta_{in}) \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \cdot in + (1 - \Theta_{io}) \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \cdot io\} \tag{N.5}$$
$$io = S_{2io} \cdot \{(1 - \Phi_{in}) \cdot S_{1in} \cdot in + (1 - \Phi_{io}) \cdot S_{1io} \cdot io\} \tag{N.6}$$
$$mn = S_{2mn} \cdot \{\Theta_{in} \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \cdot in + \Theta_{io} \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \cdot io\} \tag{N.7}$$
$$mo = S_{2mo} \cdot \{S_{1mn} \cdot mn + S_{1mo} \cdot mo\} \tag{N.8}$$

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:

$$in = R + A \cdot in + B \cdot io \tag{N.9}$$
$$io = C \cdot in + D \cdot io \tag{N.10}$$
$$mn = E \cdot in + F \cdot io \tag{N.11}$$
$$mo = G \cdot mn + H \cdot mo \tag{N.12}$$

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

$$io = \{1 - D\}^{-1} \cdot C \cdot in \tag{N.13}$$

Plugging eq. 13 into 9 and solving for *in* yields

$$in = \{1 - A - B \cdot [1 - D]^{-1} \cdot C\}^{-1} \cdot R \tag{N.14}$$

Equations 13 for *io* and 14 for *in* can simply be plugged into eq. 11 to yield *mn:*

$$mn = E \cdot in + F \cdot io \tag{N.15}$$

while eq. 12 can then be solved for *mo*, yielding:

$$mo = \{1 - H\}^{-1} \cdot G \cdot mn \tag{N.16}$$

where (for completeness):

$$A = S_{2in} \cdot (1 - \Theta_{in}) \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \tag{N.17}$$
$$B = S_{2in} \cdot (1 - \Theta_{io}) \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \tag{N.18}$$
$$C = S_{2io} \cdot (1 - \Phi_{in}) \cdot S_{1in} \tag{N.19}$$
$$D = S_{2io} \cdot (1 - \Phi_{io}) \cdot S_{1io} \tag{N.20}$$
$$E = S_{2mn} \cdot \Theta_{in} \cdot T_{in} \cdot \Phi_{in} \cdot S_{1in} \tag{N.21}$$

$$F = S_{2mn} \cdot \Theta_{io} \cdot T_{io} \cdot \Phi_{io} \cdot S_{1io} \quad \text{(N.22)}$$
$$G = S_{2mo} \cdot S_{1mn} \quad \text{(N.23)}$$
$$H = S_{2mo} \cdot S_{1mo} \quad \text{(N.24)}$$

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.

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Appendix L: Results from the CPT-Recommended Model Scenario

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Introduction

The CPT rejected all "18" model scenarios put forward by the assessment author. These scenarios were based on revised fishery data which had a substantial impact on estimates of survey catchability and, as a consequence, stock biomass levels. Given the substantial impact the change in data had, the CPT rejected the scenarios based on the revised data because the mechanisms for changes in the results were not fully understood and the data had not been previously reviewed and vetted by the CPT. Consequently, the CPT requested that the assessment author run the 2017 assessment model (17AM) using the data used in that assessment but updated with only the new data for 2017/18 (NMFS survey, retained catch biomass and size compositions from the directed fishery, and total catch biomass and size compositions from the directed fishery and bycatch fisheries). The assessment author was able to comply with this request to the extent of providing results for the maximum likelihood solution; MCMC results for the model scenario were not possible given the time constraints. This model scenario was designated 18AM17. A subset of results from this model scenario are presented in this appendix.

Management performance

Historical status and catch specifications for eastern Bering Sea Tanner crab from the CPT-recommended model scenario 18AM17.

(a) in 1000's t.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2014/15	13.40	71.57 [A]	6.85	6.16	9.16	31.48	25.18
2015/16	12.82	73.93 [A]	8.92	8.91	11.38	27.19	21.75
2016/17	14.58	77.96 [A]	0.00	0.00	1.14	25.61	20.49
2017/18	15.15[C]	64.09[A]	1.13	1.13	2.39[C]	25.42	20.33
2018/19		35.95[B,C]				20.87[C]	16.70[C]

(b) in millions lbs.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2014/15	29.53	157.78 [A]	15.10	13.58	20.19	69.40	55.51
2015/16	28.27	162.99 [A]	19.67	19.64	25.09	59.94	47.95
2016/17	32.15	171.87 [A]	0.00	0.00	2.52	56.46	45.17

2017/18	33.39 [C]	141.29 [A]	2.50	2.50	5.27 [C]	56.03	44.83
2018/19		79.26 [B,C]				46.01 [C]	36.81 [C]

A—Estimated at time of mating for the year concerned. This is a revised estimate, based on the subsequent assessment.
B—Projected biomass from the current stock assessment. This value will be updated next year.
C—Based on the CPT's recommended model scenario (Scenario 1817AM).

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})**
2014/15	3a	29.82	63.80	2.14	0.61	1982-2014	0.23
2015/16	3a	26.79	53.70	2.00	0.58	1982-2015	0.23
2016/17	3a	25.65	45.34	1.77	0.79	1982-2016	0.23
2017/18	3a	29.17	64.09	2.12	0.75	1982-2017	0.23
2018/19	3a	30.29	35.95	1.19	0.74	1982-2018	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})**
2014/15	3a	65.74	140.66	2.14	0.61	1982-2014	0.23
2015/16	3a	59.06	118.38	2.00	0.58	1982-2015	0.23
2016/17	3a	56.54	99.95	1.77	0.79	1982-2016	0.23
2017/18	3a	64.30		2.12	0.75	1982-2017	0.23
2018/19	3a	66.78	79.26	1.08	0.74	1982-2018	0.23

A—Calculated from the assessment reviewed by the Crab Plan Team in 20XX of 20XX/(XX+1) or based on the CPT's recommended model for 2018/19.
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 2018/19, is estimated at 35.95 thousand t. B_{MSY} for this stock is calculated to be 30.29 thousand t, so MSST is 15.15 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 2017/18 was 2.39 thousand t, which was less than the OFL for 2016/17 (25.42 thousand t); consequently **overfishing did not occur**. The OFL for 2018/19 based on the CPT's recommended scenario (Scenario 18AM17) is 20.87 thousand t. Because there was not time to make MCMC runs, the P* ABC could not be evaluated and thus maxABC could not be determined. In 2014, the SSC adopted a 20% buffer to calculate ABC for Tanner crab to incorporate concerns regarding model uncertainty for this stock. Based on this buffer, the ABC would be 16.70 thousand t.

Tables and Figures

Selected tables and figures from the original assessment have been updated below for the CPT's recommended scenario 18AM17. The table and figure numbers below do not correspond to those in the original assessment.

List of Table Captions

List of Figure Captions

Tables

Table 1. Comparison of fits to mature survey biomass by sex (in 1000's t) from the 2017 assessment model (17AM) and the CPT's recommended scenario (18AM17).

	17AM				18AM17			
	male		female		male		female	
year	observed	predicted	observed	predicted	observed	predicted	observed	predicted
1975	246.0	151.3	31.4	47.6	246.0	153.3	31.4	47.8
1976	126.2	135.6	31.2	42.2	126.2	137.2	31.2	42.3
1977	111.3	108.3	38.6	36.8	111.3	109.5	38.6	36.9
1978	77.9	79.5	25.8	34.1	77.9	80.2	25.8	34.2
1979	32.6	71.3	19.3	35.8	32.6	71.8	19.3	36.0
1980	86.8	74.2	63.8	38.8	86.8	74.5	63.8	39.0
1981	50.3	65.6	42.6	35.7	50.3	66.0	42.6	36.1
1982	51.7	71.8	64.1	26.1	51.7	71.9	64.1	26.2
1983	29.9	53.0	20.4	19.9	29.9	53.2	20.4	20.1
1984	25.8	36.0	14.9	15.1	25.8	36.2	14.9	15.2
1985	11.9	24.9	5.6	12.1	11.9	25.1	5.6	12.2
1986	13.3	30.2	3.4	12.3	13.3	30.4	3.4	12.4
1987	24.6	40.8	5.1	14.0	24.6	41.0	5.1	14.1
1988	61.0	55.2	25.4	16.2	61.0	55.5	25.4	16.3
1989	93.3	68.3	19.4	18.4	93.3	68.6	19.4	18.5
1990	97.8	73.2	37.7	19.8	97.8	73.5	37.7	19.8
1991	112.6	67.4	44.8	19.7	112.6	67.6	44.8	19.7
1992	105.5	60.5	26.2	17.8	105.5	60.8	26.2	17.8
1993	62.0	46.5	11.6	14.6	62.0	46.7	11.6	14.5
1994	43.8	34.9	9.8	11.3	43.8	34.9	9.8	11.2
1995	32.7	25.7	12.4	8.6	32.7	25.7	12.4	8.5
1996	27.5	19.1	9.6	6.7	27.5	19.1	9.6	6.6
1997	11.3	15.8	3.4	5.3	11.3	15.8	3.4	5.2
1998	10.9	13.9	2.3	4.5	10.9	14.1	2.3	4.4
1999	13.0	13.3	3.8	4.1	13.0	13.5	3.8	4.1
2000	16.9	14.3	4.1	4.2	16.9	14.6	4.1	4.2
2001	18.7	17.2	4.6	4.6	18.7	17.4	4.6	4.6
2002	19.0	20.8	4.5	5.2	19.0	20.9	4.5	5.2
2003	24.6	25.1	8.4	6.1	24.6	25.2	8.4	6.1
2004	27.0	31.2	4.7	7.4	27.0	31.2	4.7	7.4
2005	45.2	38.6	11.6	8.7	45.2	38.7	11.6	8.7
2006	67.9	45.7	14.9	9.9	67.9	45.6	14.9	9.9
2007	69.5	51.3	13.4	11.1	69.5	51.2	13.4	11.0
2008	65.1	57.4	11.7	11.3	65.1	57.3	11.7	11.2
2009	38.2	57.6	8.5	10.1	38.2	57.5	8.5	10.0
2010	39.1	51.0	5.5	8.6	39.1	50.8	5.5	8.5
2011	43.3	44.4	5.4	8.0	43.3	44.1	5.4	7.9
2012	42.2	42.9	12.4	9.5	42.2	42.6	12.4	9.4
2013	67.0	53.5	17.8	12.4	67.0	52.9	17.8	12.2
2014	82.4	68.9	14.9	13.9	82.4	67.7	14.9	13.6
2015	62.9	70.1	11.2	12.9	62.9	68.3	11.2	12.5
2016	61.6	58.4	7.6	10.9	61.6	56.6	7.6	10.5
2017	50.2	50.4	7.1	9.1	50.3	48.6	7.1	8.7
2018	--	--	--	--	39.7	41.4	5.0	7.3

Table 2. Comparison of estimates of mature biomass-at-mating by sex (in 1000's t) from the 2017 assessment model (17AM) and the CPT's recommended scenario (18AM17).

	17AM		18AM17	
year	male	female	male	female
1948	0.00	0.00	0.00	0.00
1949	0.00	0.00	0.00	0.00
1950	0.01	0.03	0.01	0.03
1951	0.13	0.23	0.14	0.25
1952	0.95	0.96	1.00	1.01
1953	3.61	2.16	3.80	2.27
1954	7.71	3.36	8.11	3.53
1955	11.36	4.29	11.95	4.51
1956	14.13	4.98	14.86	5.23
1957	16.23	5.52	17.08	5.79
1958	17.89	5.95	18.84	6.25
1959	19.30	6.36	20.34	6.68
1960	20.67	6.82	21.80	7.17
1961	22.21	7.45	23.46	7.84
1962	24.36	8.50	25.76	8.95
1963	28.04	10.62	29.68	11.21
1964	35.73	15.50	37.83	16.37
1965	51.93	26.24	55.00	27.66
1966	88.92	45.30	93.90	47.58
1967	140.50	69.41	148.28	72.62
1968	203.76	90.07	214.53	93.83
1969	243.21	101.15	255.76	104.91
1970	258.71	103.80	271.41	107.11
1971	260.13	102.68	271.66	105.27
1972	258.15	101.30	267.64	103.08
1973	254.69	99.15	261.58	100.18
1974	242.27	94.64	246.85	95.19
1975	227.19	87.70	230.32	87.99
1976	186.47	77.66	188.56	77.83
1977	129.97	67.55	130.97	67.71
1978	95.81	62.74	96.16	63.01
1979	74.51	65.26	74.33	65.72
1980	70.19	67.03	70.16	67.71
1981	75.02	61.86	75.57	62.61
1982	70.13	51.22	70.87	51.88
1983	53.39	39.19	54.04	39.72
1984	34.57	29.54	35.06	29.98
1985	32.59	25.26	33.03	25.61
1986	39.34	25.72	39.81	26.03
1987	51.54	29.25	52.15	29.58
1988	68.27	33.92	69.07	34.25
1989	74.35	38.16	75.18	38.49
1990	68.63	40.65	69.26	40.93
1991	65.90	40.25	66.70	40.45
1992	56.57	35.95	57.41	36.03
1993	48.77	29.72	49.31	29.65
1994	39.41	23.18	39.76	23.06
1995	29.66	17.72	29.98	17.60
1996	23.90	13.73	24.15	13.61
1997	20.05	10.99	20.44	10.90
1998	17.68	9.29	18.20	9.24
1999	17.50	8.58	17.99	8.54
2000	19.06	8.85	19.52	8.84
2001	22.76	9.70	23.13	9.69
2002	27.79	11.02	28.07	11.03
2003	33.81	12.93	34.13	12.96
2004	41.87	15.57	42.27	15.62
2005	51.23	18.29	51.63	18.33
2006	59.78	20.81	60.09	20.83
2007	66.97	23.28	67.37	23.30
2008	75.94	23.68	76.38	23.65
2009	76.55	21.19	76.87	21.09
2010	68.34	18.01	68.49	17.87
2011	59.11	16.79	59.24	16.63
2012	57.83	20.06	57.81	19.86
2013	70.61	26.14	70.27	25.76
2014	84.81	29.20	83.75	28.58
2015	83.78	27.13	82.01	26.38
2016	77.97	22.91	76.00	22.16
2017	--	--	64.09	18.40

Table 3. Estimated population size (millions) for females on July 1 of year. from the CPT's recommended scenario (18AM17).
<<Table too large: available online as a csv file in the zip file "TannerCrab.PopSizeStructure.18AM17.csvs.zip".>>

Table 4. Estimated population size (millions) for males on July 1 of year. from the CPT's recommended scenario (18AM17).
<<Table too large: available online as a csv file in the zip file "TannerCrab.PopSizeStructure.18AM17.csvs.zip".>>

Table 5. Comparison of estimates of recruitment (in millions) from the 2017 assessment model (17AM) and the CPT's recommended scenario (18AM17).

year	17AM	18AM17	year	17AM	18AM17
1948	66.59	70.09	1986	519.28	525.85
1949	66.58	70.10	1987	355.29	356.09
1950	66.64	70.20	1988	170.75	171.15
1951	66.90	70.54	1989	52.30	52.29
1952	67.56	71.30	1990	41.79	41.83
1953	68.86	72.77	1991	36.99	37.03
1954	71.24	75.38	1992	37.07	36.89
1955	75.36	79.85	1993	48.83	48.32
1956	82.49	87.53	1994	62.53	62.36
1957	95.22	101.14	1995	57.52	57.94
1958	119.81	127.33	1996	167.46	168.96
1959	174.76	185.59	1997	67.08	67.83
1960	320.74	339.61	1998	224.50	227.57
1961	719.29	757.29	1999	116.92	118.09
1962	1397.35	1462.06	2000	382.14	385.06
1963	1665.55	1736.13	2001	122.98	123.11
1964	1398.08	1452.38	2002	369.14	372.67
1965	1095.79	1131.17	2003	359.66	362.18
1966	943.74	963.73	2004	97.76	97.12
1967	937.10	943.26	2005	74.94	74.45
1968	1014.12	1008.70	2006	57.91	57.87
1969	983.26	980.62	2007	89.13	88.83
1970	834.92	843.95	2008	580.85	576.70
1971	554.32	561.90	2009	514.37	501.35
1972	362.83	369.68	2010	210.36	200.94
1973	308.42	318.01	2011	40.96	40.78
1974	632.20	641.44	2012	112.31	108.92
1975	1239.52	1257.96	2013	84.14	73.94
1976	957.43	971.55	2014	55.17	49.09
1977	420.64	424.99	2015	77.52	69.73
1978	177.55	180.91	2016	457.92	444.72
1979	108.77	110.11	2017	0.00	588.89
1980	177.84	180.47			
1981	100.63	101.42			
1982	488.76	496.01			
1983	402.54	408.57			
1984	541.74	550.02			
1985	523.34	529.77			

Table 6. Comparison of exploitation rates (i.e., catch divided by biomass) from the 2017 assessment model 17AM) and the CPT’s recommended scenario (18AM17).

year	17AM	18AM17	year	17AM	18AM17
1949	0.0018	0.0016	1986	0.0195	0.0193
1950	0.0029	0.0027	1987	0.0319	0.0317
1951	0.0045	0.0042	1988	0.0407	0.0406
1952	0.0066	0.0062	1989	0.0915	0.0915
1953	0.0097	0.0093	1990	0.1524	0.1528
1954	0.0130	0.0126	1991	0.1473	0.1458
1955	0.0152	0.0148	1992	0.1748	0.1731
1956	0.0164	0.0160	1993	0.1302	0.1308
1957	0.0167	0.0163	1994	0.0983	0.0980
1958	0.0170	0.0165	1995	0.0872	0.0853
1959	0.0168	0.0164	1996	0.0481	0.0473
1960	0.0165	0.0160	1997	0.0394	0.0336
1961	0.0160	0.0156	1998	0.0381	0.0311
1962	0.0144	0.0140	1999	0.0172	0.0151
1963	0.0123	0.0119	2000	0.0141	0.0130
1964	0.0107	0.0104	2001	0.0157	0.0168
1965	0.0167	0.0160	2002	0.0096	0.0107
1966	0.0167	0.0159	2003	0.0066	0.0060
1967	0.0452	0.0436	2004	0.0074	0.0065
1968	0.0499	0.0483	2005	0.0123	0.0123
1969	0.0656	0.0637	2006	0.0184	0.0188
1970	0.0612	0.0596	2007	0.0220	0.0209
1971	0.0521	0.0509	2008	0.0146	0.0142
1972	0.0464	0.0455	2009	0.0121	0.0120
1973	0.0561	0.0556	2010	0.0064	0.0063
1974	0.0747	0.0741	2011	0.0088	0.0078
1975	0.0648	0.0646	2012	0.0053	0.0050
1976	0.1007	0.1009	2013	0.0153	0.0151
1977	0.1398	0.1407	2014	0.0522	0.0530
1978	0.1176	0.1189	2015	0.0707	0.0724
1979	0.1509	0.1527	2016	0.0098	0.0100
1980	0.0926	0.0939	2017	0.0000	0.0200
1981	0.0468	0.0468			
1982	0.0253	0.0252			
1983	0.0132	0.0131			
1984	0.0262	0.0260			
1985	0.0156	0.0154			

Table 7. Values required to determine Tier level and OFL for selected model scenarios. These values are presented only to illustrate the effect of incremental changes in the model scenarios. Results from the CPT's recommended model (18AM17) are highlighted in green. Note: the 2017/18 MMB is for July 1, 2018, not at the time of mating.

Model scenario	objective function value	max gradient	average recruitment millions	B0 1000's t	Bmsy 1000's t	Fmsy	MSY 1000's t	Fofl	OFL 1000's t	prjB 1000's t	B/Bmsy	2017/18 MMB 1000's t
17AM	2905.84	0.00	213.96	83.34	29.17	0.75	12.26	0.75	25.42	43.32	1.49	80.58
18AM17	2962.17	0.00	223.63	86.55	30.29	0.74	12.75	0.74	20.87	35.95	1.19	66.64
18C2a	4234.40	0.01	199.49	63.01	22.05	0.91	11.54	0.91	16.76	24.06	1.09	50.12

Figures

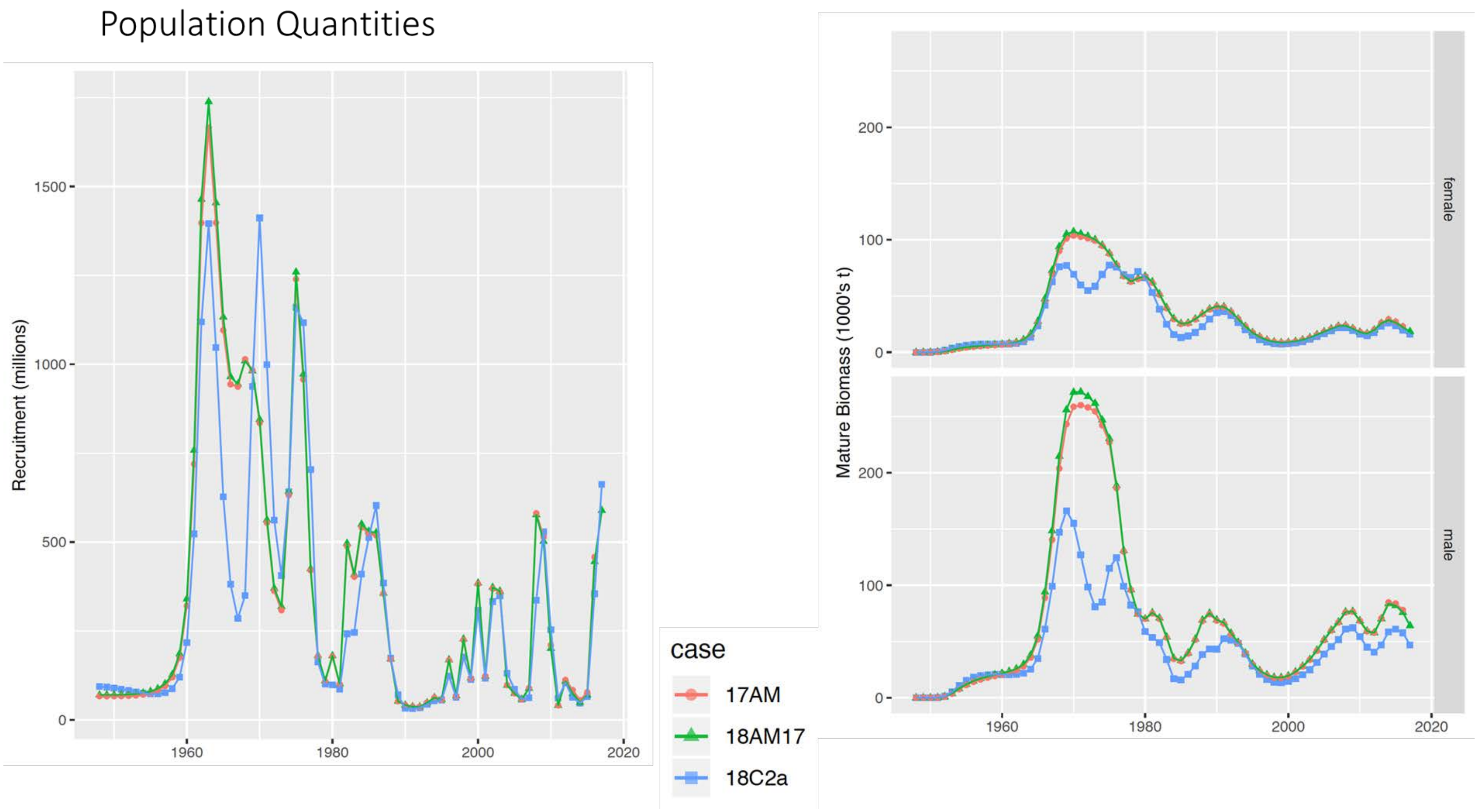


Figure 1. Comparison of estimated population quantities from the CPT's recommended scenario (18AM17), the 2017 assessment model (17AM), and the author's preferred scenario (18C2a).

Population Quantities: Biomass (1000's t)

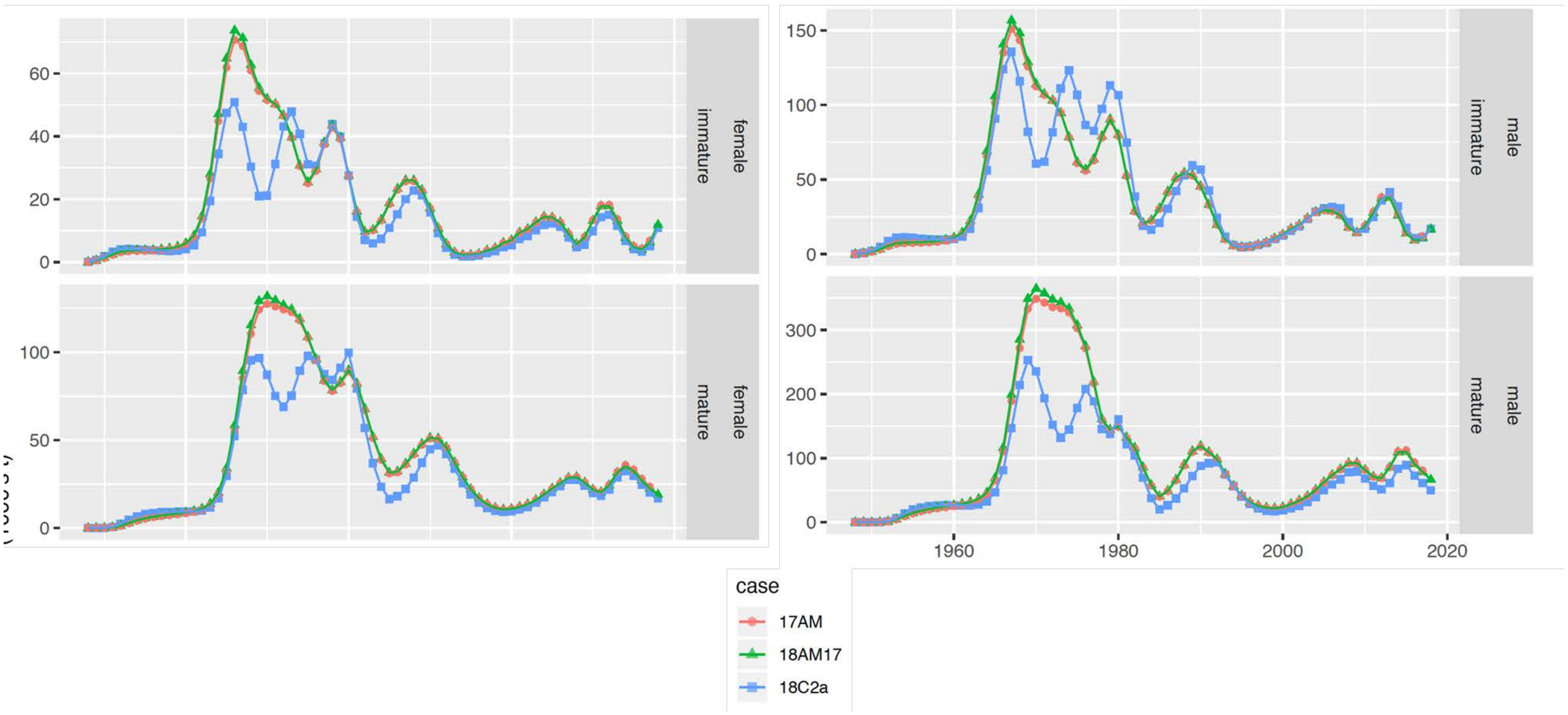


Figure 2. Comparison of estimated population quantities from the CPT's recommended scenario (18AM17), the 2017 assessment model (17AM), and the author's preferred scenario (18C2a).

Population processes

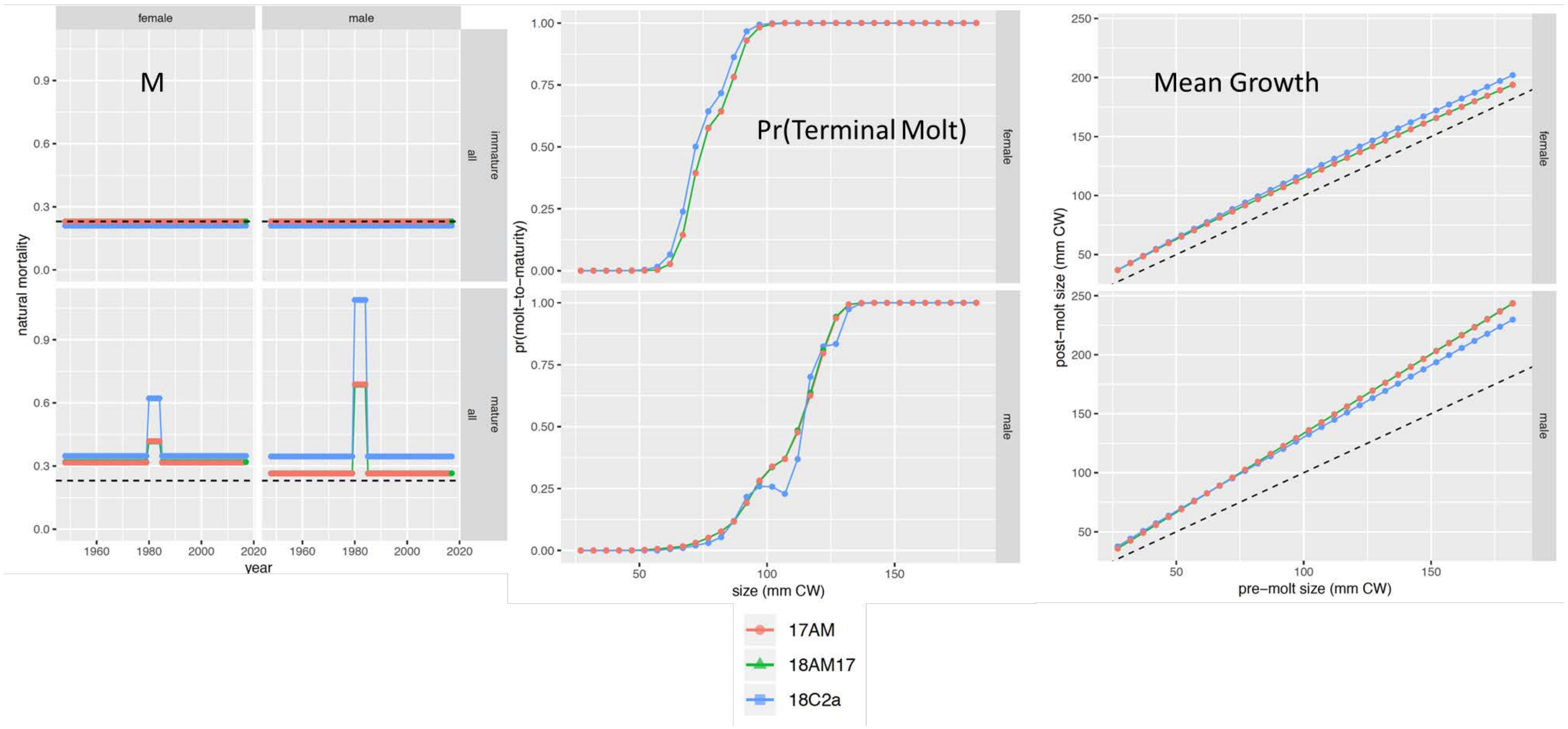
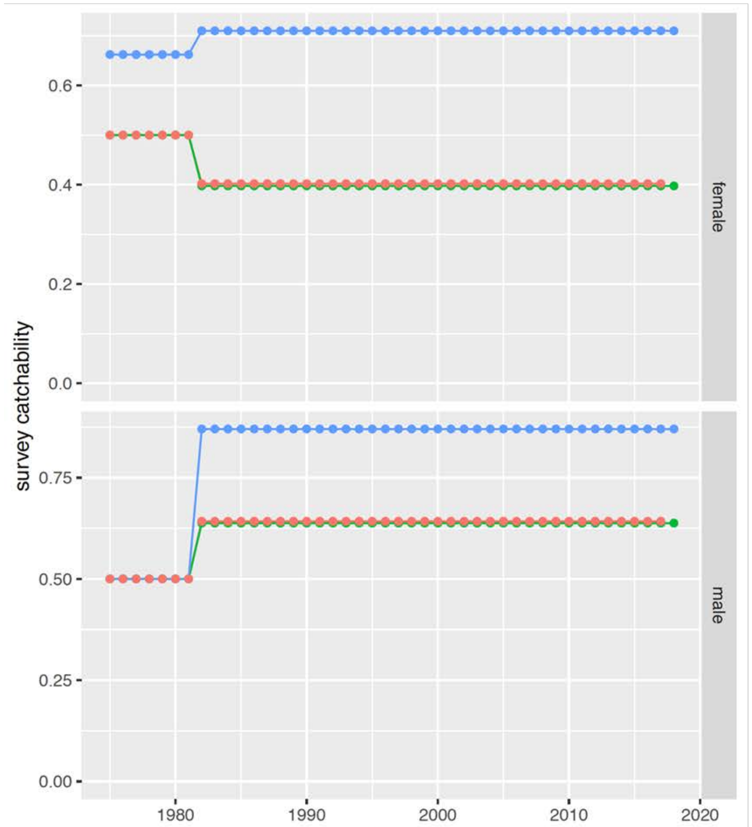
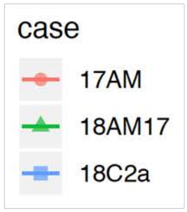


Figure 3. Comparison of estimated population processes from the CPT's recommended scenario (18AM17), the 2017 assessment model (17AM), and the author's preferred scenario (18C2a).

Survey Characteristics





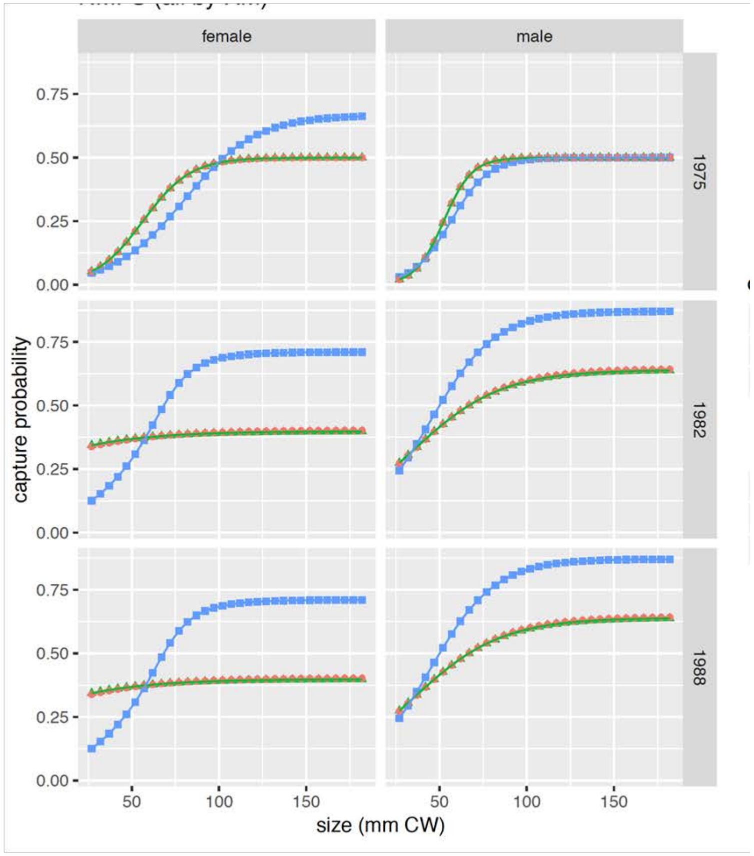


Figure 4. Comparison of estimated survey characteristics from the CPT's recommended scenario (18AM17), the 2017 assessment model (17AM), and the author's preferred scenario (18C2a).

Fishery Catchability

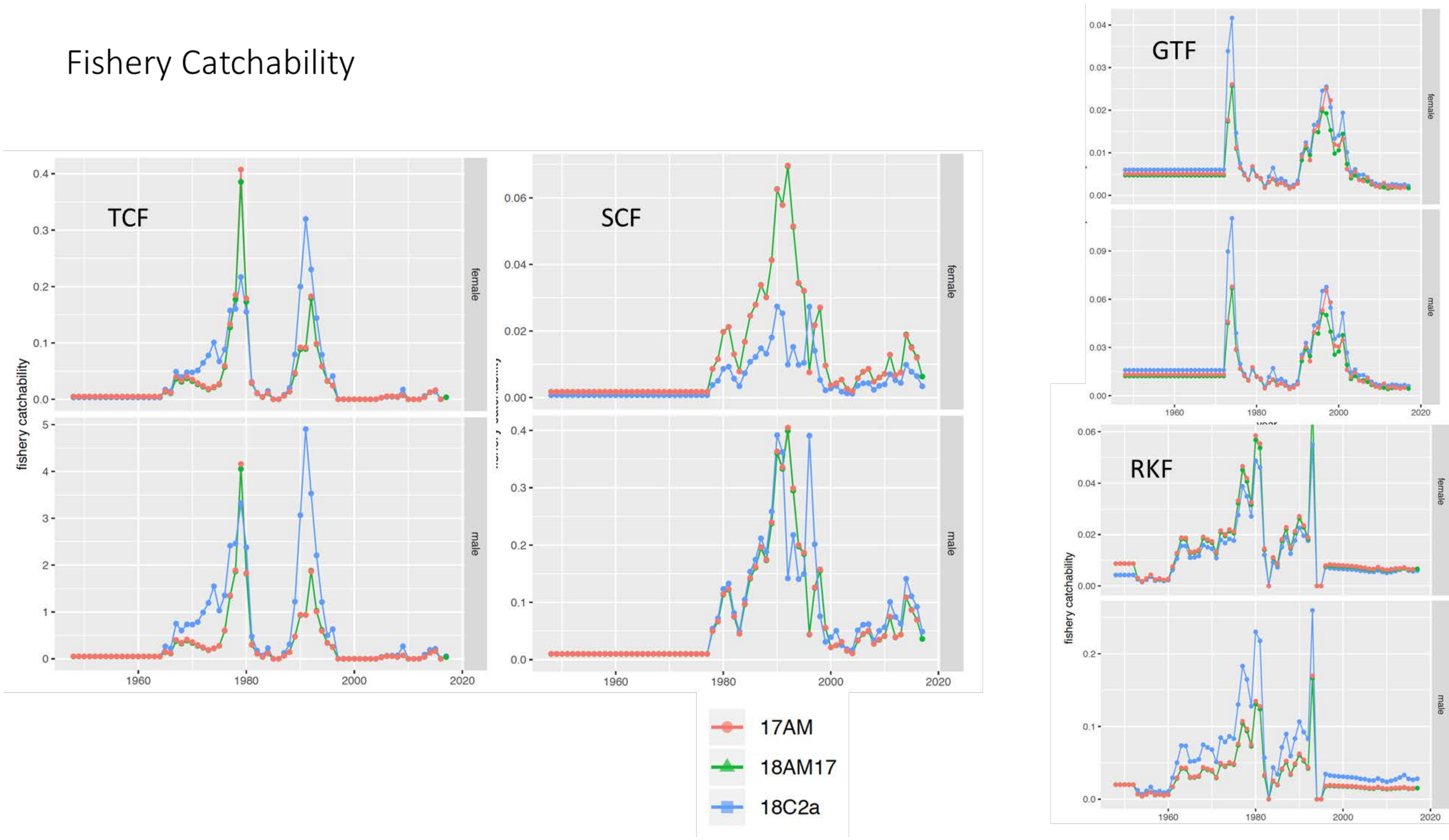


Figure 5. Comparison of estimated fully-selected catchability in the directed and bycatch fisheries from the CPT's recommended scenario (18AM17), the 2017 assessment model (17AM), and the author's preferred scenario (18C2a).

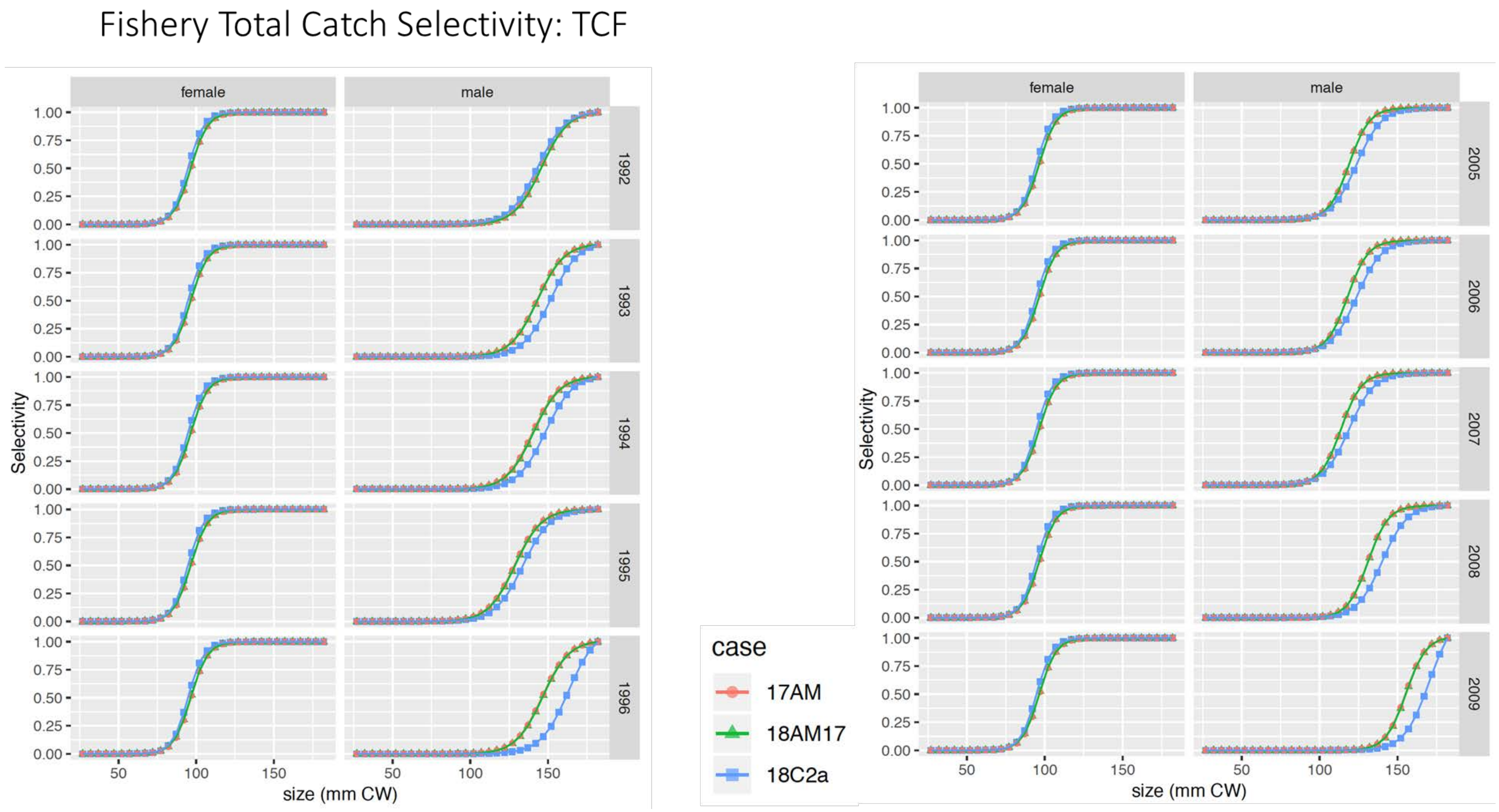


Figure 6. Comparison of estimated selectivity in the directed fishery from the CPT's recommended scenario (18AM17), the 2017 assessment model (17AM), and the author's preferred scenario (18C2a).

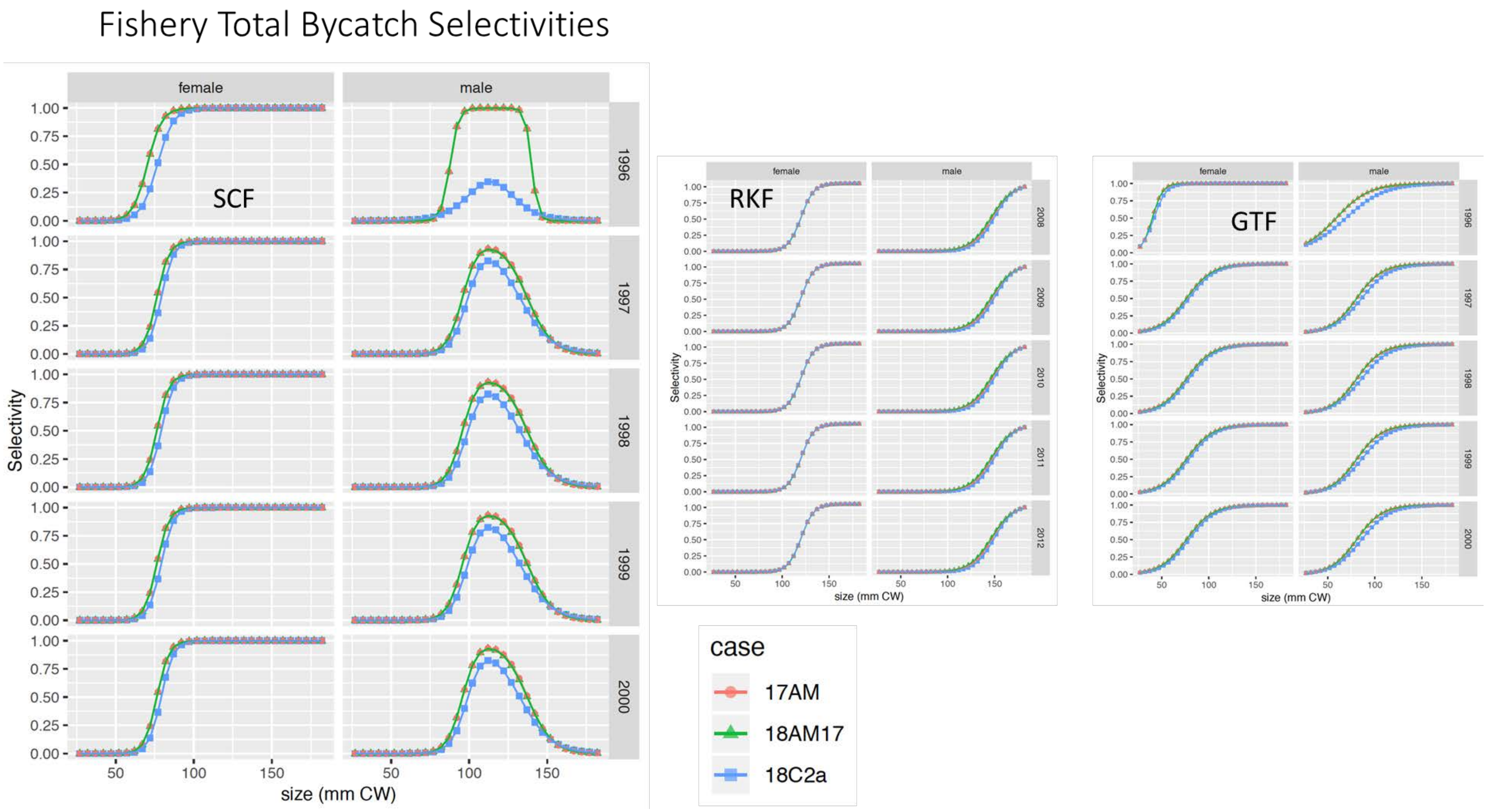


Figure 7. Comparison of estimated selectivities in the bycatch fisheries from the CPT's recommended scenario (18AM17), the 2017 assessment model (17AM), and the author's preferred scenario (18C2a).

Fits to survey biomass

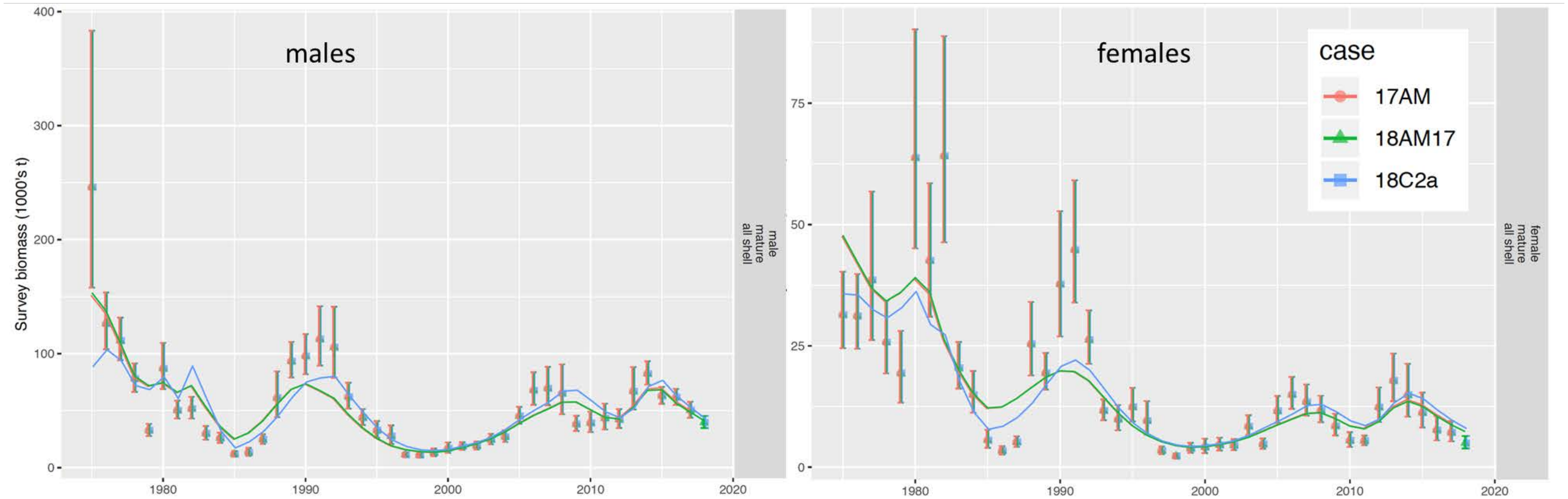


Figure 8. Comparison of fits to survey biomass from the CPT's recommended scenario (18AM17), the 2017 assessment model (17AM), and the author's preferred scenario (18C2a).

Male catch in the directed fishery

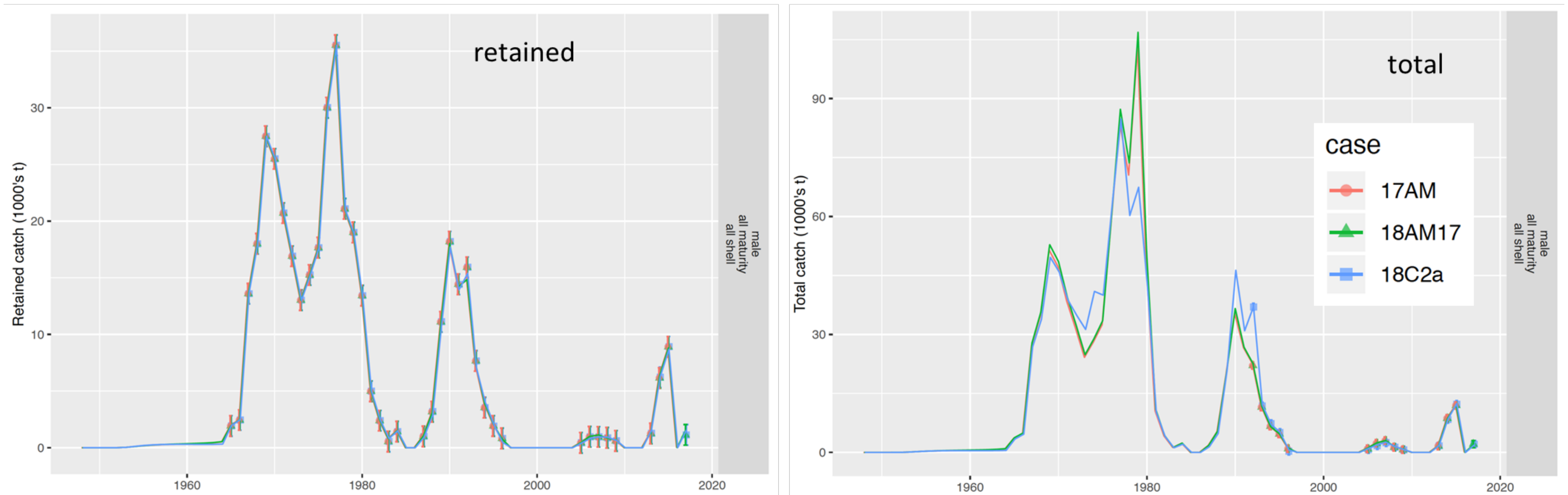


Figure 9. Comparison of fits to male catch biomass in the directed fishery from the CPT's recommended scenario (18AM17), the 2017 assessment model (17AM), and the author's preferred scenario (18C2a).

Fits to total male catch in bycatch fisheries

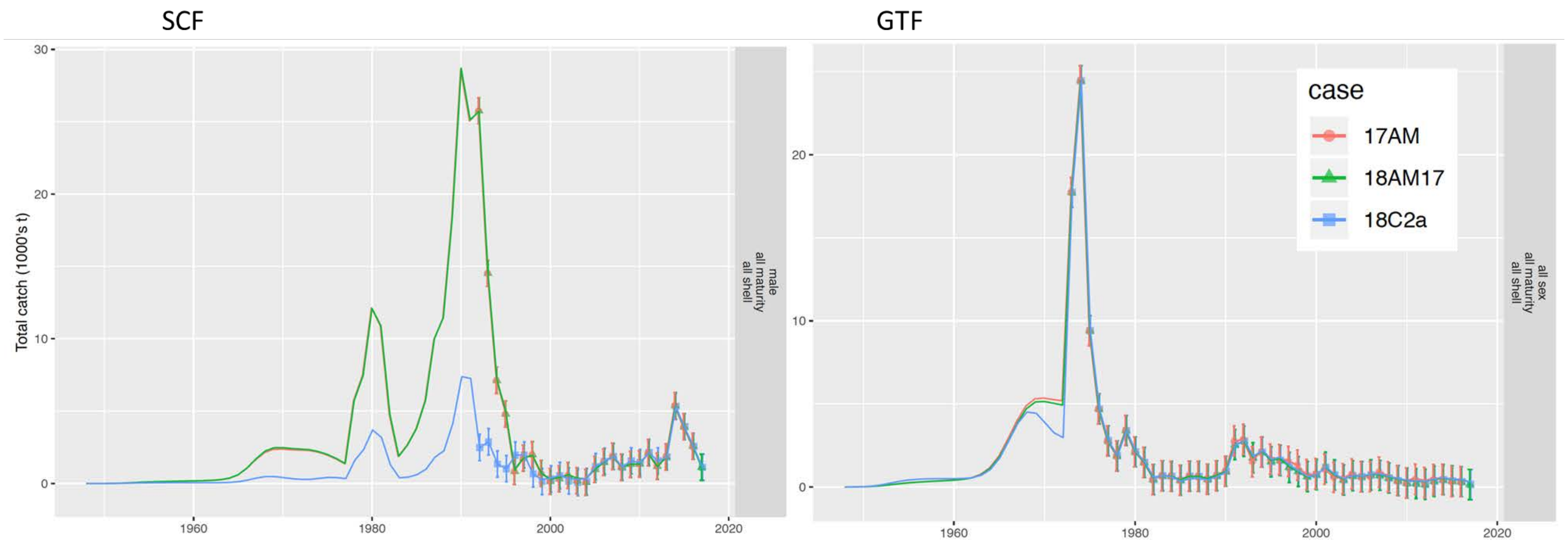


Figure 10. Comparison of fits to total male bycatch in the snow crab and groundfish fisheries from the CPT's recommended scenario (18AM17), the 2017 assessment model (17AM), and the author's preferred scenario (18C2a).

Fits to total male catch in bycatch fisheries

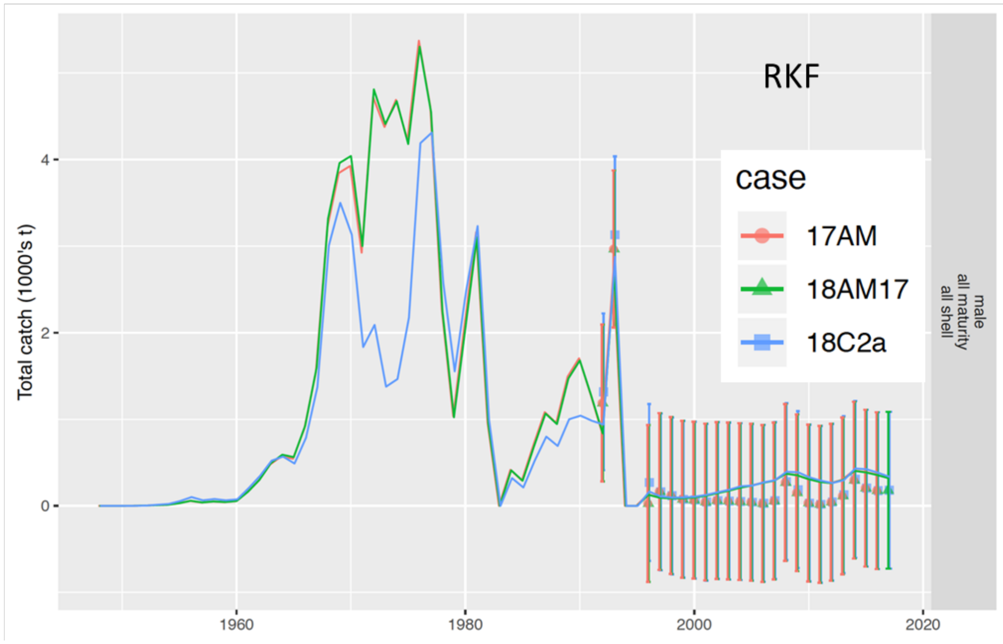


Figure 11. Comparison of fits to total male bycatch in the BBRKC fishery from the CPT's recommended scenario (18AM17), the 2017 assessment model (17AM), and the author's preferred scenario (18C2a).

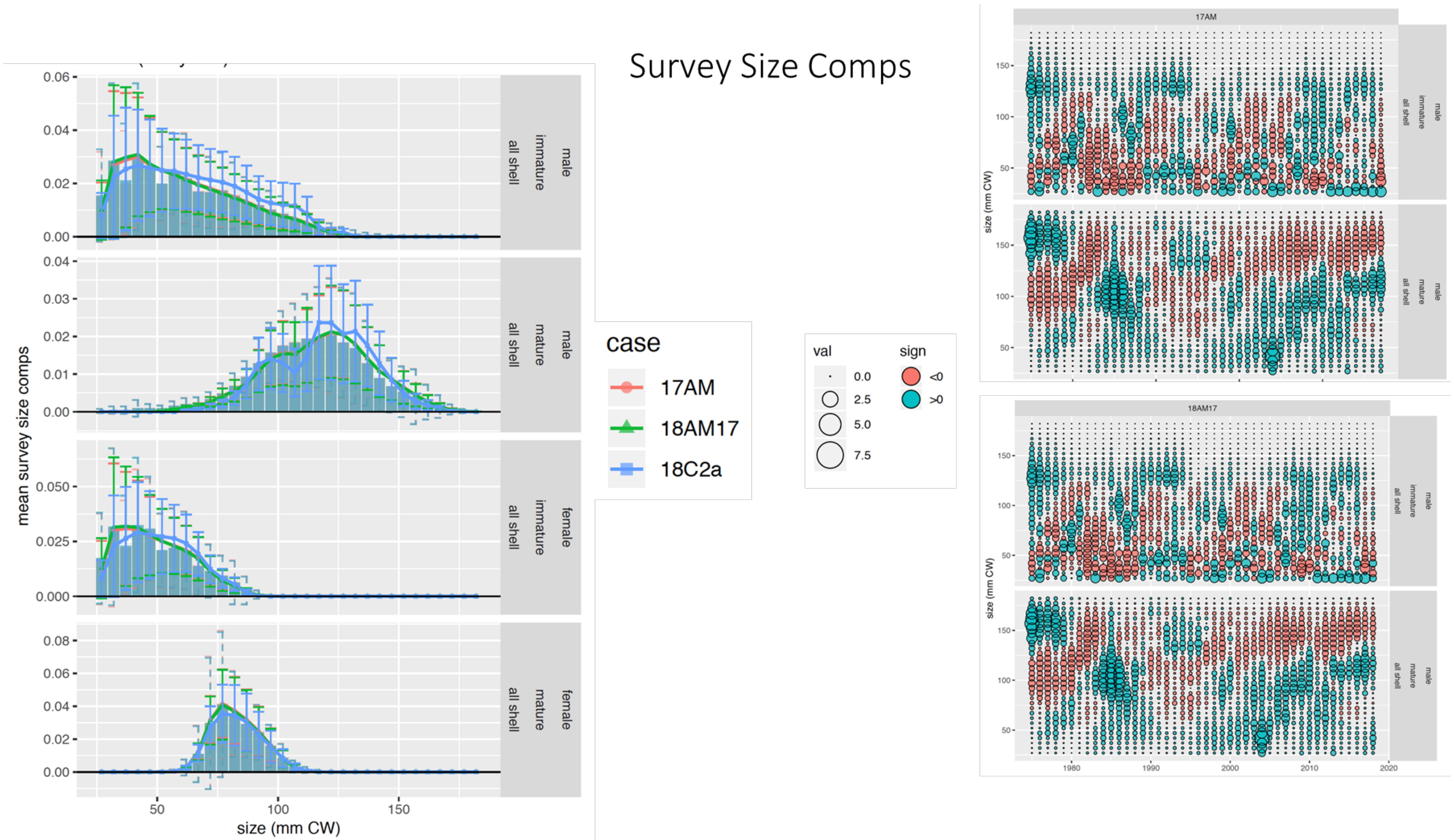


Figure 12. Comparison of mean fits to survey size compositions and residuals from the CPT's recommended scenario (18AM17), the 2017 assessment model (17AM), and the author's preferred scenario (18C2a).

Fishery Size Compositions

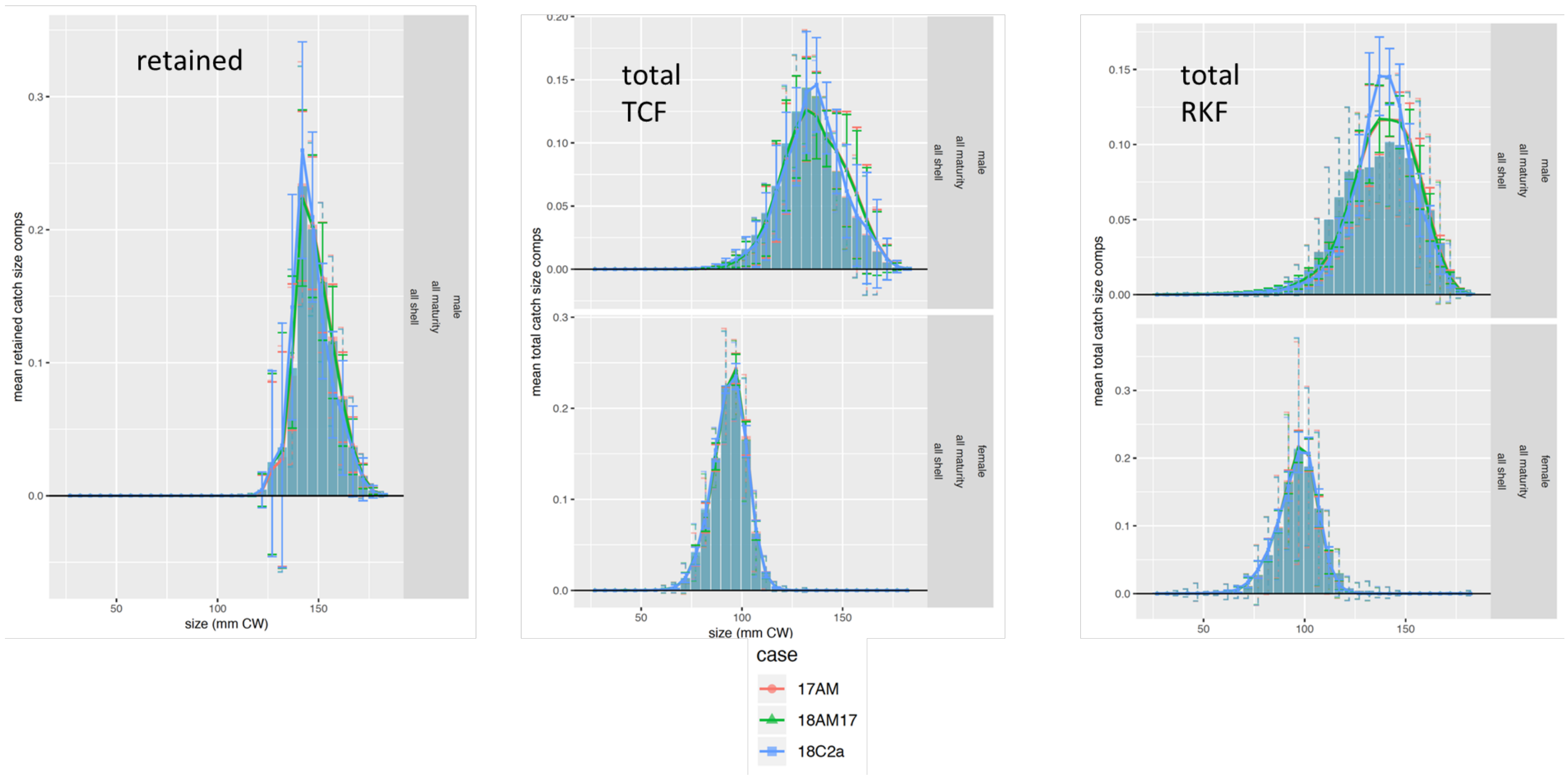


Figure 13. Comparison of mean fits to fishery size compositions from the CPT's recommended scenario (18AM17), the 2017 assessment model (17AM), and the author's preferred scenario (18C2a).

Fishery Size Compositions

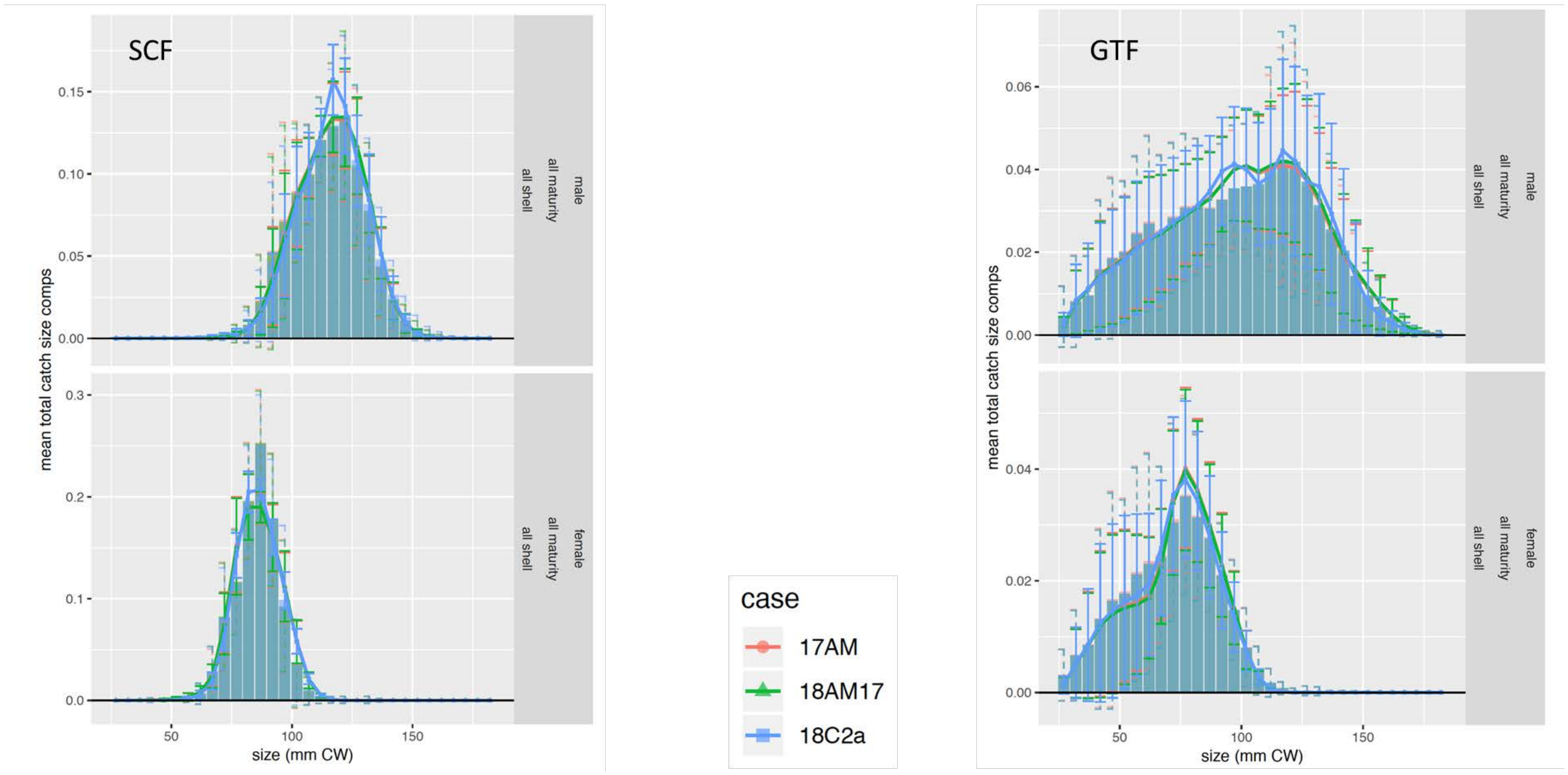


Figure 14. Comparison of mean fits to fishery size compositions from the CPT's recommended scenario (18AM17), the 2017 assessment model (17AM), and the author's preferred scenario (18C2a).

4. Assessment of Pribilof Islands Red King Crab (PIRKC)

[2017]

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[NOTE: In accordance with the approved schedule, no assessment was conducted for this stock this year, however, a full stock assessment will be conducted in 2019. Until then, the values generated from the previous stock assessment (below) will be rolled over for 2018 specifications]

Summary of Results

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
2014/15	2,871	8,894	0	0	1.76	1,359	1,019
2015/16	2,756	9,062	0	0	0.32	2,119	1,467
2016/17	2,302	4,788	0	0	0.49	1,492	1,096
2017/18	2,302	3,364*	0	0	0.28	482	362
2018/19		Not estimated				482*	362*

*Value estimated from the most recent assessment

Historical status and catch specifications for Pribilof Islands red king crab (millions 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
2014/15	6.33	19.61	0	0	0.002	3.00	2.25
2015/16	6.23	19.98	0	0	<0.001	4.67	3.23
2016/17	5.07	10.56	0	0	0.001	3.22	2.42
2017/18		7.42*	0	0	<0.001	1.06	0.80
2018/19						1.06*	0.80*

*Value estimated from the most recent assessment

2017 Stock assessment and fishery evaluation report for the Pribilof Island red king crab fishery of the Bering Sea and Aleutian Islands regions

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Executive summary

1. Stock: Pribilof Islands red king crab, *Paralithodes camtschaticus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been decreasing since 2012/13, and are low relative to the OFL.
3. Stock biomass:
   a. According to the random effects model, mature male biomass decreased from 2007 to 2010 and increased during 2011 through 2015, then declined in 2016 and 2017. MMB at mating was estimated to be above B_{MSY} (4,604 t) in 2016/17 at 4,788 t.
   b. Observed survey mature male biomass (≥120mm) declined from 15,173 t in 2015 to 4,150 t in 2016 and 3,658 t in 2017. Total female biomass declined from 1,898 t in 2016 to 505 t in 2017.

4. Recruitment: No estimates of recruitment are available.
5. Recent management statistics: OFL and ABC in 2011/12 was based on the unweighted 3-year running average. Biomass in 2011/2012 and OFL and ABC from 2012/13 to 2015/16 were based on the weighted 3-year running average using the inverse of the variance. Biomass (MMB) in 2016/17 and 2017/18 is based on the random effects model (CV=2.24) estimated biomass.

Units in tons

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	2,571	2,775	0	0	5.4	393	307
2012/13	2,609	4,025	0	0	13.1	569	455
2013/14	2,582	4,679	0	0	2.25	903	718
2014/15	2,871	8,894	0	0	1.76	1,359	1,019
2015/16	2,756	9,062	0	0	0.32	2,119	1,467
2016/17	2,302[A]	4,788[A]	0	0	0.49	1,492	1,096
2017/18	2,302[A]	3,364[A]				482	362

Units in millions of pounds

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	5.67	6.12	0	0	0.011	0.87	0.68
2012/13	5.75	8.87	0	0	0.029	1.25	1.00
2013/14	5.66	10.32	0	0	0.005	1.99	1.58
2014/15	6.33	19.61	0	0	0.004	3.00	2.25
2015/16	6.08	19.99	0	0	<0.001	4.67	3.23
2016/17	5.07[A]	10.56[A]	0	0	0.001	3.22	2.42
2017/18	5.07[A]	7.42[A]				1.06	0.80

A – Based on the Random effects model (CV=2.24)

The OFL is the total catch OFL for each year. The stock was above MSST in 2016/2017 according to the random effects model (CV=2.24) at 4,788 t (MSST = 2,302 t). The catch in 2016/17 (0.49 t) was below the OFL (1,492 t) and the ABC (1,096 t).

6. 2017/2018 OFL projections:
All biomass in tons

Tier	Assessment Method	OFL	B_{MSY}	MMB At mating[A]	B/B_{MSY} (MMB)	*MMB at mating Feb 15 2017*	γ	Years to define B_{MSY}	F_{MSY}	ABC (p*=0.49)	ABC = 0.75* OFL
4b	Running Average	330	5,502	3,139	0.57	6,445	1	1991/1992-2016/2017 (MMB)	0.06	319	248
4b	Random Effects Model fixed	442	4,711	3,274	0.69	4,683	1	1991/1992-2016/2017 (MMB)	0.12	428	332
4b	Random Effects Model prior cv 2.24	482	4,604	3,364	0.73	4,788	1	1991/1992-2016/2017 (MMB)	0.13	467	362
4b	Random Effects Model prior cv 4.0	573	4,397	3,563	0.81	4,961	1	1991/1992-2016/2017 (MMB)	0.14	554	429
4b	Observed Survey	291	5,502	2,971	0.54	3,681	1	1991/1992-2016/2017 (MMB)	0.09	280	218

A: Feb. 15, 2018 fishing at OFL

For the following Table units are in millions of pounds.

Tier	Assessment Method	OFL	B_{MSY}	MMB At mating[A]	B/B_{MSY} (MMB)	*MMB at mating Feb 15 2017*	γ	Years to define B_{MSY}	F_{MSY}	ABC (p*=0.49)	ABC = 0.75* OFL
4b	Running Average	0.73	12.13	6.92	0.57	14.21	1	1991/1992-2016/2017 (MMB)	0.06	0.70	0.55
4b	Random Effects Model fixed	0.97	10.39	7.22	0.69	10.32	1	1991/1992-2016/2017 (MMB)	0.12	0.94	0.73
4b	Random Effects Model prior cv 2.24	1.06	10.15	7.42	0.73	10.56	1	1991/1992-2016/2017 (MMB)	0.13	1.03	0.80
4b	Random Effects Model prior cv 4.0	1.26	9.69	7.85	0.81	10.94	1	1991/1992-2016/2017 (MMB)	0.14	1.22	0.95
4b	Observed Survey	0.64	12.13	6.55	0.54	8.12	1	1991/1992-2016/2017 (MMB)	0.09	0.62	0.48

A. Feb. 15, 2018 fishing at OFL

7. Probability distributions of the OFL for tier 4 methods were generated by bootstrapping values of MMB in the current year with an additional sigma of 0.3.
8. Basis for ABC: ABCs were identified as the 49th percentile of the distributions of the OFL given a p-star of 0.49. In addition the ABC was estimated using a 25% buffer from the OFL as recommended by the CPT and SSC in 2016/17.

Summary of Major Changes:

1. Management: None.
2. Input data: Survey (2017) and bycatch (2016/17) data were incorporated into the assessment.
3. Assessment methodology: The 3-year running average and random effects models only are presented in this assessment.
4. Assessment results: Male biomass estimates from the 3-year running average and a random effects model were fit to survey male biomass ≥120mm with process error fixed at the value estimated from a simple exponential model and with a prior with mean equal to the process error estimated from the simple exponential model and with cv=2.24 and cv=4.0. Tier 4 control rules are used to estimate MMB at mating, OFL, and ABC for the four models.

CPT comments May 2017

The CPT recommended that the author continue to develop the random effects model and consider the following for models at the September CPT:

1. Better describe the exponential smoother methods and bring forward one model with the exponential model result as a prior and one model with the process error based on the exponential model fixed.

Included are 3 runs of the random effects model: 1) fixed process error at simple exponential model value, 2) with cv of 2.2 in the prior, and 3) cv of 4.0 in the prior.

2. Status quo 3-year running average.

Included.

3. Consider fitting to the female biomass to determine if assessing the effects of single sex high biomass tows are informative for determining the observed error relative to process error.

The random effects model did not converge using female biomass. The simple exponential model was fit to female biomass to compare the estimate of process error to fitting male biomass.

4. Consider fitting spatial models (e.g., Thorson et al. 2015) to the survey data that may better account for zero tows and high biomass tows.

Not done in this assessment.

SSC comments June 2017

There were no comments specific to the Pribilof red king crab assessment by the SSC in June 2017.

1. Introduction

1.1 Distribution

Red king crabs, *Paralithodes camtschaticus,* (Tilesius, 1815) are anomurans in the family Lithodidae and are distributed from the Bering Sea south to the Queen Charlotte Islands and to Japan in the western Pacific (Jensen 1995; Figure 1). Red king crabs have also been introduced and become established in the Barents Sea (Jørstad et al. 2002). The Pribilof Islands red king crab stock is located in the Pribilof District of the Bering Sea Management Area Q. The Pribilof District is defined as Bering Sea waters south of the latitude of Cape Newenham (58° 39’ N lat.), west of 168° W long., east of the United States – Russian convention line of 1867 as amended in 1991, north of 54° 36’ N lat. between 168° 00’ N and 171° 00’ W long and north of 55° 30’N lat. between 171° 00’ W. long and the U.S.-Russian boundary (Figure 2).

1.2 Stock structure

Populations of red king crab in the eastern Bering Sea (EBS) for which genetic studies have been performed appear to be composed of four stocks: Aleutian Islands, Norton Sound, Southeast Alaska, and the rest of the EBS. Seeb and Smith (2005) reported micro-satellite samples from Bristol Bay, Port Moller, and the Pribilof Islands were divergent from the Aleutian Islands and Norton Sound. A more recent study describes the genetic distinction of Southeast Alaska red king crab compared to Kodiak and the Bering Sea; the latter two being similar (Grant and Cheng 2012).

1.3 Life history

Red king crabs reproduce annually and mating occurs between hard-shelled males and soft-shelled females. Red king crabs do not have spermathecae and cannot store sperm, therefore a female must mate every year to produce a fertilized clutch of eggs (Powell and Nickerson 1965). A pre-mating embrace is formed 3-7 days prior to female ecdysis, the female molts, and copulation occurs within hours. The male inverts the female so they are abdomen to abdomen and then the male extends his fifth pair of periopods to deposit sperm on the female’s gonopores. Eggs are fertilized after copulation as they are extruded through the gonopores located at the ventral surface of the coxopides of the third periopods. The eggs form a spongelike mass, adhering to the setae on the pleopods where they are brooded until hatching (Powell and Nickerson 1965). Fecundity estimates are not available for Pribilof Islands red king crab, but range from 42,736 to 497,306 for Bristol Bay red king crab (Otto et al. 1990). The estimated size at 50 percent maturity of female Pribilof Islands red king crabs is approximately 102 mm carapace length (CL) which is larger than 89 mm CL reported for Bristol Bay and 71 mm CL for Norton Sound (Otto et al. 1990). Size at maturity has not been determined specifically for Pribilof Islands red king crab males, however, approximately 103 mm CL is reported for eastern Bering Sea male red king crabs (Somerton 1980). Early studies predicted that red king crab become mature at approximately age 5 (Powell 1967; Weber 1967); however, Stevens (1990) predicted mean age at recruitment in Bristol Bay to be 7 to 12 years, and Loher et al. (2001) predicted age to recruitment to be approximately 8 to 9 years after settlement. Based upon a long-term laboratory study, longevity of red king crab males is approximately 21 years and less for females (Matsuura and Takeshita 1990).

Natural mortality of Bering Sea red king crab stocks is poorly known (Bell 2006). Siddeek et al. (2002) reviewed natural mortality estimates from various sources. Natural mortality estimates based upon historical tag-recapture data range from 0.001 to 0.93 for crabs 80-169 mm CL with natural mortality increasing with size. Natural mortality estimates based on more recent tag-recovery data for Bristol Bay red king crab males range from 0.54 to 0.70, however, the authors noted that these estimates appear high considering the longevity of red king crab. Natural mortality estimates based on trawl survey data vary from 0.08 to 1.21 for the size range 85-169 mm CL, with higher mortality for crabs <125 mm CL. In an earlier analysis that utilized the same data sets, Zheng et al. (1995) concluded that natural mortality is dome shaped over length and varies over time. Natural mortality was set at 0.2 for Bering Sea king crab stocks (NPFMC 1998) and was changed to 0.18 with Amendment 24.

The reproductive cycle of Pribilof Islands red king crabs has not been established, however, in Bristol Bay, timing of molting and mating of red king crabs is variable and occurs from the end of January through the end of June (Otto et al. 1990). Primiparous (i.e. brooding their first egg clutch) Bristol Bay red king crab females extrude eggs on average 2 months earlier in the reproductive season and brood eggs longer than multiparous (i.e. brooding their second or subsequent egg clutch) females (Stevens and Swiney 2007a, Otto et al. 1990), resulting in incubation periods that are approximately eleven to twelve months in duration (Stevens and Swiney 2007a, Shirley et al. 1990). Larval hatching among red king crabs is relatively synchronous among stocks and in Bristol Bay occurs March through June with peak hatching in May and June (Otto et al. 1990), however larvae of primiparous females hatch earlier than multiparous females (Stevens and Swiney 2007b, Shirley and Shirley 1989). As larvae, red king crabs exhibit four zoeal stages and a glaucothoe stage (Marukawa 1933).

Growth parameters have not been examined for Pribilof Islands red king crabs; however they have been studied for Bristol Bay red king crab. A review by the Center for Independent Experts (CIE) reported that growth parameters are poorly known for all red king crab stocks (Bell 2006). Growth increments of immature southeastern Bering Sea red king crabs are approximately: 23% at 10 mm CL, 27% at 50 mm CL, 20% at 80 mm CL and 16 mm for immature crabs over 69 mm CL (Weber 1967). Growth of males and females is similar up to approximately 85 mm CL, thereafter females grow more slowly than males (Weber 1967; Loher et al. 2001). In a laboratory study, growth of female red king crabs was reported to vary with age; during their pubertal molt (molt to maturity) females grew on average 18.2%, whereas primiparous females grew 6.3% and multiparous females grew 3.8% (Stevens and Swiney, 2007a). Similarly, based upon tag-recapture data from 1955-1965 researchers observed that adult female growth per molt decreases with increased size (Weber 1974). Adult male growth increment averages 17.5 mm irrespective of size (Weber 1974).

Molting frequency has been studied for Alaskan red king crabs, but Pribilof Islands specific studies have not been conducted. Powell (1967) reports that the time interval between molts increases from a minimum of approximately three weeks for young juveniles to a maximum of four years for adult males. Molt frequency for juvenile males and females is similar and once mature, females molt annually and males molt annually for a few years and then biennially, triennially and quadrennial (Powell 1967). The periodicity of mature male molting is not well understood and males may not molt synchronously like females who molt prior to mating (Stevens 1990).

1.4 Management history

Red king crab stocks in the Bering Sea and Aleutian Islands are managed by the State of Alaska through the federal Fishery Management Plan (FMP) for Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 1998). The Alaska Department of Fish and Game (ADF&G) has not published harvest regulations for the Pribilof district red king crab fishery. The king crab fishery in the Pribilof District began in 1973 with blue king crab *Paralithodes platypus* being targeted (Figure 3). A red king crab fishery in the Pribilof District opened for the first time in September 1993. Beginning in 1995, combined red and blue king crab

GHLs were established. Declines in red and blue king crab abundance from 1996 through 1998 resulted in poor fishery performance during those seasons with annual harvests below the fishery GHL. The North Pacific Fishery Management Council (NPFMC) established the Bering Sea Community Development Quota (CDQ) for Bering Sea fisheries including the Pribilof Islands red and blue king crab fisheries which was implemented in 1998. From 1999 to present the Pribilof Islands fishery was not open due to low blue king crab abundance, uncertainty with estimated red king crab abundance, and concerns for blue king crab bycatch associated with a directed red king crab fishery. Pribilof Islands blue king crab was declared overfished in September of 2002 and is still considered overfished (see Bowers et al. 2011 for complete management history).

Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 4) which prohibits the use of trawl gear in a specified area around the Pribilof Islands year round (NPFMC 1994). The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from impacts from trawl gear.

Pribilof Islands red king crab often occur as bycatch in the eastern Bering Sea snow crab (*Chionoecetes opilio*), eastern Bering Sea Tanner crab (*Chionoecetes bairdi*), Bering Sea hair crab (*Erimacrus isenbeckii*), and Pribilof Islands blue king crab fisheries (when there is one). Limited non-directed catch exists in crab fisheries and groundfish pot and hook and line fisheries (see bycatch and discards section below). However, bycatch is currently very low compared to historical levels.

2. Data

The standard groundfish discards time series data (updated through 2016/17) were used in this assessment. The crab fishery retained and discard catch time series were updated with 2016/2017 data. The following sources and years of data are available:

Data source	Years available
NMFS trawl survey	1975-2017
Retained catch	1993-2016/17
Trawl bycatch	1991-2016/17
Fixed gear bycatch	1991-2016/17
Pot discards	1998-2016/17

2.1 Retained catch

Red king crab were targeted in the Pribilof Islands District from the 1993/1994 season to 1998/1999. Live and deadloss landings data and effort data are available during that time period (Tables 1 and 2), but no retained catch has been allowed since 1999.

2.2 Bycatch and discards

Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers. Catch weight was calculated by first determining the mean weight (g) for crabs in each of three categories: legal non-retained, sublegal, and female. Length to weight parameters were available for two time periods: 1973 to 2009 (males: A=0.000361, B=3.16; females: A=0.022863, B=2.23382) and 2010 to 2013 (males: A=0.000403, B=3.141; ovigerous females: A=0.003593, B=2.666; non-ovigerous females: A=0.000408, B=3.128). The average weight for each category was multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 2).

$$\text{Weight (g)} = A * \text{CL(mm)}^{B} \quad (1)$$

$$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \quad (2)$$

Finally, weights, discards, and bycatch were the product of average weight, CPUE, and total pot lifts in the fishery. A 20% handling mortality rate was applied to these estimates (assumed the same as Bristol Bay red king crab).

Historical non-retained catch data are available from 1998/1999 to present from the snow crab, golden king crab (*Lithodes aequispina*), and Tanner crab fisheries (Table 3) although data may be incomplete for some of these fisheries. Limited observer data exists prior to 1998 for catcher-processor vessels only so non-retained catch before this date are not included here. In 2016/2017 there was no catch of Pribilof Islands red king crab from crab fisheries (Table 3).

2.3 Groundfish pot, trawl, and hook and line fisheries

The data through 2016/2017 from the NOAA Fisheries Regional Office (J. Gasper, NMFS, personal communication) assessments of non-retained catch from all groundfish fisheries are included in this SAFE report. Groundfish catches of crab are reported for all crab combined by federal reporting areas and by State of Alaska reporting areas since 2009/2010. Catches from observed fisheries were applied to non-observed fisheries to estimate a total catch. Catch counts were converted to biomass by applying the average weight measured from observed tows from July 2011 to June 2012. Prior to 2011/2012, Areas 513 and 521 were included in the estimate, a practice that likely resulted in an overestimate of the catch of Pribilof Islands red king crab due to the extent of Area 513 into the Bristol Bay District. In 2012/2013 these data were available in State of Alaska reporting areas that overlap specifically with stock boundaries so that the management unit for each stock can be more appropriately represented. To estimate sex ratios it was assumed that the male to female ratio was one. To assess crab mortalities in these groundfish fisheries a 50% handling mortality rate was applied to pot and hook and line estimates and an 80% handling mortality rate was applied to trawl estimates.

Historical non-retained groundfish catch data are available from 1991/1992 to present (J. Mondragon, NMFS, personal communication) although sex ratios have not been determined (Table 3). Prior to 1991, data are only available in INPFC reports. Between 1991 and December 2001 bycatch was estimated using the "blend method". The blend method combined data from industry production reports and observer reports to make the best, comprehensive accounting of groundfish catch. For shoreside processors, Weekly Production Reports (WPR) submitted by industry were the best source of data for retained groundfish landings. All fish delivered to shoreside processors were weighed on scales, and these weights were used to account for retained catch. Observer data from catcher vessels provided the best data on at-sea discards of groundfish by vessels delivering to shoreside processors. Discard rates from these observer data were applied to the shoreside groundfish landings to estimate total at-sea discards from both observed and unobserved catcher vessels. For observed catcher/processors and motherships, the WPR and the Observer Reports recorded estimates of total catch (retained catch plus discards). If both reports were available, one of them was selected during the "blend method" for incorporation into the catch database. If the vessel was unobserved, only the WPR was available. From January 2003 to December 2007, a new database structure named the Catch Accounting System (CAS) led to large method change. Bycatch estimates were derived from a combination of observer and landing (catcher vessels/production data). Production data included CPs and catcher vessels delivering to motherships. To obtain fishery level estimates, CAS used a ratio estimator derived from observer data (counts of crab/kg groundfish) that is applied to production/landing information. (See http://www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-205.pdf). Estimates of crab are in numbers because the PSC is managed on numbers. There were two issues with this dataset that required estimation work outside of CAS:

1) The estimated number of crab had to be converted to weights. An average weight was calculated using groundfish observer data. This weight was specific to crab year, crab species, and fixed or

trawl gear. This average was applied to the estimated number of crab for crab year by federal reporting area.

2) In some situations, crab estimates were identified and grouped in the observed data to the genus level. These crabs were apportioned to the species level using the identified crab.

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

Starting in 2013, a new data set based on the CAS system was made available for January 2009 to present. In 2009 reporting State statistical areas was required on groundfish production reports. The level of spatial resolution in CAS was formally federal reporting area since this the highest spatial resolution at which observer data is aggregated to create bycatch rates. The federal reporting area does not follow crab stock boundaries, in particular for species with small stock areas such as Pribilof Islands or St. Matthew Island stocks, so the new data was provided at the State reporting areas. This method uses ratio estimator (weight crab/weight groundfish) applied to the weight of groundfish reported on production/landing reports. Where possible, this dataset aggregates observer data to the stock area level to create bycatch estimates by stock area. There are instances where no observer data is available and aggregation may go outside of a stock area, but this practice is greatly reduced compared with the pre-2009 data, which at best was at the Federal reporting area level.

Total catch in 2015/16 was 0.32 t and in 2016/17 0.49 t below the 2016/17 OFL 1,492 t and below the ABC of 1,096 t (Tables 3 and 5, Figures 13 and 14). Catch by weight in 2016/17 was 81% from non-pelagic trawl and 19% from hook and line fisheries (Table 4).

2.4 Catch-at-length

Catch-at-length data are not available for this fishery.

2.5 Survey biomass and length frequencies

The 2017 NOAA Fisheries EBS bottom trawl survey results are included in this SAFE report. Data available for estimating the abundance of crab around the Pribilof Islands are relatively sparse. Red king crab have been observed at 35 unique tows in the Pribilof District over the years 1975 to 2017 (in 22 of the 20nm x 20nm station grids). The number of stations at which at least one crab was observed in a given year ranges from 0 (in 1975) to 14 (in 2000 and 2013) over the period from 1975-present (Figure 5).

Observed survey biomass estimates for males $\geq$120 mm are used in the Tier 4 assessment as an estimate of mature male biomass and to estimate the B_{MSY} proxy, MMB at mating and in fitting the 3-yr running average and the random effects model.

Historical survey data are available from 1975 to the present (Tables 6 and 7), and survey data analyses were standardized in 1980 (Stauffer, 2004). Male and female abundance varies widely over the history of the survey time series and uncertainty around area-swept estimates of abundance are large due to relatively low sample sizes (Table 7). Male crabs were observed at 9 of 35 stations in the Pribilof District during the 2015 NMFS survey (Figure 6); female crabs were observed at 5 (Figure 7). Two (possibly three) cohorts can be seen moving through the length frequencies over time (Figures 8 and 9). Numbers at length vary dramatically from year to year, but the cohorts can nonetheless also be discerned in these data (Figure 10 and Figure 11).

The centers of distribution for both males and females have moved within a 40 nm by 40 nm region around St. Paul Island. The center of the red king crab distribution moved to within 20 nm of the northeast side of St. Paul Island as the population abundance increased in the 1980's and remained in that region until the 1990's. Since then, the centers of distribution have been located closer to St. Paul Island the exception of 2000-2003 located towards the north east.

Survey abundance for males ≥105 mm declined from 3,662,609 in 2015 to 1,807,323 in 2016 and again in 2017 to 1,158,383 (Table 6). Female biomass (all sizes) declined from 3,859 t in 2015 to 1,898 t in 2016 and declined further in 2017 to 505 t. Survey biomass for males ≥120mm declined from 15,173 t in 2015 to 4,150 t in 2016 and declined further in 2017 to 3,658 t (Table 8).

3. Analytical approaches

3.1 History of modeling

An inverse-variance weighted 3-year running average of male biomass (≥120mm) based on densities estimated from the NMFS summer trawl survey has been used in recent years to set allowable catches. The natural mortality rate has been used as a proxy for the fishing mortality at which maximum sustainable yield occurs (F_{MSY}) and target biomasses are set by identifying a range of years over which the stock was thought to be near B_{MSY} (i.e. a tier 4 control rule).

In 2017, biomass and derived management quantities are estimated by a 3-yr running-average method and a random effects method. The Tier 4 harvest control rule (HCR) is applied to the running-average and random effects estimates of mature male biomass (≥120mm). The current year biomass estimate was projected forward to February 15 for use in the OFL control rule to estimate the OFL and ABC. The B_{MSY} proxy for both the 3-yr running average and the random effects model was estimated as the average of the 1991/92 to 2016/17 observed survey data projected forward to February 15, removing the observed catch.

3.2 Model descriptions

3.2.1. Running average

A 3 year running average of male biomass (≥120mm) at survey time was calculated using the weighted average with weights being the inverse of the variance,

$$BWRA_t = \frac{\sum_{t-1}^{t+1} \frac{MMB_t}{\sigma_t^2}}{\sum_{t-1}^{t+1} \frac{1}{\sigma_t^2}} \tag{4}$$

Where,

MMB_t	Estimated male biomass (≥120mm) from the survey data
σ_t^2	The variance associated with the estimate of MMB in year t

w_t is calculated as the variance of the log(biomass) using the CVs of the estimates of MMB from the survey provided by the Kodiak lab:

$$w_t = \ln((CV_t^{MMB})^2 + 1) \tag{5}$$

Where,

CV_t^{MMB}	Coefficient of variation associated with the estimate of MMB at time t

3.2.2 Random Effects Model

A random effects model was fit to the survey male biomass (≥120mm) for estimation of current biomass, MMB at mating, OFL and ABC (Model developed for use in NPFMC groundfish assessments). The model uses the CVs as calculated for the 3-yr running average. The random effects model was fit to the log of survey biomass at the time of the survey. The likelihood equation for the random effects model is,

$$\sum_{i=1}^{yrs}\left\{0.5\left(\log(2\pi\sigma_i^2)+\left(\frac{(\hat{B}_i-B_i)^2}{\sigma_i^2}\right)\right)\right\}+\sum_{t=2}^{yrs}\left\{0.5\left(\log(2\pi\sigma_p^2)+\left(\frac{(\hat{B}_t-\hat{B}_{t-1})^2}{\sigma_p^2}\right)\right)\right\}$$

Where,

B_i is the log of observed biomass in year i,

$\widehat{B_t}$ is the model estimated log biomass in year t,

σ_i^2 is the variance of observed log biomass in year i,

σ_p^2 is the variance of the deviations in log survey biomass between years (i.e. process error variance), σ_p^2 was estimated as $e^{(2\lambda)}$, where λ is a parameter estimated in the random effects model and,

Yrs is the number of years of survey biomass values.

In the case where the random effects model does not converge due to high observation errors, an estimate of the process error is necessary to use as a prior or to fix in the model (P. Spencer pers. comm., Figure 15). A simple exponential model can be used to estimate the ratio of observation error to process error in a time series,

$$\hat{z}_t = \alpha y_t + \alpha(1-\alpha)y_{t-1} + \alpha(1-\alpha)^2 y_{t-2} + \alpha(1-\alpha)^3 y_{t-3} + \cdots,$$

Where,

$\hat{z}_0$ is set equal to y_0, the log of observed biomass in the first year,

y_t is the log of observed biomass in year t and,

α is the parameter estimated in the model which ranges from 0 to 1.

An estimate of the ratio of observation error (σ_o^2) to process error (σ_p^2) (log scale) is,

$$\frac{\sigma_o^2}{\sigma_p^2} = \frac{(1-\alpha)}{\alpha^2}$$

.

An estimate of λ to use as a prior in the random effects model is,

$$\lambda = 0.5\log(\sigma_p^2)$$

The variance of α is an output of the arima function in R which was used to fit the simple exponential model. A bootstrap using the logit distribution on α was used to approximate the variance of λ for use in the prior that is added to the likelihood in the random effects model,

$$0.5\,\frac{(\lambda - \lambda_p)^2}{\sigma_\lambda^2}$$

Where,

λ_p is the prior estimate of λ from the simple exponential model

σ_λ^2 is the variance of λ_p estimated from the parametric bootstrap.

The random effects model was run with λ fixed at the value estimated from the simple exponential model and with λ estimated adding the prior likelihood into the random effects model.

4. Model Selection and Evaluation

The running average method with a tier 4 HCR was selected in 2016 by the SSC as the model to determine the OFL and ABC based on concerns around different trends over the last decade between the integrated model and the running average and the lack of fit of the integrated model to survey abundance data. Four assessment methods are presented here for comparison: a running average with a tier 4 HCR, a random effects model with fixed λ, and a random effects model with a prior likelihood component added for λ.

5.0 Results

5.1 Tier 4

Survey mature male biomass (≥120mm) declined from 4,150 t in 2016 to 3,658 t in 2017. The 3-yr running average estimate of mature male biomass (≥120mm) was 3,888 t in 2017 at the survey time, while the random effects model with process error fixed estimate was 4,163 t (Table 8 and Figure 16). The simple exponential model estimated α = 0.705 with a standard deviation of 0.134, which results in σ_p^2 = 0.643 and a CV=2.24 (estimated from bootstrap). When process error is estimated with a prior in the random effects model with a CV = 2.24, the 2017 biomass estimate was estimated at 4,307 t. When process error is estimated with a prior in the random effects model with a CV = 4.0, the 2017 biomass estimate was 4,633 t and results in more smoothing of the estimates (Figure 16). The random effects model was also fit with a CV on the prior of 5.0 which resulted in the model not converging. The random effects model did not converge when trying to fit female biomass due to high observed variances similar to male biomass. The increase in CV in the prior on λ results in lower process error and a smoother fit to biomass. The parameters and process error for the random effects models were,

Random effects Model	λ	σ_p^2	CV
λ fixed	-0.221	0.643	NA
with prior on λ	-0.364	0.483	2.24
with prior on λ	-0.640	0.278	4

The simple exponential model fit to female mature biomass (≥90mm) estimated process error at 0.280, which is lower than the process error estimated at 0.643 for the mature male biomass (≥120mm), however, similar to process error estimated in the random effects model (0.278) with prior on $\lambda = -0.221$ and CV=4.

MMB at mating on February 15, 2017 (2016/17 crab year) was estimated at 3,681 t for the observed survey, 6,445 t for the 3-yr weighted average, 4,683 t for the random effects model fixed process error, 4,788 t for the random effects model cv=2.24 and 4,961 t for the random effects model cv=4.0 (Table 9 and Figure 17). The estimation of process error in the random effects model with a cv=4.0 results in a smoother fit to biomass than the 3 year running average or the random effects models with lower cv or fixed process error. The 3-yr running average biomass estimate in 2016 is the weighted average of survey biomass in 2015, 2016 and 2017. The high survey biomass in 2015 results in a larger estimated biomass in 2016 (and the projected February 15, 2017 biomass) than for the random effects models which take into account the whole time series. The use of the 3-yr running average can be thought of as imposing a prior on smoothness by using 3 biomass values for each estimate. Using more biomass values for the average would result in a smoother fit to the data as well as using the random effects model with a weaker prior. The CVs of the survey biomass range from 0.36 to 1.0 with an average of 0.67.

6. Calculation of reference points

6.1 Tier 4 OFL and B_{MSY}

Natural mortality was used as a proxy for F_{MSY} and a proxy for B_{MSY} was calculated by averaging the biomass of a predetermined period of time thought to represent the time when the stock was at B_{MSY} in the tier 4 HCR. The OFL was calculated by applying a fishing mortality determined by equation 4 to the mature male biomass at the time of fishing.

$$F_{OFL} = \begin{cases} Bycatch\ only & if\ \dfrac{B_{cur}}{B_{MSY\ proxy}} \leq \beta \\ \dfrac{\gamma M \left(\dfrac{B_{cur}}{B_{MSY\ proxy}} - \alpha\right)}{1-\alpha} & if\ \beta < \dfrac{B_{cur}}{B_{MSY\ proxy}} < 1 \\ \gamma M & if\ B_{cur} > B_{MSY\ proxy} \end{cases} \quad (4)$$

Where,

B_{cur}	Estimated mature male biomass projected to time of mating fishing at the OFL
$B_{MSY\ proxy}$	Average mature male biomass over the years 1991-present
M	Natural mortality
α	Determines the slope of the descending limb of the HCR (0.05)
β	Fraction of $B_{MSY\ proxy}$ below which directed fishing mortality is zero (here set to 0.25)

6.3 Acceptable biological catches

An acceptable biological catch (ABC) was estimated below the OFL by a proportion based a predetermined probability that the ABC would exceed the OFL (P*). Currently, P* is set at 0.49 and represents a proportion of the OFL distribution that accounts for within assessment uncertainty (σ_w) in the OFL to establish the maximum permissible ABC (ABC_{max}). Any additional uncertainty outside of the assessment methods (σ_b) will be considered as a recommended ABC below ABC_{max}. Additional uncertainty will be included in the application of the ABC by adding the uncertainty components as $\sigma_{total} = \sqrt{\sigma_b^2 + \sigma_w^2}$.

6.4 Specification of the distributions of the OFL used in the ABC

A distribution for the OFL associated with estimates of MMB from the running average method was constructed by bootstrapping values of MMB_{mating} (assuming that MMB is log-normally distributed) and calculating the OFL according to equation 4. Additional uncertainty (σ_b) equal to 0.3 was added when bootstrapping values of MMB while calculating the distribution for the OFL for the tier 4 HCR. The posterior distribution for the OFL generated from the integrated assessment was used for determining the ABC.

6.6 Tier 4 Reference points and OFL

B_{MSY} was estimated at 5,502 t using observed male survey biomass (≥120mm) from 1991/92 to 2016/17. Projected MMB for 2017/18 (on February 15, 2018 removing the OFL) calculated from the 3-year running average was 3,139 t (57% of B_{MSY}). Bmsy for the random effects models was estimated from model output from 1991/92 to 2016/17. The random effects model (RE) with fixed process error estimated projected MMB for 2017/18 at 3,274 t (69% of B_{MSY} = 4,711 t). The RE with CV=2.24 estimated 2017/18 MMB at 3,364 t (73% of B_{MSY} = 4,604 t) and the RE with CV=4.0 at 3,563 t (67% of B_{MSY} = 4,397 t). The 2017/18 OFL for the 3-yr weighted average was 330 t, from the random effects model (RE) with fixed process error at 442 t, the RE with CV=2.24 at 482 t and the RE with CV=4.0 at 573 t (see Table in item 6 of the executive summary).

6.7 Recommended ABCs

The ABC estimated using a p* of 0.49 with an additional sigma of 0.30 was 319 t for the 3-yr running average, 428 t for the random effects model (RE) with fixed process error, 467 t for the RE with CV=2.24 and 554 t for the RE with CV=4.0. The ABC with a 25% buffer (ABC = OFL * 0.75) (recommended by the CPT and SSC in 2015) was 248 t for the 3-yr running average, 332 t for the random effects model (RE) with fixed process error, 362 t for the RE with CV=2.24 and 429 t for the RE with CV=4.0 (see Table in item 6 of the executive summary).

6.8 Variables related to scientific uncertainty in the OFL probability distribution

Uncertainty in estimates of stock size and OFL for Pribilof Islands red king crab was relatively high due to small sample sizes. The coefficient of variation for the estimate of mature male biomass for 2017 was 0.65 and has ranged between 0.36 and 0.92 since the 1991 peak in numbers. These CVs were calculated by assuming the data are Poisson distributed, but the data are overdispersed. Using a negative binomial (or other distribution that can allow for overdispersion) would increase the CVs. Growth and survey selectivity were estimated within the integrated assessment (and therefore uncertainty in both processes is accounted for in the posterior distributions), but maturity, survey catchability, fishery selectivity, and natural mortality were fixed. F_{MSY} was assumed to be equal to natural mortality and B_{MSY} was somewhat arbitrarily set to the average MMB over a predetermined range of years for tier 4 HCRs; both of which were assumptions that had a direct impact on the calculated OFL. Sources of mortality from discard in the crab pot fishery and the fixed gear fishery were not included in the integrated assessment because of a lack of length data to apportion removals correctly. Including these sources of mortality may alter the estimated MMB.

6.9 Author Recommendation

In the foreseeable future, low sample size will be a problem for the Pribilof Island red king crab, so extra precaution should be taken given the uncertainty associated with MMB estimates. In this respect, the tier 4 HCR is more precautionary in that it sets a higher MSST and a lower $F_{OFL,}$ OFL, and ABC for a given MMB (Turnock, et al. 2016). If there is a particularly high estimate of MMB from the survey (often associated with high variance–see 2015 for an example), the biomass and OFL can be higher for the 3-yr running average than the random effects models. The random effects model can be useful in these years because it smooths over fluctuations in estimates of biomass and numbers, which often appear to be the result of measurement error The authors recommendation is to use the random effects model with CV=2.24 in the prior on process error as this results in a more smooth fit to biomass and would be less influenced by fluctuations in biomass than the 3-yr running average model. The CV=2.24 is estimated from the variance of the parameter estimated from the simple exponential model while the CV=4.0 is arbitrary and was used as a sensitivity.

Females and males experienced similar increases in abundance in the early 1990s, and only in recent years did trends in their abundances deviate from previously correlated trajectories. This suggests that some population process (e.g. natural mortality or catchability) has changed for males or females, but it is difficult to say if the change in trends was a result of a population process for females or for males (or both) changing. It is generally inadvisable to invoke time-varying population processes within an assessment for the sake of improving fits without a hypothesis behind the changes and data to corroborate it.

7. Data gaps and research priorities

The largest data gap is the number of observations from which the population size and biomass is extrapolated. Catch-at-length data for the trawl fishery would allow trawl fishery selectivity to be estimated and discard mortality specific to PIRKC to be incorporated into the integrated model. Simulation studies designed to prioritize research on population processes for which additional information would be beneficial in achieving more accurate estimates of management quantities could be useful for this stock (e.g. Szuwalski and Punt, 2012). Research on the probability of molting at length for males would allow the use of data specific to PIRKC in specifying molting probability in the assessment. Research aimed at the catchability and availability of PIRKC may shed some light on divergent changes in abundance in recent years.

8. Ecosystem Considerations

The impact of a directed fishery for Pribilof Islands red king crab on the population of Pribilof island blue king crab will likely continue to be the largest ecosystem consideration facing this fishery and preclude the possibility of a directed fishery for red king crab. Linking changes in productivity as seen in the 1980s with environmental influences is a potential avenue of research useful in selecting management strategies for crab stocks around the Pribilof Islands (e.g. Szuwalski and Punt, 2013a). It is possible that the large year class in the mid-1980s reflected changing environmental conditions, similar to proposed relationships between the Pacific Decadal Oscillation snow crab recruitment in the EBS (Szuwalski and Punt, 2013b). Ocean acidification also appears to have a large detrimental effect on red king crab (Long et al., 2012), which may impact the productivity of this stock in the future.

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11. Tables

Table 1. Total retained catches from directed fisheries for Pribilof Islands District red king crab (Bowers et al. 2011; D. Pengilly, ADF&G, personal communications).

Year	Catch (count)	Catch (t)	Avg CPUE (legal crab count pot^{-1})
1973/1974	0	0	0
1974/1975	0	0	0
1975/1976	0	0	0
1976/1977	0	0	0
1977/1978	0	0	0
1978/1979	0	0	0
1979/1980	0	0	0
1980/1981	0	0	0
1981/1982	0	0	0
1982/1983	0	0	0
1983/1984	0	0	0
1984/1985	0	0	0
1985/1986	0	0	0
1986/1987	0	0	0
1987/1988	0	0	0
1988/1989	0	0	0
1989/1990	0	0	0
1990/1991	0	0	0
1991/1992	0	0	0
1992/1993	0	0	0
1993/1994	380,286	1183.02	11
1994/1995	167,520	607.34	6
1995/1996	110,834	407.32	3
1996/1997	25,383	90.87	<1
1997/1998	90,641	343.29	3
1998/1999	68,129	246.91	3
1999/2000 to 2016/2017	0	0	0

Table 2. Fishing effort during Pribilof Islands District commercial red king crab fisheries, (Bowers et al. 2011).

Season	Number of Vessels	Number of Landings	Number of Pots Registered	Number of Pots Pulled
1993	112	135	4,860	35,942
1994	104	121	4,675	28,976
1995	117	151	5,400	34,885
1996	66	90	2,730	29,411
1997	53	110	2,230	28,458
1998	57	57	2,398	23,381
1999-2016/17			Fishery Closed	

Table 3. Non-retained total catch mortalities from directed and non-directed fisheries for Pribilof Islands District red king crab. Handling mortalities (pot and hook/line= 0.5, trawl = 0.8) were applied to the catches. (Bowers et al. 2011; D. Pengilly, ADF&G; J. Mondragon, NMFS). ****From 2009/10 forward the calculation of bycatch uses the AKRO Catch Accounting System with data reported from State of Alaska reporting areas that encompass the Pribilof Islands red king crab district.**

	Crab pot fisheries			Groundfish fisheries	
Year	Legal male (t)	Sublegal male (t)	Female (t)	All fixed (t)	All trawl (t)
1991/1992				0.48	45.71
1992/1993				16.12	175.93
1993/1994				0.60	131.87
1994/1995				0.27	15.29
1995/1996				4.81	6.32
1996/1997				1.78	2.27
1997/1998				4.46	7.64
1998/1999	0.00	0.91	11.34	10.40	6.82
1999/2000	1.36	0.00	8.16	12.40	3.13
2000/2001	0.00	0.00	0.00	2.08	4.71
2001/2002	0.00	0.00	0.00	2.71	6.81
2002/2003	0.00	0.00	0.00	0.50	9.11
2003/2004	0.00	0.00	0.00	0.77	9.83
2004/2005	0.00	0.00	0.00	3.17	3.52
2005/2006	0.00	0.18	1.81	4.53	24.72
2006/2007	1.36	0.14	0.91	6.99	21.35
2007/2008	0.91	0.05	0.09	1.92	2.76
2008/2009	0.09	0.00	0.00	1.64	6.94
**2009/2010	0.00	0.00	0.00	0.19	1.05
2010/2011	0.00	0.00	0.00	0.45	6.25
2011/2012	0.00	0.00	0.00	0.35	4.47
2012/2013	0.00	0.00	0.00	0.12	12.98
2013/2014	0.00	0.00	0.00	0.25	1.99
2014/2015	0.00	0.00	0.00	0.73	1.03
2015/2016	0.167	0.00	0.053	0.03	0.07
2016/2017	0.00	0.00	0.00	0.06	0.43

Table 4. Percent by weight of the Pribilof Islands red king crab bycatch using the new 2014 calculation of bycatch using AKRO Catch Accounting System with data reported from State of Alaska reporting areas that encompass the Pribilof Islands red king crab district.

Crab fishing season	hook and line %	non-pelagic trawl %	pot %	pelagic trawl %	TOTAL (# crabs)
2009/10	19	77	3	1	813
2010/11	10	90	<1	<1	3,026
2011/12	10	89	1		2,167
2012/13	1	99	<1		4,517
2013/14	11	89	0	0	640
2014/2015	53	47	0	0	1,439
2015/16	40	60	0	0	382
2016/17	19	81	<1	0	857

Table 5. Total male bycatch (t), Total bycatch (t) and total catch (t) with mortality applied for Pribilof red king crab from 1991 to 2016/17.

Year	Total male bycatch (t)	total bycatch (t)	Total catch (t)
1991/1992	46.19	46.19	46.19
1992/1993	192.05	192.05	192.05
1993/1994	132.47	132.47	1315.49
1994/1995	15.56	15.56	622.9
1995/1996	11.13	11.13	418.45
1996/1997	4.05	4.05	94.92
1997/1998	12.1	12.1	355.39
1998/1999	18.13	29.47	265.04
1999/2000	16.89	25.05	16.89
2000/2001	6.79	6.79	6.79
2001/2002	9.52	9.52	9.52
2002/2003	9.61	9.61	9.61
2003/2004	10.6	10.6	10.6
2004/2005	6.69	6.69	6.69
2005/2006	29.43	31.24	29.43
2006/2007	29.84	30.75	29.84
2007/2008	5.64	5.73	5.64
2008/2009	8.67	8.67	8.67
**2009/2010	1.24	1.24	1.24
**2010/2011	6.7	6.7	6.7
**2011/2012	4.82	4.82	4.82
**2012/2013	13.1	13.1	13.1
2013/2014	2.24	2.24	2.24
2014/2015	1.76	1.76	1.76
2015/2016	0.32	0.32	0.32
2016/2017	0.49	0.49	0.49

Table 6. Pribilof Islands District red king crab male abundance, male biomass (≥ 105mm), and female biomass estimated based on the NMFS annual EBS bottom trawl survey with no running average.

Year	Total Male Abundance	Males ≥105mm at survey (t)	Total females at survey (t)
1975/1976	0	0	11
1976/1977	50778	165	102
1977/1978	228477	213	148
1978/1979	367140	1250	52
1979/1980	279707	556	93
1980/1981	400513	1269	262
1981/1982	80928	312	35
1982/1983	352166	1482	933
1983/1984	144735	553	309
1984/1985	64331	317	112
1985/1986	16823	61	0
1986/1987	38419	138	79
1987/1988	18611	54	31
1988/1989	1963775	525	836
1989/1990	1844076	1720	2251
1990/1991	6354076	8019	2723
1991/1992	3100675	4979	5032
1992/1993	1861538	3361	3432
1993/1994	3787997	10156	6478
1994/1995	3669755	9538	3964
1995/1996	7693368	18417	5149
1996/1997	683611	2378	2007
1997/1998	3155556	7254	1962
1998/1999	1192015	2655	1719
1999/2000	9102898	5751	5418
2000/2001	1674067	4477	995
2001/2002	6157584	10186	5774
2002/2003	1910263	7037	787
2003/2004	1506201	5373	2269
2004/2005	2196795	3622	1292
2005/2006	302997	1262	3118
2006/2007	1459278	7097	2183
2007/2008	1883489	5371	1811
2008/2009	1721467	5603	3017
2009/2010	923133	25645	826
2010/2011	927825	4449	840
2011/2012	1052228	3878	817
2012/2013	1609444	4753	663
2013/2014	1831377	7854	169
2014/2015	3036807	12129	1093
2015/2016	3662609	15252	3859
2016/2017	1807323	4619	1898

2017/2018	115838	3740	505

Table 7. Pribilof Islands District male red king crab abundance CV and total male and female biomass CVs estimated from the NMFS annual EBS bottom trawl survey data.

Year	Total Male Abundance CV	Males ≥105mm at survey CV	Total female at survey CV
1975/1976	0.00	0.00	1.00
1976/1977	1.00	1.00	0.78
1977/1978	1.00	1.00	1.00
1978/1979	0.83	0.83	1.00
1979/1980	0.49	0.52	1.00
1980/1981	0.40	0.38	0.73
1981/1982	0.57	0.58	1.00
1982/1983	0.70	0.70	0.77
1983/1984	0.64	0.55	0.48
1984/1985	0.48	0.55	0.57
1985/1986	1.00	1.00	0.00
1986/1987	0.70	0.70	1.00
1987/1988	1.00	1.00	1.00
1988/1989	0.74	0.56	0.67
1989/1990	0.69	0.77	0.68
1990/1991	0.87	0.89	0.72
1991/1992	0.78	0.80	0.60
1992/1993	0.68	0.61	0.91
1993/1994	0.93	0.92	0.72
1994/1995	0.81	0.78	0.88
1995/1996	0.57	0.60	0.66
1996/1997	0.37	0.37	0.74
1997/1998	0.56	0.54	0.57
1998/1999	0.42	0.37	0.77
1999/2000	0.79	0.58	0.82
2000/2001	0.40	0.38	0.63
2001/2002	0.90	0.83	0.99
2002/2003	0.67	0.69	0.52
2003/2004	0.66	0.66	0.91
2004/2005	0.83	0.60	0.53
2005/2006	0.53	0.57	0.78
2006/2007	0.39	0.38	0.61
2007/2008	0.61	0.51	0.77
2008/2009	0.52	0.50	0.68
2009/2010	0.70	0.64	0.53
2010/2011	0.45	0.43	0.71
2011/2012	0.63	0.64	0.73
2012/2013	0.65	0.59	0.55
2013/2014	0.58	0.61	0.58
2014/2015	0.71	0.78	0.94
2015/2016	0.72	0.74	0.96

2016/2017	0.72	0.69	0.61
2017/2018	0.58	0.64	0.56

Table 8. Estimates of survey male ≥ 120mm biomass (t) at the time of the survey, 3-year running weighted average, the random effects model with λ fixed at -0.221, the random effects model with a prior on λ with mean = -0.221 and cv = 2.24, the random effects model with a prior on λ with mean = -0.221 and cv = 4.0, and the simple exponential smooth.

Year	MB GE120	CV MB GE120	3-yr running avg	random effects fixed λ	random effects prior λ cv 2.24	random effects prior λ cv 4.0	Simple exponential smooth
1976/1977	165	1.00	NA	206	221	261	165
1977/1978	119	1.00	585	252	271	314	131
1978/1979	1,250	0.83	648	621	593	558	637
1979/1980	556	0.52	1,042	645	647	644	579
1980/1981	1,269	0.38	850	1,005	965	884	1,004
1981/1982	312	0.58	1,060	520	545	581	443
1982/1983	1,464	0.70	691	822	771	688	1,024
1983/1984	527	0.53	679	510	500	480	642
1984/1985	317	0.55	368	292	293	302	392
1985/1986	61	1.00	211	136	149	180	107
1986/1987	138	0.70	95	131	140	166	128
1987/1988	54	1.00	107	117	133	174	69
1988/1989	107	1.00	609	218	240	293	94
1989/1990	1,529	0.91	961	784	759	739	664
1990/1991	1,141	0.93	2,526	1,386	1,370	1,333	971
1991/1992	4,430	0.80	3,133	2,991	2,849	2,579	2,815
1992/1993	3,305	0.60	5,172	3,863	3,839	3,672	3,150
1993/1994	9,873	0.92	6,597	6,935	6,564	5,757	7,019
1994/1995	9,139	0.77	13,423	8,605	8,142	7,070	8,446
1995/1996	18,056	0.60	7,350	9,822	8,954	7,442	14,390
1996/1997	2,362	0.37	6,816	3,151	3,281	3,521	4,051
1997/1998	6,159	0.62	2,955	4,244	4,108	3,935	5,435
1998/1999	2,324	0.36	3,783	2,753	2,831	3,007	2,995
1999/2000	5,523	0.67	3,614	4,365	4,271	4,138	4,600
2000/2001	4,320	0.37	5,298	4,588	4,596	4,578	4,402
2001/2002	8,603	0.79	5,614	6,479	6,217	5,727	7,043
2002/2003	7,037	0.69	6,853	6,268	6,071	5,664	7,039
2003/2004	5,373	0.66	5,194	4,998	4,926	4,789	5,824
2004/2005	3,622	0.59	3,283	3,503	3,556	3,704	4,174
2005/2006	1,238	0.59	4,805	2,285	2,492	2,926	1,780
2006/2007	7,003	0.38	5,190	5,675	5,506	5,208	4,652
2007/2008	5,224	0.49	6,086	5,245	5,198	5,075	5,046
2008/2009	5,462	0.51	4,642	4,907	4,853	4,766	5,334
2009/2010	2,500	0.64	4,333	3,393	3,528	3,789	3,135
2010/2011	4,405	0.44	3,779	4,171	4,175	4,227	3,980
2011/2012	3,834	0.65	4,292	4,190	4,260	4,415	3,877
2012/2013	4,477	0.57	5,350	4,950	5,026	5,156	4,289
2013/2014	7,749	0.62	7,455	7,342	7,217	6,916	6,494
2014/2015	12,047	0.78	11,235	9,786	9,324	8,414	10,017
2015/2016	15,173	0.74	10,218	9,872	9,306	8,314	13,403
2016/2017	4,150	0.70	7,267	5,281	5,399	5,594	5,890
2017/2018	3,658	0.65	3,888	4,163	4,307	4,633	4,205

Table 9. MMB at mating for survey males ≥ 120mm, the 3-yr running average and the random effects model fit.

	Projected Biomass from survey time (y) to February 15 (y+1) removing catch				
	Observed survey	3-yr weighted average	Random Effects fixed = -0.221	Random Effects CV = 2.24	Random Effects CV = 4.0
1976/1977	146	NA	182	196	232
1977/1978	105	519	223	241	279
1978/1979	1,108	575	551	526	495
1979/1980	493	924	572	574	571
1980/1981	1,125	754	891	856	784
1981/1982	277	940	461	484	516
1982/1983	1,298	613	729	684	610
1983/1984	467	602	452	443	426
1984/1985	281	326	259	260	268
1985/1986	55	187	120	132	160
1986/1987	122	84	116	124	147
1987/1988	48	95	104	118	154
1988/1989	95	540	193	213	260
1989/1990	1,357	852	696	673	655
1990/1991	1,012	2,240	1,229	1,215	1,182
1991/1992	3,929	2,779	2,653	2,527	2,287
1992/1993	2,739	4,395	3,234	3,213	3,065
1993/1994	7,441	4,536	4,835	4,506	3,790
1994/1995	7,482	11,282	7,009	6,599	5,648
1995/1996	15,596	6,101	8,293	7,523	6,182
1996/1997	2,000	5,950	2,700	2,815	3,028
1997/1998	5,107	2,266	3,409	3,288	3,135
1998/1999	1,796	3,091	2,176	2,246	2,402
1999/2000	4,881	3,189	3,854	3,771	3,653
2000/2001	3,825	4,692	4,062	4,070	4,053
2001/2002	7,621	4,970	5,737	5,505	5,070
2002/2003	6,232	6,068	5,549	5,375	5,014
2003/2004	4,755	4,596	4,423	4,358	4,237
2004/2005	3,206	2,905	3,100	3,147	3,279
2005/2006	1,069	4,232	1,997	2,181	2,565
2006/2007	6,181	4,573	5,004	4,854	4,590
2007/2008	4,627	5,392	4,646	4,605	4,496
2008/2009	4,836	4,108	4,343	4,296	4,218
2009/2010	2,216	3,841	3,008	3,128	3,359
2010/2011	3,900	3,345	3,692	3,697	3,742
2011/2012	3,396	3,801	3,711	3,774	3,911
2012/2013	3,958	4,732	4,378	4,445	4,560
2013/2014	6,871	6,610	6,510	6,399	6,132
2014/2015	10,683	9,963	8,677	8,268	7,461
2015/2016	13,457	9,062	8,755	8,253	7,373
2016/2017	3,681	6,445	4,683	4,788	4,961

12. Figures

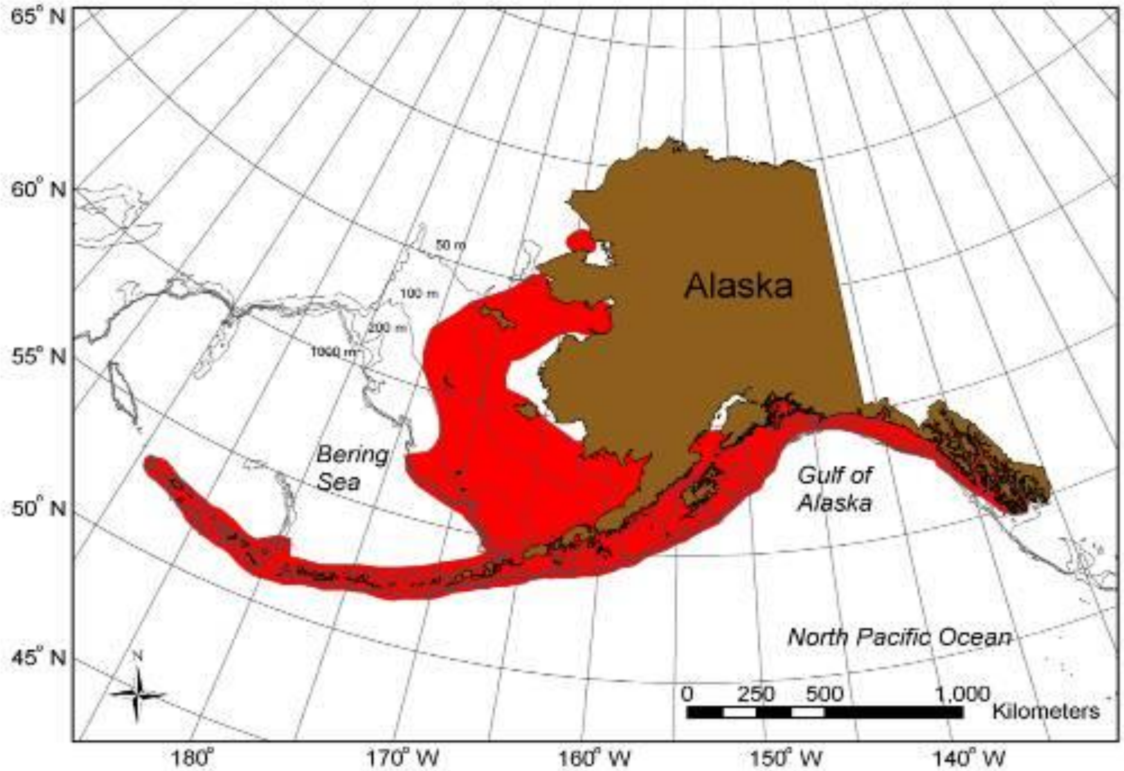

Figure 1. Red king crab distribution.

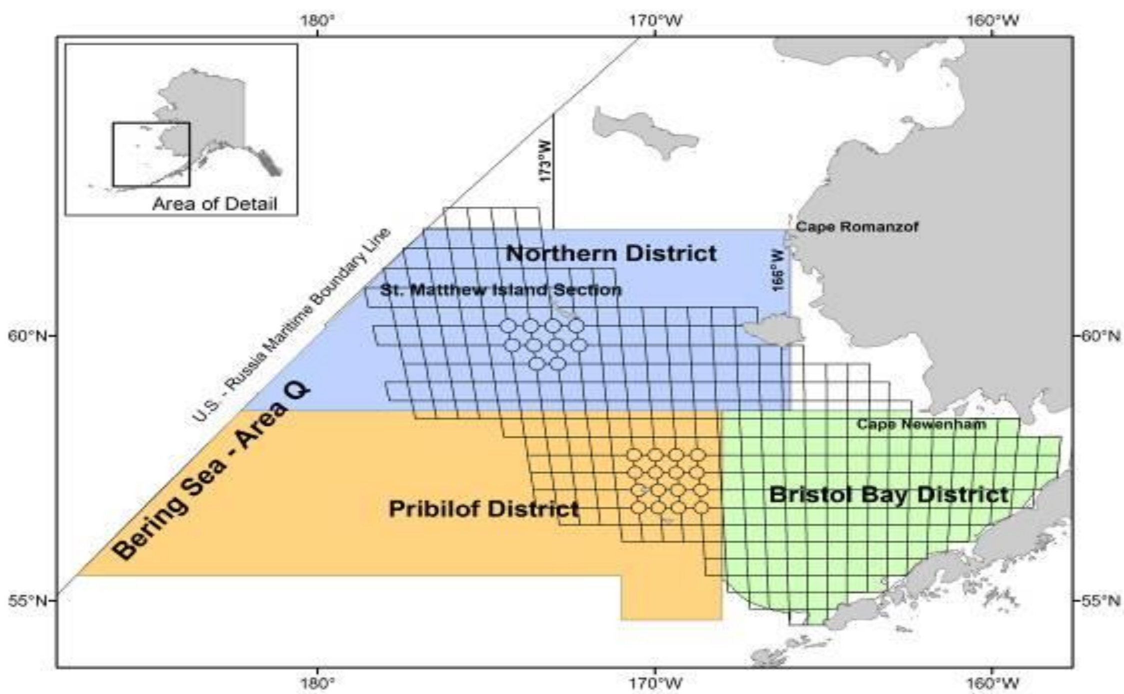

Figure 2. King crab registration area Q (Bering Sea) showing the Pribilof District.

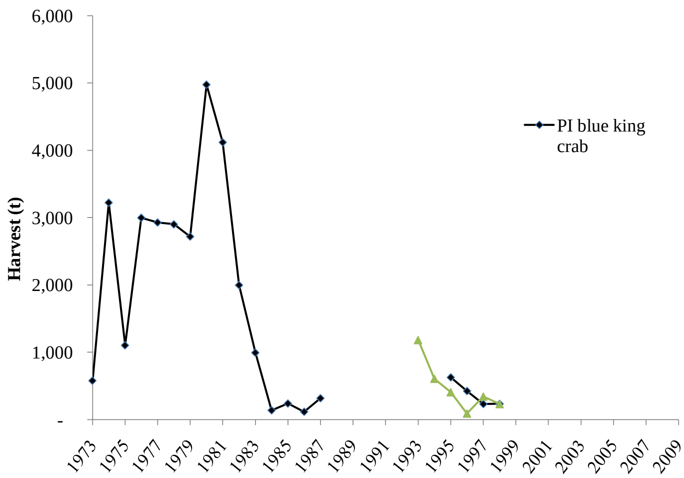

Figure 3. Historical harvests and GHLs for Pribilof Island blue (diamonds) and red king crab (triangles) (Bowers et al. 2011).

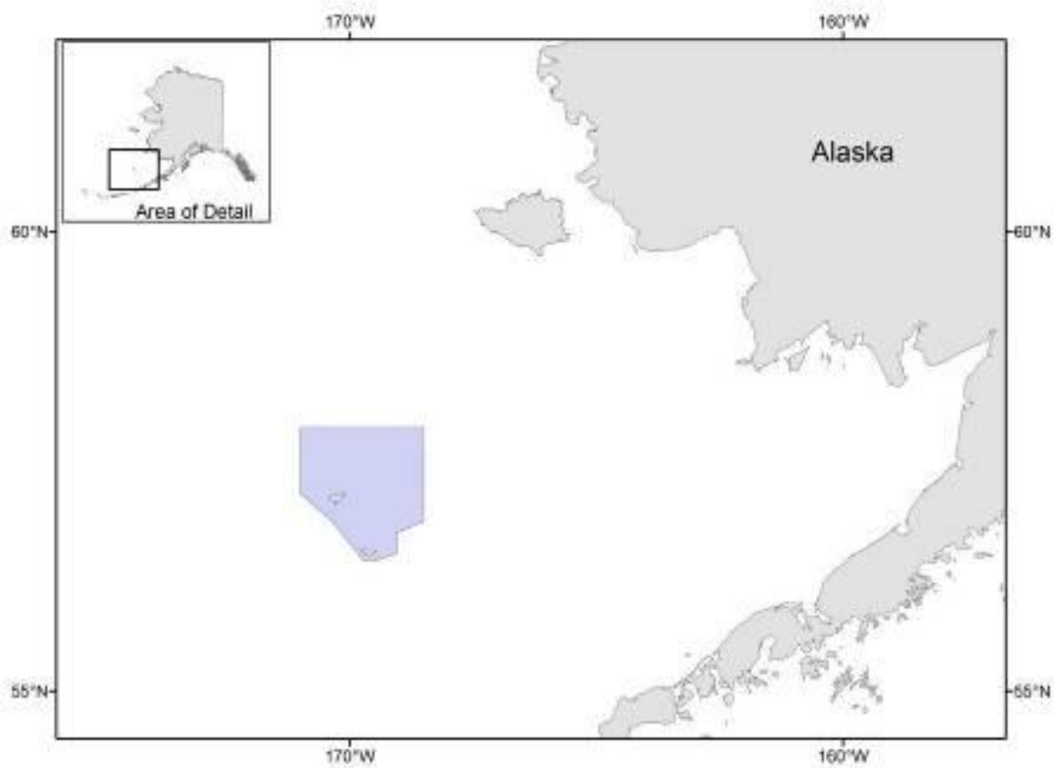

Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area.

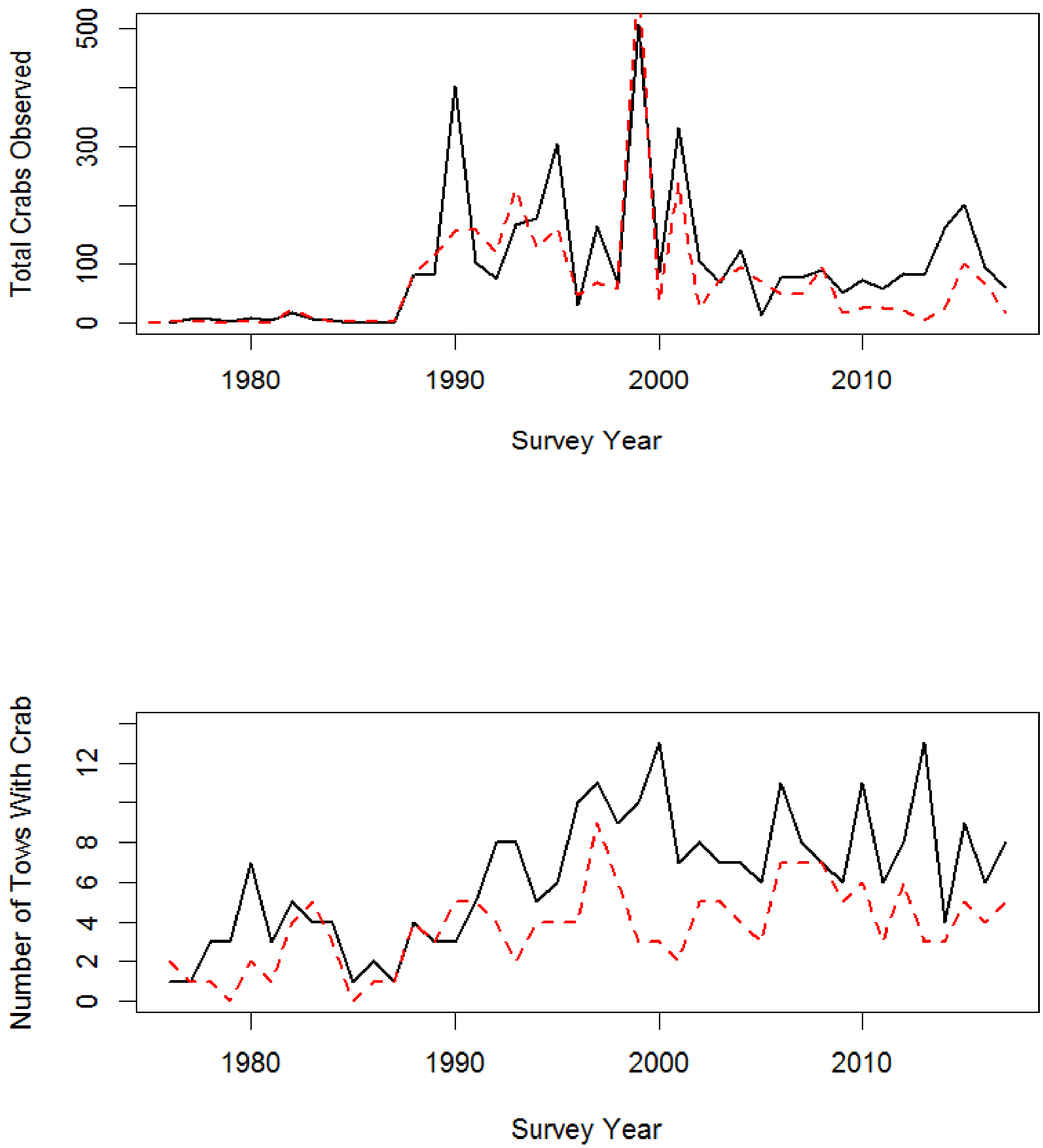

Figure 5. Total number of observed crab (top) and the number of tows that reported observations of crab (female = dashed line, male = solid line) from 1976-2017.

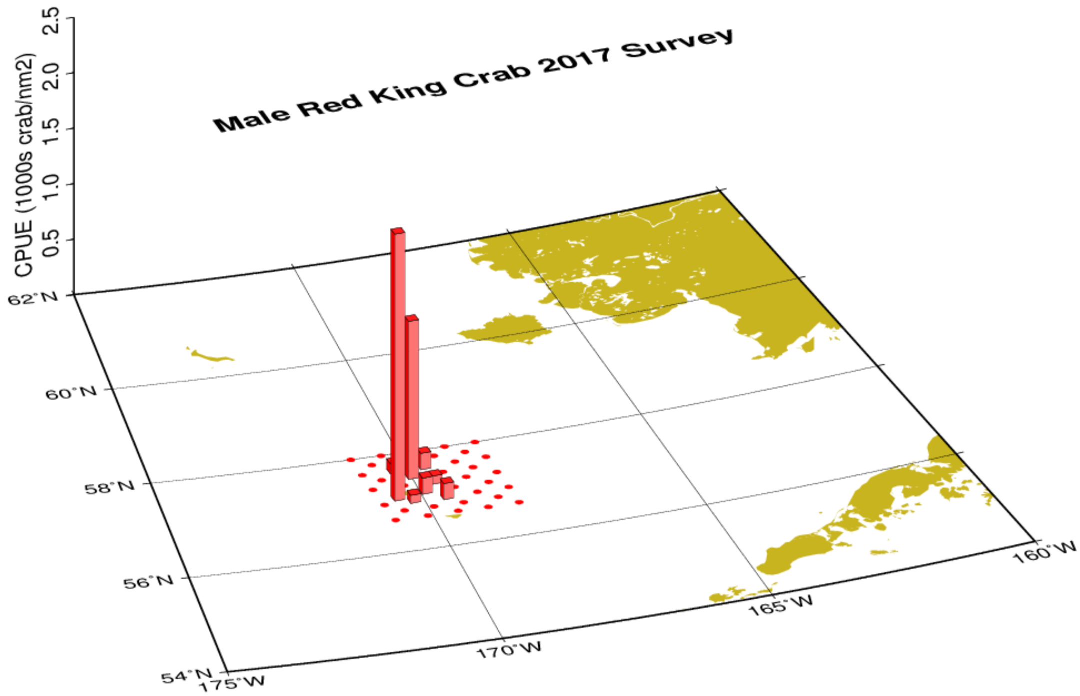

Figure 6. Male red king crab relative density by station in the Pribilof Island district in 2017. Bars represent the relative magnitude of the density calculated from the NMFS trawl survey.

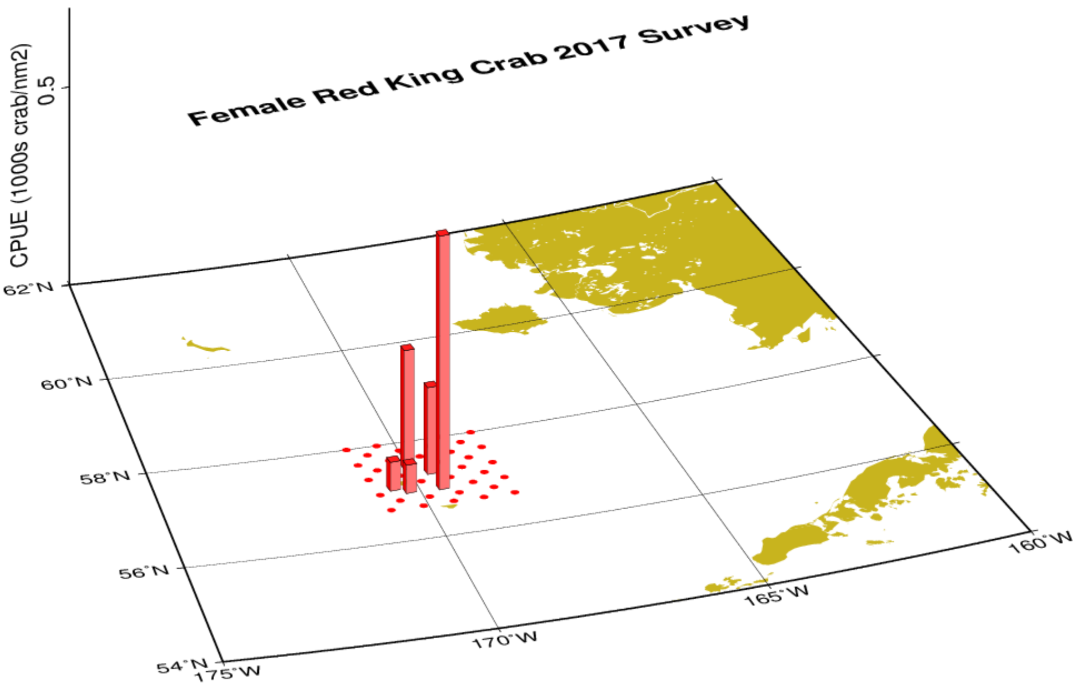

Figure 7. Female red king crab relative density by station in the Pribilof Island district in 2017. Bars represent the relative magnitude of the density calculated from the NMFS trawl survey.

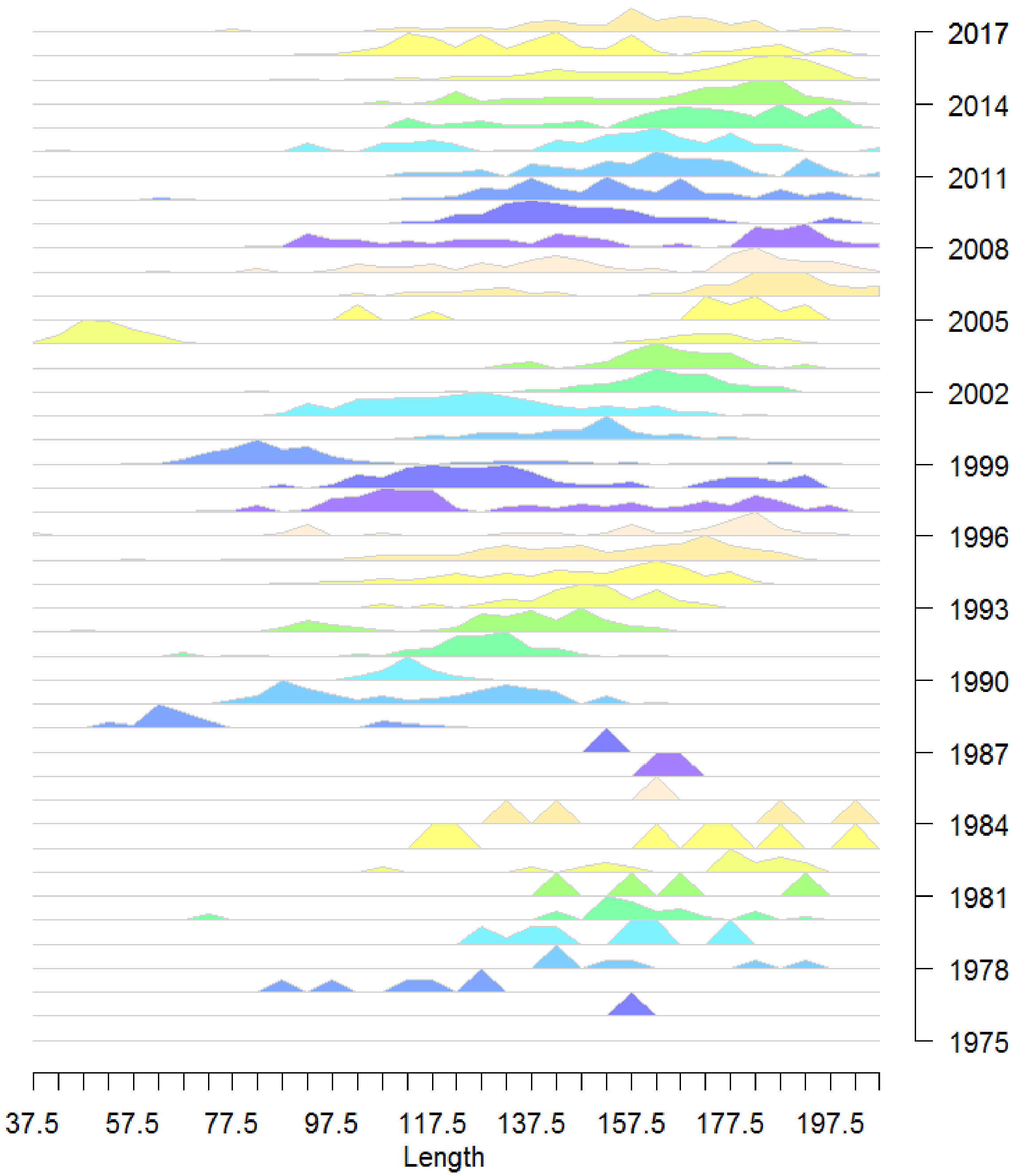

Figure 8. Observed length frequencies (proportions sum to 1.0) by 5 mm length classes of Pribilof Islands male red king crab (Paralithodes camtschaticus) from 1975 to 2017.

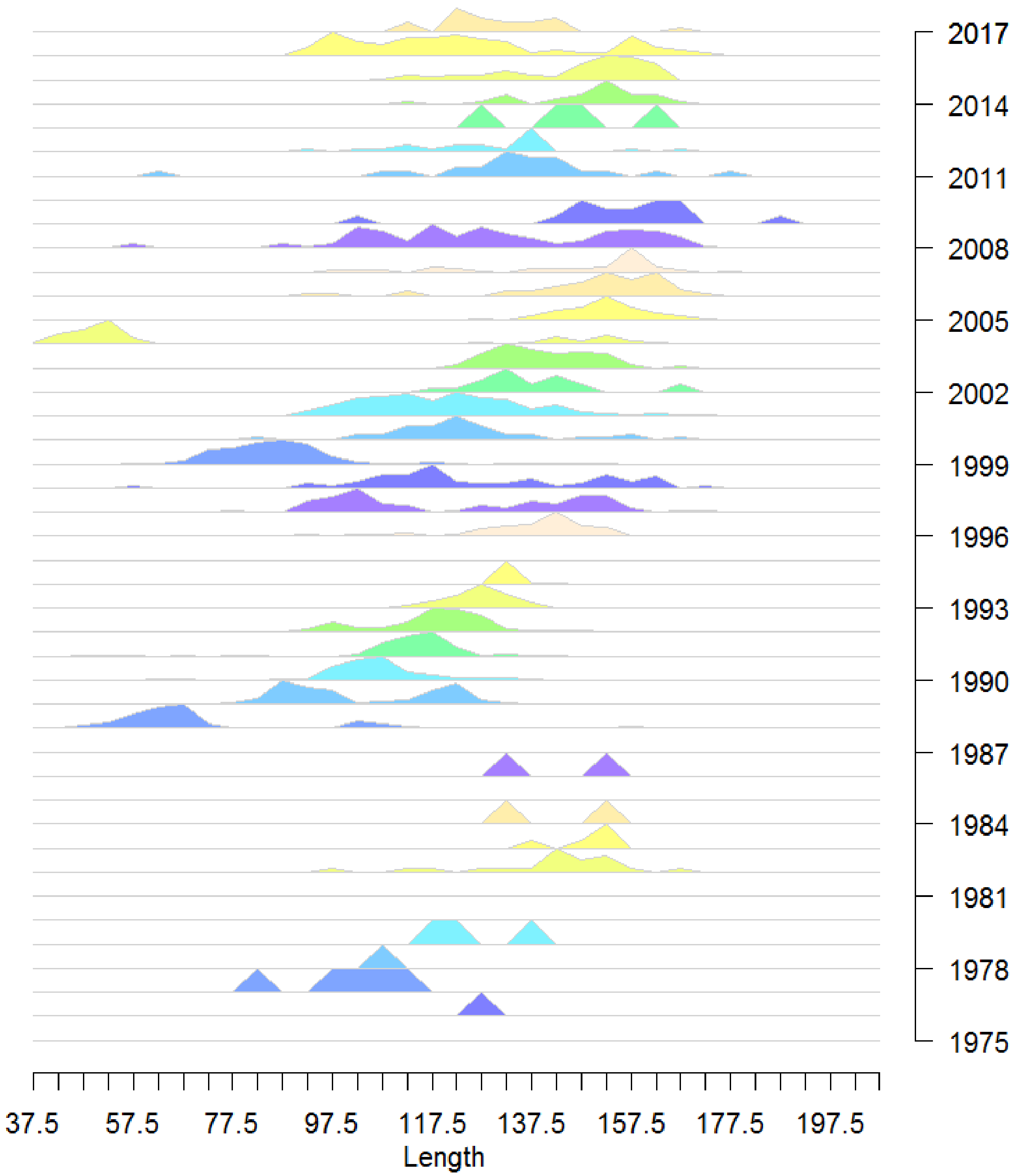

Figure 9. Observed length frequencies (proportions sum to 1.0) by 5 mm length classes of Pribilof Islands female red king crab (Paralithodes camtschaticus) from 1975 to 2017.

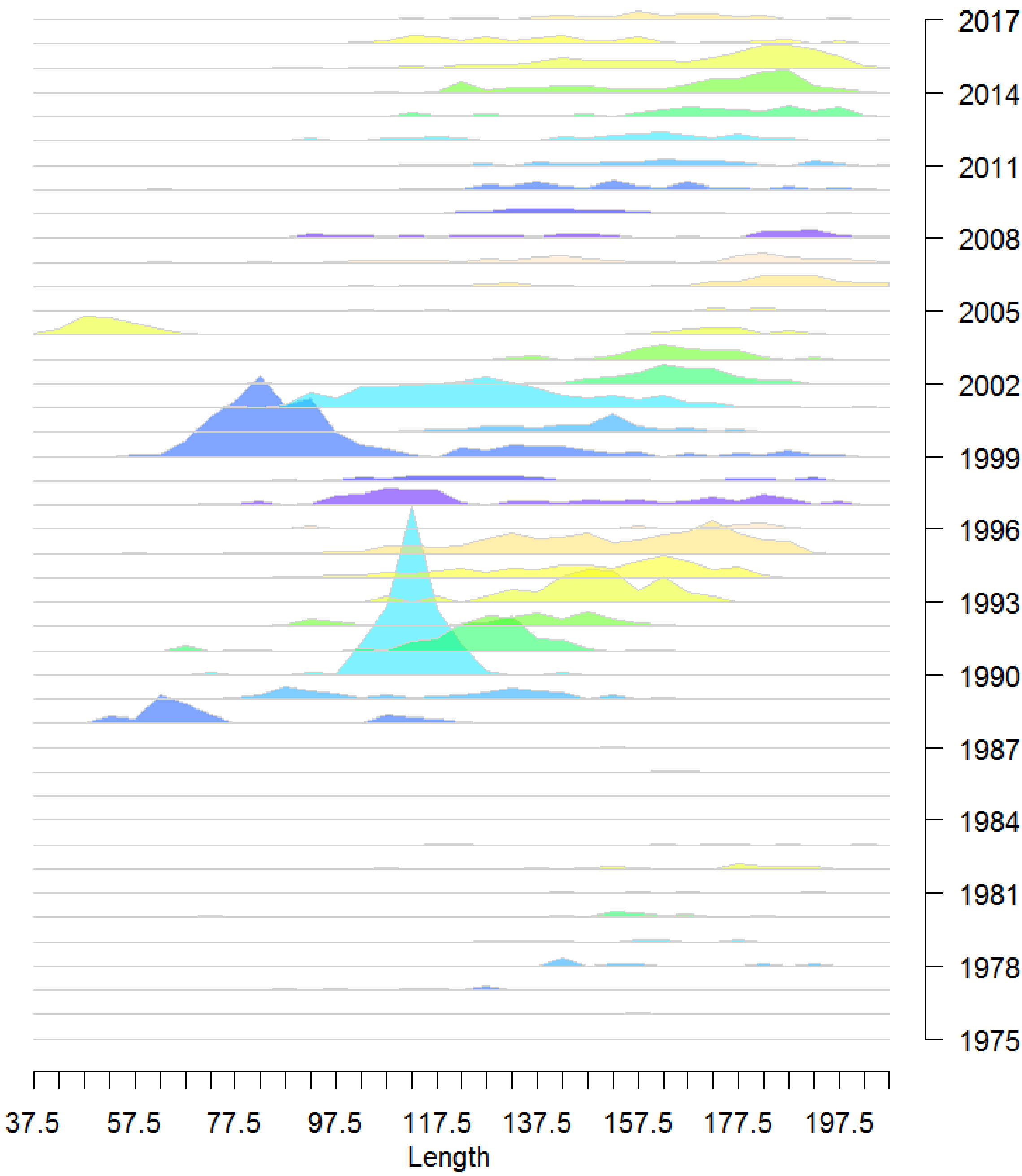

Figure 10. Observed numbers at length by 5 mm length classes of Pribilof Islands male red king crab (Paralithodes camtschaticus) from 1975 to 2017.

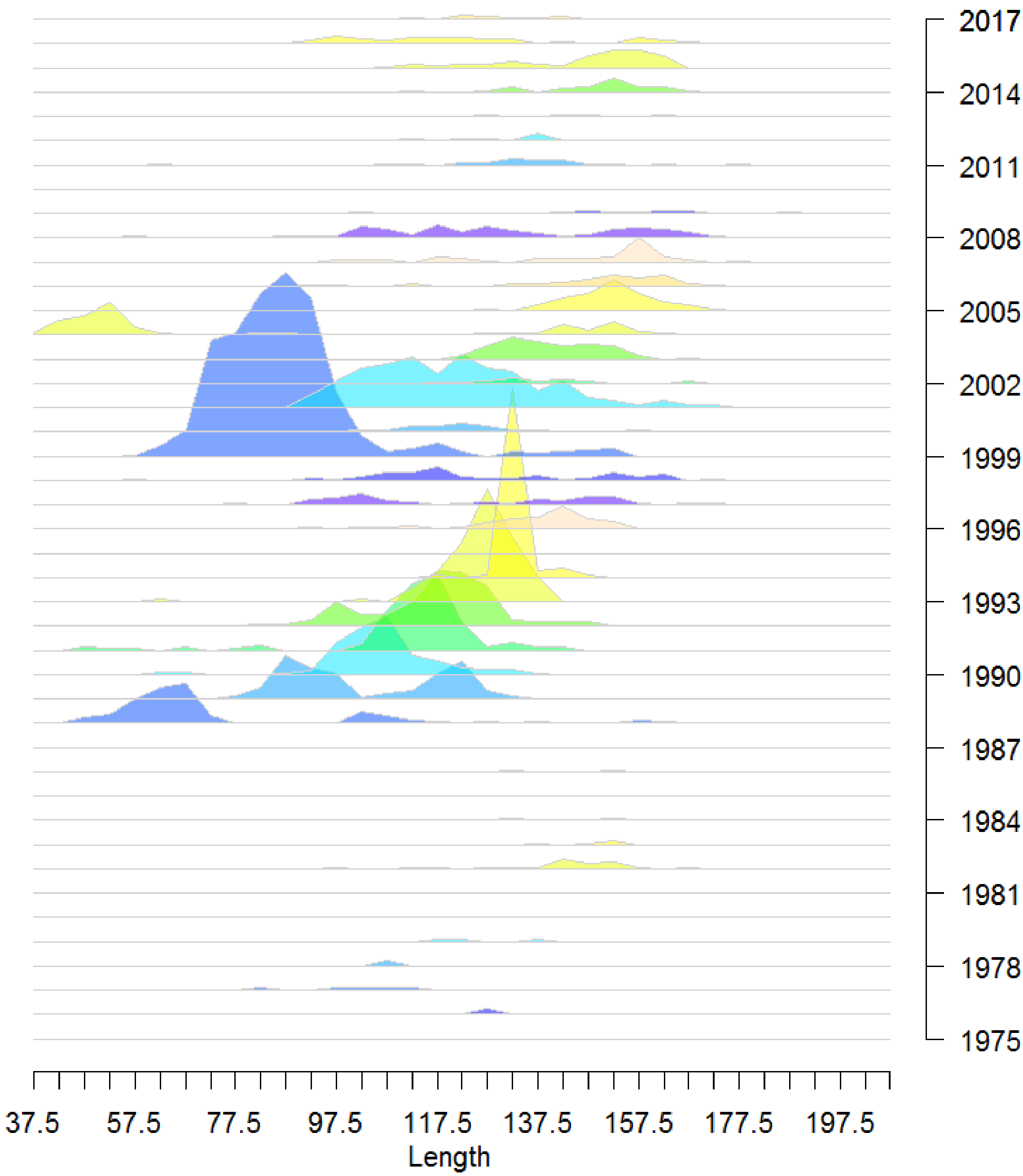

Figure 11. Observed numbers at length by 5 mm length classes of Pribilof Islands female red king crab (Paralithodes camtschaticus) from 1975 to 2017.

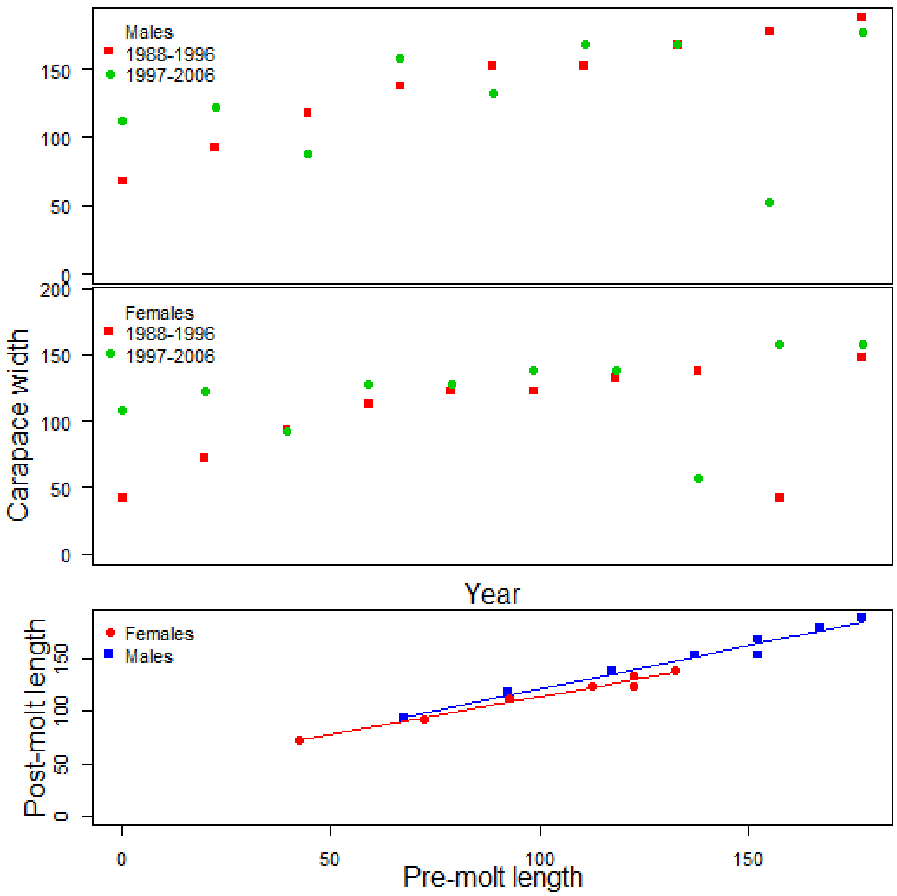

Figure 12. Modes of the length frequency distribution for males and females plotted for two time periods over which two cohorts were observed to move through the population. Growth per molt calculated from the modes from the length frequencies with fitted linear relationship (bottom).

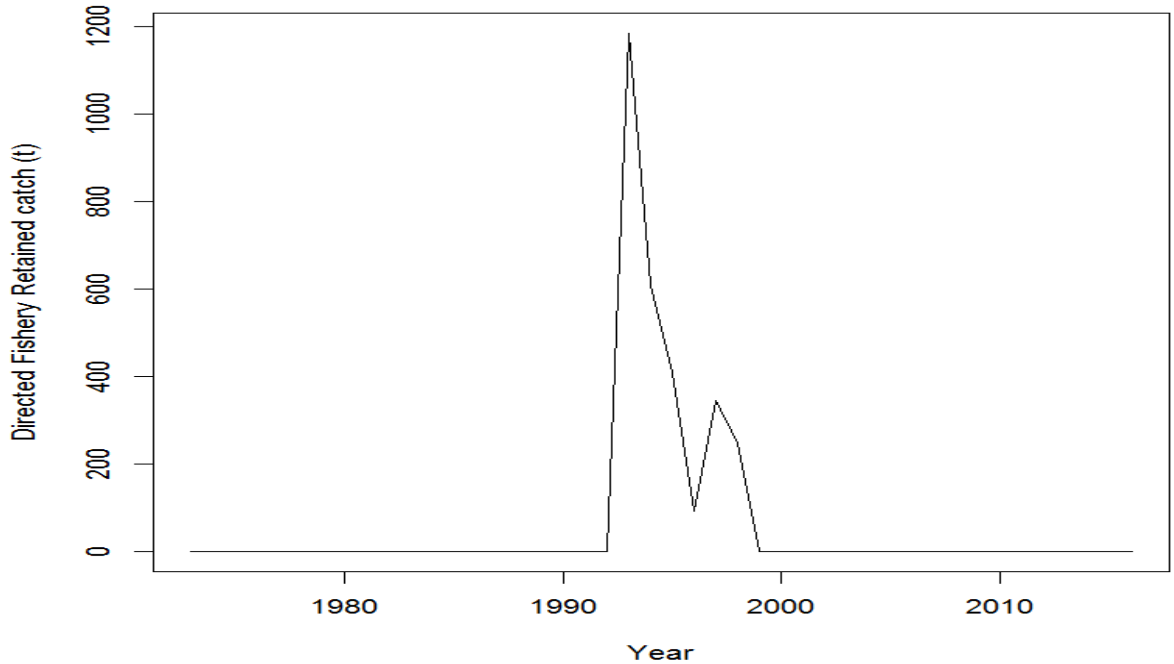

Figure 13. Directed fishery retained catch.

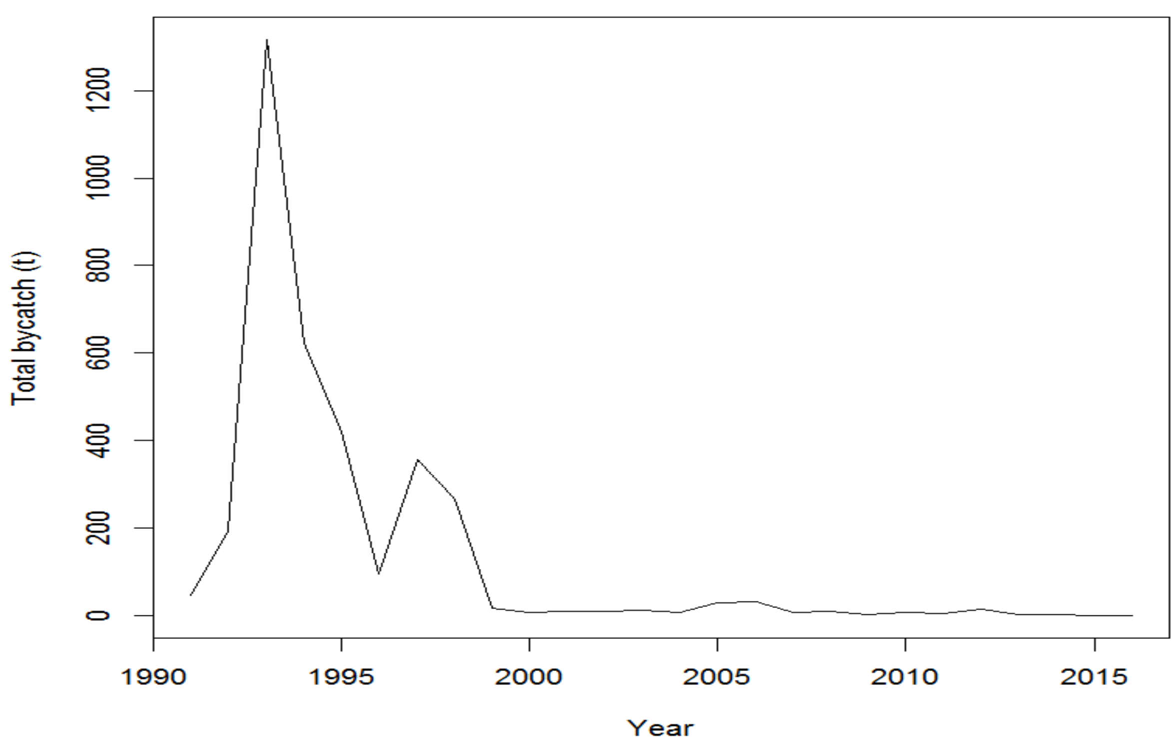

Figure 14. Total bycatch for Pribilof red king crab.

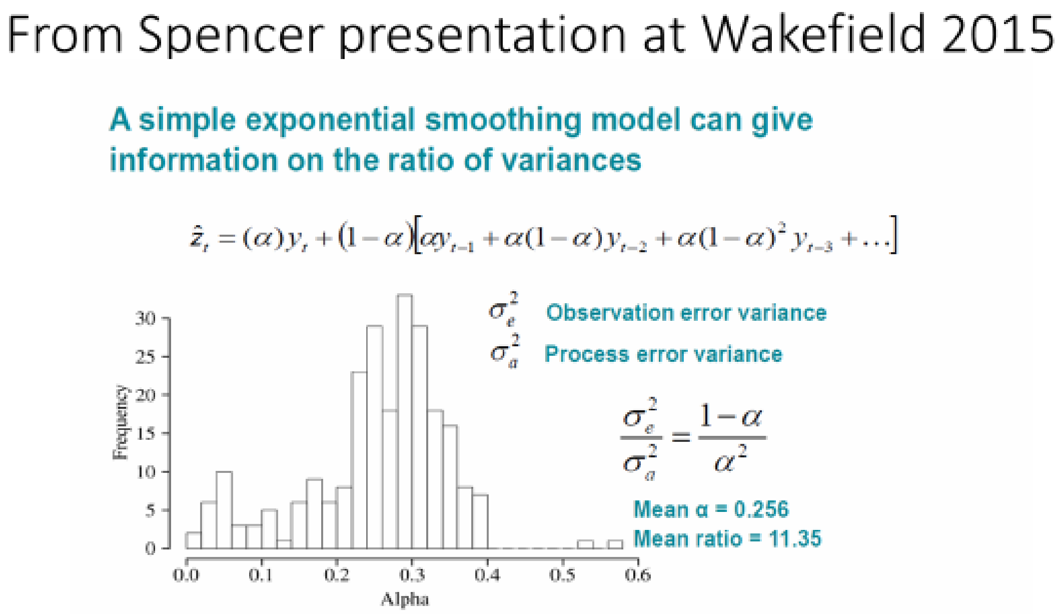

Figure 15. Using a simple exponential smoothing model to estimate the variance ratio of observation error and process error.

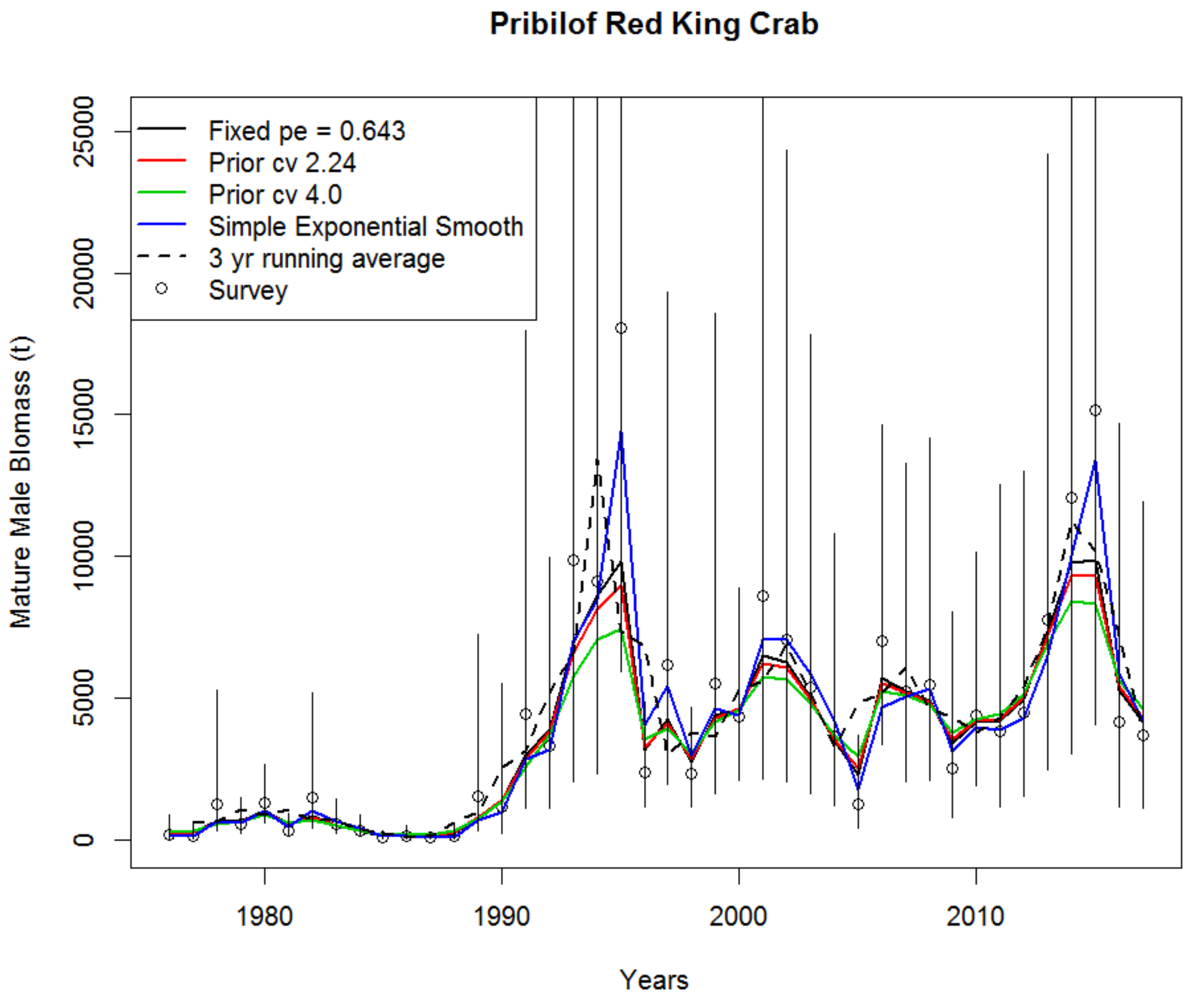

Figure 16. Mature male biomass (t) (≥120mm) at the time of the survey. Lines are the fit for the 3 year weighted average, the random effects model with process error fixed (0.643), the random effects model with cv on prior of 2.24, the random effects model with cv on prior of 4.0 and the simple exponential model.

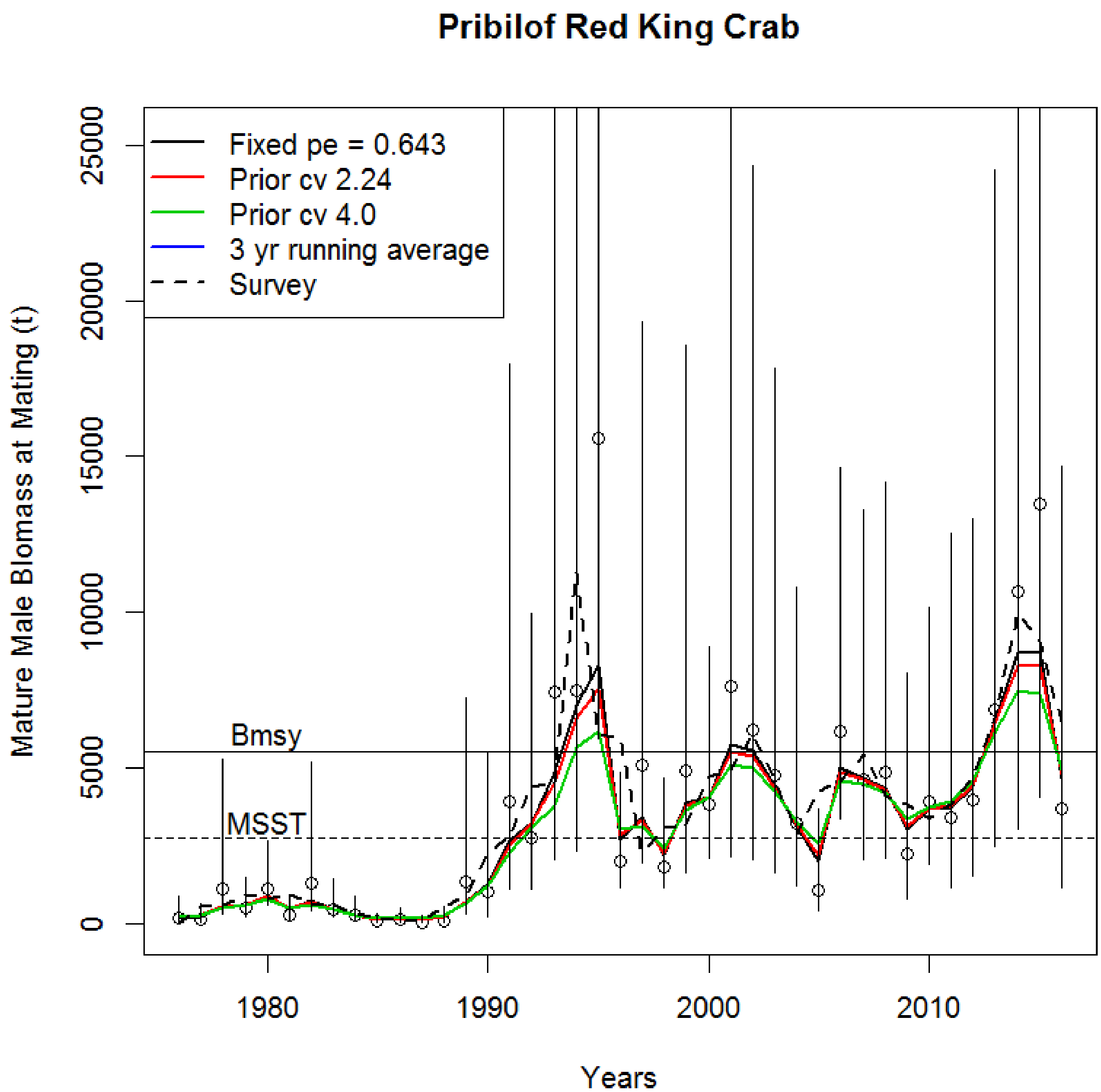

Figure 17. MMB at mating (t) for the 3 year weighted average, the random effects model with process error fixed, the random effects model with cv on prior of 2.24 and the random effects model with cv on prior of 4.0. Bmsy is the average of the survey biomass from 1991/92 to 2016/17. MSST is 50% of Bmsy.

5. Assessment of Pribilof Islands Blue King Crab (PIBKC)

[2017]

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[NOTE: In accordance with the approved schedule, no assessment was conducted for this stock this year, however, a full stock assessment will be conducted in 2019. Until then, the values generated from the previous stock assessment (below) will be rolled over for 2018 specifications]

Summary of Results

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
2014/15	2,055	344	Closed	0	0.07	1.16	0.87
2015/16	2,058	361	Closed	0	1.18	1.16	0.87
2016/17	2,054	232	Closed	0	0.38	1.16	0.87
2017/18		230*	Closed		0.33	1.16	0.87
2018/19		Not estimated				1.16*	0.87*

*Value estimated from the most recent assessment

Historical status and catch specifications for Pribilof Islands blue king crab (millions 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
2014/15	4.531	0.758	Closed	0	0.0002	0.0026	0.002
2015/16	4.537	0.796	Closed	0	0.0026	0.0026	0.002
2016/17	4.528	0.511	Closed	0	0.0008	0.0026	0.002
2017/18		0.507*	Closed	0	0.0007	0.0026	0.002
2018/19		Not estimated				0.0026*	0.002*

*Value estimated from the most recent assessment

2017 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

20 September, 2017

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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. No bycatch mortality was observed in 2016/17 in the crab (e.g., Tanner crab, snow crab) fisheries that incidentally take PIBKC. 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 other crab fisheries since 2010/11. Most bycatch mortality for PIBKC occurs in the BSAI groundfish fixed gear (pot and hook-and-line) fisheries (5-year average: 0.048 t) and trawl fisheries (5-year average: 0.309 t). In 2016/17, the estimated PIBKC bycatch mortality was 0.018 t in the groundfish fixed gear fisheries and 0.364 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 in the past 10 years.

5. *Management performance:* The stock is below MSST and consequently is overfished. Overfishing did not occur. 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 (2017/18) 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
2013/14	2,001 A	225 A	closed	0	0.03	1.16	1.04
2014/15	2,055 A	344 A	closed	0	0.07	1.16	0.87
2015/16	2,058 A	361 A	closed	0	1.18	1.16	0.87
2016/17	2,054 A	232A	closed	0	0.38	1.16	0.87
2017/18	--	230 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 2: Management performance, all units in the table are million pounds.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2013/14	4.411 A	0.496 A	closed	0	0.0001	0.0026	0.002
2014/15	4.531 A	0.758 A	closed	0	0.0002	0.0026	0.002
2015/16	4.537 A	0.796 A	closed	0	0.0026	0.0026	0.002
2016/17	4.528 A	0.511 A	closed	0	0.0008	0.0026	0.002
2016/17	--	0.507 A	--	--	--	0.0026	0.002

6. *Basis for the 2017/18 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 2017/18. 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 (2017/18) 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*
2013/14	4c	3,988	278	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	4,002	218	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2015/16	4c	4,109	361	0.09	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2016/17	4c	4,116	232	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2017/18	4c	4,108	230	0.06	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*
2013/14	4c	8.79	0.613	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	8.82	0.481	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
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	9.06	0.507	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

7. *Probability density function for the OFL:* Not applicable for this stock.

8. *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 2015/2016 data from the crab and groundfish fisheries. Abundance and biomass for PIBKC in the annual summer NMFS EBS bottom trawl survey were updated for the 2016 survey.

3. Assessment methodology

There are no changes from the 2016/17 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 2016/17 was 0.38 t, which DID NOT exceed the OFL (1.16 t). Consequently, overfishing DID NOT occur in 2016/17. The projected MMB-at-mating for 2017/18 decreased slightly from that in 2016/17 but remained below the MSST. Consequently, the stock remains overfished and a directed fishery is prohibited in 2017/18. 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 2016:

Specific remarks pertinent to this assessment

Apply the same handling mortality to bycatch of PIBKC by fixed gear as is applied to other king crab stocks (0.2).

Responses to CPT Comments:

This assessment uses 0.2 as the handling mortality applied to all fixed gear bycatch.

SSC comments October 2016:

Specific remarks pertinent to this assessment

none

CPT comments May 2017:

Specific remarks pertinent to this assessment

none

SSC comments June 2017:

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 2016/17 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 -2016/17 using NMFS Alaska Regional Office (AKRO) estimates obtained from the AKFIN database (as updated on Aug. 30, 2017). Results from the 2017 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 2016/17 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 previous assessments, 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).

No bycatch mortality occurred in the crab fisheries in 2016/17. In 2015/16, though, several PIBKC were incidentally caught in the crab fisheries, yielding an expanded estimate of 0.067 t bycatch mortality (using a handling mortality rate of 20%; Table 10). Bycatch mortality during 2015/16 was the first non-zero bycatch mortality in the crab fisheries since 2010/11.

Groundfish fisheries

The AKRO estimates of non-retained catch from all groundfish fisheries in 2016/17, as available through the AKFIN database (accessed Aug. 30, 2017), are included in this report (Tables 10-12). Updated estimates for 2009/10-2016/17 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). As noted above, previous assessments used a handling mortality rate of 50% for bycatch mortality in the fixed gear fisheries.

In 2016/17, fisheries targeting rock sole (*Lepidopsetta spp.*) accounted for 68% of the bycatch of PIBKC in the groundfish fisheries, with fisheries targeting yellowfin sole (*Limanda aspera*) and Pacific cod (*Gadus microcephalus*) accounting for 16% each. In contrast, fisheries targeting Pacific cod accounted for 48% of the estimated total PIBKC bycatch (by weight) in the groundfish fisheries in 2015/16, with fisheries targeting yellowfin sole accounting for another 43% (Table 12). In 2013/14 and 2014/15, bycatch of PIBKC occurred almost exclusively in the Pacific cod fisheries (99.4% by weight, Table 4). The flathead sole (*Hippoglossoides elasodon*) fishery has also accounted for a substantial fraction of the bycatch at times.

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 2016/17, non-pelagic trawl gear accounted for 83% (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 2013/14 and 2014/15, hook and line gear accounted for the total bycatch of PIBKC, while in 2012/13, it accounted for only 20% of the bycatch (by weight)–whereas non-pelagic trawl gear accounted for 80%. Although these appear to be large interannual changes, the actual bycatch amounts involved are fairly small and interannual variability is consequently expected to be rather high.

2.c. Catch-at-length

Not applicable.

3. Survey data

The 2017 NMFS EBS bottom trawl survey was conducted between May and August of this year. Survey results for PIBKC are based on the stock area first defined in the 2013 assessment (Foy, 2013), which includes the Pribilof District 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 2017, the survey caught 23 blue king crab in 86 stations across the stock area, while 20, 28, and 33 crab were caught across the same stations in the 2014-2016 surveys, respectively (Table **??**). Four immature males were caught in 2017, similar to numbers caught in 2014-2016 (5, 4 and 5, respectively). Four mature males (three of which was legal size) were caught in 2017, compared with 5, 13 and 3 in 2014-2016, respectively. Seven immature females were caught in 2017; only one was caught in 2014 and none in 2015, but five in 2016. Finally, eight mature females were caught in 2017, compared with only 4 in 2014, 11 in 2015, and 19 in 2016.

The area-swept estimate of mature male abundance in the stock area at the time of the survey was 91,000 (±89,000), representing an increase from 56,000 (±62,000) in 2016 (Table 15). The abundance estimate for immature males in 2017 was 68,000 (±103,000), while it was 94,000 (±95,000) in 2016. The area-swept estimate for immature female abundance in 2017 was 188,000 (±275,000), larger than in 2016 (132,000 ± 130,000), while that for mature females was only 162,000 (± 169,000), smaller than that in 2016 (323,000 ±328,000). None of the changes were statistically significant.

The area-swept estimate of mature male biomass in the stock area at the time of the 2017 survey was 253 t (±254 t), while it was 129 t (±154 t) in 2016 (Table 16). The biomass estimate for immature males in 2017 was 45 t (±68 t) , compared with 70 t (±67 t) in 2016. The area-swept estimate for immature female biomass in 2017 was 107 t (±170 t); in 2016, it was 49 t (±48 t). For mature females, the estimated swept-area biomass was 152 t (±166 t); in 2016, it was 352 t (±340 t).

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 early1990s, then generally declined (with small amplitude oscillations superimposed) to the present. Estimated female abundance generally followed a similar trend. It spiked at 180 million crab in 1980, from ~13 million crab in 1975 and only ~1 million in 1979, then returned to more typical levels in 1981 (~6 million crab). More recently, abundance has fluctuated around 200,000 females. Estimated biomass for both males and females have followed similar trends similar to those in abundance (Table 16, Figures 7 and 8).

Size frequencies for males by shell condition from recent surveys (2012-2017) 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 (2012-2017). 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.

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 FMSY and fluctuating around B_{MSY}. The SSC has endorsed using the time periods 1980-84 and 1990-97 to calculate $B_{MSY_{proxy}}$ for Pribilof Islands blue king crab to avoid time periods of low abundance possibly caused by high fishing pressure. Alternative time periods (e.g., 1975 to 1979) have also been considered but rejected (Foy 2013). Considerations for choosing the current time periods included:

A. Production potential

1) Between 2006 and 2013 the stock does appear 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 ($ASP_t = MMB_{t+1} \check{} MMB_t + totalcatch_t$) suggested that only meaningful surplus existed only in the late 1970s and early 1980s while minor surplus production in the early 1990s may have led to the increases in biomass observed in the late 1990s.
3) Although a climate regime shift where temperature and current structure changes are likely to impact blue king crab larval dispersal and subsequent juvenile crab distribution, no apparent trends in production before or after 1978 were observed (Foy 2013). There are few empirical data to identify trends that may allude to a production shift. However, further analysis is warranted given the paucity of surplus production and recruitment subsequent to 1981 and the spikes in recruits (male crab 120-134 mm) /spawner (MMB) observed in the early 1990s and 2009 (Figure 21 in Foy 2013).

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, before the fishery was closed in 1987, and increased again in 1995 before closing again in 1999 (Figure 22 in Foy 2013). The current $F_{MSY_{proxy}} = M$ is 0.18, so time periods with greater exploitation rates should not be considered to represent a period with an average rate of fishery removals.

C. 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.

Thus, MMB_{mating} is the basis for calculating $B_{MSY_{proxy}}$. The formulas used to calculate MMB_{mating} from MMB at the time of the survey (MMB_{survey}) are documented in Appendix 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 4,108 t.

In this assessment, “current B” (B) is the MMB_{mating} projected for 2017/18. Details of this calculation are also provided in Appendix C. For 2017/18, $B = 230$ 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}) = 4,108 t • M = 0.18 yr^{-1} • B = 230 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*
2013/14	4c	3,988	278	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	4,002	218	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2015/16	4c	4,109	361	0.09	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2016/17	4c	4,116	232	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2017/18	4c	4,108	230	0.06	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*
2013/14	4c	8.79	0.613	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	8.82	0.481	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
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	9.06	0.507	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

4. Specification of the retained catch portion of the total catch OFL

The retained portion of the catch for this stock is zero (0 t).

5. Recommendations:

For 2017/18, $B_{MSY_{proxy}}$ = 4,108 t, derived as the mean MMB_{mating} from 1980/81 to 1984/85 and 1990/91 to 1997/98 using the random effects model-smoothed survey time series. The stock demonstrated highly variable levels of MMB during both of these periods, likely leading to uncertain approximations for B_{MSY}. Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to limited numbers of tows with crab catches.

MMB_{mating} for 2017/18 was estimated at 230 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 2017/18, 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 is 0.51, 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 2017/18, $F_{directed} = 0$ 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
2013/14	2,001 A	225 A	closed	0	0.03	1.16	1.04
2014/15	2,055 A	344 A	closed	0	0.07	1.16	0.87
2015/16	2,058 A	361 A	closed	0	1.18	1.16	0.87
2016/17	2,054 A	232A	closed	0	0.38	1.16	0.87
2017/18	--	230 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
2013/14	4.411 A	0.496 A	closed	0	0.0001	0.0026	0.002
2014/15	4.531 A	0.758 A	closed	0	0.0002	0.0026	0.002
2015/16	4.537 A	0.796 A	closed	0	0.0026	0.0026	0.002
2016/17	4.528 A	0.511 A	closed	0	0.0008	0.0026	0.002
2016/17	--	0.507 A	--	--	--	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.

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.

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Tables

Table 9: Total retained catches from directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2011; D. Pengilly and J. Webb, ADFG, personal communications).

Year	Retained Catch		Avg. CPUE
	Abundance	Biomass (t)	legal crabs/pot
1973/1974	174,420	579	26
1974/1975	908,072	3,224	20
1975/1976	314,931	1,104	19
1976/1977	855,505	2,999	12
1977/1978	807,092	2,929	8
1978/1979	797,364	2,901	8
1979/1980	815,557	2,719	10
1980/1981	1,497,101	4,976	9
1981/1982	1,202,499	4,119	7
1982/1983	587,908	1,998	5
1983/1984	276,364	995	3
1984/1985	40,427	139	3
1985/1986	76,945	240	3
1986/1987	36,988	117	2
1987/1988	95,130	318	2
1988/1989	0	0	--
1989/1990	0	0	--
1990/1991	0	0	--
1991/1992	0	0	--
1992/1993	0	0	--
1993/1994	0	0	--
1994/1995	0	0	--
1995/1996	190,951	628	5
1996/1997	127,712	425	4
1997/1998	68,603	232	3
1998/1999	68,419	234	3
1999/2000 - 2016/2017	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	0.039	0.056
2011/12	0.000	0.000	0.000	0.112	0.007
2012/13	0.000	0.000	0.000	0.167	0.669
2013/14	0.000	0.000	0.000	0.064	0.000
2014/15	0.000	0.000	0.000	0.144	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

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	0.008	0.045	0.090
2011/12	0.000	0.000	0.000	0.022	0.006	0.028
2012/13	0.000	0.000	0.000	0.033	0.535	0.568
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	0.861
2016/17	0.000	0.000	0.000	0.018	0.364	0.382

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

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	83	0	17	0	580

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	Abundance (millions)		Biomass (mt)	
					estimate	95% CI	estimate	95% CI
2017	Immature male	86	2	4	0.068	0.103	45	68
	Mature male	86	4	4	0.091	0.089	253	254
	Legal male	86	3	3	0.072	0.083	223	250
	Immature female	86	3	7	0.188	0.275	107	170
	Mature female	86	4	8	0.162	0.169	152	166
2016	Immature male	86	4	5	0.094	0.095	70	67
	Mature male	86	3	3	0.056	0.062	129	154
	Legal male	86	1	1	0.019	0.038	68	133
	Immature female	86	4	5	0.132	0.130	49	48
	Mature female	86	7	19	0.323	0.328	352	340
2015	Immature male	86	2	4	0.076	0.113	82	120
	Mature male	86	8	13	0.234	0.168	622	480
	Legal male	86	5	7	0.125	0.109	428	385
	Immature female	86	0	0	0.000	0.000	0	0
	Mature female	86	4	11	0.202	0.260	160	207
2014	Immature male	86	3	5	0.091	0.105	83	102
	Mature male	86	2	5	0.092	0.128	233	320
	Legal male	86	2	5	0.092	0.128	233	320
	Immature female	86	1	1	0.028	0.054	16	32
	Mature female	86	3	4	0.074	0.088	91	108

Table 15: Abundance time series for Pribilof Islands blue king crab from the NMFS annual EBS bottom trawl survey.

Year	Males								Females	
	immature		mature		legal		total		total	
	abundance	cv	abundance	cv	abundance	cv	abundance	cv	abundance	cv
1975	8,475,781	0.57	15,288,169	0.50	9,051,486	0.50	23,763,950	0.47	13,147,587	0.61
1976	4,959,559	0.95	4,782,105	0.45	4,012,289	0.47	9,741,664	0.59	8,138,538	0.91
1977	4,215,865	0.46	13,043,983	0.74	11,768,927	0.77	17,259,848	0.63	14,731,651	0.86
1978	2,421,458	0.50	6,140,638	0.50	3,922,874	0.62	8,562,096	0.43	5,987,437	0.66
1979	79,355	0.70	4,107,868	0.33	3,017,119	0.31	4,187,222	0.32	1,311,351	0.77
1980	2,732,728	0.47	7,842,342	0.41	6,244,058	0.42	10,575,070	0.40	183,684,143	0.98
1981	2,099,475	0.32	3,834,431	0.18	3,245,951	0.18	5,933,906	0.21	6,260,015	0.42
1982	1,371,283	0.28	2,353,813	0.18	2,071,468	0.19	3,725,096	0.17	8,713,260	0.63
1983	1,030,732	0.36	1,851,301	0.19	1,321,395	0.17	2,882,033	0.22	9,771,695	0.76
1984	517,574	0.40	770,643	0.22	558,226	0.25	1,288,217	0.21	3,234,663	0.37
1985	67,765	0.60	428,076	0.28	270,242	0.29	495,841	0.27	746,266	0.36
1986	18,904	1.00	480,198	0.31	460,311	0.31	499,102	0.30	2,138,616	0.88
1987	621,541	0.83	903,180	0.41	830,151	0.42	1,524,721	0.43	1,072,008	0.48
1988	1,238,053	0.84	237,868	0.51	237,868	0.51	1,475,921	0.71	1,363,093	0.64
1989	3,514,764	0.59	239,948	0.62	239,948	0.62	3,754,712	0.58	3,777,855	0.58
1990	2,449,864	0.60	1,470,419	0.63	571,708	0.54	3,920,283	0.58	4,223,169	0.56
1991	1,920,443	0.37	2,014,086	0.36	1,237,558	0.44	3,934,529	0.34	3,572,899	0.35
1992	2,435,796	0.59	1,935,278	0.42	1,154,465	0.45	4,371,074	0.48	3,946,863	0.52
1993	1,483,524	0.52	1,875,500	0.31	1,114,301	0.30	3,359,024	0.34	2,663,329	0.38
1994	638,520	0.37	1,294,263	0.34	935,269	0.34	1,932,783	0.33	5,191,978	0.44
1995	1,146,803	0.89	3,101,712	0.60	2,186,409	0.62	4,248,514	0.67	4,697,035	0.49
1996	719,430	0.63	1,712,015	0.28	1,269,275	0.26	2,431,445	0.33	5,321,557	0.46
1997	467,234	0.53	1,201,296	0.29	932,852	0.28	1,668,530	0.34	2,934,717	0.39
1998	949,447	0.46	967,098	0.25	797,187	0.25	1,916,545	0.31	2,329,750	0.37
1999	159,536	0.37	617,258	0.33	452,740	0.34	776,794	0.33	2,755,976	0.49
2000	163,835	0.56	725,051	0.30	527,589	0.30	888,885	0.31	1,363,070	0.46
2001	92,918	0.65	522,239	0.71	445,863	0.74	615,157	0.69	1,715,981	0.74
2002	0	0.00	225,476	0.47	207,146	0.49	225,476	0.47	1,240,582	0.78
2003	45,271	0.72	228,897	0.39	213,572	0.40	274,168	0.34	1,187,583	0.72
2004	87,651	0.59	47,905	0.56	15,584	1.00	135,556	0.42	168,094	0.51
2005	1,981,338	0.96	91,932	0.71	91,932	0.71	2,073,270	0.92	2,557,310	0.89
2006	138,118	0.49	55,579	0.56	38,242	0.70	193,697	0.42	542,588	0.62
2007	246,165	0.72	110,080	0.85	54,403	0.75	356,245	0.64	288,245	0.59
2008	233,919	0.93	18,256	1.00	18,256	1.00	252,174	0.86	779,488	0.75
2009	267,717	0.63	248,626	0.73	68,117	0.59	516,343	0.68	629,385	0.76
2010	101,151	0.84	130,465	0.49	64,703	0.48	231,616	0.61	414,660	0.62
2011	0	0.00	165,525	0.79	129,098	0.87	165,525	0.79	54,601	0.56
2012	194,522	1.00	272,233	0.80	164,165	0.68	466,755	0.88	346,777	0.70
2013	76,351	1.00	104,361	0.86	68,726	0.80	180,712	0.64	195,644	0.53
2014	90,990	0.59	91,856	0.71	91,856	0.71	182,846	0.57	102,088	0.51
2015	75,575	0.77	233,630	0.37	124,592	0.45	309,205	0.41	202,464	0.65
2016	94,022	0.52	55,852	0.56	19,345	1.00	149,874	0.49	454,450	0.50
2017	68,238	0.77	90,645	0.50	71,937	0.59	158,884	0.46	349,659	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		total	
	biomass (t)	cv	biomass (t)	cv	biomass (t)	cv	biomass (t)	cv	biomass (t)	cv
1975	8,341	0.52	38,054	0.50	27,016	0.50	46,395	0.47	12,442	0.64
1976	4,129	0.94	14,059	0.45	12,649	0.47	18,188	0.45	5,792	0.89
1977	3,713	0.44	42,618	0.77	40,366	0.78	46,332	0.73	13,572	0.87
1978	2,765	0.51	17,370	0.56	13,517	0.64	20,135	0.51	6,492	0.72
1979	61	0.79	10,959	0.32	9,040	0.31	11,021	0.31	1,189	0.76
1980	2,084	0.49	23,553	0.43	20,679	0.45	25,637	0.42	212,303	0.98
1981	1,704	0.30	11,628	0.17	10,554	0.17	13,332	0.18	6,484	0.46
1982	1,152	0.23	7,389	0.19	6,893	0.19	8,541	0.17	9,377	0.67
1983	962	0.36	5,409	0.18	4,474	0.17	6,371	0.19	10,248	0.78
1984	130	0.36	2,216	0.23	1,824	0.25	2,345	0.22	3,085	0.38
1985	39	0.73	1,055	0.27	756	0.28	1,094	0.26	525	0.44
1986	4	1.00	1,505	0.30	1,473	0.31	1,508	0.30	2,431	0.90
1987	191	0.78	2,923	0.41	2,781	0.41	3,115	0.40	913	0.53
1988	170	0.71	842	0.53	842	0.53	1,012	0.46	718	0.47
1989	1,275	0.62	828	0.64	828	0.64	2,102	0.55	1,746	0.50
1990	2,004	0.66	3,078	0.60	1,514	0.52	5,082	0.61	2,929	0.49
1991	1,377	0.39	4,690	0.39	3,326	0.45	6,067	0.37	2,776	0.38
1992	1,801	0.51	4,391	0.42	3,035	0.45	6,192	0.43	2,649	0.46
1993	1,089	0.54	4,556	0.31	3,203	0.30	5,644	0.30	2,092	0.40
1994	619	0.39	3,410	0.34	2,806	0.35	4,029	0.34	4,893	0.44
1995	968	0.86	8,360	0.60	6,787	0.62	9,328	0.63	4,279	0.50
1996	745	0.61	4,641	0.27	3,873	0.27	5,386	0.28	5,585	0.49
1997	381	0.55	3,233	0.28	2,765	0.27	3,614	0.29	3,028	0.41
1998	692	0.41	2,798	0.25	2,510	0.25	3,490	0.25	2,182	0.39
1999	161	0.40	1,729	0.34	1,426	0.35	1,890	0.33	2,868	0.47
2000	113	0.68	2,091	0.30	1,746	0.31	2,205	0.30	1,462	0.46
2001	87	0.76	1,599	0.73	1,461	0.76	1,686	0.73	1,817	0.72
2002	0	0.00	680	0.51	647	0.52	680	0.51	1,401	0.78
2003	19	0.98	702	0.40	671	0.41	721	0.39	1,307	0.73
2004	36	0.65	107	0.58	48	1.00	143	0.46	123	0.50
2005	326	0.94	344	0.71	344	0.71	670	0.59	847	0.61
2006	87	0.58	166	0.60	139	0.70	253	0.46	576	0.71
2007	197	0.74	306	0.80	206	0.73	503	0.66	282	0.71
2008	212	0.95	46	1.00	46	1.00	258	0.80	672	0.70
2009	254	0.68	497	0.71	187	0.60	751	0.70	625	0.82
2010	92	0.85	303	0.46	190	0.48	395	0.52	394	0.63
2011	0	0.00	461	0.84	399	0.89	461	0.84	37	0.67
2012	165	1.00	644	0.74	459	0.64	809	0.79	237	0.64
2013	15	1.00	250	0.80	190	0.75	265	0.75	166	0.65
2014	83	0.62	233	0.70	233	0.70	317	0.57	108	0.53
2015	82	0.75	622	0.39	428	0.46	703	0.39	160	0.66
2016	70	0.49	129	0.61	68	1.00	199	0.52	401	0.48
2017	45	0.77	253	0.51	223	0.57	298	0.47	259	0.53

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	26,901	16,826	43,010
1976	14,059	8,104	24,391	19,927	13,389	29,657
1977	42,618	17,814	101,958	21,265	13,591	33,271
1978	17,370	8,912	33,852	16,975	11,333	25,424
1979	10,959	7,386	16,262	13,329	9,743	18,236
1980	23,553	13,894	39,925	15,605	11,032	22,074
1981	11,628	9,321	14,507	11,423	9,355	13,947
1982	7,389	5,825	9,374	7,449	6,052	9,168
1983	5,409	4,316	6,778	5,081	4,155	6,213
1984	2,216	1,659	2,959	2,347	1,841	2,993
1985	1,055	754	1,476	1,350	1,020	1,786
1986	1,505	1,030	2,199	1,555	1,157	2,091
1987	2,923	1,761	4,853	1,928	1,352	2,749
1988	842	446	1,591	1,427	946	2,153
1989	828	392	1,749	1,599	1,027	2,488
1990	3,078	1,513	6,261	2,603	1,718	3,944
1991	4,690	2,910	7,556	3,812	2,677	5,428
1992	4,391	2,612	7,382	4,181	2,940	5,947
1993	4,556	3,100	6,694	4,329	3,200	5,856
1994	3,410	2,220	5,240	4,017	2,907	5,551
1995	8,360	4,091	17,086	4,942	3,336	7,322
1996	4,641	3,309	6,509	4,384	3,316	5,796
1997	3,233	2,284	4,575	3,322	2,523	4,373
1998	2,798	2,043	3,833	2,705	2,085	3,508
1999	1,729	1,136	2,631	1,976	1,451	2,691
2000	2,091	1,443	3,031	1,836	1,358	2,483
2001	1,599	689	3,710	1,265	830	1,927
2002	680	369	1,254	784	528	1,163
2003	702	428	1,150	549	382	788
2004	107	53	214	278	179	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	210	126	351
2009	497	219	1,130	294	186	466
2010	303	173	532	321	214	482
2011	461	180	1,180	372	232	596
2012	644	277	1,496	399	248	642
2013	250	102	615	345	215	555
2014	233	104	524	339	217	529
2015	622	382	1,011	399	275	579
2016	129	62	265	258	167	400
2017	253	136	470	256	158	414

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 2017/18 estimates are projected values (see Appendix C).

year	"Raw" Survey Biomass (t)	Random Effects Model (t)
1975/76	33,223	23,182
1976/77	9,834	15,117
1977/78	35,611	16,386
1978/79	12,904	12,549
1979/80	7,304	9,438
1980/81	16,519	9,364
1981/82	6,590	6,406
1982/83	4,769	4,822
1983/84	3,934	3,639
1984/85	1,862	1,981
1985/86	723	989
1986/87	1,244	1,289
1987/88	2,333	1,436
1988/89	758	1,285
1989/90	745	1,439
1990/91	2,771	2,343
1991/92	4,220	3,430
1992/93	3,930	3,741
1993/94	4,089	3,885
1994/95	3,068	3,614
1995/96	6,937	3,859
1996/97	3,776	3,546
1997/98	2,692	2,773
1998/99	2,291	2,207
1999/00	1,555	1,777
2000/01	1,883	1,653
2001/02	1,439	1,138
2002/03	612	706
2003/04	632	494
2004/05	96	250
2005/06	309	239
2006/07	149	203
2007/08	275	206
2008/09	41	189
2009/10	447	265
2010/11	273	289
2011/12	415	335
2012/13	579	359
2013/14	225	311
2014/15	210	305
2015/16	559	359
2016/17	116	232
2017/18*	227	230

Figures

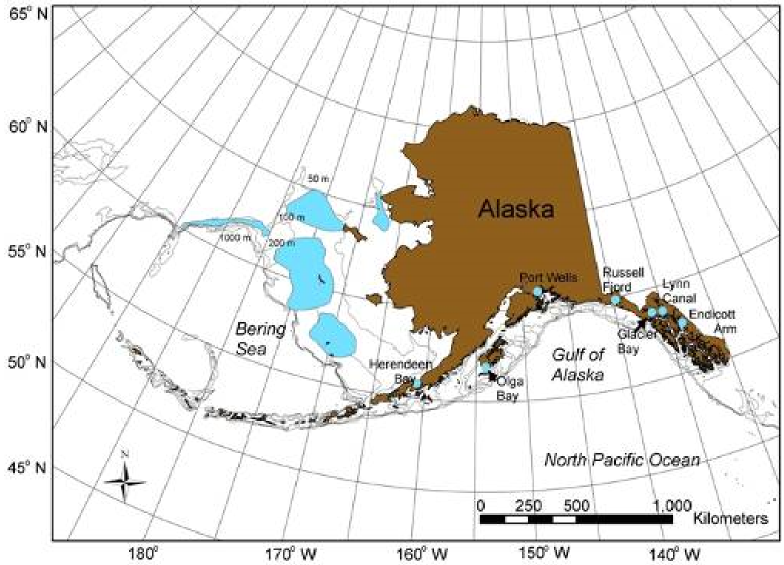


Figure 1: Distribution of blue king crab, *Paralithodes platypus*, in Alaskan waters.

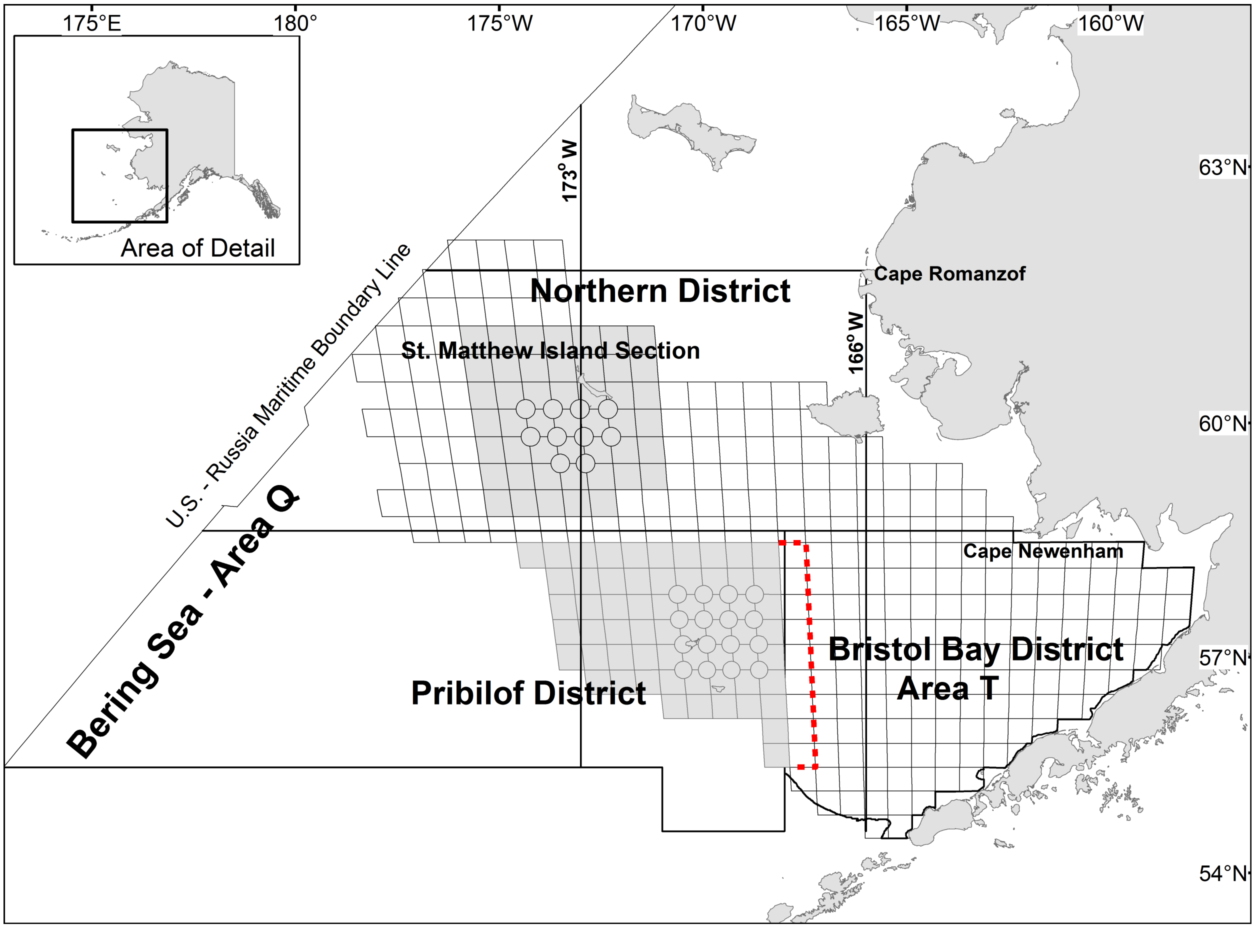


Figure 2: Map of the ADFG King Crab Registration Area Q (Bering Sea), showing (among others) the Pribilof District, which constitutes the stock boundary for PIBKC. The figure also indicates the additional 20nm strip (red dotted line) added in 2013 for calculating biomass and catch data in the Pribilof District.

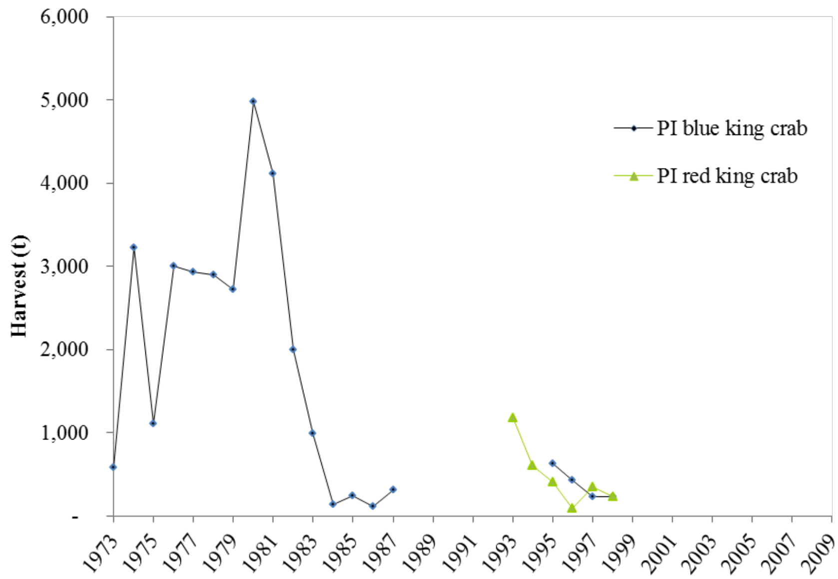


Figure 3: Historical harvests and Guideline Harvest Levels (GHLs) for Pribilof Islands red and blue king crab (from Bowers et al., 2011).

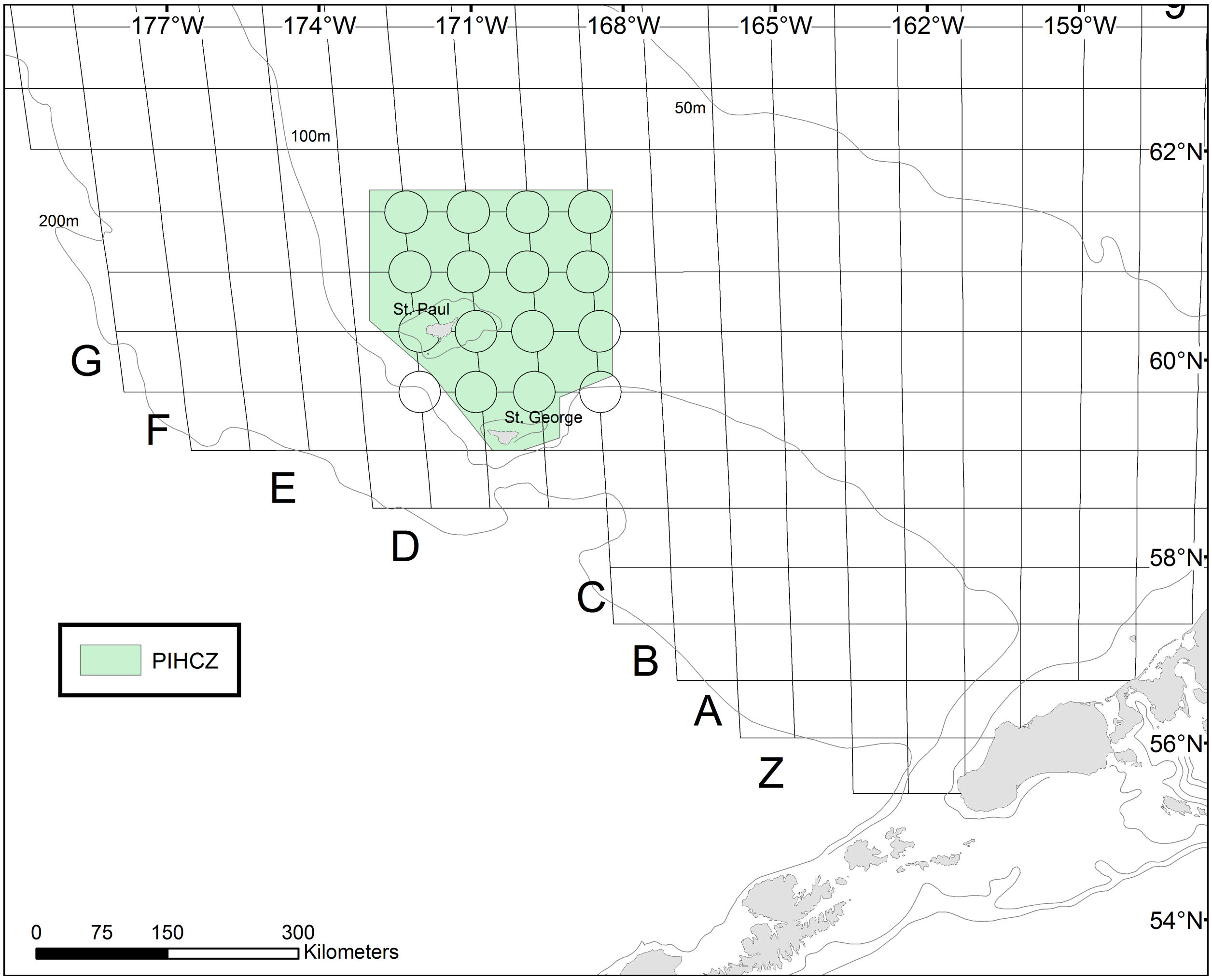


Figure 4: The shaded area shows the Pribilof Islands Habitat Conservation Zone (PIHCZ). Trawl fishing is prohibited year-round in this zone (as of 1995), as is pot fishing for Pacific cod (as of 2015). Also shown is a portion of the NMFS annual EBS bottom trawl survey grid.

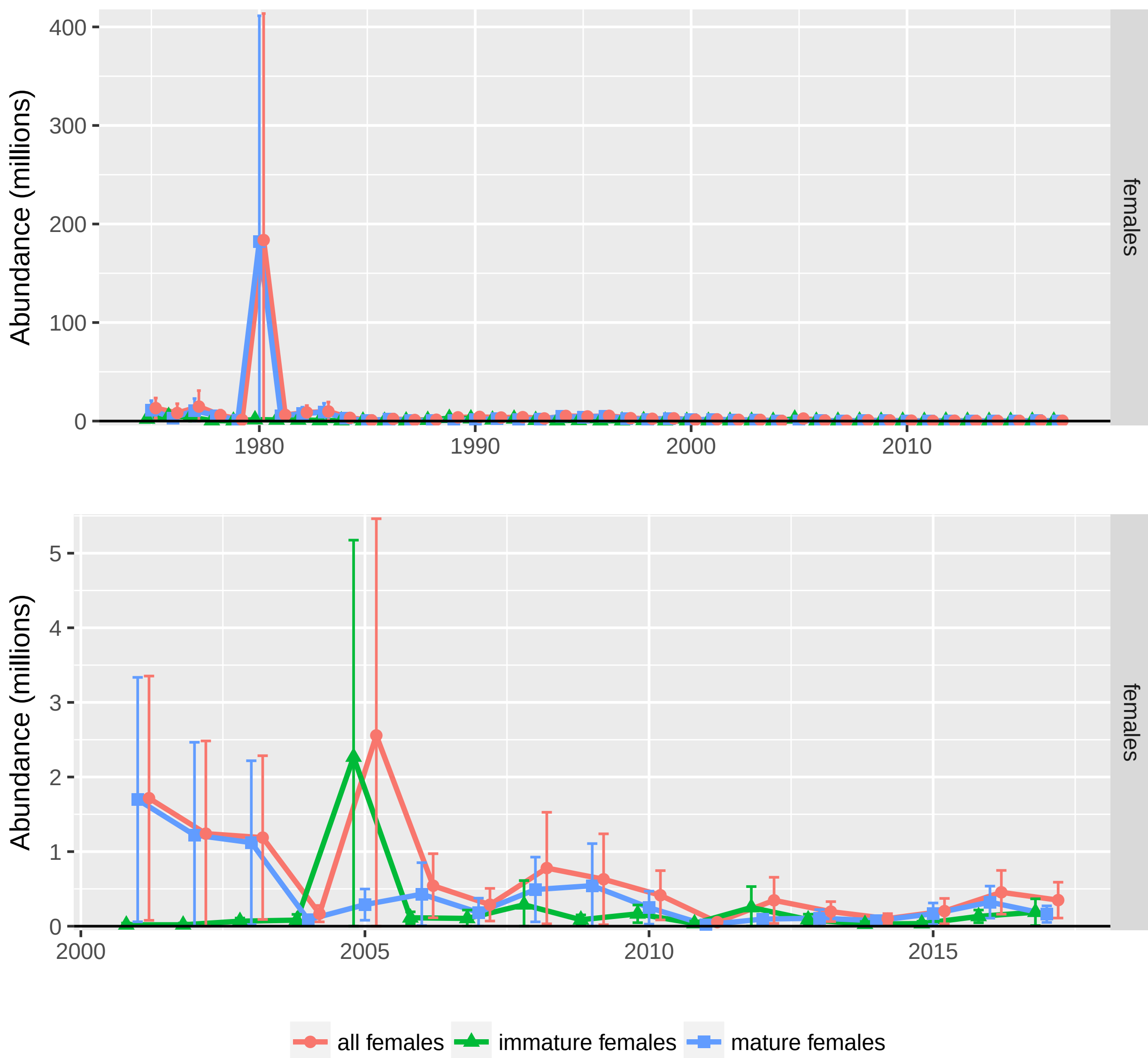


Figure 5: Time series of survey abundance for females (immature, mature, and total).

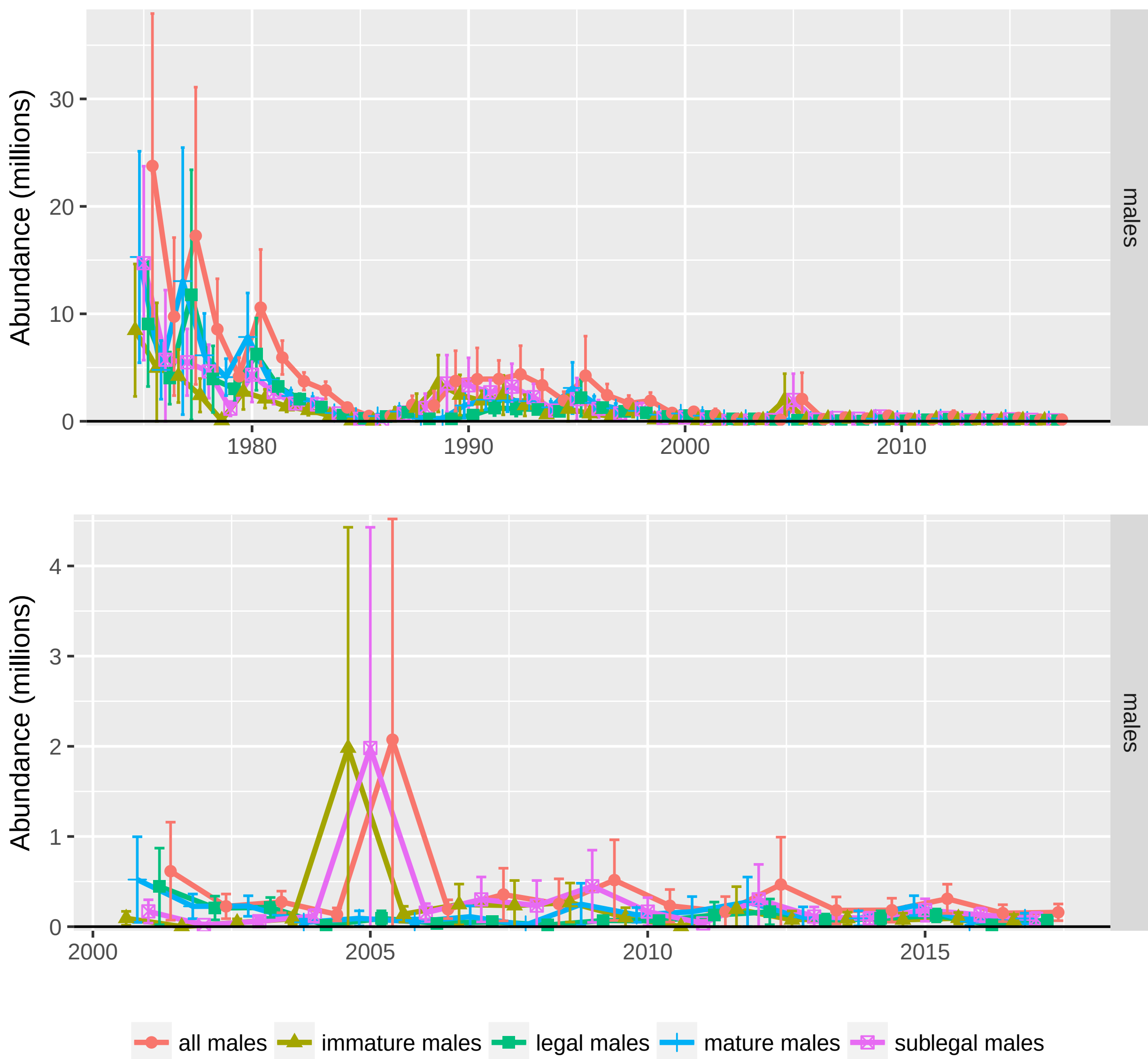


Figure 6: Time series of survey abundance for males in several categories (immature, mature, sublegal, legal and total).

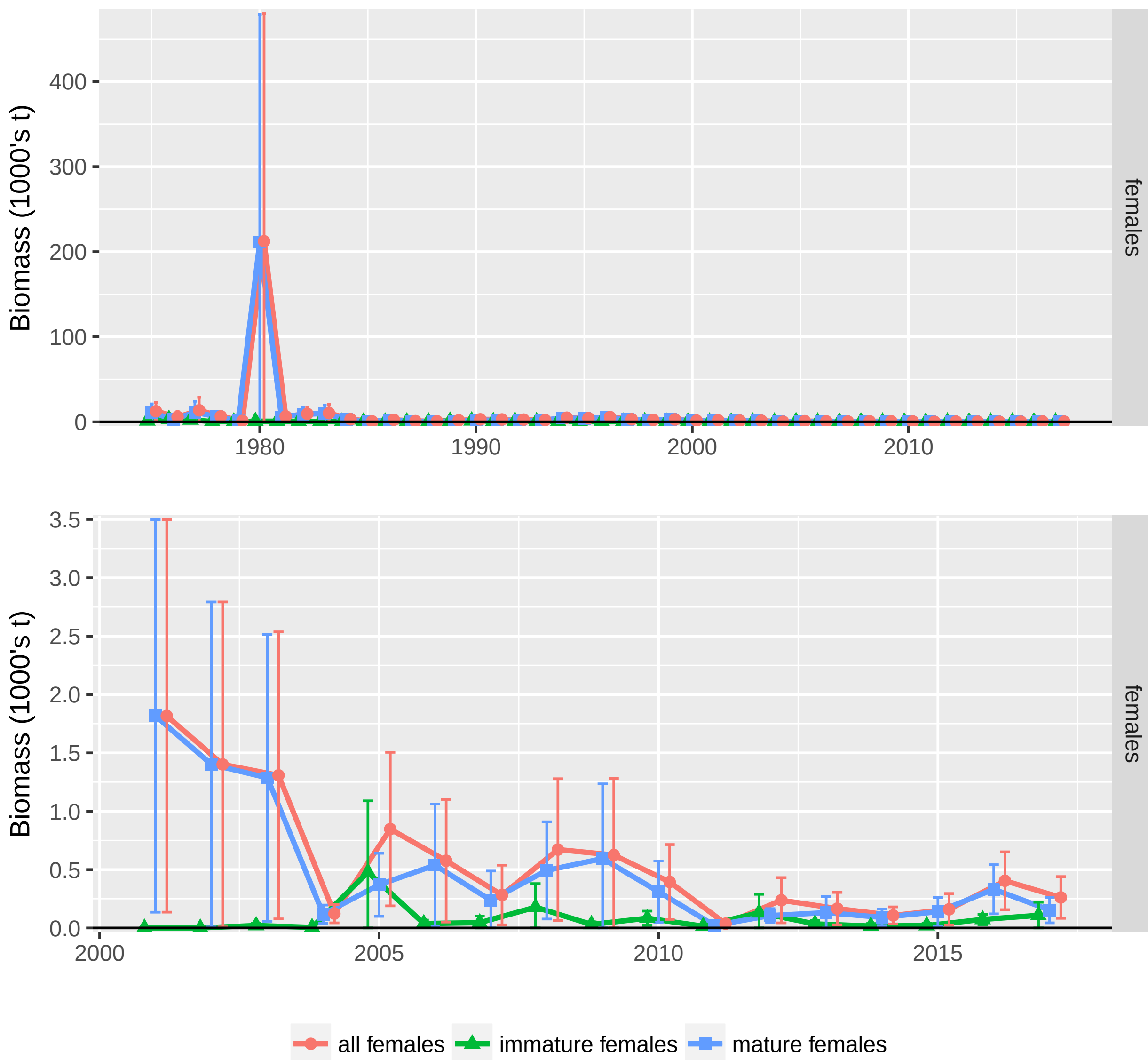


Figure 7: Time series of survey abundance for females (immature, mature, and total).

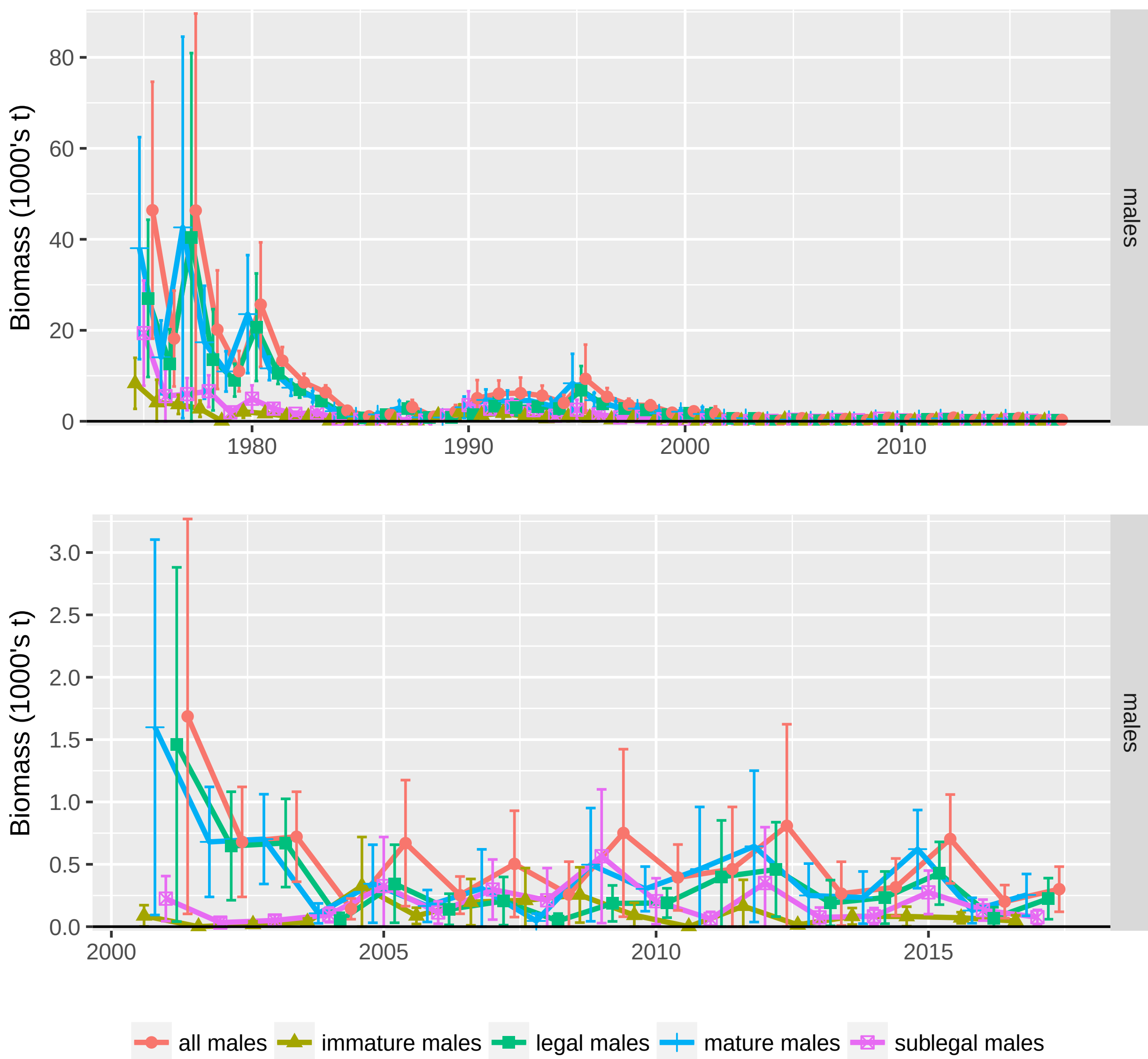


Figure 8: Time series of survey biomass for males in several categories (immature, mature, sublegal, legal and total).

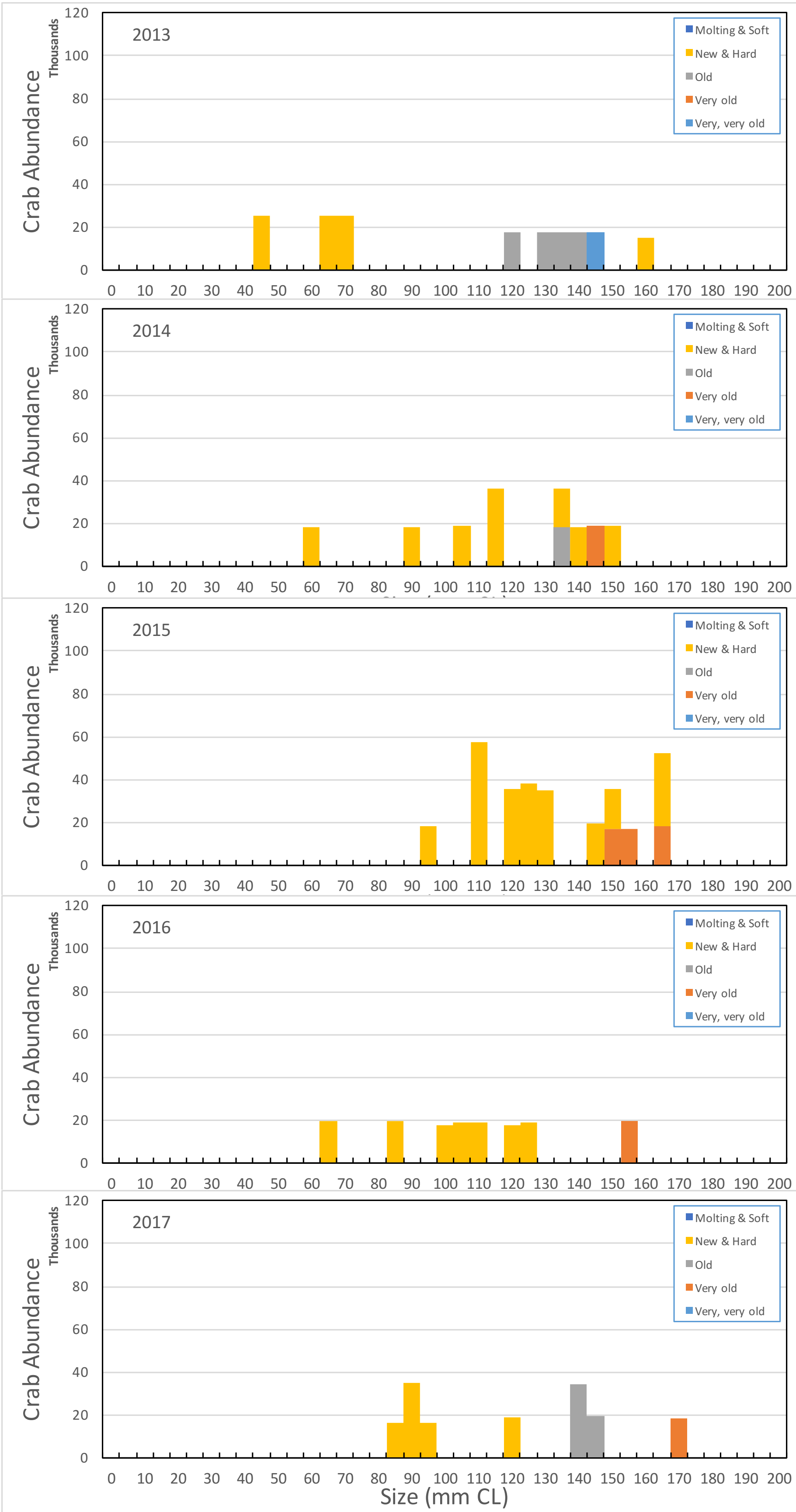


Figure 9: Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from recent NMFS EBS bottom trawl surveys.

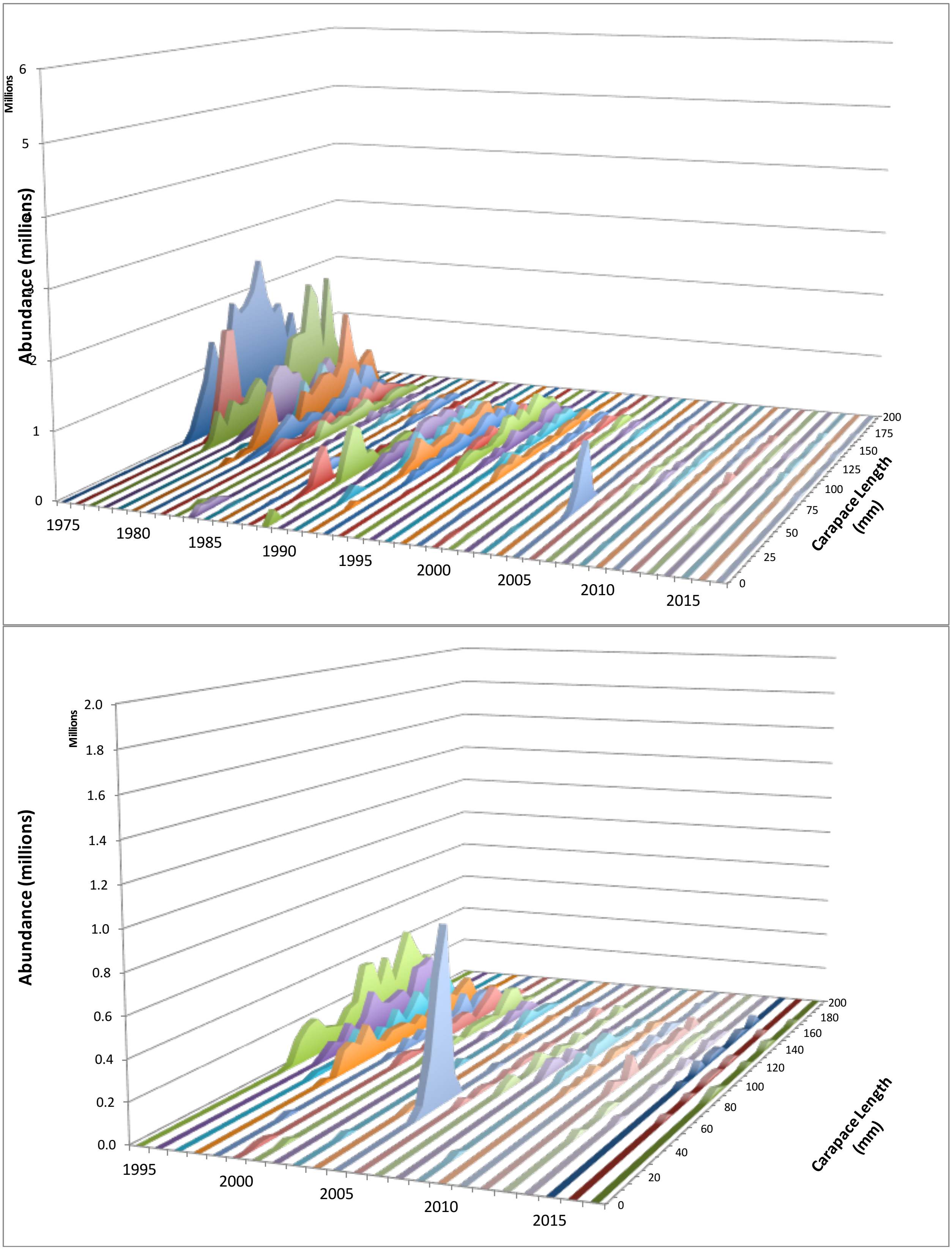


Figure 10: Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islands blue king crab by 5 mm length bins. The top row shows the entire time series, the bottom shows the size compositions since 1995.

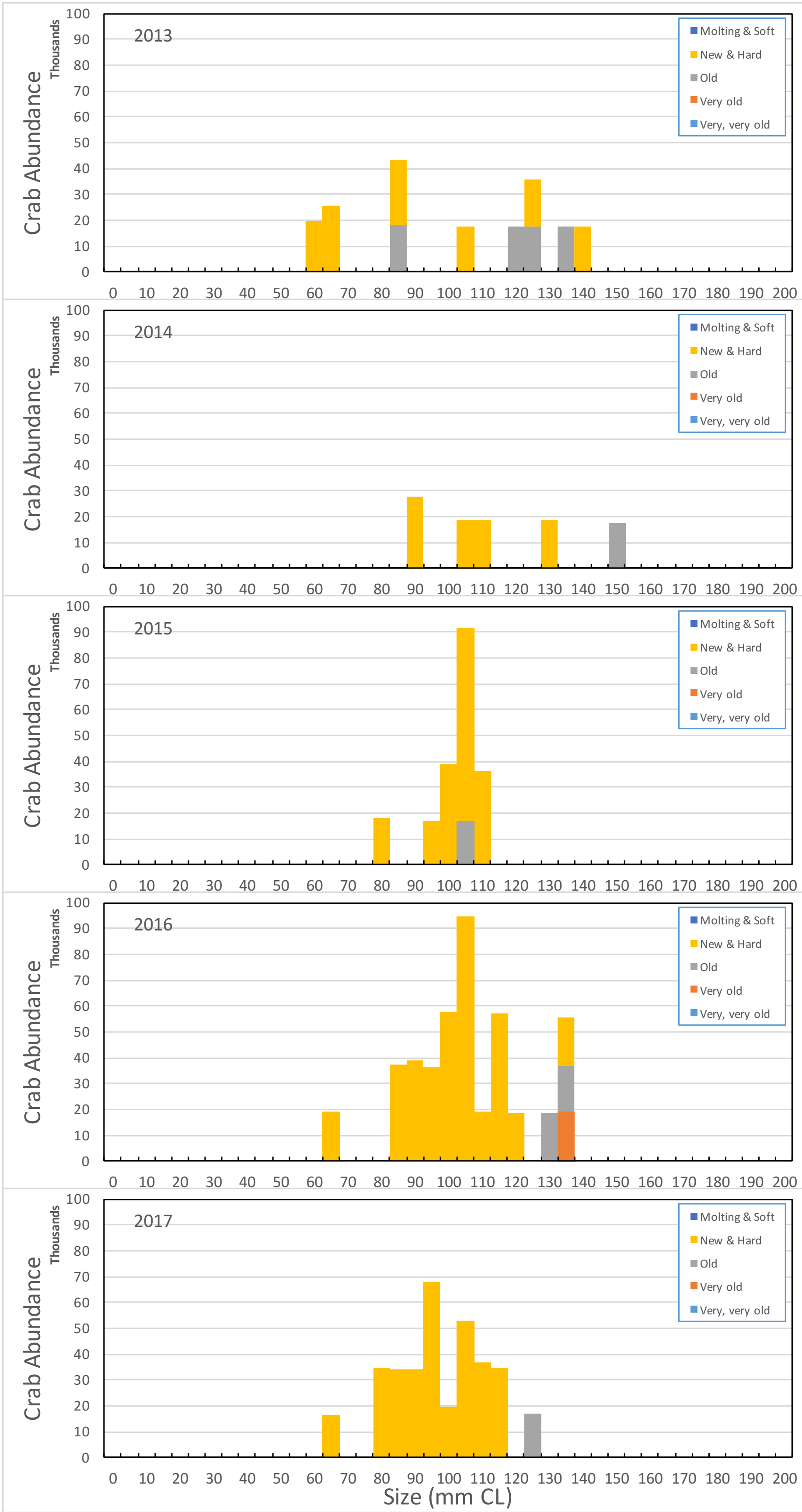
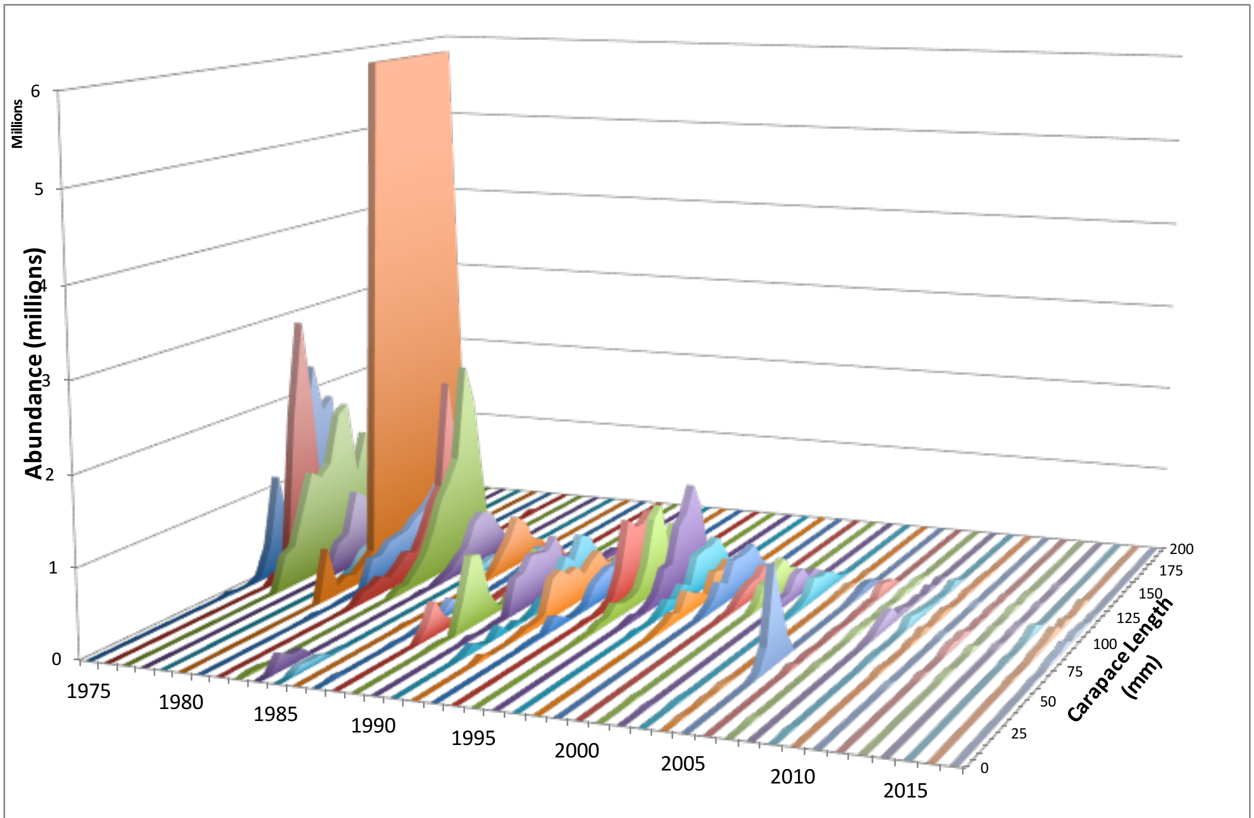


Figure 11: Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from recent NMFS EBS bottom trawl surveys.



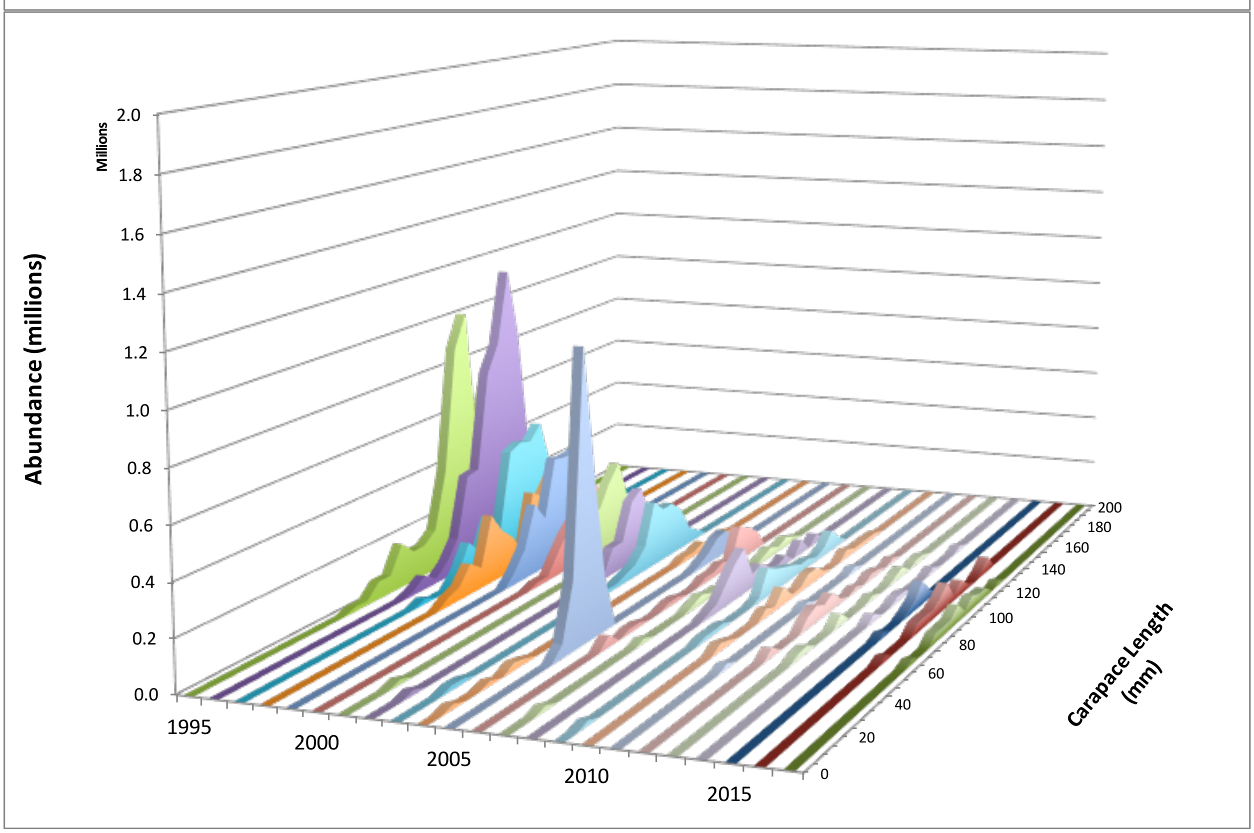


Figure 12: Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islands blue king crab by 5 mm length bins. The top row shows the entire time series, the bottom shows the size compositions since 1995.

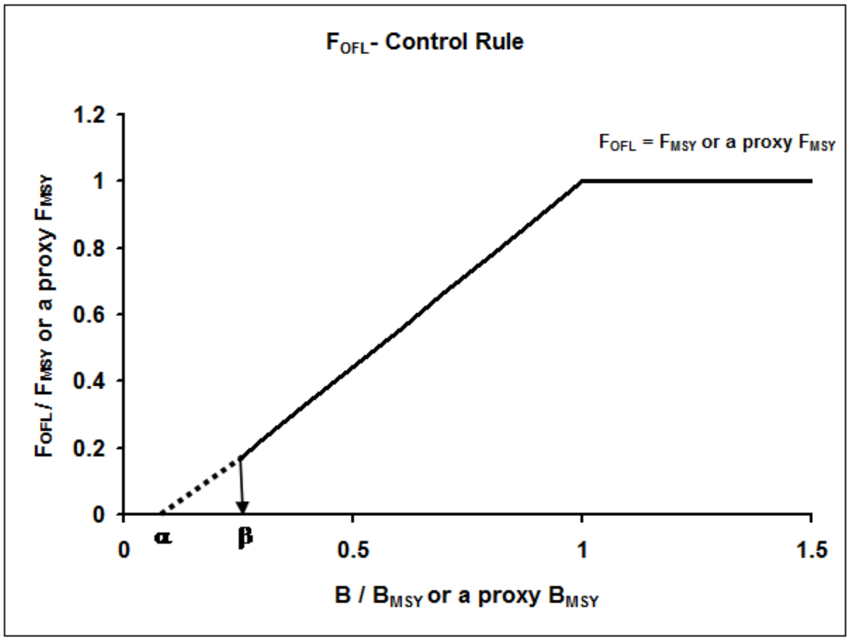


Figure 13: F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β (= 0.25).

Appendix A: PIBKC Bycatch in the Groundfish Fisheries: 2009/10-2016/17

William Stockhausen

11 September, 2017

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Introduction

Bycatch of PIBKC in the groundfish fisheries during 2009/10-2016/17 was downloaded from AKFIN on Aug. 30, 2017 as file (“`FromAKFIN.PIBKC.BycatchEstimates.2009-2016.csv`”).

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	1189582	90	57	3280	53174	455	524

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 2009-2016 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		Rock Sole - BSAI		Yellowfin Sole - BSAI	
year	biomass	number	biomass	number	biomass	number	biomass	number
2009	71	54	216	87	0	0	129	119
2010	56	35	42	14	0	0	0	0
2011	0	0	119	62	0	0	0	0
2012	24	12	170	72	0	0	645	328
2013	0	0	64	41	0	0	0	0
2014	0	0	143	64	0	0	0	0
2015	147	58	742	351	0	0	661	199
2016	0	0	89	56	368	432	87	92

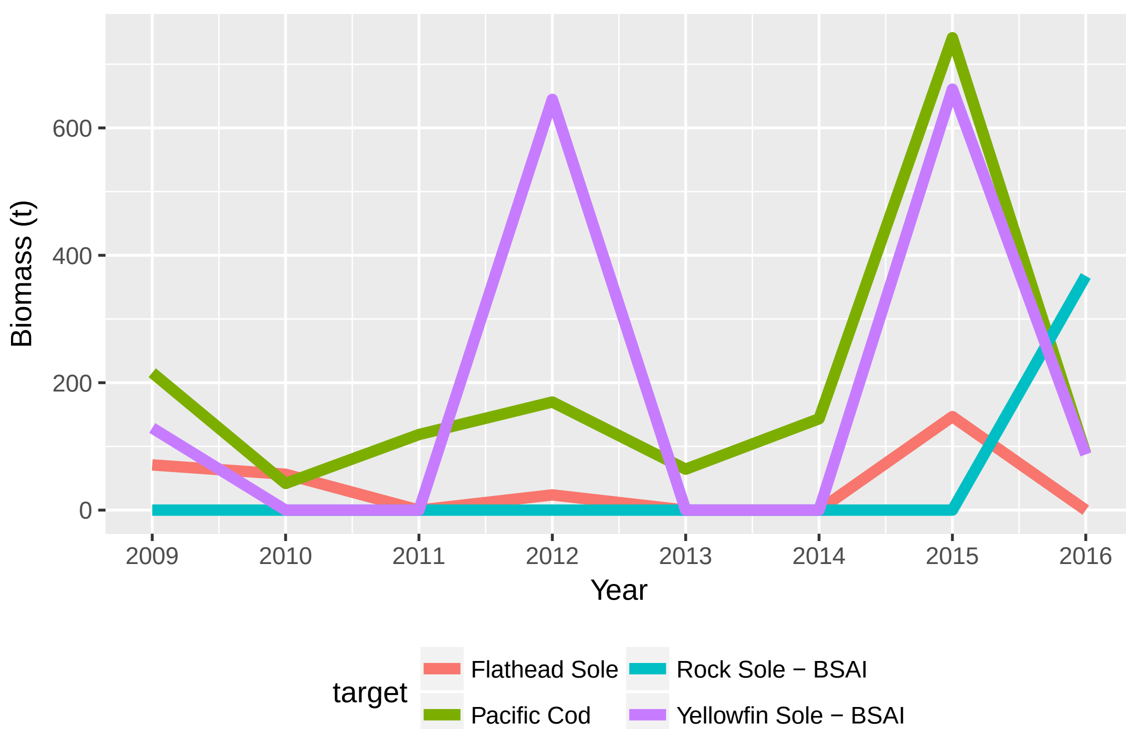

Figure 2: Bycatch of PIBKC in the groundfish fisheries, by target type.

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.

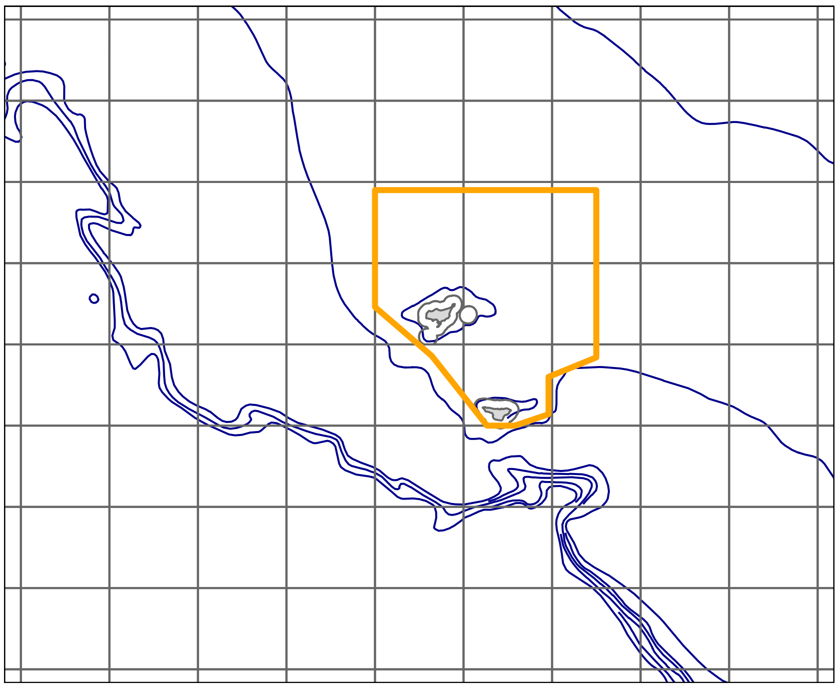

Figure 3: Basemap for subsequent maps, with EBS bathymetry (blue lines), ADFG stat areas (black rectangles), and the Pribilof Islands Habitat Conservation Area (orange outline).

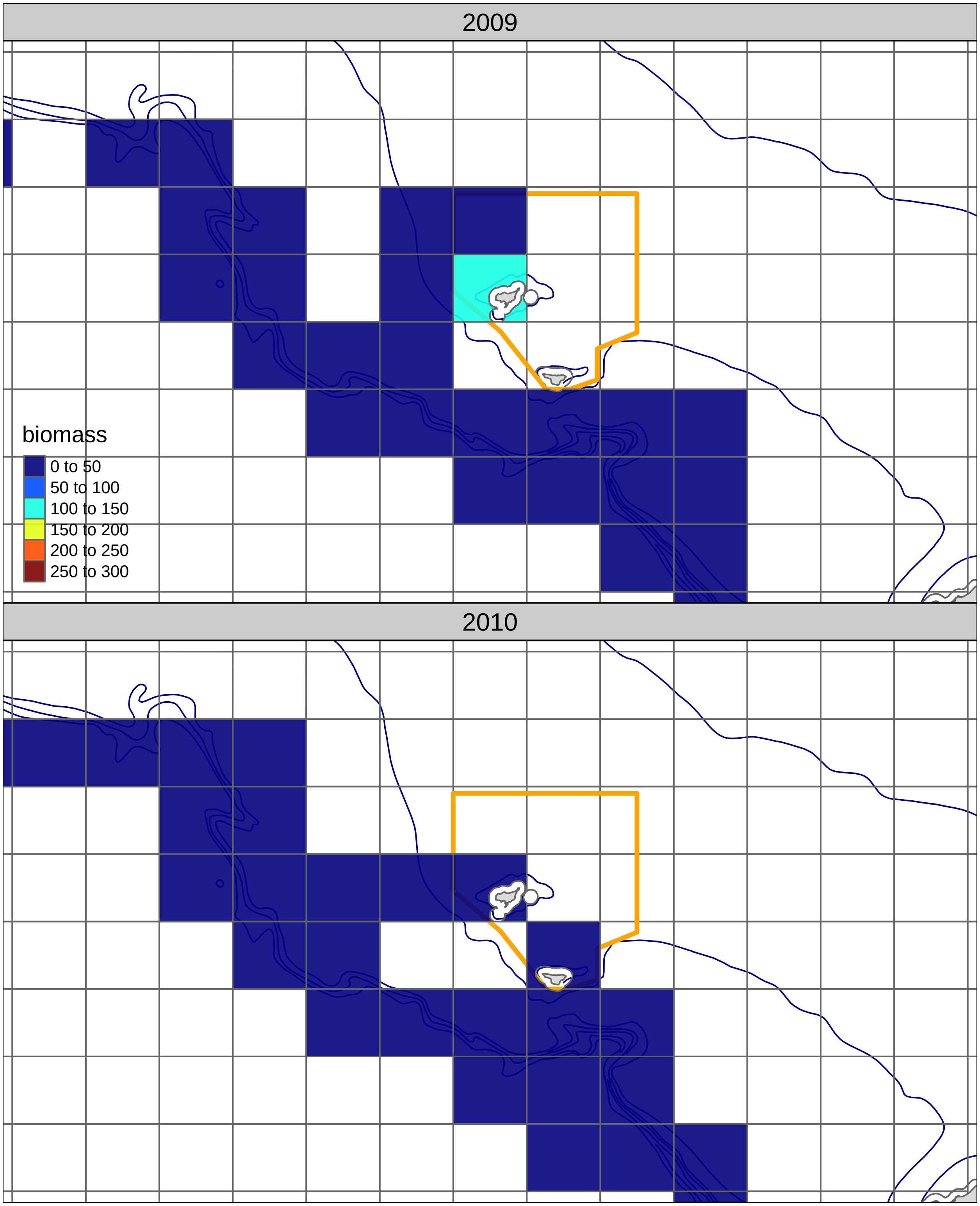

Figure 4: (1 of 4). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries.

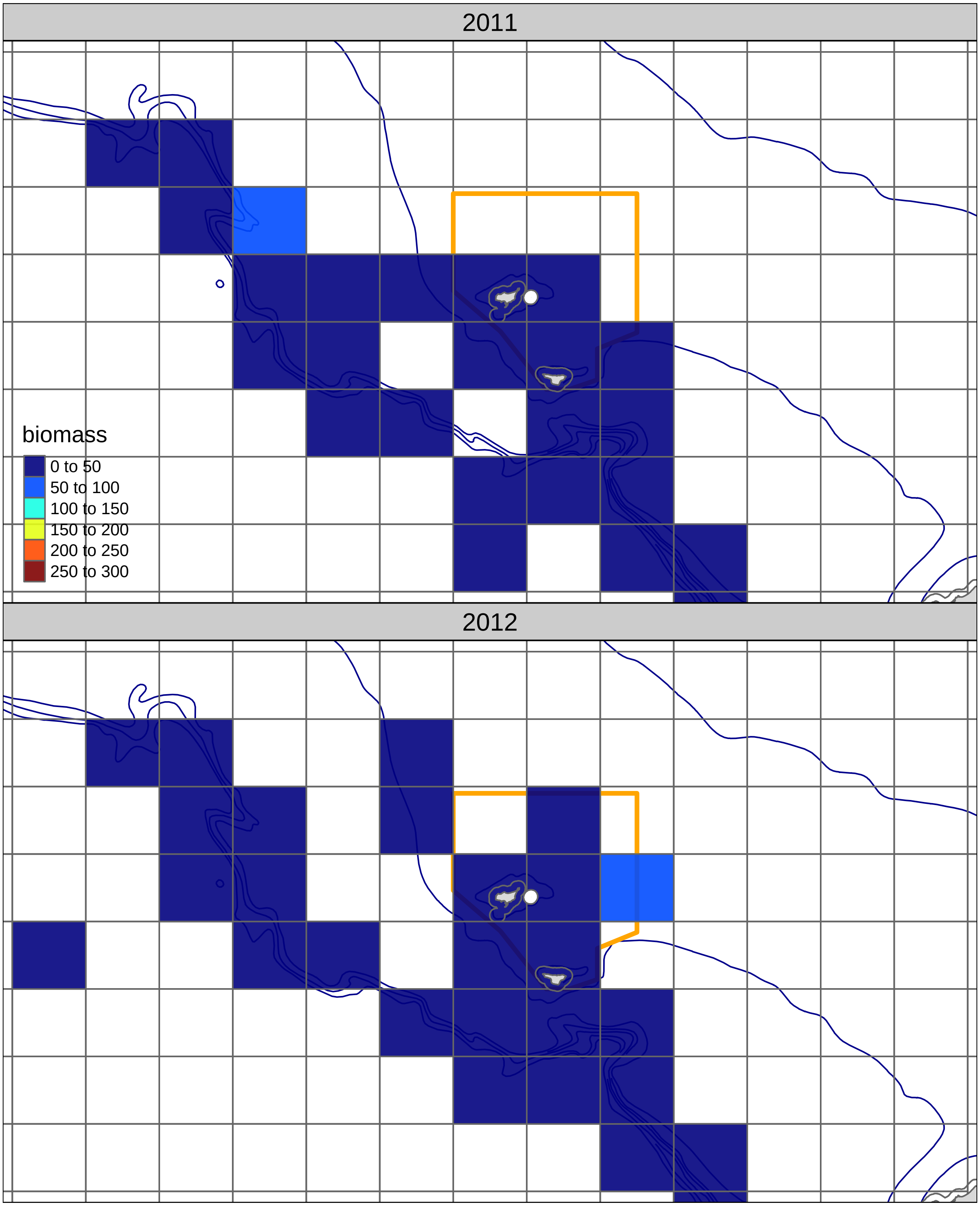

Figure 5: (2 of 4). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries.

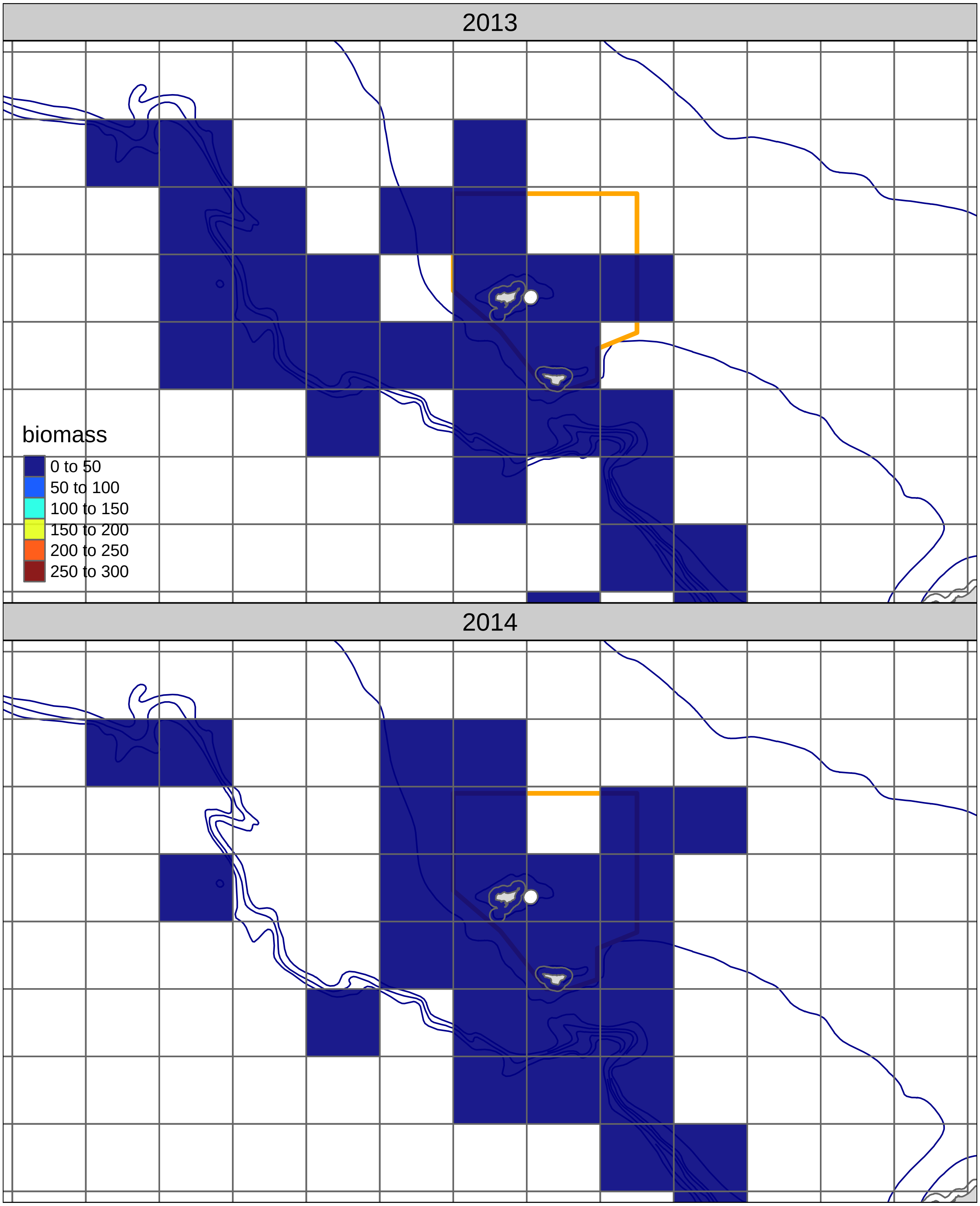

Figure 6: (3 of 4). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries.

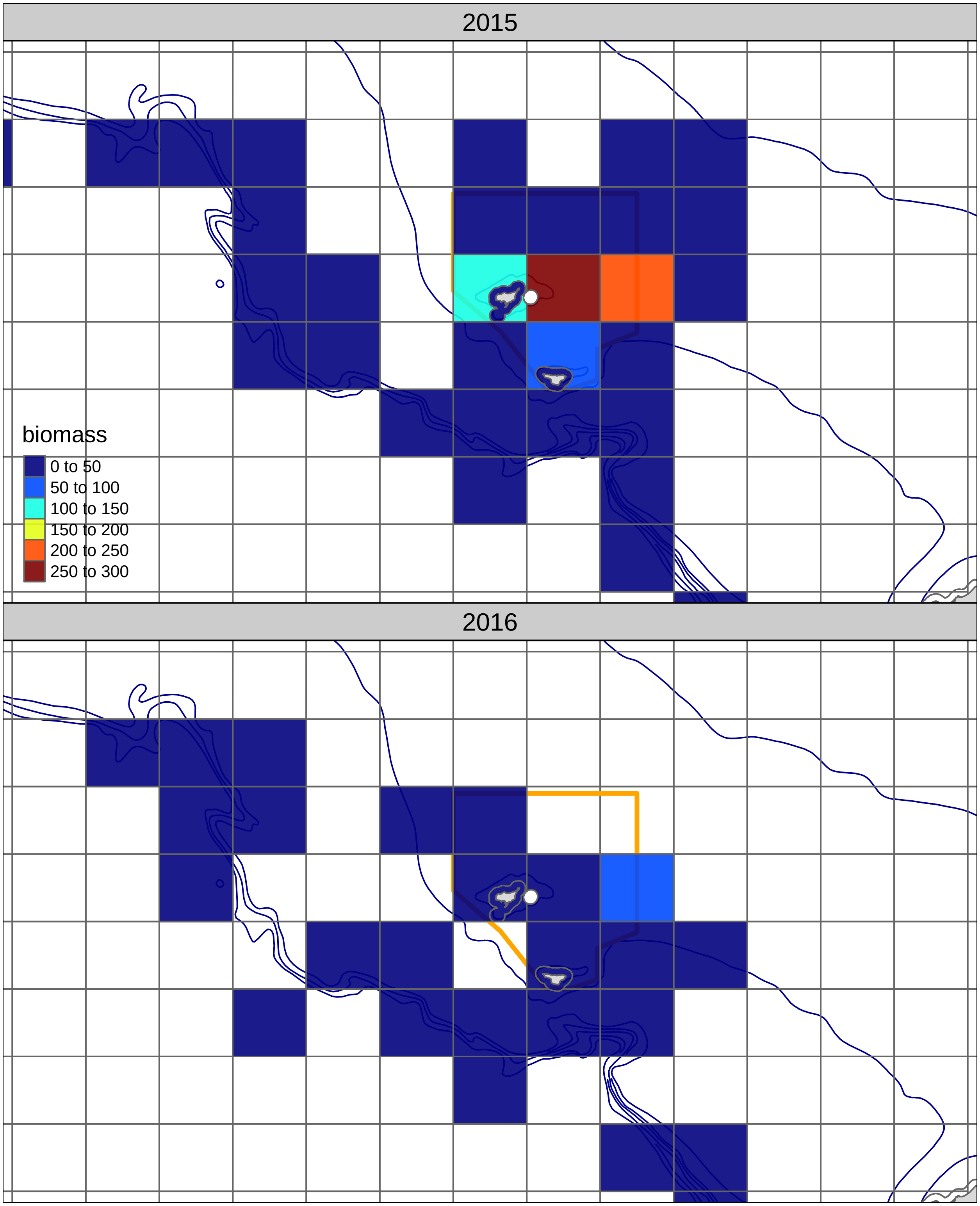

Figure 7: (4 of 4). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries.

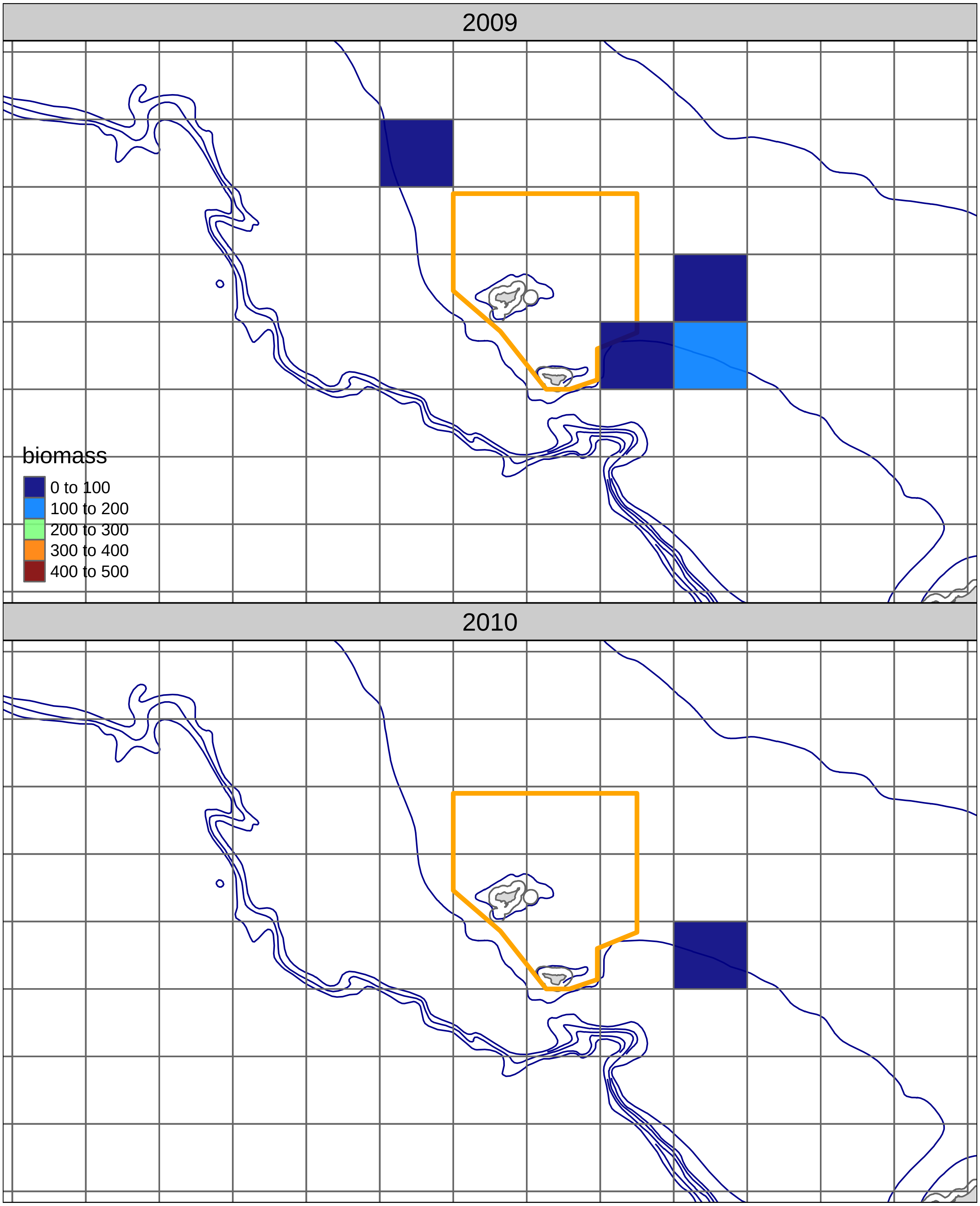

Figure 8: (1 of 4). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries.

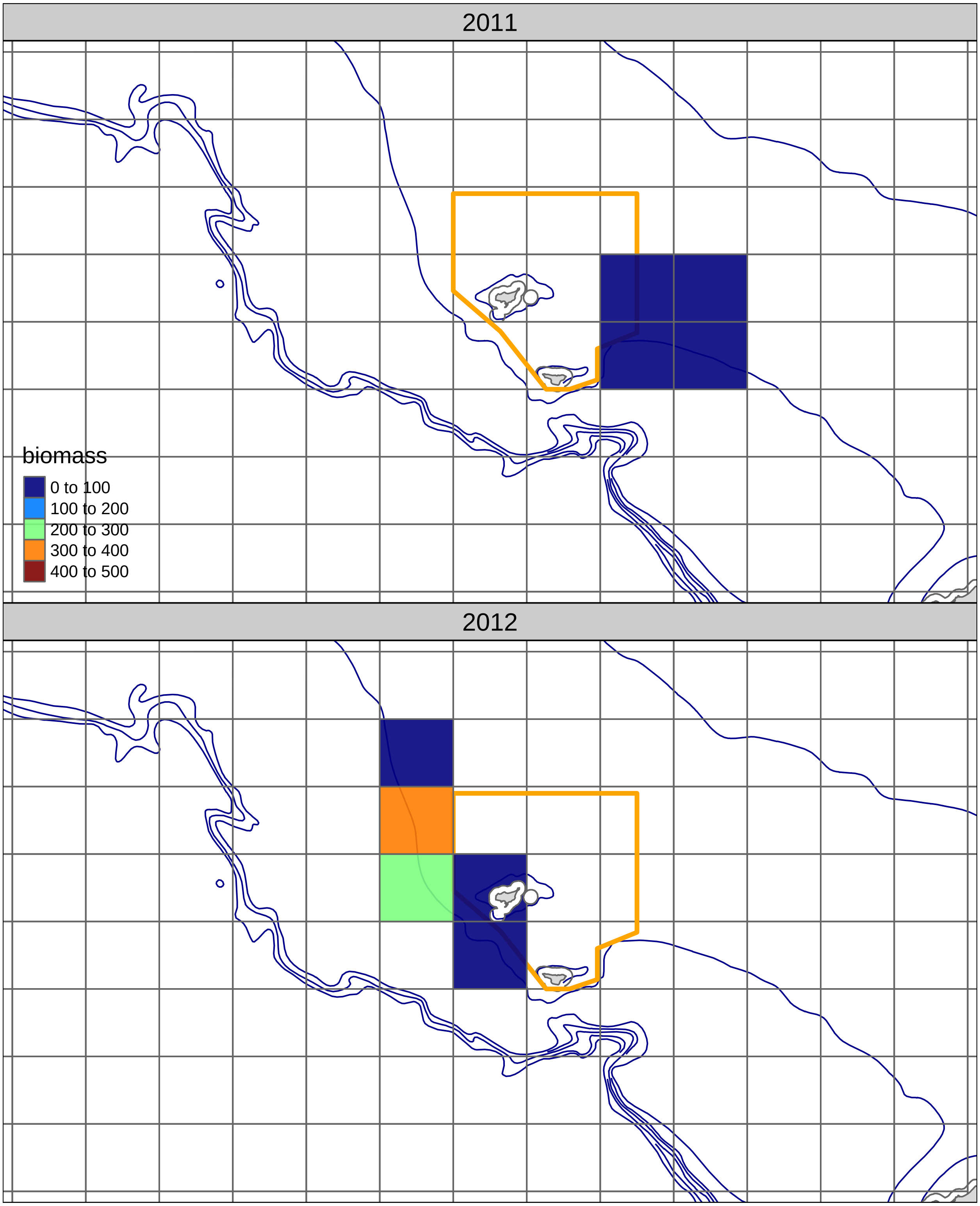

Figure 9: (2 of 4). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries.

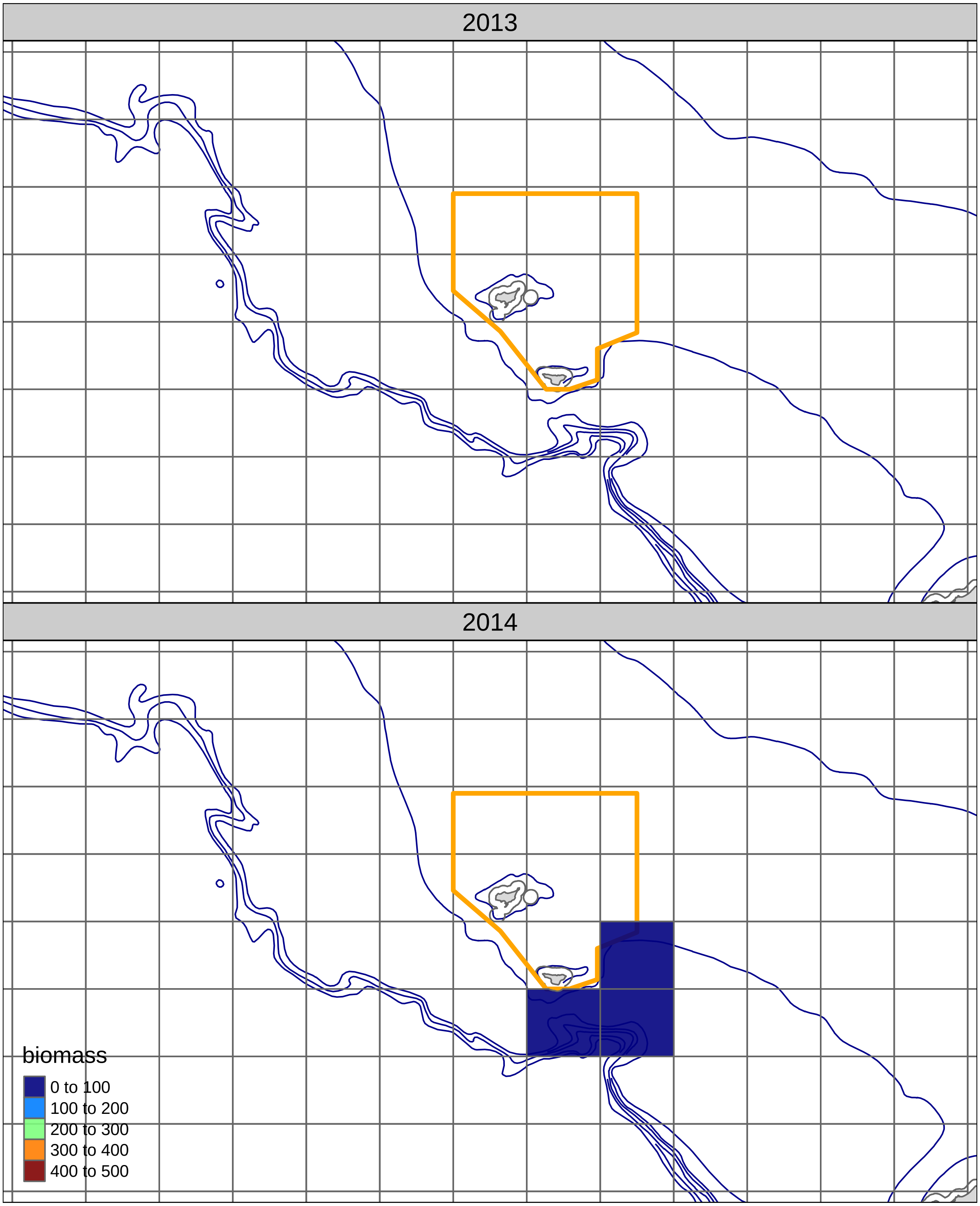

Figure 10: (3 of 4). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries.

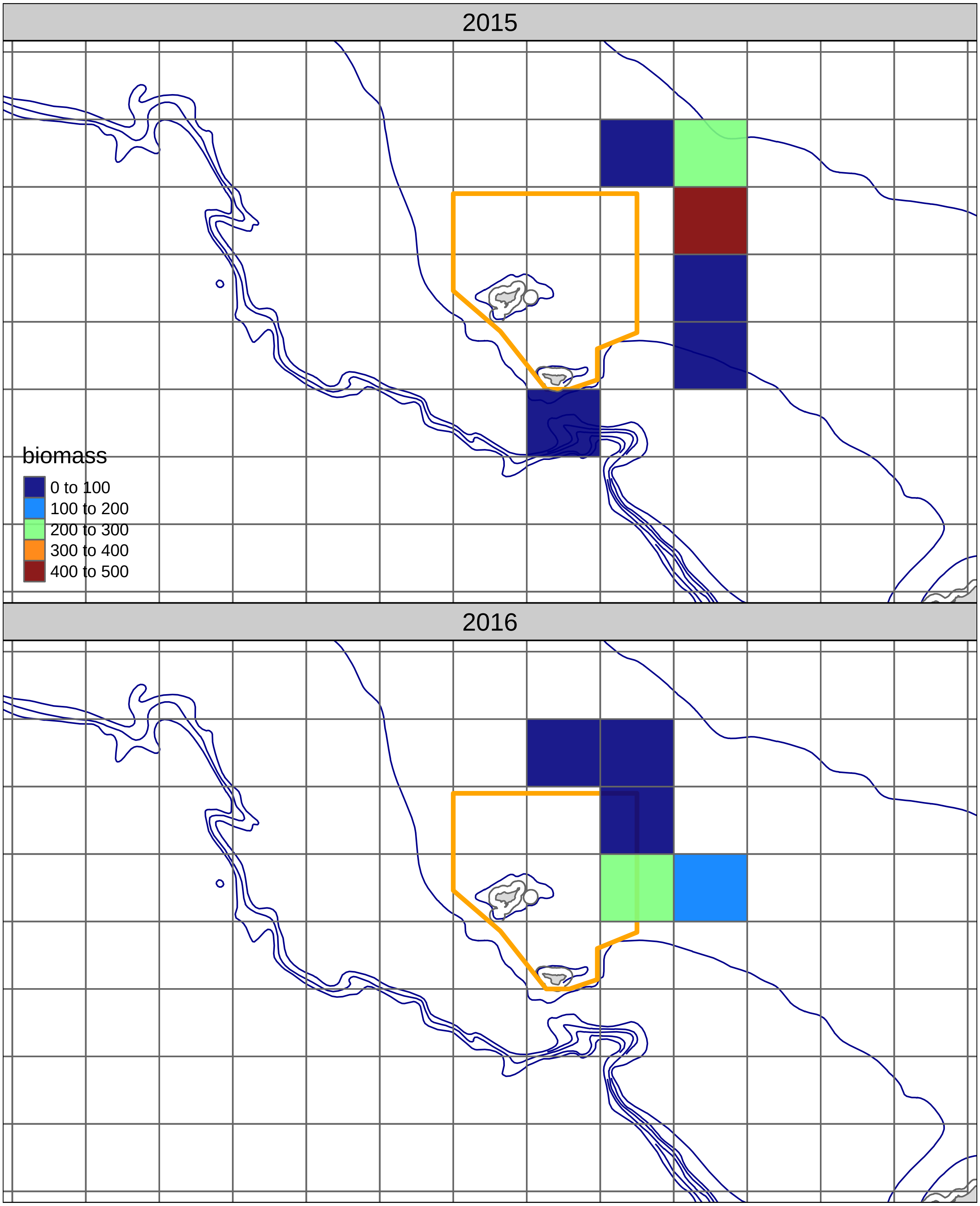

Figure 11: (4 of 4). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries.

Appendix B: NMFS Survey Data for the PIBKC Assessment

William Stockhausen

11 September, 2017

Contents

List of Tables

List of Figures

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 Aug. 30, 2017.

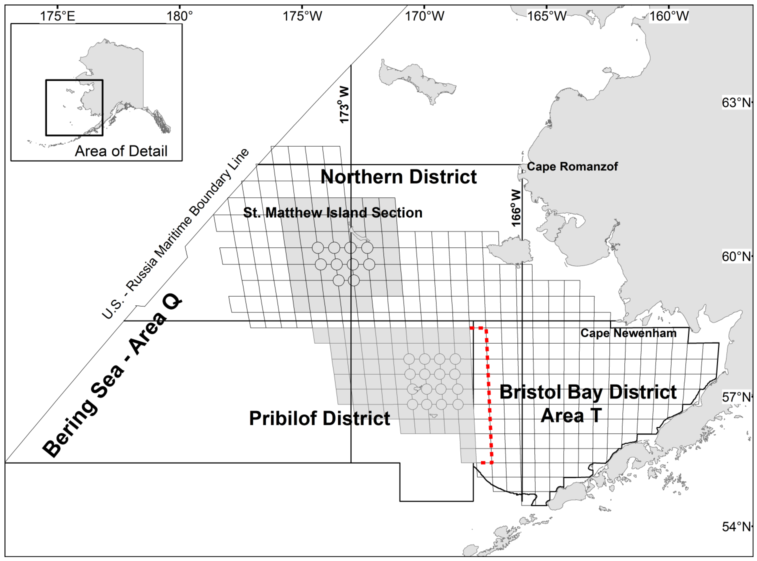

Figure 1: Map of the Pribilof District, which defines the stock area for the Pribilof Islands blue king crab stock. The grid indicates the locations of NMFS EBS survey stations.

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.

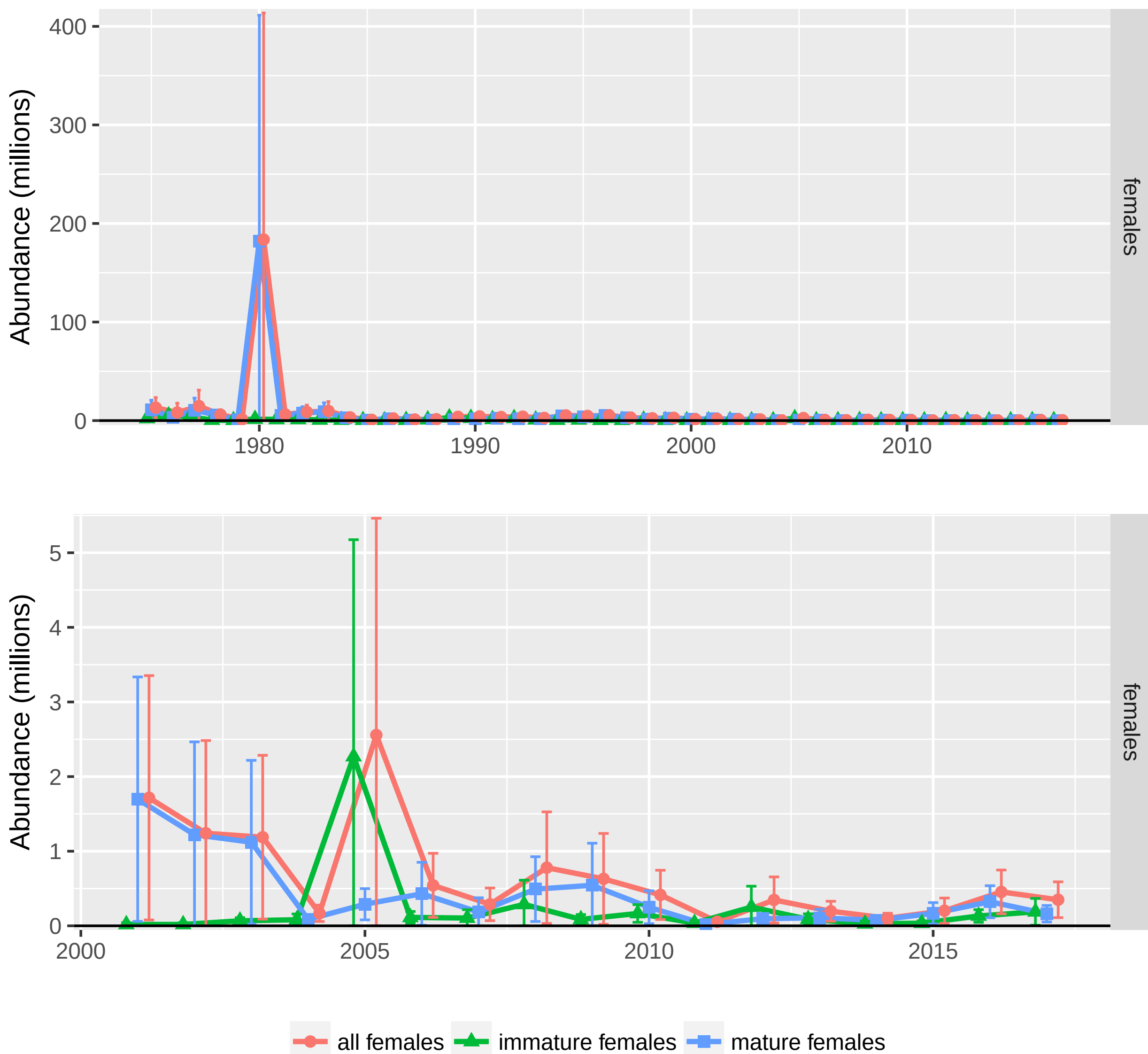

Figure 2: NMFS survey abundance time series for female PIBKC. Upper plot is entire time series, lower plot since 2001.

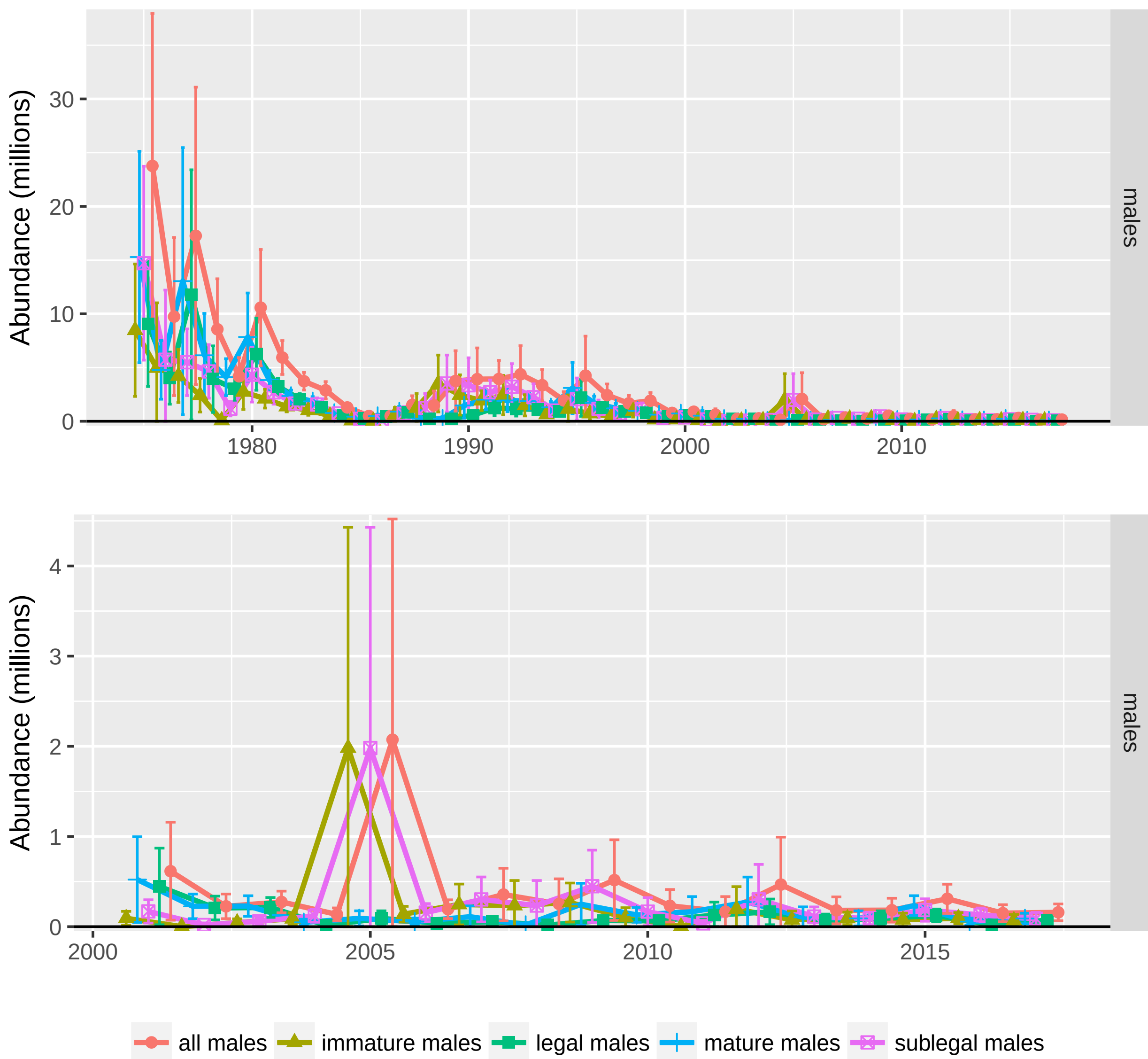

Figure 3: NMFS survey abundance time series for male PIBKC. Upper plot is entire time series, lower plot since 2001.

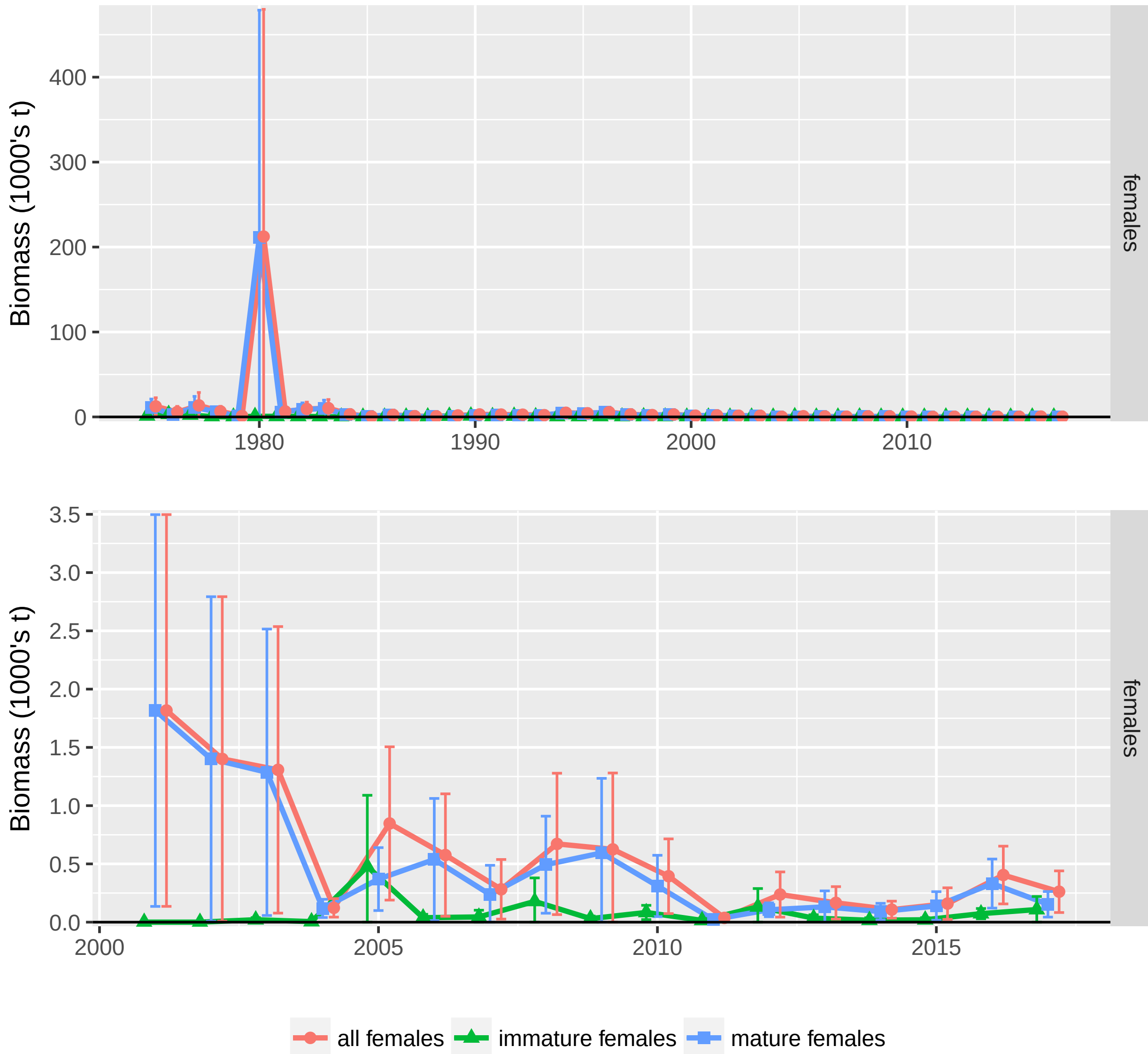

Figure 4: NMFS survey biomass time series for female PIBKC. Upper plot is entire time series, lower plot since 2001.

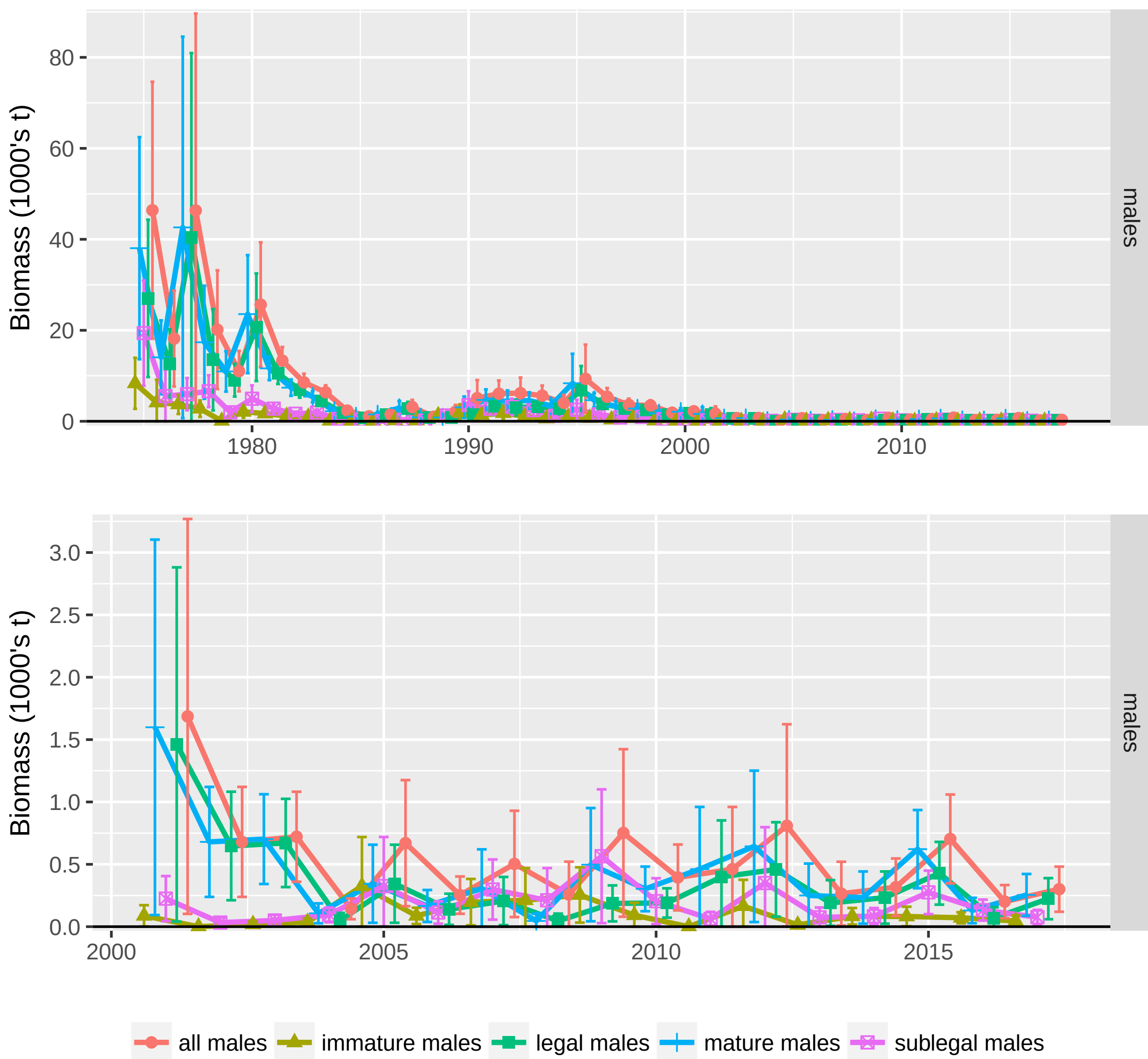

Figure 5: NMFS survey biomass time series for male PIBKC. Upper plot is entire time series, lower plot since 2001.

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

Table 3: Sample sizes (number of survey hauls, number hauls where crab were caught, number of crab caught) for the NMFS EBS trawl survey in the Pribilof District each year, for male population components.

	survey	immature males		mature males		sublegal males		legal males		all males	
	number	non-0	no.	non-0	no.	non-0	no.	non-0	no.	non-0	no.
year	of hauls	hauls	crab	hauls	crab	hauls	crab	hauls	crab	hauls	crab
1975	45	11	305	13	553	11	530	13	328	13	858
1976	59	3	105	11	91	9	122	10	74	12	196
1977	58	7	56	10	129	9	73	9	112	10	185
1978	58	8	60	11	130	10	112	10	78	12	190
1979	58	2	2	14	90	8	25	13	67	14	92
1980	70	10	41	21	133	12	64	21	110	21	174
1981	84	19	99	36	184	23	128	36	155	38	283
1982	84	19	70	35	114	21	84	31	100	38	184
1983	86	15	47	32	93	18	74	29	66	35	140
1984	86	10	27	20	37	17	37	16	27	25	64
1985	86	3	4	14	24	8	13	11	15	14	28
1986	86	1	1	13	26	2	2	13	25	13	27
1987	86	5	34	15	50	6	38	14	46	16	84
1988	85	5	52	5	12	5	52	5	12	9	64
1989	86	8	160	4	11	8	160	4	11	10	171
1990	86	8	90	10	59	11	126	7	23	14	149
1991	85	16	92	19	103	20	129	14	66	22	195
1992	86	12	89	14	73	13	119	12	43	17	162
1993	85	12	75	19	96	15	115	17	56	21	171
1994	86	8	32	18	68	12	51	18	49	19	100
1995	86	7	66	18	177	15	118	14	125	19	243
1996	86	7	32	19	87	11	54	19	65	20	119
1997	86	7	25	17	65	10	39	16	51	19	90
1998	85	12	56	20	56	15	66	17	46	21	112
1999	86	7	9	13	34	9	18	11	25	15	43
2000	85	4	9	16	40	9	20	13	29	16	49
2001	86	3	5	6	28	4	9	5	24	7	33
2002	86	0	0	6	12	1	1	6	11	6	12
2003	86	2	2	7	14	3	3	7	13	9	16
2004	85	3	5	3	3	5	7	1	1	6	8
2005	84	3	54	2	5	3	54	2	5	4	59
2006	86	4	7	3	3	4	8	2	2	6	10
2007	86	4	14	2	6	4	17	2	3	4	20
2008	86	2	13	1	1	2	13	1	1	3	14
2009	86	5	16	3	15	5	27	3	4	5	31
2010	86	2	6	5	8	3	10	4	4	5	14
2011	86	0	0	3	9	2	2	2	7	3	9
2012	86	1	9	4	13	1	14	4	8	4	22
2013	86	1	3	2	6	2	5	2	4	3	9
2014	86	3	5	2	5	3	5	2	5	4	10
2015	86	2	4	8	13	6	10	5	7	9	17
2016	86	4	5	3	3	5	7	1	1	5	8
2017	86	2	4	4	4	3	5	3	3	5	8

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

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

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

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

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.

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.

Spatial patterns

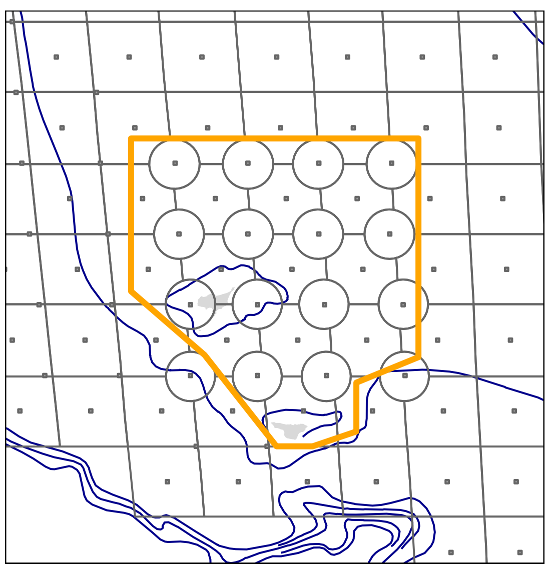

Figure 10: Basemap for future maps, with EBS bathymetry (blue lines), NMFS EBS trawl survey station grid (black) lines, and the Pribilof Islands Habitat Conservation Area (orange outline).

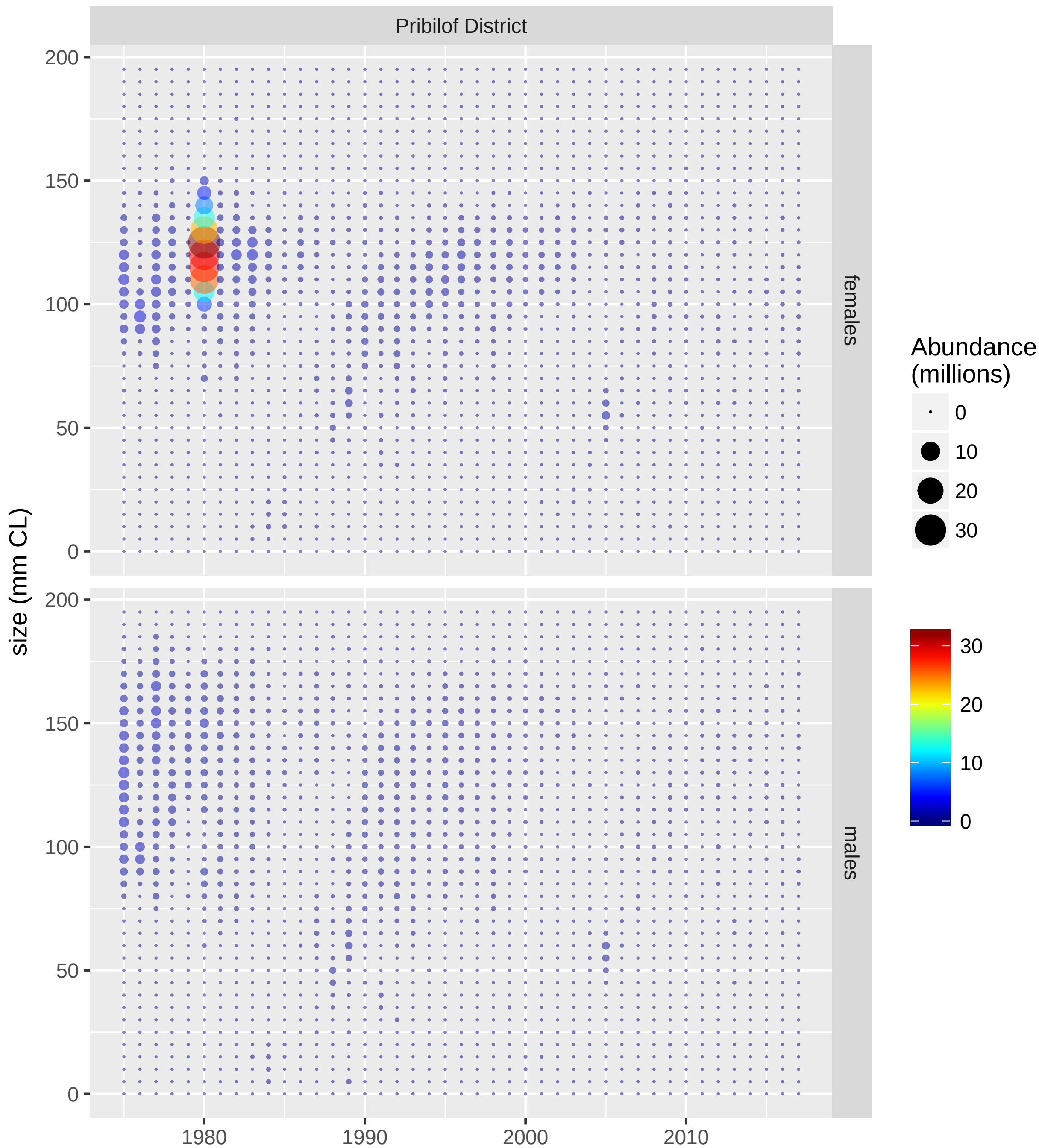

Figure 6: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, over the entire survey period.

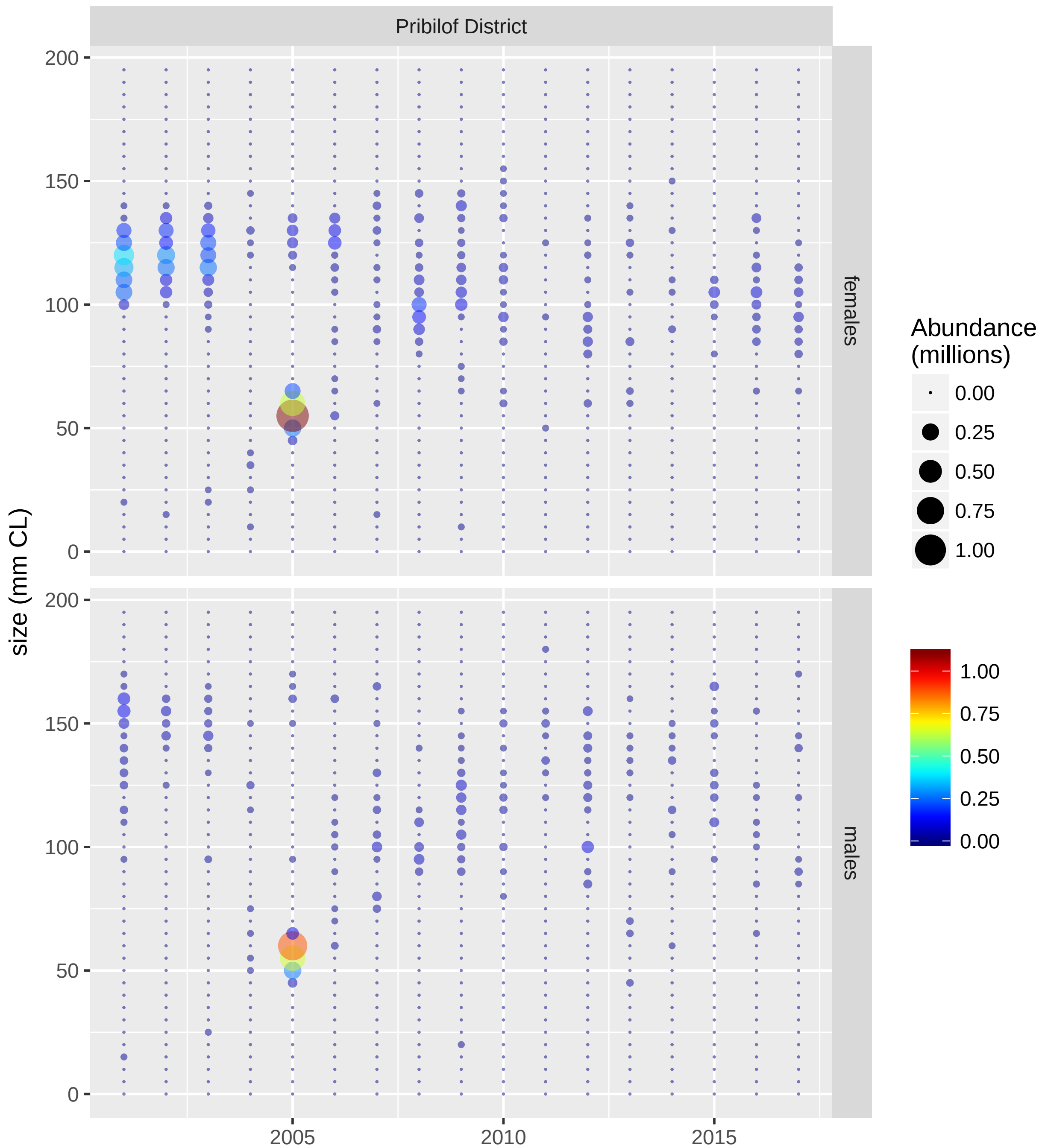

Figure 7: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, since 2001.

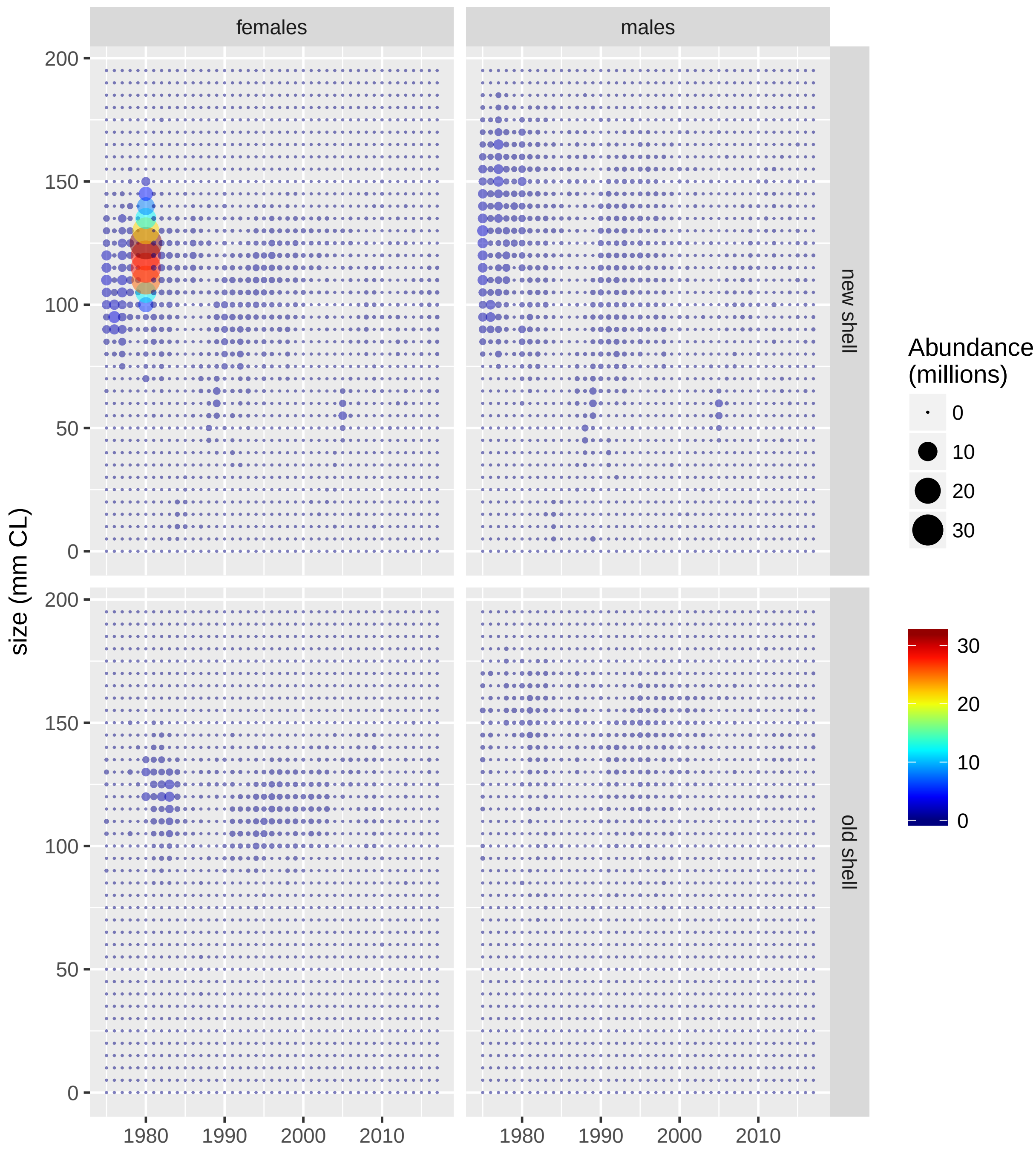

Figure 8: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex and shell condition, for entire survey period.

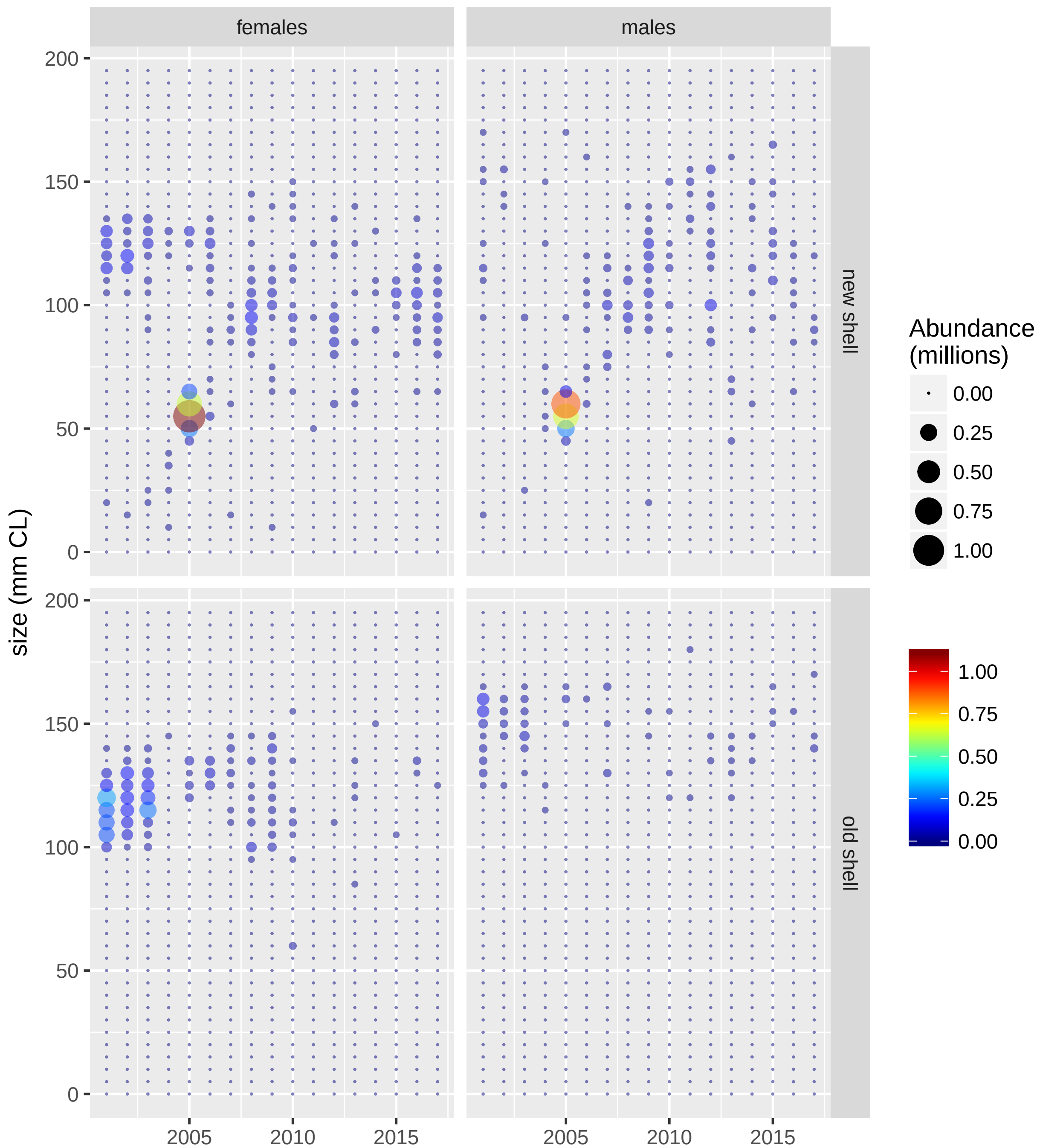

Figure 9: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex and shell condition, since 2000.

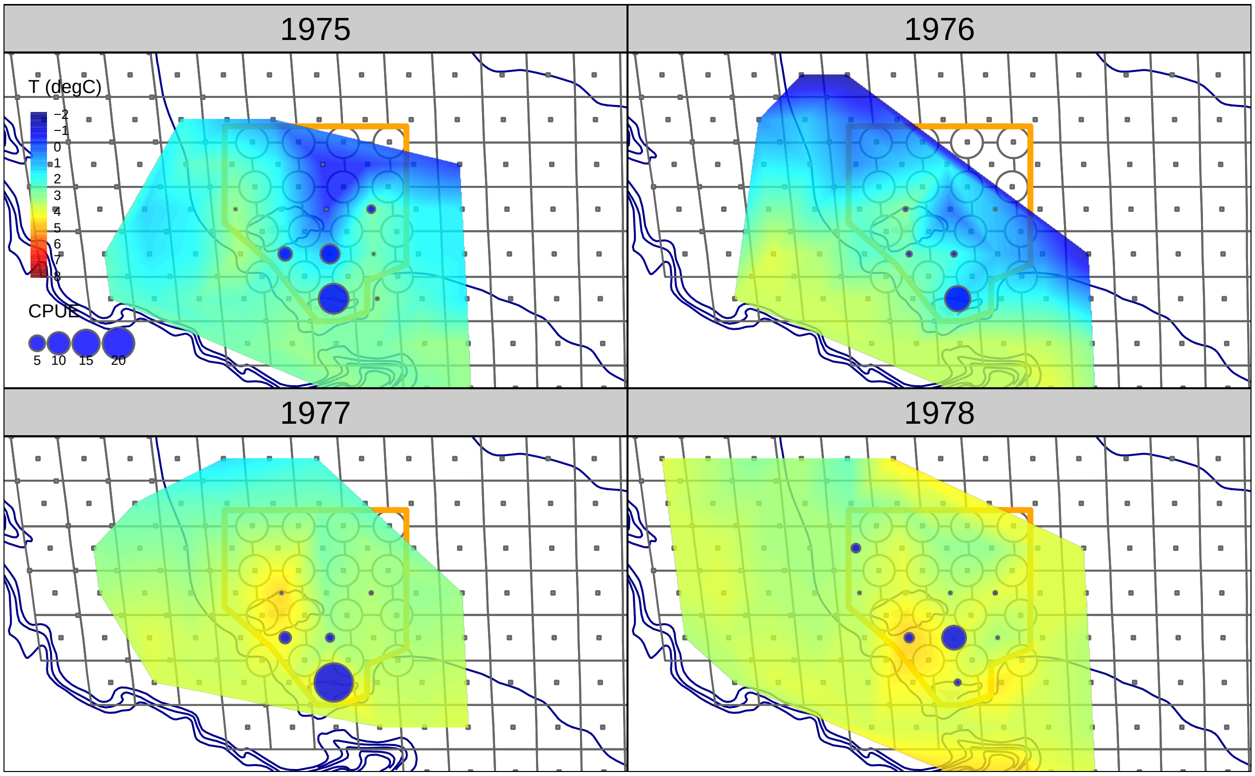

Figure 11: Survey CPUE (biomass) for females PIBKC. Page 1 of 11

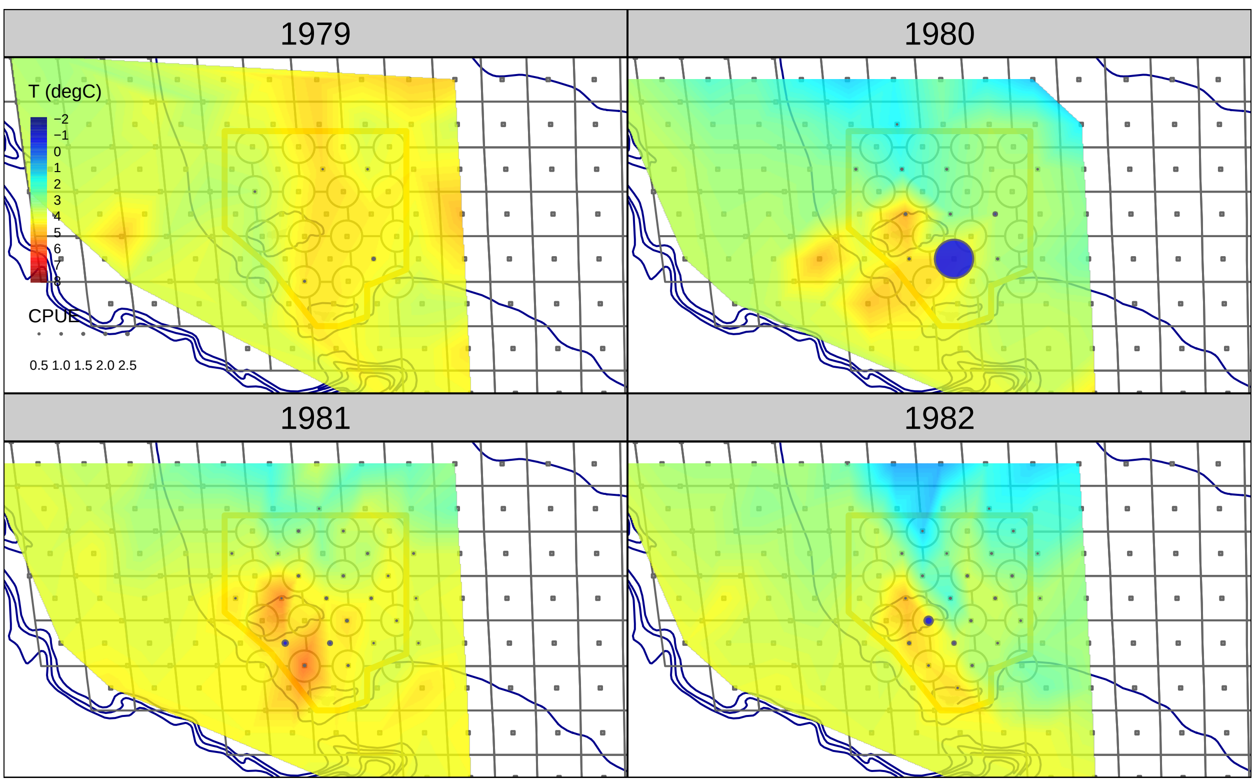

Figure 12: Survey CPUE (biomass) for females PIBKC. Page 2 of 11

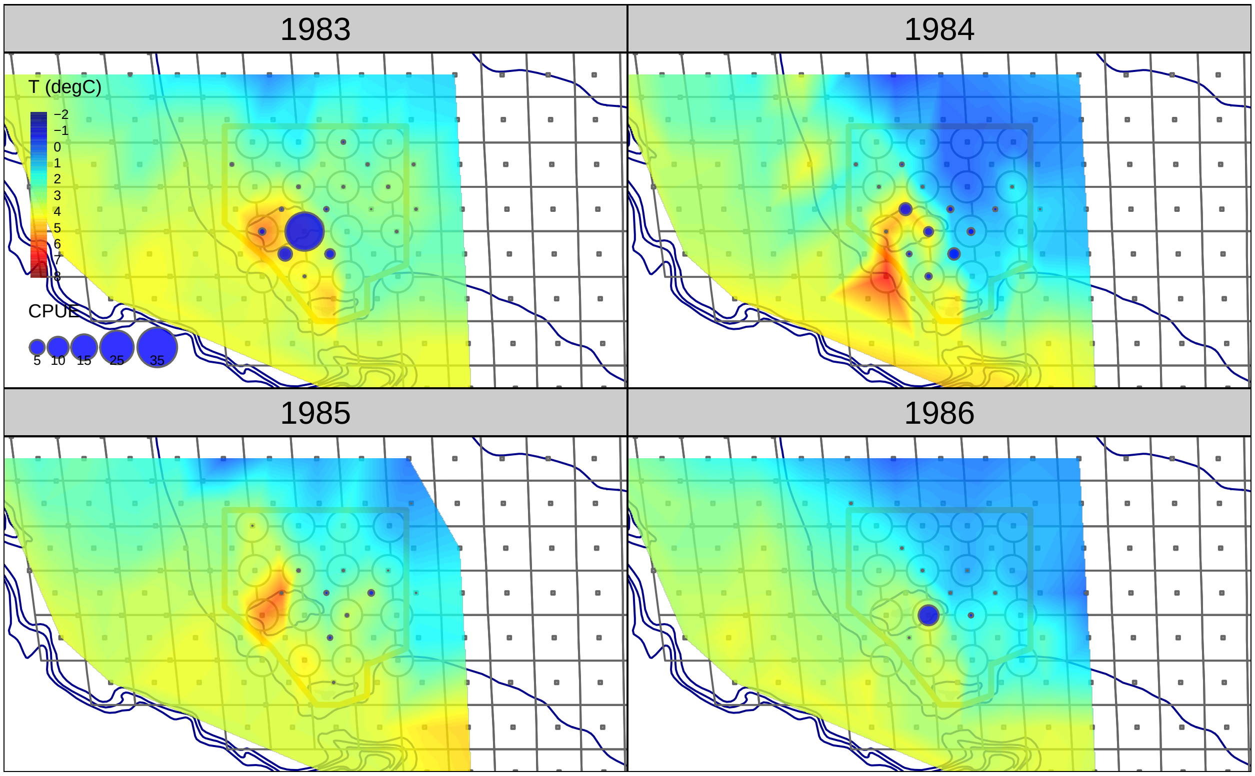

Figure 13: Survey CPUE (biomass) for females PIBKC. Page 3 of 11

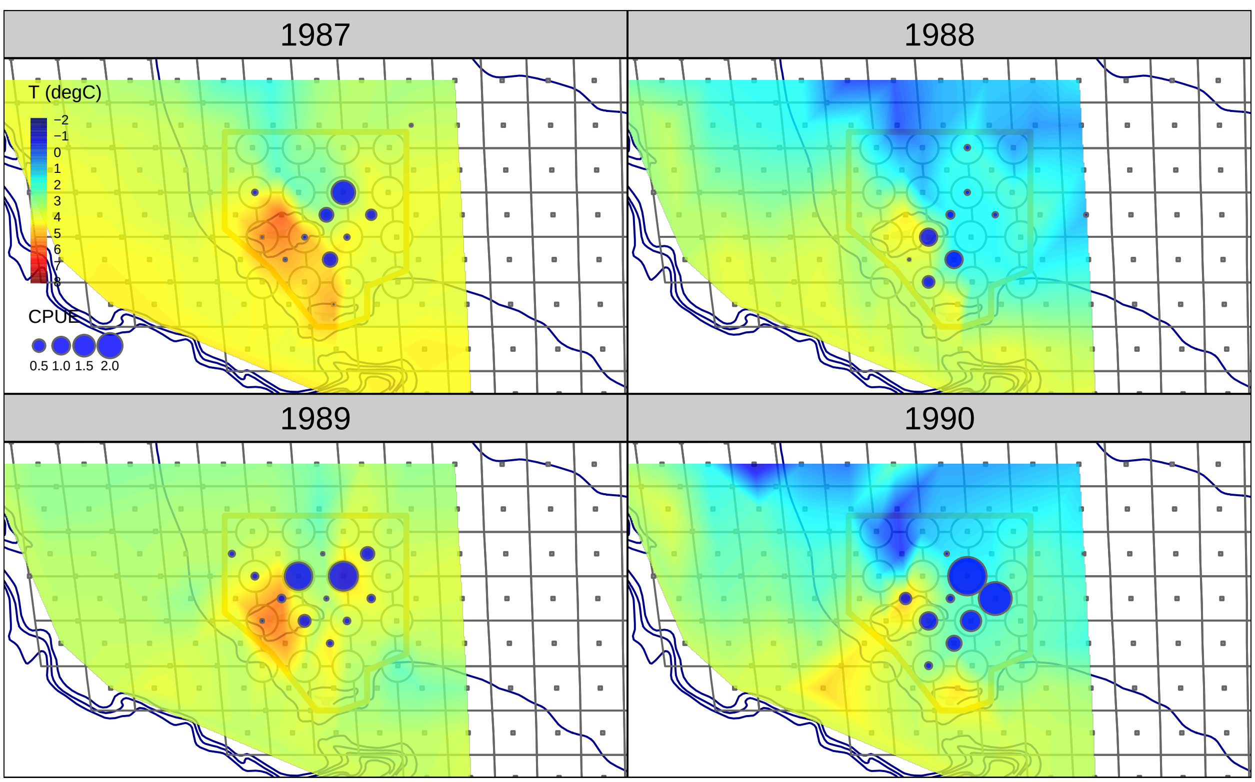

Figure 14: Survey CPUE (biomass) for females PIBKC. Page 4 of 11

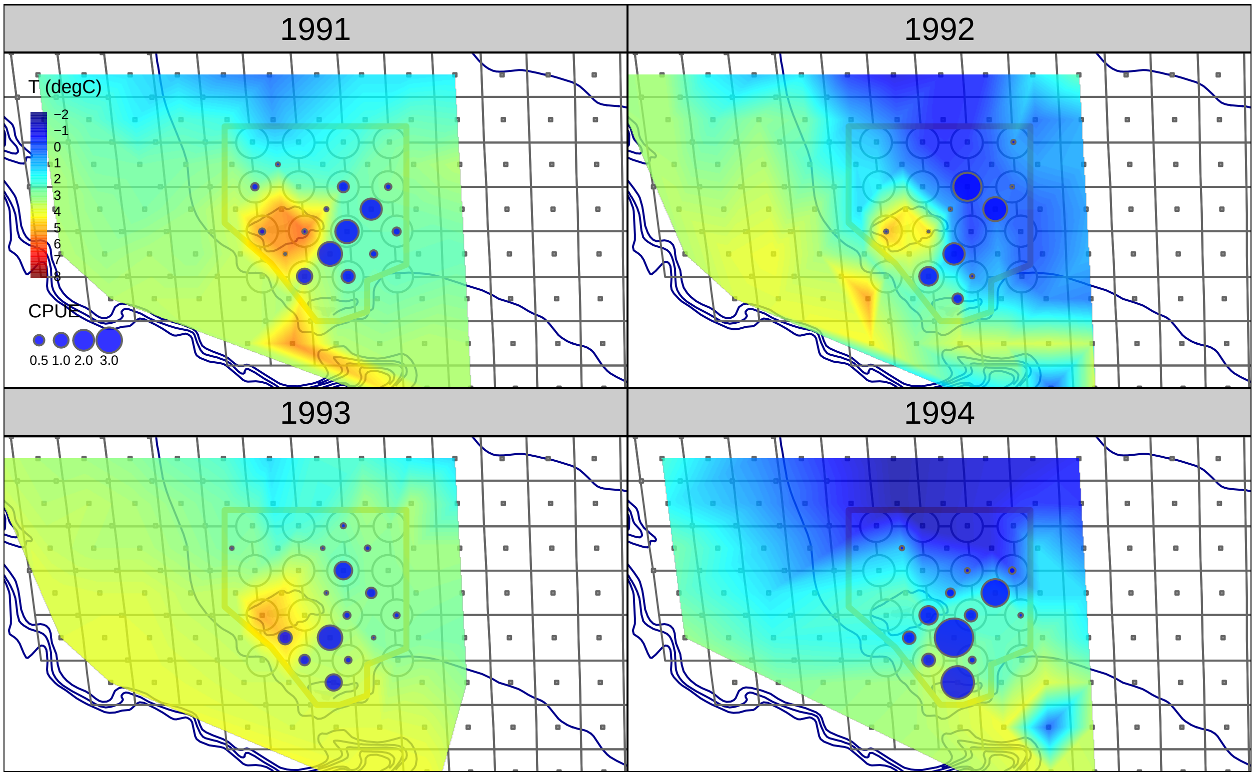

Figure 15: Survey CPUE (biomass) for females PIBKC. Page 5 of 11

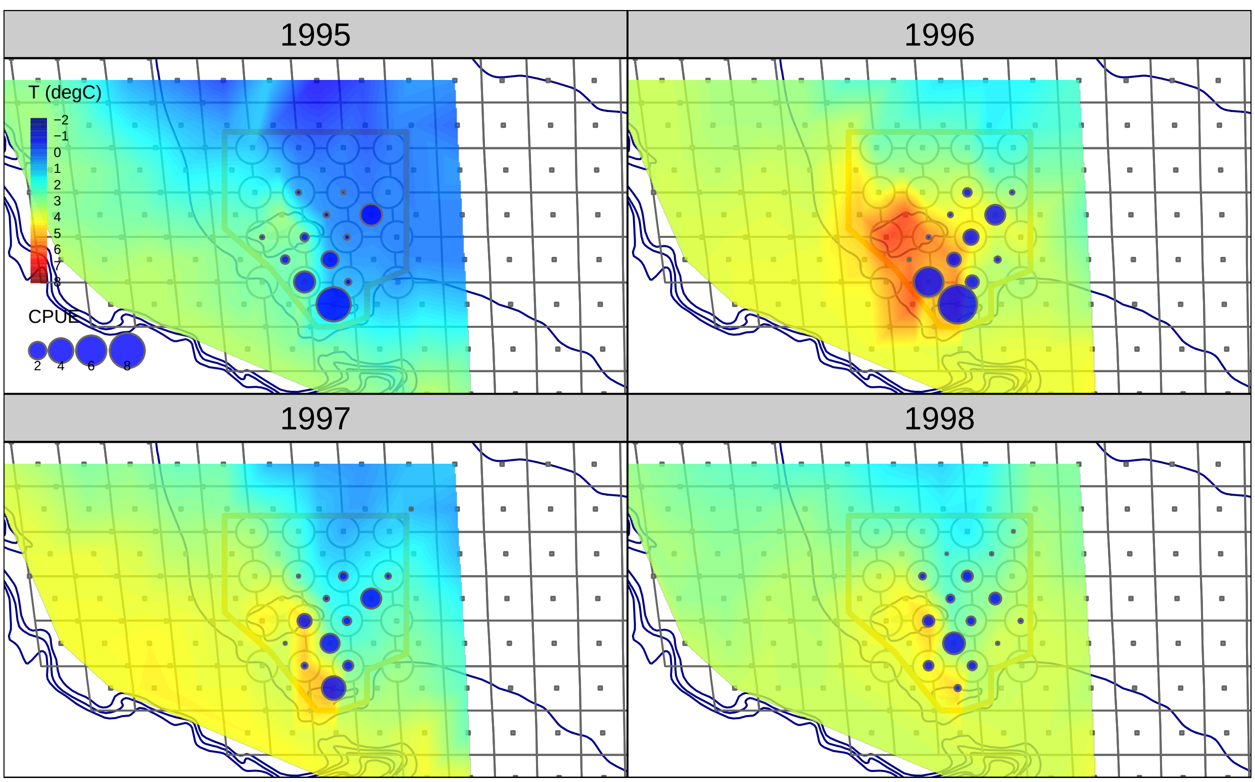

Figure 16: Survey CPUE (biomass) for females PIBKC. Page 6 of 11

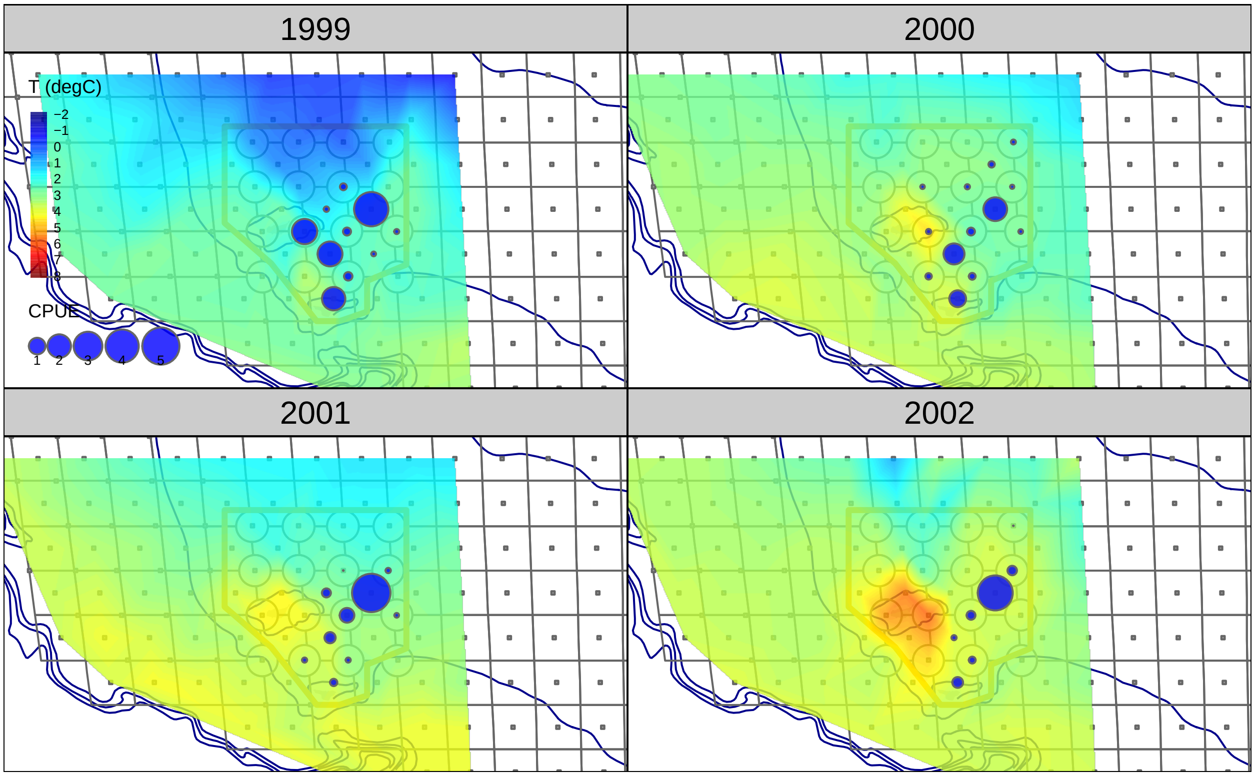

Figure 17: Survey CPUE (biomass) for females PIBKC. Page 7 of 11

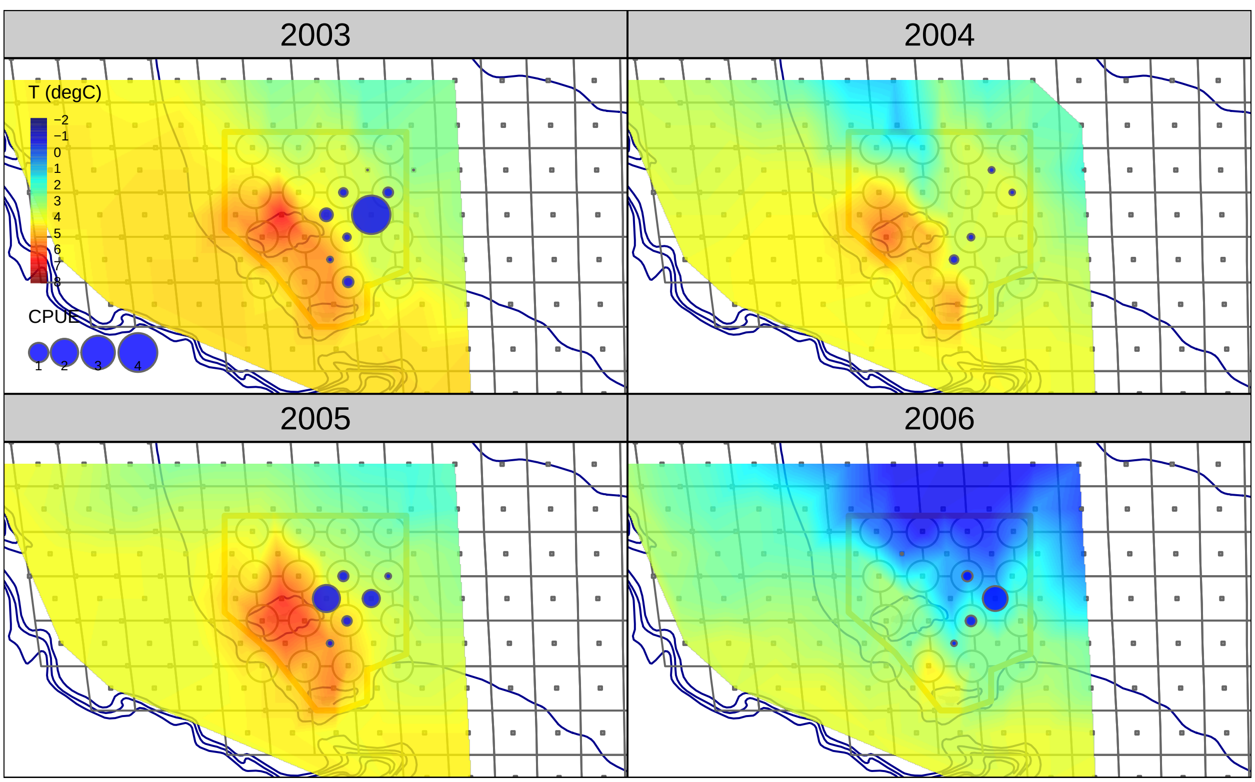

Figure 18: Survey CPUE (biomass) for females PIBKC. Page 8 of 11

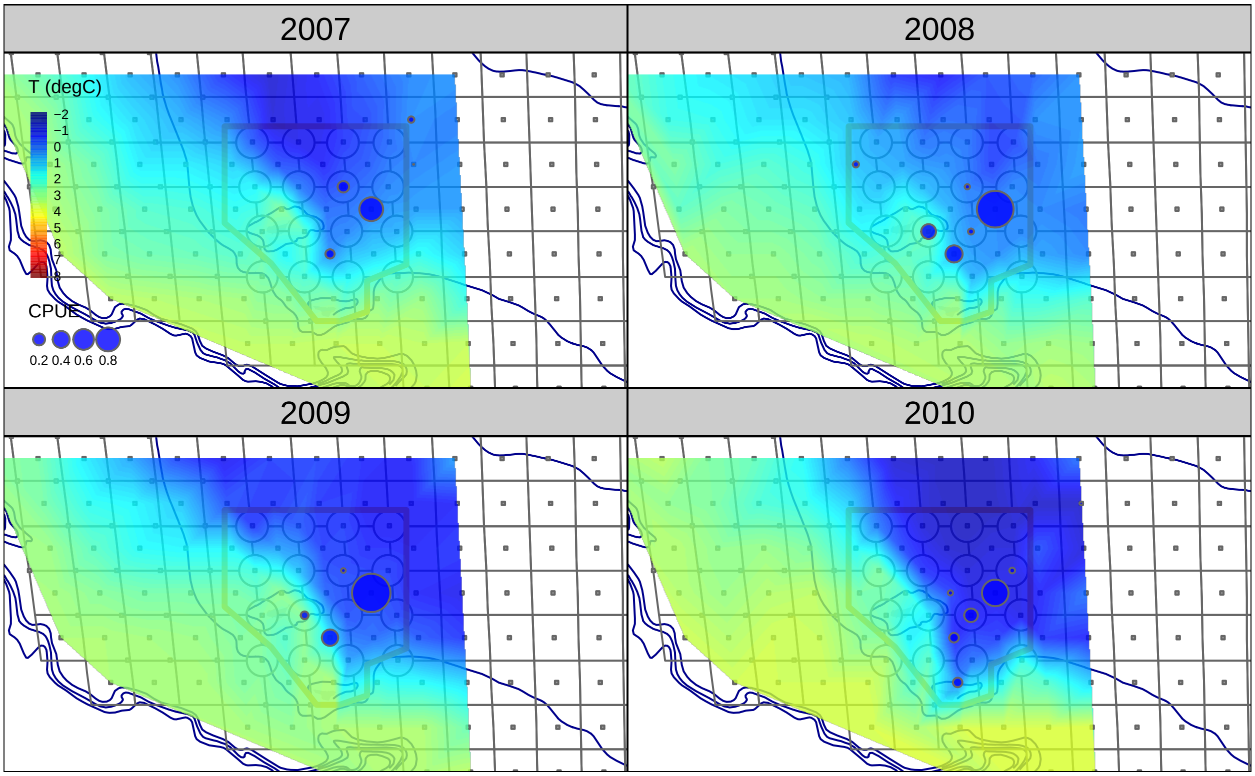

Figure 19: Survey CPUE (biomass) for females PIBKC. Page 9 of 11

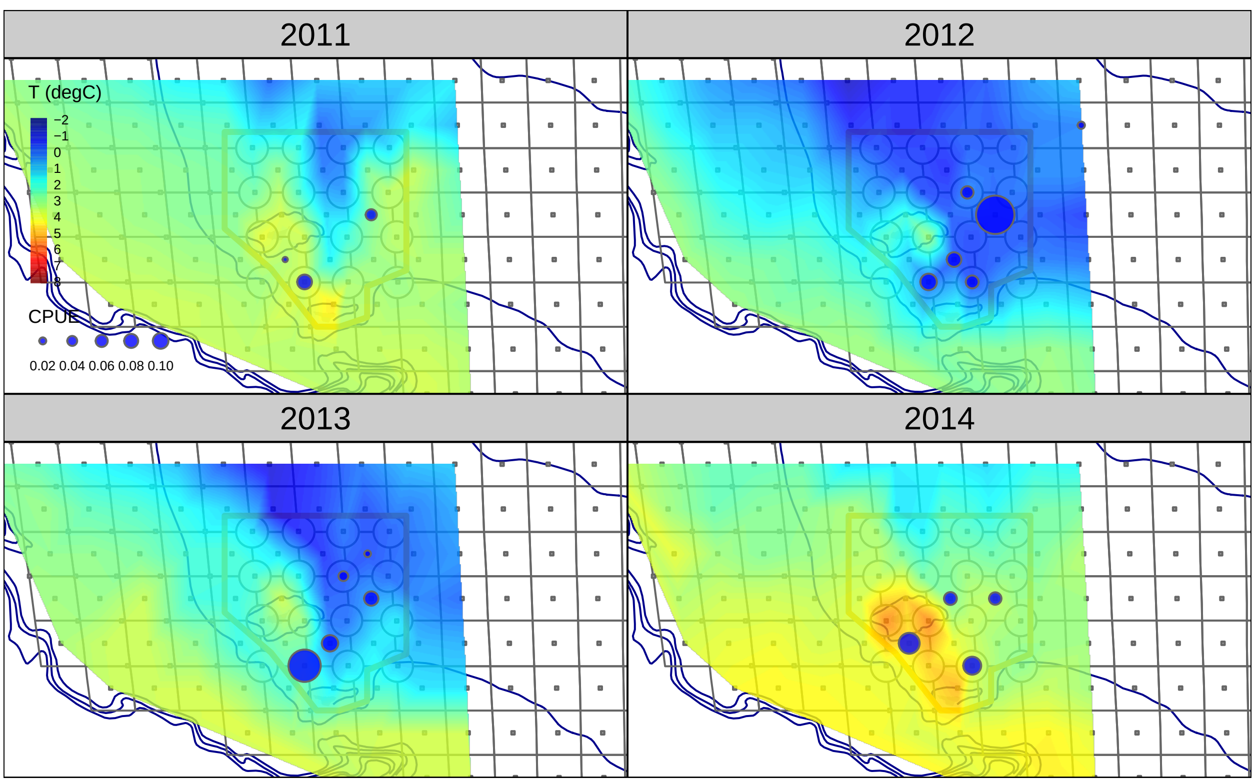

Figure 20: Survey CPUE (biomass) for females PIBKC. Page 10 of 11

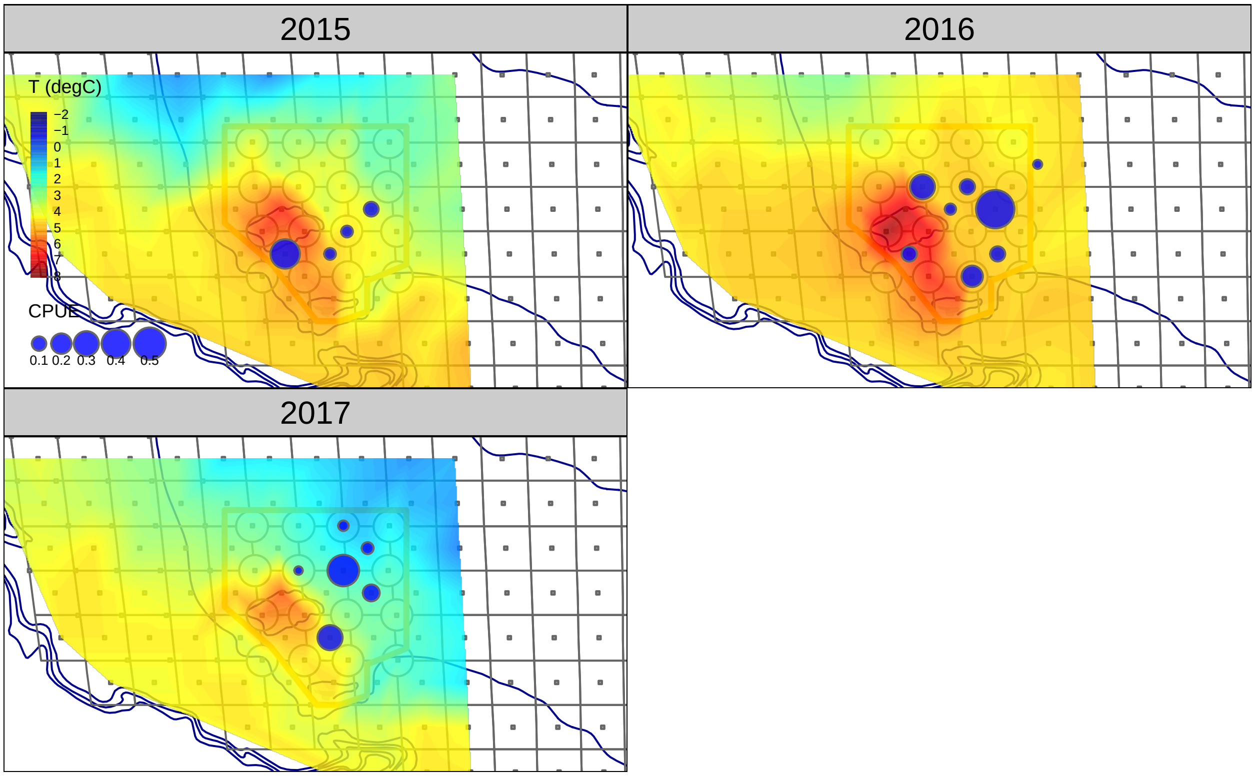

Figure 21: Survey CPUE (biomass) for females PIBKC. Page 11 of 11

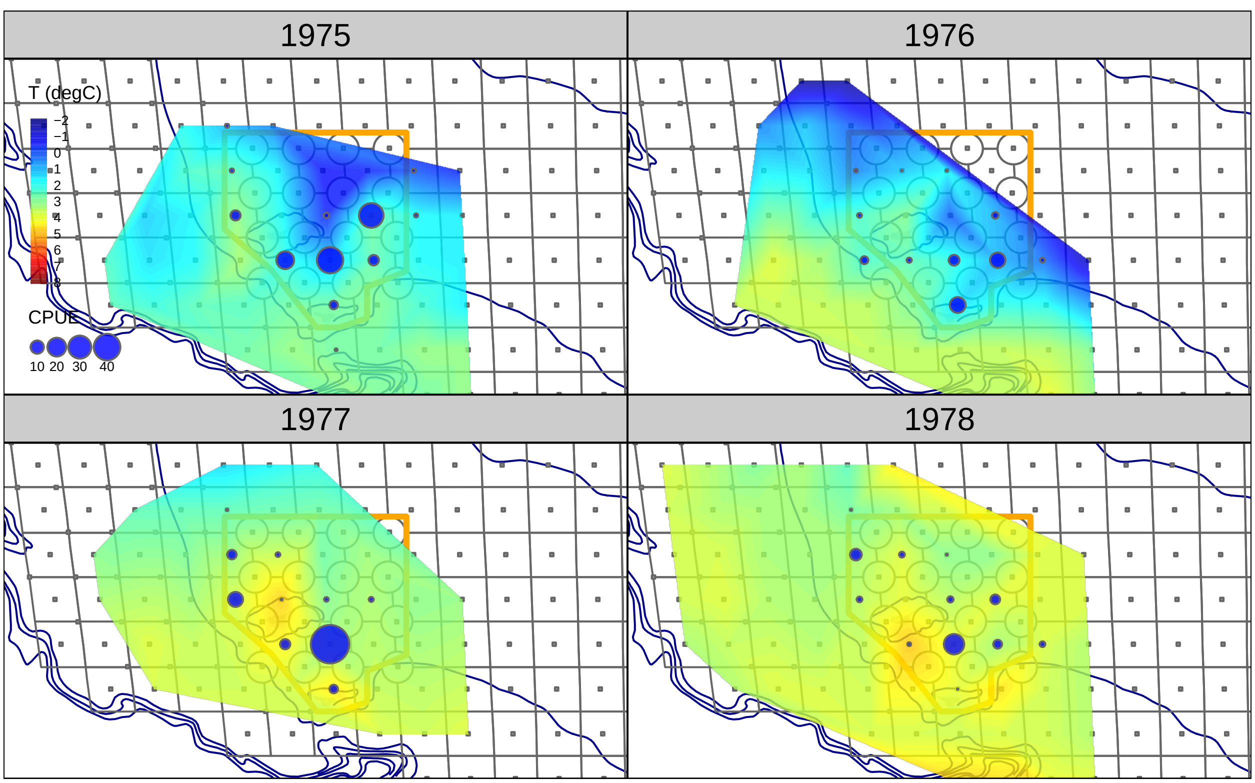

Figure 22: Survey CPUE (biomass) for males PIBKC. Page 1 of 11

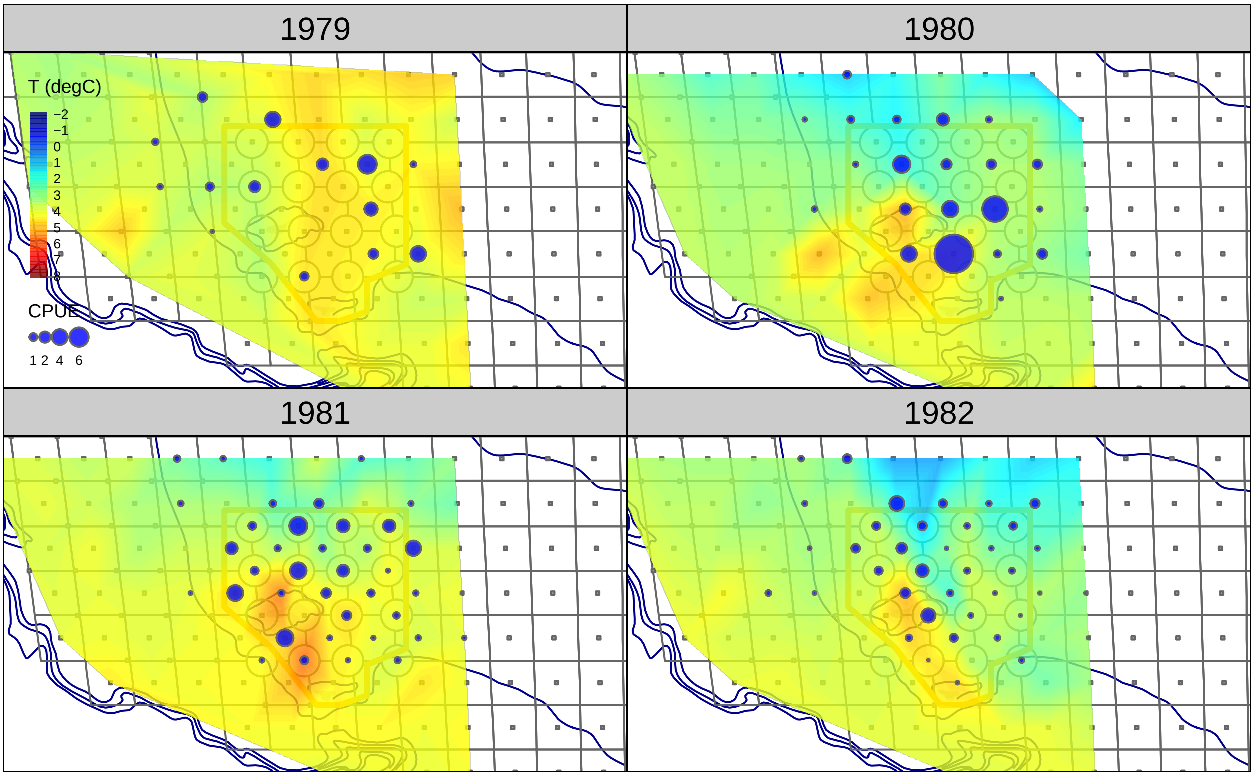

Figure 23: Survey CPUE (biomass) for males PIBKC. Page 2 of 11

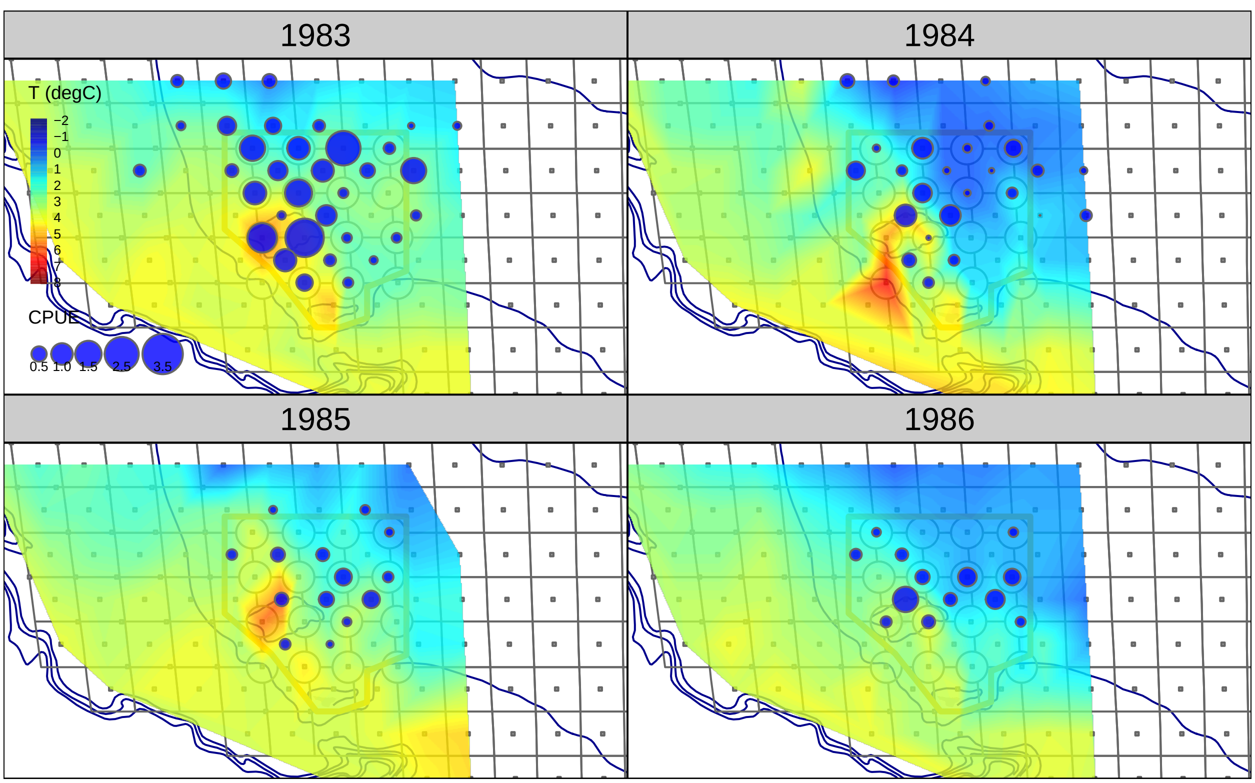

Figure 24: Survey CPUE (biomass) for males PIBKC. Page 3 of 11

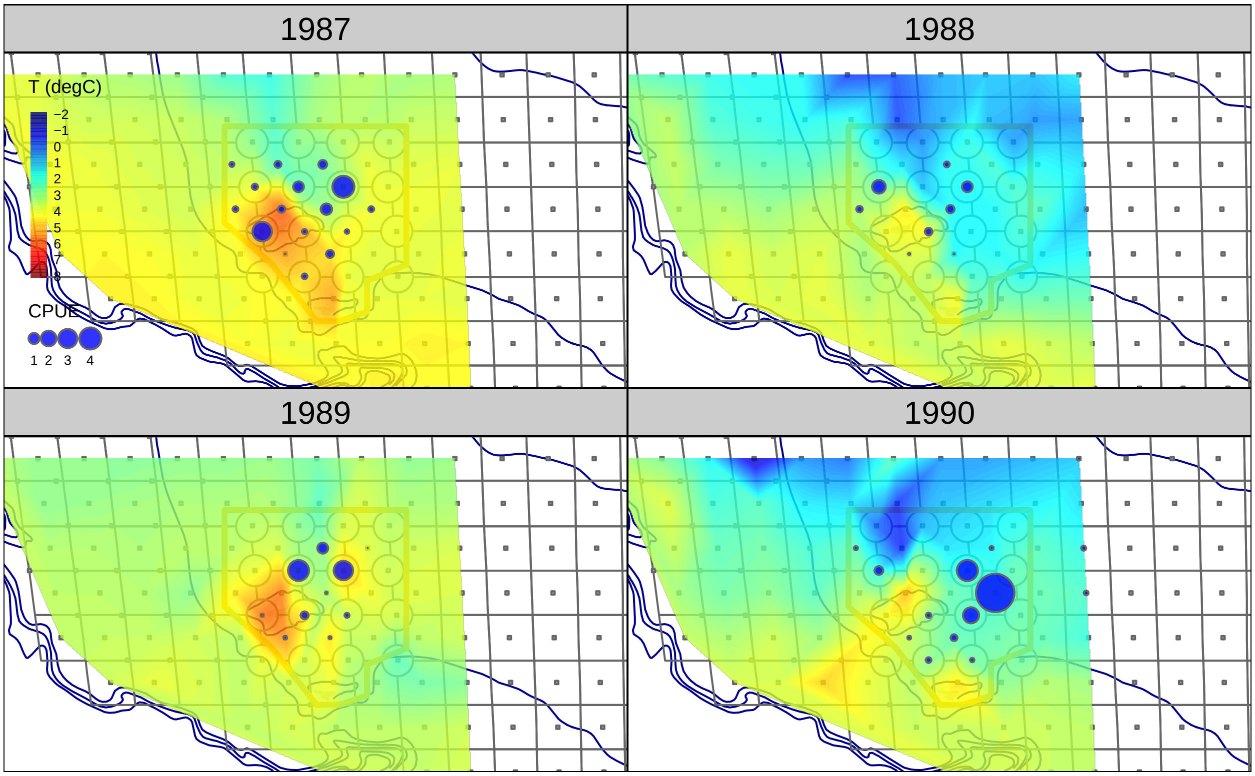

Figure 25: Survey CPUE (biomass) for males PIBKC. Page 4 of 11

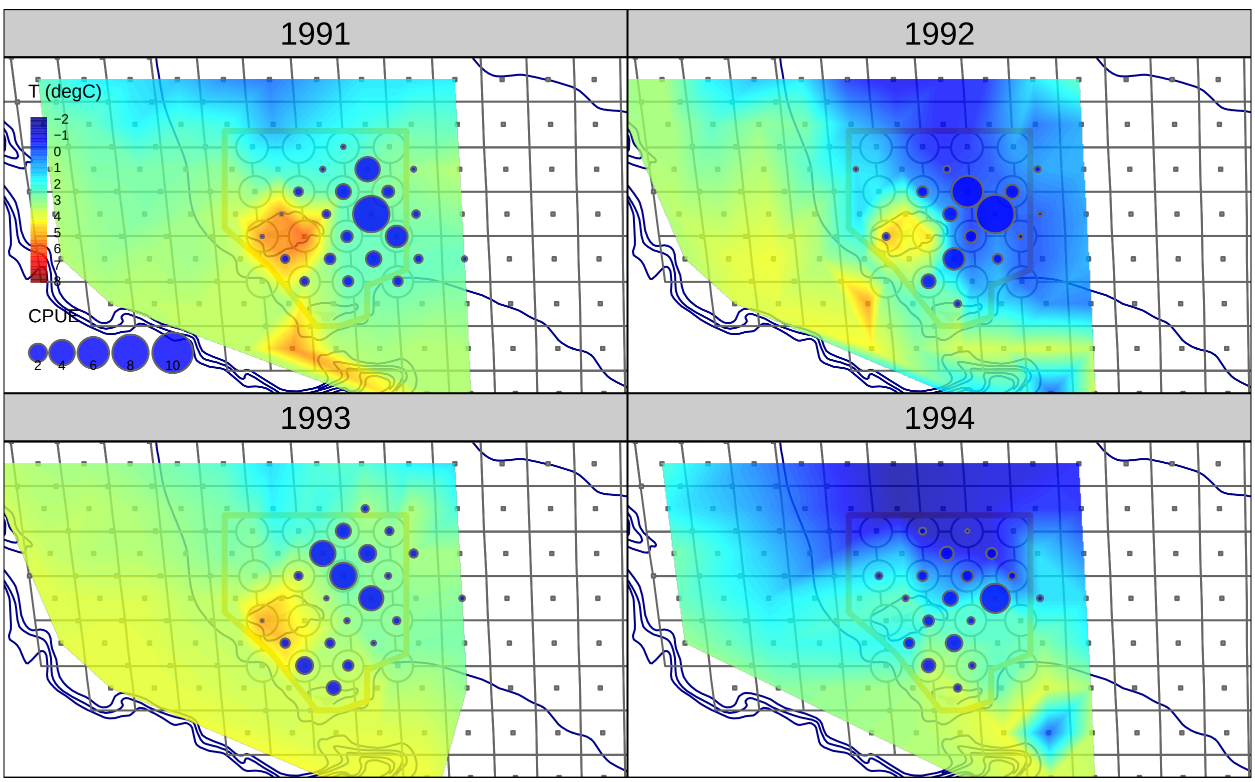

Figure 26: Survey CPUE (biomass) for males PIBKC. Page 5 of 11

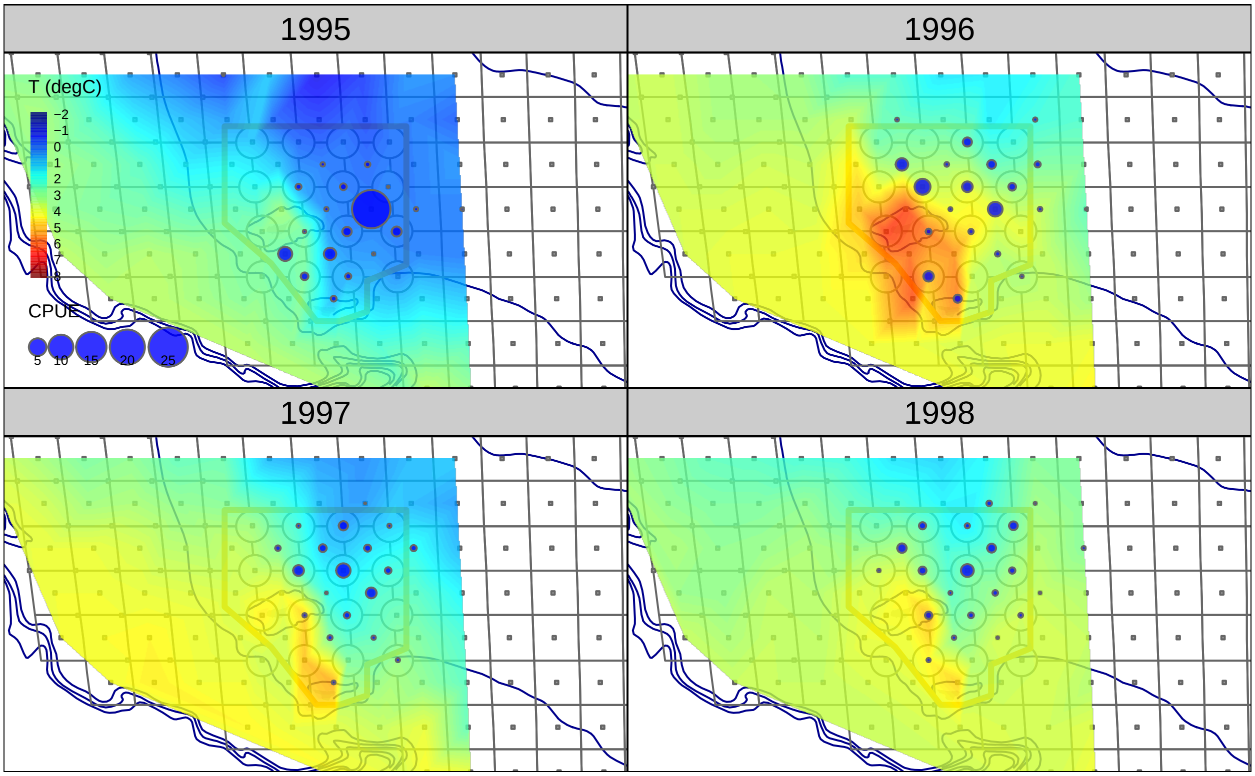

Figure 27: Survey CPUE (biomass) for males PIBKC. Page 6 of 11

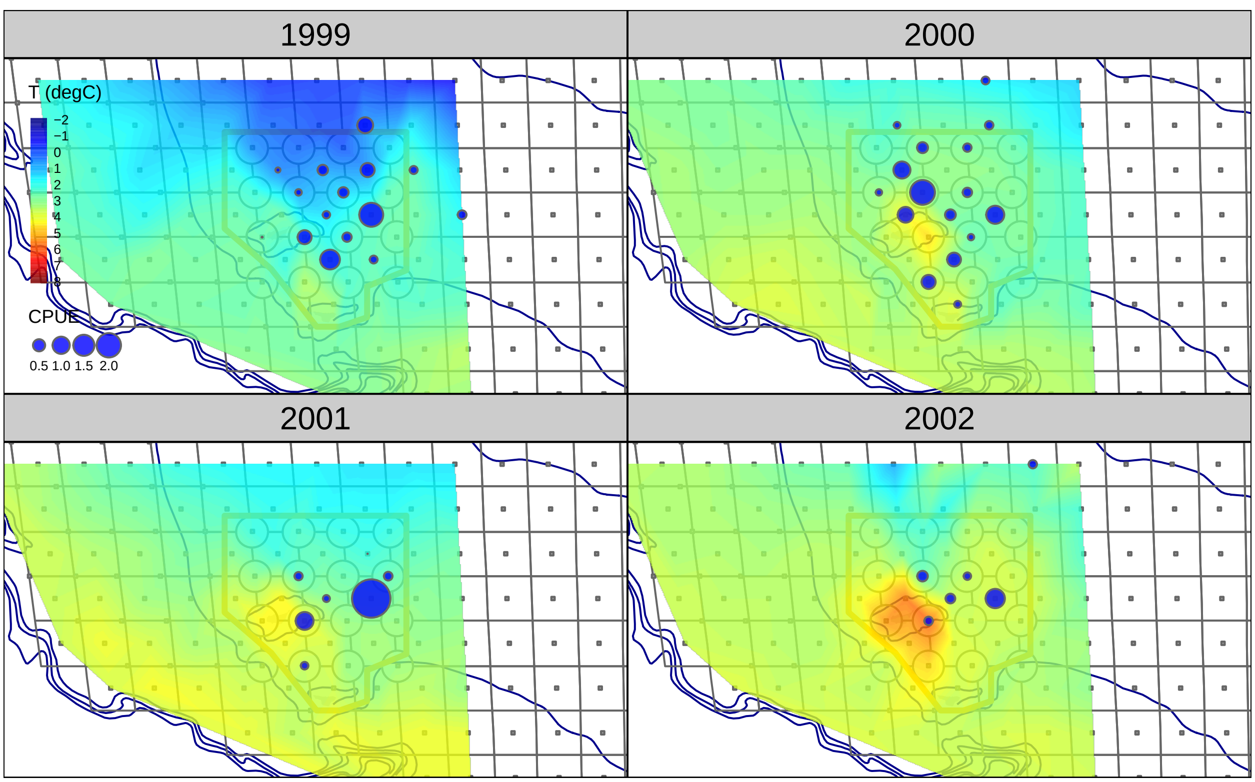

Figure 28: Survey CPUE (biomass) for males PIBKC. Page 7 of 11

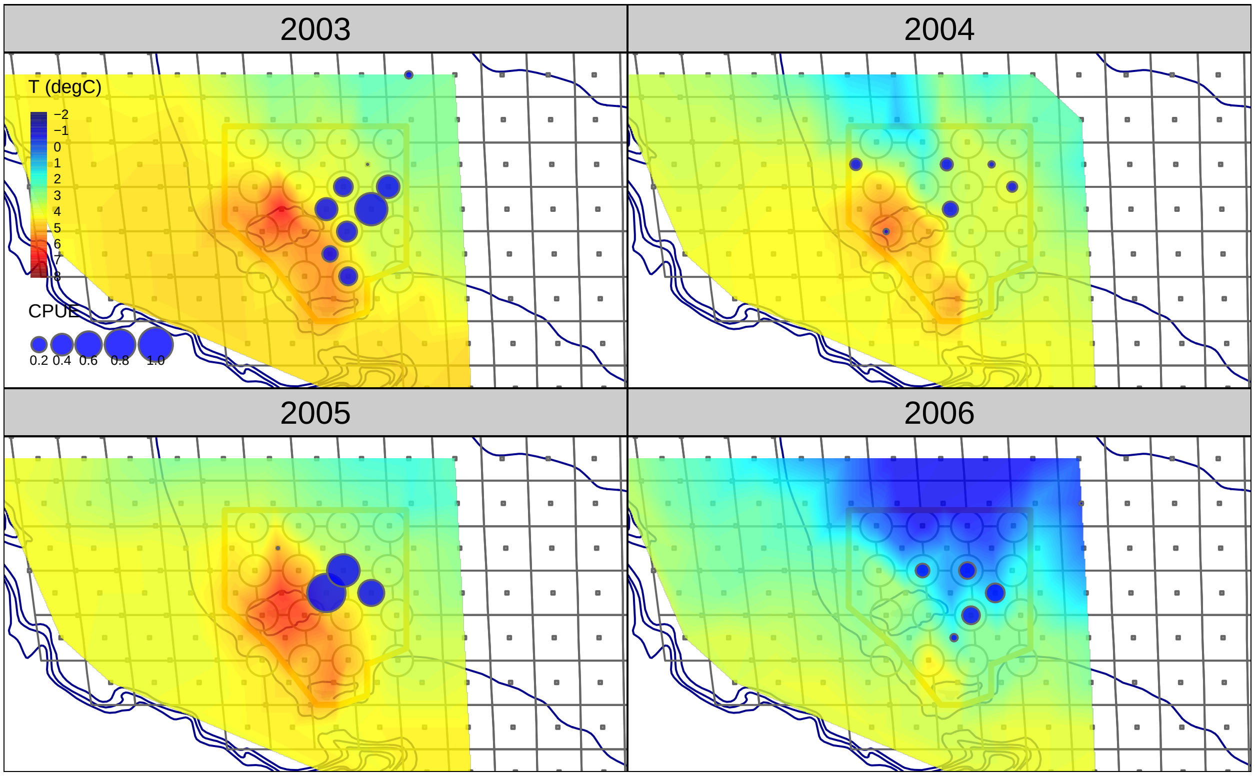

Figure 29: Survey CPUE (biomass) for males PIBKC. Page 8 of 11

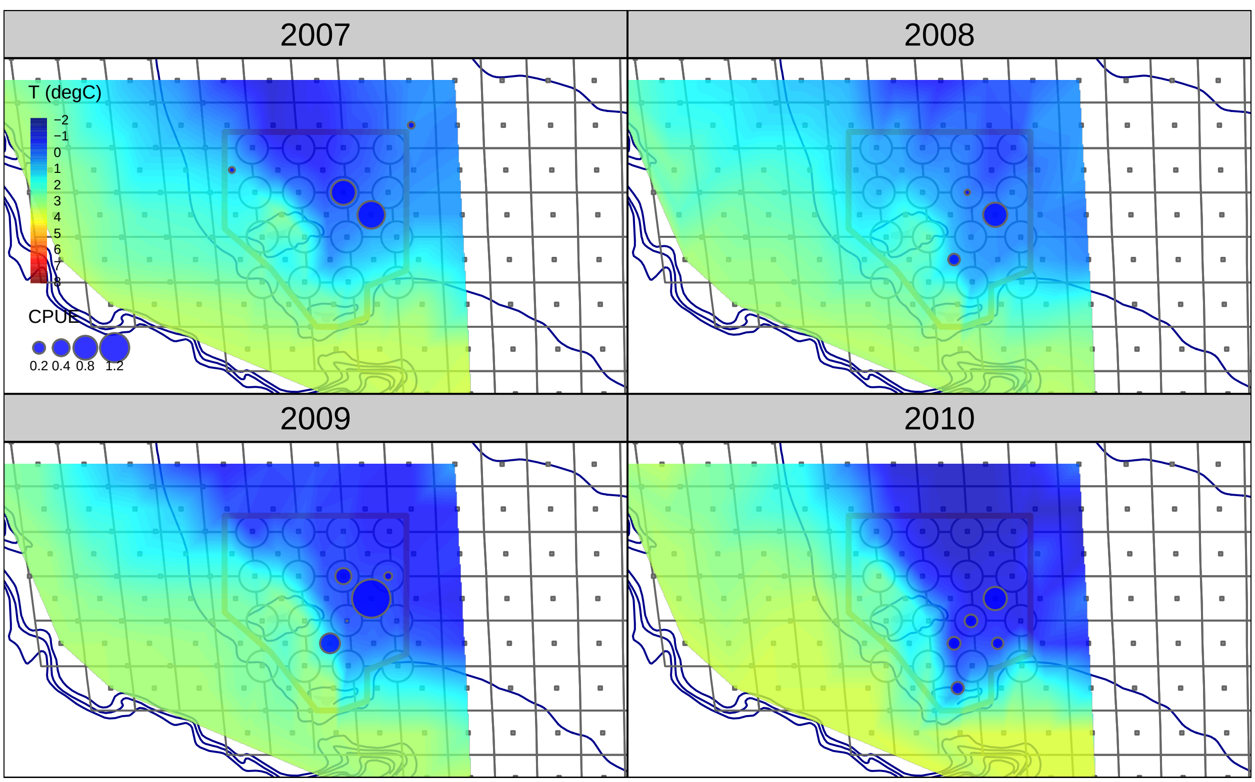

Figure 30: Survey CPUE (biomass) for males PIBKC. Page 9 of 11

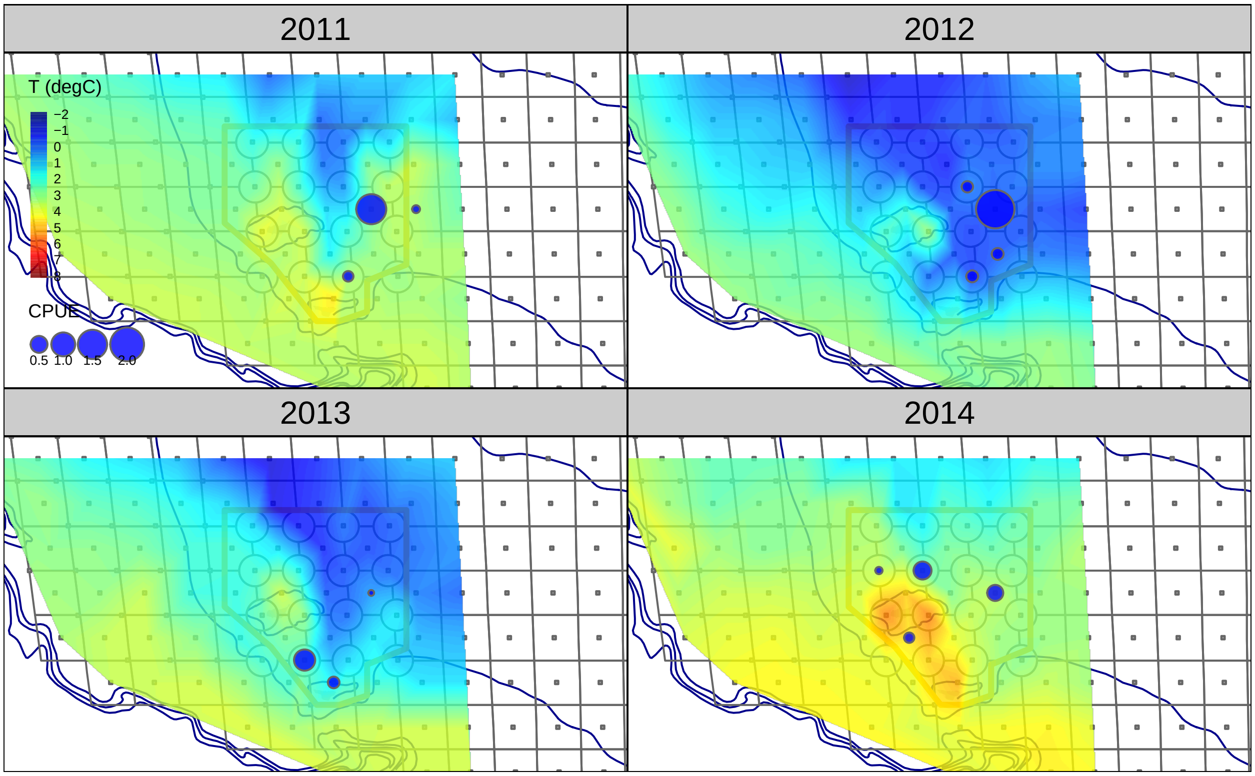

Figure 31: Survey CPUE (biomass) for males PIBKC. Page 10 of 11

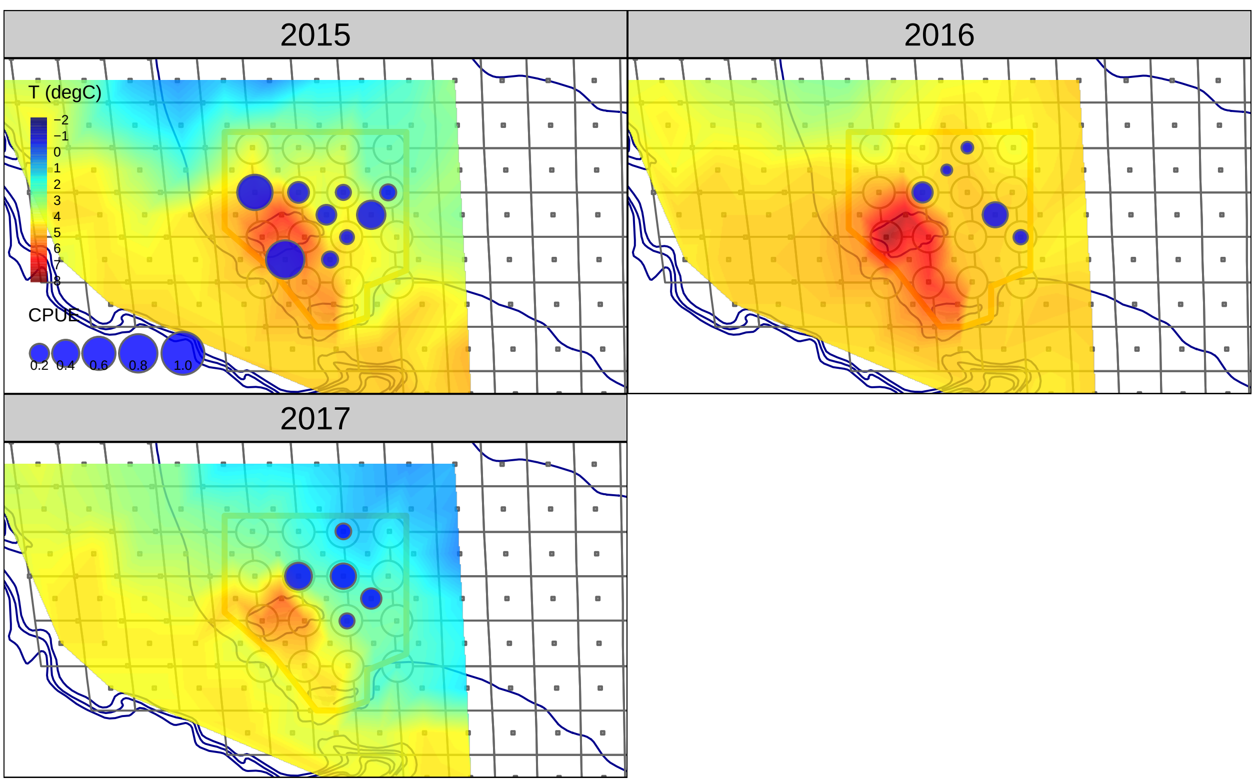

Figure 32: Survey CPUE (biomass) for males PIBKC. Page 11 of 11

Appendix C: PIBKC 2017 Status Determination

William Stockhausen

11 September, 2017

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List of Figures

Introduction

This is an appendix to the 2017 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: ./Data2017AM.Fisheries.csv
- survey data : ./Data2017AM.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):

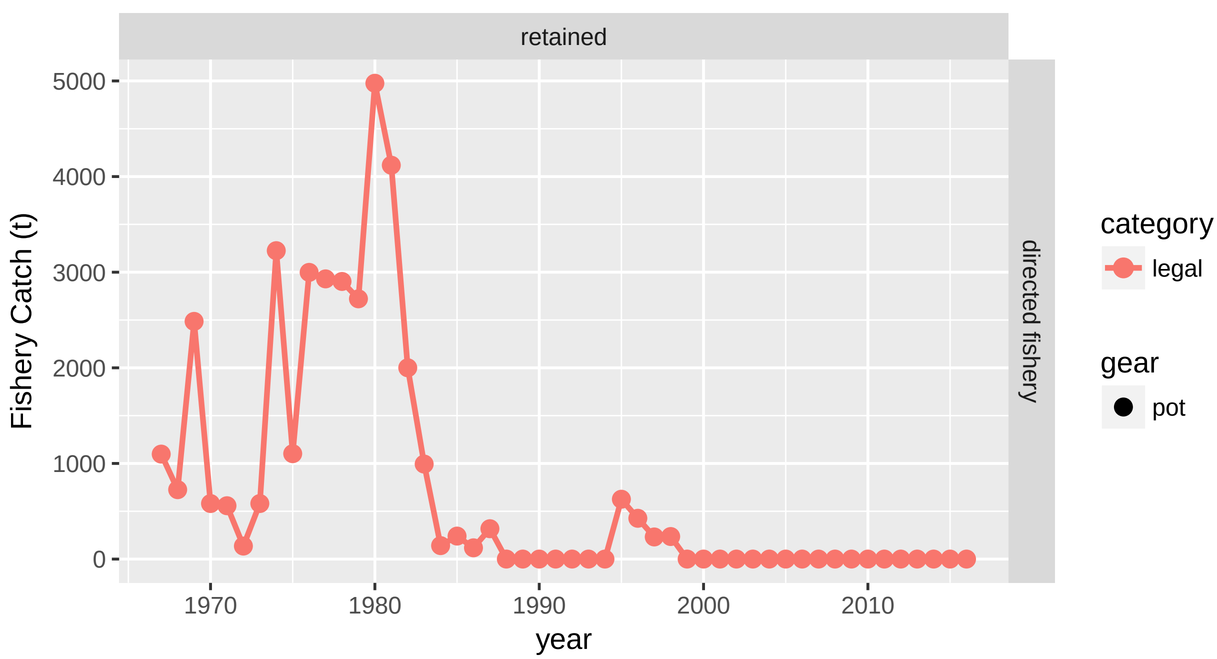

Figure 1: Time series of retained PIBKC catch in the directed fishery.

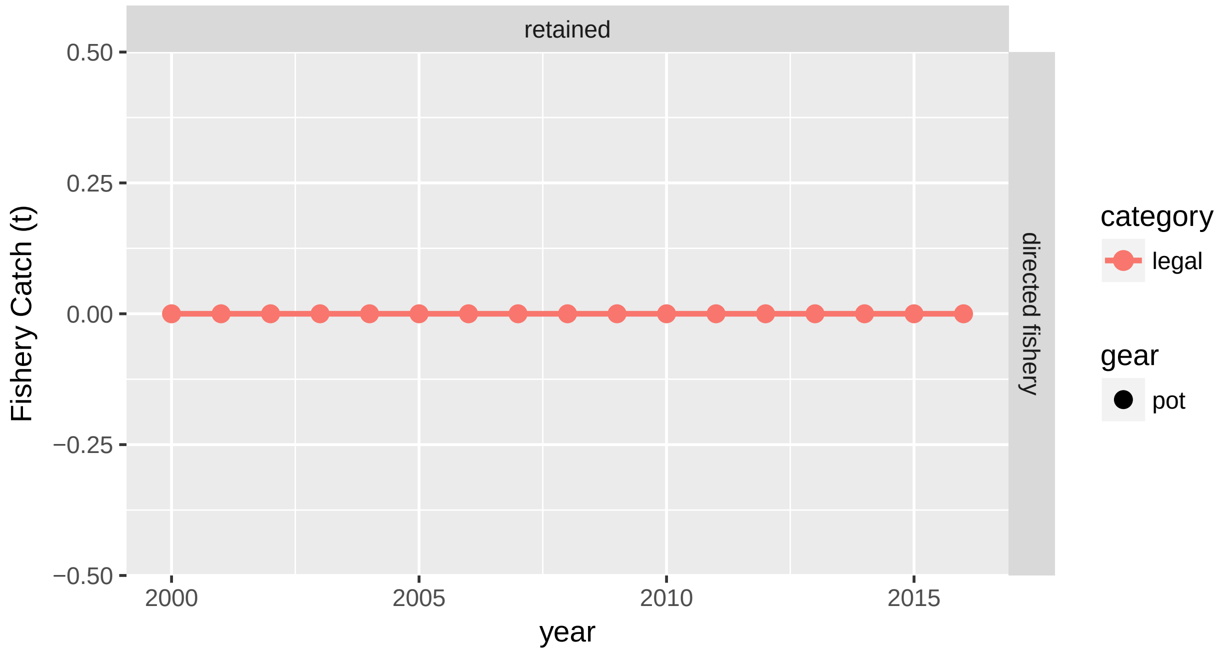

Figure 2: Time series of retained PIBKC catch in the directed fishery (recent time period).

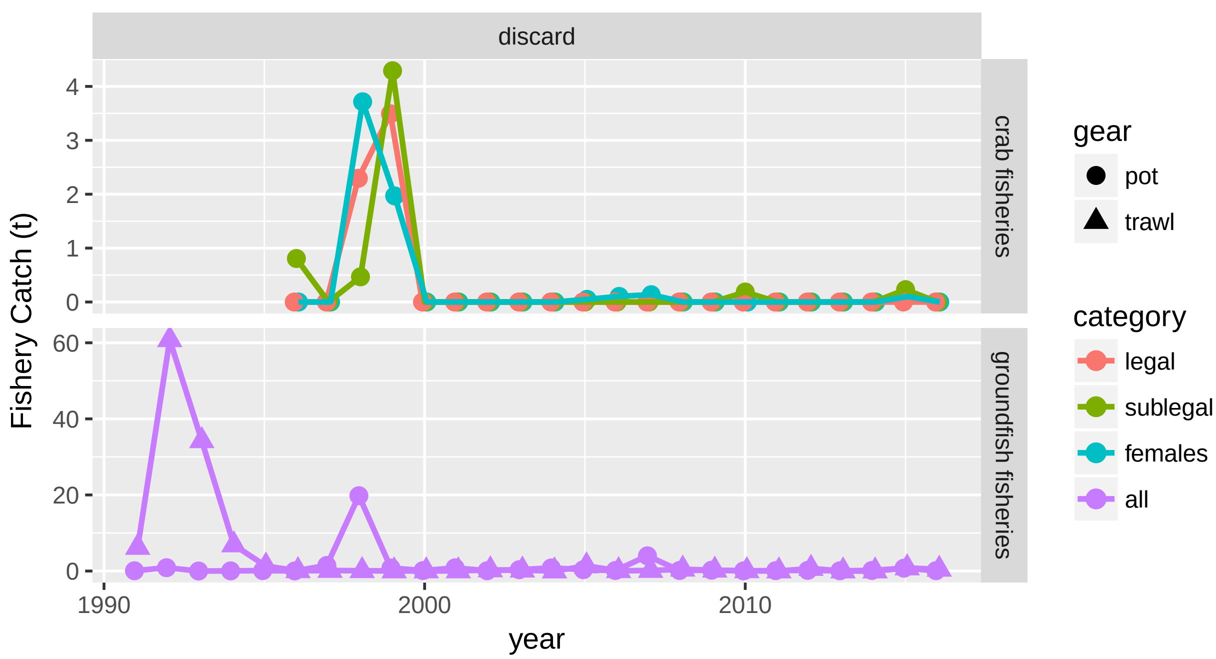

Figure 3: Time series of PIBKC bycatch in the crab and groundfish fisheries.

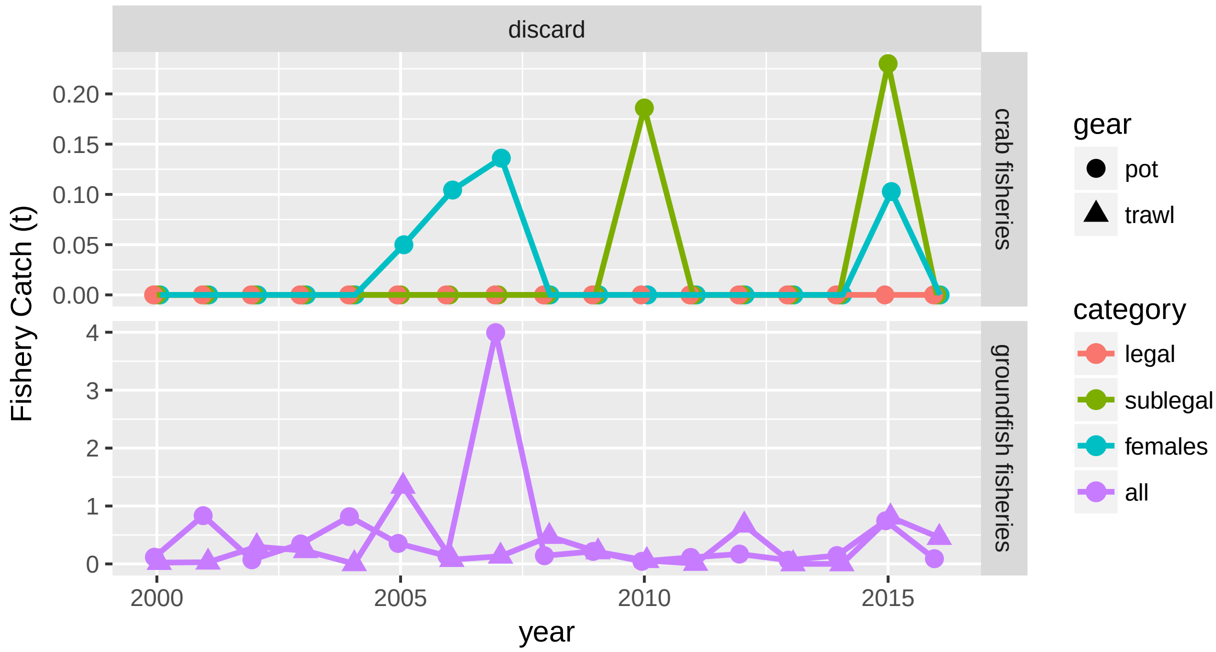

Figure 4: Time series of PIBKC bycatch in the crab and groundfish fisheries (recent time period).

The following figures illustrate the time series of PIBKC survey biomass in the NMFS EBS bottom trawl survey:

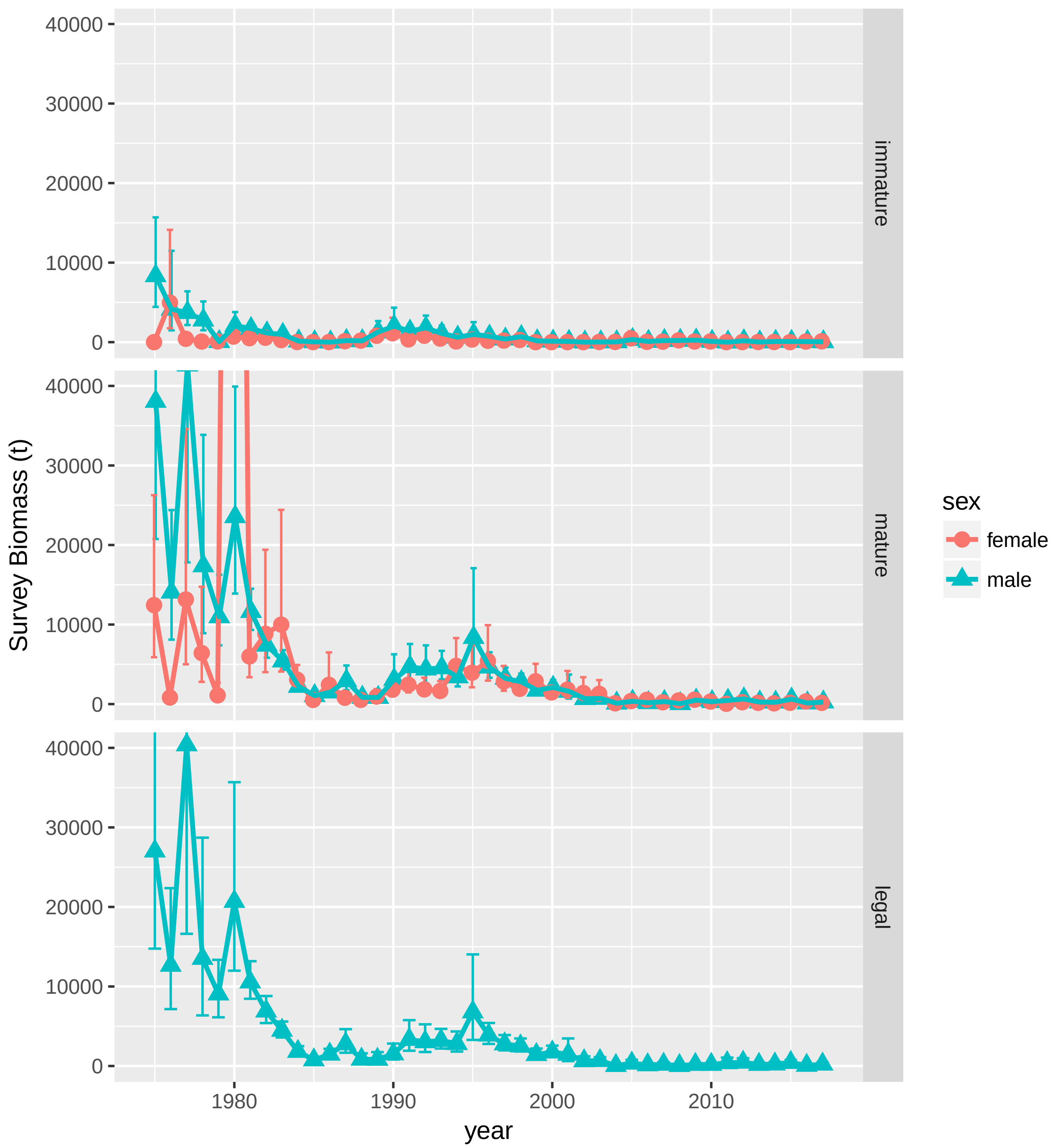

Figure 5: Time series of NMFS EBS bottom trawl survey biomass for PIBKC. Confidence intervals shown are 80% CI's, assuming lognormal error distributions.

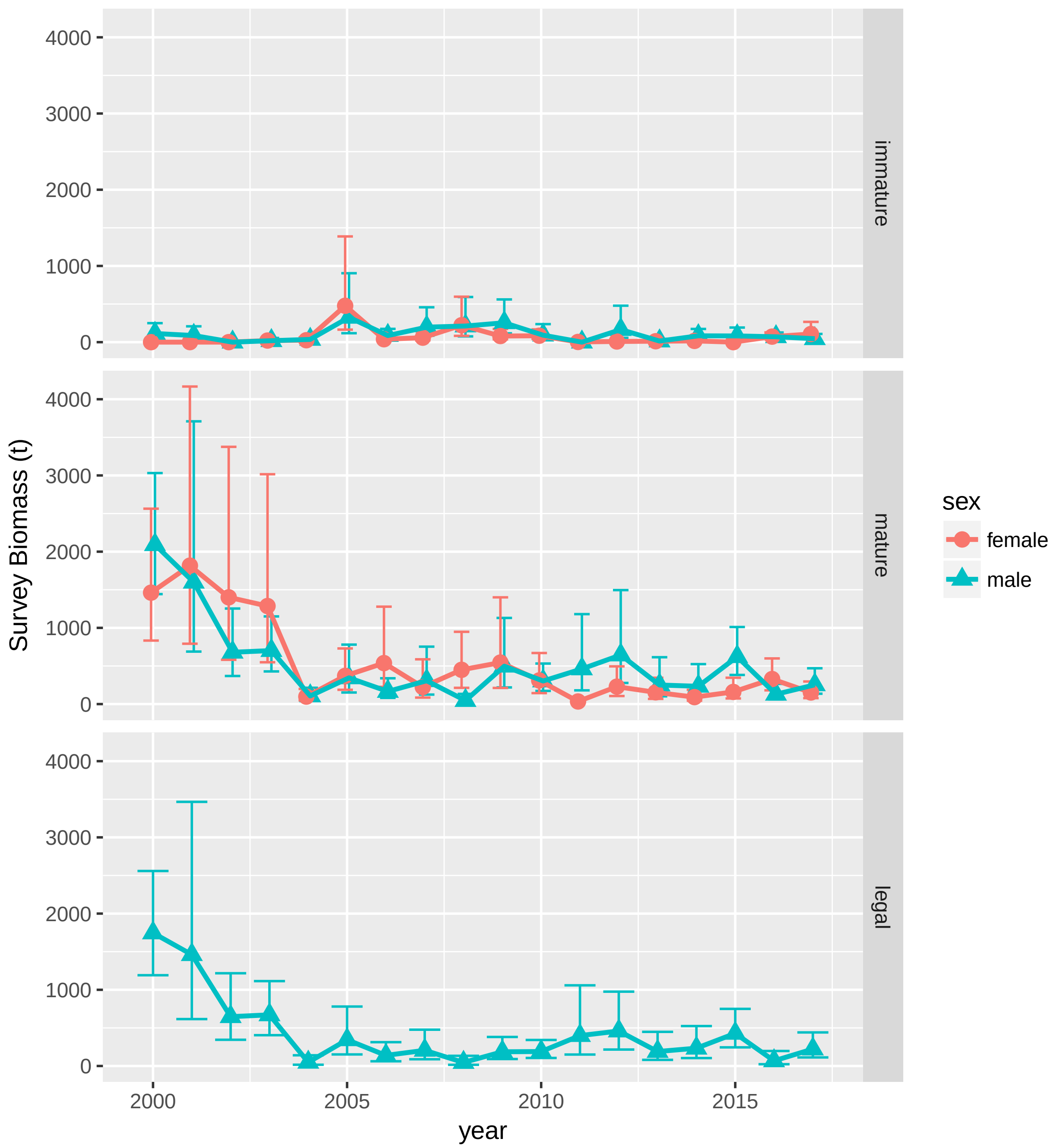

Figure 6: Time series of NMFS EBS bottom trawl survey biomass for PIBKC (recent time period). Confidence intervals shown are 80% CI's, assuming lognormal error distributions.

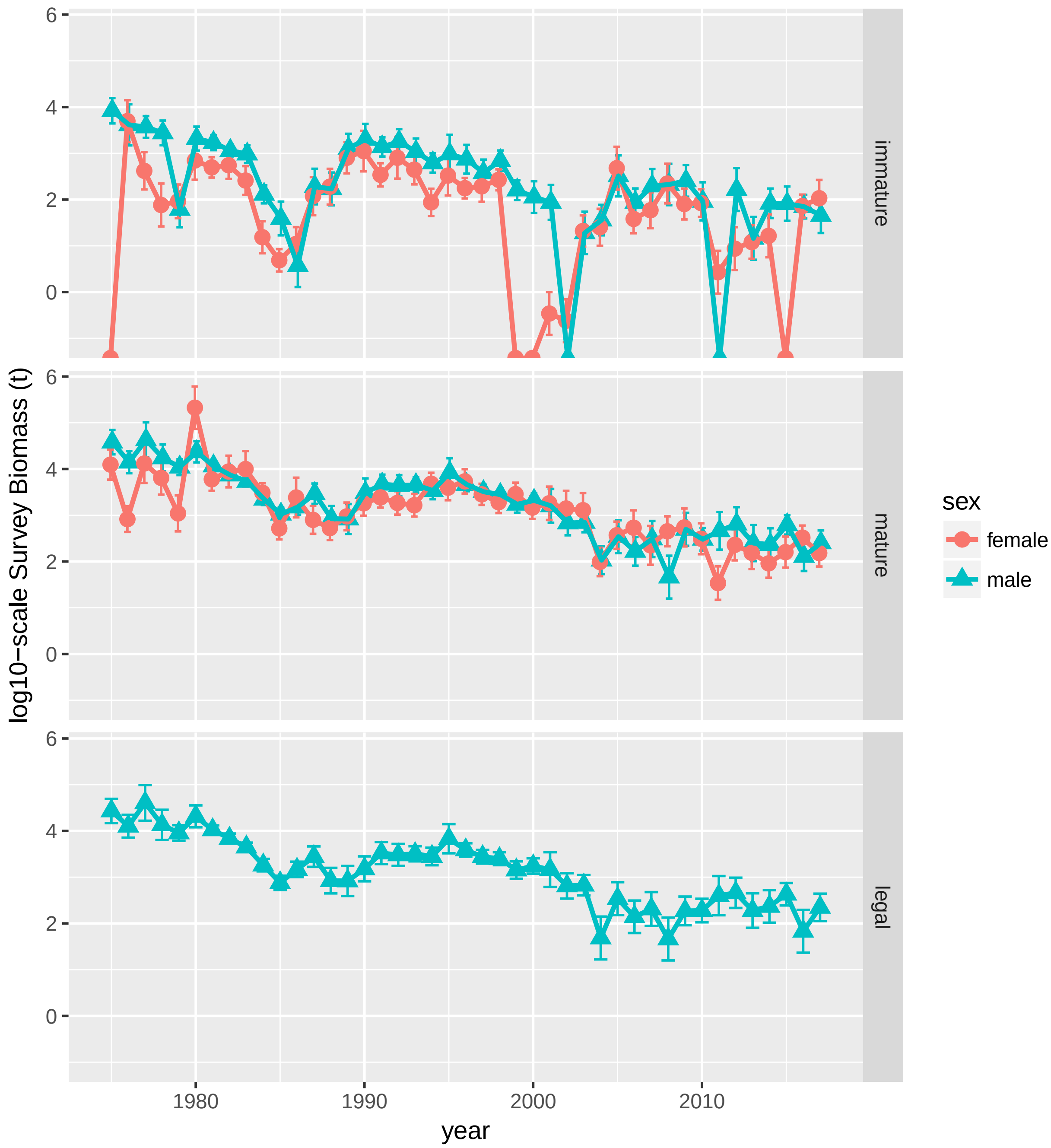

Figure 7: Log10-scale time series for the NMFS EBS bottom trawl survey biomass for PIBKC. Confidence intervals shown are 80% CI's, assuming lognormal error distributions.

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.

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.

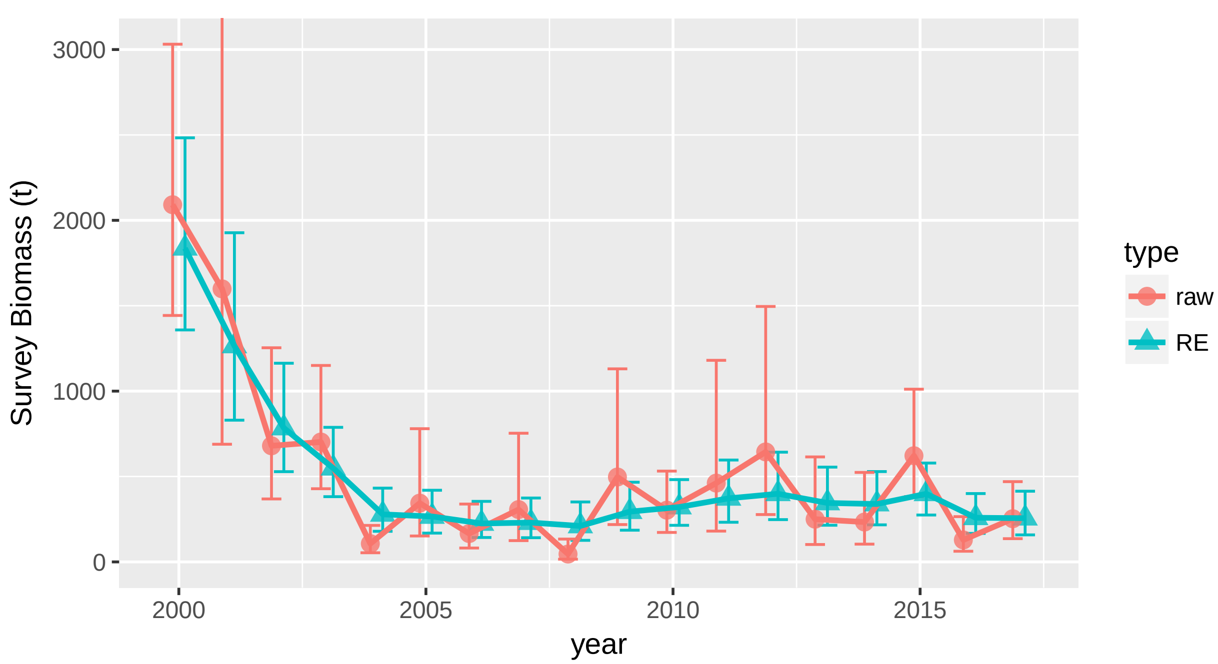

Figure 9: Arithmetic-scale raw and smoothed survey MMB time series, since 2000. Confidence intervals shown are 80% CIs, assuming lognormal error distributions.

Figure 10: Log-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormalerror distributions.

Status determination

Overfishing status

For PIBKC, the total fishing mortality in 2016/17 was 0.3820875 t while the OFL was 1.16 t. Thus, overfishing did not occur in 2016/17.

Overfished status

As discussed previously, overfished status is determined by the ratio $B/B_{MSY_{proxy}}$: the stock is overfished if the ratio is less than 0.5, where B is taken as "current" MMB-at-mating. For PIBKC, $B_{MSY_{proxy}}$ is obtained by averaging estimated MMB-at-mating over the period [1980/81-1984/85,1990/91-1997/98]. Following recommendations made by the CPT and SSC in 2015 (CPT, 2015; SSC, 2015), B and $B_{MSY_{proxy}}$ are based on MMB-at-mating calculated using the RE-smoothed time series of survey biomass projected forward to mating time.

MMB-at-mating

For comparison, time series for MMB-at-mating using both the raw (unsmoothed) survey MMB time series and the RE-smoothed survey MMB time series were calculated. The results are shown below in Figures 12 and 13:

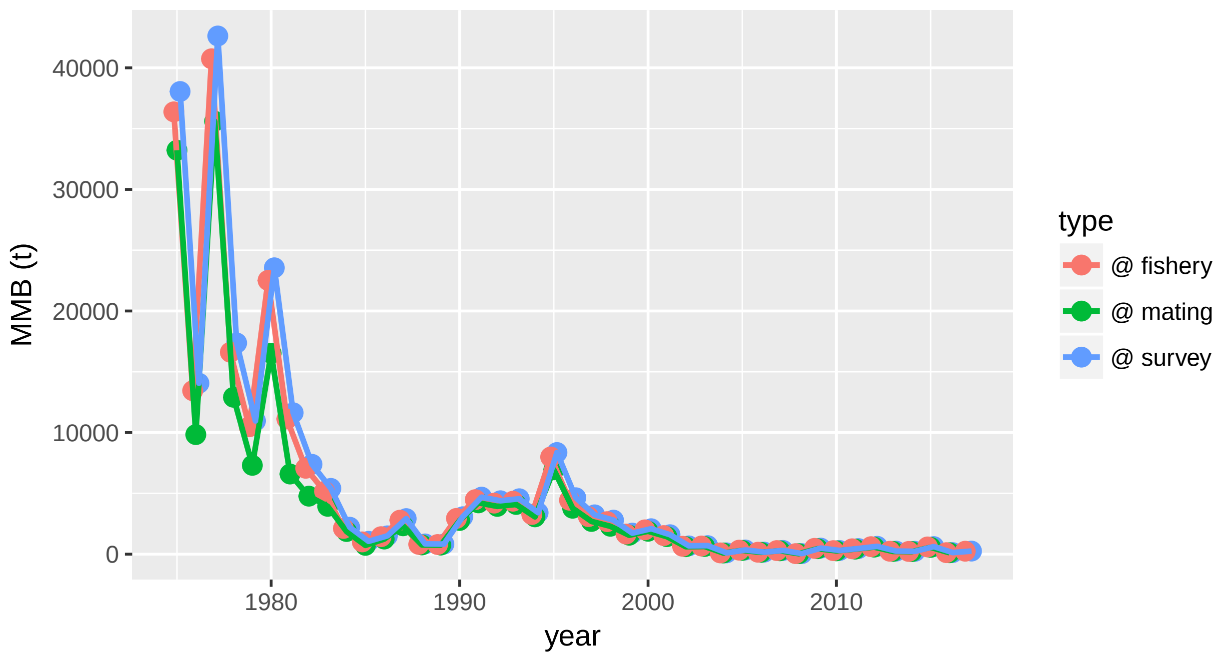

Figure 11: Estimated time series for MMB at the time of the survey (no smoothing), at the time of the fishery, and at the time of mating.

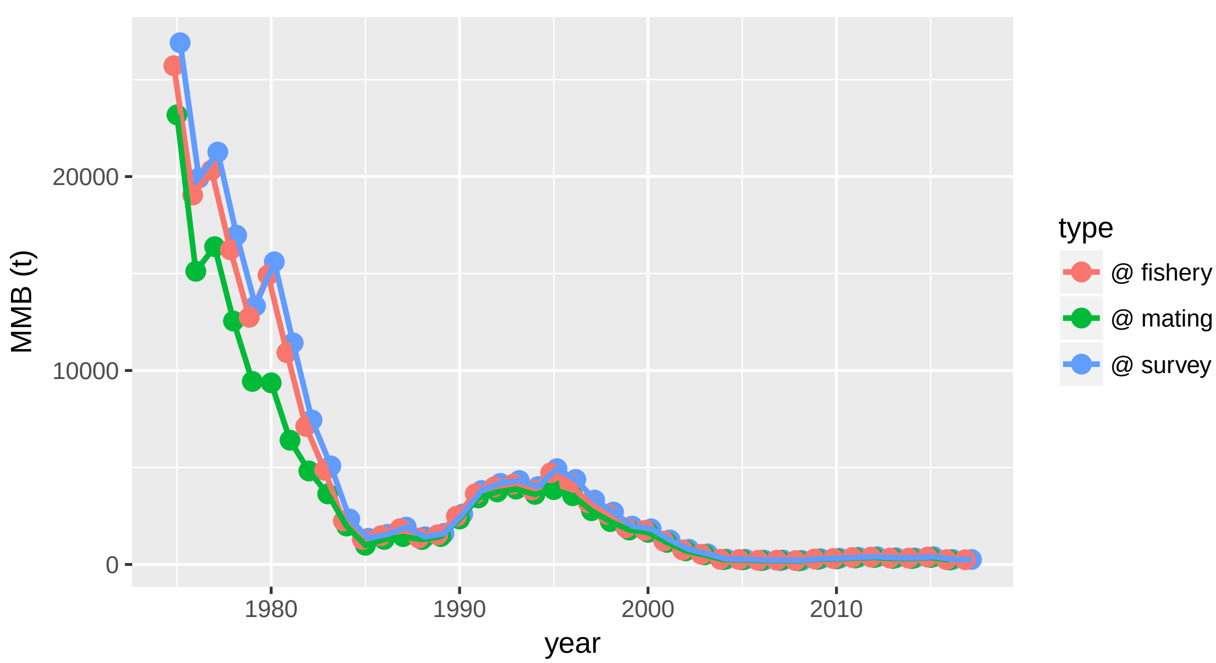

Figure 12: Estimated time series for MMB using the RE method at the time of the survey (the random effects time series), at the time of the fishery, and at the time of mating.

Values for $B_{MSY_{proxy}}$ and the estimated current (2017) MMB *at the time of the survey* from the raw survey data and the RE-smoothed results are:

Table 1: Estimated $B_{MSY_{proxy}}$ and current MMB at the time of the survey, using the raw survey data and the RE-smoothed data.

Estimation Type	Current survey MMB (t)	$B_{MSY_{proxy}}$ (t)
raw data	253	$5,012$
RE-smoothed	256	$4,108$

The value above for $B_{MSY_{proxy}}$ using the raw data is shown for illustration only. As noted previously, $B_{MSY_{proxy}}$ for this assessment is based on averaging the MMB-at-mating calculated from the RE-smoothed survey MMB (i.e., 4107.8663144 t).

Values for θ, used in the projected MMB calculations, based on averaging over the last three years, are:

Table 2: Estimated values for the *heta* coefficient.

	Estimation Type	θ
1	raw data	0.0007627
2	RE-smoothed	0.0006203

Results from the calculations for B ("current" MMB), overfished status, and an illustrative Tier 4-based OFL for 2017/18 (not used for PIBKC) are:

Table 3: More results from the OFL determination.

	quantity	units	raw.data	RE.smoothed
1	B ("current" MMB)	t	227.41	230.21
2	B_{MSY}	t	5,012.14	4,107.87
3	stock status	–	overfished	overfished
4	F_{OFL}	$year^{-1}$	0.00	0.00
5	RM_{OFL}	t	0.00	0.00
6	DM_{OFL}	t	0.37	0.30
7	OFL	t	0.37	0.30

Because B/B_{MSY} using RE-smoothed MMB-at-mating from the Table above is 0.056, 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	0.0000	NA	NA	0.0000	0.0000	NA
1967	NA	NA	NA	1,097.6928	NA	NA
1968	NA	NA	NA	725.7473	NA	NA
1969	NA	NA	NA	2,485.6846	NA	NA
1970	NA	NA	NA	580.5979	NA	NA
1971	NA	NA	NA	557.9183	NA	NA
1972	NA	NA	NA	136.0776	NA	NA
1973	NA	NA	NA	580.5979	NA	NA
1974	NA	NA	NA	3,225.0397	NA	NA
1975	NA	NA	NA	1,102.2288	NA	NA
1976	NA	NA	NA	2,998.2437	NA	NA
1977	NA	NA	NA	2,930.2049	NA	NA
1978	NA	NA	NA	2,902.9894	NA	NA
1979	NA	NA	NA	2,721.5525	NA	NA
1980	NA	NA	NA	4,975.9052	NA	NA
1981	NA	NA	NA	4,118.6161	NA	NA
1982	NA	NA	NA	2,000.3411	NA	NA
1983	NA	NA	NA	993.3667	NA	NA
1984	NA	NA	NA	140.6135	NA	NA
1985	NA	NA	NA	240.4038	NA	NA
1986	NA	NA	NA	117.9339	NA	NA
1987	NA	NA	NA	317.5145	NA	NA
1988	NA	NA	NA	0.0000	NA	NA
1989	NA	NA	NA	0.0000	NA	NA
1990	NA	NA	NA	0.0000	NA	NA
1991	NA	NA	NA	0.0000	0.0670	6.1990
1992	NA	NA	NA	0.0000	0.8790	60.7910
1993	NA	NA	NA	0.0000	0.0000	34.2320
1994	NA	NA	NA	0.0000	0.0350	6.8560
1995	NA	NA	NA	625.9571	0.1080	1.2840
1996	0.0000	0.0000	0.8074	426.3766	0.0310	0.0670
1997	0.0000	0.0000	0.0000	231.3320	1.4620	0.1300
1998	3.7149	2.2952	0.4672	235.8679	19.8000	0.0790
1999	1.9686	3.4927	4.2910	0.0000	0.7950	0.0200
2000	0.0000	0.0000	0.0000	0.0000	0.1160	0.0230
2001	0.0000	0.0000	0.0000	0.0000	0.8330	0.0290
2002	0.0000	0.0000	0.0000	0.0000	0.0710	0.2970
2003	0.0000	0.0000	0.0000	0.0000	0.3450	0.2270
2004	0.0000	0.0000	0.0000	0.0000	0.8160	0.0020
2005	0.0499	0.0000	0.0000	0.0000	0.3530	1.3390
2006	0.1043	0.0000	0.0000	0.0000	0.1380	0.0740
2007	0.1361	0.0000	0.0000	0.0000	3.9930	0.1320
2008	0.0000	0.0000	0.0000	0.0000	0.1410	0.4730
2009	0.0000	0.0000	0.0000	0.0000	0.2156	0.2068
2010	0.0000	0.0000	0.1860	0.0000	0.0443	0.0563
2011	0.0000	0.0000	0.0000	0.0000	0.1117	0.0071
2012	0.0000	0.0000	0.0000	0.0000	0.1699	0.6688
2013	0.0000	0.0000	0.0000	0.0000	0.0646	0.0000
2014	0.0000	0.0000	0.0000	0.0000	0.1443	0.0001
2015	0.1028	0.0000	0.2301	0.0000	0.7443	0.8078
2016	0.0000	0.0000	0.0000	0.0000	0.0904	0.4550

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

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

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

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

Table 9: A comparison of estimates for MMB (in t) at the time of the survey.

		raw			RE	
year	value	lci	uci	value	lci	uci
1975	38,053.59	20,759.61	69,754.48	26,901.00	16,825.61	43,009.66
1976	14,058.93	8,103.53	24,391.05	19,926.60	13,388.82	29,656.78
1977	42,618.32	17,814.39	101,958.08	21,264.90	13,591.30	33,270.99
1978	17,369.71	8,912.49	33,852.16	16,974.60	11,333.27	25,424.00
1979	10,959.38	7,385.67	16,262.32	13,329.30	9,743.03	18,235.63
1980	23,552.92	13,894.39	39,925.46	15,605.10	11,032.07	22,073.75
1981	11,628.25	9,320.75	14,507.00	11,423.00	9,355.46	13,947.47
1982	7,388.96	5,824.58	9,373.50	7,448.55	6,051.74	9,167.76
1983	5,408.73	4,315.80	6,778.45	5,081.02	4,155.14	6,213.21
1984	2,215.66	1,659.01	2,959.08	2,347.24	1,840.91	2,992.84
1985	1,054.79	753.94	1,475.68	1,349.79	1,020.02	1,786.18
1986	1,504.69	1,029.62	2,198.96	1,555.26	1,156.67	2,091.20
1987	2,923.38	1,761.10	4,852.75	1,927.64	1,351.62	2,749.15
1988	842.43	445.93	1,591.49	1,427.29	946.09	2,153.24
1989	827.50	391.56	1,748.76	1,598.80	1,027.48	2,487.79
1990	3,077.51	1,512.59	6,261.49	2,602.58	1,717.52	3,943.72
1991	4,689.67	2,910.49	7,556.46	3,812.12	2,677.47	5,427.61
1992	4,391.01	2,612.05	7,381.55	4,181.16	2,939.68	5,946.94
1993	4,555.60	3,100.43	6,693.73	4,328.92	3,200.20	5,855.75
1994	3,410.36	2,219.61	5,239.91	4,017.00	2,906.92	5,551.00
1995	8,360.23	4,090.73	17,085.84	4,941.99	3,335.75	7,321.67
1996	4,640.62	3,308.54	6,509.03	4,384.30	3,316.32	5,796.22
1997	3,232.58	2,284.30	4,574.53	3,322.05	2,523.45	4,373.38
1998	2,797.93	2,042.57	3,832.65	2,704.95	2,085.48	3,508.43
1999	1,729.24	1,136.48	2,631.17	1,976.11	1,450.90	2,691.44
2000	2,091.34	1,442.89	3,031.19	1,836.48	1,358.21	2,483.16
2001	1,598.74	688.93	3,710.05	1,264.67	829.84	1,927.36
2002	679.80	368.60	1,253.75	784.02	528.41	1,163.28
2003	702.01	428.47	1,150.19	548.55	381.89	787.92
2004	106.88	53.46	213.67	278.26	179.24	432.00
2005	344.06	151.76	780.00	265.97	168.64	419.46
2006	165.89	81.25	338.67	224.99	142.84	354.39
2007	306.46	124.64	753.49	230.18	141.64	374.08
2008	45.98	15.82	133.66	210.46	126.20	350.98
2009	497.11	218.63	1,130.34	294.20	185.57	466.43
2010	302.93	172.57	531.78	321.26	214.21	481.79
2011	461.36	180.34	1,180.27	372.10	232.13	596.46
2012	643.94	277.26	1,495.58	398.87	247.63	642.49
2013	250.14	101.79	614.66	345.09	214.61	554.90
2014	233.39	103.97	523.89	338.82	217.04	528.91
2015	621.71	382.23	1,011.25	398.72	274.64	578.88
2016	128.55	62.34	265.09	258.43	166.93	400.10
2017	252.78	135.99	469.85	255.86	158.16	413.90

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Saint Matthew Island Blue King Crab Stock Assessment 2018

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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 1975-2018 NMFS trawl survey mean biomass is 5,664 t with the 2018 value being the 5th lowest (1,731 t; the third lowest since 2000). This 2018 biomass of $\geq$ 90 mm carapace length (CL) male crab is 31% of the long term mean at 3.814 million pounds (with a CV of 28%) is 31% of the long term mean. The most recent 3-year average of the NMFS survey is 41% of the mean value, further indicating a decline in biomass compared to historical survey estimates, notably in 2010 and 2011 that were over six times the current average. The ADFG pot survey was repeated in 2018 and 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 dampen the interannual variability observed in the survey biomass and suggest that the stock (in survey biomass units) is presently at about 28% of the long term model-predicted survey biomass average. The trend from these values suggests a slight decline.
4. **Recruitment**: Recruitment is based on estimated number of male crab within the 90-104 mm CL size class in each year. The 2018 trawl-survey area-swept estimate of 0.154 million male SMBKC in this size class is the third lowest in the 41 years since 1978 and follows the lowest previously observed in 2017. The recent six-year (2013 - 2018) average recruitment is only 45% of this 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 is below the minimum stock-size threshold (MSST) in 2017/18 and is hence is in an "overfished" condition, despite fishery closures in the last two years (and hence overfishing has not occurred) (Tables 1 and 2). 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 60% of what it would have been in the absence of fishing.

Table 1: Status and catch specifications (1000 t) for the reference model. A - calculated from the assessment reviewed by the Crab Plan Team in September 2014, B - calculated from the assessment reviewed by the Crab Plan Team in September 2015, C - calculated from the assessment reviewed by the Crab Plan Team in September 2016, D - calculated from the assessment reviewed by the Crab Plan Team in September 2017, E - calculated from the assessment reviewed by the Crab Plan Team in September 2018.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained catch	Total male catch	OFL	ABC
2013/14	1.50^A	3.01^A	0.00	0.00	0.00	0.56	0.45
2014/15	1.86^B	2.48^B	0.30	0.14	0.15	0.43	0.34
2015/16	1.84^C	2.11^C	0.19	0.05	0.05	0.28	0.22
2016/17	1.97^D	2.23^D	0.00	0.00	0.05	0.14	0.11
2017/18	1.85^E	1.29^E	0.00	0.00	0.05	0.12	0.10
2018/19		1.31^E				0.04	0.03

Table 2: Status and catch specifications (million pounds) for the reference model.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained catch	Total male catch	OFL	ABC
2013/14	3.4^A	6.64^A	0.000	0.000	0.0006	1.24	0.99
2014/15	4.1^B	5.47^B	0.655	0.309	0.329	0.94	0.75
2015/16	4.1^C	4.65^C	0.419	0.110	0.110	0.62	0.49
2016/17	4.3^D	4.91^D	0.410	0.000	0.000	0.31	0.25
2017/18	4.1^E	2.85^E	0.41	0.000	0.000	0.27	0.22
2018/19		2.89^E				0.08	0.07

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 (Table 3).

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
2013/14	4b	3.06	3.01	0.98	0.18	1	1978-2013	0.18
2014/15	4b	3.28	2.71	0.82	0.14	1	1978-2014	0.18
2015/16	4b	3.71	2.45	0.66	0.11	1	1978-2015	0.18
2016/17	4b	3.67	2.23	0.61	0.09	1	1978-2016	0.18
2017/18	4b	3.86	2.05	0.53	0.08	1	1978-2017	0.18
2018/19	4b	3.7	1.31	0.35	0.043	1	1978-2018	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 makes use of two new survey data points including the 2018 NMFS trawl-survey estimate of abudance, and the 2018 ADF&G pot survey CPUE. Both of these surveys have associated size compositon data. The assessment also uses updated 2010-2017 groundfish and fixed gear bycatch estimates based on NMFS Alaska Regional Office (AKRO) data. The directed fishery has been closed since 2016/17 so fishery data in recent years are unavailable.

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 Bill Gaeuman and accepted by the CPT in May 2012. A difference from the original approach, and that used here, is that natural and fishing mortality 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 spawning biomass as estimated 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 2017. The addition of new data introduced this year area are presented sequentially. Two alternative models are presented for sensitivity. One involves a re-analysis of the NMFS trawl survey data using a spatio-temporal Delta-GLMM approach (VAST model; Thorson and Barnett 2017) and the other configuration (named "Fit survey") simply adds emphasis on the design-based survey data (by assuming a lower input variance). The VAST model suggests a modest increase from the 2017 survey estimate. However, the model tends to moderate the noise in the survey observations and declines

B. Responses to SSC and CPT Comments

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.

2. *add ability to estimate bycatch fishing mortality rates when observer data are missing but effort data is available*

   This was completed.

3. *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 to include an alternative time series estimated from the NMFS trawl survey using the VAST spatiotemporal Delta GLMM model and continued with the iterative re-weighting for composition data.

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]. NMFS tag-return data from studies on blue king crab in the Pribilof Islands and St. Matthew Island support the idea that legal-sized males do not migrate between the two areas (Otto and Cummiskey 1990). St. Matthew Island blue king crab tend to be smaller than their Pribilof conspecifics, and the two stocks are managed separately.

Life History

Like the red king crab, *Paralithodes camtshaticus*, the blue king crab is considered a shallow water species by comparison with other lithodids such as golden king crab, *Lithodes aequispinus*, and the scarlet king crab, *Lithodes couesi* (Donaldson and Byersdorfer 2005). Adult male blue king crab are found at an average depth of 70 m (NPFMC 1998). The reproductive cycle appears to be annual for the first two reproductive cycles and biennial thereafter (Jensen and Armstrong 1989), and mature crab seasonally migrate inshore where they molt and mate. Unlike red king crab, juvenile blue king crab do not form pods, but instead rely on cryptic coloration for protection from predators and require suitable habitat such as cobble and shell hash. Somerton and MacIntosh (1983) estimated SMBKC male size at sexual maturity to be 77 mm carapace length (CL). Paul et al. (1991) found that spermatophores were present in the vas deferens of 50% of the St. Matthew Island blue king crab males examined with sizes of 40-49 mm CL and in 100% of the males at least 100 mm CL. Spermataphore diameter also increased with increasing CL with an asymptote at ~ 100 mm CL. It was noted, however, that although spermataphore presence indicates physiological sexual maturity, it may not be an indicator of functional sexual maturity. For purposes of management of the St. Matthew Island blue king crab fishery, the State of Alaska uses 105 mm CL to define the lower size bound of functionally mature males (Pengilly and Schmidt 1995). Otto and Cummiskey (1990) report an average growth increment of 14.1 mm CL for adult SMBKC males.

Management History

The SMBKC fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990). Ten U.S. vessels harvested 545 t (1.202 million pounds) in 1977, and harvests peaked in 1983 when 164 vessels landed 4,288 t (9.454 million pounds) (Fitch et al. 2012; Table 7).

[2] NOAA grant Bering Sea Crab Research II, NA16FN2621, 1997.

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 during 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 makes use of two new survey data points including the 2018 NMFS trawl-survey estimate of abudance, and the 2018 ADF&G pot survey CPUE. Both of these surveys have associated size compositon data. The assessment also uses updated 1993-2016 groundfish and fixed gear bycatch estimates based on AKRO data. The fishery was closed in 2016/17 so no directed fishery catch data were available. The data used in each of the new models is shown in Figure 3.

[3]D. Pengilly, ADF&G, pers. comm.

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 (1978-2018; 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 (1992/93-2016/17; 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.

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

Five models were presented in the previous assessment. This year, four models are presented with the reference model being the same configuration as approved last year (Ianelli et al. 2017), two sensitivities are considered, one with a different treatment of NMFS bottom trawl survey (BTS) data using a geo-spatial model (VAST; Thorson and Barnett 2017; Appendix C). A second sensitivity was constructed which weights the survey data more heavily. 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. **2017 Model**: the 2017 recommended model without any new data
2. **BTS**: adds in the 2018 bottom trawl survey (BTS) data
3. **BTS and pot**: as with previous but including the 2018 ADFG pot survey data (Model 16.0 or "reference case")
4. **VAST**: applies a geo-spatial delta-GLMM model (Thorson and Barnett 2017) to the BTS data which provides a different BTS index. See appendix B for details and diagnostics. This is a preliminary examination as more work is needed to ensure options for the BTS CPUE data were specified appropriately.
5. **Fit survey**: an exploratory scenario that's the same as the reference model except the NMFS trawl survey is up-weighted by $\lambda^{\mathrm{NMFS}} = 2$ and the ADF&G pot survey is up-weighted by $\lambda^{\mathrm{ADFG}} = 2$.

Note that SSC convention would label these (item 3 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 2017 model and sensitivity new 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 more of a decline than in the 2017 assessment, especially with the addition of the pot survey.

b. Alternative NMFS bottom-trawl survey index

Results comparing model fits between the VAST model and the reference case show different time-series of data and a different model fit (Figure 10). The effect on spawning biomass suggests estimates were consistently higher since 1990 compared to the reference model (Figure 11).

c. 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 SDNR and MAR values for the trawl survey and pot survey size compositions were relatively good, ranging from 0.54 to 0.73 for the reference case. The SDNRs for the directed pot fishery and other size compositions were similar to previous estimates.

d. Parameter estimates

Model parameter estimates for each of the Gmacs scenarios are summarized in Tables 12, 13, and 15. 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” scenario 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 12). Estimated recruitment is variable over time for all models and in recent years is well below average (Figure 13). Estimated mature male biomass on 15 February also fluctuates considerably (Figure 14). Estimated natural mortality each year (M_t) is presented in Figure 15.

e. 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 is slightly above the 2017 value for the key sensitivities (Figures 16). All of the models fit the pot survey CPUE poorly (Figure 17. For both surveys the standardized residuals tend to have similar patterns with some improvement (generally) for the VAST model (Figures 18 and 19).

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 20, 21, and 22) for all scenarios. Representative residual plots of the composition data fits are generally poor (Figures 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 16 and 17). It is worth noting that that this scenario (included for exploratory purposes) resulted in worse SDNR and MAR values for the two abundance indices.

f. Retrospective and historical analyses

This is only the second year a formal assessment model developed for this stock. As such, retrospective patterns and historical analyses relative to fisheries impacts are limited.

g. 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 2017 are presented in Section F.

h. Comparison of alternative model scenarios.

The estimates of mature male biomass (Figure 14), 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). This existng scenario results in a lower MMB from the mid-1980s through to the late-1990s, and is again lower in the most recent 5 years. This scenario upweights both the trawl and pot surveys abundance indices and represents a model run that places greater emphasis on the abundance indices.

In summary, the use of the reference model for management purposes is preferred since it provides the best fit to the data and is consistent with previous model specifications. Research on alternative model specifications (e.g., natural mortality variability) was limited this year. The VAST model may take better account of spatial processes but requires more research to ensure it has been appropriately applied and the assumptions are reasonable. Consequently, the reference model appears reasonable and appropriate for ACL and OFL determinations for this stock in 2017. Nonetheless, the **Fit surveys** model, while difficult to statistically justify, portends a more dire stock status (see below) and should highlight the caution needed in managing this resource.

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

$$F_{OFL} = \begin{cases} F_{MSY}, & \text{when } B/B_{MSY} > 1 \\ F_{MSY}\frac{(B/B_{MSY}-\alpha)}{(1-\alpha)}, & \text{when } \beta < B/B_{MSY} \le 1 \end{cases} \tag{1}$$

$$F_{OFL} < F_{MSY} \text{ with directed fishery } F = 0 \text{ when } B/B_{MSY} \le \beta$$

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 2018 for all scenarios are summarized in Table 4. The ABC is 80% of the OFL.

G. Rebuilding Analysis

This stock is not currently subject to a rebuilding plan. However, interpretation of the point estimate for the reference case suggests that the mature male biomass is below 50% of B_{MSY} but slightly above for the "VAST" model configuration (Table 4).

Table 4: Comparisons of management measures for the model scenarios. Biomass and OFL are in tons.

Component	Reference	VAST	Fit surveys
MMB_{2018}	1309.025	2257.996	4038.448
B_{MSY}	3698.941	4240.714	9161.159
F_{OFL}	0.043	0.075	0.059
OFL_{2018}	38.464	117.589	191.950
ABC_{2018}	30.771	94.072	153.560

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 to stock to about 60% of what it would have been in the absence of fishing (Figure 26) . The other non-fishing contributors to the observed depleted stock trend (ignoring stock-recruit relationship) may reflect variable survival rates due to environmental conditions and also range shifts.

J. Acknowledgements

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Tables

Table 5: Observed proportion of crab by size class during the ADF&G crab observer pot-lift sampling. Source: ADF&G Crab Observer Database.

Year	Total pot lifts	Pot lifts sampled	Number of crab (90 mm+ CL)	Stage 1	Stage 2	Stage 3
1990/91	26,264	10	150	0.113	0.393	0.493
1991/92	37,104	125	3,393	0.133	0.177	0.690
1992/93	56,630	71	1,606	0.191	0.268	0.542
1993/94	58,647	84	2,241	0.281	0.210	0.510
1994/95	60,860	203	4,735	0.294	0.271	0.434
1995/96	48,560	47	663	0.148	0.212	0.640
1996/97	91,085	96	489	0.160	0.223	0.618
1997/98	81,117	133	3,195	0.182	0.205	0.613
1998/99	91,826	135	1.322	0.193	0.216	0.591
1999/00 - 2008/09			FISHERY CLOSED			
2009/10	10,484	989	19,802	0.141	0.324	0.535
2010/11	29,356	2,419	45,466	0.131	0.315	0.553
2011/12	48,554	3,359	58,666	0.131	0.305	0.564
2012/13	37,065	2,841	57,298	0.141	0.318	0.541
2013/14			FISHERY CLOSED			
2014/15	10,133	895	9,906	0.094	0.228	0.679
2015/16	5,475	419	3,248	0.115	0.252	0.633
2016/17			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

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				

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

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

Table 12: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the reference model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.622	0.127
$\log(\bar{R})$	13.915	0.060
$\log(n^0_1)$	14.932	0.171
$\log(n^0_2)$	14.551	0.202
$\log(n^0_3)$	14.366	0.206
q_{pot}	3.535	0.265
$\log(\bar{F}^{\mathrm{df}})$	-2.166	0.055
$\log(\bar{F}^{\mathrm{tb}})$	-9.330	0.081
$\log(\bar{F}^{\mathrm{fb}})$	-8.245	0.081
log Stage-1 directed pot selectivity 1978-2008	-0.638	0.173
log Stage-2 directed pot selectivity 1978-2008	-0.321	0.126
log Stage-1 directed pot selectivity 2009-2017	-0.000	0.002
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.001
log Stage-1 NMFS trawl selectivity	-0.258	0.064
log Stage-2 NMFS trawl selectivity	-0.000	0.002
log Stage-1 ADF&G pot selectivity	-0.792	0.124
log Stage-2 ADF&G pot selectivity	-0.003	0.024
F_{OFL}	0.043	0.007
OFL	38.464	10.360

Table 13: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the VAST model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.708	0.107
$\log(\bar{R})$	14.118	0.055
$\log(n^0_1)$	14.952	0.167
$\log(n^0_2)$	14.558	0.191
$\log(n^0_3)$	14.369	0.198
q_{pot}	2.483	0.155
$\log(\bar{F}^{\mathrm{df}})$	-2.280	0.044
$\log(\bar{F}^{\mathrm{tb}})$	-9.628	0.074
$\log(\bar{F}^{\mathrm{fb}})$	-8.556	0.074
log Stage-1 directed pot selectivity 1978-2008	-0.750	0.171
log Stage-2 directed pot selectivity 1978-2008	-0.356	0.123
log Stage-1 directed pot selectivity 2009-2017	-0.001	0.101
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.264	0.065
log Stage-2 NMFS trawl selectivity	-0.015	0.020
log Stage-1 ADF&G pot selectivity	-0.582	0.116
log Stage-2 ADF&G pot selectivity	-0.010	0.022
F_{OFL}	0.075	0.008
OFL	117.590	22.383

Table 14: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the "Fit survey" model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	2.014	0.072
$\log(\bar{R})$	14.544	0.048
$\log(n^0_1)$	15.358	0.199
$\log(n^0_2)$	15.184	0.208
$\log(n^0_3)$	14.989	0.207
q_{pot}	1.051	0.041
$\log(\bar{F}^{\mathrm{df}})$	-3.158	0.031
$\log(\bar{F}^{\mathrm{tb}})$	-10.364	0.066
$\log(\bar{F}^{\mathrm{fb}})$	-9.278	0.066
log Stage-1 directed pot selectivity 1978-2008	-0.323	0.177
log Stage-2 directed pot selectivity 1978-2008	-0.058	0.145
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	-0.000	0.001
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}	0.059	0.003
OFL	191.950	19.291

Table 15: Comparisons of parameter estimates for the model scenarios.

Parameter	Ref	VAST	FitSurvey
$\log(\bar{F}^{\mathrm{df}})$	-2.166	-2.280	-3.158
$\log(\bar{F}^{\mathrm{fb}})$	-8.245	-8.556	-9.278
$\log(\bar{F}^{\mathrm{tb}})$	-9.330	-9.628	-10.364
$\log(\bar{R})$	13.915	14.118	14.544
$\log(n^0_1)$	14.932	14.952	15.358
$\log(n^0_2)$	14.551	14.558	15.184
$\log(n^0_3)$	14.366	14.369	14.989
F_{OFL}	0.043	0.075	0.059
q_{pot}	3.535	2.483	1.051
log Stage-1 ADF&G pot selectivity	-0.792	-0.582	-0.000
log Stage-1 directed pot selectivity 1978-2008	-0.638	-0.750	-0.323
log Stage-1 directed pot selectivity 2009-2017	-0.000	-0.001	-0.000
log Stage-1 NMFS trawl selectivity	-0.258	-0.264	-0.000
log Stage-2 ADF&G pot selectivity	-0.003	-0.010	-0.000
log Stage-2 directed pot selectivity 1978-2008	-0.321	-0.356	-0.058
log Stage-2 directed pot selectivity 2009-2017	-0.000	-0.000	-0.000
log Stage-2 NMFS trawl selectivity	-0.000	-0.015	-0.000
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.622	1.708	2.014
OFL	38.464	117.590	191.950

Table 16: Comparisons of data weights, Francis LF weights (i.e. the new weights that should be applied to the LFs), SDNR and MAR (standard deviation of normalized residuals and median absolute residual) values for the model scenarios.

Component	Reference	VAST	Fit surveys
NMFS trawl survey weight	1.00	1.00	2.00
ADF&G pot survey weight	1.00	1.00	2.00
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
Fancis weight for directed pot LF	1.47	1.43	1.15
Francis weight for NMFS trawl survey LF	0.42	0.38	0.30
Francis weight for ADF&G pot survey LF	1.01	0.88	0.18
SDNR NMFS trawl survey	1.66	1.97	2.66
SDNR ADF&G pot survey	4.51	4.82	7.83
SDNR directed pot LF	0.90	0.93	1.19
SDNR NMFS trawl survey LF	1.35	1.44	1.93
SDNR ADF&G pot survey LF	1.02	1.08	2.35
MAR NMFS trawl survey	1.21	1.10	1.99
MAR ADF&G pot survey	2.81	2.74	4.75
MAR directed pot LF	0.70	0.64	0.68
MAR NMFS trawl survey LF	0.54	0.67	1.06
MAR ADF&G pot survey LF	0.70	0.97	2.03

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	Reference	VAST	Fit surveys
Pot Retained Catch	-73.35	-72.70	-68.87
Pot Discarded Catch	33.61	16.32	112.35
Trawl bycatch Discarded Catch	-7.43	-7.36	-7.43
Fixed bycatch Discarded Catch	-7.41	-7.33	-7.40
NMFS Trawl Survey	12.32	9.05	80.05
ADF&G Pot Survey CPUE	92.53	110.62	317.70
Directed Pot LF	-5.07	-3.89	24.31
NMFS Trawl LF	26.33	40.25	121.33
ADF&G Pot LF	-2.78	-0.48	47.58
Recruitment deviations	57.16	55.13	60.17
F penalty	9.66	9.66	9.66
M penalty	6.47	6.47	6.48
Prior	12.66	12.66	13.61
Total	154.70	168.40	709.54
Total estimated parameters	142.00	142.00	142.00

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	3023781	2049075	1702338	4768	0.170
1979	4243623	2395504	2377772	6646	0.119
1980	3602053	3203035	3555172	10372	0.083
1981	1357467	3105955	4901100	10757	0.065
1982	1475563	1798956	4913154	7752	0.076
1983	773712	1433358	3526836	4848	0.102
1984	665874	913703	2117136	3416	0.121
1985	941768	680553	1585505	3136	0.135
1986	1400419	760107	1389117	3070	0.129
1987	1353705	1046932	1491960	3577	0.118
1988	1238729	1115338	1711452	3874	0.113
1989	2797116	1072696	1873823	4383	0.108
1990	1754660	1943624	2164515	5438	0.088
1991	1821352	1639841	2626200	5454	0.089
1992	1949025	1576546	2579597	5600	0.081
1993	2189645	1628140	2673947	5817	0.075
1994	1535697	1782114	2728665	5547	0.072
1995	1805851	1461927	2624902	5457	0.074
1996	1607645	1509341	2540504	5289	0.077
1997	905249	1412491	2479049	4703	0.096
1998	678831	981495	2076444	3286	0.108
1999	400143	330674	800288	1868	0.103
2000	443486	336548	873018	2011	0.088
2001	410226	363174	941043	2168	0.081
2002	145725	353078	1008033	2282	0.077
2003	333277	199574	1033616	2156	0.078
2004	235025	255197	995281	2148	0.078
2005	512012	217920	982315	2082	0.078
2006	768757	362826	979052	2237	0.081
2007	525023	556119	1073083	2602	0.083
2008	942465	476388	1211965	2800	0.070
2009	740685	692255	1341278	2896	0.069
2010	721575	649030	1447778	2574	0.075
2011	589723	623688	1340120	2146	0.094
2012	338049	541129	1101914	1752	0.121
2013	443928	370924	889881	1986	0.113
2014	349998	374790	972470	1979	0.118
2015	342929	322745	974238	1969	0.119
2016	468871	301480	987479	2084	0.119
2017	289905	365759	1020732	2215	0.121
2018	667955	285723	1064712	2207	0.124

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	3055234	2086108	1734507	4866	0.168
1979	4257442	2425626	2423713	6757	0.118
1980	3598122	3220853	3609886	10496	0.083
1981	1393219	3109621	4955215	10850	0.064
1982	1478218	1820475	4958541	7843	0.075
1983	780696	1441989	3567176	4896	0.102
1984	662579	920526	2138027	3447	0.121
1985	941431	680941	1599201	3151	0.136
1986	1398365	760044	1395461	3077	0.131
1987	1375810	1045746	1494783	3575	0.120
1988	1249940	1127499	1712417	3883	0.115
1989	2871869	1083089	1878810	4399	0.110
1990	1772504	1989518	2178735	5506	0.088
1991	1855773	1665166	2658312	5523	0.088
1992	1967394	1604535	2613415	5680	0.080
1993	2233267	1647885	2711451	5893	0.074
1994	1552353	1813449	2765581	5626	0.070
1995	1772244	1481762	2661725	5530	0.074
1996	1640690	1496832	2568650	5305	0.077
1997	911676	1427124	2489066	4708	0.096
1998	664027	989997	2079572	3217	0.109
1999	386325	338975	804976	1886	0.102
2000	444883	331450	879792	2018	0.086
2001	409179	362279	944263	2173	0.079
2002	143080	352188	1010174	2285	0.075
2003	337248	197779	1034707	2156	0.076
2004	214735	256857	995667	2151	0.076
2005	524236	206948	981535	2068	0.076
2006	772777	366135	974037	2232	0.076
2007	386826	559490	1070944	2601	0.075
2008	886023	399837	1198460	2689	0.064
2009	566036	634887	1285999	2731	0.058
2010	513068	530956	1352570	2266	0.067
2011	391462	466386	1169874	1652	0.088
2012	206041	376581	842952	1112	0.133
2013	268807	241573	562999	1264	0.123
2014	171187	232582	617641	1200	0.133
2015	185938	174176	586573	1144	0.135
2016	304931	163212	573050	1197	0.132
2017	189110	227051	589688	1294	0.128
2018	135140	182181	623814	1309	0.128

Table 20: 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 model that uses the VAST BTS index.

Year	n_1	n_2	n_3	MMB	CV MMB
1978	3115589	2101690	1739151	4886	0.152
1979	4245149	2465063	2438549	6827	0.102
1980	3495583	3226925	3640655	10562	0.071
1981	1400316	3053397	4974270	10826	0.055
1982	1403527	1805901	4948868	7803	0.065
1983	768712	1394751	3542238	4788	0.088
1984	644044	898093	2091002	3323	0.105
1985	884197	662990	1541757	3010	0.117
1986	1156489	721595	1332084	2913	0.114
1987	1361692	895651	1399045	3225	0.111
1988	1268964	1069802	1556458	3531	0.109
1989	2952458	1074794	1720430	4081	0.107
1990	1926237	2032541	2049636	5323	0.081
1991	2010839	1766715	2588514	5504	0.081
1992	2271322	1726149	2620661	5837	0.074
1993	2524916	1860671	2810045	6329	0.068
1994	1797600	2049489	2984629	6296	0.064
1995	1981816	1699175	2984717	6407	0.064
1996	2171903	1687825	2969005	6282	0.066
1997	1287692	1792037	2968533	6095	0.076
1998	861162	1324336	2700596	4499	0.079
1999	482750	410980	1048751	2423	0.094
2000	569663	410052	1128931	2573	0.076
2001	518006	459164	1203922	2768	0.068
2002	158654	446063	1286310	2907	0.063
2003	467661	237700	1314172	2724	0.064
2004	227302	344128	1261691	2747	0.064
2005	884111	242979	1248943	2608	0.064
2006	1038396	582426	1249969	2992	0.066
2007	563303	781930	1435907	3533	0.062
2008	1235648	573282	1631919	3695	0.054
2009	855319	890854	1768939	3850	0.055
2010	713124	779941	1912604	3463	0.065
2011	551612	662414	1782194	2888	0.080
2012	364563	532437	1464980	2306	0.107
2013	412392	383213	1169945	2500	0.105
2014	336213	361024	1209753	2374	0.109
2015	301365	310420	1161469	2274	0.113
2016	379614	273872	1133038	2315	0.105
2017	264416	306139	1120348	2326	0.100
2018	189768	251211	1114103	2258	0.099

Table 21: 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 **fit surveys** model.

Year	n_1	n_2	n_3	MMB
1978	4677797	3931215	3233480	9847.621
1979	5679580	3957870	4761422	12429.887
1980	4358175	4535723	6470984	17440.543
1981	1550583	3976517	8080689	17667.453
1982	1771589	2196807	8020714	14103.998
1983	1110443	1733193	6327543	10774.815
1984	927307	1204239	4596325	8346.268
1985	1186602	925224	3815633	8001.730
1986	1650986	980157	3392512	7101.786
1987	2226342	1262092	3297483	7230.783
1988	2382673	1682172	3408749	7607.552
1989	6435258	1910040	3683373	8854.045
1990	3174076	4286999	4442908	12246.472
1991	3423526	3221651	5841869	13342.566
1992	3587881	3010182	6204095	14023.149
1993	4268479	3033588	6573651	15008.615
1994	3342537	3428049	6882154	15134.784
1995	2525485	3032932	7080947	15892.025
1996	4861574	2438146	7111327	15060.520
1997	3292361	3567980	7064527	16409.957
1998	1540701	3050706	7203276	12728.373
1999	1039257	585643	2182516	4739.948
2000	1819898	783942	2217206	5029.007
2001	1681408	1292948	2420978	5984.209
2002	358473	1382745	2834538	6858.585
2003	472151	661228	3098790	6537.758
2004	212213	486929	2966306	6094.289
2005	1357220	281699	2743319	5445.624
2006	2380434	863978	2562915	5763.848
2007	1840517	1637276	2802824	7056.285
2008	1319399	1580307	3328015	8001.663
2009	1402575	1271943	3701339	7635.693
2010	1274346	1217025	3770188	7008.231
2011	743295	1125918	3604064	6443.673
2012	503022	794749	3232990	5529.164
2013	527615	548703	2786488	5561.484
2014	546449	481256	2654458	5030.626
2015	450669	469626	2448183	4644.903
2016	587170	411375	2302053	4548.767
2017	248210	469551	2185962	4402.360
2018	112647	296202	2085007	4038.448

Figures

Figure 1: Distribution of blue king crab (*Paralithodes platypus*) in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters (shown in blue).

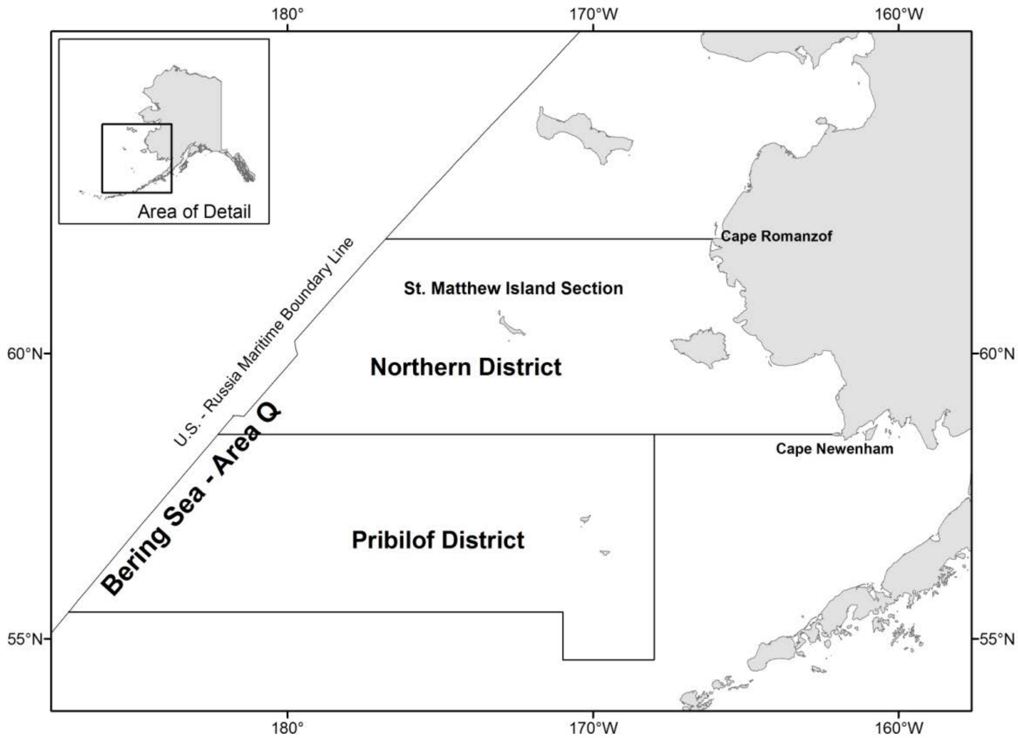

Figure 2: King crab Registration Area Q (Bering Sea).

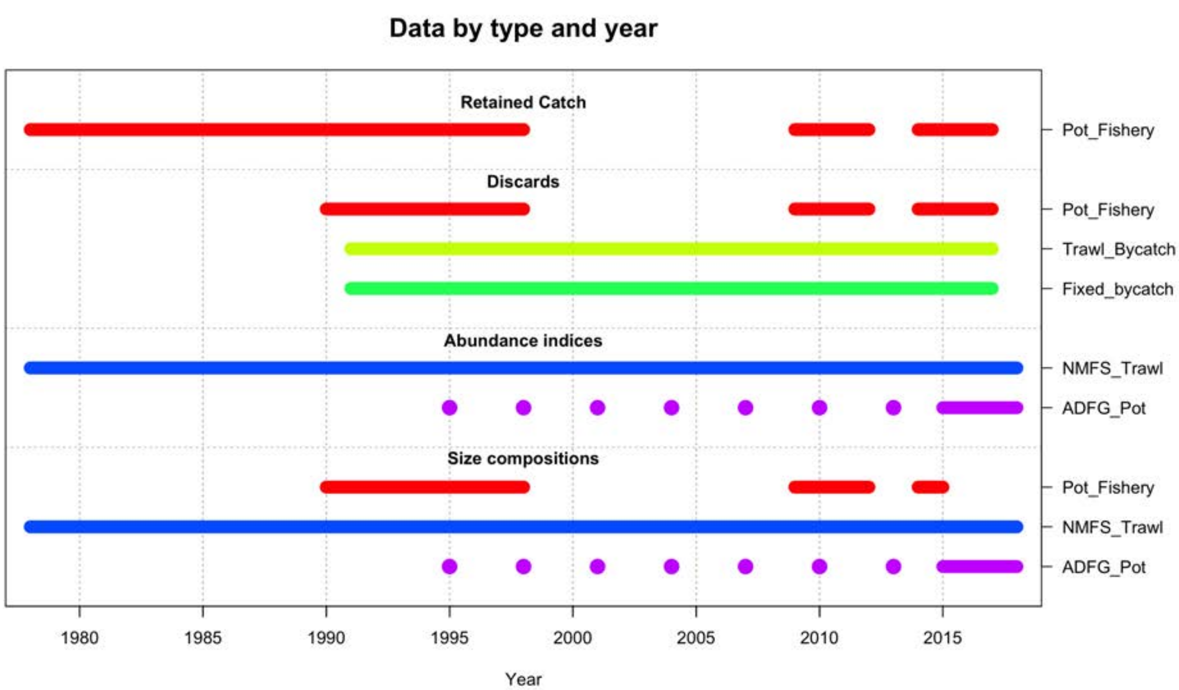

Figure 3: Data extent for the SMBKC assessment (with the 2017 Pot survey included).

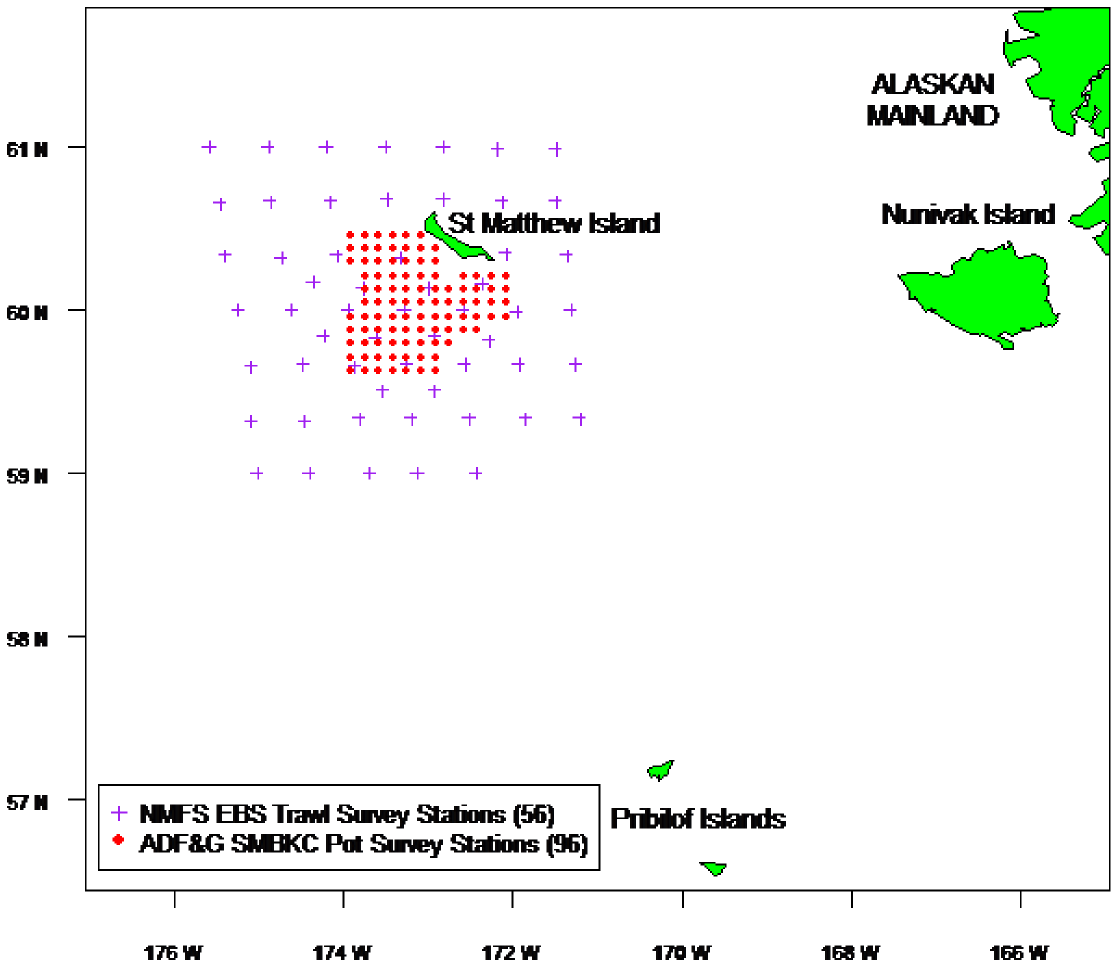

Figure 4: Trawl and pot-survey stations used in the SMBKC stock assessment.

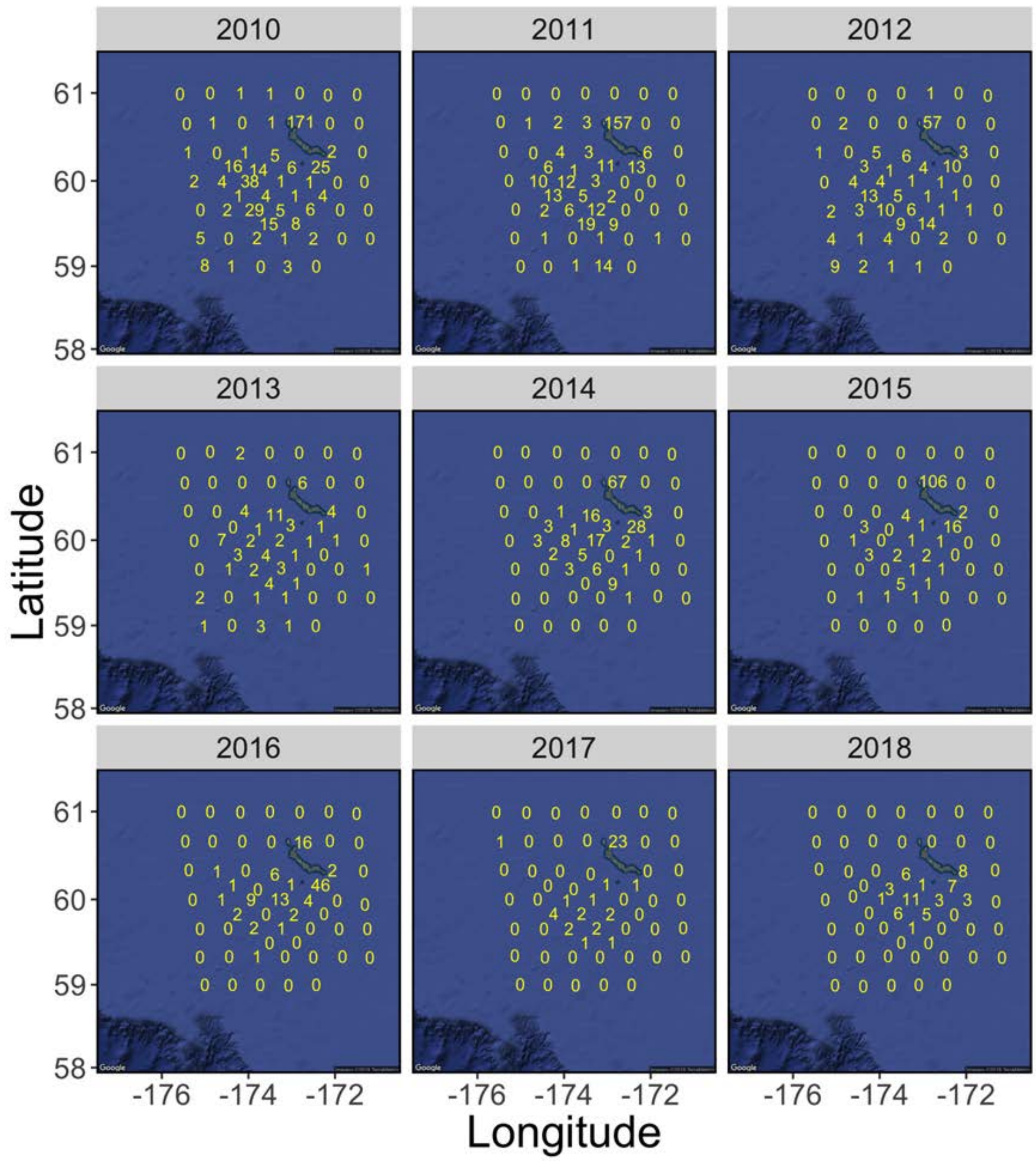

Figure 5: Catches (in numbers) of male blue king crab /ge 90 mm CL from the 2012-2017 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock. Note that the area north of St. Matthew Island, which often shows large catches of crab at station R-24 is not covered in the ADF&G pot-survey data used in the assessment.

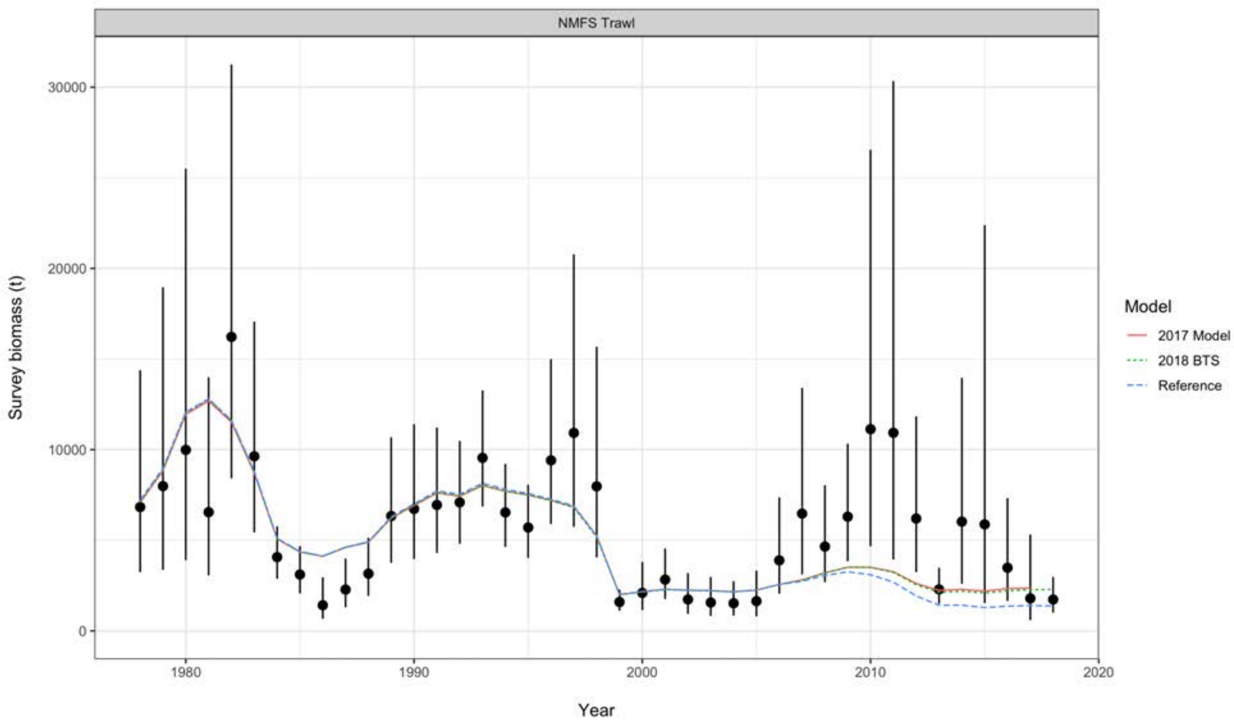

Figure 6: Fits to NMFS area-swept trawl estimates of total (/ge 90mm) male survey biomass with the addition of new data (the Reference Model is with all new data while 2018 BTS is just with the 2018 NMFS trawl survey data added). Error bars are plus and minus 2 standard deviations.

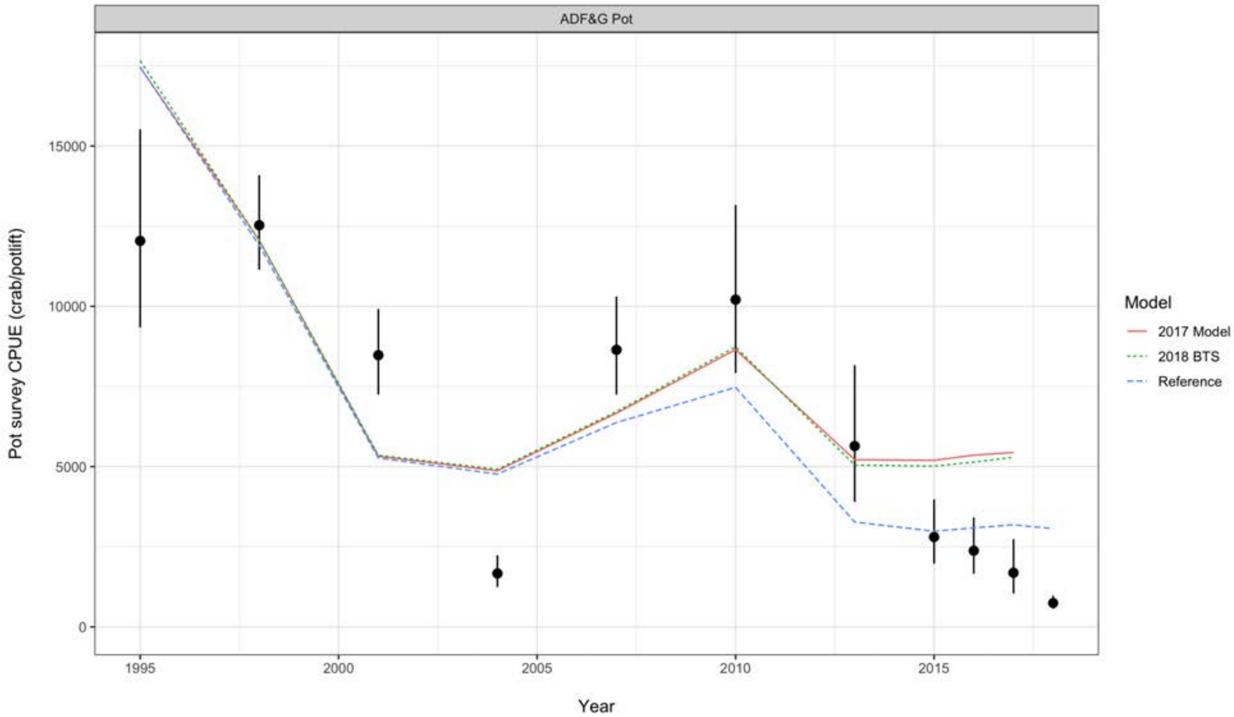

Figure 7: Comparisons of fits to CPUE from the ADF&G pot surveys with the addition of new data (note that for the 2018 BTS model the prediction for the 2018 pot survey year is ommitted from plotting routine). Error bars are plus and minus 2 standard deviations.

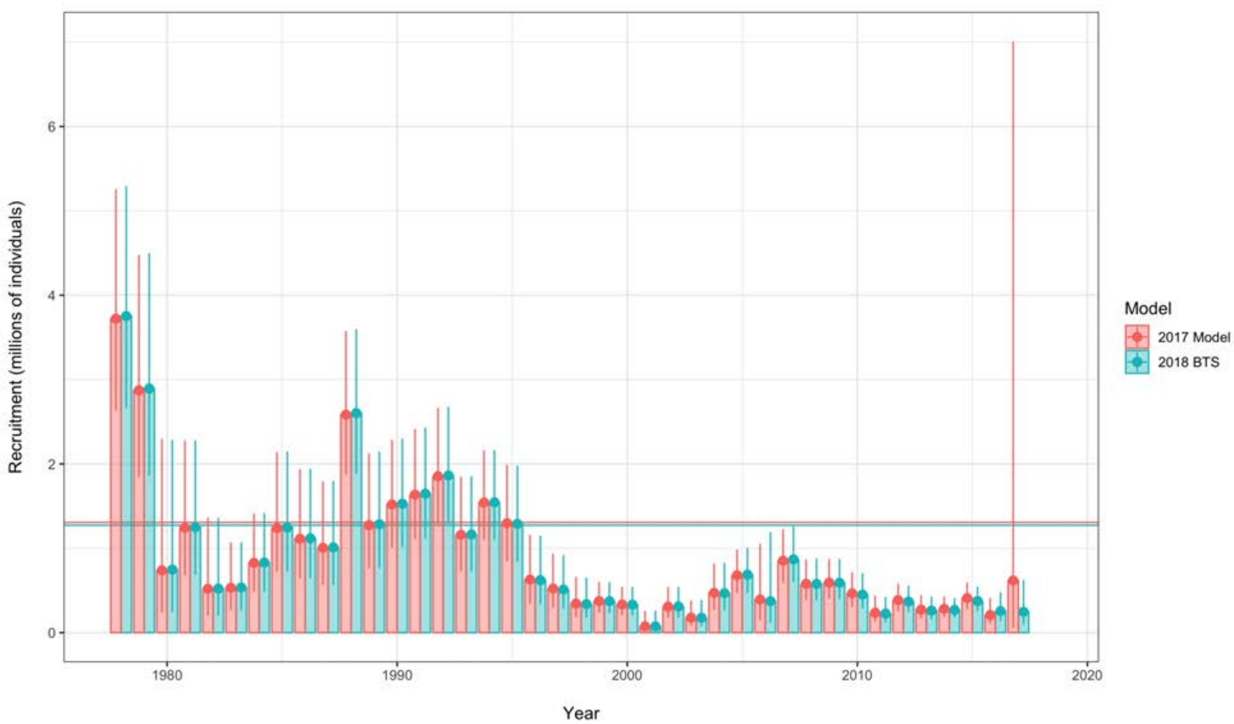

Figure 8: Sensitivity of new data in 2018 on estimated recruitment ; 1978-2018.

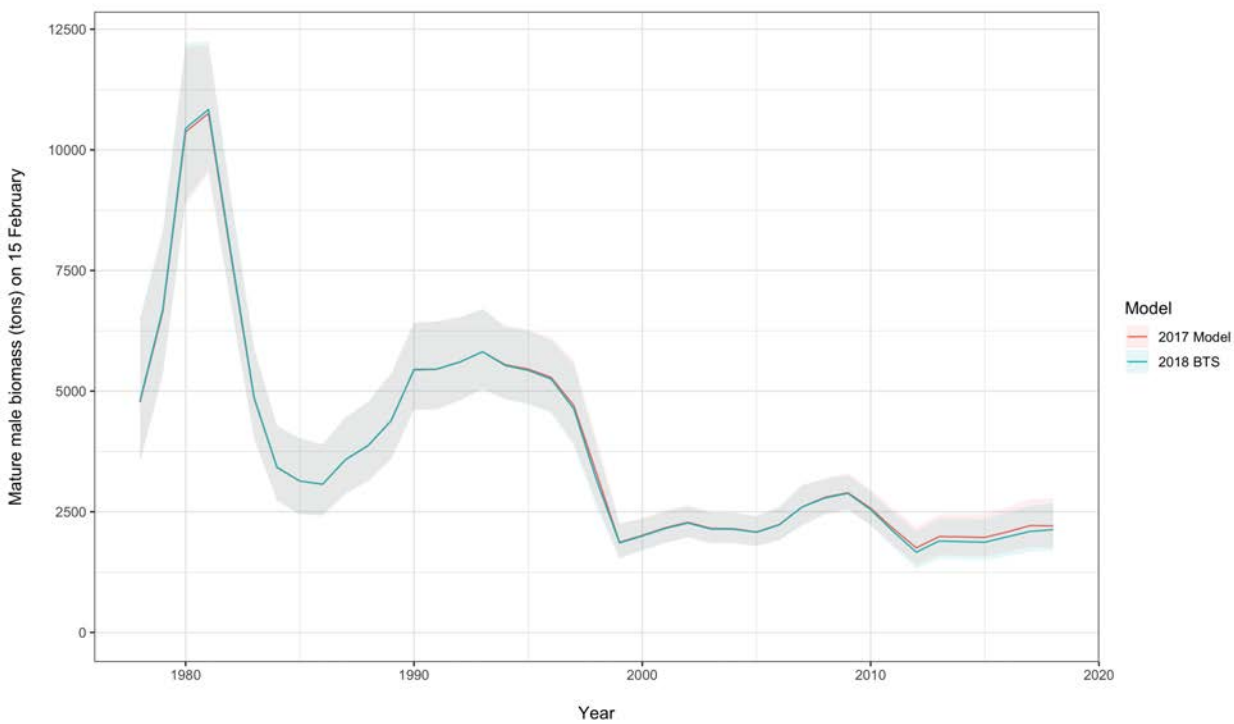

Figure 9: Sensitivity of new data in 2018 on estimated mature male biomass (MMB); 1978-2018.

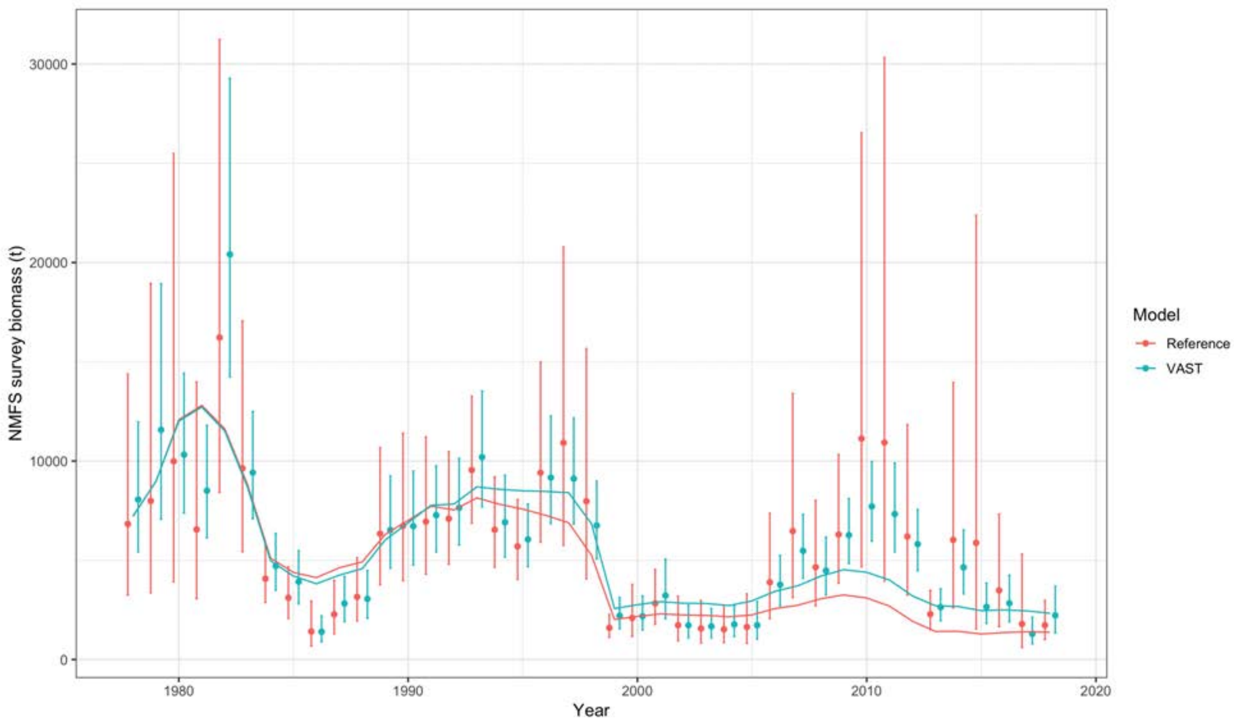

Figure 10: Comparisons of fits to area-swept estimates of total (>90mm) male survey biomass (t) for the standard design-based estimate and for estimates derived from the VAST spatio-temporal model of Thorson and Barnett (2017). Error bars are plus and minus 2 standard deviations.

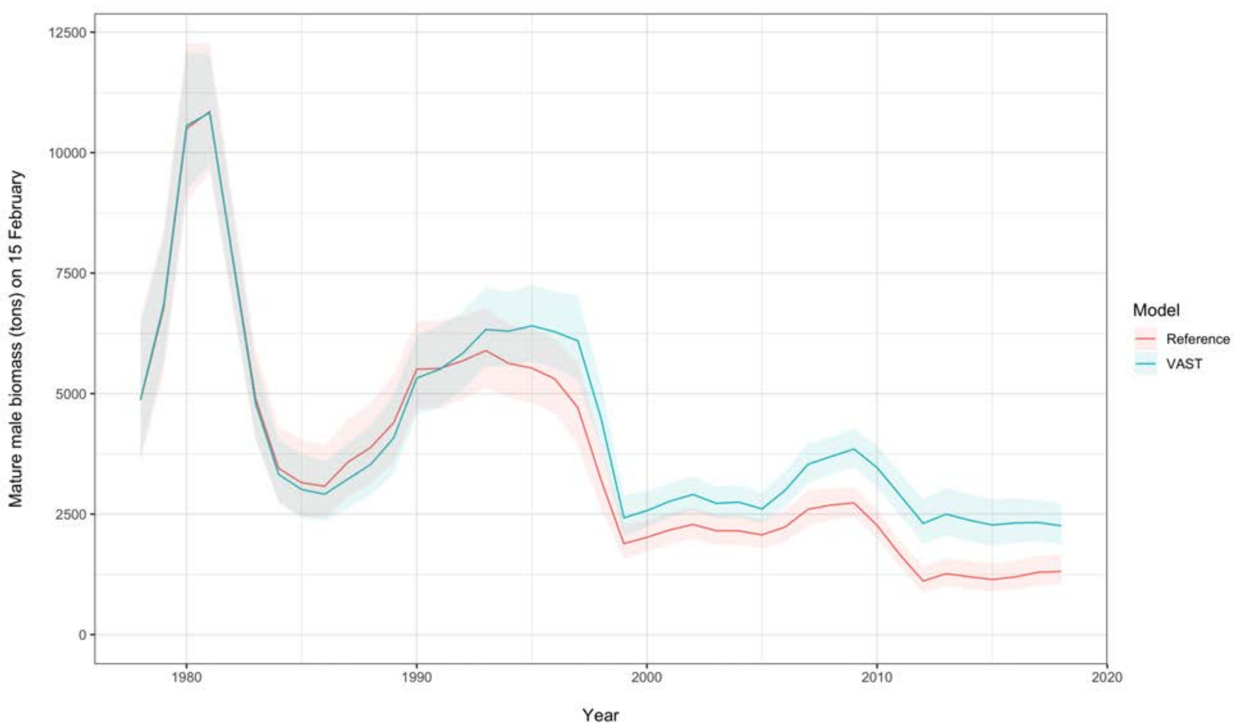

Figure 11: Sensitivity of new data in 2018 on estimated mature male biomass (MMB); 1978-2018 comparing the reference model with that fitted to the VAST BTS estimates.

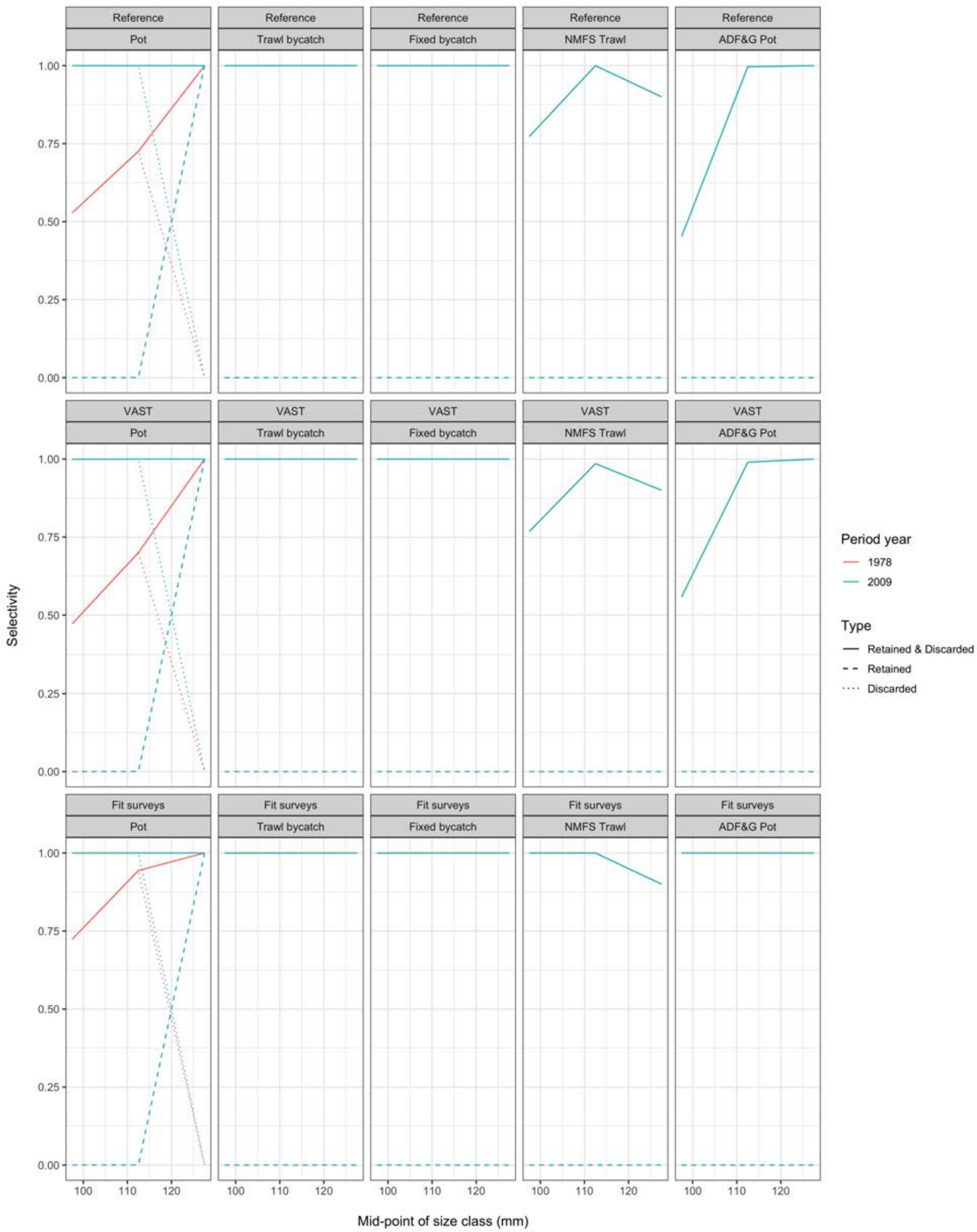

Figure 12: Comparisons of the estimated stage-1 and stage-2 selectivities for the different model scenarios (the stage-3 selectivities are all fixed at 1). Estimated selectivities are shown for the directed pot fishery, the trawl bycatch fishery, the fixed bycatch fishery, the NMFS trawl survey, and the ADF&G pot survey. Two selectivity periods are estimated in the directed pot fishery, from 1978-2008 and 2009-2017.

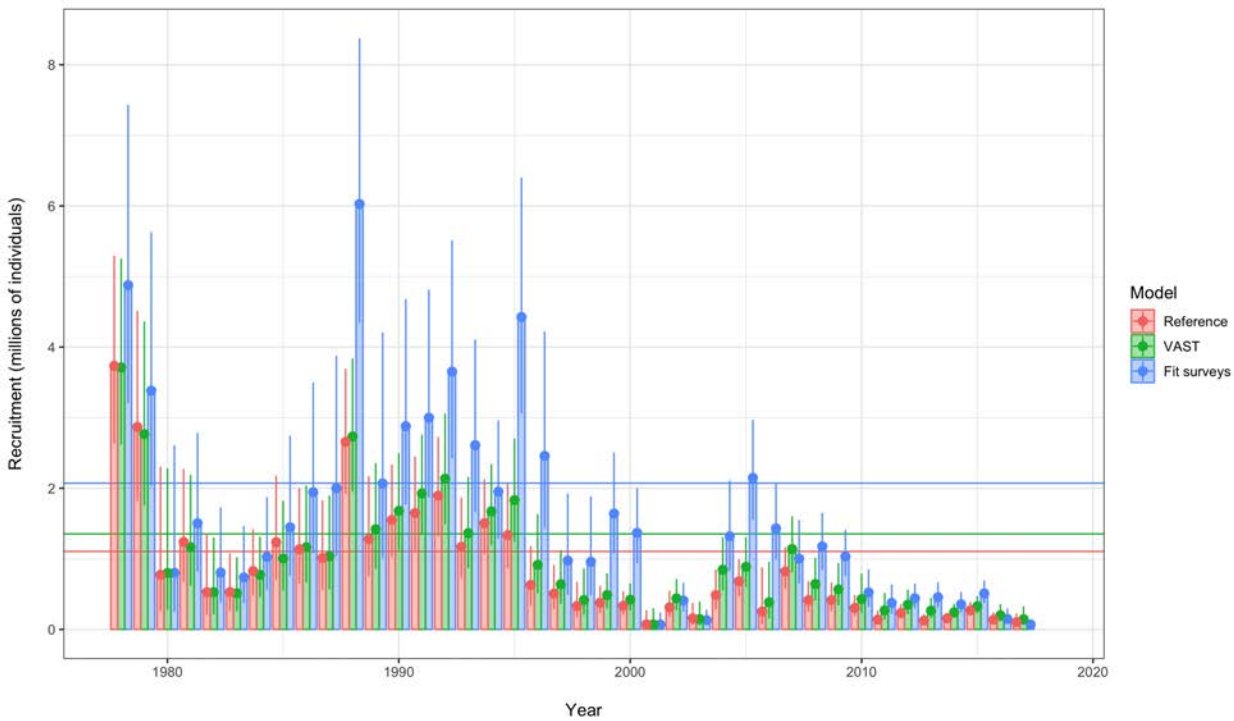

Figure 13: Estimated recruitment 1979-2017 comparing model alternatives. The solid horizontal lines in the background represent the estimate of the average recruitment parameter ($\bar{R}$) in each model scenario.

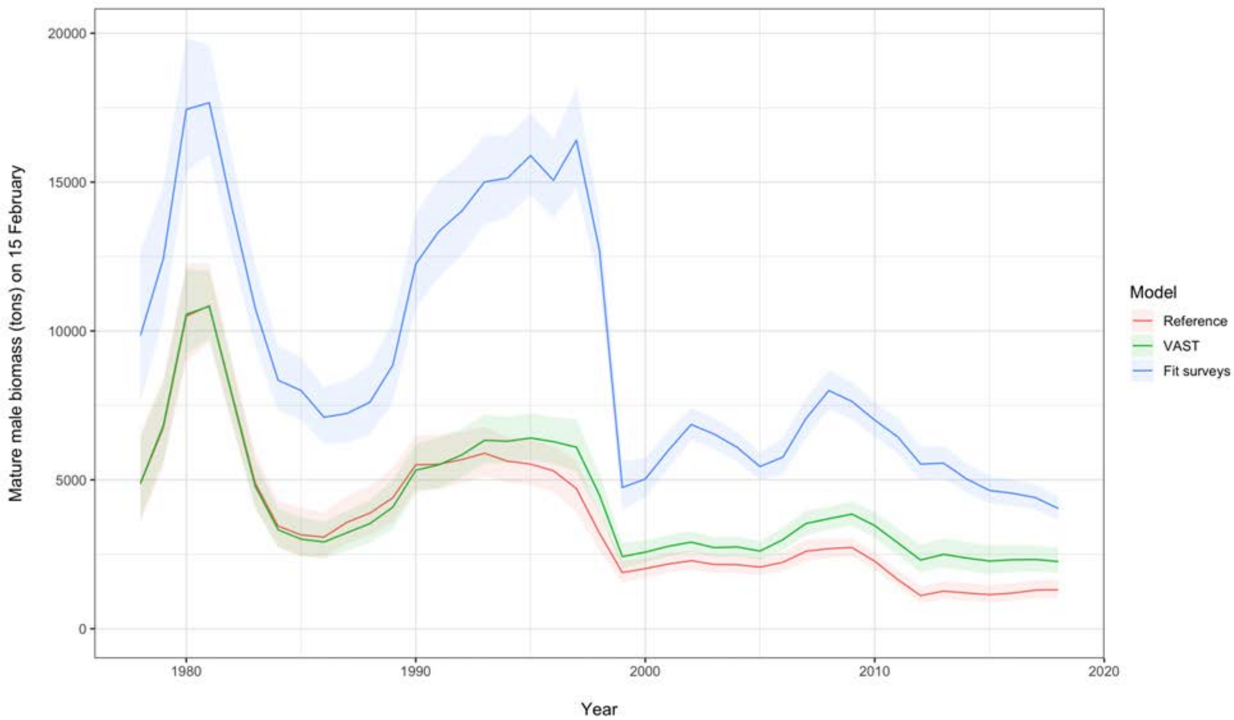

Figure 14: Comparisons of estimated mature male biomass (MMB) time series on 15 February during 1978-2018 for each of the model scenarios.

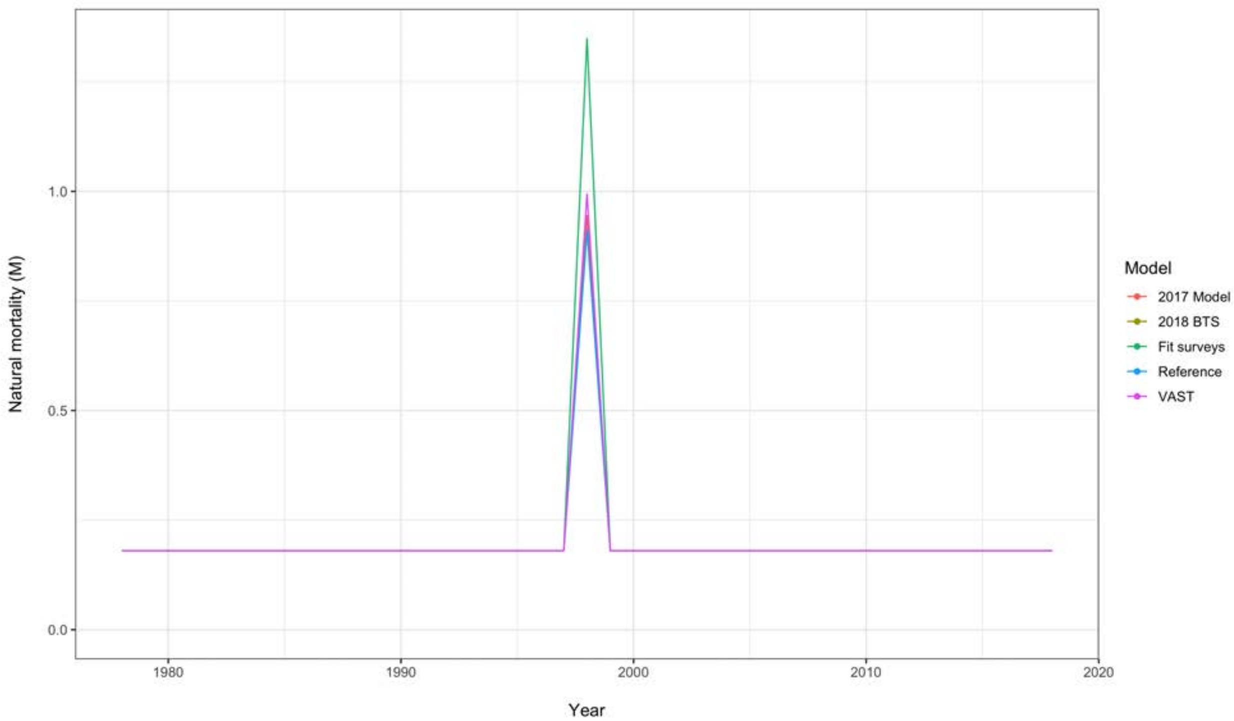

Figure 15: Time-varying natural mortality (M_t). Estimated pulse period occurs in 1998/99 (i.e. M_{1998}).

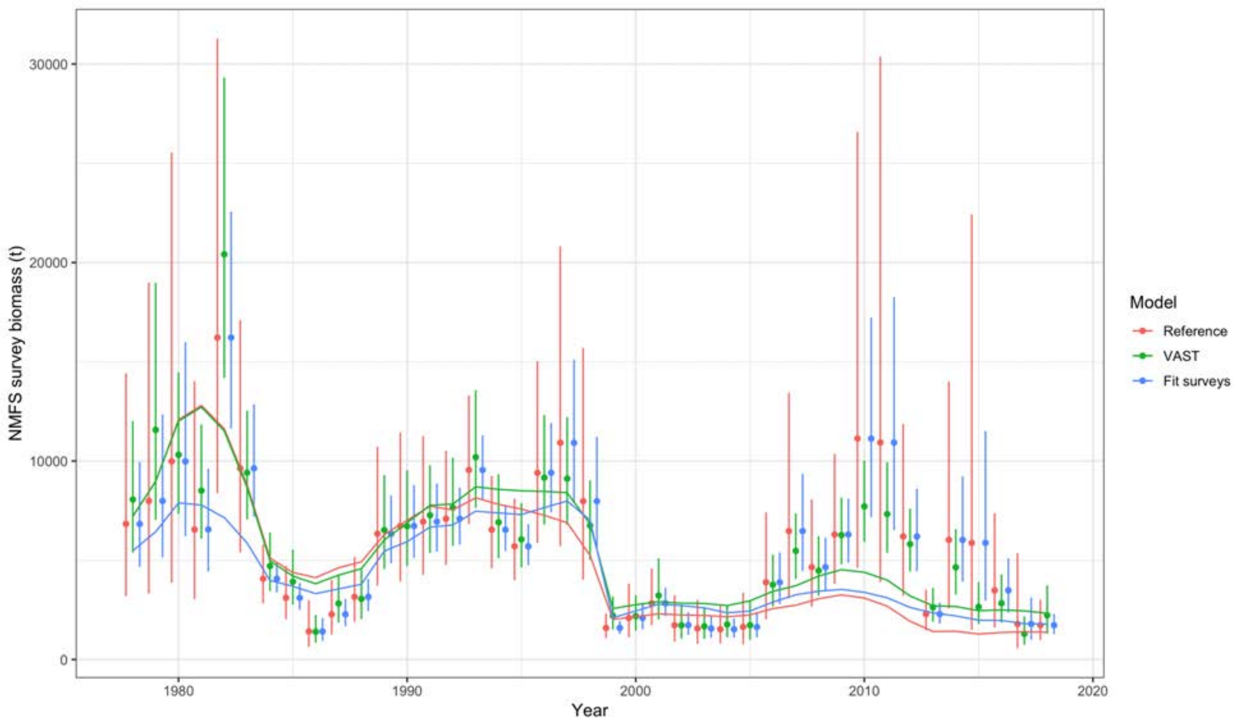

Figure 16: Comparisons of area-swept estimates of total (90+ mm CL) male survey biomass (tons) and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

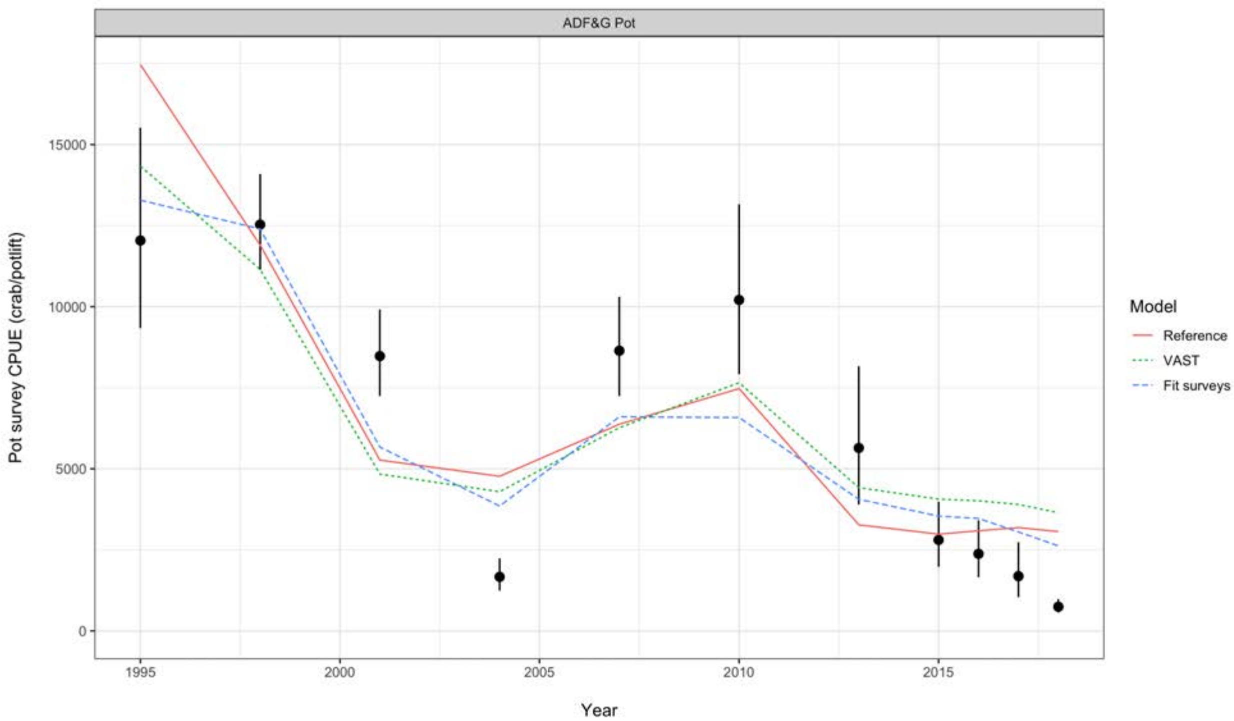

Figure 17: Comparisons of total (90+ mm CL) male pot survey CPUEs and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

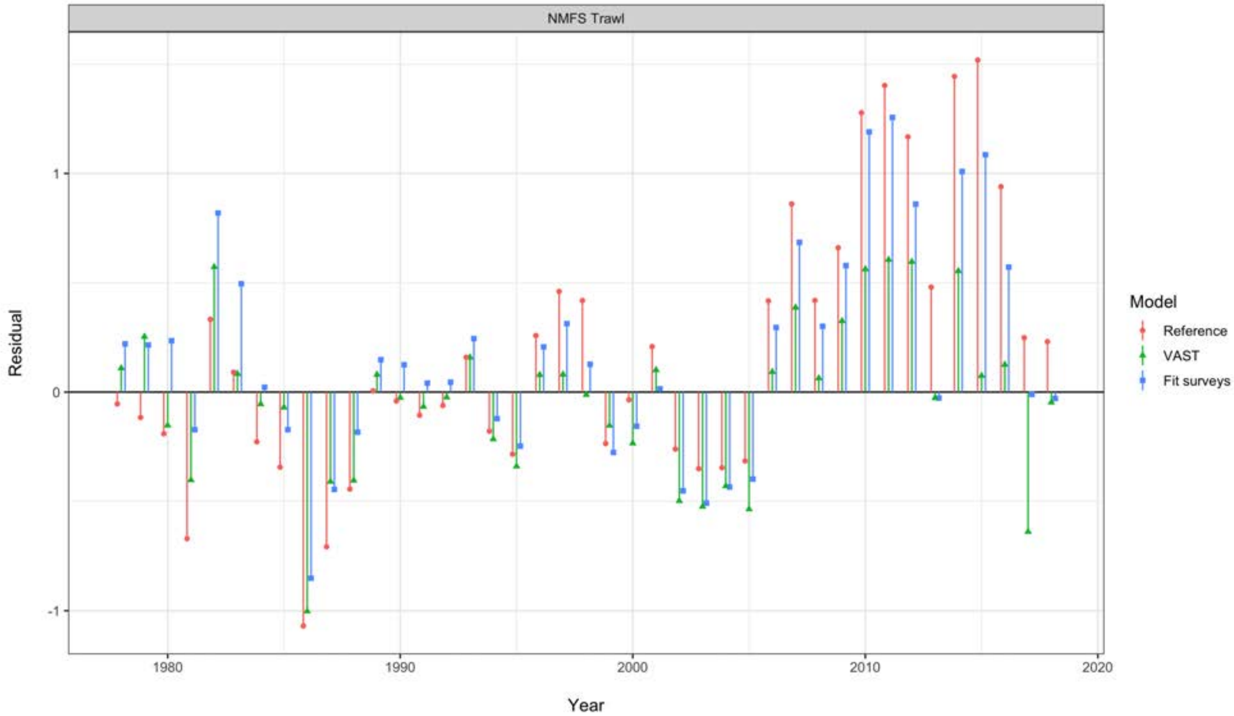

Figure 18: Standardized residuals for area-swept estimates of total male survey biomass for the model scenarios.

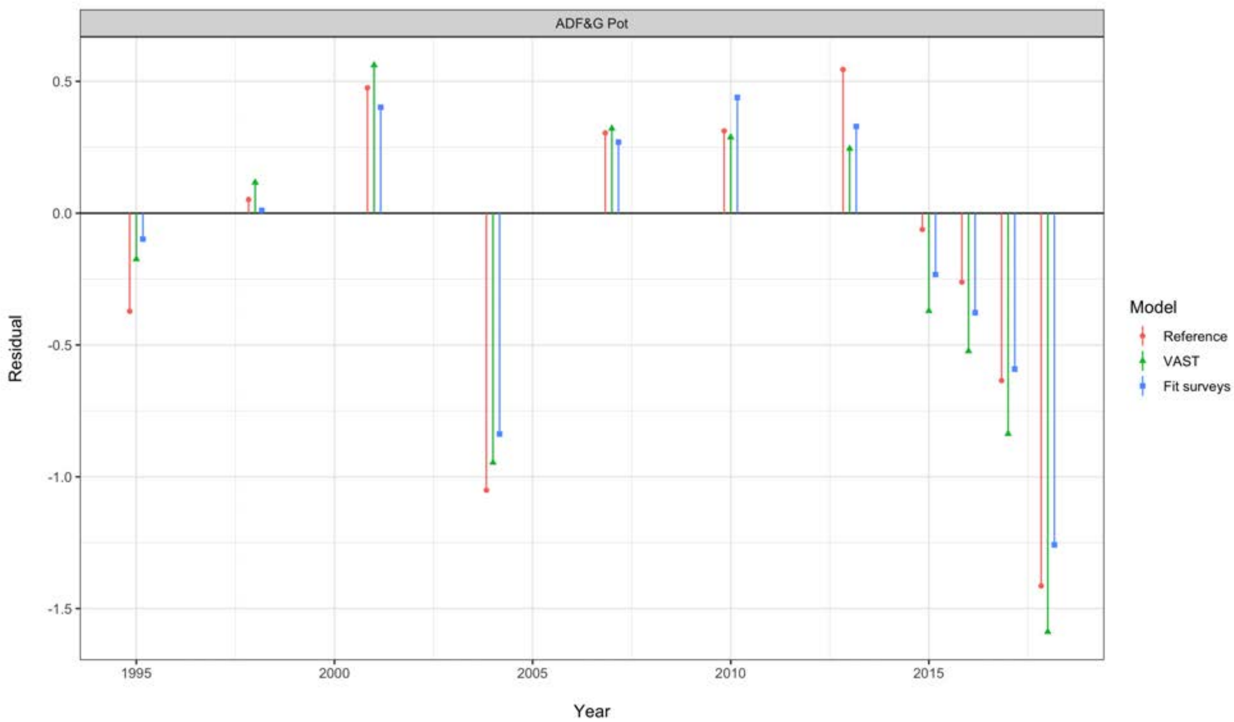

Figure 19: Standardized residuals for total male pot survey CPUEs for each of the Gmacs model scenarios.

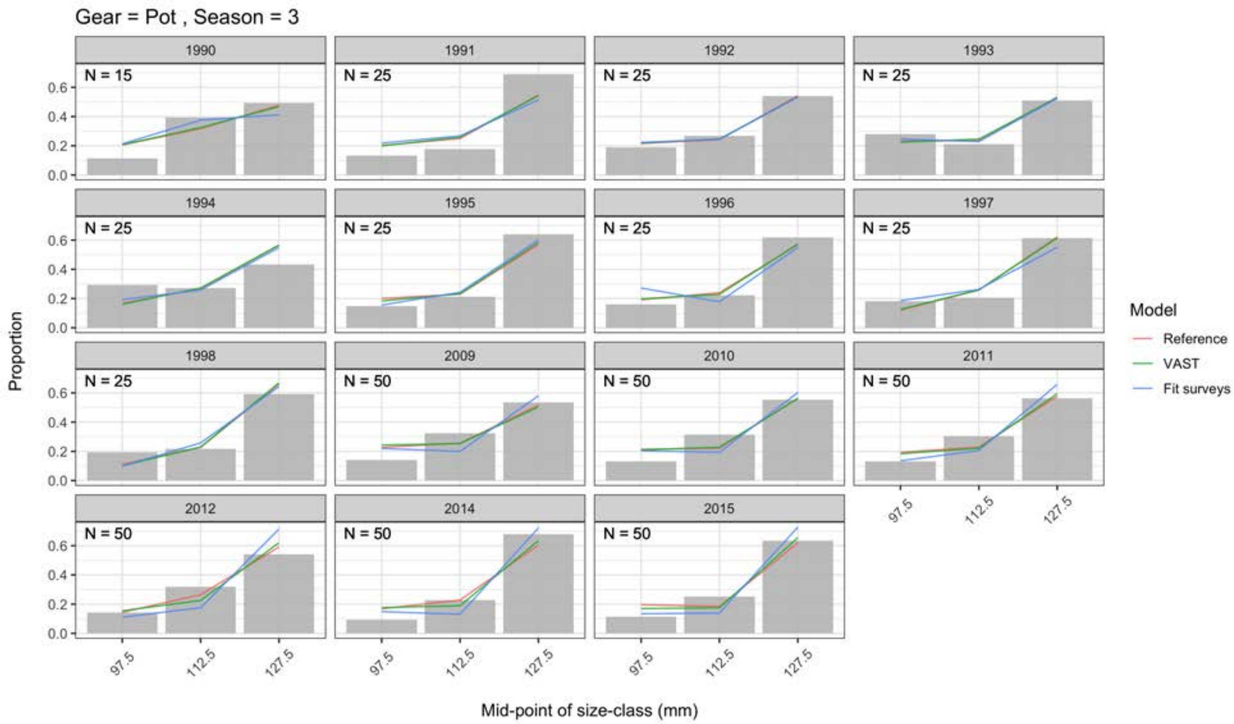

Figure 20: Observed and model estimated size-frequencies of SMBKC by year retained in the directed pot fishery for the model scenarios.

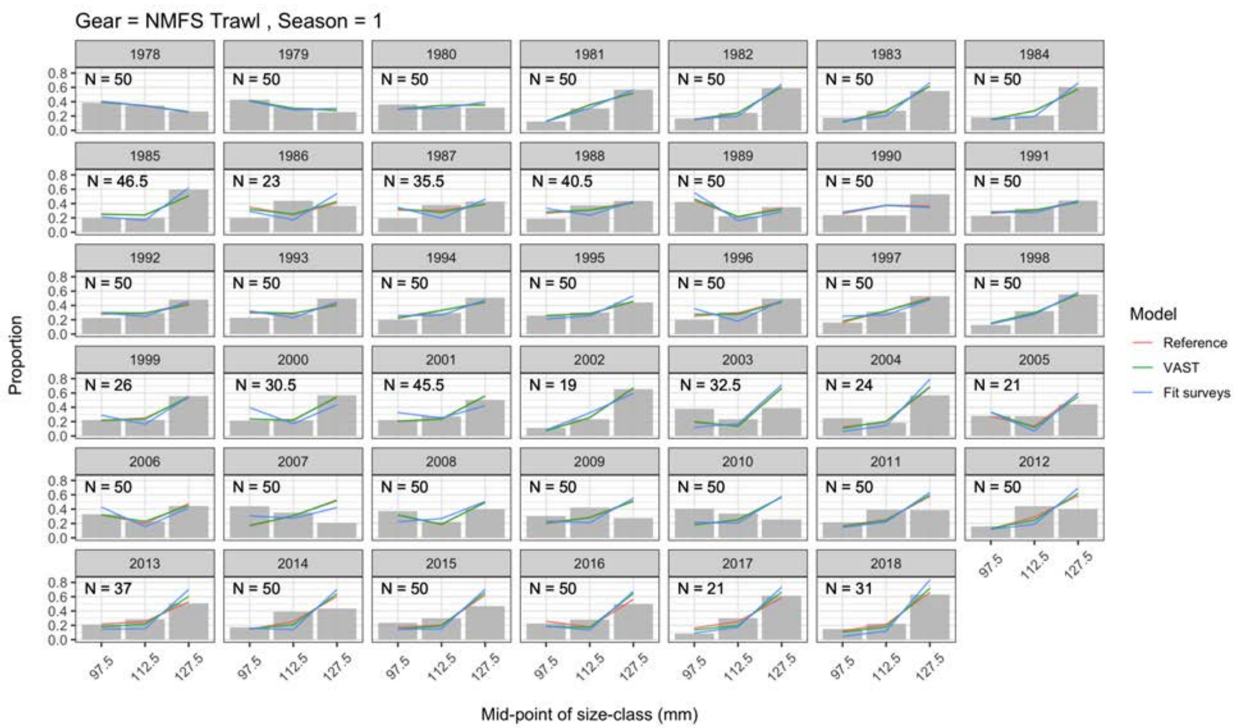

Figure 21: Observed and model estimated size-frequencies of discarded male SMBKC by year in the NMFS trawl survey for the model scenarios.

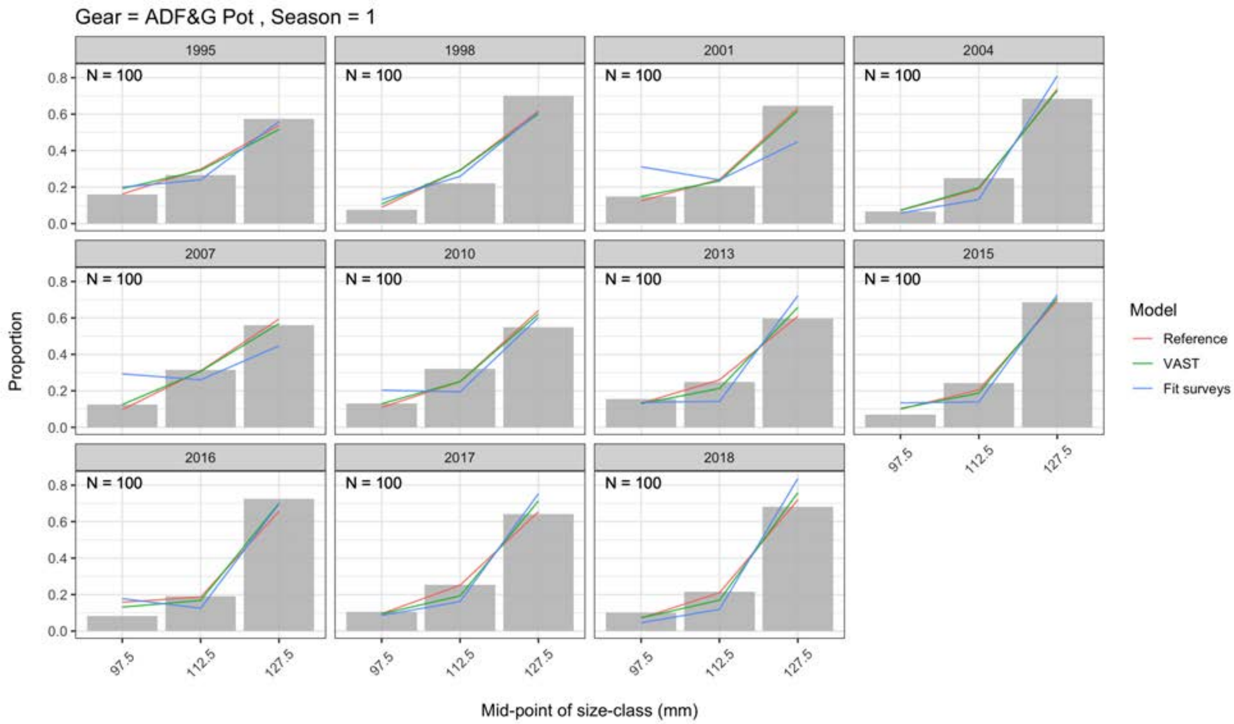

Figure 22: Observed and model estimated size-frequencies of discarded SMBKC by year in the ADF&G pot survey for the model scenarios.

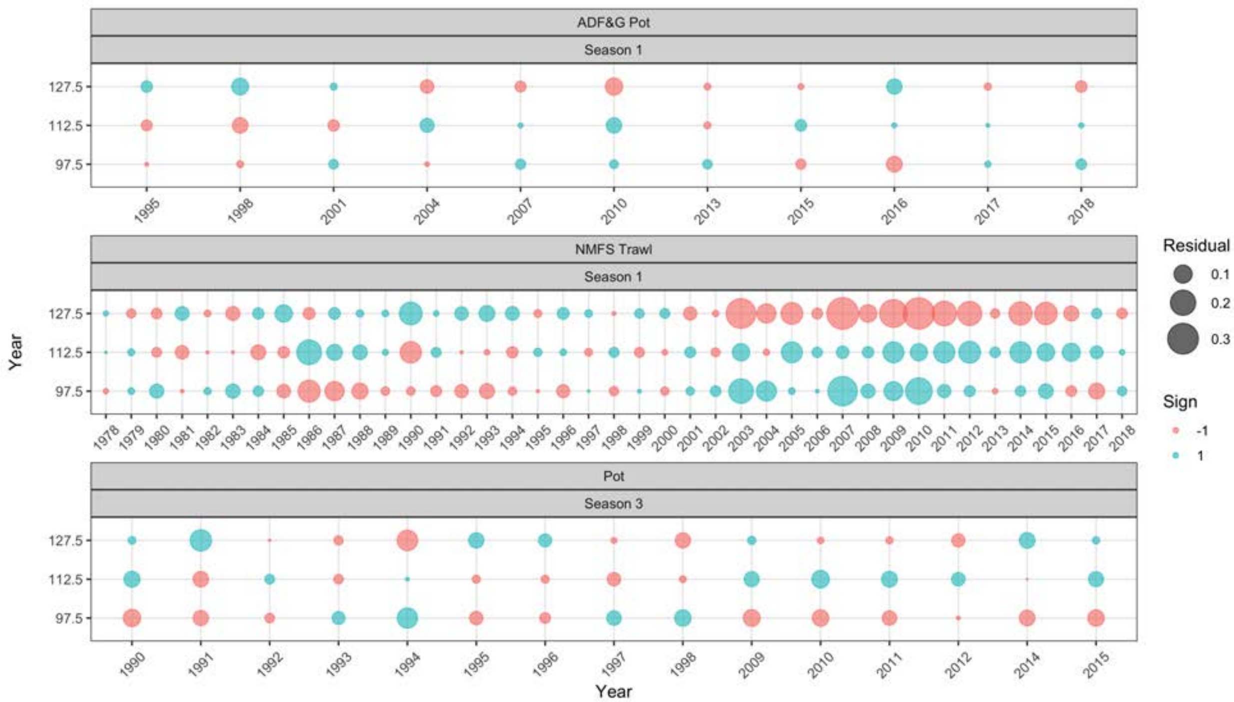

Figure 23: Bubble plots of residuals by stage and year for the directed pot fishery size composition data for SMBKC in the reference model.

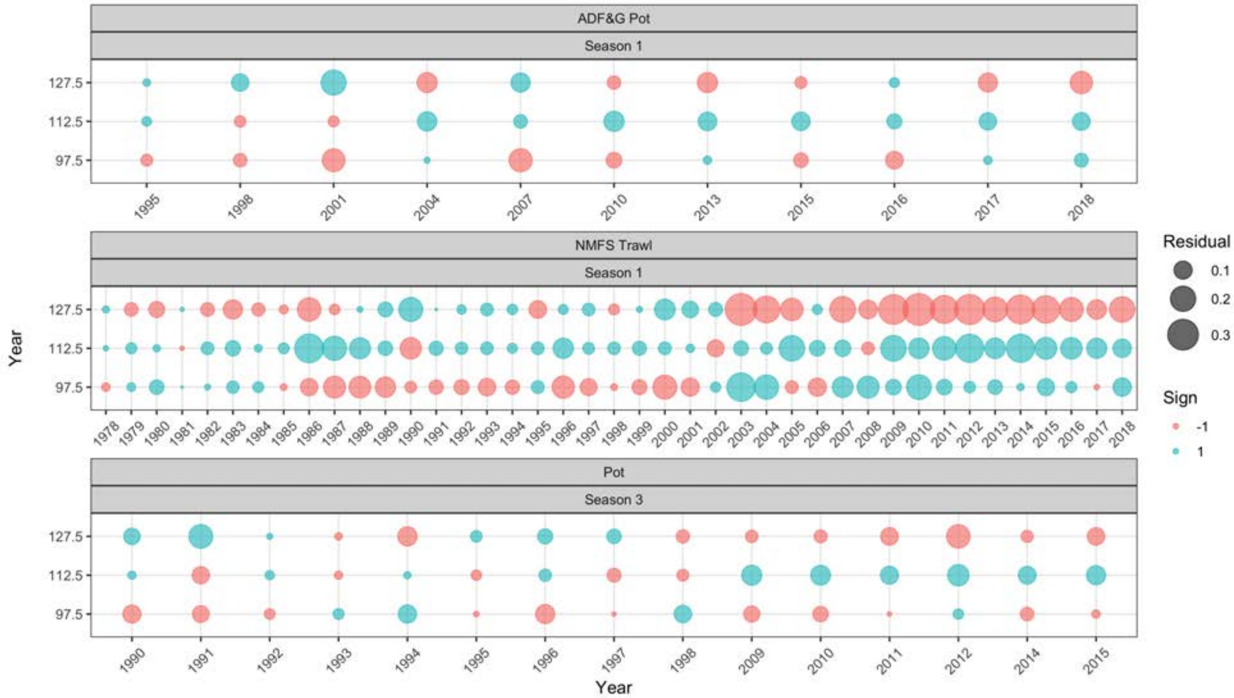

Figure 24: Bubble plots of residuals by stage and year for the ADF&G pot survey size composition data for SMBKC in the **fit surveys** model.

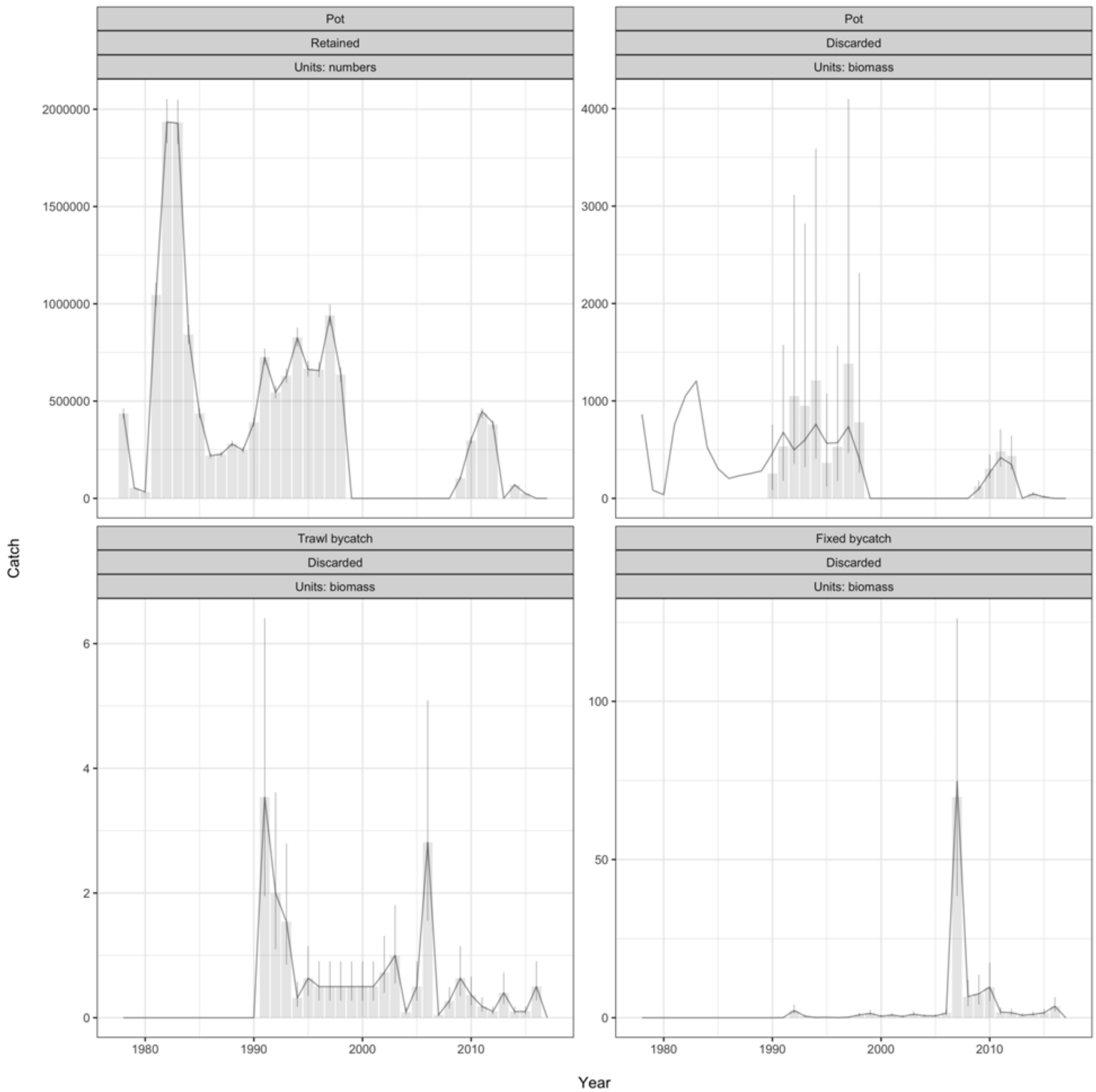

Figure 25: Comparison of observed and model predicted retained catch and bycatches in each of the Gmacs models. Note that difference in units between each of the panels, some panels are expressed in numbers of crab, some as biomass (tons).

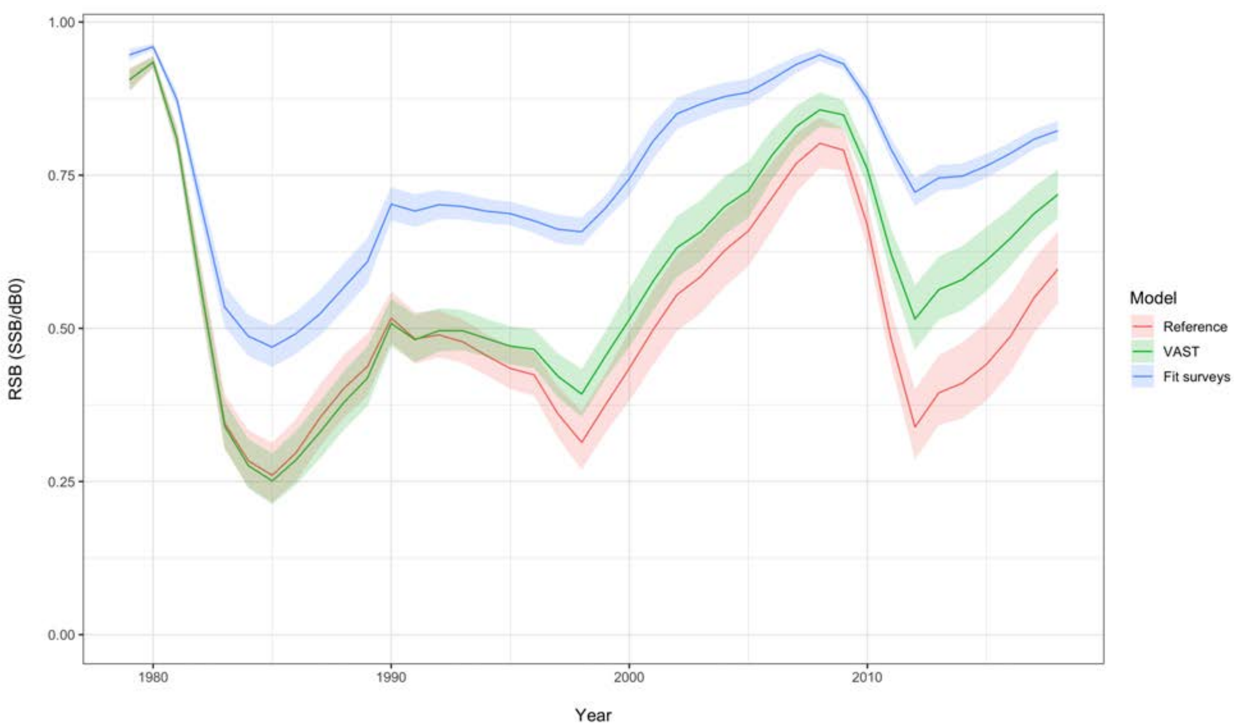

Figure 26: Comparisons of mature male biomass relative to the dynamic B_0 value, (15 February, 1978-2018) for each of the model scenarios.

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 7)
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 22. 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 23.

4. Model Parameters

Table 24 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 25 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.

Appendix B. Data files for the reference model (16.0)

The reference model (16.0) data file

```
#==========================================================================================================
# 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
2019  # Projection year
5    # Number of seasons
5    # Number of distinct data groups (among fishing fleets and surveys)
1    # Number of sexes
1    # Number of shell condition types
1    # Number of maturity types
3    # Number of size-classes in the model
5    # Season recruitment occurs
5    # Season molting and growth occurs
4    # Season to calculate SSB
1    # Season for N output
# size_breaks (a vector giving the break points between size intervals with dimension nclass+1)
90  105  120  135
# weight-at-length input method (1 = allometry i.e. w_l = a*l^b, 2 = vector by sex, 3 = matrix by sex)
3
# weight-at-length allometry w_l = a*l^b
4.03E-07
# b (male, female)
3.141334
# Male weight-at-length
0.000748427    0.001165731    0.001930510
0.000748427    0.001165731    0.001688886
0.000748427    0.001165731    0.001922246
0.000748427    0.001165731    0.001877957
0.000748427    0.001165731    0.001938634
0.000748427    0.001165731    0.002076413
0.000748427    0.001165731    0.001899330
0.000748427    0.001165731    0.002116687
0.000748427    0.001165731    0.001938784
0.000748427    0.001165731    0.001939764
0.000748427    0.001165731    0.001871067
0.000748427    0.001165731    0.001998295
0.000748427    0.001165731    0.001870418
0.000748427    0.001165731    0.001969415
0.000748427    0.001165731    0.001926859
0.000748427    0.001165731    0.002021492
0.000748427    0.001165731    0.001931318
0.000748427    0.001165731    0.002014407
0.000748427    0.001165731    0.001977471
0.000748427    0.001165731    0.002099246
```

```
0.000748427    0.001165731    0.001982478
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001891628
0.000748427    0.001165731    0.001795721
0.000748427    0.001165731    0.001823113
0.000748427    0.001165731    0.001807433
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001894627
0.000748427    0.001165731    0.001850611
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
# Male mature weight-at-length (weight * proportion  mature)
0 0.001165732 0.001945911
# Proportion mature by sex
0 1 1
# Natural mortality per season input type (1 = vector by season, 2 = matrix by season/year)
2
# Proportion of the total natural mortality to be applied each season (each row must add to 1)
0.000   0.070   0.000   0.560   0.370
0.000   0.060   0.000   0.570   0.370
0.000   0.070   0.000   0.560   0.370
0.000   0.050   0.000   0.580   0.370
0.000   0.070   0.000   0.560   0.370
0.000   0.120   0.000   0.510   0.370
0.000   0.100   0.000   0.530   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
#0  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
# Number  of  catch data  frames
4
# Number  of  rows  in  each  data  frame
29  17  27  27
##  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
1979   3     1     1     52966   0.03   1     2     1     0     0
1980   3     1     1     33162   0.03   1     2     1     0     0
1981   3     1     1     1045619 0.03   1     2     1     0     0
1982   3     1     1     1935886 0.03   1     2     1     0     0
1983   3     1     1     1931990 0.03   1     2     1     0     0
1984   3     1     1     841017  0.03   1     2     1     0     0
1985   3     1     1     436021  0.03   1     2     1     0     0
1986   3     1     1     219548  0.03   1     2     1     0     0
1987   3     1     1     227447  0.03   1     2     1     0     0
1988   3     1     1     280401  0.03   1     2     1     0     0
1989   3     1     1     247641  0.03   1     2     1     0     0
1990   3     1     1     391405  0.03   1     2     1     0     0
1991   3     1     1     726519  0.03   1     2     1     0     0
1992   3     1     1     545222  0.03   1     2     1     0     0
1993   3     1     1     630353  0.03   1     2     1     0     0
1994   3     1     1     827015  0.03   1     2     1     0     0
1995   3     1     1     666905  0.03   1     2     1     0     0
1996   3     1     1     660665  0.03   1     2     1     0     0
1997   3     1     1     939822  0.03   1     2     1     0     0
1998   3     1     1     635370  0.03   1     2     1     0     0
2009   3     1     1     103376  0.03   1     2     1     0     0
2010   3     1     1     298669  0.03   1     2     1     0     0
2011   3     1     1     437862  0.03   1     2     1     0     0
2012   3     1     1     379386  0.03   1     2     1     0     0
2014   3     1     1     69109   0.03   1     2     1     0     0
2015   3     1     1     24407   0.03   1     2     1     0     0
2016   3     1     1     10.000  0.03   1     2     1     0     0
2017   3     1     1     10.000  0.03   1     2     1     0     0
# 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
#   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
#   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
##  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
41  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 1730.74  0.281 1
1995  1 5 1 12042.000 0.130 2
1998  1 5 1 12531.000 0.060 2
2001  1 5 1 8477.000  0.080 2
2004  1 5 1 1667.000  0.150 2
2007  1 5 1 8643.000  0.090 2
2010  1 5 1 10209.000 0.130 2
2013  1 5 1 5643.000  0.190 2
2015  1 5 1 2805.000  0.180 2
2016  1 5 1 2378.000  0.186 2
2017  1 5 1 1689.000  0.250 2
2018  1 5 1  745.000  0.140 2
##  Number  of  length  frequency matrices
3
##  Number  of  rows  in  each  matrix
15  41  11
##  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
##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
  ##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)
# nobs_growth
3
# MidPoint Sex Increment CV
 97.5  1  14.1  0.2197
112.5  1  14.1  0.2197
127.5  1  14.1  0.2197
#  97.5  1 13.8 0.2197
#  112.5  1 14.1 0.2197
#  127.5  1 14.4 0.2197
# Use custom transition matrix (0=no, 1=growth matrix, 2=transition matrix, i.e. growth and molting)
0
# The custom growth matrix (if not using just fill with zeros)
# Alternative TM (loosely) based on Otto and Cummiskey (1990)
0.2  0.7  0.1
0.0  0.4  0.6
0.0  0.0  1.0
#  Use  custom  natural  mortality  (0=no,  1=yes,  by  sex  and  year)
0
0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12
0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12
0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12
0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12
## eof
9999
```

The reference model (16.0) control file

```
## ------------------------------------------------------------------------------------ ##
## 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)
  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
## GROWTH PARAM CONTROLS                                                                ##
## 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)
## ------------------------------------------------------------------------------------ ##
# ival        lb        ub         phz  prior     p1      p2        # parameter        #
  14.1      10.0      30.0         -3       0    0.0   999.0        # alpha males or combined
   0.0001    0.0       0.01        -3       0    0.0   999.0        # beta males or combined
   0.45      0.01      1.0         -3       0    0.0   999.0        # gscale males or combined
 121.5      65.0     145.0         -4       0    0.0   999.0        # molt_mu males or combined
   0.060     0.0       1.0         -3       0    0.0   999.0        # molt_cv males or combined

## ------------------------------------------------------------------------------------ ##
## SELECTIVITY CONTROLS                                                                 ##
##     Each gear must have a selectivity and a retention selectivity. If a uniform      ##
##     prior is selected for a parameter then the lb and ub are used (p1 and p2 are     ##
##     ignored)                                                                         ##
## LEGEND                                                                               ##
##     sel type: 0 = parametric, 1 = coefficients, 2 = logistic, 3 = logistic95,        ##
##               4 = double normal (NIY)                                                ##
##     gear index: use +ve for selectivity, -ve for retention                           ##
##     sex dep: 0 for sex-independent, 1 for sex-dependent                              ##
## ------------------------------------------------------------------------------------ ##
## ivector for number of year periods or nodes                                          ##
## POT       TBycatch FBycatch  NMFS_S   ADFG_pot
## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
   2         1        1         1        1         # Selectivity periods
   0         0        0         0        0         # sex specific selectivity
   0         3        3         0        0         # male selectivity type
## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
   1         1        1         1        1         # Retention periods
   0         0        0         0        0         # sex specific retention
   3         2        2         2        2         # male retention type
   1         0        0         0        0         # male retention flag (0 -> no, 1 -> yes)
## gear  par   sel                                                phz    start  end        ##
## index index par sex  ival  lb    ub     prior p1     p2     mirror period period     ##
# Gear-1
   1     1     1   0    0.4   0.001 1.0    0       0      1     3      1978   2008
   1     2     2   0    0.7   0.001 1.0    0       0      1     3      1978   2008
   1     3     3   0    1.0   0.001 2.0    0       0      1    -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    8    1  0   0.7    0.001 1.0   0      0      1    4     1978   2018
  4    9    2  0   0.7    0.001 1.0   0      0      1    4     1978   2018
  4   10    3  0   0.9    0.001 1.0   0      0      1   -5     1978   2018
# Gear-5
  5   11    1  0   0.4    0.001 1.0   0      0      1    4     1978   2018
  5   12    2  0   0.7    0.001 1.0   0      0      1    4     1978   2018
  5   13    3  0   1.0    0.001 2.0   0      0      1   -2     1978   2018
## Retained
# Gear-1
 -1   14    1  0  120   100   200   0     1    900   -1     1978   2018
 -1   15    2  0  123   110   200   0     1    900   -1     1978   2018
# Gear-2
 -2   16    1  0  595     1   700   0     1    900   -3     1978   2018
 -2   17    2  0   10     1   700   0     1    900   -3     1978   2018
# Gear-3
 -3   18    1  0  590     1   700   0     1    900   -3     1978   2018
 -3   19    2  0   10     1   700   0     1    900   -3     1978   2018
# Gear-4
 -4   20    1  0  580     1   700   0     1    900   -3     1978   2018
 -4   21    2  0   20     1   700   0     1    900   -3     1978   2018
# Gear-5
 -5   22    1  0  580     1   700   0     1    900   -3     1978   2018
 -5   23    2  0   20     1   700   0     1    900   -3     1978   2018

## ------------------------------------------------------------------------------------ ##
## PRIORS FOR CATCHABILITY
##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
##     and p2 are ignored). ival must be > 0                                            ##
## LEGEND                                                                               ##
##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma               ##
## ------------------------------------------------------------------------------------ ##
##  LAMBDA: Arbitrary relative weights for each series, 0 = do not fit.
## SURVEYS/INDICES ONLY
## ival    lb      ub    phz   prior   p1      p2    Analytic?   LAMBDA
   1.0     0.5     1.2   -4    0       0       9.0   0           1       # NMFS trawl
 0.003     0       5      3    0       0       9.0   0           1       # ADF&G pot
## ------------------------------------------------------------------------------------ ##

## ------------------------------------------------------------------------------------ ##
## ADDITIONAL CV FOR SURVEYS/INDICES                                                    ##
##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
##     and p2 are ignored). ival must be > 0                                            ##
## LEGEND                                                                               ##
##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma               ##
## ------------------------------------------------------------------------------------ ##
## ival        lb        ub        phz   prior     p1      p2
   0.0000001      0.00000001   10.0      -4    4         1.0     100   # NMFS
   0.0000001      0.00000001   10.0      -4    4         1.0     100   # ADF&G
## ------------------------------------------------------------------------------------ ##

## ------------------------------------------------------------------------------------ ##
## PENALTIES FOR AVERAGE FISHING MORTALITY RATE FOR EACH GEAR
## ------------------------------------------------------------------------------------ ##
## Mean_F  STD_PHZ1  STD_PHZ2     PHZ
   0.2       0.05     50.0       1   # Pot
   0.0001     0.05     50.0       1   # Trawl
   0.0001     0.05     50.0       1   # Fixed
   0.00      2.00     20.00     -1   # NMFS
   0.00      2.00     20.00     -1   # ADF&G
## ------------------------------------------------------------------------------------ ##

## ----------------------------------------------------------------------------------- ##
## OPTIONS FOR SIZE COMPOSTION DATA (COLUMN FOR EACH MATRIX)
## ------------------------------------------------------------------------------------ ##
## LIKELIHOOD OPTIONS
##   -1) Multinomial with estimated/fixed sample size
##   -2) Robust approximation to multinomial
```

```
##   -3) logistic normal (NIY)
##   -4) multivariate-t (NIY)
##   -5) Dirichlet
## AUTOTAIL COMPRESSION
##   pmin is the cumulative proportion used in tail compression.
## ------------------------------------------------------------------------------------ ##
#  1   1   1  # Type of likelihood
  2   2   2  # Type of likelihood
#  5   5   5   # Type of likelihood
  0   0   0   # Auto tail compression (pmin)
  1   1   1   # Initial value for effective sample size multiplier
 -4  -4  -4   # Phz for estimating effective sample size (if appl.)
  1   2   3   # Composition aggregator
  1   1   1   # LAMBDA
## ------------------------------------------------------------------------------------ ##

## ------------------------------------------------------------------------------------ ##
## TIME VARYING NATURAL MORTALIIY RATES                                                 ##
## ------------------------------------------------------------------------------------ ##
## TYPE:
##      0 = constant natural mortality
##      1 = Random walk (deviates constrained by variance in M)
##      2 = Cubic Spline (deviates constrained by nodes & node-placement)
##      3 = Blocked changes (deviates constrained by variance at specific knots)
##      4 = Time blocks
## ------------------------------------------------------------------------------------ ##
## Sex-specific? (0=no, 1=yes)
0
## Type
3
## Phase of estimation
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
0 # Females (ignored if single sex...)
## Year position of the knots (vector must be equal to the number of nodes)
1998 1999
# 1976 1980 1985 1994 # Females (ignored if single sex...)
## ------------------------------------------------------------------------------------ ##

## ------------------------------------------------------------------------------------ ##
## OTHER CONTROLS
## ------------------------------------------------------------------------------------ ##
  3       # Estimated rec_dev phase
  3       # Estimated rec_ini phase
  0       # VERBOSE FLAG (0 = off, 1 = on, 2 = objective func)
  2       # Initial conditions (0 = Unfished, 1 = Steady-state fished, 2 = Free parameters)
  1978    # First year for average recruitment for Bspr calculation
  2018    # Last year for average recruitment for Bspr calculation
  0.35    # Target SPR ratio for Bmsy proxy
  1       # Gear index for SPR calculations (i.e. directed fishery)
  1       # Lambda (proportion of mature male biomass for SPR reference points)
  1       # Use empirical molt increment data (0 = FALSE, 1 = TRUE)
  0       # Stock-Recruit-Relationship (0 = None, 1 = Beverton-Holt)
## EOF
9999
```

Appendix C. Spatio-temporal analysis of NMFS bottom-trawl survey SMBKC data

Overview

This application of VAST was configured to model a subset of NMFS/AFSC bottom trawl survey data. Specifically, the station-specific CPUE (kg per hectare) for male crab great than or equal to 90mm CW were compiled from 1978-2018. Further details can be found at the GitHub repo mainpage, wiki, and glossary. The R help files, e.g., `?Data_Fn` for explanation of data inputs, or `?Param_Fn` for explanation of parameters. VAST has involved many publications for developing individual features (see references section below). What follows is intended as a step by step documentation of applying the model to these data.

Model configuration

The following loads in the main libraries.

Spatial settings

The following settings define the spatial resolution for the model, and whether to use a grid or mesh approximation as well as specific model settings.

Data preparation

Data-frame for catch-rate data

The following extracts a subset of the data file downloaded from AKFIN.

Build and run model

To estimate parameters, first create a list of data-inputs used for parameter estimation. `Data_Fn` has some simple checks for buggy inputs, but also please read the help file `?Data_Fn`.

Diagnostic plots

Convergence

Diagnostics generated during parameter estimation can confirm that parameter estimates are away from upper or lower bounds and that the final gradient for each fixed-effect is close to zero. For explanation of parameters, please see references (and specifically `Data_Fn` in R).

Encounter-probability component

One can check to ensure that observed encounter frequencies for either low or high probability samples are within the 95% predictive interval for predicted encounter probability (Figure . Diagnostics for positive-catch-rate component was evaluated using a standard Q-Q plot. Qualitatively, the fits to SMBKC are reasonable but could stand some more evaluation for improvement as only one configuration was tested here (Figures ?? and .

Pearson residuals

Spatially the residual pattern can be evaluated over time. Results for SMBKC shows that consistent positive or negative residuals accross or within years is limited for the encounter probability component of the model and for the positive catch rate component (Figures 30 and 31, respectively). Some VAST plots for visualizing results can be seen by examining the direction of faster or slower spatial decorrelation (termed "geometric anisotropy"; Figure 32).

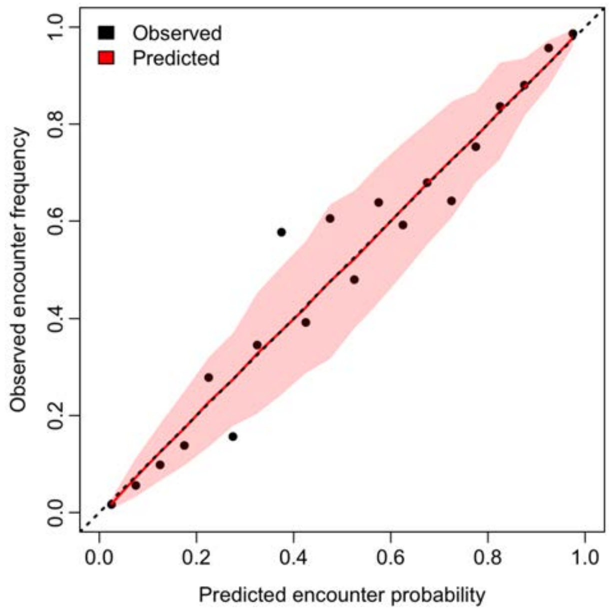

Figure 27: Observed encounter rates and predicted probabilities for SMBKC.

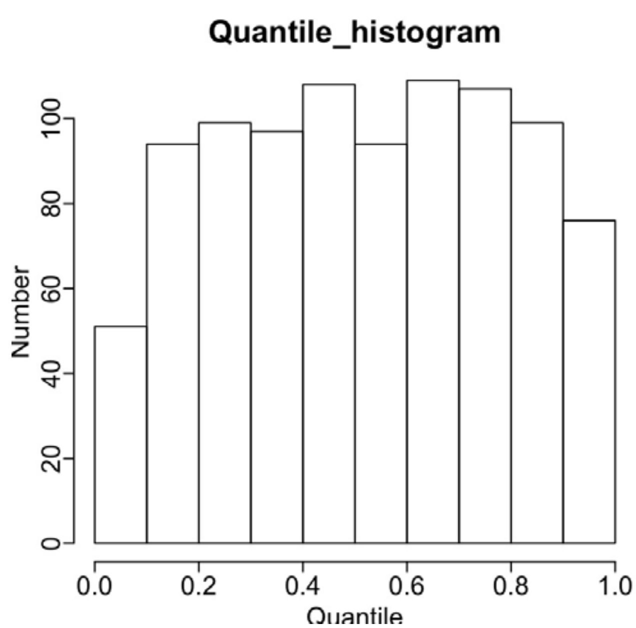

Figure 28: Plot indicating distribution of quantiles for "positive catch rate" component.

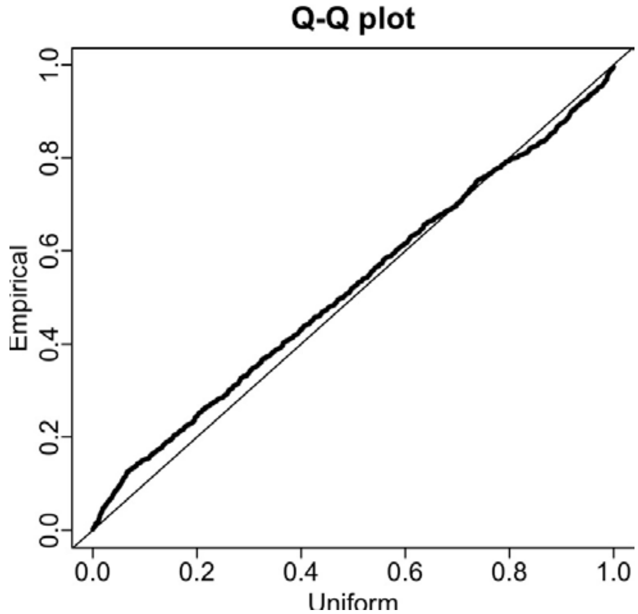

Figure 29: Quantile-quantile plot of residuals for "positive catch rate" component.

Densities and biomass estimates

Relative densities over time suggests that the biomass of males >89mm are generally concentrated within the central part of the survey region (Figure 33). For the application to SMBKC, the biomass index was scaled to have the same mean as that from the design-based estimate (5,764 t) of abundance (Table 27).

Appendix C references

Please cite 2016 (ICES J. Mar. Sci. J. Cons.) if using the package; 2016 (Glob. Ecol. Biogeogr) if exploring factor decomposition of spatio-temporal variation; 2015 (ICES J. Mar. Sci. J. Cons.) if calculating an index of abundance; 2016 (Methods Ecol. Evol.) if using the center-of-gravity metric; 2016 (Fish. Res.) if using the bias-correction feature; 2016 (Proc R Soc B) if using the effective-area-occupied metric.

Thorson, J.T., and Barnett, L.A.K. In press. Comparing estimates of abundance trends and distribution shifts using single- and multispecies models of fishes and biogenic habitat. ICES J. Mar. Sci. J. Cons

Thorson, J.T., Ianelli, J.N., Larsen, E., Ries, L., Scheuerell, M.D., Szuwalski, C., and Zipkin, E. 2016. Joint dynamic species distribution models: a tool for community ordination and spatiotemporal monitoring. Glob. Ecol. Biogeogr. 25(9): 1144-1158. doi:10.1111/geb.12464. url: http://onlinelibrary.wiley.com/doi/10.1111/geb.12464/abstract

Thorson, J.T., Shelton, A.O., Ward, E.J., Skaug, H.J., 2015. Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. ICES J. Mar. Sci. J. Cons. 72(5), 1297-1310. doi:10.1093/icesjms/fsu243. URL: http://icesjms.oxfordjournals.org/content/72/5/1297

Thorson, J.T., and Kristensen, K. 2016. Implementing a generic method for bias correction in statistical models using random effects, with spatial and population dynamics examples. Fish. Res. 175: 66-74. doi:10.1016/j.fishres.2015.11.016. url: http://www.sciencedirect.com/science/article/pii/S0165783615301399

Thorson, J.T., Pinsky, M.L., Ward, E.J., 2016. Model-based inference for estimating shifts in species distribution, area occupied, and center of gravity. Methods Ecol. Evol. 7(8), 990-1008. doi:10.1111/2041-210X.12567. URL: http://onlinelibrary.wiley.com/doi/10.1111/2041-210X.12567/full

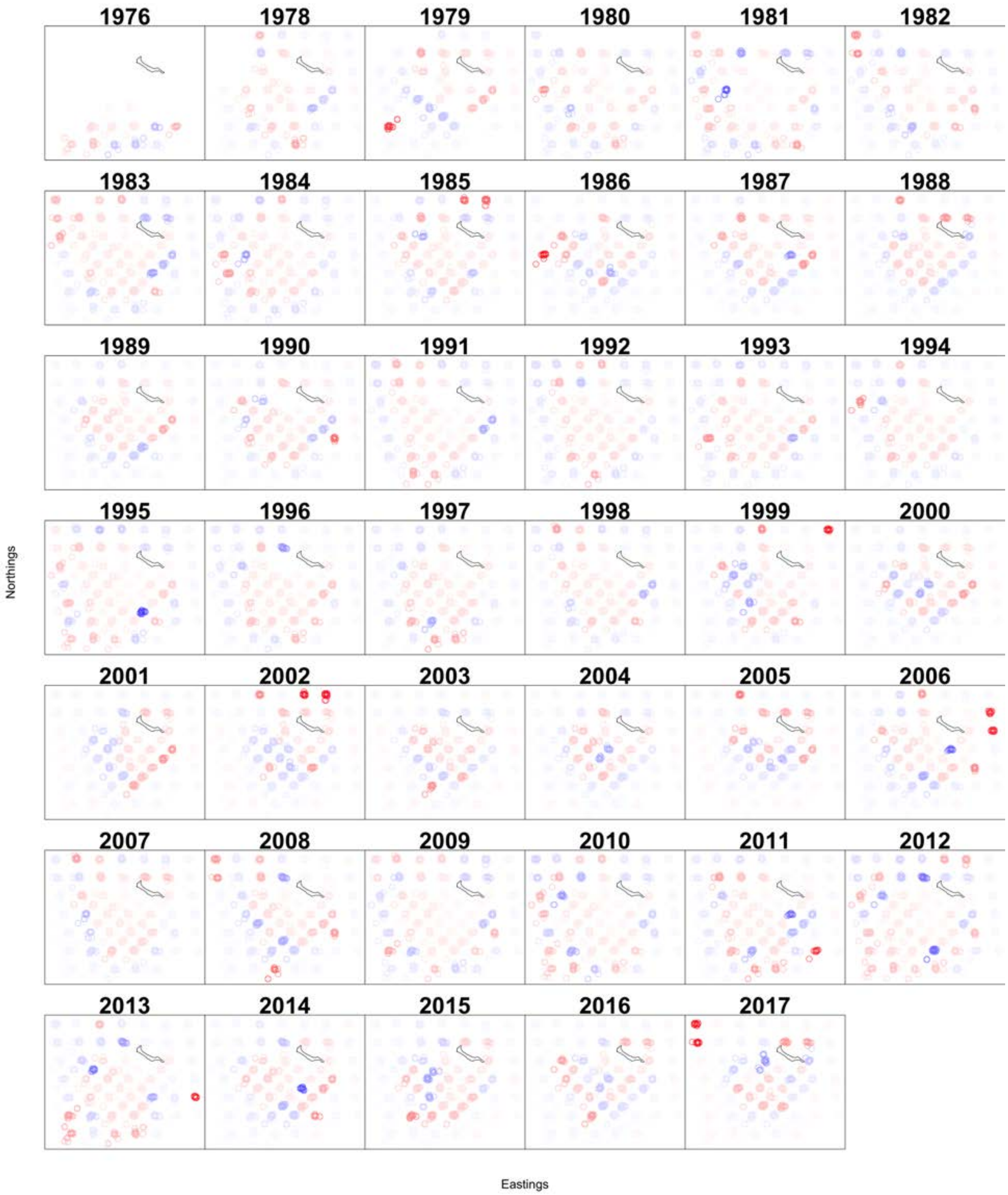

Figure 30: Pearson residuals of the encounter probability component at SMBKC stations, 1976-2018.

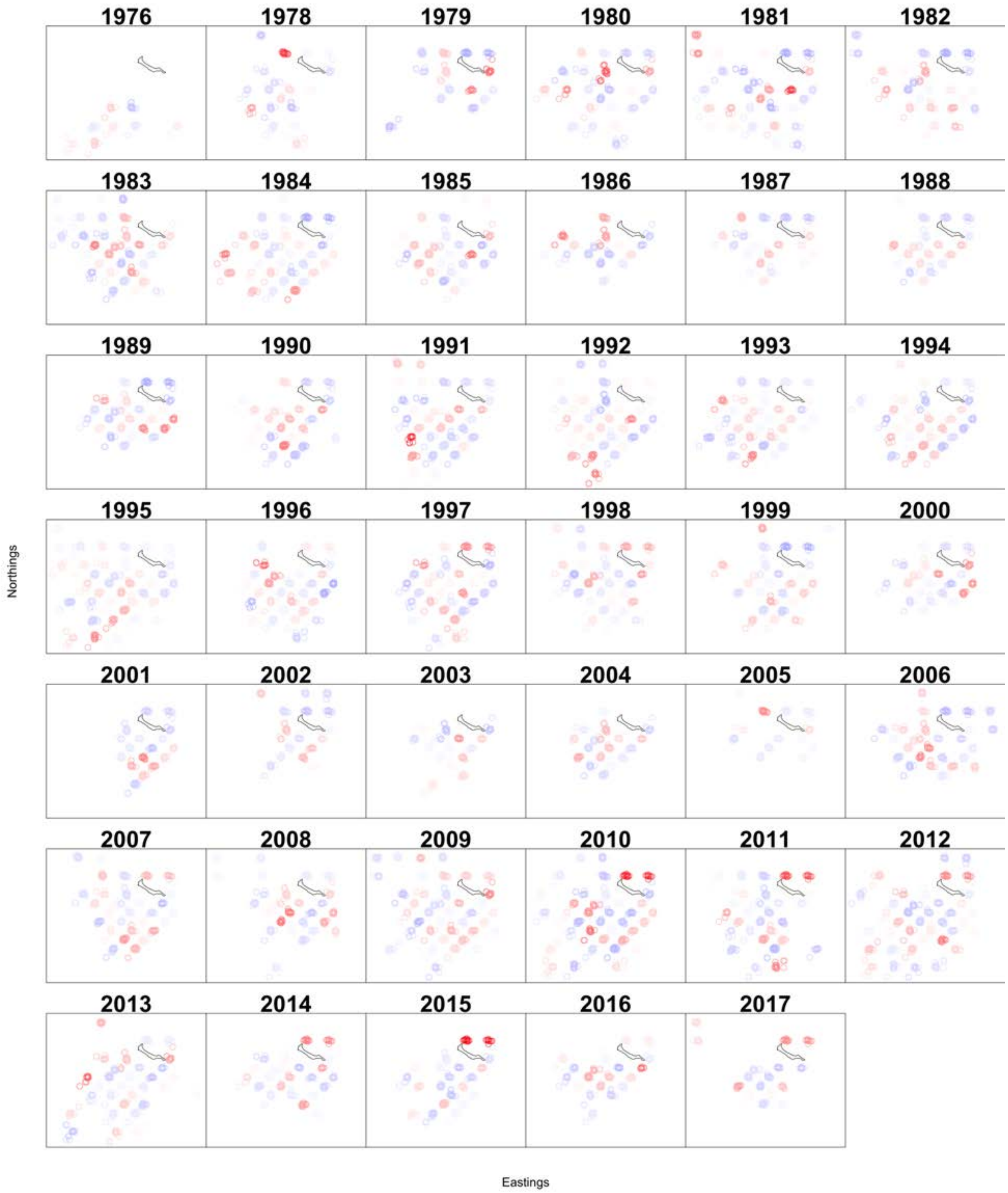

Figure 31: Pearson residuals of the positive catch rate component for SMBKC stations, 1976-2018.

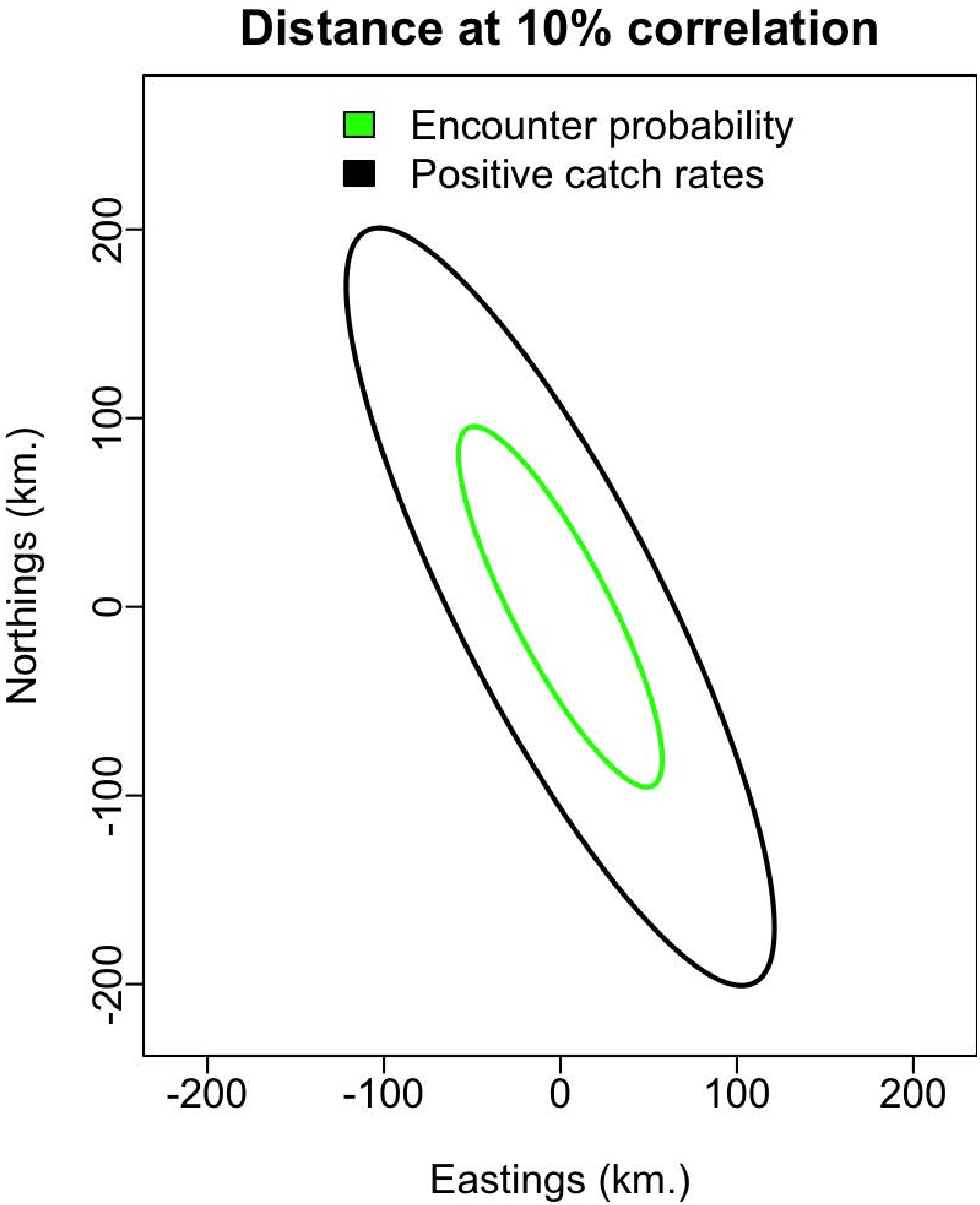

Figure 32: Directional decorrelation for SMBKC stations, 1978-2018.

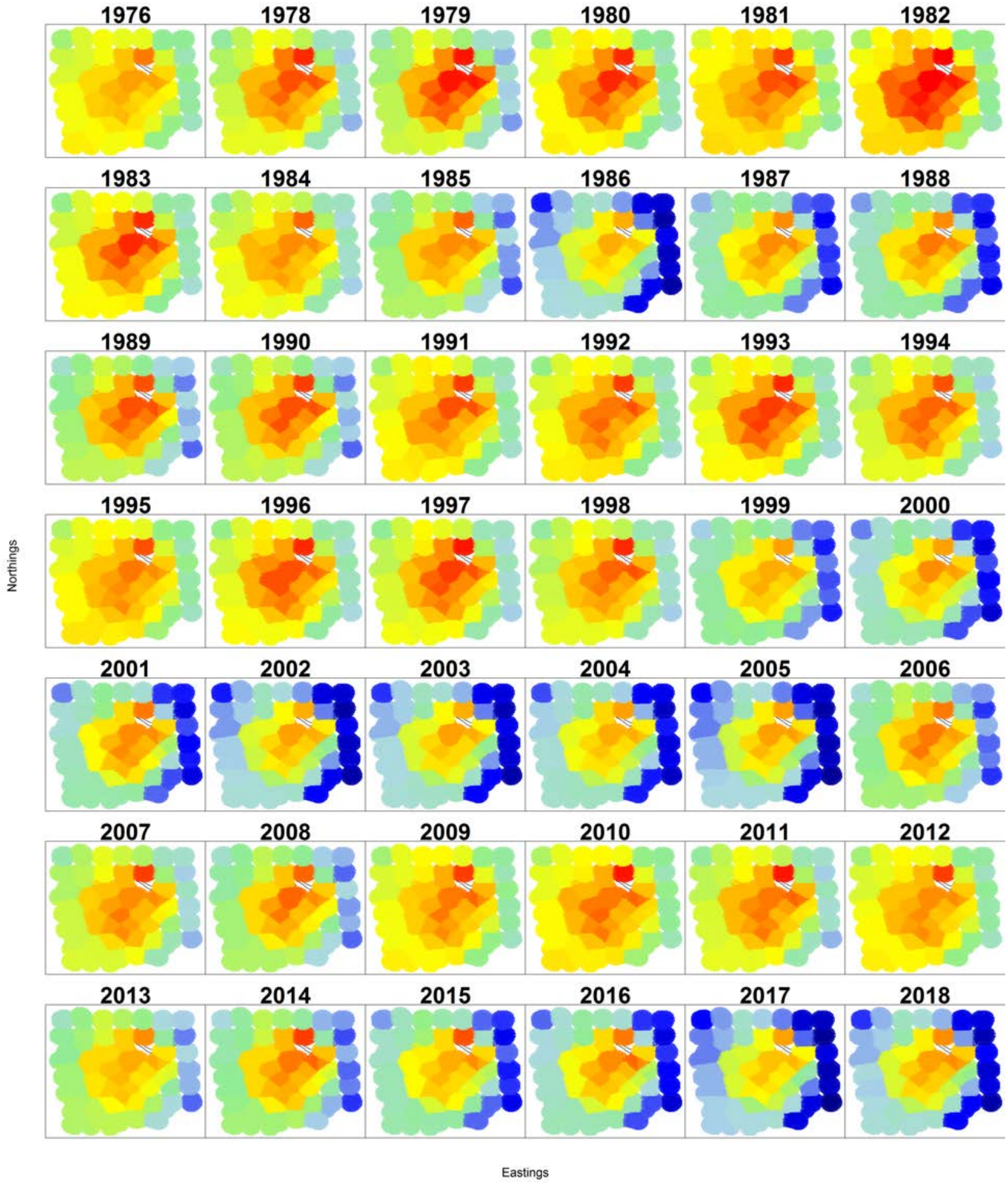

Figure 33: St. Matthews Island blue king crab (males >89mm) density maps as predicted using the VAST model approach, 1976-2018.

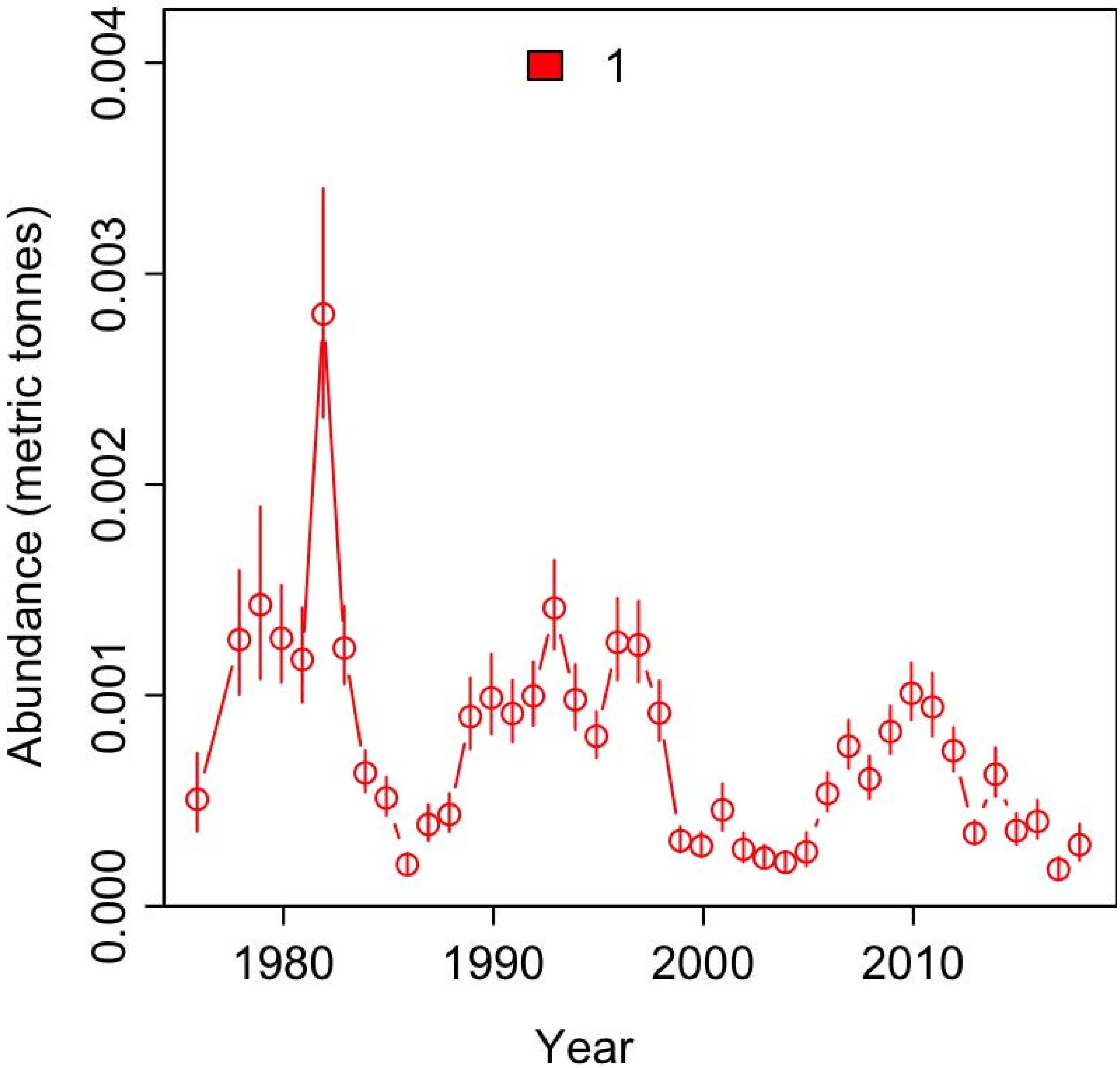

Figure 34: St. Matthews Island blue king crab (males >89mm) relative abundance as predicted using the VAST model approach.

Thorson, J.T., Rindorf, A., Gao, J., Hanselman, D.H., and Winker, H. 2016. Density-dependent changes in effective area occupied for sea-bottom-associated marine fishes. Proc R Soc B 283(1840): 20161853. doi:10.1098/rspb.2016.1853. URL: http://rspb.royalsocietypublishing.org/content/283/1840/20161853.

To see these entries in BibTeX format, use 'print(, bibtex=TRUE)', 'toBibtex(.)', or set 'options(citation.bibtex.max=999)'.

Table 22: 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 23: 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)
Groundfish trawl bycatch biomass	1992/93 - 2016/17	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93 - 2016/17	NMFS groundfish observer program
NMFS trawl-survey biomass index (area-swept estimate) and CV	1978-2018	NMFS EBS trawl survey
ADF&G pot-survey abundance index (CPUE) and CV	1995-2017	ADF&G SMBKC pot survey
NMFS trawl-survey stage proportions and total number of measured crab	1978-2018	NMFS EBS trawl survey
ADF&G pot-survey stage proportions and total number of measured crab	1995-2017	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)

Table 24: Fixed model parameters for all scenarios.

Parameter	Symbol	Value	Source/rationale
Trawl-survey catchability	q	1.0	Default
Natural mortality	M	0.18 yr^{-1}	NPFMC (2007)
Size transition matrix	$\boldsymbol{G}$	Equation 13	Otto and Cummiskey (1990)
Stage-1 and stage-2 mean weights	w_1, w_2	0.7, 1.2 kg	Length-weight equation (B. Foy, NMFS) applied to stage midpoints
Stage-3 mean weight	$w_{3,y}$	Depends on year Table 10	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 25: The lower bound (LB), upper bound (UB), initial value, prior, and estimation phase for each estimated model parameter.

Parameter	LB	Initial value	UB	Prior	Phase
Average recruitment $\log(\bar{R})$	-7	10.0	20	Uniform(-7,20)	1
Stage-1 initial numbers $\log(n_1^0)$	5	14.5	20	Uniform(5,20)	1
Stage-2 initial numbers $\log(n_2^0)$	5	14.0	20	Uniform(5,20)	1
Stage-3 initial numbers $\log(n_3^0)$	5	13.5	20	Uniform(5,20)	1
ADF&G pot survey catchability q	0	3.0	5	Uniform(0,5)	1
Stage-1 directed fishery selectivity 1978-2008	0	0.4	1	Uniform(0,1)	3
Stage-2 directed fishery selectivity 1978-2008	0	0.7	1	Uniform(0,1)	3
Stage-1 directed fishery selectivity 2009-2017	0	0.4	1	Uniform(0,1)	3
Stage-2 directed fishery selectivity 2009-2017	0	0.7	1	Uniform(0,1)	3
Stage-1 NMFS trawl survey selectivity	0	0.4	1	Uniform(0,1)	4
Stage-2 NMFS trawl survey selectivity	0	0.7	1	Uniform(0,1)	4
Stage-1 ADF&G pot survey selectivity	0	0.4	1	Uniform(0,1)	4
Stage-2 ADF&G pot survey selectivity	0	0.7	1	Uniform(0,1)	4
Natural mortality deviation during 1998 δ_{1998}^M	-3	0.0	3	Normal(0, σ_M^2)	4
Recruitment deviations δ_y^R	-7	0.0	7	Normal(0, σ_R^2)	3
Average directed fishery fishing mortality $\bar{F}^{\mathrm{df}}$	-	0.2	-	-	1
Average trawl bycatch fishing mortality $\bar{F}^{\mathrm{tb}}$	-	0.001	-	-	1
Average fixed gear bycatch fishing mortality $\bar{F}^{\mathrm{fb}}$	-	0.001	-	-	1

Table 26: SMBKC parameter estimates, bounds, and final gradients as derived from the VAST modeling framework.

Param	Lower	MLE	Upper	final_gradient
ln_H_input	-50.0	-0.157	50.0	0.00001
ln_H_input	-50.0	-0.637	50.0	-0.00006
beta1_ct	-50.0	1.068	50.0	0.00001
beta1_ct	-50.0	-1.381	50.0	0.00001
beta1_ct	-50.0	-2.306	50.0	-0.00002
beta1_ct	-50.0	-0.486	50.0	0.00001
beta1_ct	-50.0	0.556	50.0	0.00001
beta1_ct	-50.0	-0.774	50.0	0.00001
beta1_ct	-50.0	-0.643	50.0	-0.00004
beta1_ct	-50.0	-0.616	50.0	0.00000
beta1_ct	-50.0	-1.786	50.0	0.00000
beta1_ct	-50.0	-3.240	50.0	-0.00000
beta1_ct	-50.0	-2.464	50.0	0.00001
beta1_ct	-50.0	-2.955	50.0	0.00002
beta1_ct	-50.0	-2.080	50.0	0.00001
beta1_ct	-50.0	-1.924	50.0	-0.00001
beta1_ct	-50.0	-0.402	50.0	-0.00002
beta1_ct	-50.0	-0.534	50.0	-0.00001
beta1_ct	-50.0	-0.867	50.0	-0.00001
beta1_ct	-50.0	-1.032	50.0	-0.00001
beta1_ct	-50.0	0.265	50.0	-0.00002
beta1_ct	-50.0	-0.869	50.0	-0.00001
beta1_ct	-50.0	-1.201	50.0	-0.00001
beta1_ct	-50.0	-1.061	50.0	-0.00004
beta1_ct	-50.0	-1.742	50.0	0.00001
beta1_ct	-50.0	-2.691	50.0	-0.00001
beta1_ct	-50.0	-3.145	50.0	-0.00001
beta1_ct	-50.0	-3.401	50.0	-0.00004
beta1_ct	-50.0	-3.412	50.0	0.00002
beta1_ct	-50.0	-3.214	50.0	0.00002
beta1_ct	-50.0	-3.797	50.0	-0.00001
beta1_ct	-50.0	-1.776	50.0	0.00000
beta1_ct	-50.0	-1.032	50.0	-0.00002
beta1_ct	-50.0	-1.630	50.0	-0.00001
beta1_ct	-50.0	0.157	50.0	0.00001
beta1_ct	-50.0	0.141	50.0	0.00001
beta1_ct	-50.0	-1.206	50.0	-0.00003
beta1_ct	-50.0	0.143	50.0	0.00001
beta1_ct	-50.0	-0.956	50.0	0.00005
beta1_ct	-50.0	-2.236	50.0	0.00001
beta1_ct	-50.0	-2.546	50.0	-0.00001
beta1_ct	-50.0	-3.100	50.0	-0.00000
beta1_ct	-50.0	-3.756	50.0	0.00002
L_omega1_z	-50.0	2.282	50.0	0.00007
L_epsilon1_z	-50.0	0.683	50.0	-0.00009
logkappa1	-4.7	-3.695	-1.9	-0.00003
beta2_ct	-50.0	-8.669	50.0	0.00004
beta2_ct	-50.0	-7.498	50.0	0.00008
beta2_ct	-50.0	-7.295	50.0	0.00011
beta2_ct	-50.0	-7.582	50.0	0.00008
beta2_ct	-50.0	-7.801	50.0	-0.00014
beta2_ct	-50.0	-6.802	50.0	0.00000
beta2_ct	-50.0	-7.813	50.0	0.00013
beta2_ct	-50.0	-8.131	50.0	-0.00000
beta2_ct	-50.0	-8.362	50.0	-0.00010
beta2_ct	-50.0	-8.978	50.0	-0.00006
beta2_ct	-50.0	-8.486	50.0	0.00001

Table 27: SMBKC male >89mm biomass (t) estimates as derived from the VAST modeling framework.

Year	Estimate	CV
1977	4149.9	0.933
1978	8257.2	0.204
1979	11852.5	0.255
1980	10570.5	0.172
1981	8714.3	0.168
1982	20910.3	0.186
1983	9646.5	0.145
1984	4824.5	0.154
1985	4017.3	0.173
1986	1435.4	0.232
1987	2894.2	0.203
1988	3131.6	0.198
1989	6685.3	0.180
1990	6882.2	0.178
1991	7448.5	0.151
1992	7835.2	0.144
1993	10445.3	0.145
1994	7084.7	0.151
1995	6202.7	0.132
1996	9390.2	0.150
1997	9335.1	0.149
1998	6917.6	0.147
1999	2260.9	0.181
2000	2237.3	0.197
2001	3305.7	0.233
2002	1767.8	0.239
2003	1714.8	0.222
2004	1812.2	0.219
2005	1773.7	0.273
2006	3862.7	0.169
2007	5607.0	0.149
2008	4587.6	0.165
2009	6419.3	0.132
2010	7902.4	0.132
2011	7510.2	0.154
2012	5958.9	0.135
2013	2702.6	0.155
2014	4759.7	0.175
2015	2719.7	0.192
2016	2905.8	0.209
2017	1325.5	0.259
2018	2281.2	0.264

Norton Sound Red King Crab Stock Assessment for the fishing year 2018

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Executive Summary

1. Stock. Red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska.

2. Catches. This stock supports three important fisheries: summer commercial, winter commercial, and winter subsistence fisheries. Of those, the summer commercial fishery accounts for more than 90% of total harvest. The summer commercial fishery started in 1977, and catch peaked in the late 1970s with retained catch of over 2.9 million pounds. Since 1982, retained catches have been below 0.5 million pounds, averaging 0.275 million pounds, including several low years in the 1990s. Retained catches have increased to about 0.4 million pounds. Since mid-2010s, winter commercial fisheries catches has been increased greatly.

3. Stock Biomass. Following a peak in 1977, abundance of the stock collapsed to a historic low in 1982. Estimated mature male biomass (MMB) has shown an increasing trend since 1997, but is highly uncertain due, in part, to infrequent trawl (every 3 to 5 years) and limited winter pot surveys.

4. Recruitment. Model estimated recruitment was weak during the late 1970s and high during the early 1980s, with a slightly downward trend from 1983 to 1993. Estimated recruitment has been highly variable but on an increasing trend in recent years.

5. Management performance.

Status and catch specifications (million lb.)

Year	MSST	Biomass (MMB)	GHL	Retained Commercial Catch	Total Retained Catch	Retained OFL	Retained ABC
2014/15	2.11[A]	3.71	0.38	0.39	0.39	0.46[A]	0.42
2015	2.41[B]	5.13	0.39	0.40	0.52	0.72[B]	0.58
2016	2.26[C]	5.87	0.52	0.51	0.52	0.71[C]	0.57
2017	2.31[D]	5.14	0.50	0.49	0.50	0.67[D]	0.54
2018	4.41[E]	4.08	TBD	TBD	TBD	0.43[E]	0.35

Status and catch specifications (1000t)

Year	MSST	Biomass (MMB)	GHL	Retained Commercial Catch	Total Retained Catch	Retained OFL	Retained ABC
2014/15	0.96[A]	1.68	0.17	0.18	0.18	0.21[A]	0.19
2015	1.09[B]	2.33	0.18	0.18	0.24	0.33[B]	0.26
2016	1.03[C]	2.66	0.24	0.23	0.24	0.32[C]	0.26
2017	1.05[D]	2.33	0.23	0.22	0.24	0.30[D]	0.24
2018	2.00 [E]	1.85	TBD	TBD	TBD	0.20 [E]	0.16

Notes:
MSST was calculated as $B_{MSY}/2$
A-Calculated from the assessment reviewed by the Crab Plan Team in May 2014
B-Calculated from the assessment reviewed by the Crab Plan Team in May 2015
C-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2016
D-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2017
E-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2018

Conversion to Metric ton: 1 Metric ton (t) = 2.2046×1000 lb

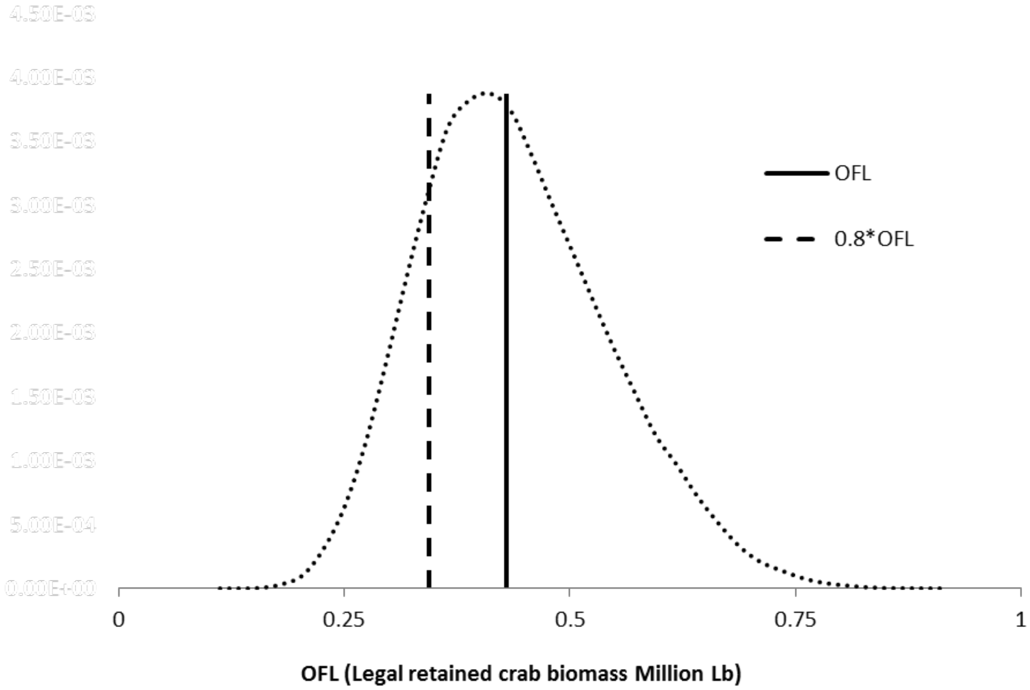
Biomass in millions of pounds

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	Retained ABC
2014/15	4b	4.19	3.71	0.9	0.16	1980-2014	0.18	0.9	0.42
2015	4a	4.81	5.13	1.1	0.18	1980-2015	0.18	0.8	0.58
2016	4a	4.53	5.87	1.3	0.18	1980-2016	0.18	0.8	0.57
2017	4a	4.62	5.14	1.1	0.18	1980-2017	0.18	0.8	0.54
2018	4b	4.41	4.08	0.9	0.15	1980-2018	0.18	0.8	0.35

Biomass in 1000t

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	Retained ABC
2014/15	4b	1.90	1.68	0.9	0.16	1980-2014	0.18	0.9	0.19
2015	4a	2.18	2.33	1.1	0.18	1980-2015	0.18	0.8	0.26
2016	4a	2.06	2.66	1.3	0.18	1980-2016	0.18	0.8	0.26
2017	4a	2.10	2.33	1.1	0.18	1980-2017	0.18	0.8	0.24
2018	4b	2.00	1.85	0.9	0.15	1980-2018	0.18	0.8	0.16

6. Probability Density Function of the OFL, OFL profile, and mcmc estimates.



7. The basis for the ABC recommendation

   For Tier 4 stocks, the default maximum ABC is based on P*=49% that is essentially identical to the OFL. Accounting for uncertainties in assessment and model results, the SSC chose to use 90% OFL (10% Buffer) for the Norton Sound red king crab stock from 2011 to 2014. In 2015, the buffer was increased to 20% (ABC = 80% OFL).

8. A summary of the results of any rebuilding analyses.

   N/A

A. *Summary of Major Changes in 2017*

1. Changes to the management of the fishery**:**

   Winter commercial GHL went into effect

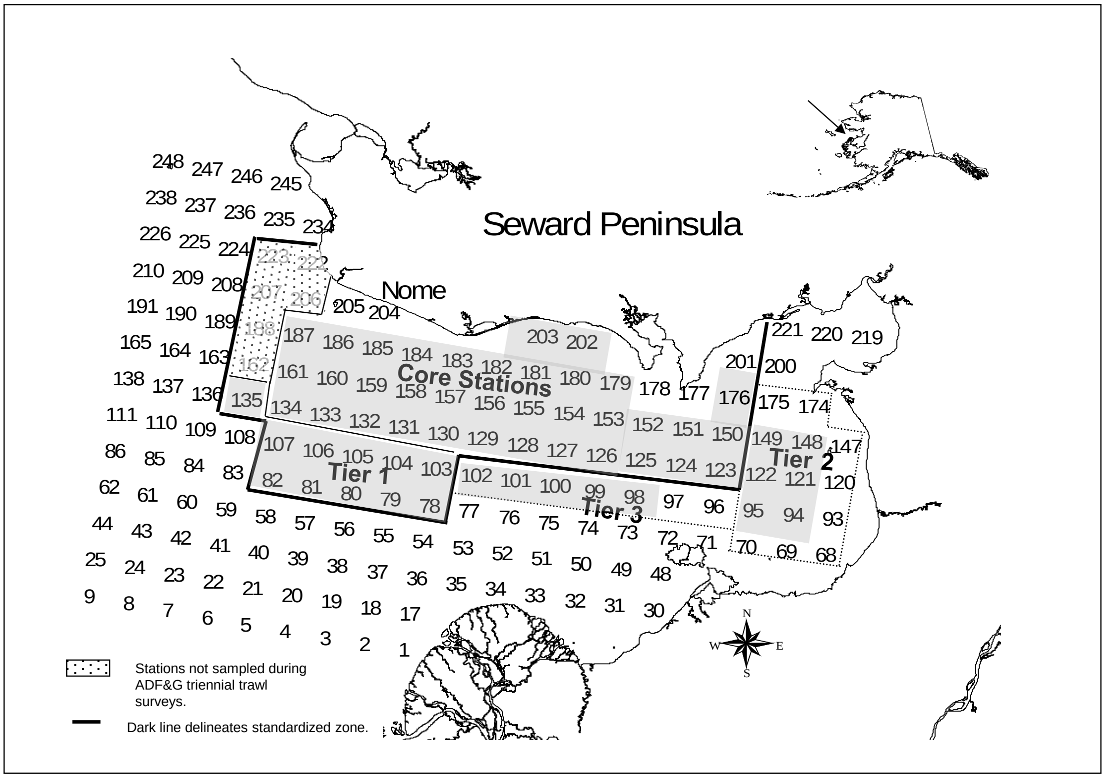
2. Changes to the input data

   a. Data update: 1977-2017 standardized commercial catch CPUE and CV. No changes in standardization methodology (NPFMC 2013).

   b. Recalculation and standardization of 1996-2017ADFG trawl survey abundance.
      i. Size class was changed from ≥ 74mm to ≥ 64mm to be consistent with the modeled size range
      ii. Re-tow data were removed from abundance calculation, unless the first trawl failed.

iii. Estimates of abundance are based on core, tier 1, and tier 3 area only.

iv. Abundance of untrawled stations within the standard station was considered zero crabs. All untrawled stations were outer edge of standard stations (Appendix E).



Gray shaded area is standard stations.

3. Changes to the assessment methodology:

   None

4. Changes to the assessment results.

   None

B. Response to SSC and CPT Comments

Crab Plan Team – January 17, 2017

- The CPT recommends breaking out natural mortality by size class for future model evaluation.

  Authors' reply:

  OFL calculation will change from

$$OFL = Legal\_B_w \left(1 - e^{-(F_{OFL}+0.42M)} - (1 - e^{-0.42M}) \left(\frac{1 - p(1 - e^{-(F_{OFL}+0.42M)})}{1 - p(1 - e^{-0.42M})} \right) \right)$$

to

$$OFL = \sum_l \left[Legal\_B_{w,l} \left(1 - e^{-(F_{OFL,l}+0.42M_l)} - (1 - e^{-0.42M_l}) \left(\frac{1 - p(1 - e^{-(F_{OFL,l}+0.42M_l)})}{1 - p(1 - e^{-0.42M_l})} \right) \right) \right]$$

- Assess which (2017 NOAA vs. ADFG survey) data inputs are most influential for the assessment.

Author reply: Model fit to ADFG trawl survey was better than NOAA trawl survey.

Model	Model 4 ADFG trawl	Model 4 NOAA trawl
No. Parameters	69	69
Total	261.0	266.2
TSA	8.0	9.1
St.CPUE	-30.7	-30.7
TLP	85.1	88.6
WLP	39.2	39.2
CLP	50.5	50.6
OBS	23.0	23.3
REC	13.8	13.7
TAG	72.2	72.5
MMB(mil.lb)	4.25	4.16

- Assess which (discard length data, survey data, etc.) data inputs are most influential for the assessment.

Author reply:
Likelihood was calculated as follows

Model	Model 3*	-TSA	-CPUE	-TLP	-WLP	-CLP	-OBS	-TAG
Total	260.0	244.8	283.6	159.2	215.8	193.9	222.3	182.7
TSA	8.5	ND	8.1	9.4	9.7	8.7	8.7	9.1
St.CPUE	-30.4	-31.8	ND	-33.7	-30.8	-29.3	-30.3	-29.8
TLP	84.0	83.0	81.6	ND	84.0	67.0	80.4	79.0
WLP	38.7	38.7	37.9	41.5	ND	38.2	39.4	22.0
CLP	50.2	49.0	49.0	39.2	46.5	ND	49.7	48.0
OBS	22.9	23.0	22.6	26.2	22.8	24.0	ND	22.0
REC	14.1	12.8	13.8	12.4	12.3	14.7	15.2	13.8
TAG	71.9	69.6	70.5	67.1	71.5	71.5	59.1	ND
MMB(mil.lb)	3.52	10.9	3.33	3.41	3.58	3.89	3.43	3.42
Legal (mil.lb)	3.05	9.1	2.80	2.87	3.03	3.39	2.87	2.88
Diff		-6.8	-6.8	-12.2	-5.7	-16.1	-12.7	+0.7

*: Model 3 is 2017 final model with commercial fishery selectivity changed to 2 parameters logistic function. (See alternative model section)
TSA: Trawl Survey Abundance
St. CPUE: Summer commercial catch standardized CPUE
TLP: Trawl survey length composition:
WLP: Winter pot survey length composition
CLP: Summer commercial catch length composition
REC: Recruitment deviation
OBS: Summer commercial catch observer discards length composition
TAG: Tagging recovery data composition
Legal: Exploitable legal male crab

See Appendix C6-C13 for standard output figures. Estimates of parameters for each model are available by request.

The most influential data for the assessment is trawl survey abundance data that determined biomass. For length proportion data, model seems to resolve conflicts among various data, so that removing one data would increase fit to other data.

- Explore bycatch data to see if it is possible to determine the OFL as total catch.

  Author reply:
  Only discard length data were collected during the summer observer surveys. The author appreciates CPT's guidance for estimating the number and biomass of discarded crab from the length data.

SSC – January 30

- SSC suggests that the author examine available evidence for higher mortality rates at larger sizes and perhaps an alternative way to parameterizing higher mortality at age rather than a step change at the largest size class.

  Author's reply:

  Because NSRKC has only 8 size classes, we examined step change for each length classes in the following scenario:

  1. One mortality for the last 2 length classes (default: ms = 1)
  2. Two separate mortalities for the last 2 length classes (ms = 2)
  3. Three separate mortalities for the last 3 length classes (ms = 3)

The results showed that estimating mortality of the last 3 length classes seem to improve model fit, especially when fishery selectivity was converted from 1 parameter logistic to 2 parameters logistic model

Scenario	M	ms	Fishery Selectivity	Estimated Mortality
0	0.18	1	1p	0.558
1	0.18	2	1p	0.52, 0.63
2	0.18	3	1p	0.23, 0.52, 0.62
3	0.18	1	2p	0.571
4	0.18	2	2p	0.55,0.61
5	0.18	3	2p	0.34,0.55,0.58

1 parameter logistic selectivity model

$$S_l = \frac{1}{1+e^{(\phi(L_{\max}-L)+\ln(1/0.999-1))}}$$

2 parameters logistic selectivity model

$$S_l = \frac{1}{1+e^{-\alpha(L-\beta)}}$$

a. Evaluation of negative log likelihood alternative models results:

Model	Model 0	Model 1	Model 2	Model 3	Model 4	Model 5
No. Parameters	67	68	69	68	69	70
Total	272.5	272.1	271.7	260.0	259.9	256.5
TSA	8.4	8.4	8.6	8.5	8.4	9.0
St.CPUE	-30.4	-30.4	-30.3	-30.4	-30.4	-30.0
TLP	88.6	88.5	87.2	84.0	84.0	82.7
WLP	38.5	38.5	38.3	38.7	38.8	38.3
CLP	50.0	49.6	49.8	50.2	50.0	48.3
OBS	25.1	25.1	25.1	22.9	23.0	22.9
REC	13.6	13.7	13.7	14.1	14.1	14.5
TAG	78.6	78.7	78.6	71.9	72.0	70.8
MMB(mil.lb)	3.66	3.67	3.68	3.52	3.52	3.56
Legal (mil.lb)	3.21	3.21	3.21	3.05	3.06	3.03
OFL(mil.lb)						

TSA: Trawl Survey Abundance
St. CPUE: Summer commercial catch standardized CPUE
TLP: Trawl survey length composition:
WLP: Winter pot survey length composition
CLP: Summer commercial catch length composition
REC: Recruitment deviation
OBS: Summer commercial catch observer discards length composition
TAG: Tagging recovery data composition
Legal: Exploitable legal male crab

Crab Plan Team – Sept 20, 2017

- Include a graphic on where pot-pulls have been observed.

  Author's reply
  See Appendix D. The majority of observer surveys were conducted where the majority of crabs were harvested. This is expected. Observers can board on boats that are large enough that can harvest more crabs.

Bring forward default model, model 3, 4, 5 for the January 2018 assessment

  Author's reply:
  Base model along with alternative model 3,4,5 were presented in the result section.

- Conduct likelihood profile on the M parameter

  Author's reply:
  See Appendix F.
  Likelihood profile shows that M = 0.26 appeared to be the lowest. Among the likelihood components, influential factors were trawl and summer commercial length compositions.

- Include results for 2014-2016 pot survey data (but not for assessment)
  This was conducted only for the model 3.

SSC – Oct 02, 2017

- Same as CPT

C. Introduction

1. Species: red king crab (*Paralithodes camtschaticus*) in Norton Sound, Alaska.
2. General Distribution: Norton Sound red king crab is one of the northernmost red king crab populations that can support a commercial fishery (Powell et al. 1983). It is distributed throughout Norton Sound with a westward limit of 167-168^{o} W. longitude, depths less than 30 m, and summer bottom temperatures above 4^{o}C. The Norton Sound red king crab management area consists of two units: Norton Sound Section (Q3) and Kotzebue Section (Q4) (Menard et al. 2011). The Norton Sound Section (Q3) consists of all waters in Registration Area Q north of the latitude of Cape Romanzof, east of the International Dateline, and south of 66°N latitude (Figure 1). The Kotzebue Section (Q4) lies immediately north of the Norton Sound Section and includes Kotzebue Sound. Commercial fisheries have not occurred regularly in the Kotzebue Section. This report deals with the Norton Sound Section of the Norton Sound red king crab management area.
3. Evidence of stock structure: Thus far, no studies have investigated possible stock separation within the putative Norton Sound red king crab stock.
4. Life history characteristics relevant to management: One of the unique life-history traits of Norton Sound red king crab is that they spend their entire lives in shallow water since Norton Sound is generally less than 40 m in depth. Distribution and migration patterns of Norton Sound red king crab have not been well studied. Based on the 1976-2006 trawl surveys, red

king crab in Norton Sound are found in areas with a mean depth range of 19 ± 6 (SD) m and bottom temperatures of 7.4 ± 2.5 (SD) ^{o}C during summer. Norton Sound red king crab are consistently abundant offshore of Nome.

Norton Sound red king crab migrate between deeper offshore and inshore shallow waters. Timing of the inshore mating migration is unknown, but is assumed to be during late fall to winter (Powell et al. 1983). Offshore migration occurs in late May - July (Jennifer Bell, ADF&G, personal communication). The results from a study funded by North Pacific Research Board (NPRB) during 2012-2014 suggest that older/large crab (> 104mm CL) stay offshore in winter, based on findings that large crab are not found nearshore during spring offshore migration periods (Jennifer Bell, ADF&G, personal communication). Timing of molting is unknown but likely occurs in late August – September, based on increase catches of newly-molted crab late in the fishing season (August- September) (Joyce Soong, ADF&G personal communication) and evaluation of molting hormone profiles in the hemolymph (Jennifer Bell, ADF&G, personal communication). Recent observations also indicate that mating may be biennial (Robert Foy, NOAA, personal communication). Trawl surveys show that crab distribution is dynamic with recent surveys showing high abundance on the southeast side of Norton Sound, offshore of Stebbins and Saint Michael.

5. Brief management history: Norton Sound red king crab fisheries consist of commercial and subsistence fisheries. The commercial red king crab fishery started in 1977 and occurs in summer (June – August) and winter (December – May). The majority of red king crab harvest occurs offshore during the summer commercial fishery, whereas the winter commercial and subsistence fisheries occur nearshore through ice.

<u>Summer Commercial Fishery</u>

A large-vessel summer commercial crab fishery started in 1977 in the Norton Sound Section (Table 1) and continued from 1977 through 1990. No summer commercial fishery occurred in 1991 because there were no staff to manage the fishery. In March 1993, the Alaska Board of Fisheries (BOF) limited participation in the fishery to small boats. Then on June 27, 1994, a super-exclusive designation went into effect for the fishery. This designation stated that a vessel registered for the Norton Sound crab fishery may not be used to take king crabs in any other registration areas during that registration year. A vessel moratorium was put into place before the 1996 season. This was intended to precede a license limitation program. In 1998, Community Development Quota (CDQ) groups were allocated a portion of the summer harvest; however, no CDQ harvest occurred until the 2000 season. On January 1, 2000 the North Pacific License Limitation Program (LLP) went into effect for the Norton Sound crab fishery. The program dictates that a vessel which exceeds 32 feet in length overall must hold a valid crab license issued under the LLP by the National Marine Fisheries Service. Changes in regulations and the location of buyers resulted in eastward movement of the harvest distribution in Norton Sound in the mid-1990s. In Norton Sound, a legal crab is defined as ≥ 4-3/4 inch carapace width (CW, Menard et al. 2011), which is approximately equivalent to ≥ 104 mm carapace length mm CL. Since 2005, commercial buyers (Norton Sound Economic Development Corporation) started accepting only legal crab of ≥ 5 inch CW. This may have increased discards; however, because discards have not been monitored until 2012, impact of this change on discards is unknown. This issue was also examined in assessment model selection, which showed no difference in estimates of selectivity functions before and after 2005 (NPFMC 2016).

Portions of Norton Sound area are closed to commercial fishing for red king crab. Since the beginning of the commercial fisheries in 1977, waters approximately 5-10 miles offshore of southern Seward Peninsula from Port Clarence to St. Michael have been closed to protect crab nursery grounds during the summer commercial crab fishery (Figure 2). The spatial extent of closed waters has varied historically.

CDQ Fishery

The Norton Sound and Lower Yukon CDQ groups divide the CDQ allocation. Only fishers designated by the Norton Sound and Lower Yukon CDQ groups are allowed to participate in this portion of the king crab fishery. Fishers are required to have a CDQ fishing permit from the Commercial Fisheries Entry Commission (CFEC) and register their vessel with the Alaska Department of Fish and Game (ADF&G) before begin fishing. Fishers operate under the authority of each CDQ group who decides how their crab quota is to be harvested. During the March 2002 BOF meeting, new regulations for the CDQ crab fishery were adopted that affected; closed-water boundaries were relaxed in eastern Norton Sound and waters west of Sledge Island. In March 2008, the BOF changed the start date of the Norton Sound open-access portion of the fishery to be opened by emergency order as early as June 15. The CDQ fishery may open at any time (as soon as ice is out), by emergency order. CDQ harvest share is 7.5% of total projected harvest.

Winter Commercial Fishery

The winter commercial crab fishery is a small fishery using hand lines and pots through the nearshore ice. On average 10 permit holders harvested 2,500 crabs during 1978-2009. From 2007 to 2015 the winter commercial catch increased from 3,000 crabs to over 40,000 (Table 2). In 2015 winter commercial catch reached 20% of total crab catch. The BOF responded in May 2015 by amending regulations to allocate 8% of the total commercial guideline harvest level (GHL) to the winter commercial fishery, which became in effect since 2017 season. The winter red king crab commercial fishing season was also set from January 15 to April 30, unless changed by emergency order. The new regulation became in effect since the 2016 season.

Subsistence Fishery

While the winter subsistence fishery has a long history, harvest information is available only since the 1977/78 season. The majority of the subsistence crab fishery harvest occurs using hand lines and pots through nearshore ice. Average annual winter subsistence harvest was 5,400 crab (1977-2010). Subsistence harvesters need to obtain a permit before fishing and record daily effort and catch. There are no size or sex specific harvest limits; however, the majority of retained catches are males of near legal size. The subsistence fishery catch is influenced not only by crab abundance, but also by changes in distribution, changes in gear (e.g., more use of pots instead of hand lines since 1980s), and ice conditions (e.g., reduced catch due to unstable ice conditions: 1987-88, 1988-89, 1992-93, 2000-01, 2003-04, 2004-05, and 2006-07).

The summer subsistence crab fishery harvest has been monitored since 2004 with an average harvest of 712 crab per year. Since this harvest is very small, the summer subsistence fishery was not included in the assessment model.

6. Brief description of the annual ADF&G harvest strategy

Since 1997 Norton Sound red king crab has been managed based on a guideline harvest level (GHL). From 1999 to 2011 the GHL for the summer commercial fishery was determined by a prediction model and the model estimated predicted biomass: (1) 0% harvest rate of legal crab when estimated legal biomass < 1.5 million lb; (2) ≤ 5% of legal male abundance when the estimated legal biomass falls within the range 1.5-2.5 million lb; and (3) ≤ 10% of legal male when estimated legal biomass >2.5 million lb.

In 2012 a revised GHL for the summer commercial fishery was implemented: (1) 0% harvest rate of legal crab when estimated legal biomass < 1.25 million lb; (2) ≤ 7% of legal male abundance when the estimated legal biomass falls within the range 1.25-2.0 million lb; (3) ≤ 13% of legal male abundance when the estimated legal biomass falls within the range 2.0-3.0 million lb; and (3) ≤ 15% of legal male biomass when estimated legal biomass >3.0 million lb.

In 2015 the Alaska Board of Fisheries passed the following regulations regarding winter commercial fisheries:

1. Revised GHL to include summer and winter commercial fisheries.
2. Set guideline harvest level for winter commercial fishery (GHL_w) at 8% of the total GHL
3. Dates of the winter red king crab commercial fishing season are from January 15 to April 30.

Year	Notable historical management changes
1976	The abundance survey started
1977	Large vessel commercial fisheries began
1991	Fishery closed due to staff constraints
1994	Super exclusive designation went into effect. The end of large vessel commercial fishery operation. The majority of commercial fishery subsequently shifted to east of 164°W longitude.
1998	Community Development Quota (CDQ) allocation went into effect
1999	Guideline Harvest Level (GHL) went into effect
2000	North Pacific License Limitation Program (LLP) went into effect.
2002	Change in closed water boundaries (Figure 2)
2005	Commercially accepted legal crab size changed from ≥ 4-3/4 inch CW to ≥ 5 inch CW
2006	The Statistical area Q3 section expanded (Figure 1)
2008	Start date of the open access fishery changed from July 1 to after June 15 by emergency order. Pot configuration requirement: at least 4 escape rings (>4½ inch diameter) per pot located within one mesh of the bottom of the pot, or at least ½ of the vertical surface of a square pot or sloping side-wall surface of a conical or pyramid pot with mesh size > 6½ inches.
2012	The Board of Fisheries adopted a revised GHL for summer fishery.
2016	Winter GHL for commercial fisheries was established and modified winter fishing season dates were implemented.

7. Summary of the history of the $B_{MSY.}$

   NSRKC is a Tier 4 crab stock. Direct estimation of the B_{MSY} is not possible. The B_{MSY} proxy is calculated as mean model estimated mature male biomass (MMB) from 1980 to present. Choice of this period was based on a hypothesized shift in stock productivity a due to a climatic regime shift indexed by the Pacific Decadal Oscillation (PDO) in 1976-77. Stock status of the NSRKC was Tier 4a until 2013. In 2014 the stock fell to Tier 4b, but came back to Tier 4a for the 2015-2016 seasons.

D. Data

1. Summary of new information:

   Winter commercial and subsistence fishery:

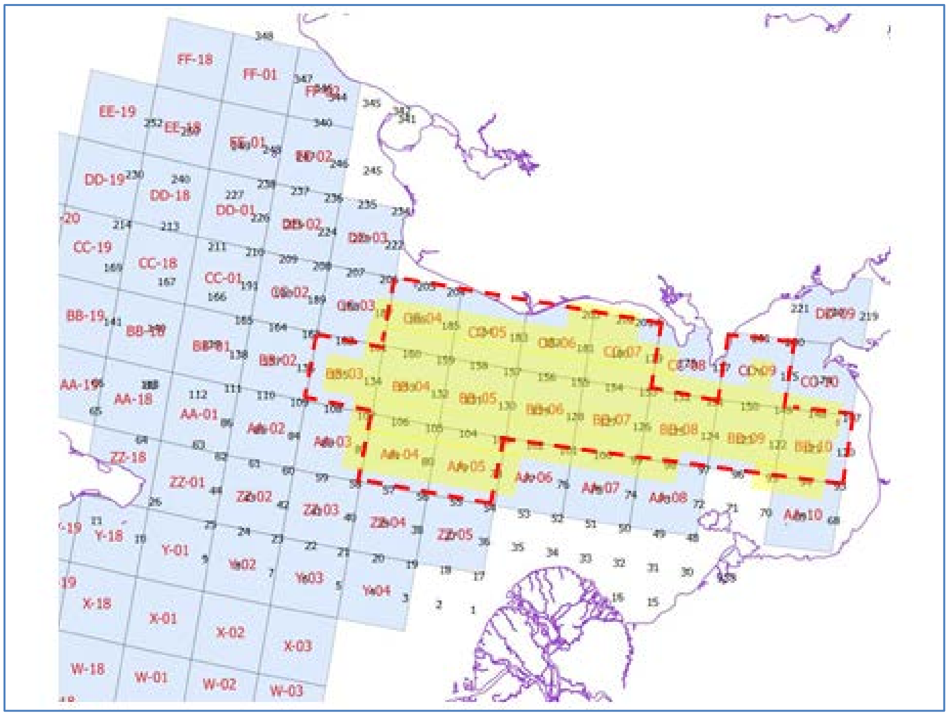
   Winter commercial fishery catch in 2017 was 26,008 crab (77,843 lb.), declined slightly from 2016. Subsistence retained crab catch was 6,039 and unretained was 1,146 or 16% of total catch (Table 2).

   Summer commercial fishery:

   The summer commercial fishery opened on June 26 and closed on July 25. Total of 135,322 crab (411,736 lb.) were harvested (Table 1).

   Total retained harvest for 2017 season was 167,369 crab (501,637 lb.) and did not exceed the 2017 ABC of 0.54 million lb.

   Summer Trawl abundance survey ADFG (7/28-8/08), and NOAA (8/18-829).
   Abundance estimated by ADFG survey was 1762.1 (x 1000) crab with CV 0.22, and that by NOAA survey was 1035.8 (x 1000) crab with CV 0.40 (Table 3). It should be noted that total estimation arear and survey station density differ between the two trawl surveys. ADFG survey is based on 10nm grids whereas NOAA survey is based on 20nm grids.



2017 ADFG trawl survey coverage (Yellow shade) and NOAA Trawl survey coverage where abundance estimates were made (Red hashed line)

2. Available survey, catch, and tagging data

	Years	Data Types	Tables
Summer trawl survey	NMFS: 76,79,82,85,88,91,10, 17	Abundance	3
	ADFG: 96, 99, 02,06,08,11, 14, 17	Length proportion	5
Winter pot survey	81-87, 89-91,93,95-00,02-12	Length proportion	6
Summer commercial fishery	76-90,92-17	Retained catch	1
		Standardized CPUE,	1
		Length proportion	4
Summer commercial Discards	87-90,92,94, 2012-2017	Length proportion (sublegal only)	7
Winter subsistence fishery	76-17	Total catch	2
		Retained catch	2
Winter commercial fishery	78-17	Retained catch	2
Tag recovery	80-17	Recovered tagged crab	8

Data available but not used for assessment

Data	Years	Data Types	Reason for not used
Summer pot survey	80-82,85	Abundance Length proportion	Uncertainties on how estimates were made.
Summer preseason survey	95	Length proportion	Just one year of data
Summer subsistence fishery	2005-2013	retained catch	Too few catches compared to commercial
Winter Pot survey	87, 89-91,93,95-00,02-12	CPUE, Length	CPUE data Not reliable due to ice conditions
Winter Commercial	2015-17	Length proportion	Years of data too short
Preseason Spring pot survey	2011-15	CPUE, Length proportion	Years of data too short
Postseason Fall pot survey	2013-15	CPUE, Length proportion	Years of data too short

Time series of available data

	Survey			Harvests			Tag	Data Not Used[3]				
	S. Trawl NMFS	S. Trawl ADFG	W. Pot	S.Com	S.Com Discards	W. Com, Sub	Tag recovery	S. Pot	Pre fish	Sp. Tag	F. Tag,	W. Com
N[1]	N			H, CPUE		H						
Length[2]	X		X	X	X		X	X	X	X	X	X
1976												
1977												
1978												
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1: Index of abundance data: N: Abundance, H: Harvest, CPUE: Catch cpue
2: Length data available
3: Data were not used for the assessment model because of short term data.
4: Different colors indicate changes in fishery characteristics or survey methodologies.

Catches in other fisheries

In Norton Sound, no other crab, groundfish, or shellfish fisheries exist.

	Fishery	Data availability
Bycatch in other crab fisheries	Does not exist	NA
Bycatch in groundfish pot	Does not exist	NA
Bycatch in groundfish trawl	Does not exist	NA
Bycatch in the scallop fishery	Does not exist	NA

3. Other miscellaneous data:

   Satellite tag migration tracking (NOAA 2016)

   Spring offshore migration distance and direction (2013-2015)

   Monthly blood hormone level (indication of molting timing) (2014-2015)

Data aggregated:

   Proportion of legal size crab, estimated from trawl survey and observer data. (Table 11)

Data estimated outside the model:

   Summer commercial catch standardized CPUE (Table 1, Appendix A2)

E. Analytic Approach

1. History of the modeling approach.

The Norton Sound red king crab stock was assessed using a length-based synthesis model (Zheng et al. 1998). Since adoption of the model, the major challenge is a conflict between model projection and data, specifically the model projects higher abundance-proportion of large size class (> 123mm CL) of crab than observed. This problem was further exasperated when natural mortality *M* was set to 0.18 from previous *M* = 0.3 in 2011 (NPFMC 2011). This issue has been resolved by assuming (3-4 times) higher *M* for the length crabs (i.e., *M* = 1.8 for length classes ≤ 123mm, and higher M for > 123mm) (NPFMC 2012, 2013, 2014, 2015, 2016, 2017). Alternative assumptions have been explored, such as changing molting probability (i.e., crab matured quicker or delayed maturation), higher natural mortality, and dorm shaped selectivity (i.e., large crab are not caught, or moved out of fishery/survey grounds). However, those alternative assumptions did not produce better model fits. Model estimated length specific molting probability was similar to inverse logistic curve, and did not improve model fit (NPFMC 2016). Assuming constant across all length classes resulted in higher *M* (0.3-0.45) (NPFMC 2013, 2017). Assuming dome shaped selectivity resulted in large (>123mm CL) of crabs consisting of 50% of MMB move out of Norton Sound fishery and survey area and never been seen. For the 2018 gradual increase of *M* across length classes was assessed.

Historical Model configuration progression:

2011 (NPFMC 2011)
1. M =0.18
2. M of the last length class = 0.288
3. Include summer commercial discards mortality = 0.2
4. Weight of fishing effort = 20,
5. The maximum effective sample size for commercial catch and winter surveys = 100,

2012 (NPFMC 2012)
1. M of the last length class = 3.6×M
2. The maximum effective sample size for commercial catch and winter surveys = 50,
3. Weight of fishing effort = 50.

2013 (NPFMC 2013)
1. Eliminate likelihood for fishing effort and use standardized commercial catch cpue likelihood. weight = 1.0
2. Eliminate summer pot survey data from likelihood
3. Estimate survey q of 1976-1991 NMFS survey with maximum of 1.0
4. The maximum input sample size for commercial catch and winter surveys = 10.
5. The maximum input sample size for trawl survey = 20.

2014 (NPFMC 2014)
1. Modify functional form of selectivity and molting probability to improve parameter estimates (2 parameter logistic to 1 parameter logistic)
2. Include additional variance for the standardized cpue.
3. Include winter pot survey cpue (But was removed from the final model due to lack of fit)
4. Estimate growth transition matrix from tagged recovery data.

2015 (NPFMC 2015)
1. Change winter pot survey selectivity is to inverse logistic, estimating selectivity of the smallest length group independently
2. Reduce weight of tag-recovery: W = 0.5
3. Model parsimony: one trawl survey selectivity and one commercial pot selectivity
4. Change assessment model periods from July 01 – June 30 to Feb 01 – Jam 31.
5. OFL winter and summer fishery combined.

2016 (NPFMC 2016)
1. Length range extended from 74mm – 124mm above (6 length classes) to 64mm – 134mm above (8 length classes).
2. Estimate multiplier for the largest (> 123mm) length classes.

2017 (NPFMC 2017)
1. Change molting probability function form 1 to 2 parameter logistic. Assume molting probability not reaching 1 for the smallest length class.

2. OFL account for winter and summer fishery separately. Account for natural mortality between the two fishery periods (5 months)

2. Model Description

a. Description of overall modeling approach:

The model is a male-only size structured model that combines multiple sources of survey, catch, and mark-recovery data using a maximum likelihood approach to estimate abundance, recruitment, catchability of the commercial pot gear, and parameters for selectivity and molting probabilities (See Appendix A for full model description).

Unlike other crab assessment models, NSRK modeling year is starts from February 1st to January 31st of the following year. This schedule was selected because Norton Sound winter crab fisheries can start when Norton Sound ice become thick enough to operate fishery safely, which can be as earliest as mid-late January.

b-f. See Appendix A.

g. Critical assumptions of the model:

i. Male crab mature at CL length 94mm.

Size at maturity of NSRKC (CL 94 mm) was determined by adjusting that of BBRKC (CL 120mm) reflect the slower growth and smaller size of NSRKC.

ii. Molting occurs in the fall after the summer fishery

iii. Instantaneous natural mortality *M* is 0.18 for all length classes, except for the last length group (> 123mm).

iv. Trawl survey selectivity is a logistic function with 1.0 for length classes 5-6. . Selectivity is constant over time.

v. Winter pot survey selectivity is a dome shaped function: Reverse logistic function of 1.0 for length class CL 84mm, and model estimate for CL < 84mm length classes. Selectivity is constant over time.

This assumption is based on the fact that a low proportion of large crab are caught in the nearshore area where winter surveys occur. Causes of this pattern may be that (1) large crab do not migrate into nearshore waters in winter or (2) large crab are fished out by winter fisheries where the survey occurs (i.e., local depletion). Recent studies suggest that the first explanation is more likely than second (Jennifer Bell, ADFG, personal communication).

vi. Summer commercial fisheries selectivity is an asymptotic logistic function of 1.0 at the length class CL 134mm. While the fishery changed greatly between the periods (1977-1992 and 1993-present) in terms of fishing vessel composition and pot configuration, the selectivity of each period was assumed to be identical. Model fits of separating and combining the two periods were examined in 2015, and showed no difference between the two models (NPFMC 2015). For model parsimony, the two were combined.

vii. Summer trawl survey selectivity is an asymptotic logistic function of 1.0 at the length of CL 124mm. While the survey changed greatly between NOAA (1976-1991) and ADF&G (1996-present) in terms of survey vessel and trawl net structure, selectivity of both periods was assumed to be identical. Model fits separating and combining the two surveys were examined in 2015. No differences between the two models were observed (NPFMC 2015) and for model parsimony the two were combined.

viii. Winter commercial and subsistence fishery selectivity and length-shell conditions are the same as those of the winter pot survey. All winter commercial and subsistence harvests occur February 1st.

Winter commercial king crab pots can be any dimension (5AAC 34.925(d)). No length composition data exists for crab harvested in the winter commercial or subsistence fisheries. However, because commercial fishers are also subsistence fishers, it is reasonable to assume that the commercial fishers used crab pots that they use for subsistence harvest, and hence both fisheries have the same selectivity.

ix. Growth increments are a function of length, are constant over time, estimated from tag recovery data.

x. Molting probability is an inverse logistic function of length for males.

xi. A summer fishing season for the directed fishery is short. All summer commercial harvests occur July 1st.

xii. Discards handling mortality rate for all fisheries is 20%.

No empirical estimate is available.

xiii. Annual retained catch is measured without error.

xiv. All legal size crab (≥ 4-3/4 inch CW) are retained, and sublegal size crab or commercially unacceptable size crab (< 5 inch CW, since 2005) are discarded.

Since 2005, buyers announced that only legal crab with ≥ 5 inch CW are acceptable for purchase. Since samples are taken at a commercial dock, it was anticipated that this change would lower the proportion of legal crab. However, the model was not sensitive to this change (NPFMC 2013, 2017).

xv. Length compositions have a multinomial error structure and abundance has a log-normal error structure.

h. Changes of assumptions since last assessment:

None.

3. Model Selection and Evaluation

a. Description of alternative model configurations.

Following CPT and SSC's recommendation in fall 2017, we brought base model (2017 assessment model), model 3, 4, and 5. Also, we examined potential impacts of spring survey data (model 6).

List of model scenarios explored:

Scenario	I	ms	Fishery Selectivity	Estimated *M*
0	0.18	1	1p	0.579
3	0.18	1	2p	0.595
4	0.18	2	2p	0.576, 0.634
5	0.18	3	2p	0.340, 0.547, 0.584
6	0.18	1	2p	0.592

ms=1: Estimate one mortality for the last 2 length classes (124mm, 134mm)
ms=2: Estimate two separate mortalities for the last 2 length classes (124mm, 134mm)
ms=3: Estimate three separate mortalities for the last 3 length classes (114mm,124mm, 134mm)

Fishery selectivity model function

1 parameter logistic selectivity model

$$S_l = \frac{1}{1+e^{(\phi(L_{\max}-L)+\ln(1/0.999-1))}}$$

2 parameters logistic selectivity model

$$S_l = \frac{1}{1+e^{-\alpha(L-\beta)}}$$

b. Evaluation of negative log-likelihood alternative models results:

Model	Model 0	Model 3	Model 4	Model 5	Model 6
No. Parameters	67	68	69	70	68
Total	281.1	269.2	269.1	265.44	286.01
TSA	9.1	9.1	9.1	9.36	9.24
St.CPUE	-30.6	-30.7	-30.7	-30.4	-30.6
TLP	95.1	90.6	90.6	89.8	90.8
WLP	38.7	39.1	39.1	38.5	39.3
CLP	50.8	51.4	51.2	49.2	51.3
OBS	25.2	23.2	23.2	23.1	23.0
REC	13.6	14.0	13.9	14.5	16.5
TAG	79.2	72.5	72.6	71.3	72.5
SP					14.0
MMB(mil.lb)	4.08	3.94	3.95	3.91	4.00
Legal crab Catchable (mil.lb)	3.55	2.58	2.60	2.13	2.63

TSA: Trawl Survey Abundance

St. CPUE: Summer commercial catch standardized CPUE
TLP: Trawl survey length composition:
WLP: Winter pot survey length composition
CLP: Summer commercial catch length composition
REC: Recruitment deviation
OBS: Summer commercial catch observer discards length composition
TAG: Tagging recovery data composition
Legal: Exploitable legal male crab

See Appendix C1-C5 for standard output figures and estimated parameters.

a. Search for balance:

Changing to 2 parameters logistic model and stepwise length specific mortality decreased negative log-likelihood and improved model fit. Relative gain of model improvement was the largest from model 0 to model 3 (i.e., changing the shape of commercial pot selectivity). The majority of model fit was attributed to likelihood of Trawl survey and tag recovery length proportion (cf. Appendix C1, C2 Figures 11, 12, 13). Simultaneously, it should be noted that extent of reduction depends upon assumed input sample size. Subdividing natural mortality and increasing one more parameter size (from model 3 to 4) did not change model fit. Though some improvement was seen from model 4 to 5, it was argued that assuming natural mortality increase of crab size 114-123mm would be biologically unreasonable (CPT Sept 2017). Changing of fishery selectivity or subdividing mortality did not change MMB projections, but reduced legal crab biomass catchable to commercial fishery. This is because the shape of the selectivity became steeper (cf. Appendix C1, C2 Figure 3).

While there was an improvement in fit from model 0 to model 3, the improvement in fit was not to the fishery length composition data as would be expected, but instead to other data sets unrelated to the fishery, such as the tagging data and the survey size composition. In addition, the estimated selectivity pattern was gradually inclining curve that continued to increase at sizes above the legal limit, a pattern which the CPT found difficult to rationalize. This suggests that the model uses more flexible two-parameter selectivity curve to account for some other unmodeled process, and therefore should not be considered a model improvement.

Based on the above arguments the Model 0 was selected for assessment of 2018

4. Results

1. List of effective sample sizes and weighting factors (Figure 4)

“Implied” effective sample sizes were calculated as

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

Where $P_{y,l}$ and $\hat{P}_{y,l}$ are observed and estimated length compositions in year *y* and length group *l*, respectively. Estimated effective sample sizes vary greatly over time.

Maximum input sample sizes for length proportions: The maximum input sample size was arbitrary selected for better fit (NPFMC 2013)

Survey data	Sample size
Summer commercial, winter pot, and summer observer	minimum of 0.1 × actual sample size or 10
Summer trawl	minimum of 0.5 × actual sample size or 20
Tag recovery	0.5× actual sample size

Weighting factor

Recruitment SD 0.5

2. Tables of estimates.
   a. Model parameter estimates (Tables 10, 11, 12, 13).
   b. Abundance and biomass time series (Table 13)
   c. Recruitment time series (Table 13).
   d. Time series of catch/biomass (Tables 13 and 14)

3. Graphs of estimates.
   a. Molting probability and trawl/pot selectivity (Figure 5)
   b. Trawl survey and model estimated trawl survey abundance (Figure 6)
   c. Estimated male abundances (recruits, legal, and total) (Figure 7)
   d. Estimated mature male biomass (Figure 8)
   e. Time series of standardized cpue for the summer commercial fishery (Figure 9).
   f. Time series of catch and estimated harvest rate (Figure 10).

4. Evaluation of the fit to the data.
   a. Fits to observed and model predicted catches.

      Not applicable. Catch is assumed to be measured without error; however fits of cpue are available (Figures 9, 11).
   b. Model fits to survey numbers (Figures 6, 11).

      All model estimated abundances of total crab were within the 95% confidence interval of the survey observed abundance, except for 1976 and 1979, where model estimates were higher than the observed abundances.
   c. Fits of catch proportions by lengths (Figures 12, 13).
   d. Model fits to catch and survey proportions by length (Figures 12, 14, 15, 16).
   e. Marginal distribution for the fits to the composition data

f. Plots of implied versus input effective sample sizes and time-series of implied effective sample size (Figure 4).

g. Tables of RMSEs for the indices:

Trawl survey:
Summer commercial standardized CPUE: (Table 1)

h. QQ plots and histograms of residuals (Figure 11).

5. Retrospective analyses (Figure 17).

Mohn's rho was 0.213 from 2007-2017. Mohn's rho suggests that retrospective projections are more likely to overestimate abundance. However, Mohns' rho has NO statistical range criteria of whether an assessment model is deemed acceptable/ unacceptable.

6. Uncertainty and sensitivity analyses.

See Sections 2 and 5.

a) Calculation of the OFL

1. Specification of the Tier level and stock status.

The Norton Sound red king crab stock is placed in Tier 4. It is not possible to estimate the spawner-recruit relationship, but some abundance and harvest estimates are available to build a computer simulation model that captures the essential population dynamics. Tier 4 stocks are assumed to have reliable estimates of current survey biomass and instantaneous M; however, the estimates for the Norton Sound red king crab stock are uncertain.

Tier 4 level and the OFL are determined by the F_{MSY} proxy, B_{MSY} proxy, and estimated legal male abundance and biomass:

level	Criteria	F_{OFL}
a	$B/B_{MSY^{prox}} > 1$	$F_{OFL} = \gamma\, M$
b	$\beta < B/B_{MSY^{prox}} \le 1$	$F_{OFL} = \gamma\, M_l\,(B/B_{MSY^{prox}} - \alpha)/(1-\alpha)$
c	$B/B_{MSY^{prox}} \le \beta$	$F_{OFL} = bycatch\ mortality\ \&\ directed\ \ fishery\ F = 0$

where B is a mature male biomass (MMB), B_{MSY} proxy is average mature male biomass over a specified time period, M = 0.18, γ = 1, α = 0.1, and β = 0.25

For Norton Sound red king crab, MMB is defined as the biomass of males > 94 mm CL on February 01 (Appendix A). B_{MSY} proxy is

B_{MSY} proxy = average model estimated MMB from 1980-2018

Predicted mature male biomass in 2018 on February 01 is:

Mature male biomass: 4.08 (SD 0.54) million lb.

Estimated B_{MSY} proxy is:

4.82 million lb.

Since projected MMB is less than B_{MSY} proxy, **Norton Sound red king crab stock status is Tier 4b**

2. Calculation of OFL.

OFL for the Norton Sound Red King Crab is retained (OFL_r) of legal sized crab biomass, *Legal_B*.

Legal_B is a biomass of legal sized crab subject to fisheries and is calculated as: Projected abundance by length class on Feb 01 ($N_{w,l} + O_{w,l}$)× summer fishing selectivity by length class ($S_{s,l}$)× Proportion of legal crab per length class ($P_{lg,l}$)× average lb per length class (wm_l).

For the Norton Sound red king crab assessment, *Legal_B* was defined as winter biomass catchable to summer commercial pot fishery gear $Legal\_B_w$, as

$$Legal\_B_w = \sum_l (N_{w,l,} + O_{w,l,}) S_{s,l} P_{lg,l} wm_l$$

The Norton Sound red king crab fishery consists of two distinct fisheries: winter and summer. The two fisheries are discontinuous with 5 months between the two fisheries during which natural mortalities occur. To incorporate this fishery, the CPT in 2016 recommended the following formula:

$$Legal\_B_s = Legal\_B_w (1 - \exp(-x \cdot F_{OFL})) e^{-0.42M}$$
$$OFL_r = (1 - \exp(-(1-x) \cdot F_{OFL})) Legal\_B_s$$

And $$p = \frac{Legal\_B_w (1 - \exp(-x \cdot F_{OFL}))}{OFL_r}$$

Where p is a specific proportion of winter crab harvest to total (winter + summer) harvest.

Solving x of the above, a revised retained OFL is

$$OFL_r = Legal\_B_w \left(1 - e^{-(F_{OFl} + 0.42M)} - (1 - e^{-0.42M}) \left(\frac{1 - p \cdot (1 - e^{-(F_{OFL} + 0.42M)})}{1 - p \cdot (1 - e^{-0.42M})} \right) \right)$$

Accounting for difference in length specific natural mortality

$$OFL_r = \sum_l \left[Legal\_B_{w,l} \left(1 - e^{-(F_{OF,l} + 0.42M_l)} - (1 - e^{-0.42M_l}) \left(\frac{1 - p \cdot (1 - e^{-(F_{OFL,l} + 0.42M_l)})}{1 - p \cdot (1 - e^{-0.42M_l})} \right) \right) \right]$$

For calculation of the OFL_r 2018, we specified p = 0.16, M_l = 0.18 for all length classes for calculation of F_{OFL}, and M_l = 0.58 for length classes greater than 123mm.

Legal male biomass catchable to fishery (Feb 01): 3.549 million lb
OFL_r = 0.43 million lb. or 0.20 kMT

b) Calculation of the ABC

1. Specification of the probability distribution of the OFL.

Retained ABC for legal male crab is 80% of OFL

ABC = 0.35 million lb or 0.16 kMT

c) Rebuilding Analyses

Not applicable

d) Data Gaps and Research Priorities

The major data gap is the fate of crab greater than 123 mm.
Estimates of discard is needed for calculation of total OFL.

Acknowledgments

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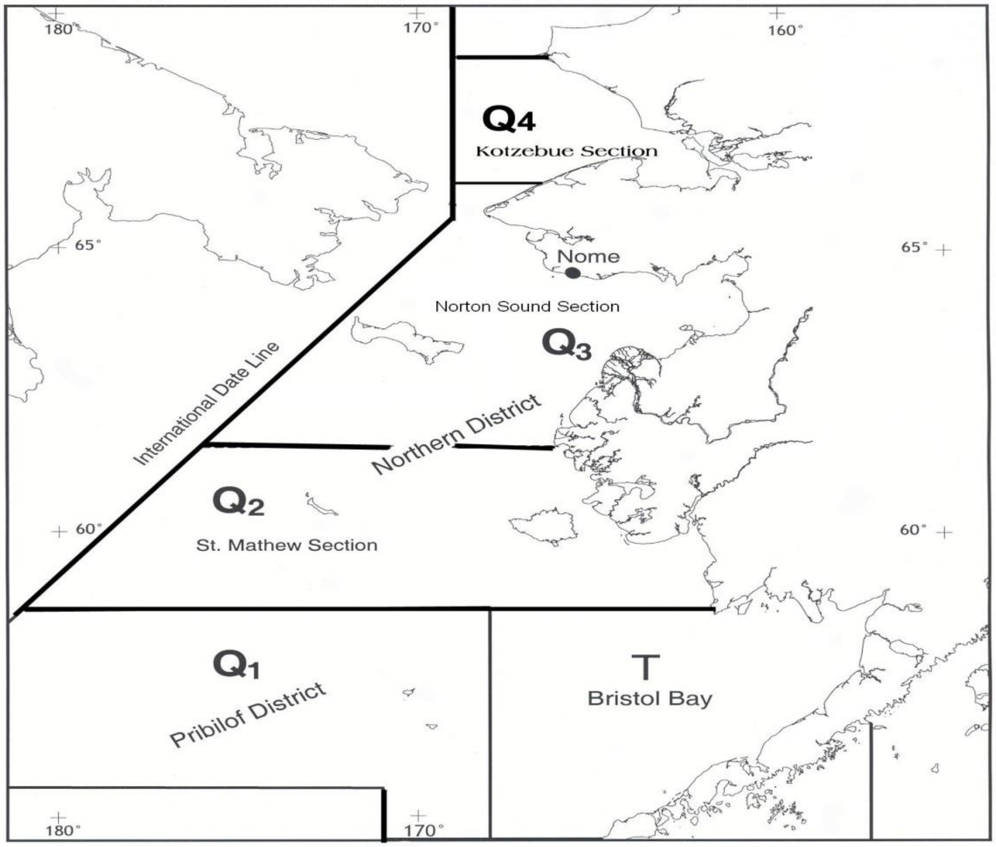


Figure 1. King crab fishing districts and sections of Statistical Area Q.

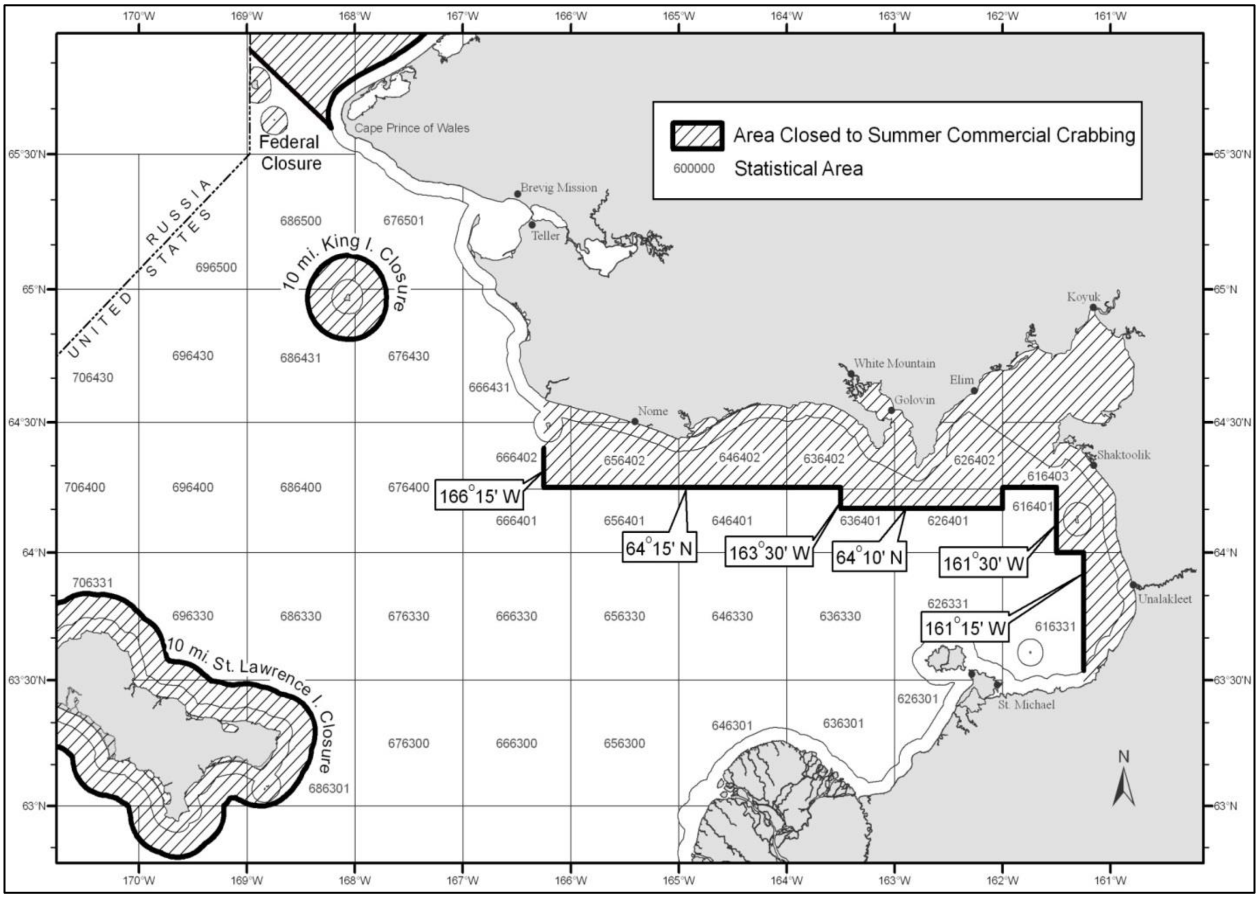


Figure 2. Closed water regulations in effect for the Norton Sound commercial crab fishery. Line around the coastline delineates the 3-mil3 state waters zone.

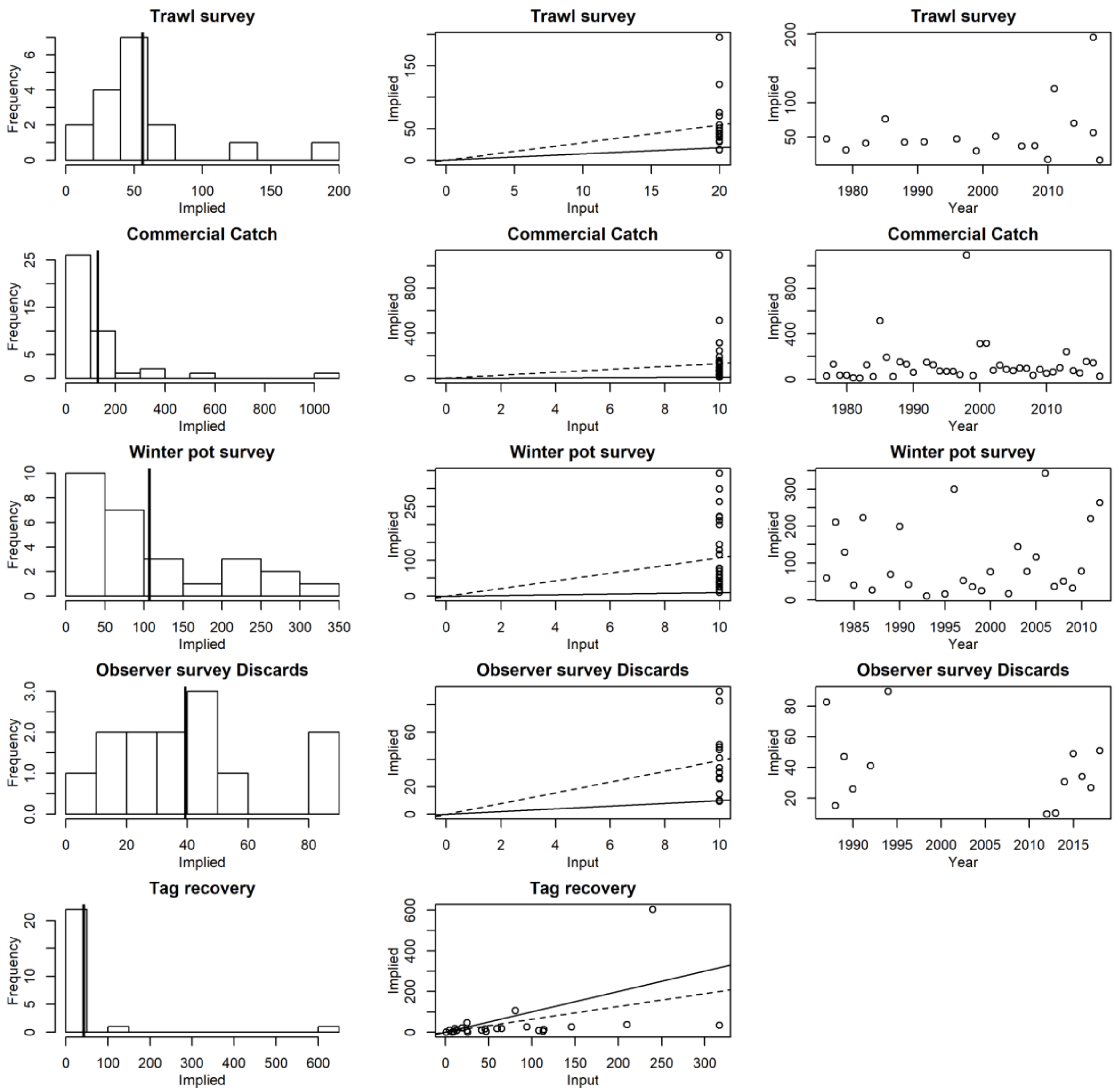


Figure 4. Input vs. model implied effective sample size. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis). Vertical solid line is the implied sample size. Figures in the second column show input sample sizes (x-axis) vs. implied effective sample sizes (y-axis). Dashed line indicates the linear regression slope, and solid line is 1:1 line. Figures in the third column show years (x-axis) vs. implied effective sample sizes (y-axis).

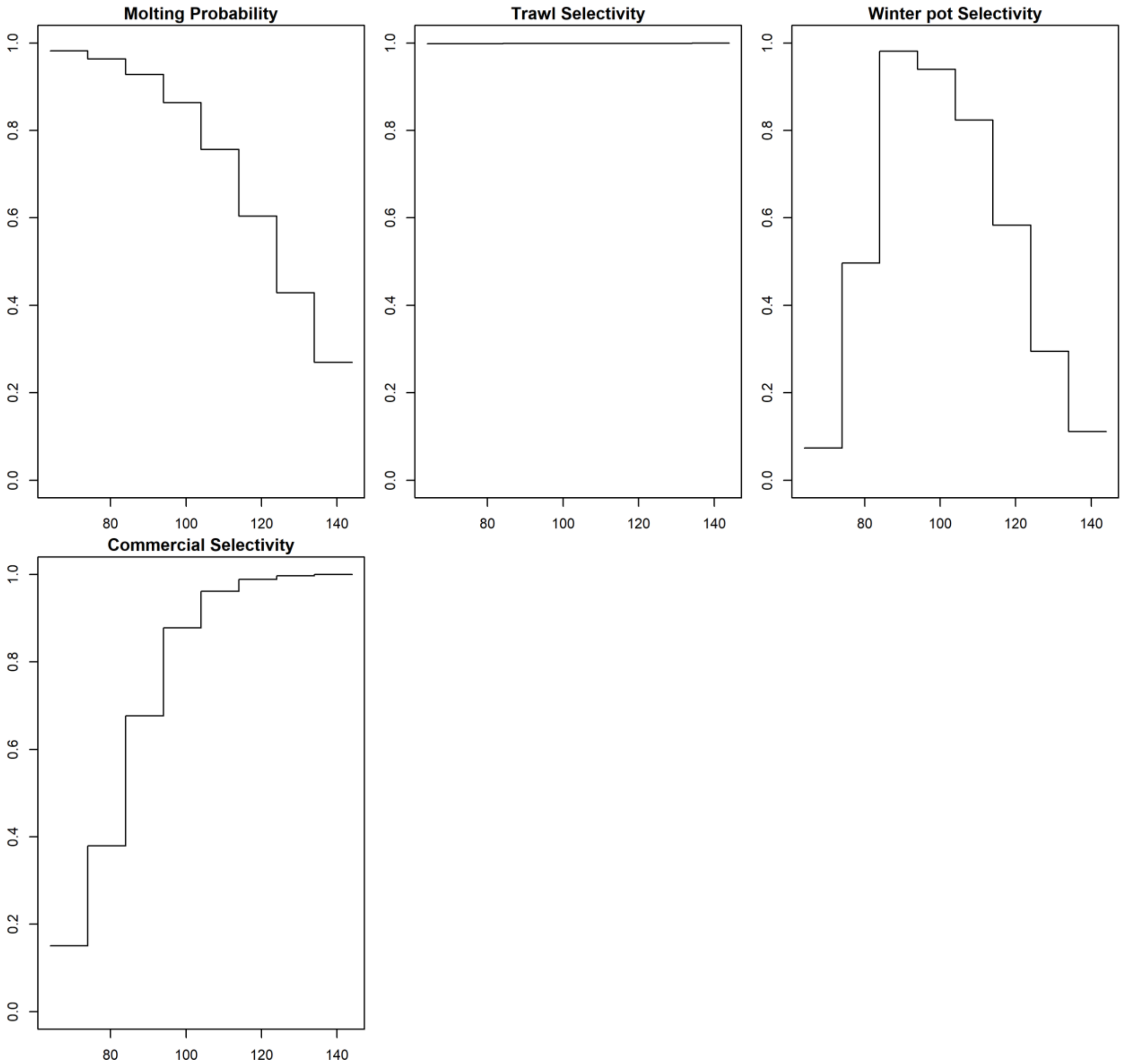


Figure 5. Model estimated annual molting probability, trawl survey selectivity, winter pot survey selectivity, and summer commercial fishery selectivity. X-axis is carapace length (mm).

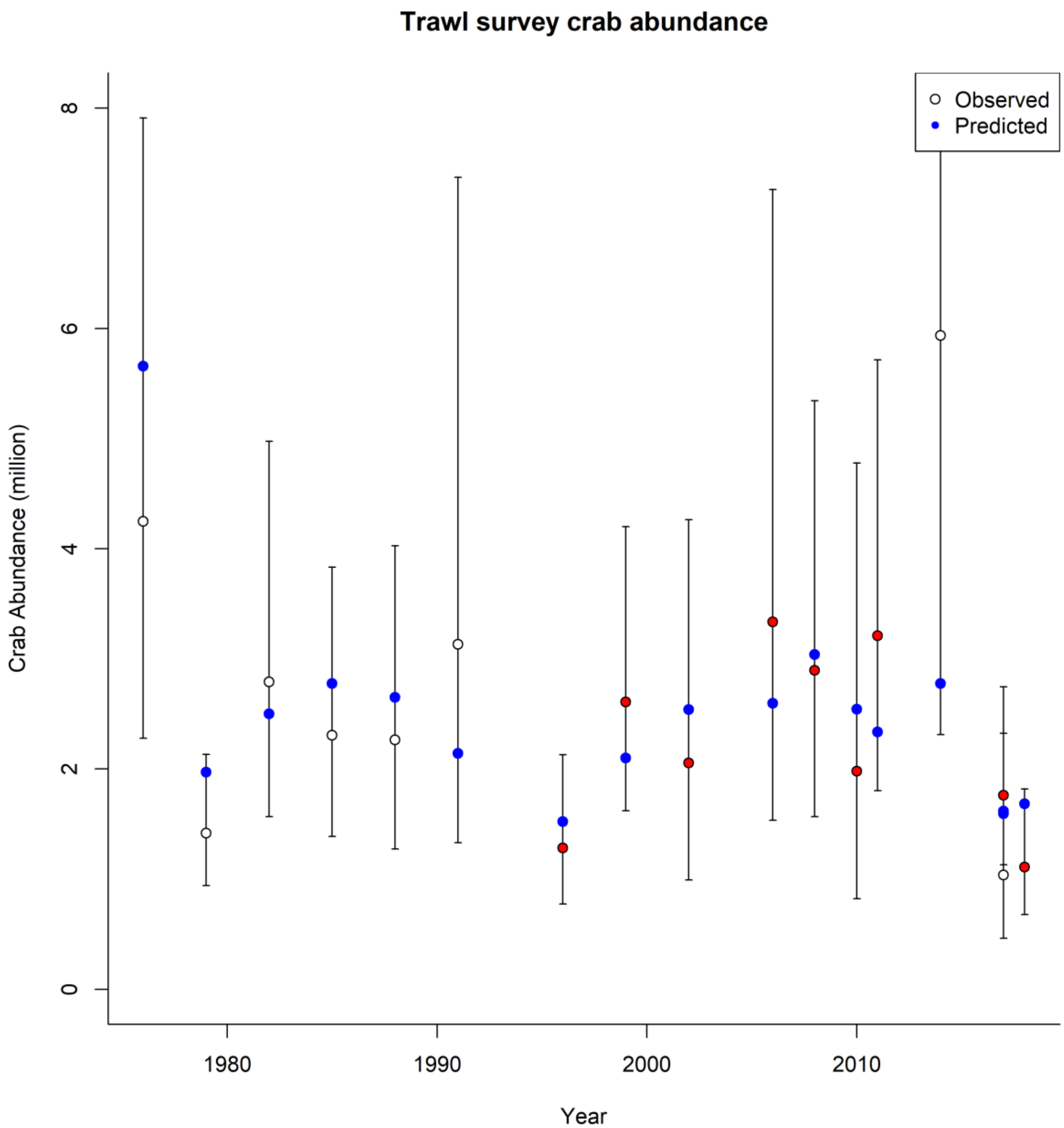


Figure 6. Observed (open circle) (White: NMFS, Red ADF&G) and model estimated (dots) trawl survey male abundances with 95% lognormal Confidence Intervals (1976-1991:crab ≥ 74 mm CL, 1996-2017:crab ≥ 64 mm CL)

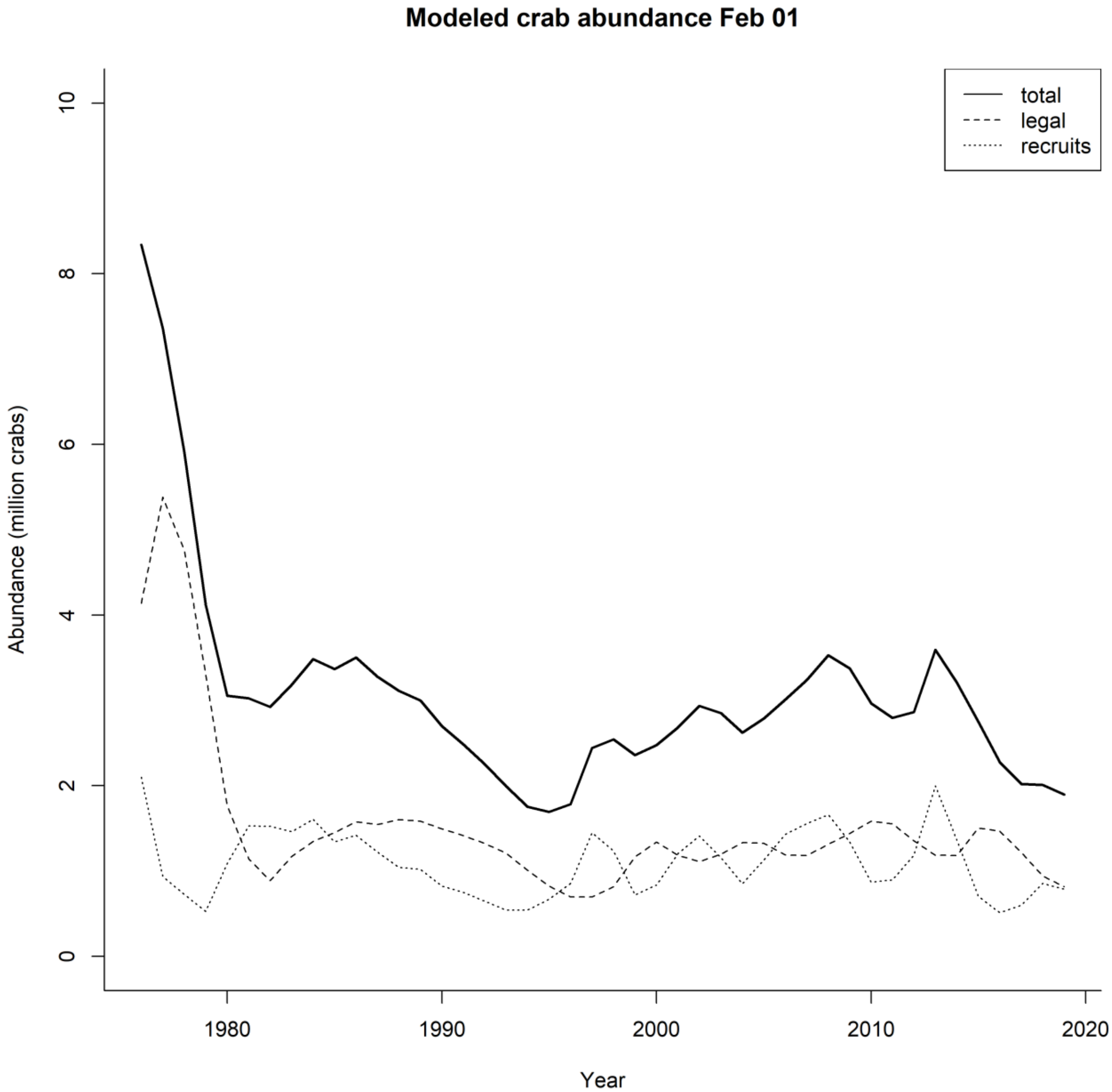


Figure 7. Model estimated abundances of total, legal (CL>104mm) and recruit (CL 64-94nn) males during1976-2018.

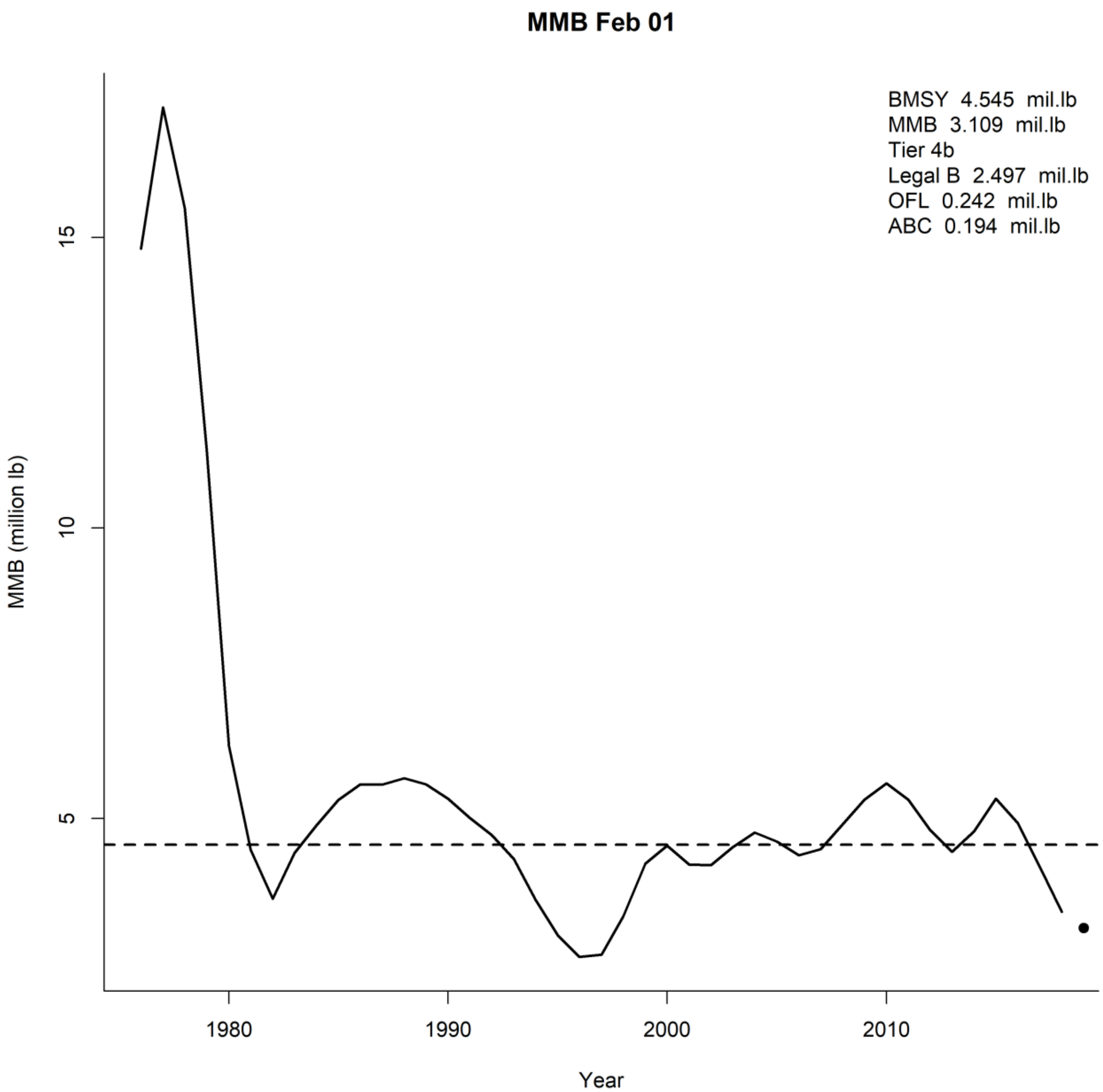


Figure 8. Estimated MMB during 1976-2018. Dash line shows Bmsy (Average MMB of 1980-2018). The black point indicates the projected MMB of 2018.

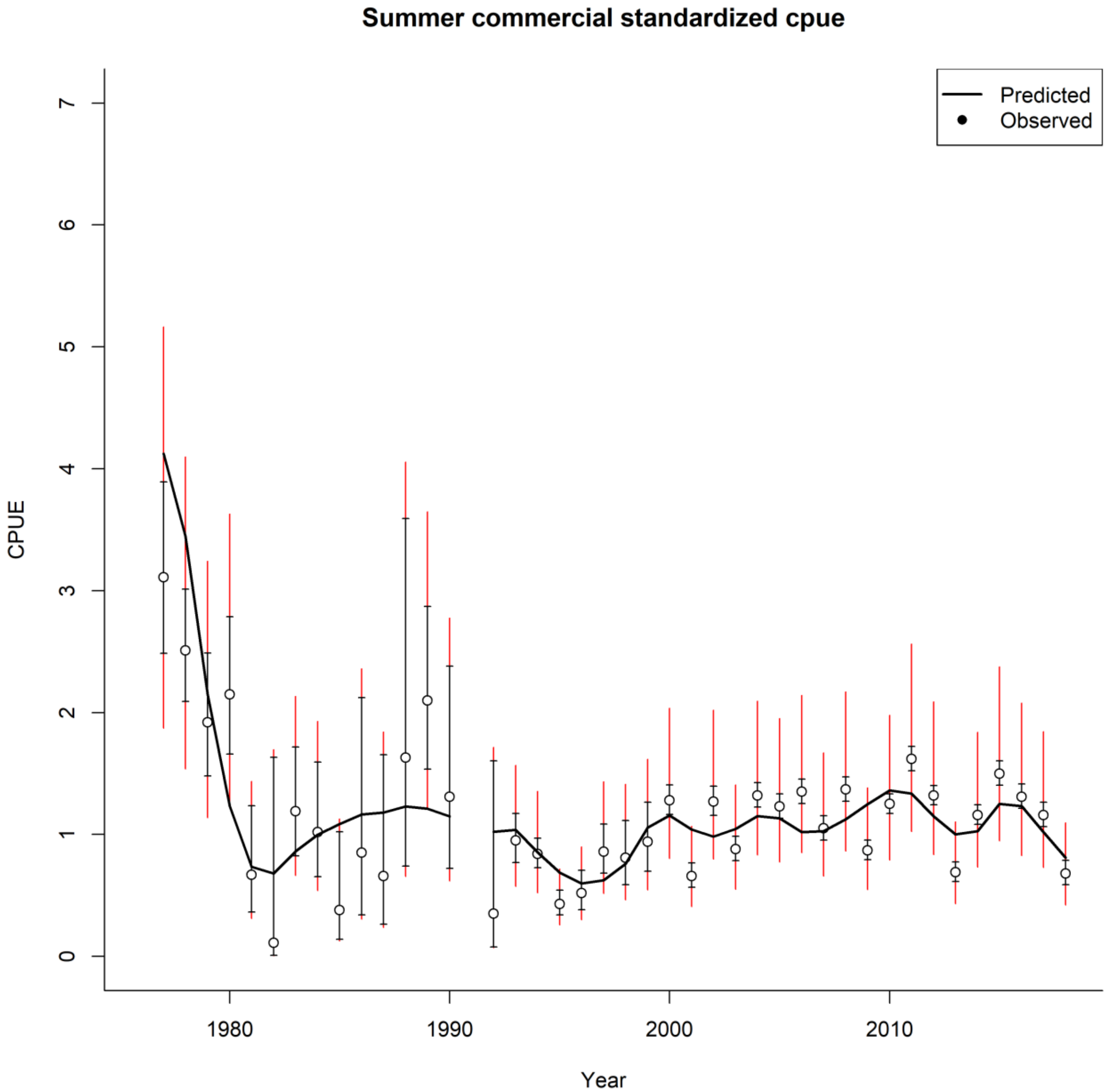


Figure 9. Summer commercial fishery standardized cpue. Vertical black lines are input SD and red lines are input and estimated additional SD.

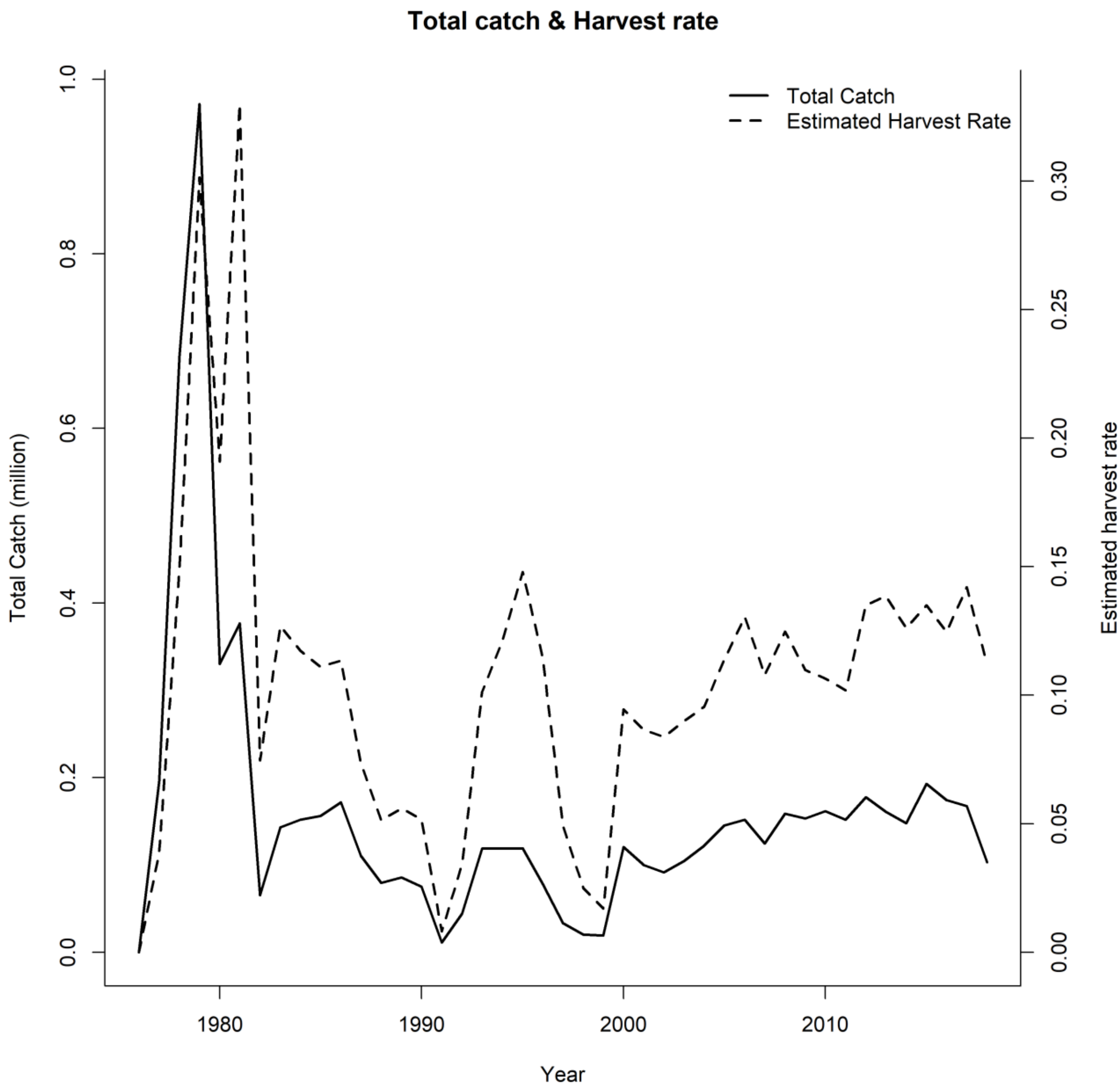


Figure 10. Commercial catch and estimated harvest rates of legal males over time.

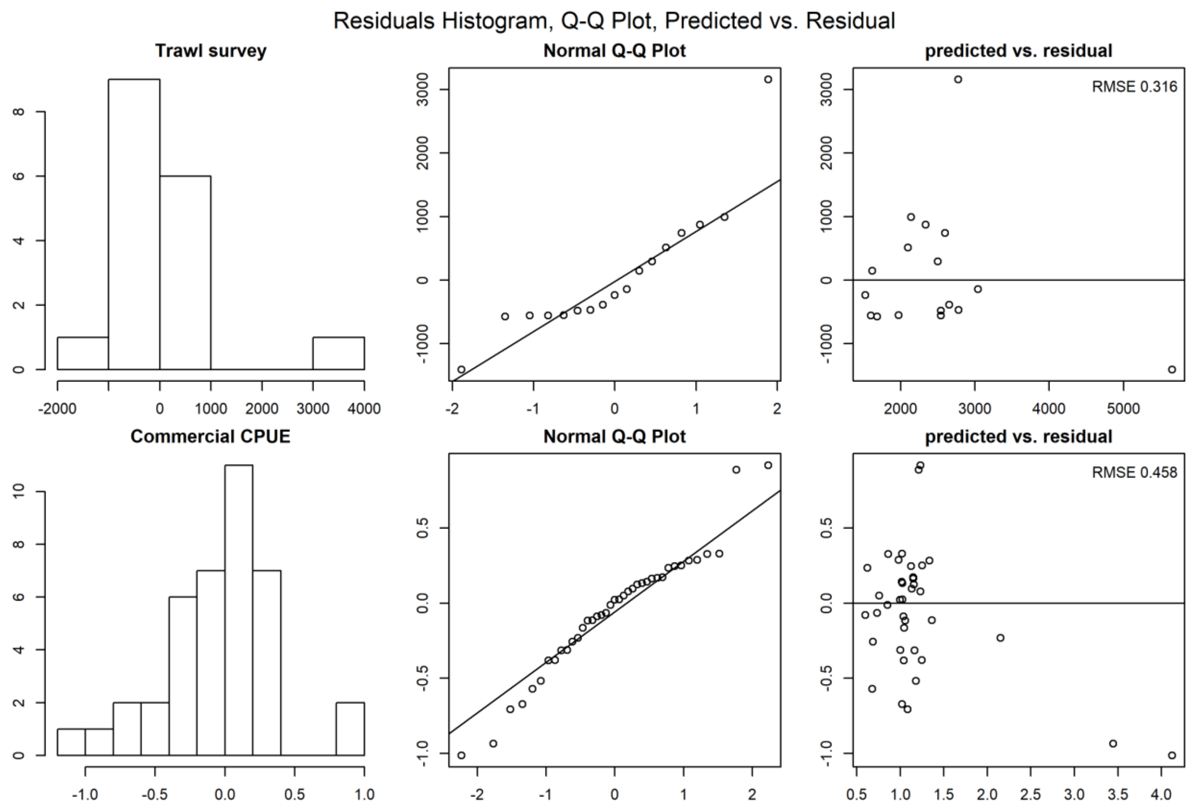
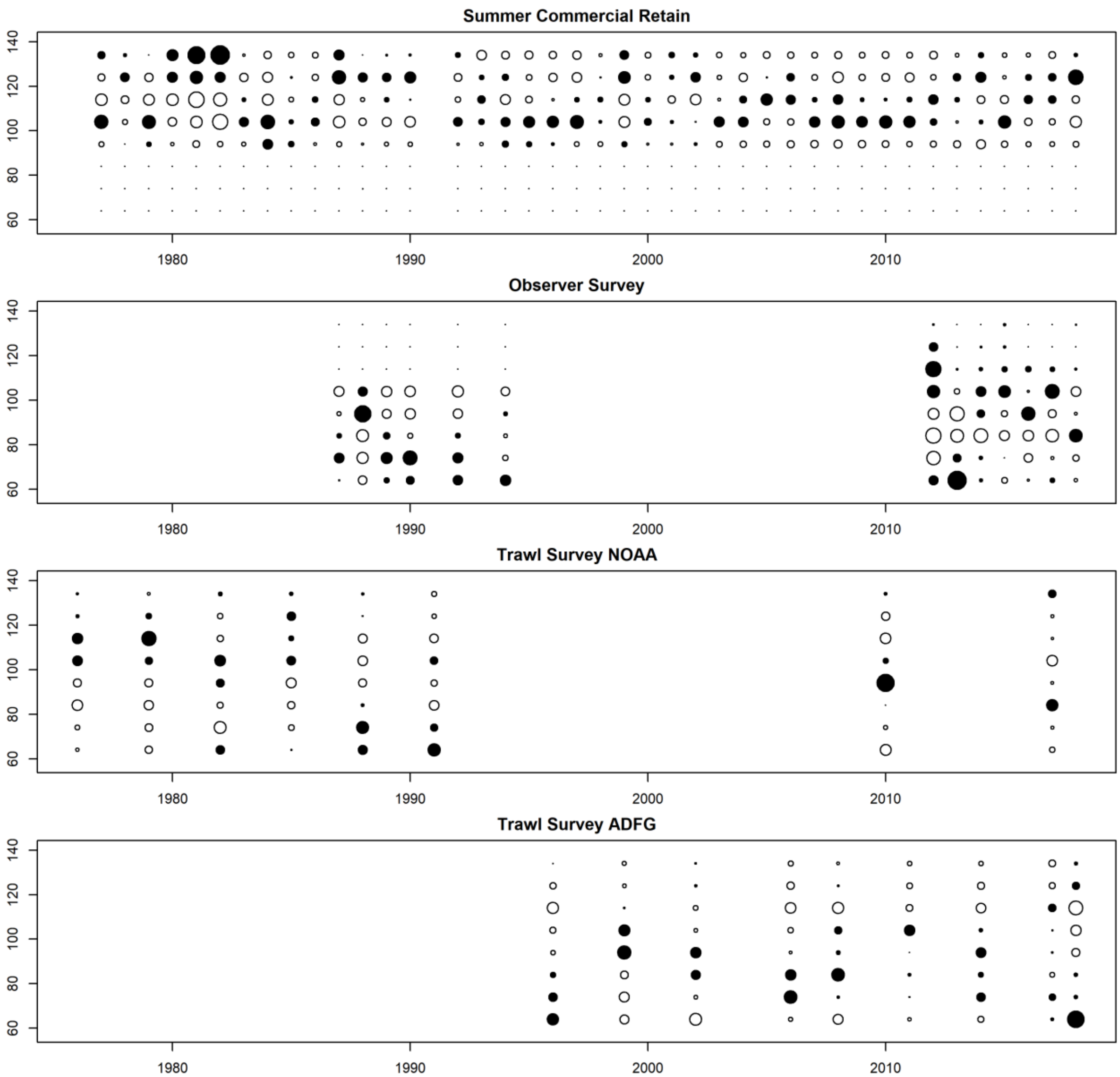
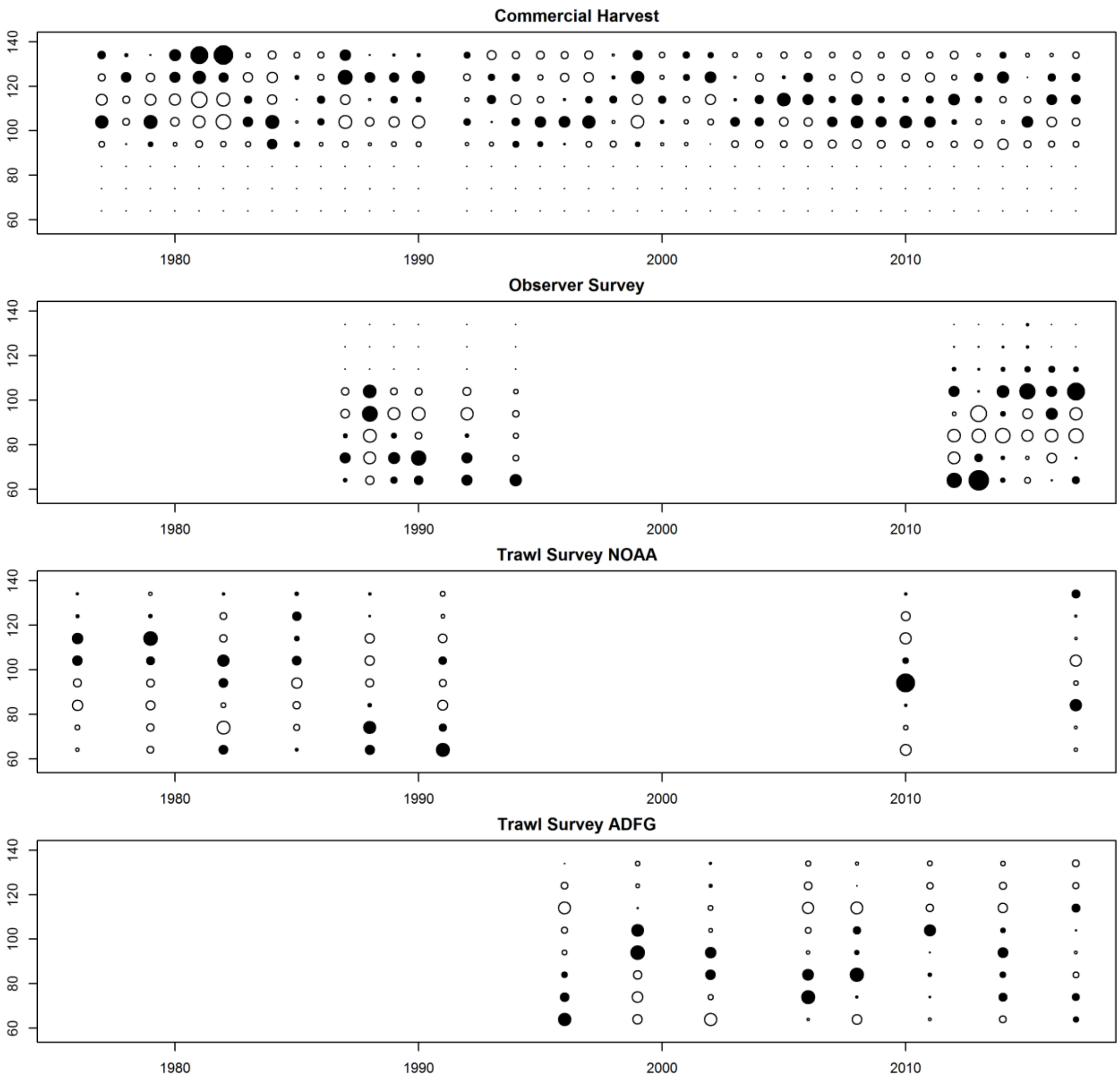


Figure 11. QQ plots of trawl survey abundance and commercial CPUE residuals.


Summer Commercial Retain
Observer Survey
Trawl Survey NOAA
Trawl Survey ADFG
60
80
100
120
140
1980
1990
2000
2010


Commercial Harvest
Observer Survey
Trawl Survey NOAA
Trawl Survey ADFG
140
120
100
80
60
1980
1990
2000
2010

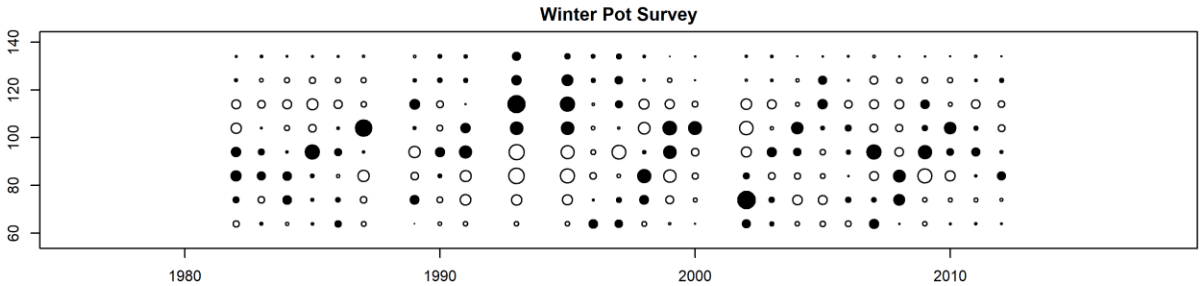


Figure 12. Bubble plot of predicted and observed length proportions. Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

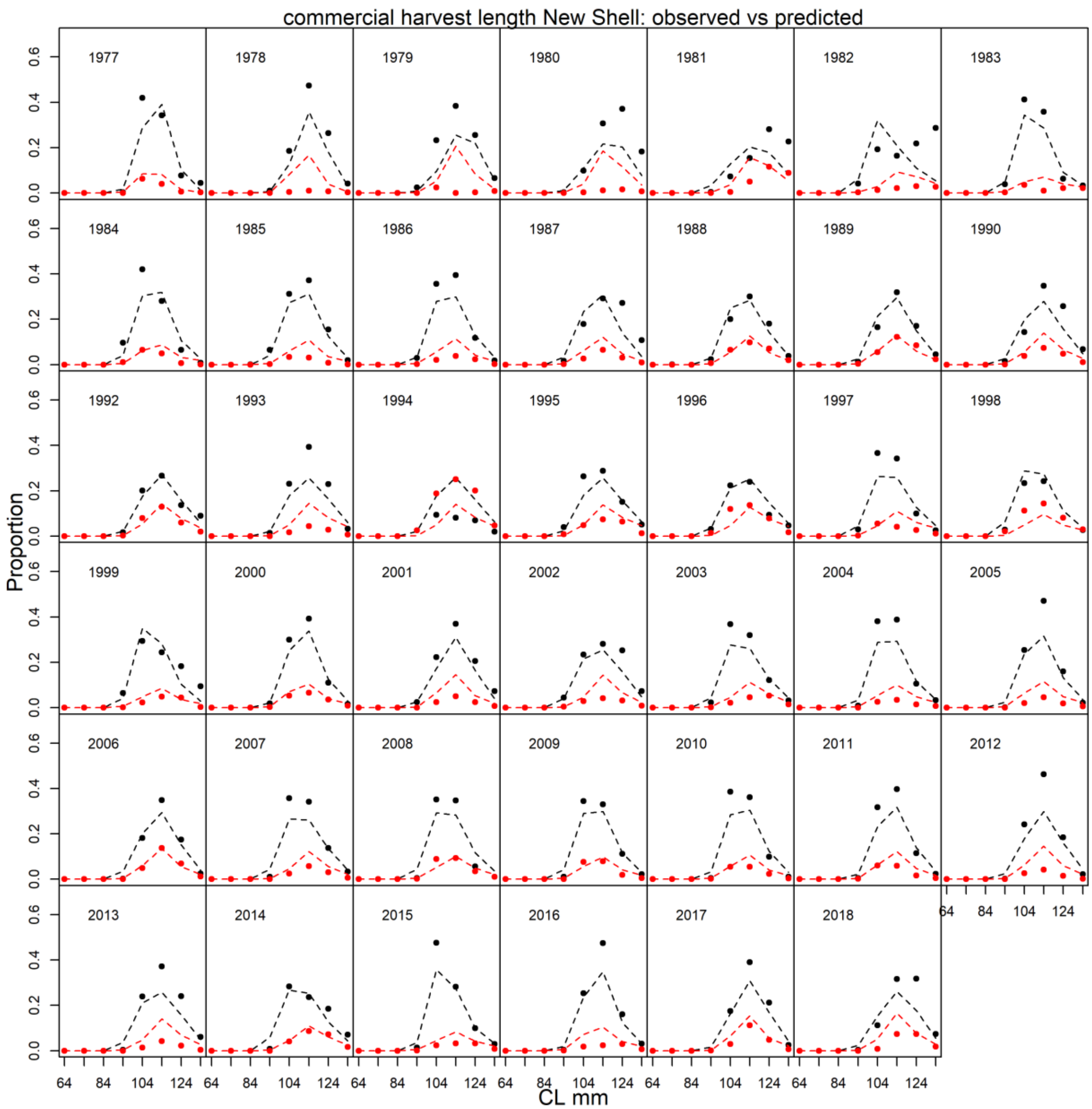


Figure 13. Predicted (dashed line) vs. observed (black dots) length class proportions for the summer commercial catch. Black: New Shell, Red: Old Shell

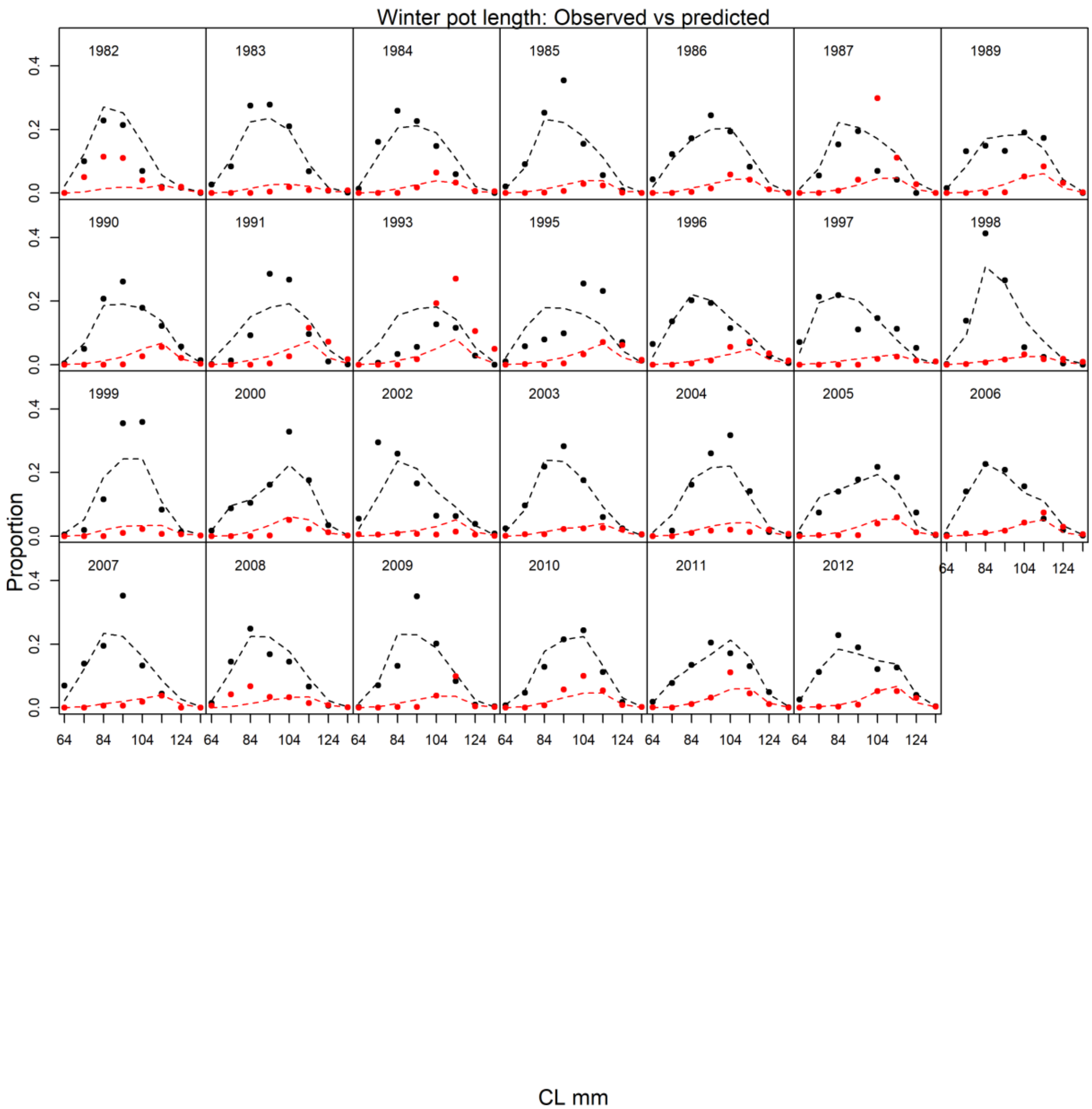
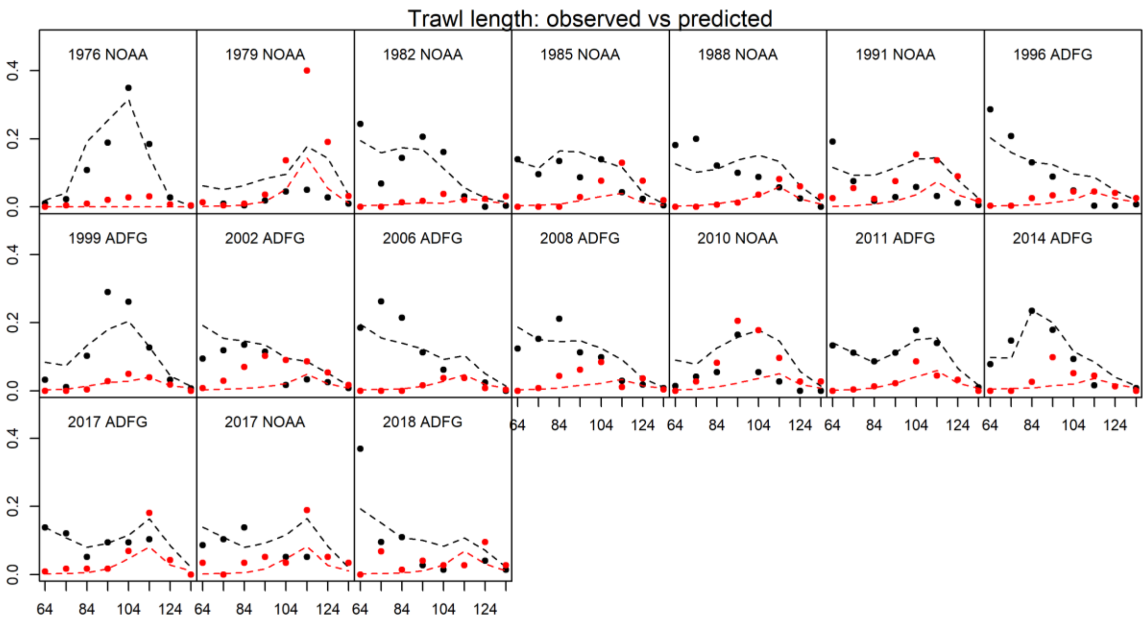


Figure 14. Predicted vs. observed length class proportions for winter pot survey. Black: New Shell, Red: Old Shell



Trawl length: observed vs predicted
1976 NOAA
1979 NOAA
1982 NOAA
1985 NOAA
1988 NOAA
1991 NOAA
1996 ADFG
1999 ADFG
2002 ADFG
2006 ADFG
2008 ADFG
2010 NOAA
2011 ADFG
2014 ADFG
2017 ADFG
2017 NOAA
2018 ADFG
0.0
0.2
0.4
64
84
104
124

\

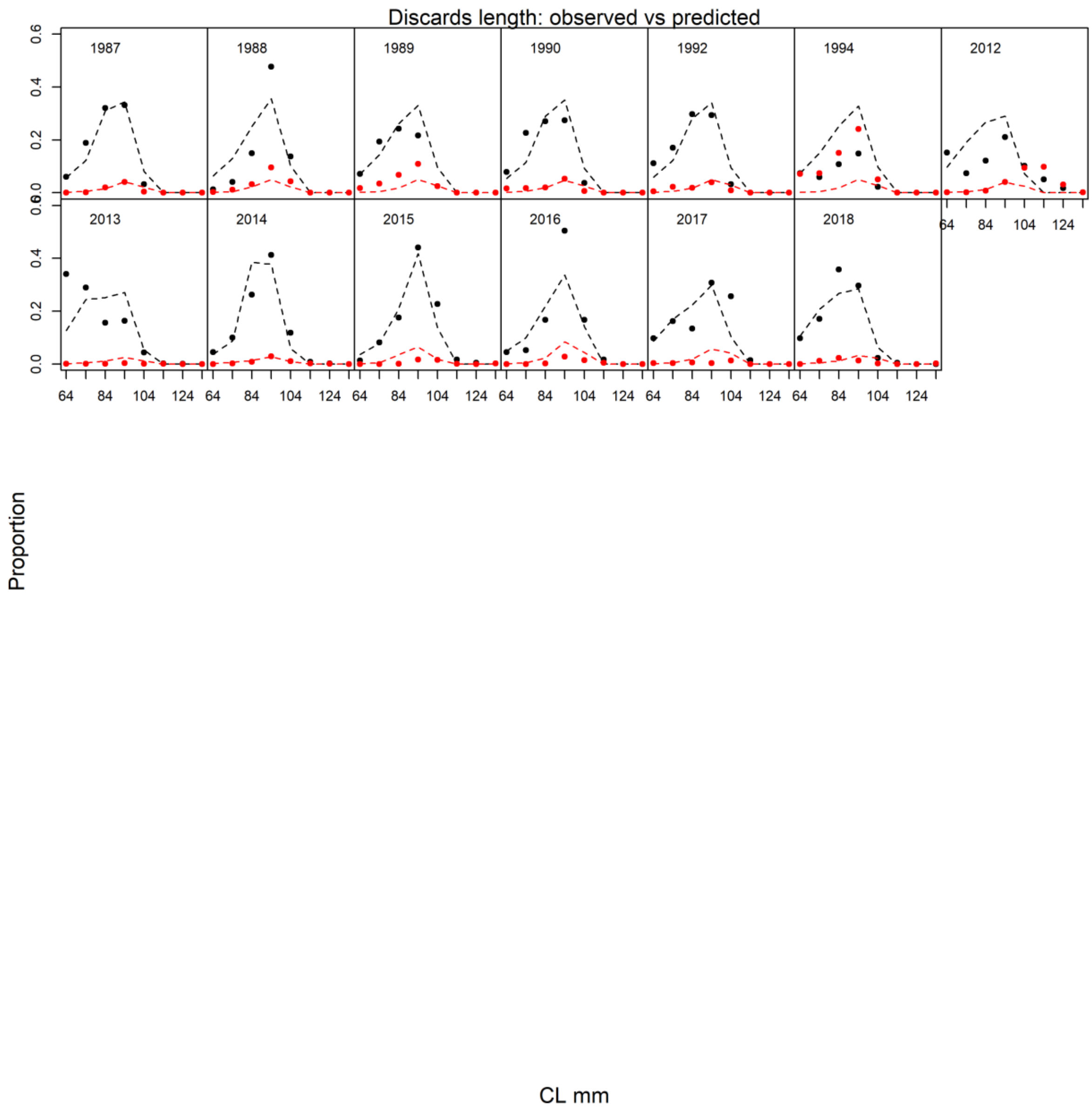


Figure 15. Predicted vs. observed length class proportions for trawl survey and commercial observer data. Black: New Shell, Red: Old Shell

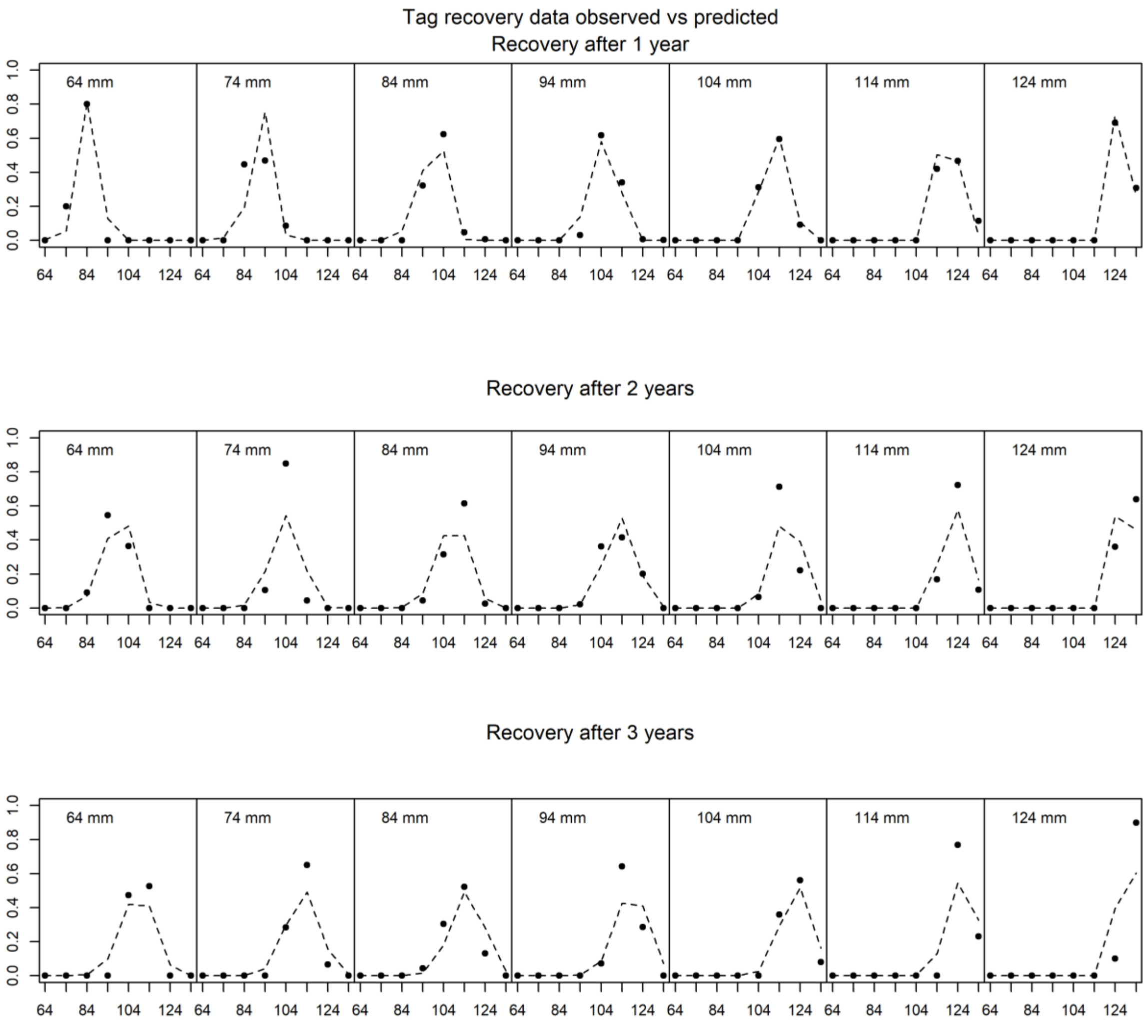


Figure 16. Predicted vs. observed length class proportions for tag recovery data.

Figure 17. Retrospective analyses. Each line shows a series of retrospective MMB.

Table 1. Historical summer commercial red king crab fishery economic performance, Norton Sound Section, eastern Bering Sea, 1977-2017. Bold type shows data that are used for the assessment model.

Year	Guideline Harvest Level (lb) [b]	Commercial Harvest (lb) [a, b] Open Access	CDQ	Number Harvest	Total Number (Open Access) Vessels	Permits	Landings	Total Pots Registered	Pulls	ST CPUE CPUE	SD	Season Length Days	Dates	Mid-day from July
1977	[c]	517.787		**195,877**	7	7	13		5,457	**3.32**	**0.67**	60	[c]	**0.049**
1978	3,000.000	2,091.961		**660,829**	8	8	54		10,817	**4.72**	**0.64**	60	6/07-8/15	**0.142**
1979	3,000.000	2,931.672		**970,962**	34	34	76		34,773	**2.89**	**0.63**	16	7/15-7/31	**0.088**
1980	1,000.000	1,186.596		**329,778**	9	9	50		11,199	**3.11**	**0.64**	16	7/15-7/31	**0.066**
1981	2,500.000	1,379.014		**376,313**	36	36	108		33,745	**0.87**	**0.62**	38	7/15-8/22	**0.096**
1982	500.000	228.921		**63,949**	11	11	33		11,230	**0.20**	**0.61**	23	8/09-9/01	**0.151**
1983	300.000	368.032		**132,205**	23	23	26	3,583	11,195	**0.90**	**0.64**	3.8	8/01-8/05	**0.096**
\1984	400.000	387.427		**139,759**	8	8	21	1,245	9,706	**1.61**	**0.64**	13.6	8/01-8/15	**0.110**
1985	450.000	427.011		**146,669**	6	6	72	1,116	13,209	**0.50**	**0.65**	21.7	8/01-8/23	**0.118**
1986	420.000	479.463		**162,438**	3	3		578	4,284	**1.79**	**0.69**	13	8/01-8/25	**0.153**
1987	400.000	327.121		**103,338**	9	9		1,430	10,258	**0.62**	**0.63**	11	8/01-8/12	**0.107**
1988	200.000	236.688		**76,148**	2	2		360	2,350	**2.39**	**0.84**	9.9	8/01-8/11	**0.110**
1989	200.000	246.487		**79,116**	10	10		2,555	5,149	**1.21**	**0.60**	3	8/01-8/04	**0.096**
1990	200.000	192.831		**59,132**	4	4		1,388	3,172	**1.09**	**0.67**	4	8/01-8/05	**0.099**
1991	340.000			**0**	No Summer Fishery									
1992	340.000	74.029		**24,902**	27	27		2,635	5,746	**0.17**	**0.59**	2	8/01-8/03	**0.093**
1993	340.000	335.790		**115,913**	14	20	208	560	7,063	**0.85**	**0.35**	52	7/01-8/28	**0.093**
1994	340.000	327.858		**108,824**	34	52	407	1,360	11,729	**0.75**	**0.34**	31	7/01-7/31	**0.044**
1995	340.000	322.676		**105,967**	48	81	665	1,900	18,782	**0.39**	**0.34**	67	7/01-9/05	**0.093**
1996	340.000	224.231		**74,752**	41	50	264	1,640	10,453	**0.48**	**0.35**	57	7/01-9/03	**0.101**
1997	80.000	92.988		**32,606**	13	15	100	520	2,982	**0.79**	**0.36**	44	7/01-8/13	**0.074**
1998	80.000	29.684	0.00	**10,661**	8	11	50	360	1,639	**0.74**	**0.37**	65	7/01-9/03	**0.110**
1999	80.000	23.553	0.00	**8,734**	10	9	53	360	1,630	**0.86**	**0.37**	66	7/01-9/04	**0.104**
2000	336.000	297.654	14.87	**111,728**	15	22	201	560	6,345	**1.17**	**0.34**	91	7/01- 9/29	**0.126**
2001	303.000	288.199	0	**98,321**	30	37	319	1,200	11,918	**0.60**	**0.34**	97	7/01- 9/09	**0.104**
2002	248.000	244.376	15.226	**86,666**	32	49	201	1,120	6,491	**1.16**	**0.34**	77	6/15-9/03	**0.060**
2003	253.000	253.284	13.923	**93,638**	25	43	236	960	8,494	**0.80**	**0.34**	68	6/15-8/24	**0.058**
2004	326.500	314.472	26.274	**120,289**	26	39	227	1,120	8,066	**1.20**	**0.34**	51	6/15-8/08	**0.033**
2005	370.000	370.744	30.06	**138,926**	31	42	255	1,320	8,867	**1.13**	**0.34**	73	6/15-8/27	**0.058**
2006	454.000	419.191	32.557	**150,358**	28	40	249	1,120	8,867	**1.23**	**0.34**	68	6/15-8/22	**0.052**
2007	315.000	289.264	23.611	**110,344**	38	30	251	1,200	9,118	**0.97**	**0.34**	52	6/15-8/17	**0.036**
2008	412.000	364.235	30.9	**143,337**	23	30	248	920	8,721	**1.25**	**0.34**	73	6/23-9/03	**0.079**
2009	375.000	369.462	28.125	**143,485**	22	27	359	920	11,934	**0.79**	**0.34**	98	6/15-9/20	**0.090**
2010	400.000	387.304	30	**149,822**	23	32	286	1,040	9,698	**1.14**	**0.34**	58	6/28-8/24	**0.074**
2011	358.000	373.990	26.851	**141,626**	24	25	173	1,040	6,808	**1.48**	**0.34**	33	6/28-7/30	**0.038**
2012	465.450	441.080	34.91	**161,113**	40	29	312	1,200	10,041	**1.22**	**0.34**	72	6/29-9/08	**0.093**
2013	495.600	373.278	18.585	**130,603**	37	33	460	1,420	15,058	**0.63**	**0.34**	74	7/3-9/14	**0.110**
2014	382.800	360.860	28.148	**129,657**	52	33	309	1,560	10,127	**1.06**	**0.34**	52	6/25-8/15	**0.052**
2015	394.600	371.520	29.595	**144,255**	42	36	251	1,480	8,356	**1.37**	**0.34**	26	6/29-7/24	**0.033**
2016	517.200	416.576	3,583	**138,997**	36	37	220	1,520	8,009	**1.20**	**0.34**	25	6/27-7/21	**0.025**
2017	496,800	411,736	0	**135,322**	36	36	270	1,640	9,401	**1.06**	**0.34**	30	6/26-7/25	**0.027**
2018	290,282	298,396	0	**89,613**	34	34	256	1,400	8,797	**0.62**	**0.34**	35	6/24-7/29	**0.038**

[a] Deadloss included in total. [b] Millions of pounds. [c] Information not available.

Table 2. Historical winter commercial and subsistence red king crab fisheries, Norton Sound Section, eastern Bering Sea, 1977-2016. Bold typed data are used for the assessment model.

		Commercial			Subsistence				
Model Year	Year[a]	# of Fishers	# of Crab Harvested	Winter[b]	Permits Issued	Permits Returned	Permits Fished	Total Crab Caught[c]	Total Crab Retained[d]
1978	1978	37	**9,625**	1977/78	290	206	149	**NA**	**12,506**
1979	1979	1[f]	**221**[f]	1978/79	48	43	38	**NA**	**224**
1980	1980	1[f]	**22**[f]	1979/80	22	14	9	**NA**	**213**
1981	1981	0	**0**	1980/81	51	39	23	**NA**	**360**
1982	1982	1[f]	**17**[f]	1981/82	101	76	54	**NA**	**1,288**
1983	1983	5	**549**	1982/83	172	106	85	**NA**	**10,432**
1984	1984	8	**856**	1983/84	222	183	143	**15,923**	**11,220**
1985	1985	9	**1,168**	1984/85	203	166	132	**10,757**	**8,377**
1986	1985/86	5	**2,168**	1985/86	136	133	107	**10,751**	**7,052**
1987	1986/87	7	**1,040**	1986/87	138	134	98	**7,406**	**5,772**
1988	1987/88	10	**425**	1987/88	71	58	40	**3,573**	**2,724**
1989	1988/89	5	**403**	1988/89	139	115	94	**7,945**	**6,126**
1990	1989/90	13	**3,626**	1989/90	136	118	107	**16,635**	**12,152**
1991	1990/91	11	**3,800**	1990/91	119	104	79	**9,295**	**7,366**
1992	1991/92	13	**7,478**	1991/92	158	105	105	**15,051**	**11,736**
1993	1992/93	8	**1,788**	1992/93	88	79	37	**1,193**	**1,097**
1994	1993/94	25	**5,753**	1993/94	118	95	71	**4,894**	**4,113**
1995	1994/95	42	**7,538**	1994/95	166	131	97	**7,777**	**5,426**
1996	1995/96	9	**1,778**	1995/96	84	44	35	**2,936**	**1,679**
1997	1996/97	2[f]	**83**[f]	1996/97	38	22	13	**1,617**	**745**
1998	1997/98	5	**984**	1997/98	94	73	64	**20,327**	**8,622**
1999	1998/99	5	**2,714**	1998/99	95	80	71	**10,651**	**7,533**
2000	1999/00	10	**3,045**	1999/00	98	64	52	**9,816**	**5,723**
2001	2000/01	3	**1,098**	2000/01	50	27	12	**366**	**256**
2002	2001/02	11	**2,591**	2001/02	114	61	45	**5,119**	**2,177**
2003	2002/03	13	**6,853**	2002/03	107	70	61	**9,052**	**4,140**
2004	2003/04	2[f]	**522** [f]	2003/04[g]	96	77	41	**1,775**	**1,181**
2005	2004/05	4	**2,091**	2004/05	170	98	58	**6,484**	**3,973**
2006	2005/06	1[f]	**75**[f]	2005/06	98	97	67	**2,083**	**1,239**
2007	2006/07	8	**3,313**	2006/07	129	127	116	**21,444**	**10,690**
2008	2007/08	9	**5,796**	2007/08	139	137	108	**18,621**	**9,485**
2009	2008/09	7	**4,951**	2008/09	105	105	70	**6,971**	**4,752**
2010	2009/10	10	**4,834**	2009/10	125	123	85	**9,004**	**7,044**
2011	2010/11	5	**3,365**	2010/11	148	148	95	**9,183**	**6,640**
2012	2011/12	35	**9,157**	2011/12	204	204	138	**11,341**	**7,311**
2013	2012/13	26	**22,639**	2012/13	149	148	104	**21,524**	**7,622**
2014	2013/14	21	**14,986**	2013/14	103	103	75	**5,421**	**3,252**
2015	2014/15	44	**41,062**	2014/15	155	153	107	**9,840**	**7,651**
2016	2015/16	25	**29,792**	2015/16	139	97	64	**6,468**	**5,340**
2017	2017	43	**26,008**	2017	163	163	109	**7,185**	**6,039**
2018	2018	28	**9,180**	2018	123	120	82	**5,767**	**4,424**

a Prior to 1985 the winter commercial fishery occurred from January 1 - April 30. As of March 1985, fishing may occur from November 15 - May 15.
b The winter subsistence fishery occurs during months of two calendar years (as early as December, through May).
c The number of crab actually caught; some may have been returned.
d The number of crab retained is the number of crab caught and kept.
f Confidentiality was waived by the fishers.
h Prior to 2005, permits were only given out of the Nome ADF&G office. Starting with the 2004-5 season, permits were given out in Elim, Golovin, Shaktoolik, and White Mountain.

Table 3. Summary of triennial trawl survey Norton Sound male red king crab abundance estimates (CL ≥ 64mm) . Trawl survey abundance estimate is based on 10×10 nm^2 grid, except for 2010 and 2017 (20×20 nm^2). Bold typed data are used for the assessment model.

Year	Dates	Survey Agency	Survey method	Survey coverage			Abundance ≥74 mm (1982-1991) ≥64 mm (1996- 2007)	
				Total surveyed stations	Stations w/ NSRKC	n mile² covered		CV
1976	9/02 – 9/25	NMFS	Trawl	103	62	10260	**4247.5**	**0.31**
1979	7/26 - 8/05	NMFS	Trawl	85	22	8421	**1417.2**	**0.20**
1980	7/04 - 7/14	ADFG	Pots				2092.3	N/A
1981	6/28 - 7/14	ADFG	Pots				2153.4	N/A
1982	7/06 - 7/20	ADFG	Pots				1140.5	N/A
1982	9/05 - 9/11	NMFS	Trawl	58	37	5721	**2791.7**	**0.29**
1985	7/01 - 7/14	ADFG	Pots				2320.4	0.083
1985	9/16 -10/01	NMFS	Trawl	78	49	7688	**2306.3**	**0.25**
1988	8/16 - 8/30	NMFS	Trawl	78	41	7721	**2263.4**	**0.29**
1991	8/22 - 8/30	NMFS	Trawl	52	38	5183	**3132.5**	**0.43**
1996	8/07 - 8/18	ADFG	Trawl	50	30	4938	**1283.0**	**0.25**
1999	7/28 - 8/07	ADFG	Trawl	52	31	5221	**2608.0**	**0.24**
2002	7/27 - 8/06	ADFG	Trawl	57	37	5621	**2056.0**	**0.36**
2006	7/25 - 8/08	ADFG	Trawl	114	45	10008	**3336.0**	**0.39**
2008	7/24 - 8/11	ADFG	Trawl	86	44	7330	**2894.2**	**0.31**
2010[a]	7/27 - 8/09	NMFS	Trawl	35	15	5841	**1980.1**	**0.44**
2011	7/18 - 8/15	ADFG	Trawl	65	34	6447	**3209.3**	**0.29**
2014	7/18 - 7/30	ADFG	Trawl	47	34	4700	**5934.6**	**0.47**
2017	7/28 - 8/08	ADFG	Trawl	60	41	6000	**1762.1**	**0.22**
2017	8/18 - 8/29	NMFS	Trawl	35	18	5841	**1035.8**	**0.40**
2018	7/22 - 7/29	ADFG	Trawl	60	34	6000	**1108.9**	**0.25**

Table 4. Summer commercial retained catch length-shell compositions.

		New Shell								Old Shell							
Year	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1977	1549	0	0	0	0.00	0.42	0.34	0.08	0.05	0	0	0	0.00	0.06	0.04	0.01	0.00
1978	389	0	0	0	0.01	0.19	0.47	0.26	0.04	0	0	0	0.00	0.01	0.01	0.01	0.00
1979	1660	0	0	0	0.03	0.23	0.38	0.26	0.07	0	0	0	0.00	0.03	0.00	0.00	0.01
1980	1068	0	0	0	0.00	0.10	0.31	0.37	0.18	0	0	0	0.00	0.00	0.01	0.02	0.01
1981	1784	0	0	0	0.00	0.07	0.15	0.28	0.23	0	0	0	0.00	0.00	0.05	0.12	0.09
1982	1093	0	0	0	0.04	0.19	0.16	0.22	0.29	0	0	0	0.00	0.01	0.02	0.03	0.03
1983	802	0	0	0	0.04	0.41	0.36	0.06	0.03	0	0	0	0.00	0.04	0.01	0.02	0.02
1984	963	0	0	0	0.10	0.42	0.28	0.06	0.01	0	0	0	0.01	0.07	0.05	0.01	0.00
1985	2691	0	0	0.00	0.06	0.31	0.37	0.15	0.02	0	0	0	0.00	0.03	0.03	0.01	0.00
1986	1138	0	0	0	0.03	0.36	0.39	0.12	0.02	0	0	0	0.00	0.02	0.04	0.02	0.00
1987	1985	0	0	0	0.02	0.18	0.29	0.27	0.11	0	0	0	0.00	0.03	0.06	0.03	0.01
1988	1522	0	0.00	0	0.02	0.20	0.30	0.18	0.04	0	0	0	0.01	0.06	0.10	0.07	0.02
1989	2595	0	0	0	0.01	0.16	0.32	0.17	0.05	0	0	0	0.00	0.06	0.12	0.09	0.02
1990	1289	0	0	0	0.01	0.14	0.35	0.26	0.07	0	0	0	0.00	0.04	0.07	0.05	0.01
1991																	
1992	2566	0	0	0	0.02	0.20	0.27	0.14	0.09	0	0	0	0.00	0.08	0.13	0.06	0.02
1993	17804	0	0	0	0.01	0.23	0.39	0.23	0.03	0	0	0	0.00	0.02	0.04	0.03	0.01
1994	404	0	0	0	0.02	0.09	0.08	0.07	0.02	0	0	0	0.02	0.19	0.25	0.20	0.05
1995	1167	0	0	0	0.04	0.26	0.29	0.15	0.05	0	0	0	0.01	0.05	0.07	0.06	0.01
1996	787	0	0	0	0.03	0.22	0.24	0.09	0.05	0	0	0	0.01	0.12	0.14	0.08	0.02
1997	1198	0	0	0	0.03	0.37	0.34	0.10	0.03	0	0	0	0.00	0.06	0.04	0.03	0.01
1998	1055	0	0	0	0.03	0.23	0.24	0.08	0.03	0	0	0	0.02	0.11	0.14	0.08	0.03
1999	562	0	0	0	0.06	0.29	0.24	0.18	0.09	0	0	0	0.00	0.02	0.05	0.04	0.00
2000	17213	0	0	0	0.02	0.30	0.39	0.11	0.02	0	0	0	0.00	0.05	0.07	0.04	0.01
2001	20030	0	0	0	0.02	0.22	0.37	0.21	0.07	0	0	0	0.00	0.02	0.05	0.02	0.01
2002	5219	0	0	0	0.04	0.23	0.28	0.25	0.07	0	0	0	0.00	0.03	0.04	0.03	0.01
2003	5226	0	0	0	0.02	0.37	0.32	0.12	0.03	0	0	0	0.00	0.02	0.05	0.05	0.01
2004	9606	0	0	0	0.01	0.38	0.39	0.11	0.03	0	0	0	0.00	0.03	0.03	0.01	0.01
2005	5360	0	0	0	0.00	0.25	0.47	0.16	0.02	0	0	0	0.00	0.02	0.05	0.02	0.01
2006	6707	0	0	0	0.00	0.18	0.35	0.17	0.02	0	0	0	0.00	0.05	0.14	0.07	0.01
2007	6125	0	0	0	0.01	0.36	0.34	0.14	0.03	0	0	0	0.00	0.02	0.06	0.03	0.01
2008	5766	0	0	0	0.00	0.35	0.35	0.06	0.01	0	0	0	0.00	0.09	0.09	0.04	0.01
2009	6026	0	0	0	0.01	0.34	0.33	0.11	0.02	0	0	0	0.00	0.08	0.08	0.02	0.01
2010	5902	0	0	0	0.01	0.39	0.36	0.10	0.01	0	0	0	0.00	0.05	0.05	0.02	0.00
2011	2552	0	0	0	0.00	0.32	0.40	0.12	0.02	0	0	0	0.00	0.06	0.06	0.02	0.00
2012	5056	0	0	0	0.00	0.24	0.46	0.18	0.02	0	0	0	0.00	0.03	0.04	0.02	0.00
2013	6072	0	0	0	0.00	0.24	0.37	0.24	0.06	0	0	0	0.00	0.01	0.04	0.02	0.00
2014	4682	0	0	0	0.01	0.28	0.24	0.18	0.07	0	0	0	0.00	0.04	0.09	0.07	0.02
2015	4173	0	0	0	0.01	0.48	0.28	0.10	0.03	0	0	0	0.00	0.02	0.03	0.03	0.01
2016	1543	0	0	0	0.00	0.25	0.47	0.16	0.03	0	0	0	0.00	0.02	0.02	0.03	0.01
2017	3412	0	0	0	0.00	0.18	0.39	0.21	0.03	0	0	0	0.01	0.03	0.12	0.05	0.01
2018	2609	0	0	0	0.00	0.11	0.32	0.32	0.08	0	0	0	0	0.01	0.08	0.08	0.02

Table 5. Winter commercial catch length-shell compositions.

		New Shell								Old Shell							
Year	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
2016	1016	0	0	0	0.03	0.45	0.31	0.03	0.00	0	0	0	0.01	0.09	0.04	0.02	0.01
2017	540	0	0	0	0.00	0.20	0.30	0.13	0.02	0	0	0	0.00	0.08	0.19	0.06	0.02
2018	401	0	0	0	0.00	0.11	0.25	0.27	0.05	0	0	0	0	0.04	0.16	0.10	0.02

Table 6. Summer Trawl Survey length-shell compositions.

			New Shell								Old Shell							
Year	Survey	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1976	NMFS	1326	0.01	0.02	0.10	0.19	0.34	0.18	0.02	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.01	0.01
1979	NMFS	220	0.01	0.01	0.00	0.02	0.05	0.05	0.03	0.01	0.01	0.00	0.01	0.04	0.14	0.40	0.19	0.03
1982	NMFS	327	0.22	0.07	0.16	0.23	0.17	0.03	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.02	0.03
1985	NMFS	350	0.11	0.11	0.19	0.17	0.16	0.06	0.01	0.00	0.00	0.00	0.00	0.02	0.05	0.08	0.05	0.01
1988	NMFS	366	0.16	0.19	0.12	0.13	0.11	0.06	0.03	0.00	0.00	0.00	0.01	0.01	0.03	0.07	0.05	0.03
1991	NMFS	340	0.18	0.08	0.02	0.03	0.06	0.03	0.01	0.01	0.03	0.06	0.02	0.08	0.16	0.14	0.09	0.02
1996	ADFG	269	0.29	0.21	0.13	0.09	0.05	0.00	0.00	0.01	0.00	0.00	0.03	0.03	0.04	0.04	0.04	0.03
1999	ADFG	283	0.03	0.01	0.10	0.29	0.26	0.13	0.03	0.01	0.00	0.00	0.00	0.03	0.05	0.04	0.02	0.00
2002	ADFG	244	0.09	0.12	0.14	0.11	0.02	0.03	0.02	0.01	0.01	0.03	0.07	0.10	0.09	0.09	0.05	0.02
2006	ADFG	373	0.18	0.26	0.21	0.11	0.06	0.04	0.02	0.00	0.00	0.00	0.00	0.02	0.04	0.04	0.01	0.00
2008	ADFG	275	0.12	0.15	0.21	0.11	0.10	0.03	0.02	0.01	0.00	0.01	0.04	0.06	0.08	0.01	0.04	0.00
2010	NMFS	69	0.01	0.04	0.06	0.17	0.06	0.03	0.00	0.00	0.00	0.03	0.09	0.20	0.19	0.07	0.03	0.01
2011	ADFG	315	0.13	0.11	0.09	0.11	0.18	0.14	0.03	0.01	0.00	0.00	0.01	0.02	0.09	0.04	0.03	0.00
2014	ADFG	387	0.08	0.15	0.24	0.18	0.09	0.02	0.01	0.01	0.00	0.00	0.03	0.10	0.05	0.04	0.01	0.00
2017	ADFG	116	0.14	0.12	0.05	0.09	0.10	0.04	0.00	0.00	0.01	0.02	0.02	0.02	0.07	0.18	0.04	0.00
2017	NMFS	58	0.09	0.10	0.14	0.05	0.05	0.05	0.05	0.03	0.03	0.00	0.03	0.05	0.03	0.19	0.05	0.03
2018	ADFG	73	0.37	0.10	0.11	0.03	0.01	0.03	0.04	0.01	0	0.07	0.01	0.04	0.03	0.03	0.10	0.03

Table 7. Winter pot survey length-shell compositions.

			New Shell								Old Shell							
Year	CPUE	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1981/82	NA	719	0.00	0.10	0.23	0.21	0.07	0.02	0.02	0.00	0.00	0.05	0.11	0.11	0.04	0.02	0.02	0.00
1982/83	24.2	2583	0.03	0.08	0.28	0.28	0.21	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.01
1983/84	24.0	1677	0.01	0.16	0.26	0.23	0.15	0.06	0.01	0.00	0.00	0.00	0.00	0.02	0.06	0.03	0.01	0.01
1984/85	24.5	789	0.02	0.09	0.25	0.35	0.16	0.06	0.01	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.00	0.00
1985/86	19.2	594	0.04	0.12	0.17	0.24	0.19	0.08	0.01	0.00	0.00	0.00	0.00	0.01	0.06	0.04	0.01	0.00
1986/87	5.8	144	0.00	0.06	0.15	0.19	0.07	0.04	0.00	0.00	0.00	0.00	0.01	0.04	0.30	0.11	0.03	0.00
1987/88																		
1988/89	13.0	500	0.02	0.13	0.15	0.13	0.19	0.17	0.03	0.00	0.00	0.00	0.00	0.00	0.05	0.08	0.03	0.00
1989/90	21.0	2076	0.00	0.05	0.21	0.26	0.18	0.12	0.06	0.01	0.00	0.00	0.00	0.00	0.03	0.06	0.02	0.00
1990/91	22.9	1283	0.00	0.01	0.09	0.29	0.27	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.12	0.07	0.02
1992/93	5.5	181	0.00	0.01	0.03	0.06	0.13	0.12	0.03	0.00	0.00	0.00	0.00	0.02	0.19	0.27	0.10	0.05
1993/94																		
1994/95	6.2	858	0.01	0.06	0.08	0.10	0.26	0.23	0.07	0.01	0.00	0.00	0.00	0.00	0.03	0.07	0.06	0.02
1995/96	9.9	1580	0.06	0.14	0.20	0.19	0.11	0.07	0.03	0.00	0.00	0.00	0.00	0.01	0.06	0.07	0.03	0.01
1996/97	2.9	398	0.07	0.21	0.22	0.11	0.15	0.11	0.05	0.01	0.00	0.00	0.00	0.00	0.02	0.03	0.01	0.01
1997/98	10.9	881	0.00	0.14	0.41	0.27	0.05	0.02	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.02	0.02	0.01
1998/99	10.7	1307	0.00	0.02	0.12	0.36	0.36	0.08	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.01	0.00
1999/00	6.2	575	0.02	0.09	0.10	0.16	0.33	0.18	0.03	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.01	0.00
2000/01	3.1	44																
2001/02	13.0	828	0.05	0.29	0.26	0.17	0.06	0.06	0.04	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.00
2002/03	9.6	824	0.02	0.10	0.22	0.28	0.18	0.06	0.02	0.00	0.00	0.01	0.01	0.02	0.02	0.03	0.02	0.01
2003/04	3.7	296	0.00	0.02	0.16	0.26	0.32	0.14	0.01	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.02	0.01
2004/05	4.4	405	0.00	0.07	0.14	0.18	0.22	0.19	0.07	0.00	0.00	0.00	0.00	0.00	0.04	0.06	0.01	0.00
2005/06	6.0	512	0.00	0.14	0.23	0.21	0.16	0.05	0.02	0.00	0.00	0.01	0.01	0.02	0.04	0.07	0.03	0.01
2006/07	7.3	159	0.07	0.14	0.19	0.35	0.13	0.04	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.04	0.00	0.00
2007/08	25.0	3552	0.01	0.14	0.25	0.17	0.14	0.07	0.01	0.00	0.01	0.04	0.07	0.03	0.03	0.01	0.01	0.00
2008/09	21.9	525	0.00	0.07	0.13	0.35	0.20	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.04	0.10	0.00	0.00
2009/10	25.3	578	0.01	0.05	0.13	0.21	0.24	0.11	0.02	0.00	0.00	0.00	0.01	0.06	0.10	0.05	0.01	0.00
2010/11	22.1	596	0.02	0.08	0.13	0.20	0.17	0.13	0.05	0.00	0.00	0.00	0.01	0.03	0.11	0.05	0.01	0.00
2011/12	29.4	675	0.03	0.11	0.23	0.19	0.12	0.13	0.04	0.00	0.00	0.00	0.00	0.01	0.05	0.05	0.03	0.00

Table 8. Summer commercial1987-1994, 2012-2017 observer discards length-shell compositions.

		New Shell								Old Shell							
Year	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
1987	1146	0.06	0.19	0.32	0.33	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.00	0.00	0.00	0.00
1988	722	0.01	0.04	0.15	0.48	0.14	0.00	0.00	0.00	0.00	0.01	0.03	0.10	0.04	0.00	0.00	0.00
1989	1000	0.07	0.19	0.24	0.22	0.03	0.00	0.00	0.00	0.02	0.03	0.07	0.11	0.03	0.00	0.00	0.00
1990	507	0.08	0.23	0.27	0.27	0.04	0.00	0.00	0.00	0.02	0.02	0.02	0.05	0.01	0.00	0.00	0.00
1992	580	0.11	0.17	0.30	0.29	0.03	0.00	0.00	0.00	0.01	0.02	0.02	0.04	0.01	0.00	0.00	0.00
1994	850	0.07	0.06	0.11	0.15	0.02	0.00	0.00	0.00	0.07	0.07	0.15	0.24	0.05	0.00	0.00	0.00
2012	939	0.21	0.11	0.19	0.32	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00
2013	2617	0.34	0.29	0.16	0.16	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2014	1755	0.05	0.10	0.26	0.41	0.12	0.01	0.00	0.00	0.00	0.00	0.01	0.03	0.01	0.00	0.00	0.00
2015	824	0.01	0.08	0.18	0.44	0.23	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00
2016	426	0.04	0.05	0.17	0.50	0.17	0.02	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00	0.00
2017	544	0.10	0.16	0.13	0.31	0.26	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00
2018	532	0.10	0.17	0.36	0.30	0.02	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.00

Table 9. Summer commercial1 2012-2018 observer total catch length-shell compositions.

		New Shell								Old Shell							
Year	Sample	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
2012	3055	0.10	0.05	0.08	0.15	0.15	0.17	0.06	0.01	0.00	0.00	0.00	0.03	0.08	0.09	0.03	0.00
2013	4762	0.19	0.16	0.09	0.10	0.16	0.16	0.09	0.01	0.00	0.00	0.00	0.00	0.01	0.02	0.01	0.00
2014	3506	0.02	0.05	0.13	0.22	0.22	0.12	0.08	0.03	0.00	0.00	0.00	0.02	0.03	0.03	0.02	0.01
2015	1671	0.01	0.04	0.09	0.23	0.37	0.14	0.05	0.01	0.00	0.00	0.00	0.01	0.02	0.02	0.01	0.00
2016	2114	0.01	0.01	0.03	0.12	0.29	0.36	0.08	0.02	0.00	0.00	0.00	0.01	0.03	0.03	0.02	0.00
2017	2748	0.02	0.03	0.03	0.06	0.19	0.33	0.18	0.02	0.00	0.00	0.00	0.00	0.02	0.07	0.03	0.01
2018	1628	0.03	0.06	0.12	0.11	0.09	0.17	0.18	0.04	0.00	0.00	0.01	0.01	0.15	0.07	0.08	0.02

Table 10. The number of tagged data released and recovered after 1 year (Y1) – 3 year (Y3) during 1980-1992 and 1993-2017 periods.

Release Length Class	Recap Length Class	1980-1992			1993-2017		
		Y1	Y2	Y3	Y1	Y2	Y3
64 – 73	64 – 73						
64 – 73	74 - 83	1					
64 – 73	84 - 93	1	1		3		
64 – 73	94 - 103		1			5	
64 – 73	104 – 113		1			3	6
64 – 73	114 – 123						7
64 – 73	124 – 133						
64 – 73	134+						
74 - 83	74 - 83						
74 - 83	84 - 93	3			18		
74 - 83	94 - 103	7			15	11	
74 - 83	104 – 113		13		4	79	14
74 - 83	114 – 123		1	2		4	22
74 - 83	124 – 133						2
74 - 83	134+						
84 - 93	84 - 93						
84 - 93	94 - 103	15	1		34	4	1
84 - 93	104 – 113	19	5	1	72	21	11
84 - 93	114 – 123		5	2	7	53	5
84 - 93	124 – 133				1	2	2
84 - 93	134+						
94 - 103	94 - 103	4	1		6	1	
94 - 103	104 – 113	53	5	1	143	20	
94 - 103	114 – 123	31	5	7	77	8	9
94 - 103	124 – 133	2	2	2		11	6
94 - 103	134+				1		
104 – 113	104 – 113	18			57	2	
104 – 113	114 – 123	38	15	3	105	27	3
104 – 113	124 – 133	7	8	4	15	3	8
104 – 113	134+						1
114 – 123	114 – 123	17	2		71	5	
114 – 123	124 – 133	27	10	2	71	31	8
114 – 123	134+	5	1		19	4	3
124 – 133	124 – 133	15			41	6	
124 – 133	134+	10	4	2	15	8	6
134+	134+	15	6	1	11		

Table 11. Summary of initial input parameter values and bounds for a length-based population model of Norton Sound red king crab. Parameters with "log_" indicate log scaled parameters.

Parameter	Parameter description	Equation Number in Appendix A	Lower	Upper
log_$q_{1,2}$	Commercial fishery catchability (1977-92, 1993-2017)	(22)	-20.5	20
log_N_{76}	Initial abundance	(1)	2.0	15.0
R_0	Mean Recruit	(13)	2.0	12.0
log_σ_R^2	Recruit standard deviation	(13)	-40.0	40.0
a_{1-7}	Intimal length proportion	(2)	0	10.0
r_1	Proportion of length class 1 for recruit	(14)	0	10.0
log_α	Inverse logistic molting parameter	(15)	-5.0	-1.0
log_β	Inverse logistic molting parameter	(15)	1.0	5.5
log_ϕ_{st1}	Logistic trawl selectivity parameter	(16)	-5.0	1.0
log_ϕ_{w1}	Inverse logistic winter pot selectivity parameter	(18)	-5.0	1.0
log_ϕ_{w2}	Inverse logistic winter pot selectivity parameter	(18)	0.0	6.0
$Sw_{1,2}$	Winter pot selectivity of length class 1,2	(18)	0.1	1.0
log_ϕ_1	Logistic commercial catch selectivity parameter	(17)	-5.0	1.0
log_ϕ_2	Logistic commercial catch selectivity parameter	(17)	0.0	6.0
w^2_t	Additional variance for standard CPUE	(31)	0.0	6.0
ms	Natural mortality multipliers		0.5	5.0
q	Survey q for NMFS trawl 1976-91	(31)	0.1	1.0
σ	Growth transition sigma	(19)	0.0	30.0
β_1	Growth transition mean	(19)	0.0	20.0
β_2	Growth transition increment	(19)	0.0	20.0

Table 12. Summary of parameter estimates and standard deviations of Norton Sound red king crab. (Base Model 0)

name	Estimate	std.dev
log_q_1	-6.965	0.168
log_q_2	-6.816	0.109
log_N_{76}	9.029	0.130
R_0	6.440	0.081
log_R_{76}	0.013	0.416
log_R_{77}	-0.541	0.370
log_R_{78}	-0.725	0.353
log_R_{79}	0.373	0.315
log_R_{80}	0.500	0.283
log_R_{81}	0.404	0.263
log_R_{82}	0.372	0.314
log_R_{83}	0.540	0.275
log_R_{84}	0.147	0.291
log_R_{85}	0.447	0.276
log_R_{86}	0.061	0.286
log_R_{87}	0.021	0.246
log_R_{88}	0.025	0.258
log_R_{89}	-0.329	0.280
log_R_{90}	-0.276	0.253
log_R_{91}	-0.526	0.285
log_R_{92}	-0.673	0.302
log_R_{93}	-0.577	0.289
log_R_{94}	-0.292	0.257
log_R_{95}	-0.063	0.225
log_R_{96}	0.576	0.217
log_R_{97}	-0.016	0.293
log_R_{98}	-0.624	0.320
log_R_{99}	-0.008	0.310
log_R_{00}	0.311	0.263
log_R_{01}	0.390	0.241
log_R_{02}	-0.005	0.314
log_R_{03}	-0.280	0.330
log_R_{04}	0.300	0.241
log_R_{05}	0.425	0.222
log_R_{06}	0.477	0.243

name	Estimate	std.dev
log_R_{07}	0.540	0.231
log_R_{08}	0.134	0.287
log_R_{09}	-0.367	0.294
log_R_{10}	-0.002	0.253
log_R_{11}	0.282	0.274
log_R_{12}	0.890	0.185
log_R_{13}	-0.196	0.284
log_R_{14}	-0.568	0.294
log_R_{15}	-0.751	0.269
log_R_{16}	-0.389	0.226
log_R_{17}	-0.018	0.275
a_1	1.543	4.575
a_2	2.316	4.264
a_3	3.826	4.069
a_4	4.106	4.055
a_5	4.325	4.046
a_6	3.550	4.075
a_7	2.117	4.335
r1	10.000	0.845
r2	9.680	0.863
log_a	-2.645	0.087
log_b	4.824	0.014553
log_ϕ_{st1}	3.145	5183.900
log_ϕ_{wa}	-2.115	0.317
log_ϕ_{wb}	4.798	0.028
Sw1	0.073	0.035
Sw2	0.500	353.550
log_ϕ_1	3.795	6501.300
w^2_t	0.052	0.016
q	0.766	0.131
σ	3.876	0.216
β_1	12.301	0.705
β_2	7.700	0.175
ms78	3.189	0.272

Table 13. Estimated selectivity, mortality, molting probabilities, and proportions of legal crab by length class (mm CL) for Norton Sound male red king crab (Model 0).

Model 0

Length Class	Legal Proportion	Summer Com Retention (Model 1)	Winter Com Retention (Model 2)	Mean weight (lb)	Natural mortality (*M*)	Selectivity: Trawl	Selectivity: Winter Pot	Selectivity: Summer Fishery	Selectivity: Molting Probability
64 - 73	0.00	0.00	0.00	0.44	0.18	1.00	0.07	0.15	0.98
74 - 83	0.00	0.00	0.00	0.87	0.18	1.00	0.50	0.38	0.96
84 - 93	0.00	0.00	0.00	1.31	0.18	1.00	0.98	0.68	0.93
94 - 103	0.14	0.08	0.03	1.80	0.18	1.00	0.94	0.88	0.86
104 - 113	0.88	0.86	0.73	2.37	0.18	1.00	0.82	0.96	0.76
114 - 123	1.00	1.00	1.00	3.04	0.18	1.00	0.58	0.99	0.60
124 - 133	1.00	1.00	1.00	3.80	0.57	1.00	0.30	1.00	0.43
134+	1.00	1.00	1.00	4.60	0.57	1.00	0.11	1.00	0.27

Model 1

Length Class	Natural mortality (*M*)	Selectivity: Trawl	Selectivity: Winter Pot	Selectivity: Summer Fishery	Selectivity: Molting Probability
64 - 73	0.18	1.00	0.07	0.06	0.98
74 - 83	0.18	1.00	0.50	0.21	0.97
84 - 93	0.18	1.00	0.98	0.51	0.93
94 - 103	0.18	1.00	0.94	0.80	0.87
104 - 113	0.18	1.00	0.83	0.94	0.76
114 - 123	0.18	1.00	0.60	0.98	0.61
124 - 133	0.58	1.00	0.30	1.00	0.43
134+	0.58	1.00	0.11	1.00	0.27

Table 14. Estimated molting probability incorporated transition matrix.

Model 0

Pre-molt Length Class	Post-molt Length Class							
	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
64 - 73	0.02	0.10	0.79	0.10	0.00	0.00	0.00	0.00
74 - 83		0.04	0.23	0.70	0.03	0.00	0.00	0.00
84 - 93			0.08	0.42	0.50	0.01	0.00	0.00
94 - 103				0.15	0.58	0.27	0.00	0.00
104 - 113					0.29	0.60	0.11	0.00
114 - 123						0.50	0.47	0.03
124 - 133							0.73	0.27
134+								1.00

Model 1

Pre-molt Length Class	Post-molt Length Class							
	64-73	74-83	84-93	94-103	104-113	114-123	124-133	134+
64 - 73	0.02	0.10	0.78	0.09	0.00	0.00	0.00	0.00
74 - 83		0.04	0.26	0.68	0.03	0.00	0.00	0.00
84 - 93			0.07	0.44	0.48	0.00	0.00	0.00
94 - 103				0.15	0.58	0.26	0.00	0.00
104 - 113					0.29	0.60	0.11	0.00
114 - 123						0.51	0.47	0.03
124 - 133							0.73	0.27
134+								1.00

Table 15. Annual abundance estimates (million crab) and mature male biomass (Feb 01) (MMB, million lb) for Norton Sound red king crab estimated by a length-based analysis from 1976 to 2018.

	Abundance			Legal (≥ 104 mm)				MMB	
Year	Recruits	Total (≥ 64 mm)	Mature (≥ 94 mm)	Abundance	S.D	Biomass	S.D	Biomass	S.D.
1976									
1977									
1978									
1979									
1980									
1981									
1982									
1983									
1984									
1985									
1986									
1987									
1988									
1989									
1990									
1991									
1992									
1993									
1994									
1995									
1996									
1997									
1998									
1999									
2000									
2001									
2002									
2003									
2004									
2005									
2006									
2007									
2008									
2009									
2010									
2011									
2012									
2013									
2014									
2015									
2016									
2017									
2018									

Table 16. Summary of catch and estimated discards (million lb) for Norton Sound red king crab. Assumed average crab weight is 2.0 lb for winter subsistence catch and 1.0 lb for Winter subsistence discards. Summer and winter commercial discards were estimated from the model.

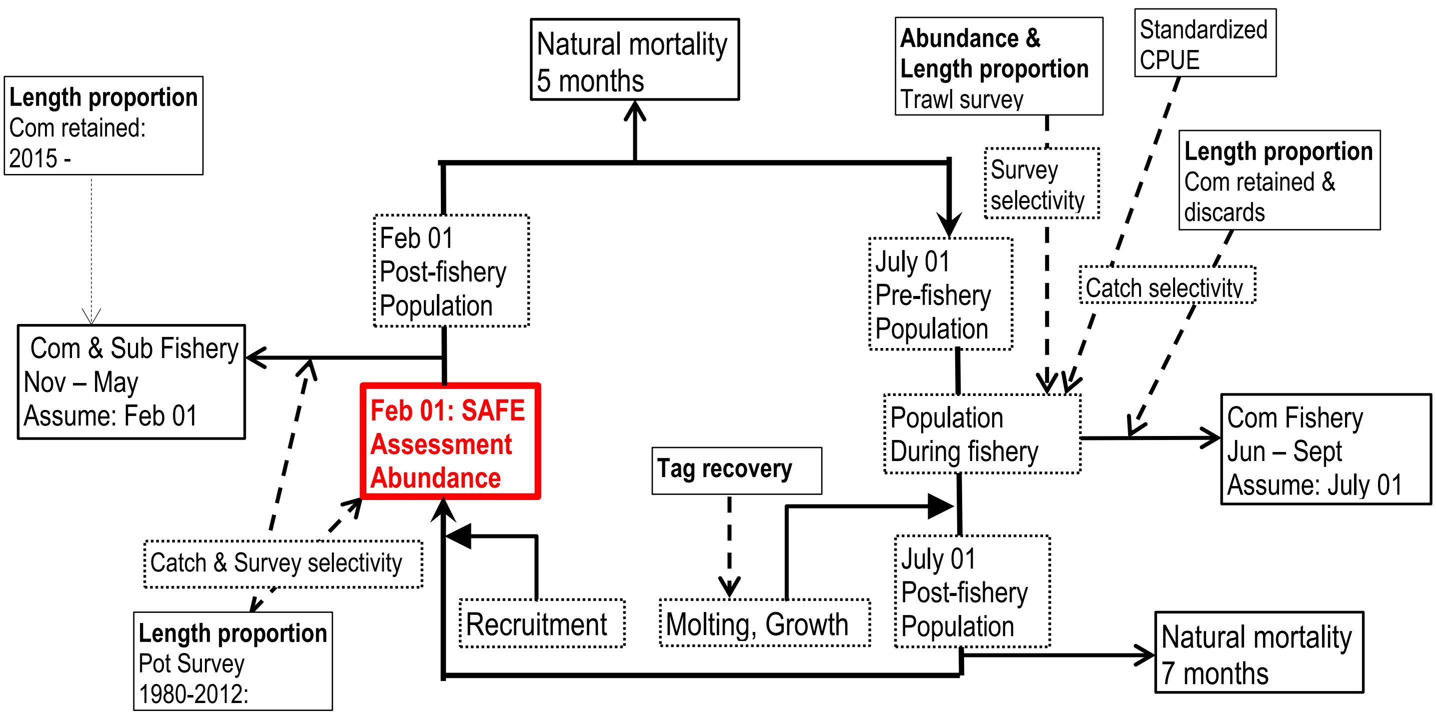
Year	Summer Com	Winter Com	Winter Sub	Modeled Discards Summer	Discards Winter Sub	Modeled Discards Winter com	Total	Catch/ MMB
1977	0.52	0.000	0.000		0.000			
1978	2.09	0.024	0.025		0.008			
1979	2.93	0.001	0.000		0.000			
1980	1.19	0.000	0.000		0.000			
1981	1.38	0.000	0.001		0.000			
1982	0.23	0.000	0.003		0.001			
1983	0.37	0.001	0.021		0.006			
1984	0.39	0.002	0.022		0.005			
1985	0.43	0.003	0.017		0.002			
1986	0.48	0.005	0.014		0.004			
1987	0.33	0.003	0.012		0.002			
1988	0.24	0.001	0.005		0.001			
1989	0.25	0.000	0.012		0.002			
1990	0.19	0.010	0.024		0.004			
1991	0	0.010	0.015		0.002			
1992	0.07	0.021	0.023		0.003			
1993	0.33	0.005	0.002		0.000			
1994	0.32	0.017	0.008		0.001			
1995	0.32	0.022	0.011		0.002			
1996	0.22	0.005	0.003		0.001			
1997	0.09	0.000	0.001		0.001			
1998	0.03	0.002	0.017		0.012			
1999	0.02	0.007	0.015		0.003			
2000	0.3	0.008	0.011		0.004			
2001	0.28	0.003	0.001		0.000			
2002	0.25	0.007	0.004		0.003			
2003	0.26	0.017	0.008		0.005			
2004	0.34	0.001	0.002		0.001			
2005	0.4	0.006	0.008		0.003			
2006	0.45	0.000	0.002		0.001			
2007	0.31	0.008	0.021		0.011			
2008	0.39	0.015	0.019		0.009			
2009	0.4	0.012	0.010		0.002			
2010	0.42	0.012	0.014		0.002			
2011	0.4	0.009	0.013		0.003			
2012	0.47	0.025	0.015		0.004			
2013	0.35	0.061	0.015		0.014			
2014	0.39	0.035	0.007		0.002			
2015	0.40	0.099	0.019		0.005			
2016	0.42	0.080	0.011		0.001			
2017	0.41	0.078	0.012		0.001			
2018	0.30	0.029	0.008		0.002			

Appendix A. Description of the Norton Sound Red King Crab Model

a. Model description.

The model is an extension of the length-based model developed by Zheng et al. (1998) for Norton Sound red king crab. The model has 8 male length classes with model parameters estimated by the maximum likelihood method. The model estimates abundances of crab with CL ≥64 mm and with 10-mm length intervals (8 length classes, ≥134mm) because few crab measuring less than 64 mm CL were caught during surveys or fisheries and there were relatively small sample sizes for trawl and winter pot surveys. The model treats newshell and oldshell male crab separately but assumes they have the same molting probability and natural mortality.

Norton Sound Red King Crab Modeling Scheme



Timeline of calendar events and crab modeling events:

- **Model year starts February 1st to January 31st of the following year.**
- **All winter fishery harvest occurs on February 1st**
- **Molting and recruitment occur on July 1st**
- **Initial Population Date: February 1st 1976**

Initial pre-fishery summer crab abundance on February 1st 1976

Abundance of the initial pre-fishery population was assumed to consist of newshell crab to reduce the number of parameters, and estimated as

$$N_{l,1} = p_l e^{\log\_N_{76}} \tag{1}$$

where, length proportion of the first year (p_l) was calculated as

$$\begin{aligned} p_l &= \frac{\exp(a_l)}{1+\sum_{l=1}^{n-1}\exp(a_l)} \text{ for } l = 1,..,n\text{-}1 \\ p_n &= 1 - \frac{\sum_{l=1}^{n-1}\exp(a_l)}{1+\sum_{l=1}^{n-1}\exp(a_l)} \end{aligned} \tag{2}$$

for model estimated parameters a_l.

Crab abundance on July 1st

Summer (01 July) crab abundance of new and oldshells consists of survivors of winter commercial and subsistence crab fisheries and natural mortality from 01Feb to 01July:

$$\begin{aligned} N_{s,l,t} &= (N_{w,l,t-1} - C_{w,t-1}P_{w,n,l,t-1} - C_{p,t}P_{p,n,l,t-1} - D_{w,n,l,t-1} - D_{p,n,l,t-1})e^{-0.42M_l} \\ O_{s,l,t} &= (O_{w,l,t-1} - C_{w,t-1}P_{w,o,l,t-1} - C_{p,t}P_{p,o,l,t-1} - D_{w,o,l,t-1} - D_{p,o,l,t-1})e^{-0.42M_l} \end{aligned} \tag{3}$$

where

$N_{s,l,t}$, $O_{s,l,t}$: summer abundances of newshell and oldshell crab in length class *l* in year *t* ,
$N_{w,l,t-1}$, $O_{w,l,t-1}$: winter abundances of newshell and oldshell crab in length class *l* in year *t-1* ,
$C_{w,t-1}$, $C_{p,t-1}$: total winter commercial and subsistence catches in year *t-1*,
$P_{w,n,l,t-1}$, $P_{w,o,l,t-1}$: Proportion of newshell and oldshell length class *l* crab in year *t-1*, harvested by winter commercial fishery,
$P_{p,n,l,t-1}$, $P_{p,o,l,t-1}$: Proportion of newshell and oldshell length class *l* crab in year *t-1*, harvested by winter subsistence fishery,
$D_{w,n,l,t-1}$, $D_{w,o,l,t-1}$: Discard mortality of newshell and oldshell length class *l* crab in winter commercial fishery in year *t-1* ,

$D_{p,n,l,t-1}$, $D_{p,o,l,t-1}$: Discard mortality of newshell and oldshell length class l crab in winter subsistence fishery in year $t-1$,
M_l : instantaneous natural mortality in length class l,
0.42 : proportion of the year from Feb 1 to July 1 is 5 months.

Length proportion compositions of winter commercial catch ($P_{w,n,l,t}$, $P_{w,o,l,t}$) in year t were estimated as:

$$\begin{aligned} P_{w,n,l,t} &= N_{w,l,t} S_{w,l} P_{lg,l} / \sum_{l=1} [(N_{w,l,t} + O_{w,l,t}) S_{w,l} P_{lg,l}] \\ P_{w,o,l,t} &= O_{w,l,t} S_{w,l} P_{lg,l} / \sum_{l=1} [(N_{w,l,t} + O_{w,l,t}) S_{w,l} P_{lg,l}] \end{aligned} \tag{4}$$

where
$P_{lg,l}$: the proportion of legal males in length class l ,
$S_{w,l}$: Selectivity of winter fishery pot.

Subsistence fishery does not have a size limit; however, crab of size smaller than length class 3 are generally not retained. Hence, we assumed proportion of length composition l = 1 and 2 as 0, and estimated length compositions ($l \geq 3$) as follows

$$\begin{aligned} P_{p,n,l,t} &= N_{w,l,t} S_{w,l} / \sum_{l=3} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \\ P_{p,o,l,t} &= O_{w,l,t} S_{w,l} / \sum_{l=3} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \end{aligned} \tag{5}$$

Crab abundance on Feb 1st

Newshell Crab: Abundance of newshell crab of year t and length-class l ($N_{w,l,t}$) year-t consist of: (1) new and oldshell crab that survived the summer commercial fishery and molted, and (2) recruitment ($R_{l,t}$) .

$$N_{w,l,t} = \sum_{l'=1}^{l'=l} G_{l',l} [(N_{s,l',t-1} + O_{s,l',t-1}) e^{-y_c M_l} - C_{s,t} (P_{s,n,l',t-1} + P_{s,o,l',t-1}) - D_{l',t-1}] m_{l'} e^{-(0.58-y_c) M_l} + R_{l,t} \tag{6}$$

Oldshell Crab: Abundance of oldshell crabs of year t and length-class l ($O_{w,l,t}$) consists of the non-molting portion of survivors from the summer fishery:

$$O_{w,l,t} = [(N_{s,l,t-1} + O_{s,l,t-1}) e^{-y_c M_l} - C_{s,t} (P_{s,n,l,t-1} + P_{s,o,l,t-1}) - D_{l,t-1}] (1 - m_l) e^{-(0.58-y_c) M_l} \tag{7}$$

where

$G_{l',l}$: a growth matrix representing the expected proportion of crabs growing from length class l' to length class l
$C_{s,t}$: total summer catch in year t
$P_{s,n,l,t}$, $P_{s,o,l,t}$: proportion of summer catch for newshell and oldshell crabs of length class l in year t,
$D_{l,t}$: summer discard mortality of length class l in year t,
m_l : molting probability of length class l,
y_c : the time in year from July 1 to the mid-point of the summer fishery,
0.58: Proportion of the year from July 1st to Feb 1st is 7 months is 0.58 year,
$R_{l,t}$: recruitment into length class l in year t.

Discards

Discards are crabs that were caught by fisheries but were not retained, which consists of summer commercial, winter commercial and winter subsistence.

Summer and winter commercial discards

In summer ($D_{l,t}$) and winter ($D_{w,n,l,t}$, $D_{w,o,l,t}$) commercial fisheries, sublegal males (<4.75 inch CW and <5.0 inch CW since 2005) are discarded. Those discarded crabs are subject to handling mortality. The number of discards was not directly observed, and thus was estimated from the model as: Observed Catch x (estimated abundance of crab that are not caught by commercial pot)/(estimated abundance of crab that are caught by commercial pot)

Model discard mortality in length-class l in year t from the summer and winter commercial pot fisheries is given by

$$D_{l,t} = C_{s,t}\frac{(N_{s,l,t}+O_{s,l,t})\,S_{s,l}\,(1-P_{lg,l})}{\sum_l (N_{s,l,t}+O_{s,l,t})\,S_{s,l}\,P_{lg,l}}hm_s \quad \text{(Baseline model)}$$

$$D_{l,t} = C_{s,t}\frac{(N_{s,l,t}+O_{s,l,t})S_{s,l}\,(1-S_{r,l})}{\sum_l (N_{s,l,t}+O_{s,l,t})\,S_{s,l}S_{r,l}}hm_s \quad \text{(Alternative model)} \tag{8}$$

$$D_{w,n,l,t} = C_{w,t}\frac{N_{w,l,t}\,S_{w,l}\,(1-P_{lg,l})}{\sum_l (N_{w,l,t}+O_{w,l,t})\,S_{w,l}\,P_{lg,l}}hm_w \tag{9}$$

$$D_{w,o,l,t} = C_{w,t}\frac{O_{w,l,t}\,S_{w,l}\,(1-P_{lg,l})}{\sum_l (N_{w,l,t}+O_{w,l,t})\,S_{w,l}\,P_{lg,l}}hm_w \tag{10}$$

where

hm_s: summer commercial handling mortality rate assumed to be 0.2,
hm_w: winter commercial handling mortality rate assumed to be 0.2,
$S_{s,l}$: Selectivity of the summer commercial fishery,

$S_{w,l}$: Selectivity of the winter commercial fishery,
$S_{r,l}$: Retention selectivity of the summer commercial fishery,

Winter subsistence Discards

Discards (unretained) of winter subsistence fishery is reported in a permit survey ($C_{d,t}$), though its size composition is unknown.   We assumed that subsistence fishers discarded all crabs of length classes 1 -2.

$$D_{p,n,l,t} = C_{d,t} \frac{N_{w,l,t} S_{w,l}}{\sum_{l=1}^{2} (N_{w,l,t} + O_{w,l,t}) S_{w,l}} hm_w \tag{11}$$

$$D_{p,o,l,t} = C_{d,t} \frac{O_{w,l,t} S_{w,l}}{\sum_{l=1}^{2} (N_{w,l,t} + O_{w,l,t}) S_{w,l}} hm_w \tag{12}$$

$C_{d,t}$: Winter subsistence discards catch,

Recruitment

Recruitment of year t, R_t, is a stochastic process around the geometric mean, R_0:

$$R_t = R_0 e^{\tau_t}, \tau_t \sim N(0, \sigma_R^2) \tag{13}$$

R_t of the last year was assumed to be an average of previous 5 years: $R_t = (R_{t-1} + R_{t-2} + R_{t-3} + R_{t-4} + R_{t-5})/5$.

R_t was assumed to be newshell crab of immature (< 94mm) length classes 1 to r:

$$R_{r,t} = p_r R_t \tag{14}$$

where r takes multinomial distribution, same as the equation (2)

Molting Probability

Molting probability for length class l, m_l, was estimated as an inverse logistic function of length-class mid carapace length (L) and parameters (α, β) where β corresponds to L_{50}.

$$m_l = \frac{1}{1+e^{\alpha(L-\beta)}} \tag{15}$$

Trawl net, summer commercial pot, retention selectivity

Trawl and summer commercial pot selectivity was assumed to be a logistic function of mid-length-class, constrained to be 0.999 at the largest length-class (L_{max}):

$$S_l = \frac{1}{1+e^{(\alpha(L_{\max}-L)+\ln(1/0.999-1))}} \tag{16}$$

Alternative Summer commercial pot, retention selectivity

Summer pot selectivity was assumed to be a logistic function of length-class mid carapace length (L) and parameters (α, β) where β corresponds to L_{50}.

$$S_{c,l} = \frac{1}{1+e^{-\alpha(L-\beta)}} \tag{16'}$$

Winter pot selectivity

Winter pot selectivity was assumed to be a dome-shaped with inverse logistic function of length-class mid carapace length (L) and parameters (α, β) where β corresponds to L_{50}.

$$S_{w,l} = \frac{1}{1+e^{\alpha(L-\beta)}} \tag{17}$$

Selectivity of the length classes $S_{w,s}$ (S= l_1, l_2) were individually estimated.

Growth transition matrix

The growth matrix $G_{l',l}$ (the expected proportion of crab molting from length class l' to length class l) was assumed to be normally distributed:

$$G_{l',l} = \begin{cases} \dfrac{\int_{lm_l-h}^{lm_l+h} N(L \mid \mu_{l'}, \sigma^2)\,dL}{\sum_{l=1}^{n} \int_{lm_l-h}^{lm_l+h} N(L \mid \mu_{l'}, \sigma^2)\,dL} & \text{when } l \geq l' \\ 0 & \text{when } l < l' \end{cases} \tag{18}$$

Where

$$N(x \mid \mu_{l'}, \sigma^2) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(L-\mu_{l'})^2}{\sigma^2} \right)$$

$$lm_l = L_1 + st \cdot l$$

$$\mu_l = L_1 + \beta_0 + \beta_1 \cdot l$$

Observation model

Summer trawl survey abundance

Modeled trawl survey abundance of year t ($B_{st,t}$) is July 1st abundance subtracted by summer commercial fishery harvest occurring from July 1st to the mid-point of summer trawl survey, multiplied by natural mortality occurring between the mid-point of commercial fishery date and trawl survey date, and multiplied by trawl survey selectivity. For the first year (1976) trawl survey, the commercial fishery did not occur.

$$\hat{B}_{st,t} = \sum_l [(N_{s,l,t} + O_{s,l,t}) e^{-y_c M_l} - C_{s,t} P_{c,t} (P_{s,n,l,t} + P_{s,o,l,t})] e^{-(y_{st} - y_c) M_l} S_{st,l} \tag{19}$$

where
y_{st} : the time in year from July 1 to the mid-point of the summer trawl survey,
y_c: the time in year from July 1 to the mid-point for the catch before the survey, ($y_{st} > y_c$: Trawl survey starts after opening of commercial fisheries),
$P_{c,t}$: the proportion of summer commercial crab harvested before the mid-point of trawl survey date.
$S_{st,l}$: Selectivity of the trawl survey.

Winter pot survey CPUE

Winter pot survey cpue (f_{wt}) was calculated with catchability coefficient q and exploitable abundance:

$$\hat{f}_{wt} = q_w \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \tag{20}$$

Summer commercial CPUE

Summer commercial fishing CPUE (f_t) was calculated as a product of catchability coefficient q and mean exploitable abundance minus one half of summer catch, A_t:

$$\hat{f}_t = q_i (A_t - 0.5 C_t) \tag{21}$$

Because the fishing fleet and pot limit configuration changed in 1993, q_1 is for fishing efforts before

1993, q_2 is from 1994 to present.

Baseline model

Where A_t is exploitable legal abundance in year t, estimated as

$$A_t = \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} P_{\lg,l}] \text{ (Baseline model)}$$
$$A_t = \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} S_{r,l}] \text{ (Alternative model)} \quad (22)$$

Summer pot survey abundance (Removed from likelihood components)
Abundance of t-th year pot survey was estimated as

$$\hat{B}_{p,t} = \sum_l [(N_{s,l,t} + O_{s,l,t}) e^{-y_p M_l}] S_{p,l} \quad (23)$$

Where
y_p : the time in year from July 1 to the mid-point of the summer pot survey.
Length composition

Summer commercial catch

Length compositions of the summer commercial catch for new and old shell crabs $P_{s,n,l,t}$ and $P_{s,o,l,t}$, were modeled based on the summer population, selectivity, and legal abundance:

$$\hat{P}_{s,n,l,t} = N_{s,l,t} S_{s,l} P_{\lg,l} / A_t$$
$$\hat{P}_{s,o,l,t} = O_{s,l,t} S_{s,l} P_{\lg,l} / A_t \quad \text{(Baseline model)}$$
$$\hat{P}_{s,n,l,t} = N_{s,l,t} S_{s,l} S_{r,l} / A_t$$
$$\hat{P}_{s,o,l,t} = O_{s,l,t} S_{s,l} S_{r,l} / A_t \quad \text{(Alternative model)} \quad (24)$$

Summer commercial fishery discards (Base model)

Length/shell compositions of observer discards were modeled as

$$\hat{P}_{b,n,l,t} = N_{s,l,t} S_{s,l} (1 - P_{lg,l}) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - P_{lg,l})]$$
$$\hat{P}_{b,o,l,t} = O_{s,l,t} S_{s,l} (1 - P_{lg,l}) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - P_{lg,l})] \quad (25)$$

Summer commercial fishery total catch (Alternative model)

Length/shell compositions of observer discards were modeled as

$$\hat{P}_{t,n,l,t} = N_{s,l,t} S_{s,l} / \sum_{l} [(N_{s,l,t} + O_{s,l,t}) S_{s,l}]$$
$$\hat{P}_{t,o,l,t} = O_{s,l,t} S_{s,l} / \sum_{l} [(N_{s,l,t} + O_{s,l,t}) S_{s,l}] \qquad (25')$$

Summer trawl survey

Proportions of newshell and oldshell crab, $P_{st,n,l,t}$ and $P_{st,o,l,t}$ were given by

$$\hat{P}_{st,n,l,t} = \frac{[N_{s,l,t}\, e^{-y_c M_l} - C_{s,t}\, P_{c,t}\, \hat{P}_{s,n,l',t}] e^{-(y_{st} - y_c) M_l} S_{st,l}}{\sum_l [(N_{s,l,t} + O_{s,l,t}) e^{-y_c M_l} - C_{s,t} P_{c,t} (\hat{P}_{s,n,l',t} + \hat{P}_{s,o,l',t})] e^{-(y_{st} - y_c) M_l} S_{st,l}}$$
$$\hat{P}_{st,o,l,t} = \frac{[O_{s,l,t}\, e^{-y_c M_l} - C_{s,t}\, \hat{P}_{s,o,l',t}\, P_{c,t}] e^{-(y_{st} - y_c) M_l} S_{st,l}}{\sum_l [(N_{s,l,t} + O_{s,l,t}) e^{-y_c M_l} - C_{s,t} P_{c,t} (\hat{P}_{s,n,l,t} + \hat{P}_{s,o,l,t})] e^{-(y_{st} - y_c) M_l} S_{st,l}} \qquad (26)$$

Winter pot survey

Winter pot survey length compositions for newshell and oldshell crab, $P_{sw,n,l,t}$ and $P_{sw,o,l,t}$ ($l \geq 1$) were calculated as

$$\hat{P}_{sw,n,l,t} = N_{w,l,t} S_{w,l} / \sum_{l} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}]$$
$$\hat{P}_{sw,o,l,t} = O_{w,l,t} S_{w,l} / \sum_{l} [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \qquad (27)$$

Spring Pot survey 2012-2015

Winter pot survey length compositions for newshell and oldshell crab, $P_{sw,n,l,t}$ and $P_{sw,o,l,t}$ ($l \geq 1$) were assumed to be supper crab population caught by winter pot survey gears

$$\hat{P}_{sp,n,l,t} = N_{s,l,t} S_{w,l} / \sum_{l} [(N_{s,l,t} + O_{s,l,t}) S_{w,l}]$$
$$\hat{P}_{sp,o,l,t} = O_{s,l,t} S_{s,l} / \sum_{l} [(N_{s,l,t} + O_{s,l,t}) S_{w,l}] \qquad (28)$$

Estimates of tag recovery

The proportion of released tagged length class *l'* crab recovered after *t-th* year with length class of *l* by a fishery of *s-th* selectivity (S_l) was assumed to be proportional to the growth matrix, catch selectivity, and molting probability (m_l) as

$$\hat{P}_{l',l,t,s} = \frac{S_l \cdot [X^t]_{l',l}}{\sum_{l=1}^{n} S_l \cdot [X^t]_{l',l}} \tag{29}$$

where X is a molting probability adjusted growth matrix with each component consisting of

$$X_{l',l} = \begin{cases} m_{l'} \cdot G_{l',l} & \text{when } l' \neq l \\ m_l \cdot G_{l',l} + (1\text{-}m_i) & \text{when } l' = l \end{cases} \tag{30}$$

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

c. Likelihood components.

Under assumptions that measurement errors of annual total survey abundances and summer commercial fishing efforts follow lognormal distributions and each type of length composition has a multinomial error structure (Fournier and Archibald 1982; Methot 1989), the log-likelihood function is

$$
\begin{aligned}
&\sum_{i=1}^{i=4}\sum_{t=1}^{t=n_i} K_{i,t}\left[\sum_{l=1}^{l=n} P_{i,l,t}\ln(\hat{P}_{i,l,t}+\kappa) - \sum_{l=1}^{l=n} P_{i,l,t}\ln(P_{i,l,t}+\kappa)\right] \\
&-\sum_{t=1}^{t=n_i}\frac{[\ln(q\cdot\hat{B}_{i,t}+\kappa)-\ln(B_{i,t}+\kappa)]^2}{2\cdot ln(CV_{i,t}^2+1)} \\
&-\sum_{t=1}^{t=n_i}\left[\frac{\ln\left[\ln(CV_t^2+1)+w_t\right]}{2}+\frac{[\ln(\hat{f}_t+\kappa)-\ln(f_t+\kappa)]^2}{2\cdot\left[\ln(CV_t^2+1)+w_t\right]}\right] \qquad (32) \\
&-\sum_{t=1}\frac{\tau_t^2}{2\cdot SDR^2} \\
&+W\sum_{s=1}^{s=2}\sum_{t=1}^{t=3}\sum_{l'=1}^{l'=n} K_{l',t,s}\left[\sum_{l=1}^{l=n} P_{l',l,t}\ln(\hat{P}_{l',l,t,s}+\kappa) - \sum_{l=1}^{l=n} P_{l',l,t}\ln(P_{l',l,t,s}+\kappa)\right]
\end{aligned}
$$

where

i: length/shell compositions of :

1 triennial summer trawl survey,
2 annual winter pot survey,
3 summer commercial fishery retained catch,
4 observer discards or total catch during the summer fishery
5 spring pot survey.

$K_{i,t}$: the effective sample size of length/shell compositions for data set i in year t,
$P_{i,l,t}$: observed and estimated length compositions for data set i, length class l, and year t.
κ : a constant equal to 0.0001,
CV : coefficient of variation for the survey abundance,
$B_{i,k,t}$: observed and estimated annual total abundances for data set i and year t,
f_t : observed and estimated summer fishing CPUE,
w^2_t: extra variance factor,
SDR : Standard deviation of recruitment = 0.5,
$K_{l',t}$: sample size of length class l' released and recovered after t-th in year,
$P_{l',l,t,s}$: observed and estimated proportion of tagged crab released at length l' and recaptured at length l, after t-th year by commercial fishy pot selectivity s,
W: weighting for the tagging survey likelihood

It is generally believed that total annual commercial crab catches in Alaska are fairly accurately reported. Thus, total annual catch was assumed known.

d. Parameter estimation framework:

i. Parameters Estimated Independently

The following parameters were estimated independently: natural mortality (M =0.18), proportions of legal males by length group.

Natural mortality was based on an assumed maximum age, t_{max}, and the 1% rule (Zheng 2005):

$$M = -\ln(p)/t_{\max},$$

where p is the proportion of animals that reach the maximum age and is assumed to be 0.01 for the 1% rule (Shepherd and Breen 1992, Clarke et al. 2003). The maximum age of 25, which was used to estimate M for U.S. federal overfishing limits for red king crab stocks results in an estimated M of 0.18. Among the 199 recovered crabs from the tagging returns during 1991-2007 in Norton Sound, the longest time at liberty was 6 years and 4 months from a crab tagged at 85 mm CL. The crab was below the mature size and was likely less than 6 years old when tagged. Therefore, the maximum age from tagging data is about 12, which does not support the maximum age of 25 chosen by the CPT.

Proportions of legal males (CW > 4.75 inches) by length group were estimated from the ADF&G trawl data 1996-2011 (Table 11).

ii. Parameters Estimated Conditionally

Estimated parameters are listed in Table 10. Selectivity and molting probabilities based on these estimated parameters are summarized in Tables 11.

A likelihood approach was used to estimate parameters

e. Definition of model outputs.

i. Estimate of mature male biomass (MMB) is on **February 1st** and is consisting of the biomass of male crab in length classes 4 to 8

$$MMB = \sum_{l=4} (N_{w,l,} + O_{w,l,}) wm_l$$

wm_l: mean weight of each length class (Table 11).

ii. Projected legal male biomass for winter and summer fishery OFL was calculated as

$$Legal\_B = \sum_{l} (N_{w,l,} + O_{w,l,}) S_{s,l} P_{lg,l} wm_l \text{ Baseline model}$$

$$Legal\_B = \sum_{l}(N_{w,l,} + O_{w,l,})S_{s,l}S_{r,l}wm_l \text{ Alternative model}$$

iii. Recruitment: the number of males in length classes 1, 2, and 3.

iv.

f. OFL

The Norton Sound red king crab fishery consists of two distinct fisheries: winter and summer. The two fisheries are discontinuous with 5 months between the two fisheries during which natural mortalities occur. To incorporate this fishery, the CPT in 2016 recommended the following formula:

$$OFL_r = \text{Winter harvest (Hw)} + \text{Summer harvest (Hs)} \quad (1)$$

And

$$p = \frac{Hw}{OFL_r} \quad (2)$$

Where p is a specific proportion of winter crab harvest to total (winter + summer) harvest

At given fishery mortality (F_{OFL}), Winter harvest is a fishing mortality

$$Hw = (1 - e^{-x \cdot F})B_w \quad (3)$$

$$Hs = (1 - e^{-(1-x) \cdot F})B_s \quad (4)$$

where B_s is a summer crab biomass after winter fishery and x ($0 \leq x \leq 1$) is a fraction that satisfies equation (2)

Since B_s is a summer crab biomass after winter fishery and 5 months of natural morality ($e^{-0.42M}$)

$$\begin{aligned} B_s &= (B_w - Hw)e^{-0.42M} \quad (5) \\ &= (B_w - (1 - e^{-x \cdot F})B_w)e^{-0.42M} \\ &= B_w e^{-x \cdot F - 0.42M} \end{aligned}$$

Substituting *0.42M* to *m*, summer harvest is

$$\begin{aligned} Hs &= (1 - e^{-(1-x) \cdot F})B_s \quad (6) \\ &= (1 - e^{-(1-x) \cdot F})B_w e^{-x \cdot F - m} = (e^{-(x \cdot F + m)} - e^{-(F+m)})B_w \end{aligned}$$

Thus, OFL is

$$OFL = Hw + Hs = (1 - e^{-xF})B_w + (e^{-(x \cdot F + m)} - e^{-(F+m)})B_w \tag{7}$$
$$= (1 - e^{-xF} + e^{-(xF+m)\cdot} - e^{-(F+m)\cdot})B_w$$
$$= [1 - e^{-(F+m)\cdot} - (1 - e^{-m\cdot})e^{-xF\cdot}]B_w$$

Combining (2) and (7),

$$p = \frac{Hw}{OFL_r} = \frac{(1 - e^{-xF})B_w}{[1 - e^{-(F+m)\cdot} - (1 - e^{-m\cdot})e^{-xF\cdot}]B_w} \tag{8}$$

Solving (8) for x

$$(1 - e^{-xF}) = p[1 - e^{-(F+m)\cdot} - (1 - e^{-m\cdot})e^{-xF\cdot}] \tag{9}$$
$$e^{-xF} - p(1 - e^{-m\cdot})e^{-xF\cdot} = 1 - p[1 - e^{-(F+m)\cdot}]$$
$$[1 - p(1 - e^{-m\cdot})]e^{-xF\cdot} = 1 - p[1 - e^{-(F+m)\cdot}]$$
$$e^{-xF\cdot} = \frac{1 - p[1 - e^{-(F+m)\cdot}]}{1 - p(1 - e^{-m\cdot})}$$

Combining (7) and (9), and substituting back,

revised retained OFL is

$$OFL = Legal\_B_w\left(1 - e^{-(F_{OFL}+0,42M)} - (1 - e^{-0.42M})\left(\frac{1 - p(1 - e^{-(F_{OFL}+0.42M)})}{1 - p(1 - e^{-0.42M})}\right)\right)$$

Further combining (3) and (9), Winter fishery harvest rate (Fw) i

$$Fw = (1 - e^{-x \cdot F}) = 1 - \frac{1 - p[1 - e^{-(F+m)\cdot}]}{1 - p(1 - e^{-m\cdot})} = \frac{1 - p(1 - e^{-m\cdot}) - 1 + p[1 - e^{-(F+m)\cdot}]}{1 - p(1 - e^{-m\cdot})} \tag{10}$$
$$= \frac{p(e^{-m\cdot} - e^{-(F+m)\cdot})}{1 - p(1 - e^{-m\cdot})} = \frac{p(1 - e^{-F\cdot})e^{-0.42M\cdot}}{1 - p(1 - e^{-0.42M\cdot})}$$

Summer fishery harvest rate (Fs) is

$$Fs = (e^{-(x \cdot F+m)} - e^{-(F+m)}) = (e^{-x \cdot F} - e^{-F})e^{-m} \tag{11}$$

$$= \left(\frac{1- p[1-e^{-(F+m)\cdot}]}{1-p(1-e^{-m\cdot})} - e^{-F} \right) e^{-m}$$

$$= \left(\frac{1- p[1-e^{-(F+m)\cdot}] - e^{-F} + p(e^{-F} - e^{-(F+m\cdot)})}{1-p(1-e^{-m\cdot})} \right) e^{-m}$$

$$= \left(\frac{1- p + pe^{-(F+m)\cdot} - e^{-F} + pe^{-F} - pe^{-(F+m\cdot)}}{1-p(1-e^{-m\cdot})} \right) e^{-m}$$

$$= \frac{(1- p)(1-e^{-F})e^{-m}}{1-p(1-e^{-m\cdot})} = \frac{(1- p)(1-e^{-F})e^{-0.24M}}{1-p(1-e^{-0.24M\cdot})}$$

Appendix B

Norton Sound Red King Crab CPUE Standardization

Note: This is an update of model by G. Bishop (SAFE 2013).

Methods

Data Source & Cleaning

Commercial fishery harvest data were obtained from a fish ticket database, which included: Landing Date, Fish Ticket Number, Vessel Number, Permit Fishery ID, Statistical Area(s) fished, Effort, and Number and Pounds of Crab harvested (Table A2-1,2,3, Figure A2-1). Fish ticket database may have multiple entries of identical Fish Ticket Number, Vessel Number, Permit Fishery ID, and Statistical Area. In those cases, at least one Effort data are missing or zero with the Number and Pounds of Crab harvested. These entries indicate that crabs were either retained from commercial fishery (i.e., not sold), or dead loss.

Following data cleaning and combining methods were conducted.

1. Sum crab number and efforts by Fish Ticket Number, Vessel Number, Permit Fishery ID, Statistical Area
2. Remove data of missing or zero Efforts, Number of Crab, Pounds of Crab (Those are considered as true missing data)
3. Calculate CPUE as Number of Crab/Effort

Data Censoring

During 1977-92 period, vessels of 1 year of operation and/or 1 delivery per year harvested 20-90% of crabs (Table A2-5, Figure A2-2). For instance, all vessels did only 1 delivery in 1989, and in 1988 64% of crabs were harvested by 1 vessel that did only 1 delivery. On the other hand, during the 1993-2017 period of post super-exclusive fishery status, the majority of commercial crab fishery and harvest was done by vessels with more than 5 years of operations and more than 5 deliveries per year. For 1977 – 1992, censoring was made for vessels of more than 2 years of operations. Increasing deliveries to more than one would result in no estimates for some years. For 1993 – 2018, censoring was made for vessels of more than 5 years of operations and 5 deliveries per year.

Analyses

A GLM was constructed as

$$\ln(CPUE) = YR + PD + VSL + MSA + WOY + PF$$

Where YR: Year, PD: Fishery periods (1977-1992, 1993-2004,2005-2018), VSL: Vessel, MSA: Statistical Area, WOY: Week of Year, PF: Permit vs open fishery (Table 1). All variables were treated as categorical. Inclusion of interaction terms were not considered because they were absent (SAFE 2013).

For selection of the best model, forward and backward stepwise selection was conducted. (R step function)

```
fit <- glm(L.CPUE.NO ~ factor(YR) + factor(VSL) + factor(WOY) +
factor(MSA) + factor(PF),data=NSdata.C)
step <- step(fit, direction='both', trace = 10)
best.glm<-glm(formula(step), data=NSdata.C)
```

The analyses were conducted for both censored and full data.
Generally, censoring had little effects on standardized CPUE.

Table B-1. List of variables in the fish ticket database. Variables in bold face were used for generalized linear modeling.

Variable	Description
YR	Year of commercial fishery
VSL	Unique vessel identification number
Fish Ticket Number	Unique delivery to a processor by a vessel.
PF	Unique Permit Fishery categories
Statistical Area	Unique fishery area.
MOA	Modified statistical area, combining each statistical area into 4 larger areas: Inner, Mid, Outer, Outer North
Fishing beginning date	Date of pots set
Landing date	Date of crab landed to processor
WOY	Week of Landing Date **(calculated)**
Effort	The number of pot lift
Crab Numbers	Total number of crabs harvested from pots
Crab Pounds	Total pounds of crab harvested from pots
ln(CPUE)	ln(Crab Numbers/Effort) **(calculated)**

Table B-2. Permit fisheries, descriptions, and years with deliveries for Norton Sound summer commercial red king crab harvest data.

Permit fishery	Type	Description	Years
K09Q	Open access	KING CRAB , POT GEAR VESSEL UNDER 60', BERING SEA	1994–2002
K09Z	Open access	KING CRAB , POT GEAR VESSEL UNDER 60', NORTON SOUND	1992–2017
K09ZE	CDQ	KING CRAB , POT GEAR VESSEL UNDER 60', NORTON SOUND CDQ, NSEDC	2000–2017
K09ZF	CDQ	KING CRAB , POT GEAR VESSEL UNDER 60', NORTON SOUND CDQ, YDFDA	2002–2004
K91Q	Open access	KING CRAB , POT GEAR VESSEL 60' OR OVER, BERING SEA	1978–1989
K91Z	Open access	KING CRAB , POT GEAR VESSEL 60' OR OVER, NORTON SOUND	1982–1994

Table B-3. Modified statistical area definitions used for analysis of Norton Sound summer commercial red king crab harvest data.

Modified statistical area	Statistical areas included
Inner	616331, 616401, 626331, 626401, 626402
Mid	636330, 636401, 636402, 646301, 646330, 646401, 646402
Outer	656300, 656330, 656401, 656402, 666230, 666300, 666330, 666401
Outer North	666402, 666431, 676300, 676330 ,676400, 676430, 676501, 686330

Table B-4. Final generalized linear model formulae and AIC selected for Norton Sound summer commercial red king crab fishery. The dependent variable is ln(CPUE) in numbers.

Data	Explanatory variables	Null dev.	Null df	Resid. dev.	Resid. df	AIC
1977-1992	YR+VSL+MOY+MSA	703.7	483	247.6	418	1183
1993-2018	YR+VSL+WOY+MSA+PF	4024.0	5638	2626.6	5538	11899

Table B-5. Standardized (Censored/full data), and scaled arithmetic observed CPUE indices from 1977–1992.

Year	Censored		Full data		Observed
	CPUE	SE	CPUE	SE	CPUE
1977	2.31	0.24	3.11	0.35	2.05
1978	4.15	0.13	2.51	0.23	4.77
1979	1.72	0.11	1.92	0.25	1.88
1980	2.14	0.16	2.15	0.28	1.90
1981	0.65	0.09	0.67	0.21	0.71
1982	0.25	0.12	0.11	0.25	0.30
1983	0.55	0.17	1.19	0.22	0.67
1984	1.10	0.18	1.02	0.23	0.97
1985	0.44	0.14	0.38	0.20	0.56
1986	1.63	0.33	0.85	0.41	1.75
1987	0.80	0.29	0.66	0.32	0.66
1988	2.09	0.33	1.63	0.67	1.72
1989	0.90	0.29	2.10	0.33	0.79
1990	1.60	0.41	1.31	0.40	1.31
1991					
1992	0.17	0.25	0.35	0.31	0.18
1993	0.96	0.09	1.03	0.10	1.04
1994	0.63	0.05	0.82	0.07	0.67
1995	0.40	0.05	0.44	0.06	0.42
1996	0.54	0.08	0.52	0.08	0.55
1997	0.76	0.10	0.81	0.10	0.88
1998	0.67	0.13	0.76	0.13	0.63
1999	0.47	0.13	0.96	0.14	0.53
2000	1.35	0.06	1.25	0.06	1.36
2001	0.74	0.05	0.64	0.05	0.67
2002	1.10	0.06	1.32	0.06	1.05
2003	0.90	0.05	0.86	0.05	0.87
2004	1.35	0.05	1.31	0.05	1.37
2005	1.24	0.05	1.23	0.05	1.26
2006	1.45	0.05	1.33	0.05	1.38
2007	1.10	0.05	1.06	0.05	1.00
2008	1.54	0.05	1.35	0.05	1.40
2009	1.04	0.04	0.87	0.04	1.00
2010	1.40	0.04	1.25	0.04	1.29
2011	1.69	0.05	1.64	0.05	1.66
2012	1.58	0.04	1.33	0.04	1.51
2013	0.74	0.04	0.70	0.04	0.82
2014	1.18	0.04	1.18	0.04	1.19
2015	1.55	0.05	1.52	0.05	1.47
2016	1.46	0.05	1.33	0.05	1.50
2017	1.27	0.05	1.16	0.05	1.28
2018	0.81	0.05	0.68	0.05	0.85

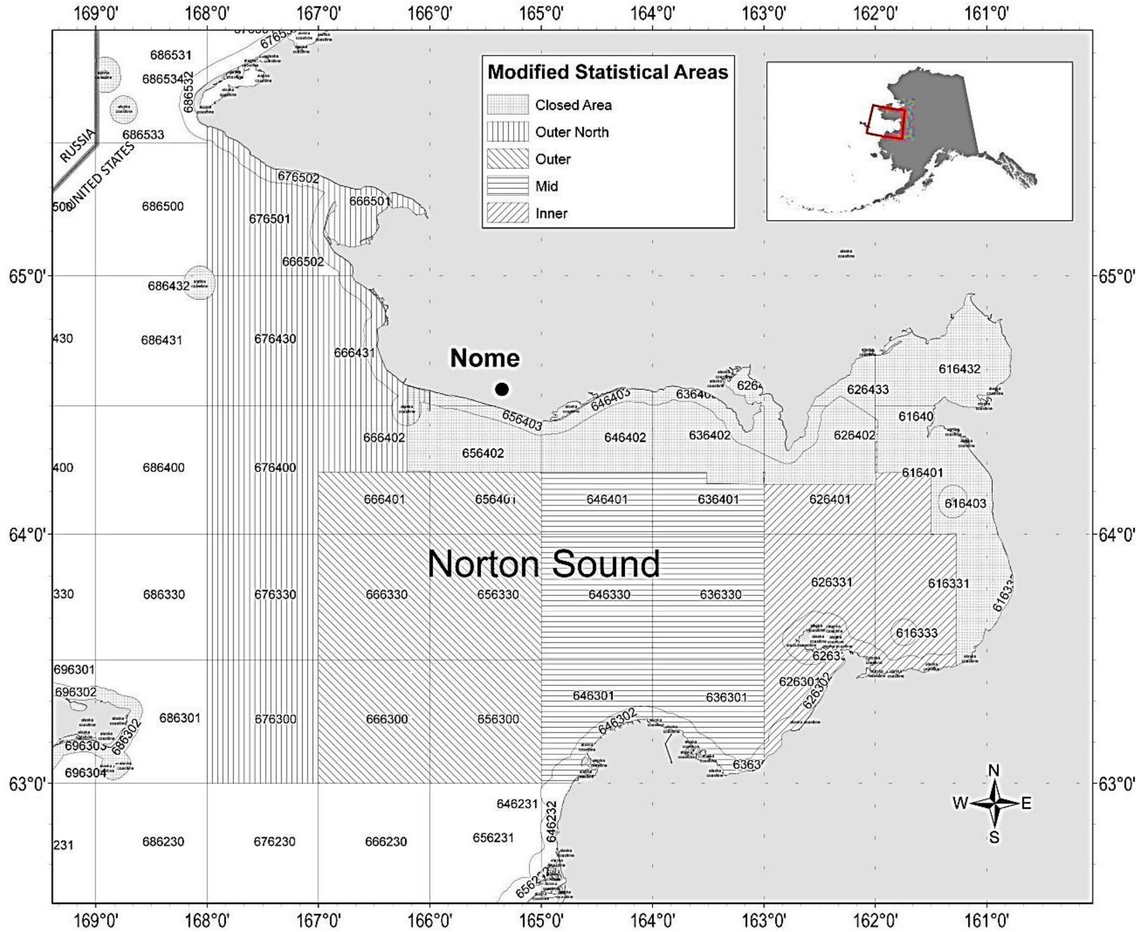


Figure A2-1. Closed area and statistical area boundaries used for reporting commercial harvest information for red king crab in Registration Area Q, Northern District, Norton Sound Section and boundaries of the new *Modified Statistical Areas* used in this analysis.

Appendix C1: Model 0 Results

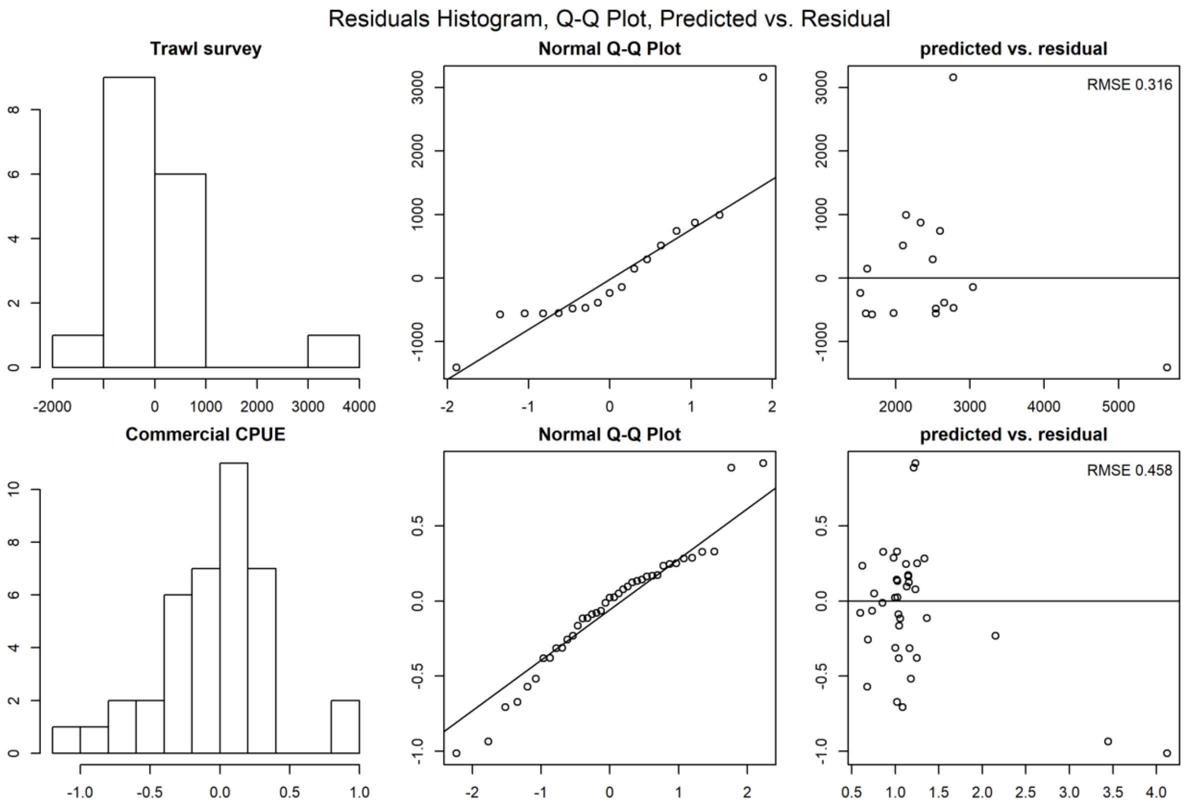


Figure C1-1. QQ Plot of Trawl survey and Commercial CPUE.

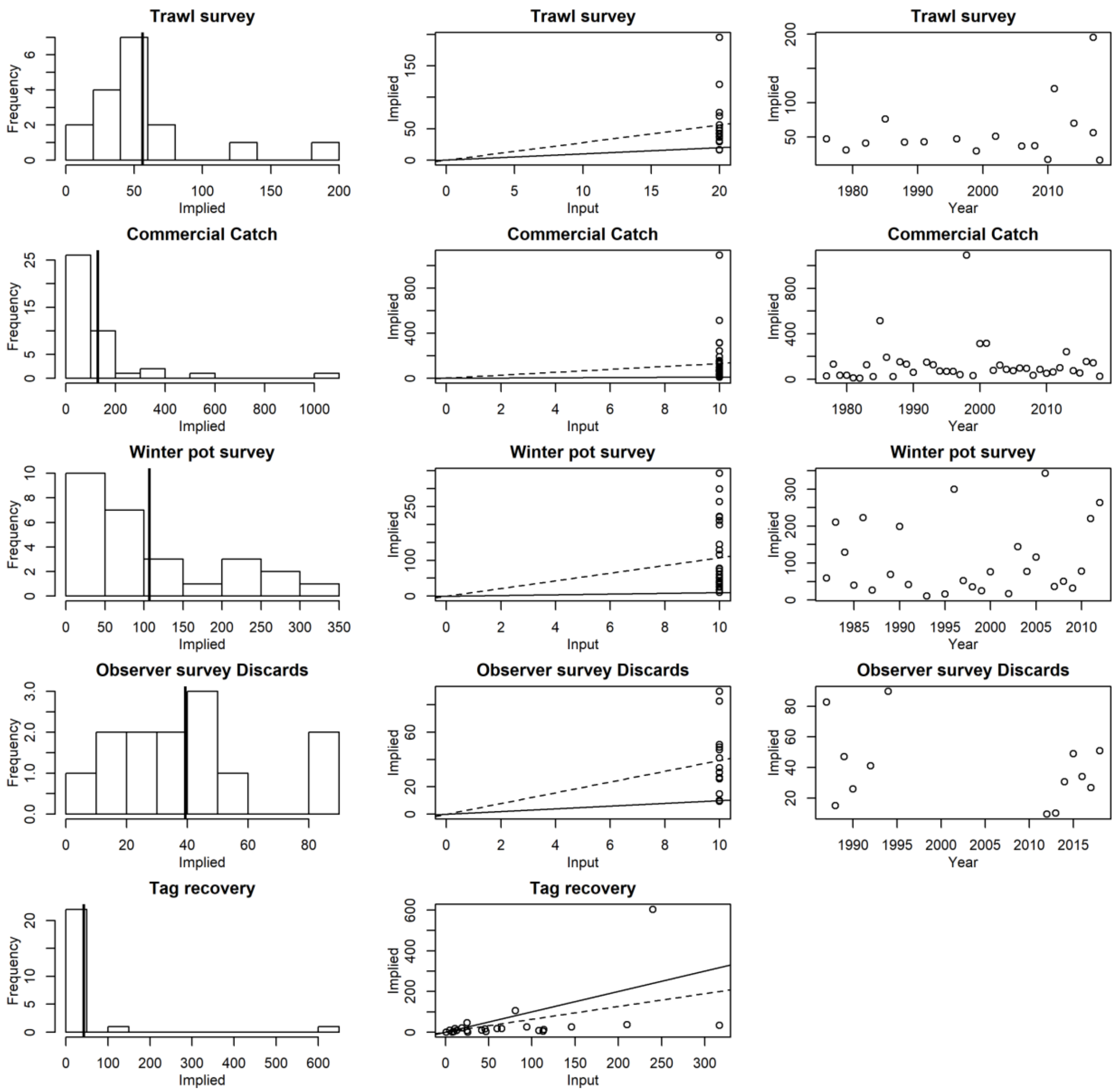


Figure C1-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column show input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

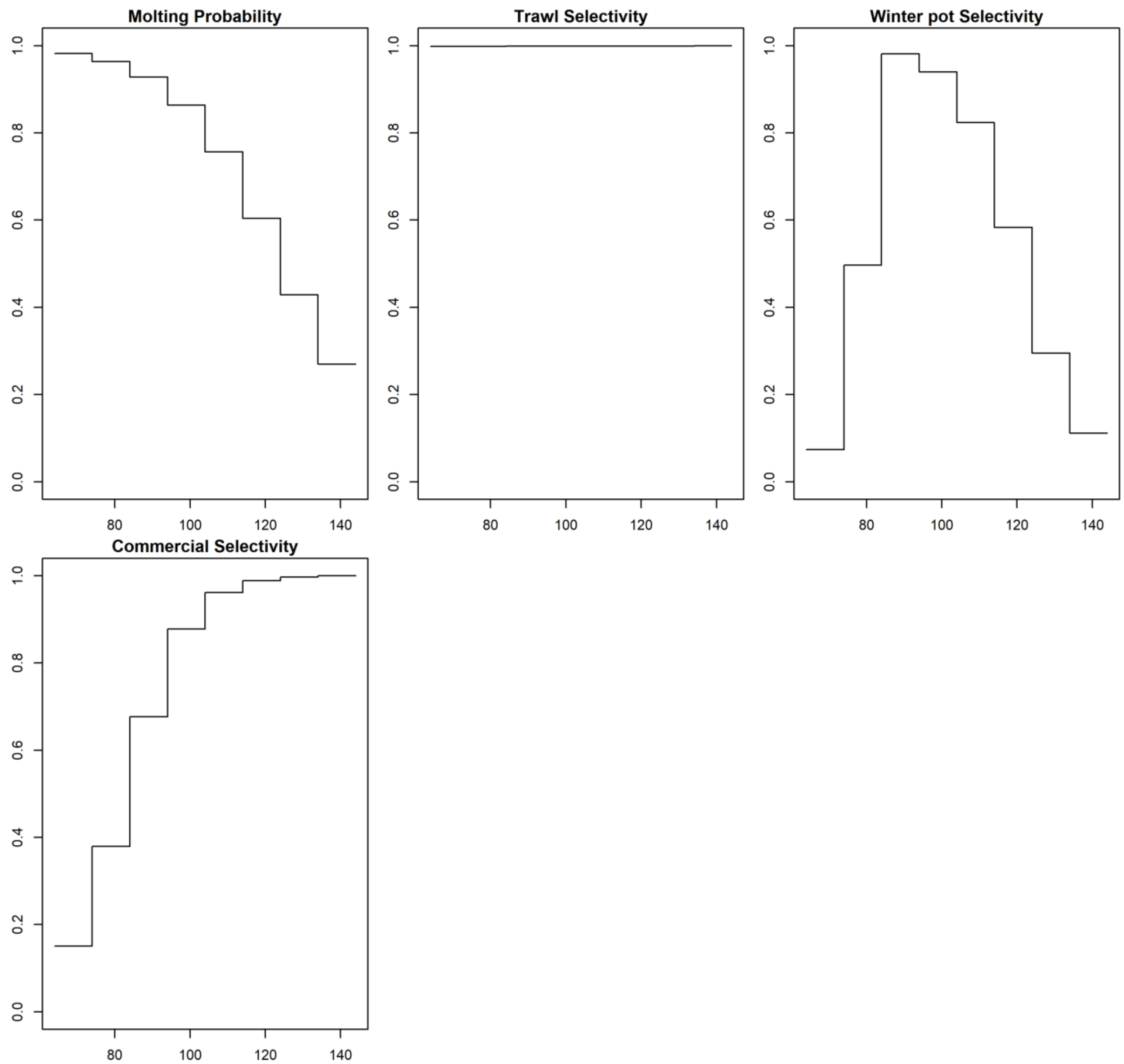


Figure C1-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

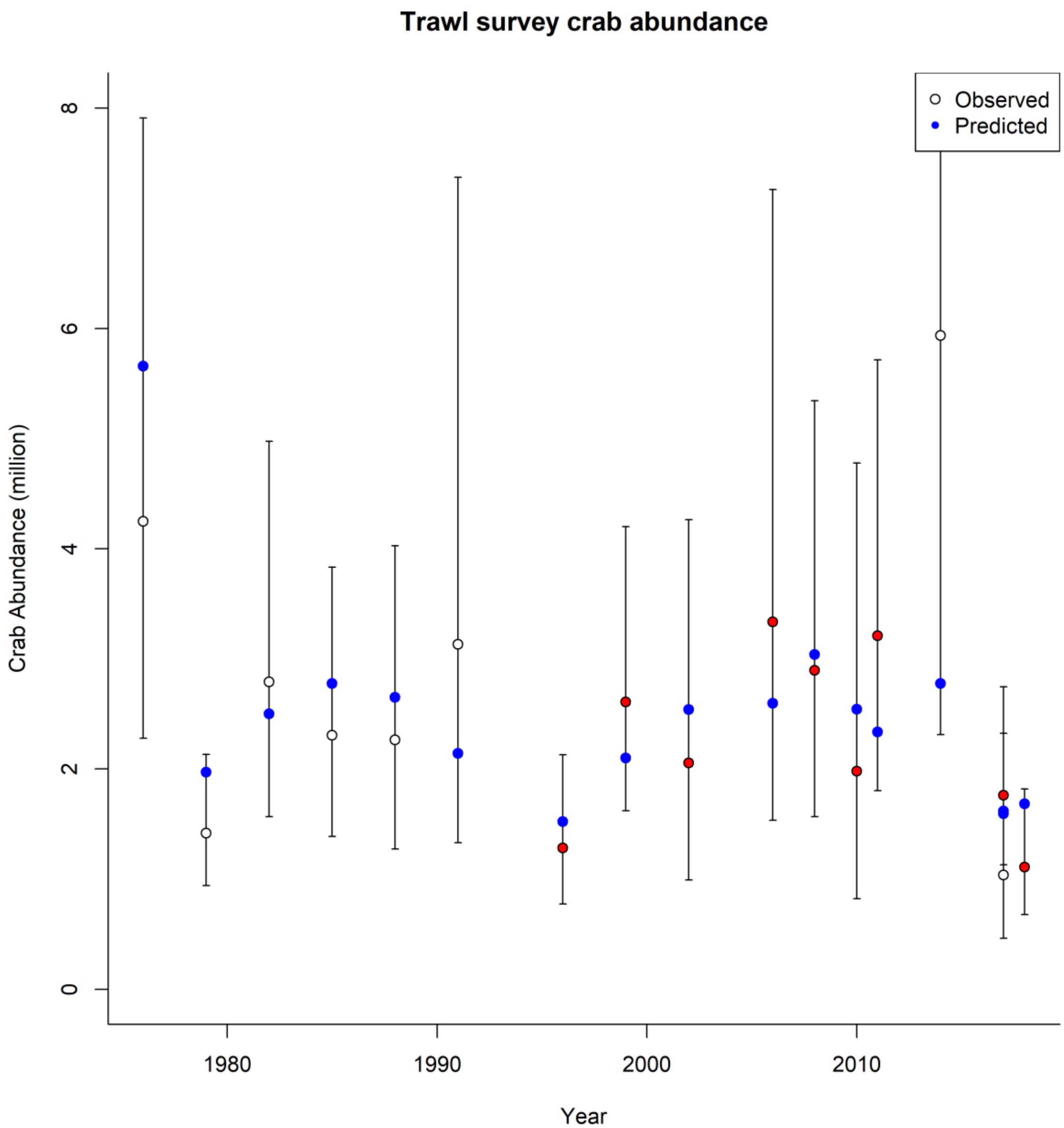


Figure C1-4. Estimated trawl survey male abundance (crab >= 64 mm CL). Observed: White: NOAA Trawl Survey, Red: ADG&G Trawl Survey

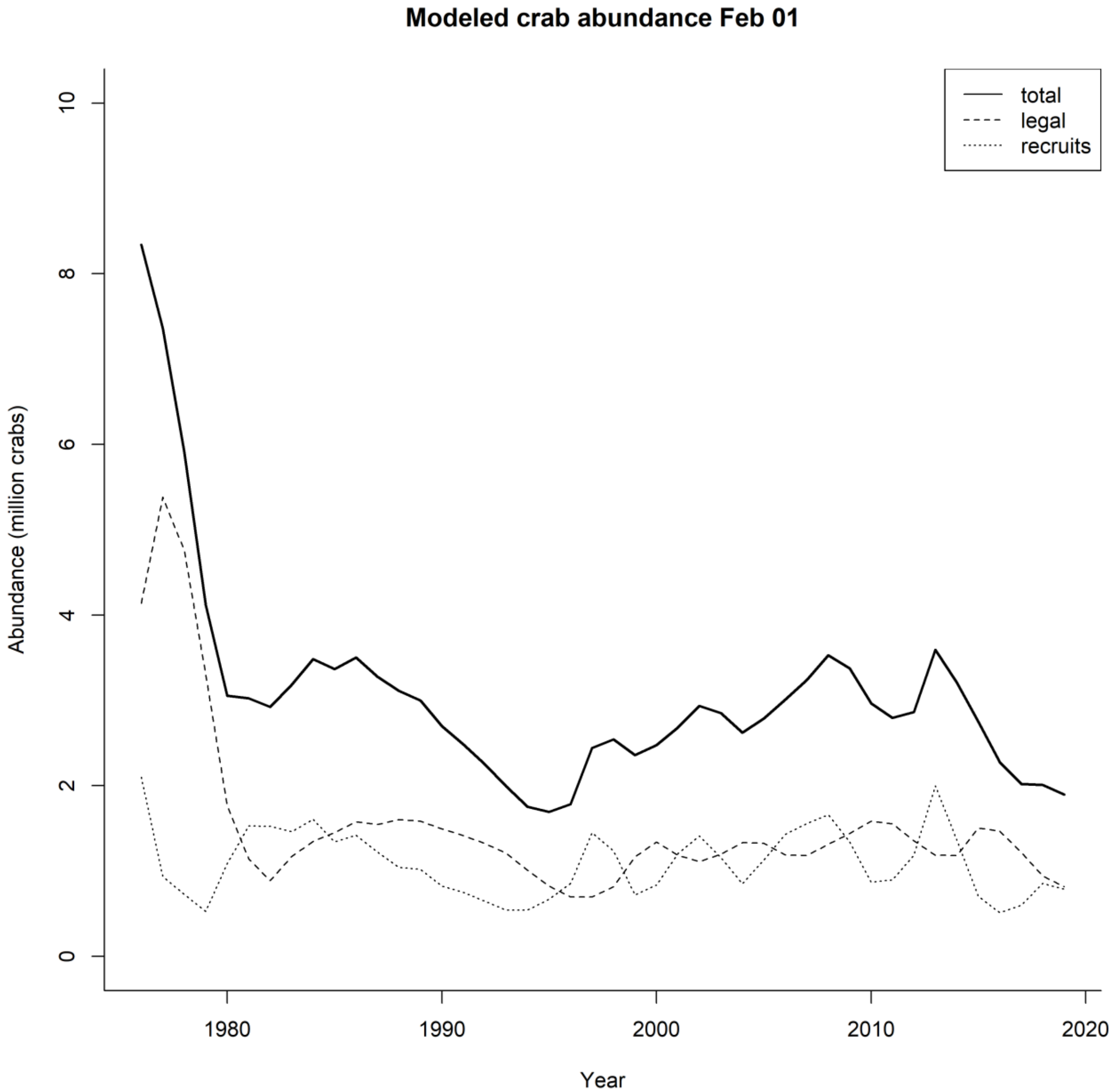


Figure C1-5. Estimated abundance of legal males from 1976-2015.

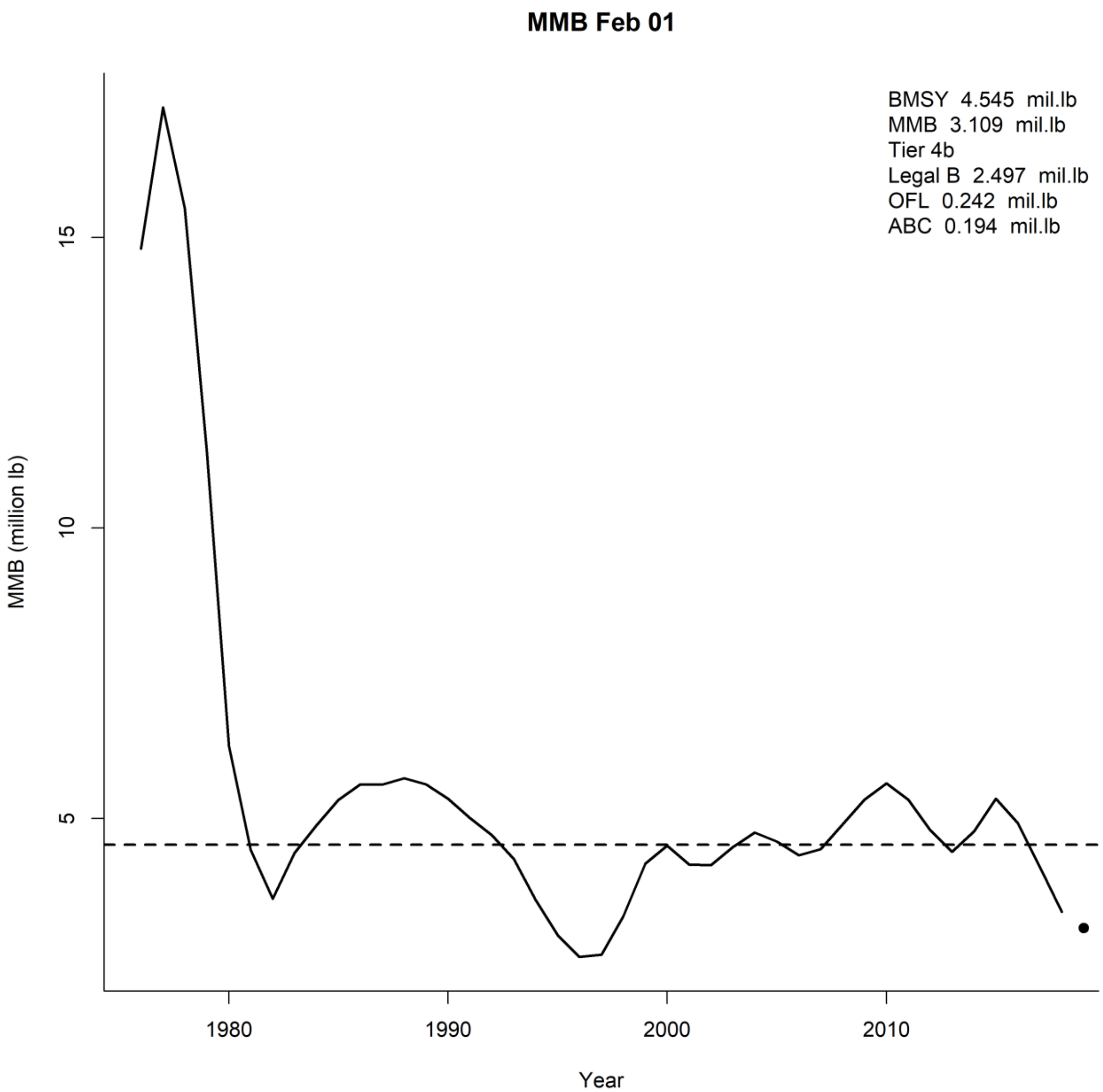


Figure C1-6. Estimated abundance of Mature Male Biomass from 1976-2019. Dash line shows Bmsy (Average MMB of 1980-2019).

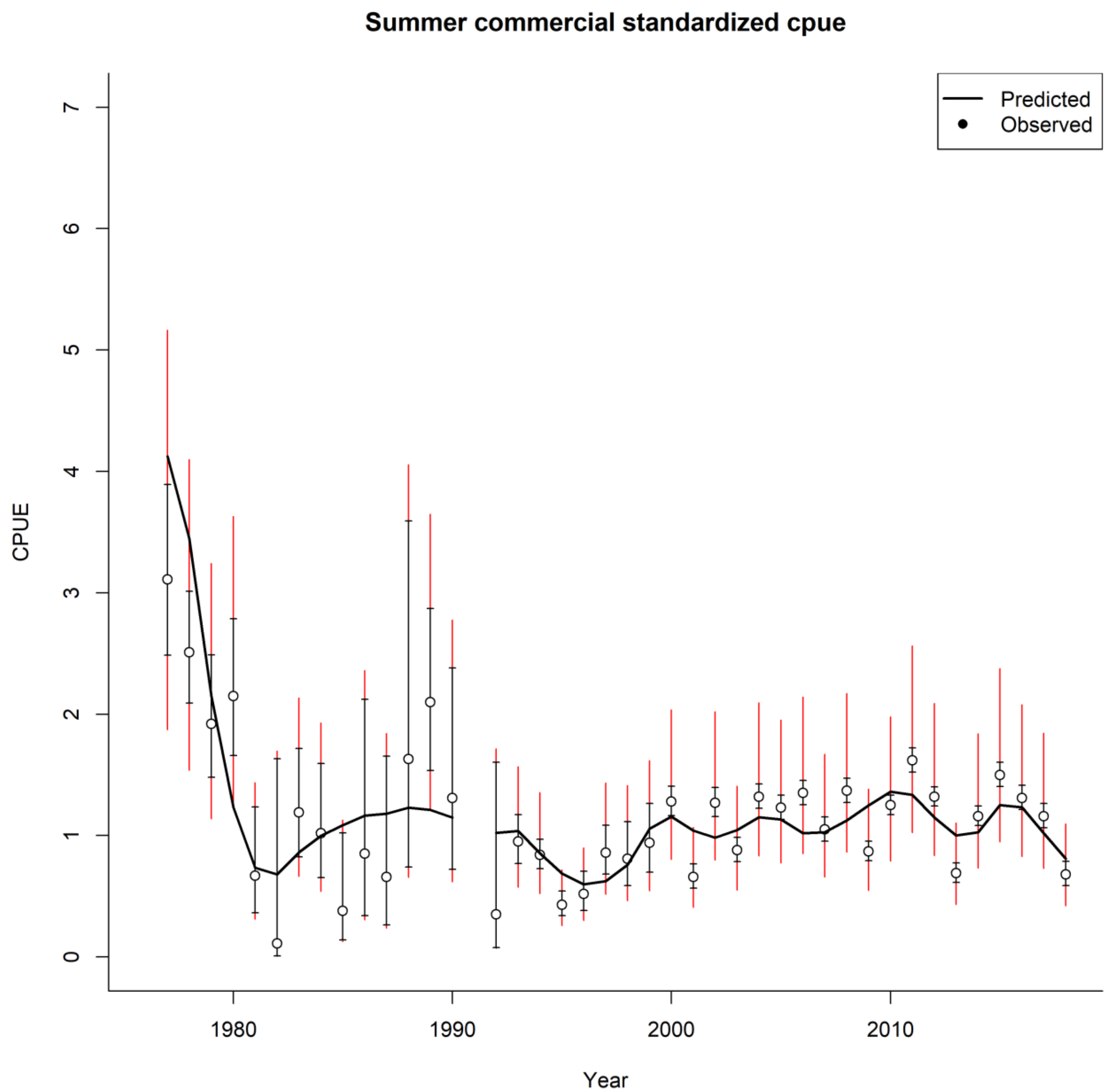


Figure C1-7. Summer commercial standardized cpue 1977-2018.

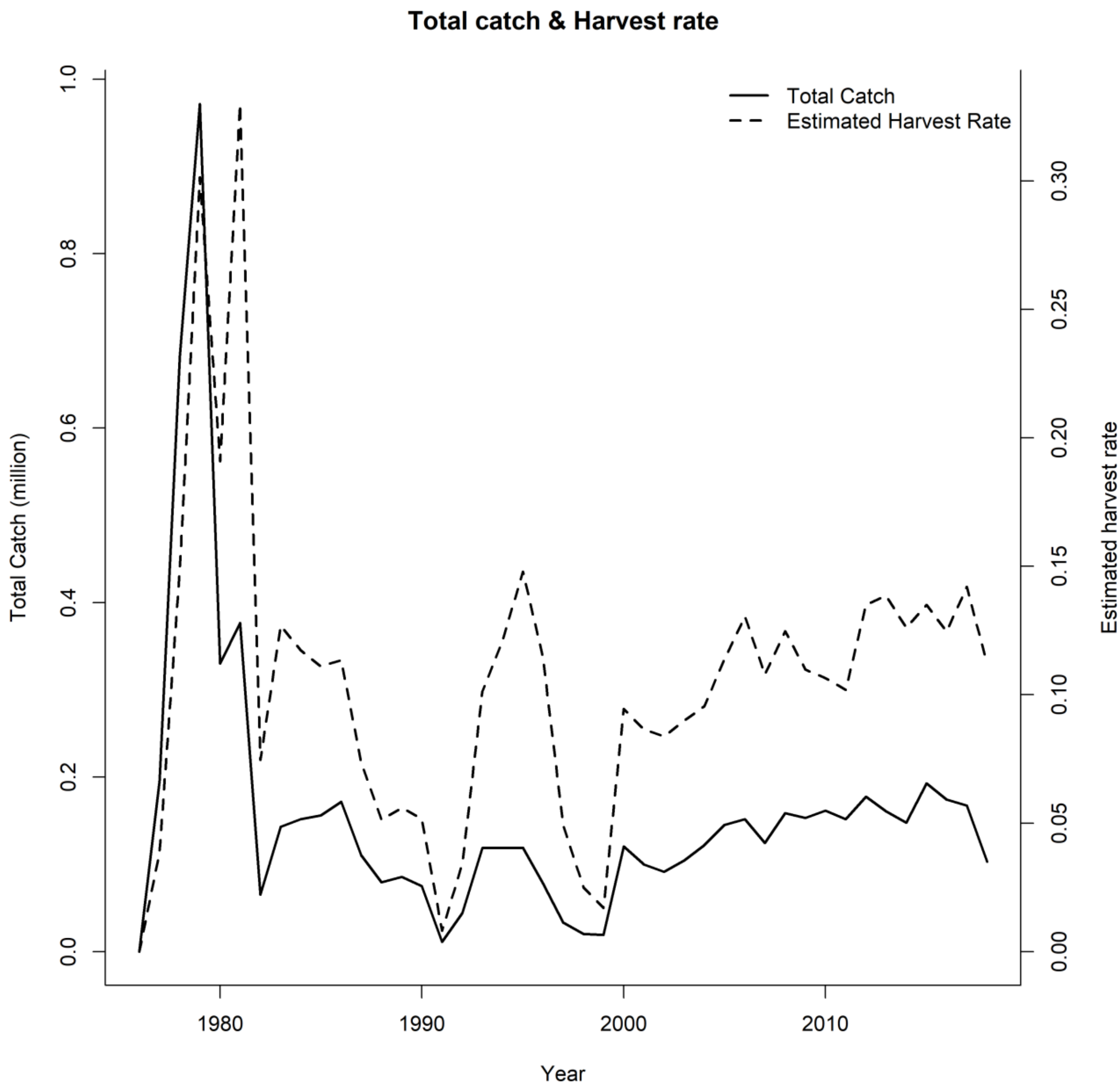


Figure C1-8. Total catch and estimated harvest rate 1976-2018.

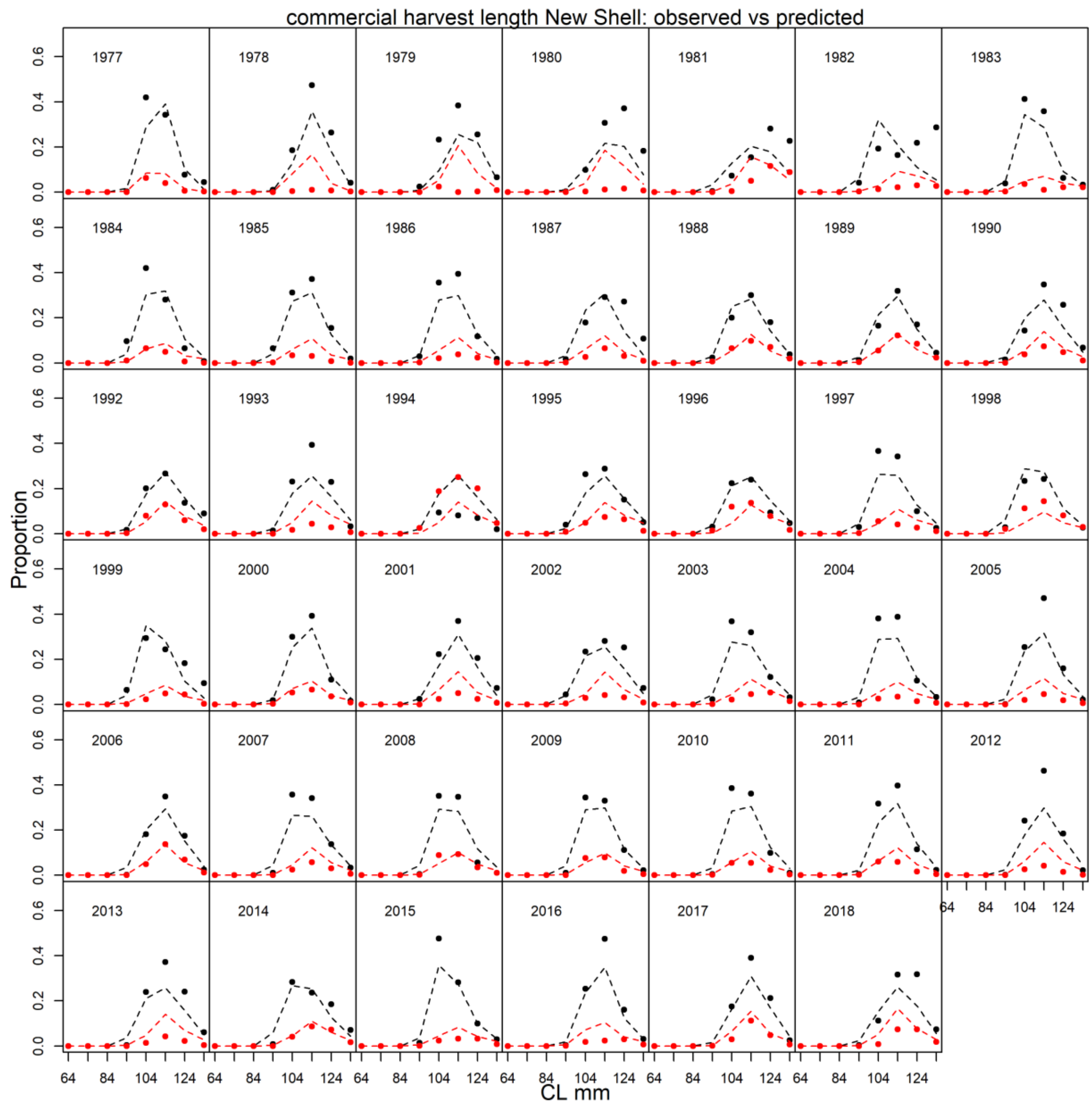


Figure C1-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Bladk: New Shell, Red: Old Shell

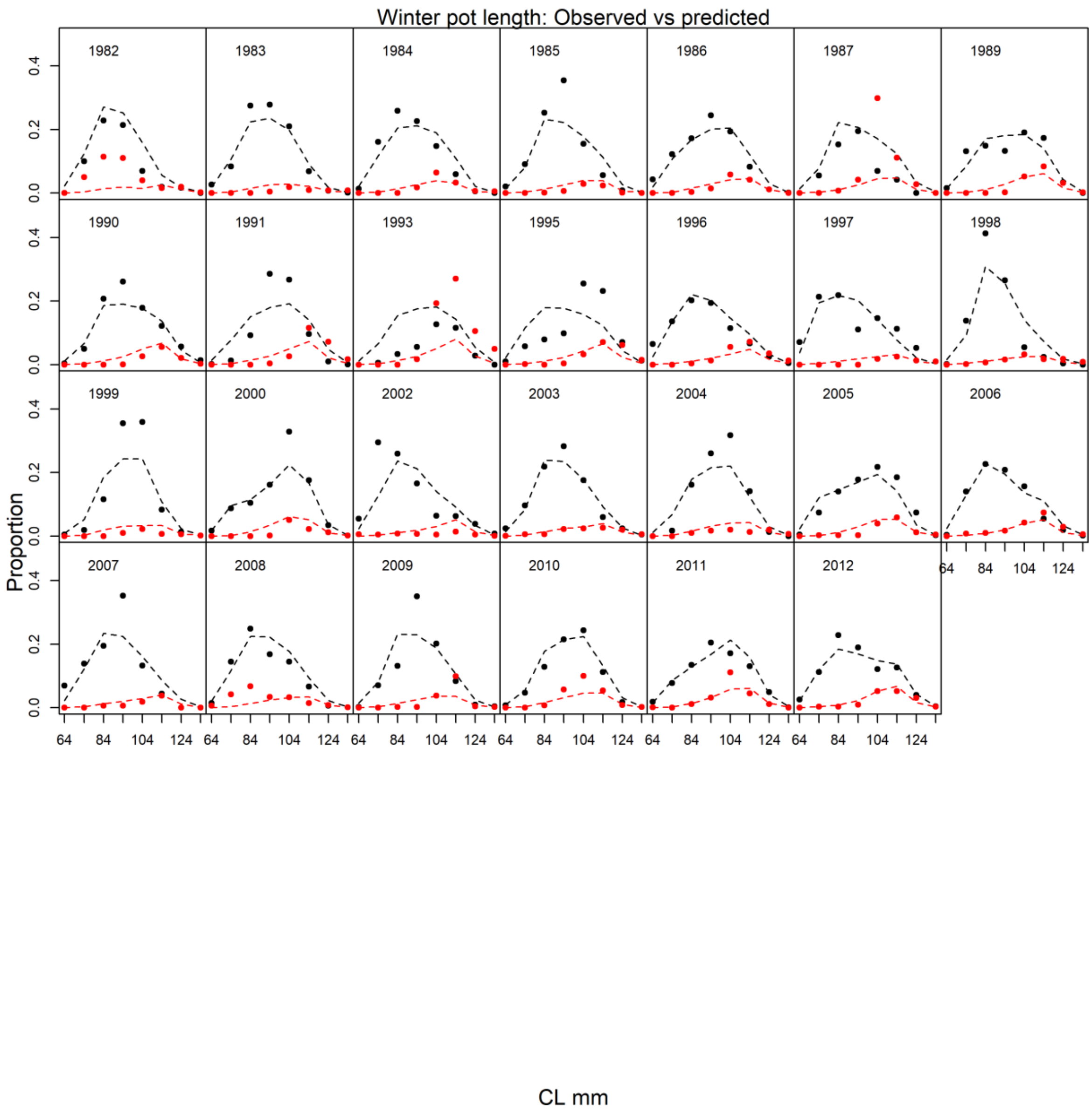
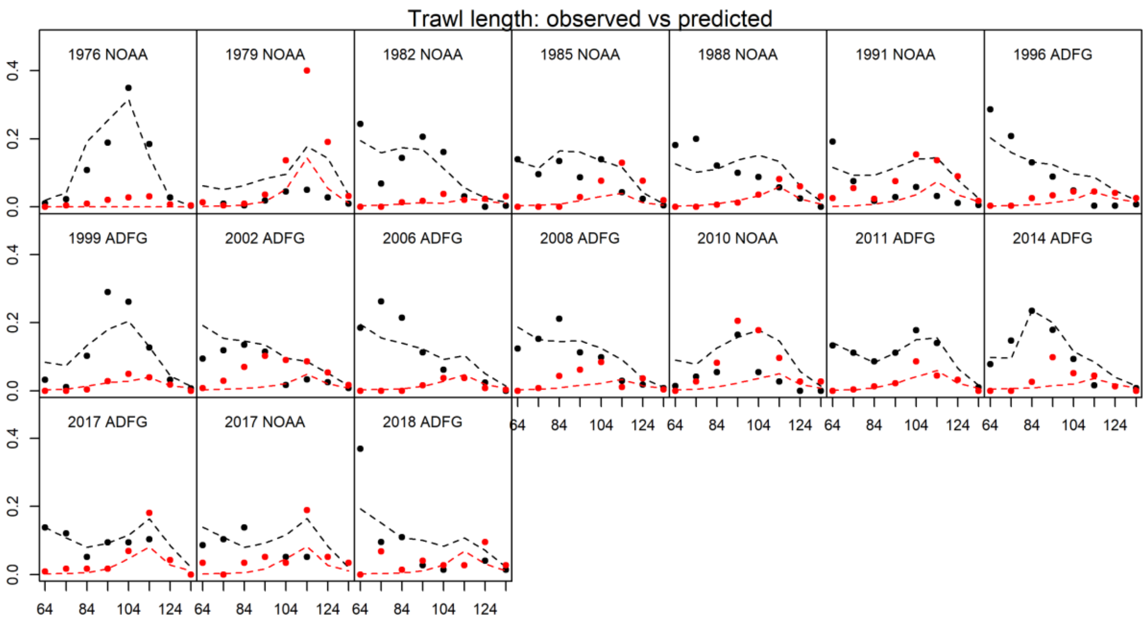


Figure C1-10. Predicted (dashed line) vs. observed (black dots) length class proportions for the winter and spring pot survey.


Trawl length: observed vs predicted
1976 NOAA
1979 NOAA
1982 NOAA
1985 NOAA
1988 NOAA
1991 NOAA
1996 ADFG
1999 ADFG
2002 ADFG
2006 ADFG
2008 ADFG
2010 NOAA
2011 ADFG
2014 ADFG
2017 ADFG
2017 NOAA
2018 ADFG
0.0
0.2
0.4
64
84
104
124

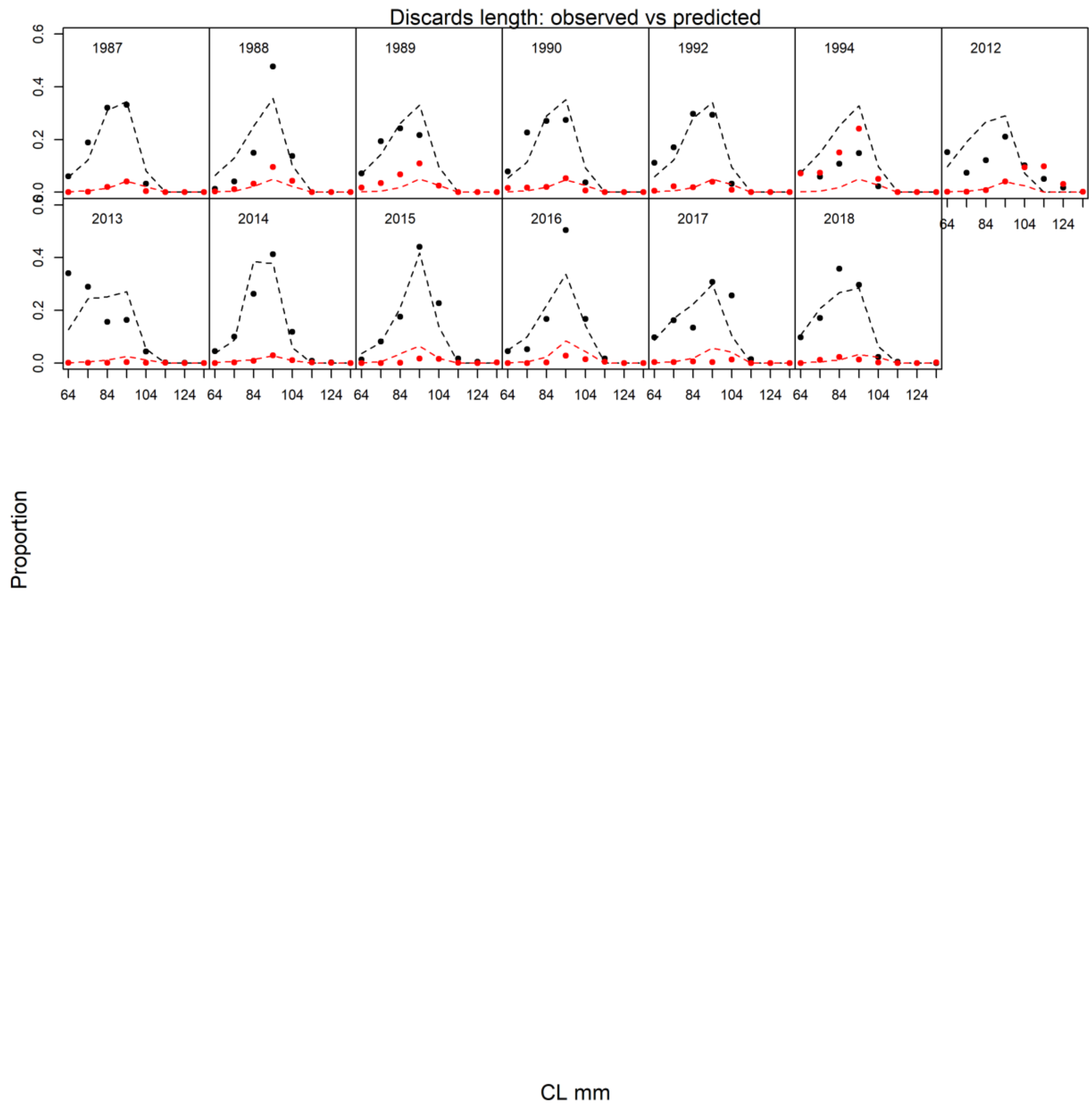


Figure C1-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey.

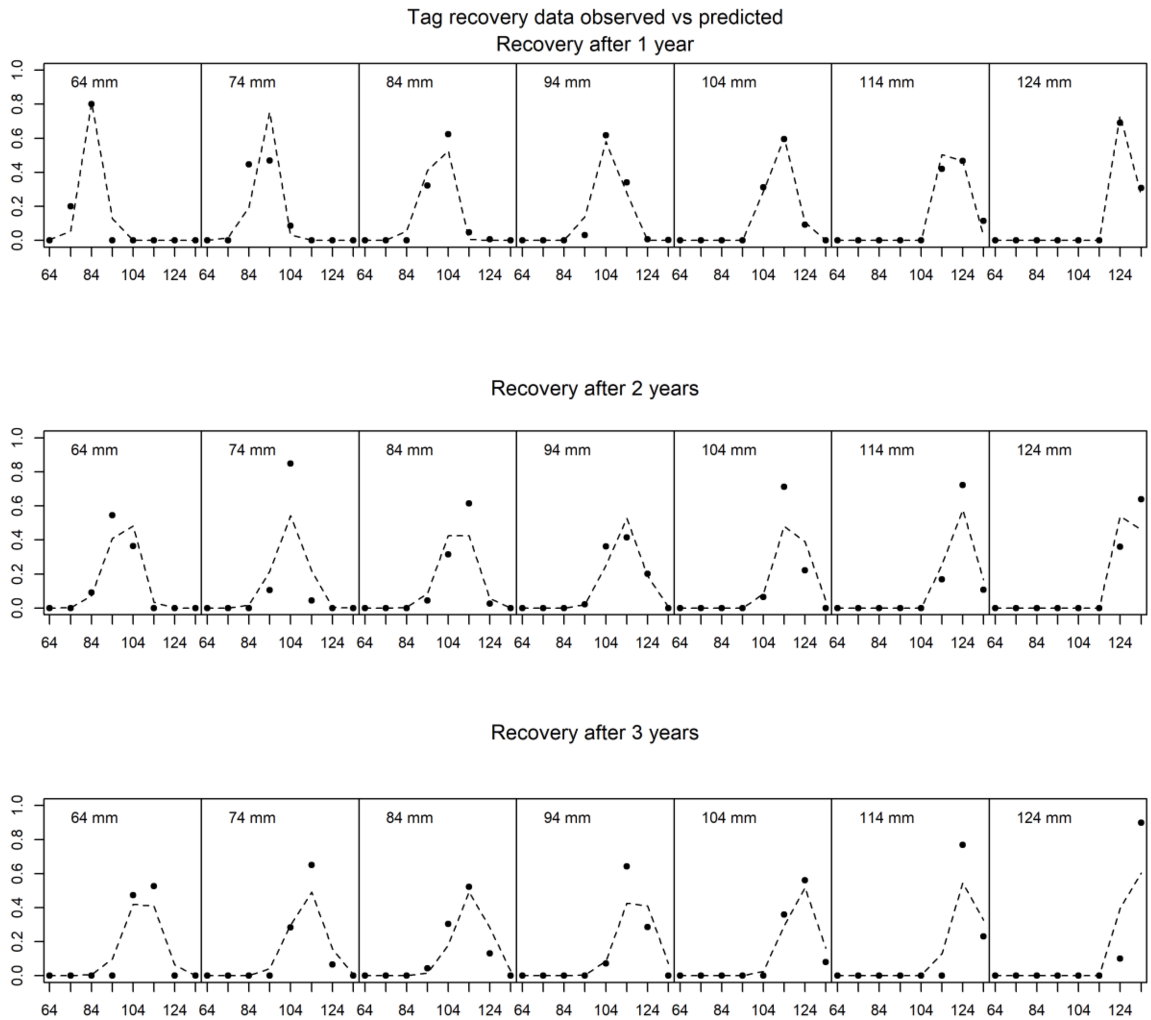


Figure C1-13. Predicted vs. observed length class proportions for tag recovery data.

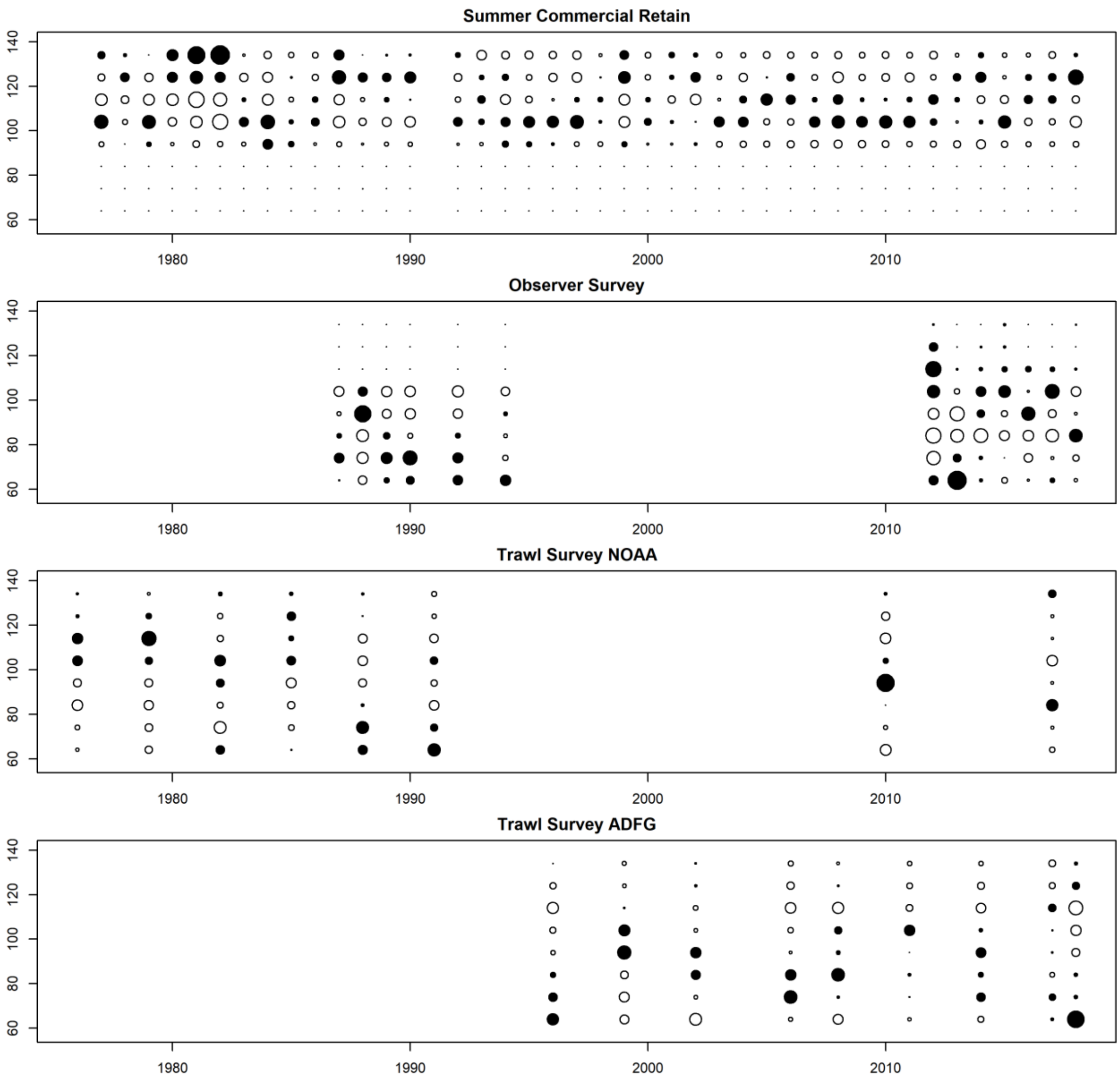


Figure C1-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

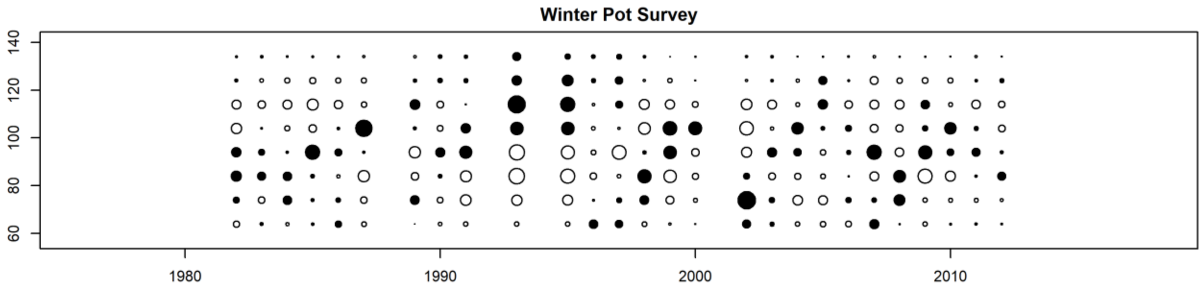


Figure C1-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table C1 . Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.965	0.168
log_q_2	-6.816	0.109
log_N_{76}	9.029	0.130
R_0	6.440	0.081
log_R_{76}	0.013	0.416
log_R_{77}	-0.541	0.370
log_R_{78}	-0.725	0.353
log_R_{79}	0.373	0.315
log_R_{80}	0.500	0.283
log_R_{81}	0.404	0.263
log_R_{82}	0.372	0.314
log_R_{83}	0.540	0.275
log_R_{84}	0.147	0.291
log_R_{85}	0.447	0.276
log_R_{86}	0.061	0.286
log_R_{87}	0.021	0.246
log_R_{88}	0.025	0.258
log_R_{89}	-0.329	0.280
log_R_{90}	-0.276	0.253
log_R_{91}	-0.526	0.285
log_R_{92}	-0.673	0.302
log_R_{93}	-0.577	0.289
log_R_{94}	-0.292	0.257
log_R_{95}	-0.063	0.225
log_R_{96}	0.576	0.217
log_R_{97}	-0.016	0.293
log_R_{98}	-0.624	0.320
log_R_{99}	-0.008	0.310
log_R_{00}	0.311	0.263
log_R_{01}	0.390	0.241
log_R_{02}	-0.005	0.314
log_R_{03}	-0.280	0.330
log_R_{04}	0.300	0.241
log_R_{05}	0.425	0.222
log_R_{06}	0.477	0.243

name	Estimate	std.dev
log_R_{07}	0.540	0.231
log_R_{08}	0.134	0.287
log_R_{09}	-0.367	0.294
log_R_{10}	-0.002	0.253
log_R_{11}	0.282	0.274
log_R_{12}	0.890	0.185
log_R_{13}	-0.196	0.284
log_R_{14}	-0.568	0.294
log_R_{15}	-0.751	0.269
log_R_{16}	-0.389	0.226
log_R_{17}	-0.018	0.275
a_1	1.543	4.575
a_2	2.316	4.264
a_3	3.826	4.069
a_4	4.106	4.055
a_5	4.325	4.046
a_6	3.550	4.075
a_7	2.117	4.335
r1	10.000	0.845
r2	9.680	0.863
log_a	-2.645	0.087
log_b	4.824	0.014553
log_ϕ_{st1}	3.145	5183.900
log_ϕ_{wa}	-2.115	0.317
log_ϕ_{wb}	4.798	0.028
Sw1	0.073	0.035
Sw2	0.500	353.550
log_ϕ_1	3.795	6501.300
w^2_t	0.052	0.016
q	0.766	0.131
σ	3.876	0.216
β_1	12.301	0.705
β_2	7.700	0.175
ms78	3.189	0.272

Appendix C2: Model 1 Results

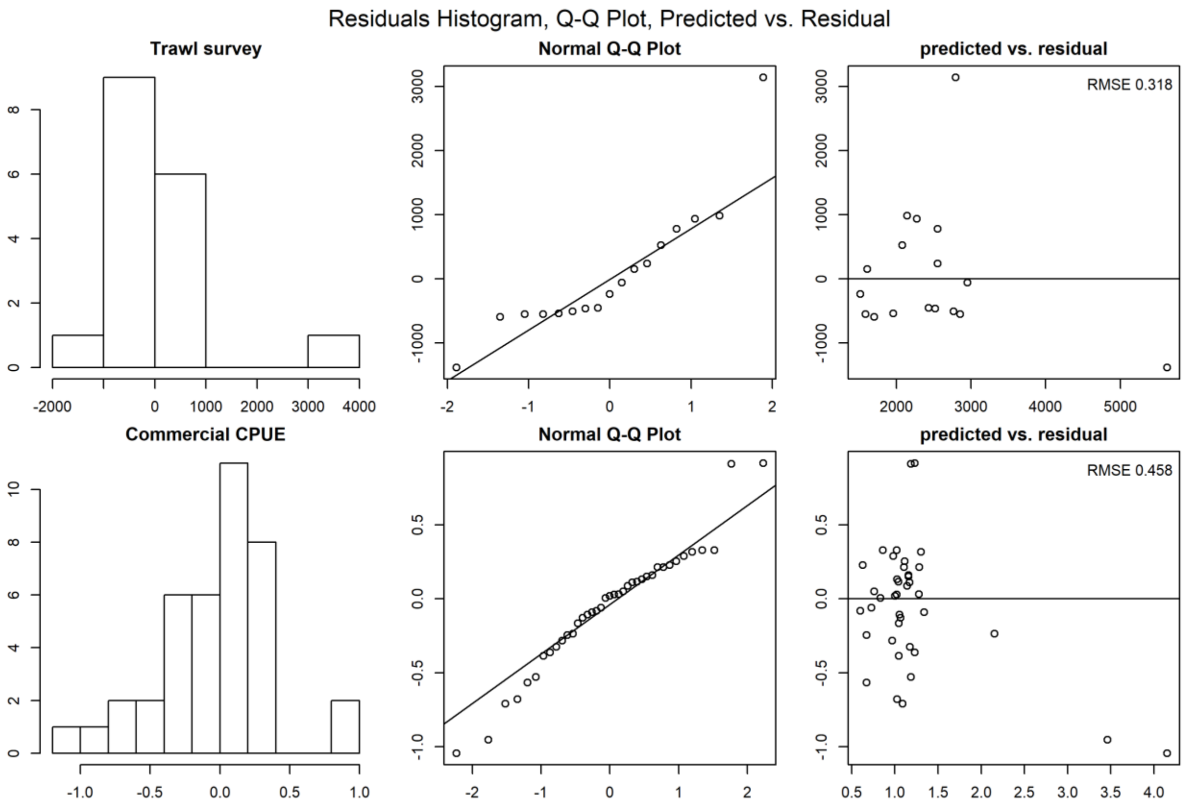


Figure C2-1. QQ Plot of Trawl survey and Commercial CPUE.

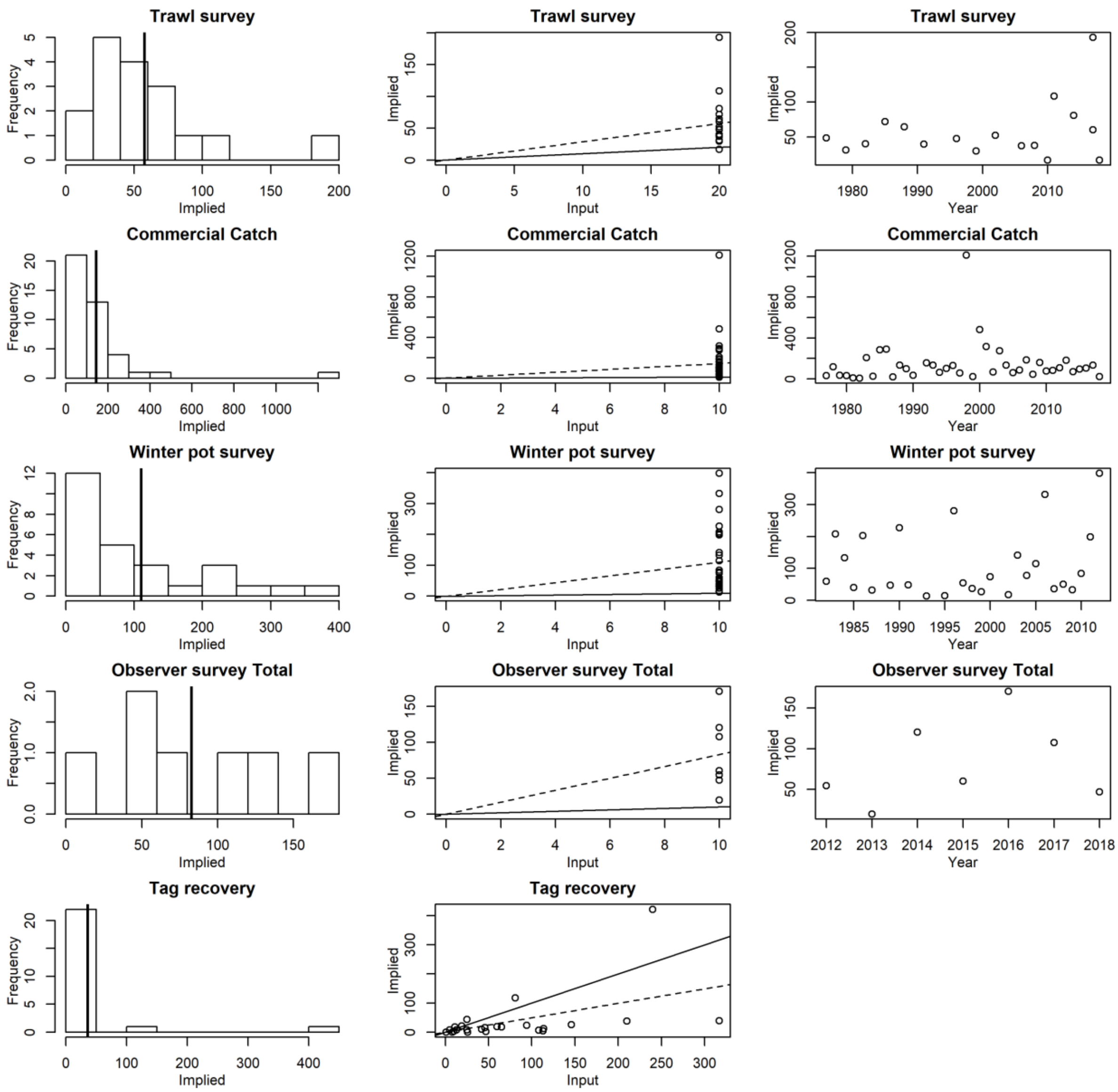


Figure C2-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column show input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

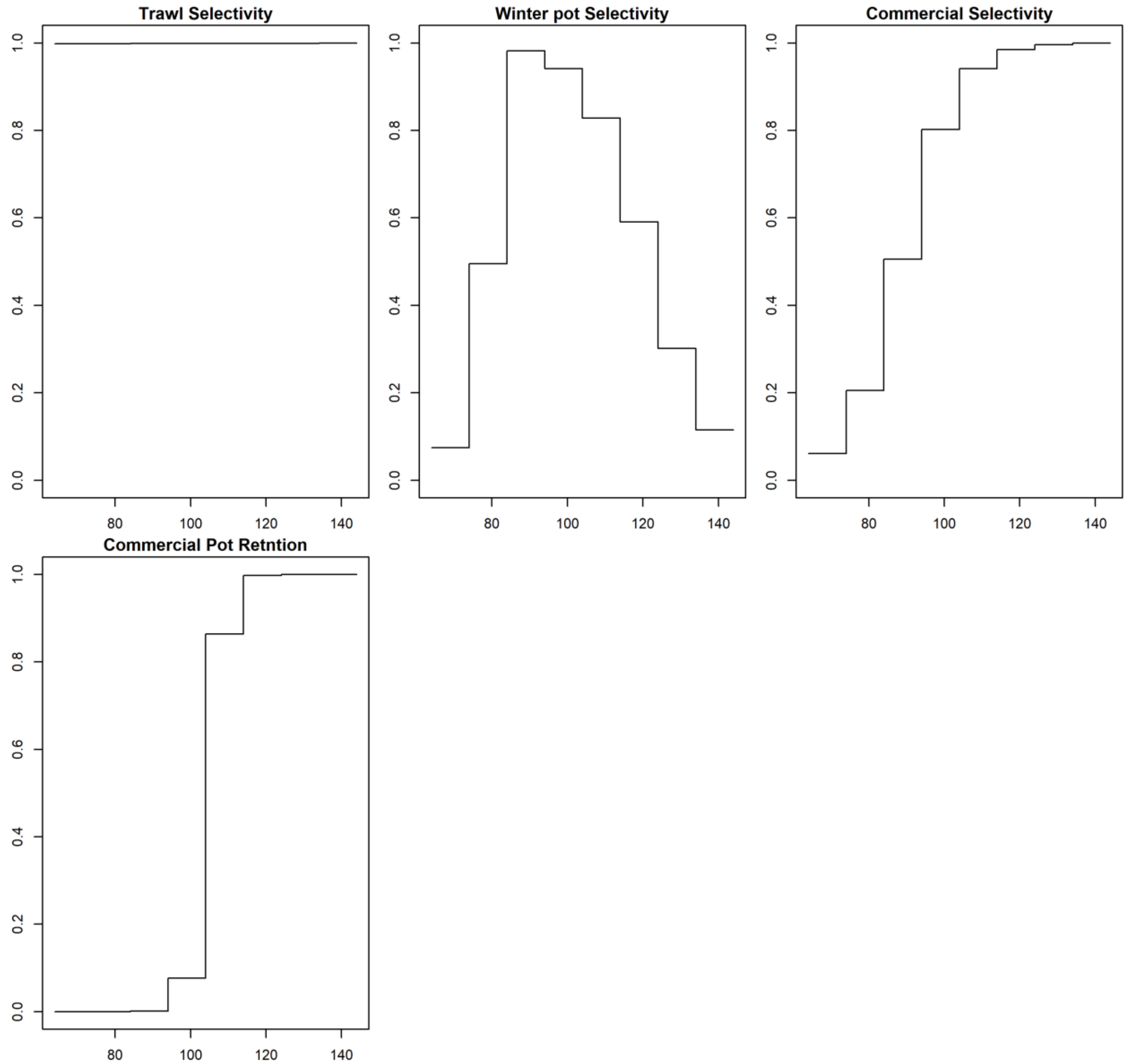


Figure C2-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

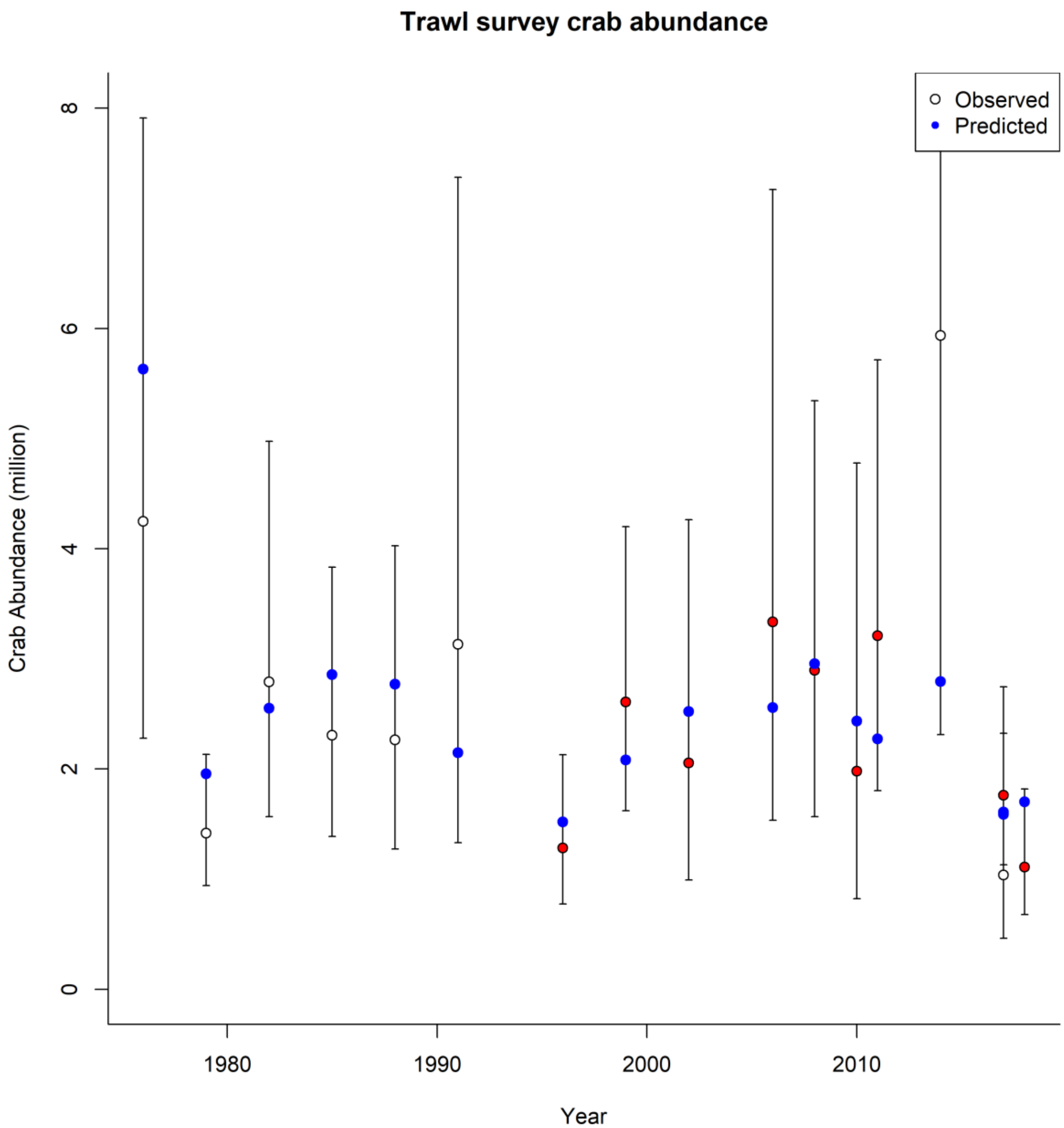


Figure C2-4. Estimated trawl survey male abundance (crab >= 64 mm CL). Observed: White: NOAA Trawl Survey, Red: ADG&G Trawl Survey

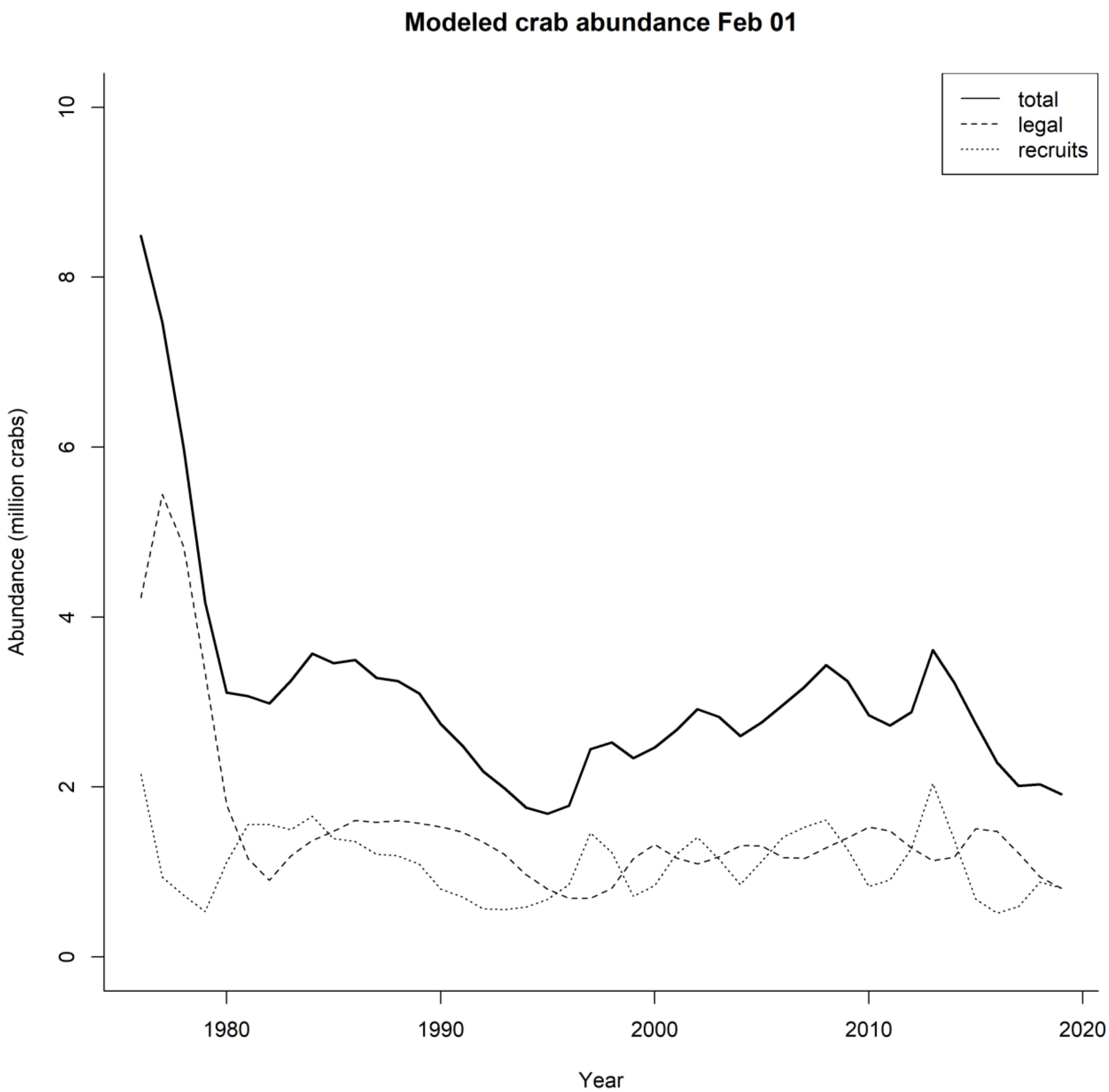


Figure C2-5. Estimated abundance of legal males from 1976-2015.

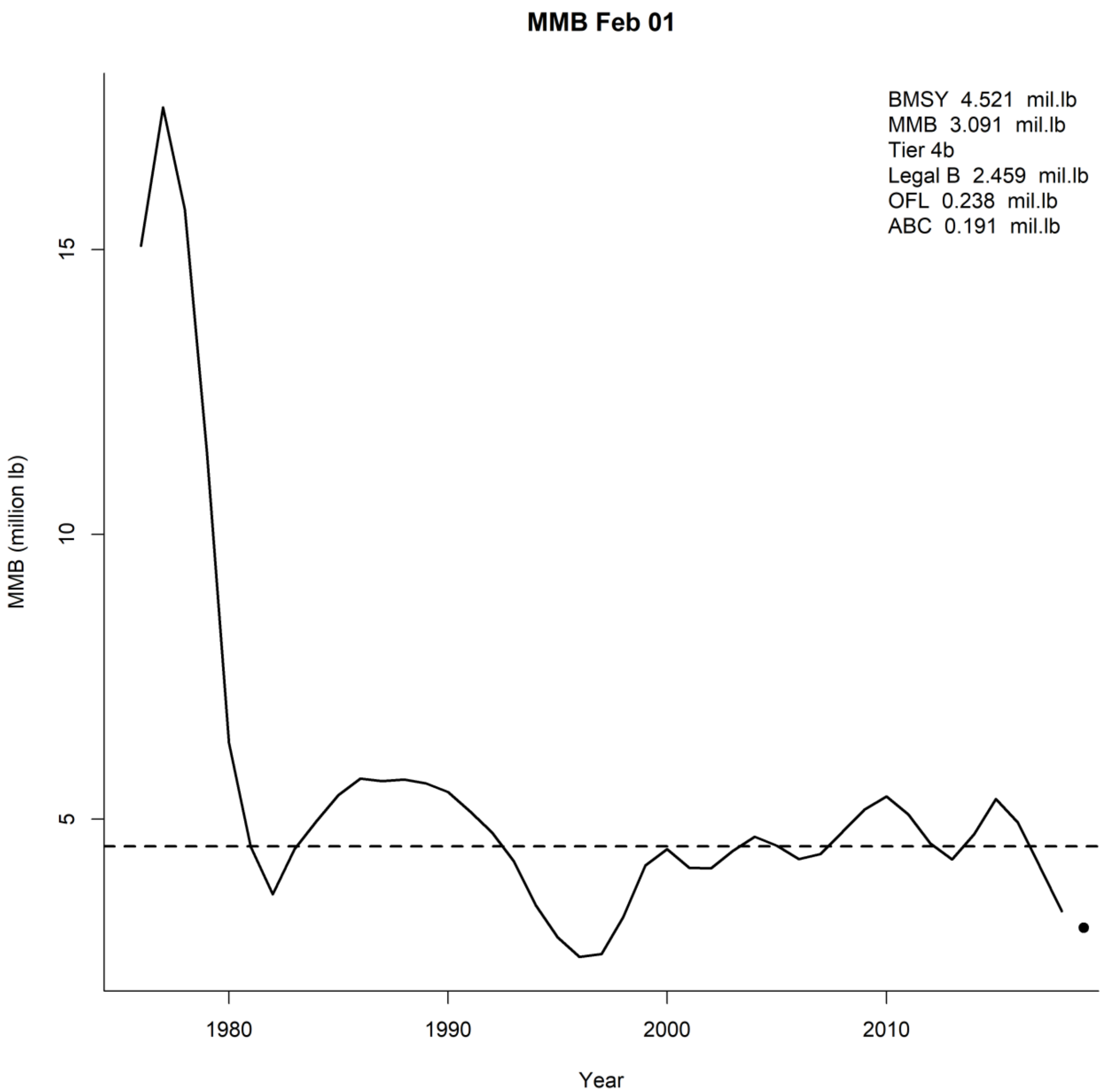


Figure C2-6. Estimated abundance of Mature Male Biomass from 1976-2019. Dash line shows Bmsy (Average MMB of 1980-2019).

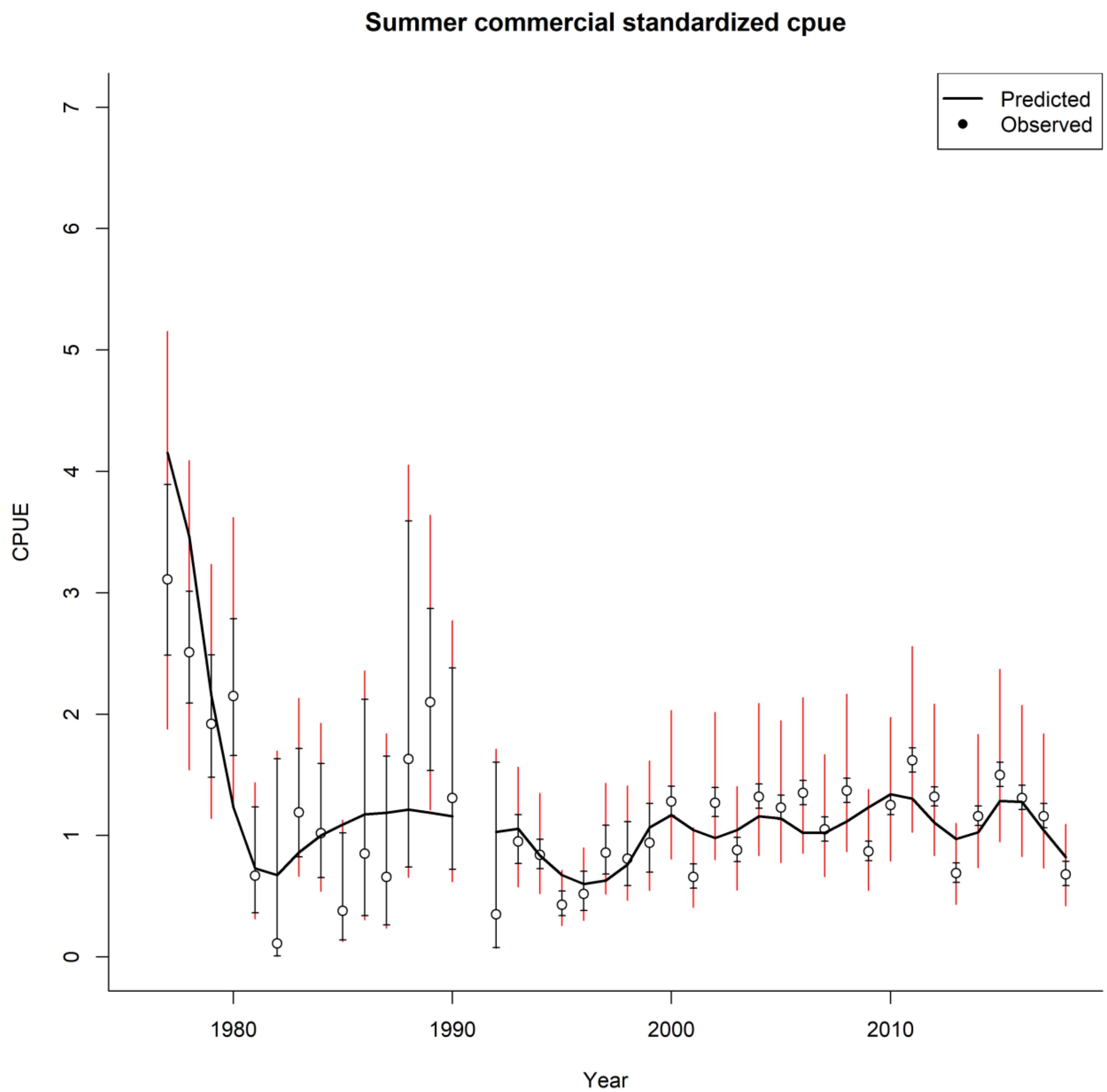


Figure C2-7. Summer commercial standardized cpue 1977-2018.

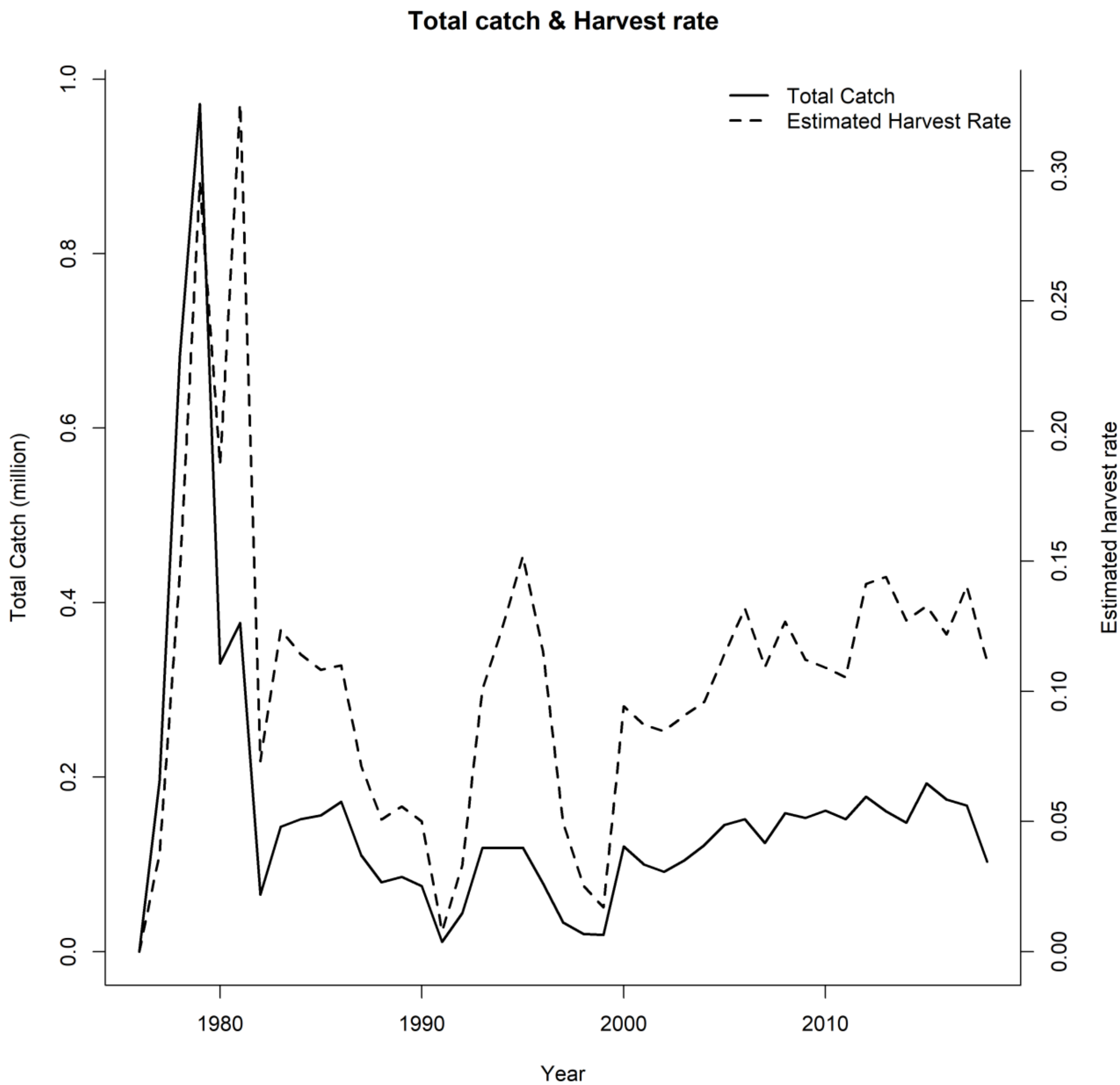


Figure C2-8. Total catch and estimated harvest rate 1976-2018.

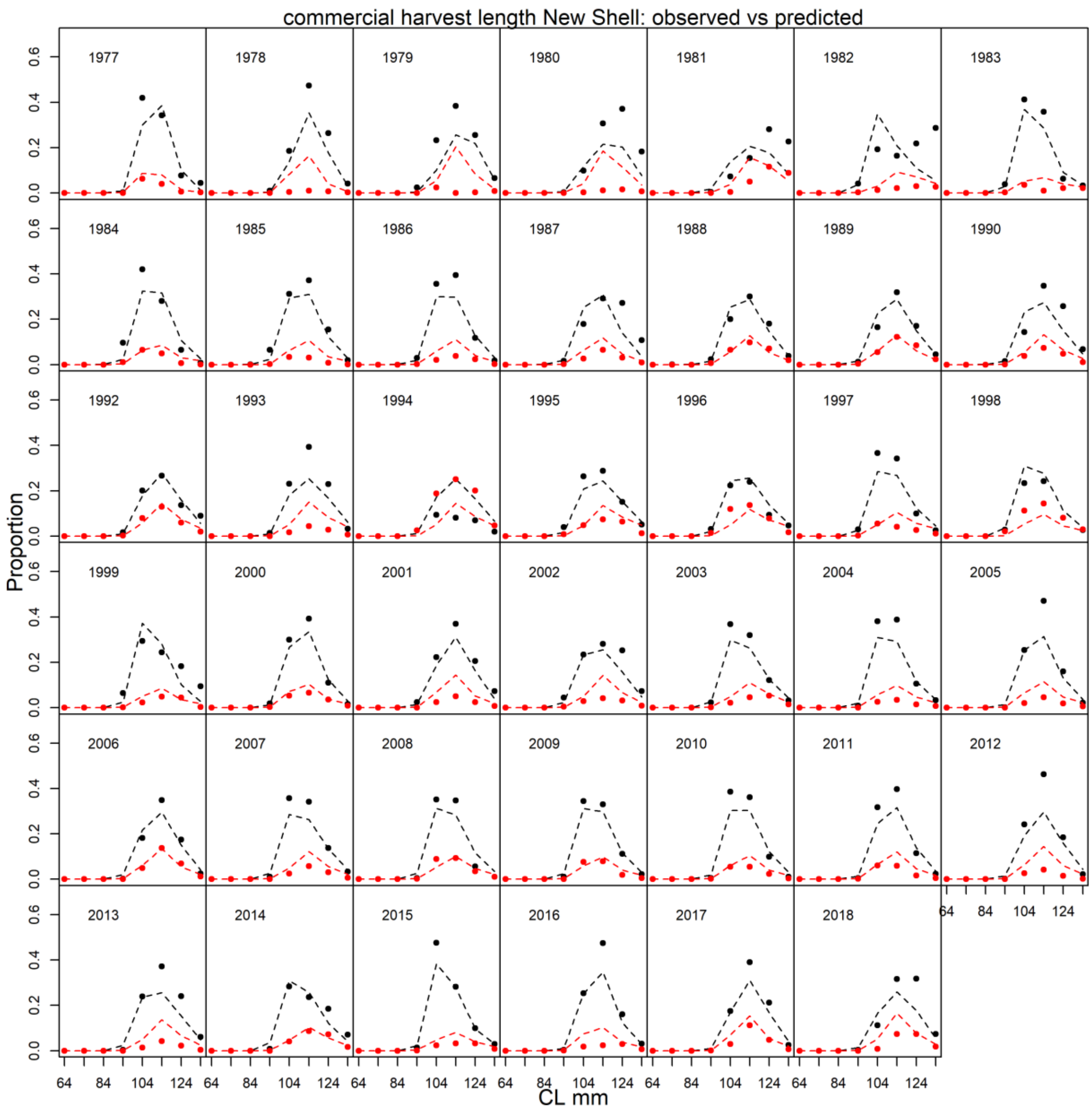


Figure C2-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Bladk: New Shell, Red: Old Shell

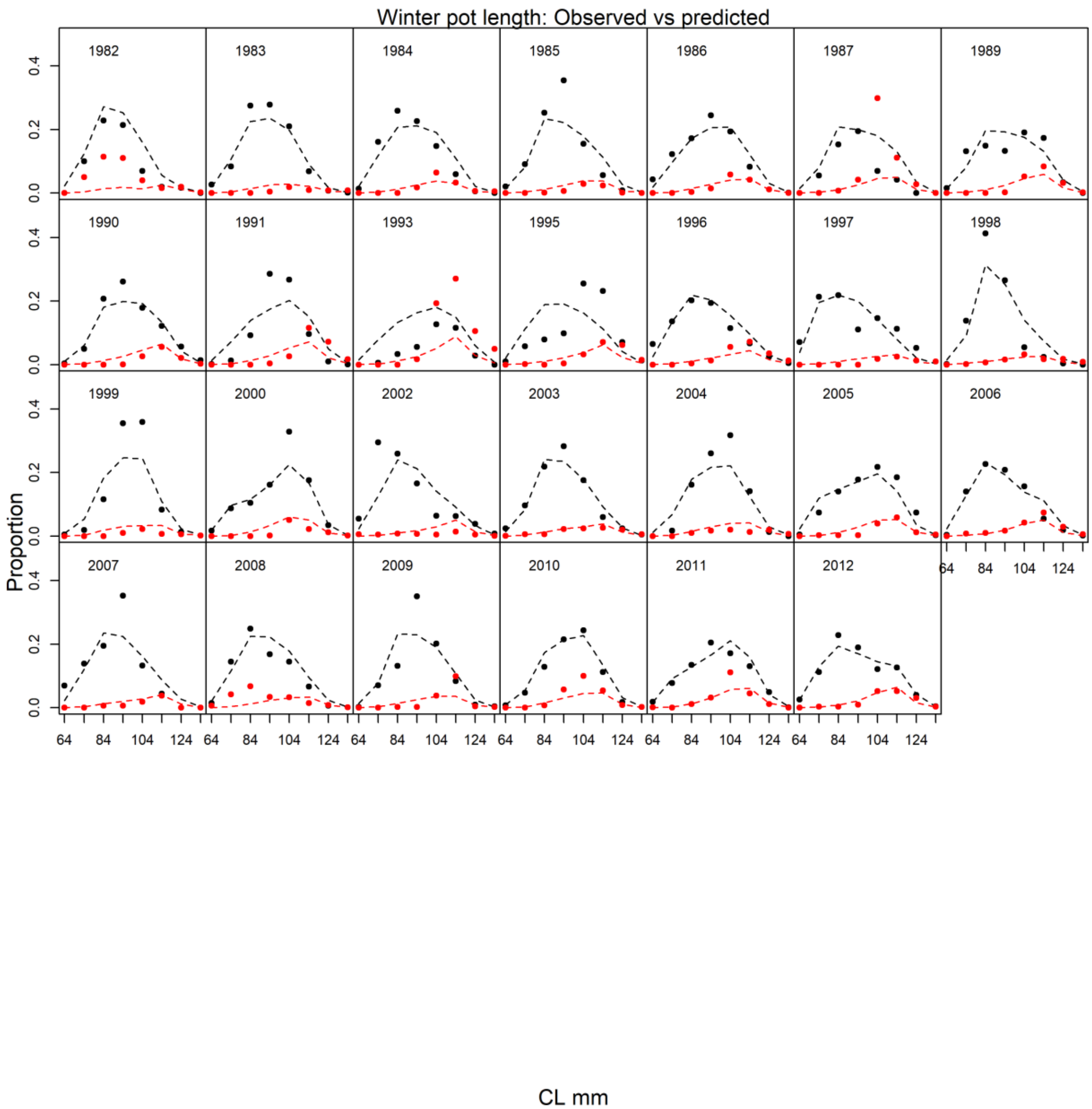
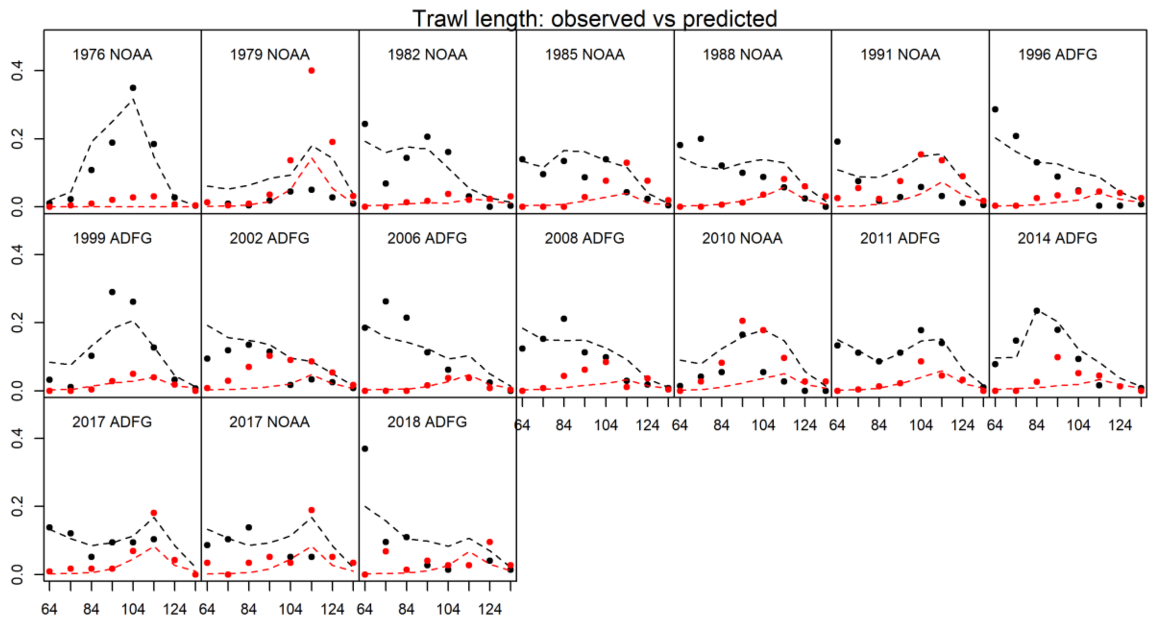


Figure C2-10. Predicted (dashed line) vs. observed (black dots) length class proportions for the winter and spring pot survey.


Trawl length: observed vs predicted
1976 NOAA
1979 NOAA
1982 NOAA
1985 NOAA
1988 NOAA
1991 NOAA
1996 ADFG
1999 ADFG
2002 ADFG
2006 ADFG
2008 ADFG
2010 NOAA
2011 ADFG
2014 ADFG
2017 ADFG
2017 NOAA
2018 ADFG
0.0
0.2
0.4
64
84
104
124

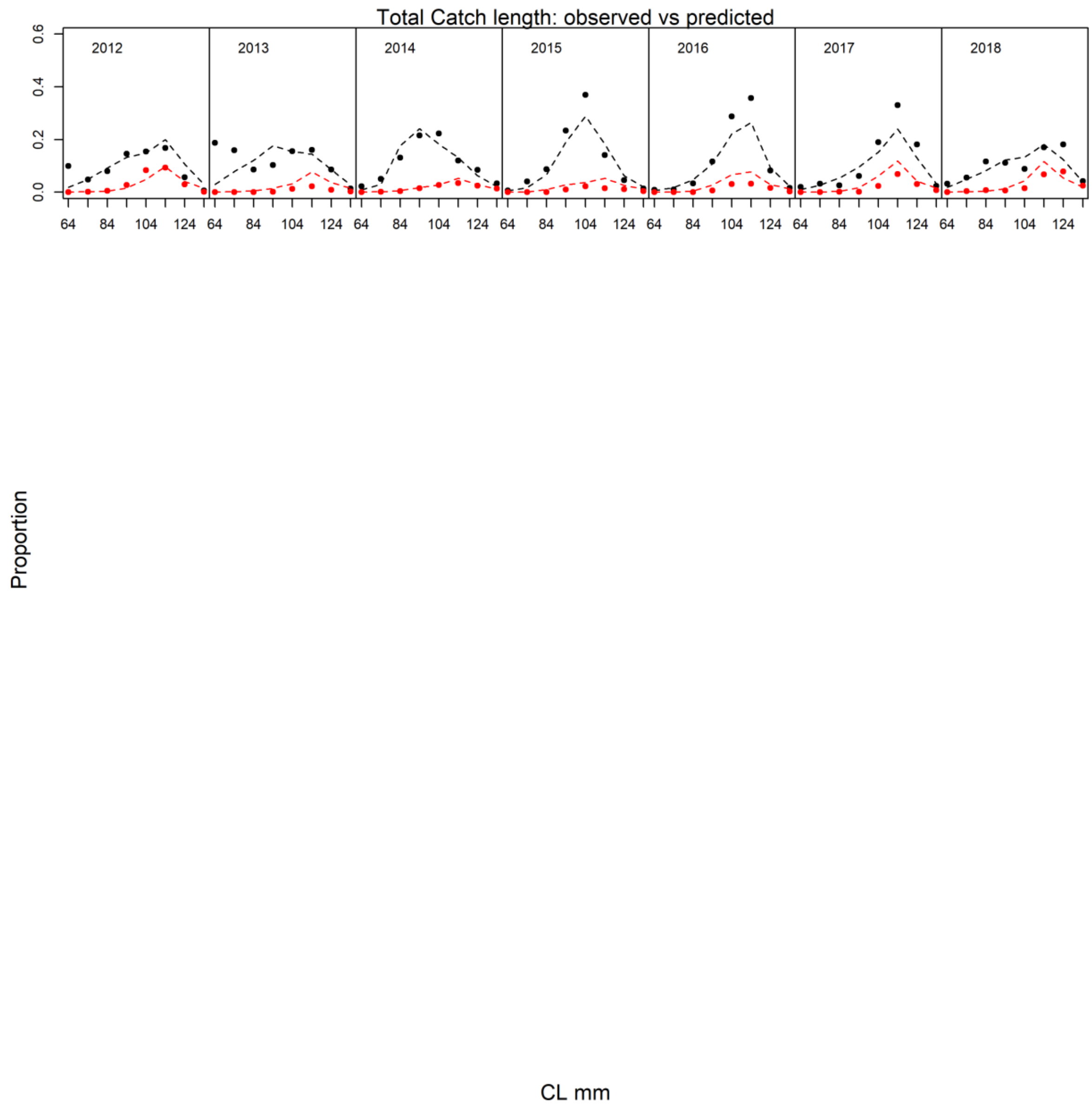


Figure C2-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey.

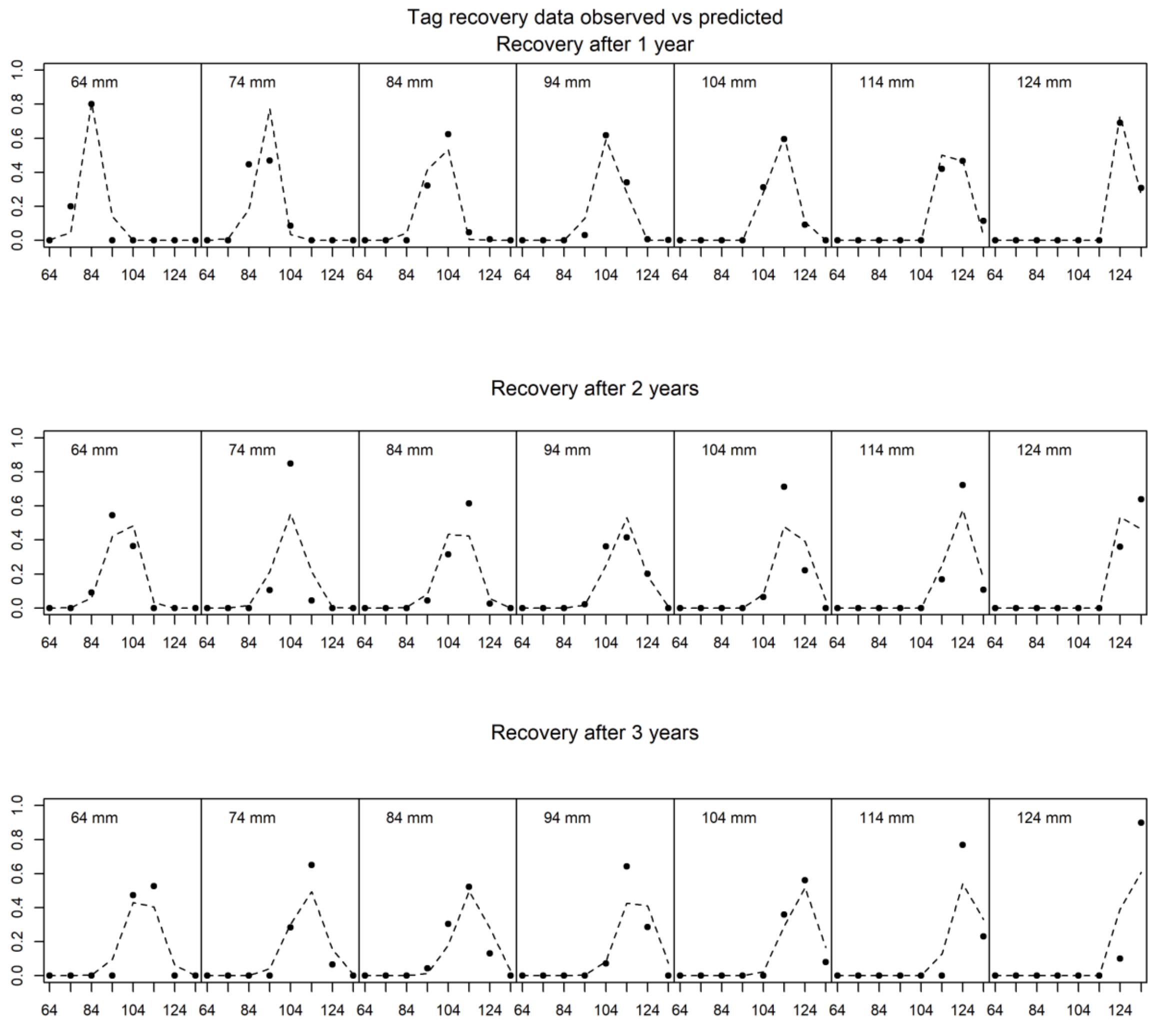


Figure C2-13. Predicted vs. observed length class proportions for tag recovery data.

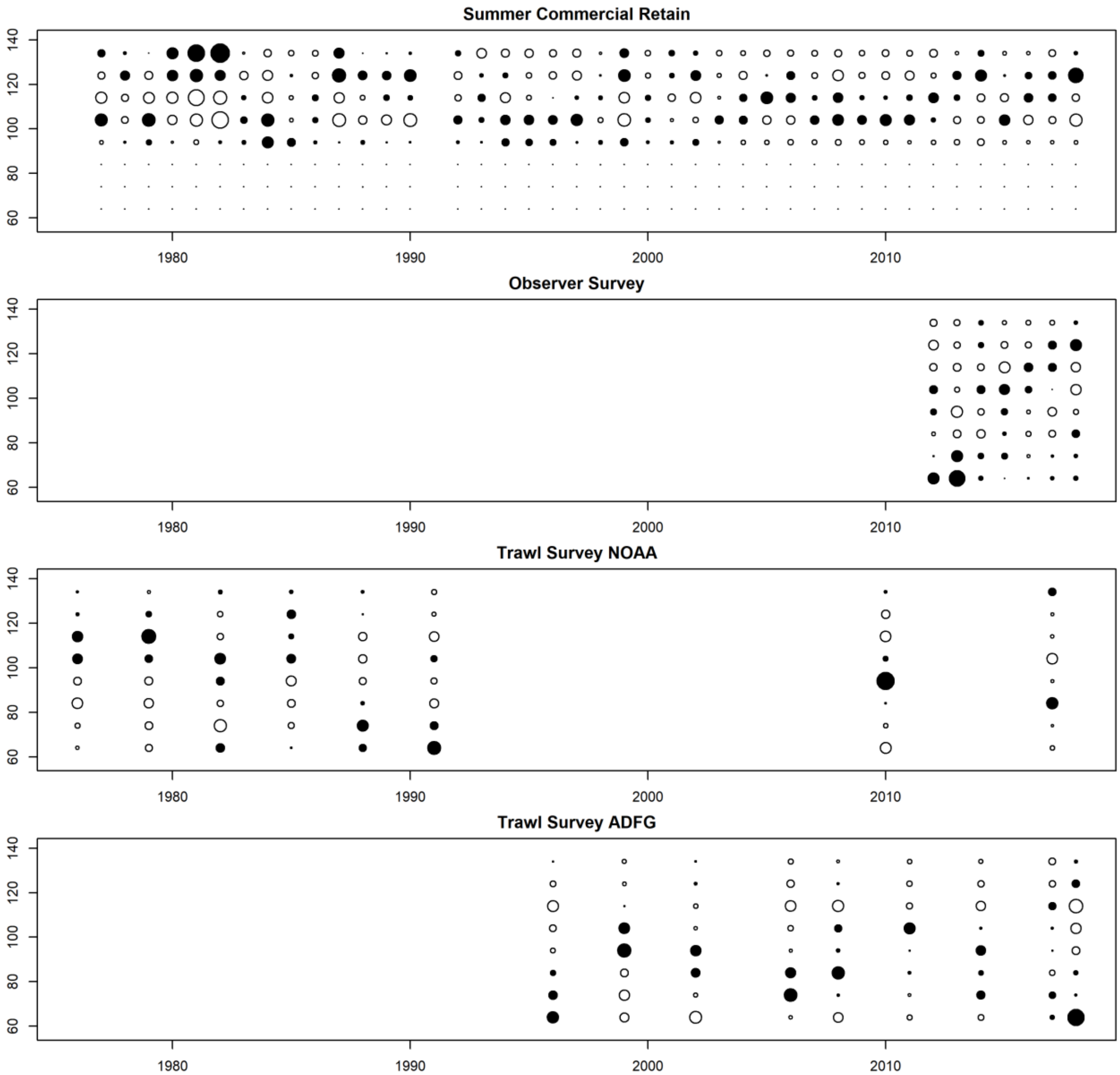


Figure C2-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

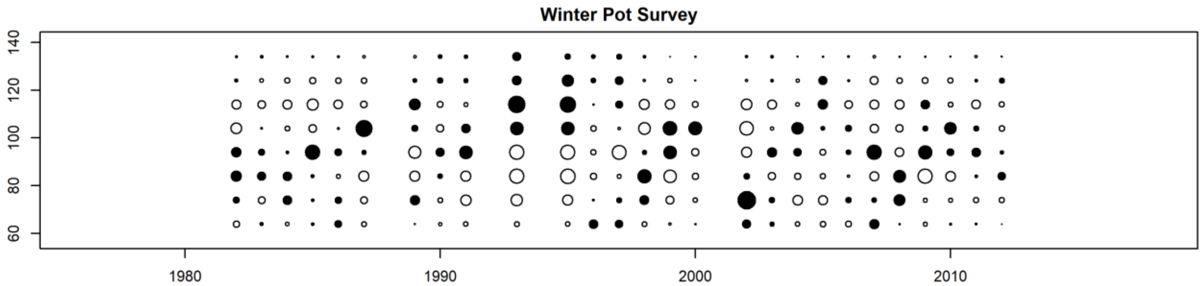


Figure C2-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table C2 . Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.979	0.177
log_q_2	-6.795	0.124
log_N_{76}	9.046	0.130
R_0	6.433	0.082
log_R_{76}	0.003	0.420
log_R_{77}	-0.542	0.370
log_R_{78}	-0.714	0.355
log_R_{79}	0.401	0.319
log_R_{80}	0.510	0.290
log_R_{81}	0.422	0.267
log_R_{82}	0.397	0.320
log_R_{83}	0.570	0.282
log_R_{84}	0.180	0.301
log_R_{85}	0.364	0.325
log_R_{86}	0.088	0.341
log_R_{87}	0.214	0.269
log_R_{88}	0.022	0.305
log_R_{89}	-0.415	0.321
log_R_{90}	-0.322	0.272
log_R_{91}	-0.739	0.337
log_R_{92}	-0.511	0.309
log_R_{93}	-0.524	0.306
log_R_{94}	-0.310	0.262
log_R_{95}	-0.062	0.227
log_R_{96}	0.587	0.217
log_R_{97}	-0.051	0.302
log_R_{98}	-0.625	0.321
log_R_{99}	0.004	0.311
log_R_{00}	0.311	0.266
log_R_{01}	0.385	0.243
log_R_{02}	-0.020	0.317
log_R_{03}	-0.282	0.332
log_R_{04}	0.295	0.242
log_R_{05}	0.404	0.224
log_R_{06}	0.454	0.244

name	Estimate	std.dev
log_R_{07}	0.503	0.232
log_R_{08}	0.056	0.291
log_R_{09}	-0.409	0.293
log_R_{10}	0.040	0.248
log_R_{11}	0.370	0.279
log_R_{12}	0.894	0.193
log_R_{13}	-0.205	0.301
log_R_{14}	-0.649	0.315
log_R_{15}	-0.701	0.282
log_R_{16}	-0.425	0.243
log_R_{17}	0.033	0.285
a_1	1.577	4.605
a_2	2.386	4.297
a_3	3.842	4.108
a_4	4.116	4.094
a_5	4.349	4.085
a_6	3.579	4.114
a_7	2.137	4.367
r1	10.000	0.870
r2	9.678	0.894
log_a	-2.625	0.092
log_b	4.825	0.014
log_ϕ_{st1}	-5.000	0.102
log_ϕ_{wa}	-2.117	0.322
log_ϕ_{wb}	4.800	0.029
Sw1	0.074	0.036
Sw2	0.500	353.550
log_ϕ_1	3.766	6510.100
log_ar	-0.836	0.204
log_br	4.647	0.012
w^2_t	0.051	0.016
q	0.749	0.129
σ	3.926	0.219
β_1	11.921	0.784
β_2	7.763	0.187
ms78	3.236	0.270

Appendix C3: Model 2 Results

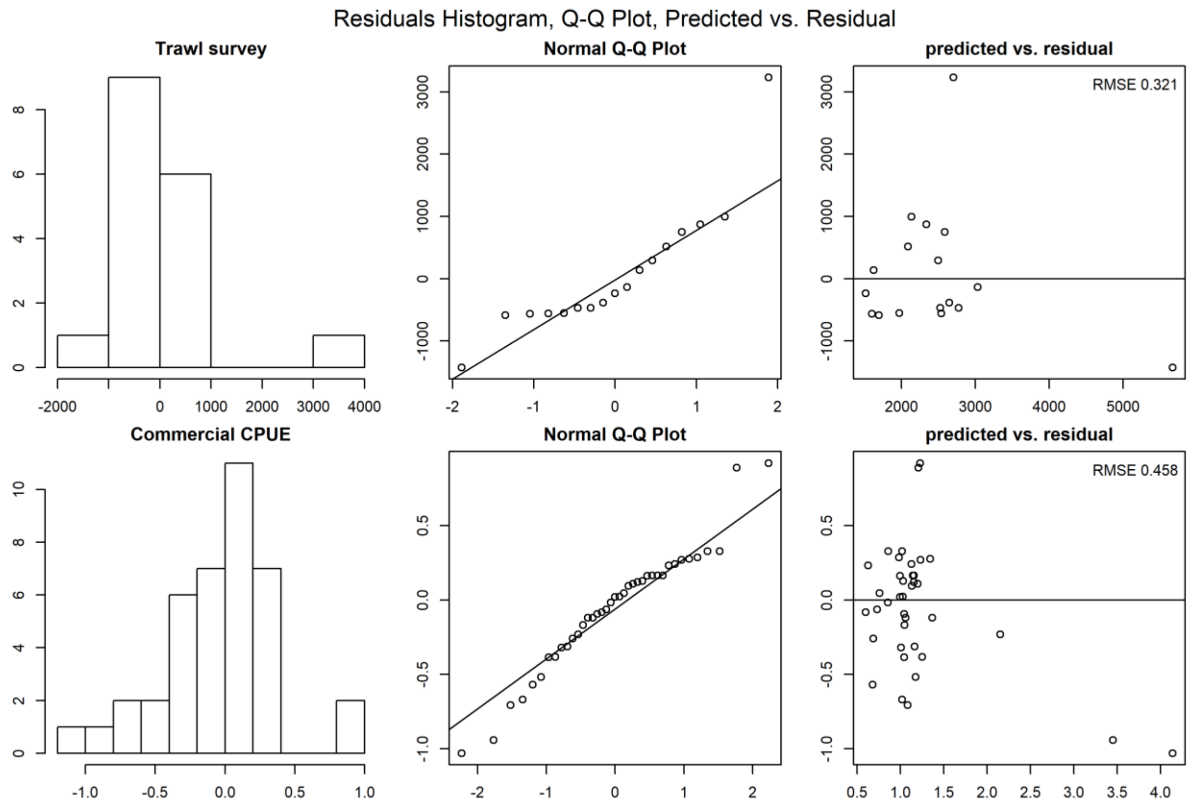


Figure C3-1. QQ Plot of Trawl survey and Commercial CPUE.

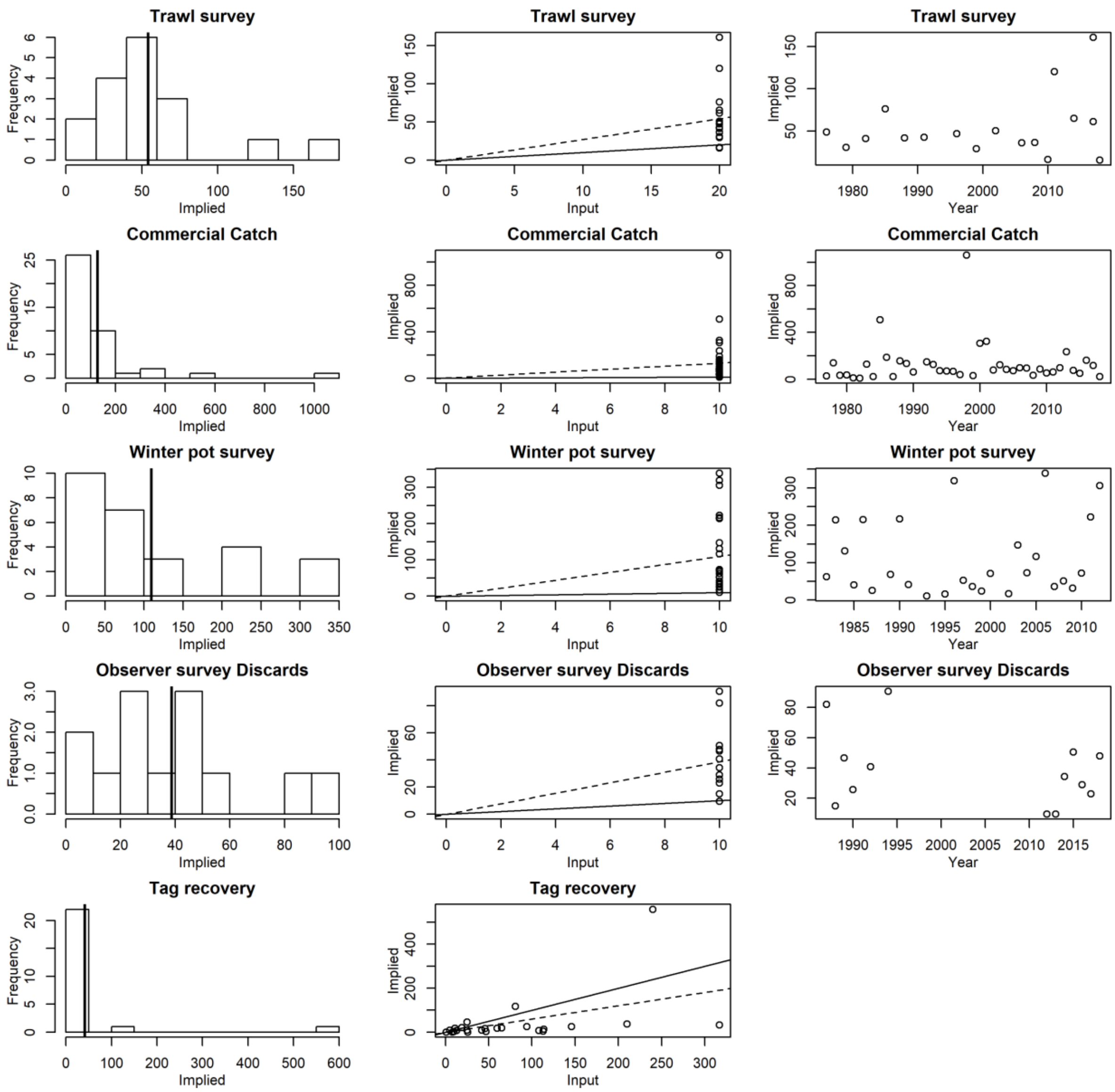


Figure C3-2: Implied effective samples. Figures in the first column show implied effective sample size (x-axis) vs. frequency (y-axis).
Vertical solid line is the mean implied effective sample size.
The second column show input sample size (x-axis) vs. implied effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. The third column show year (x-axis) vs. implied effective sample size (y-axis).

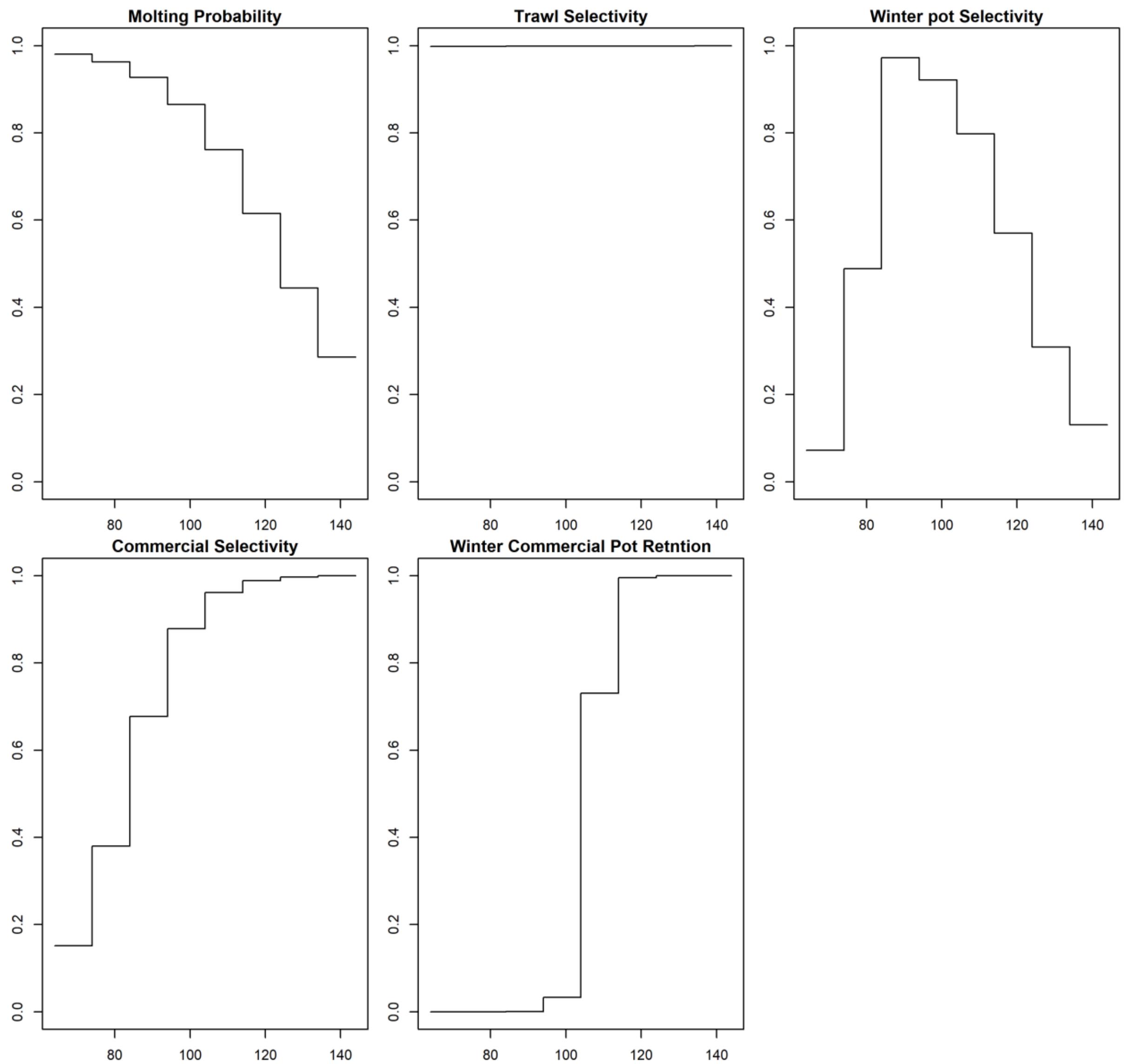


Figure C3-3. Molting probability and trawl/pot selectivity. X-axis is carapace length.

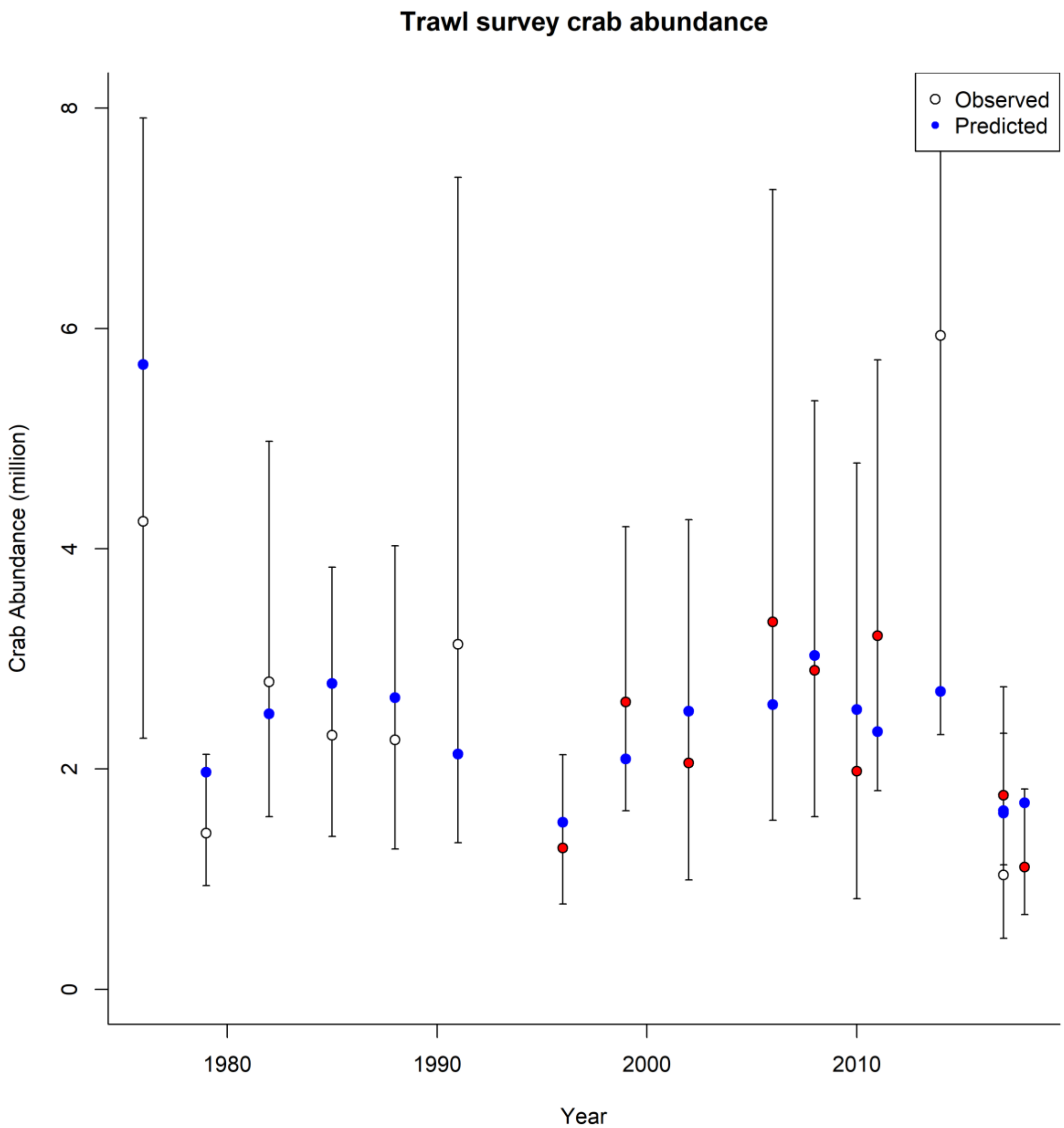


Figure C3-4. Estimated trawl survey male abundance (crab >= 64 mm CL). Observed: White: NOAA Trawl Survey, Red: ADG&G Trawl Survey

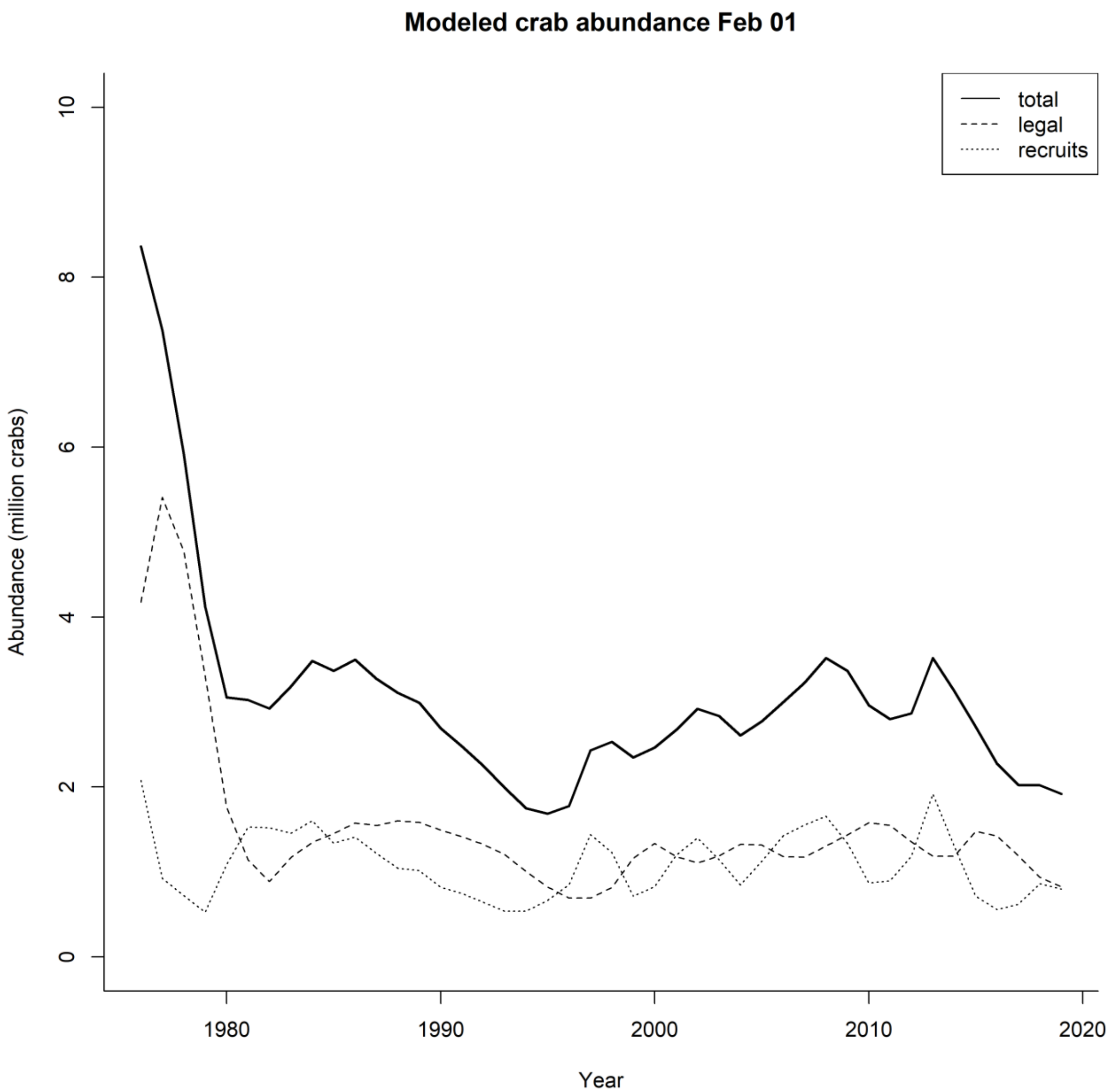


Figure C3-5. Estimated abundance of legal males from 1976-2015.

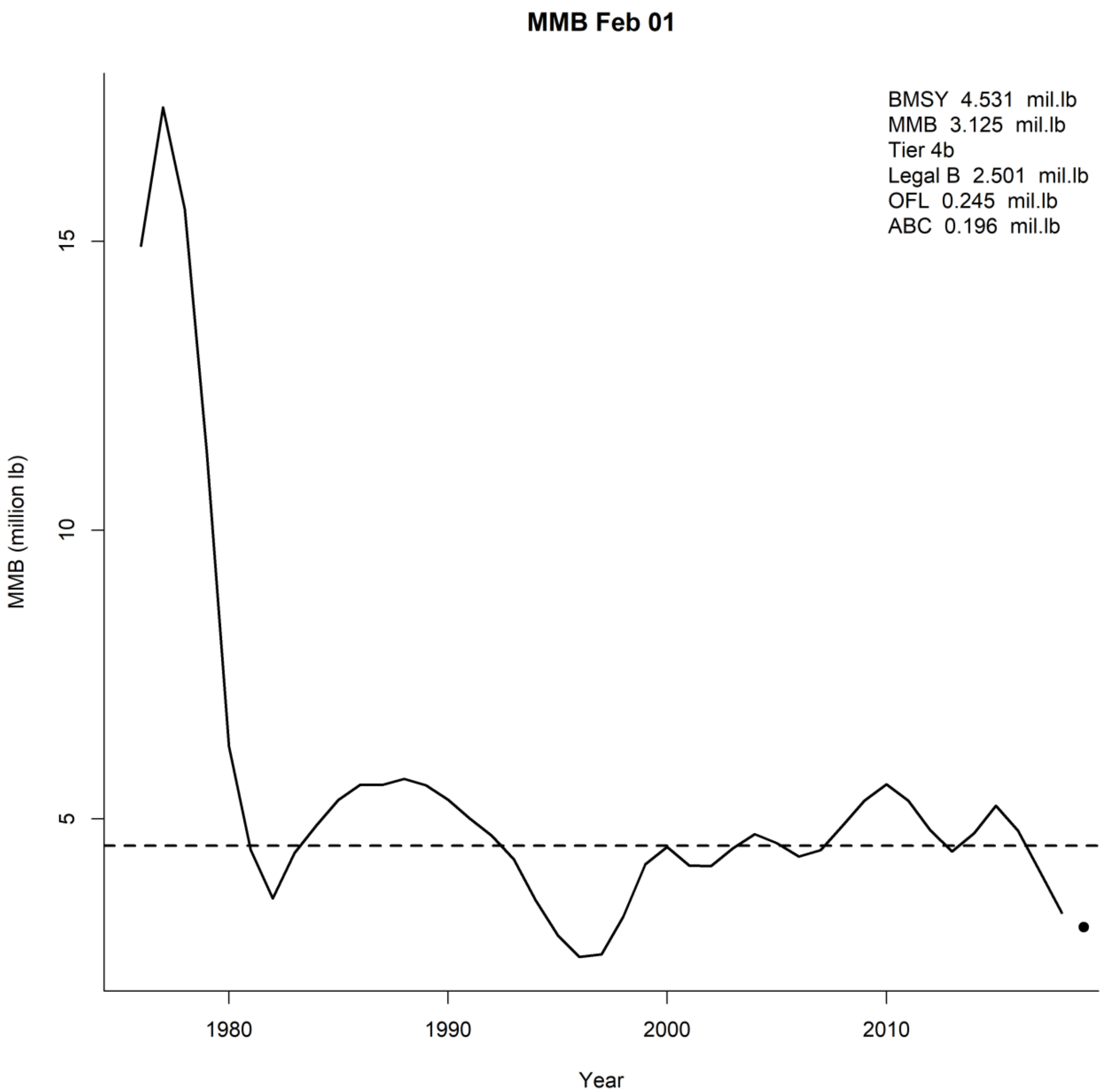


Figure C3-6. Estimated abundance of Mature Male Biomass from 1976-2019. Dash line shows Bmsy (Average MMB of 1980-2019).

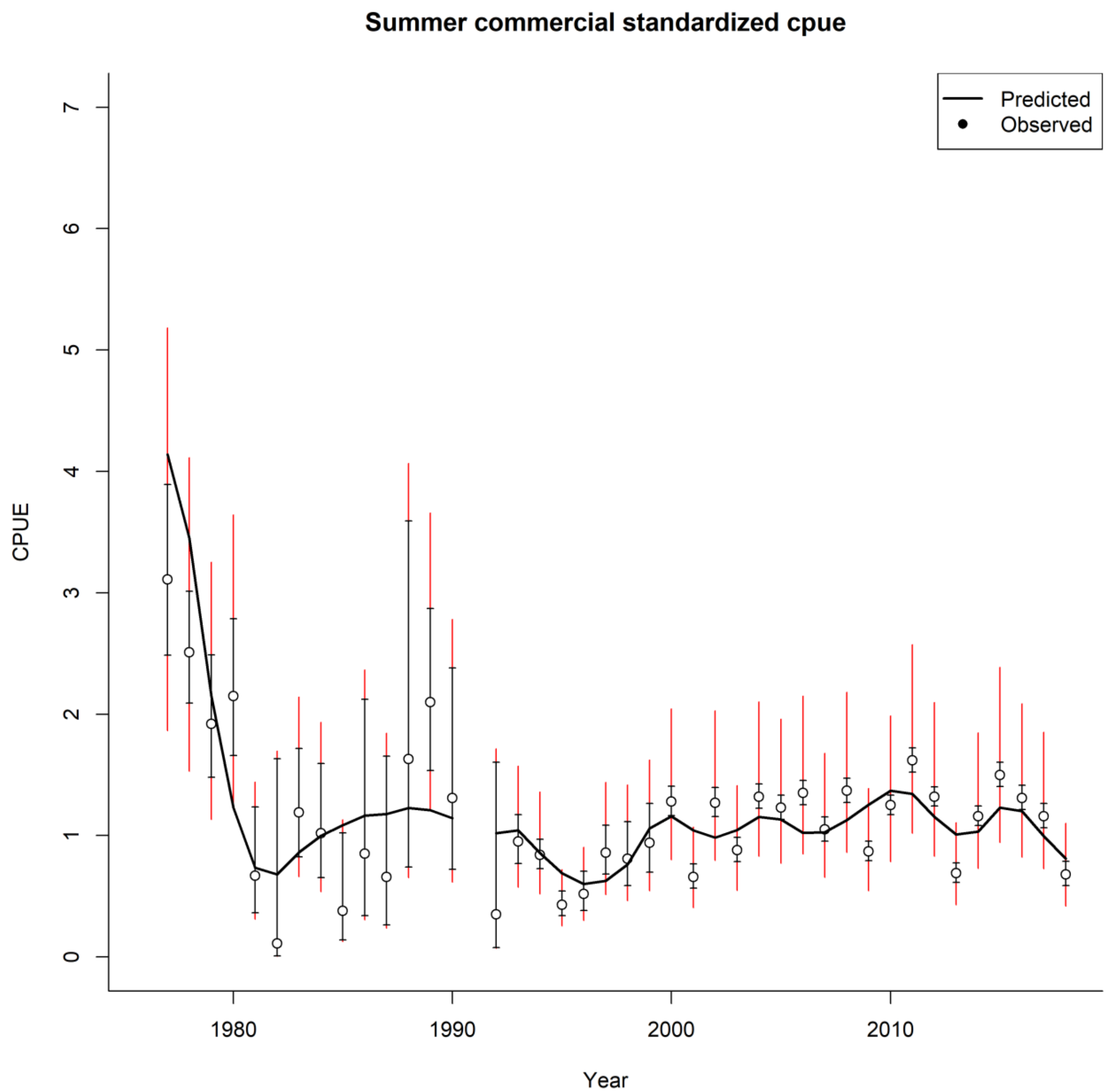


Figure C3-7. Summer commercial standardized cpue 1977-2018.

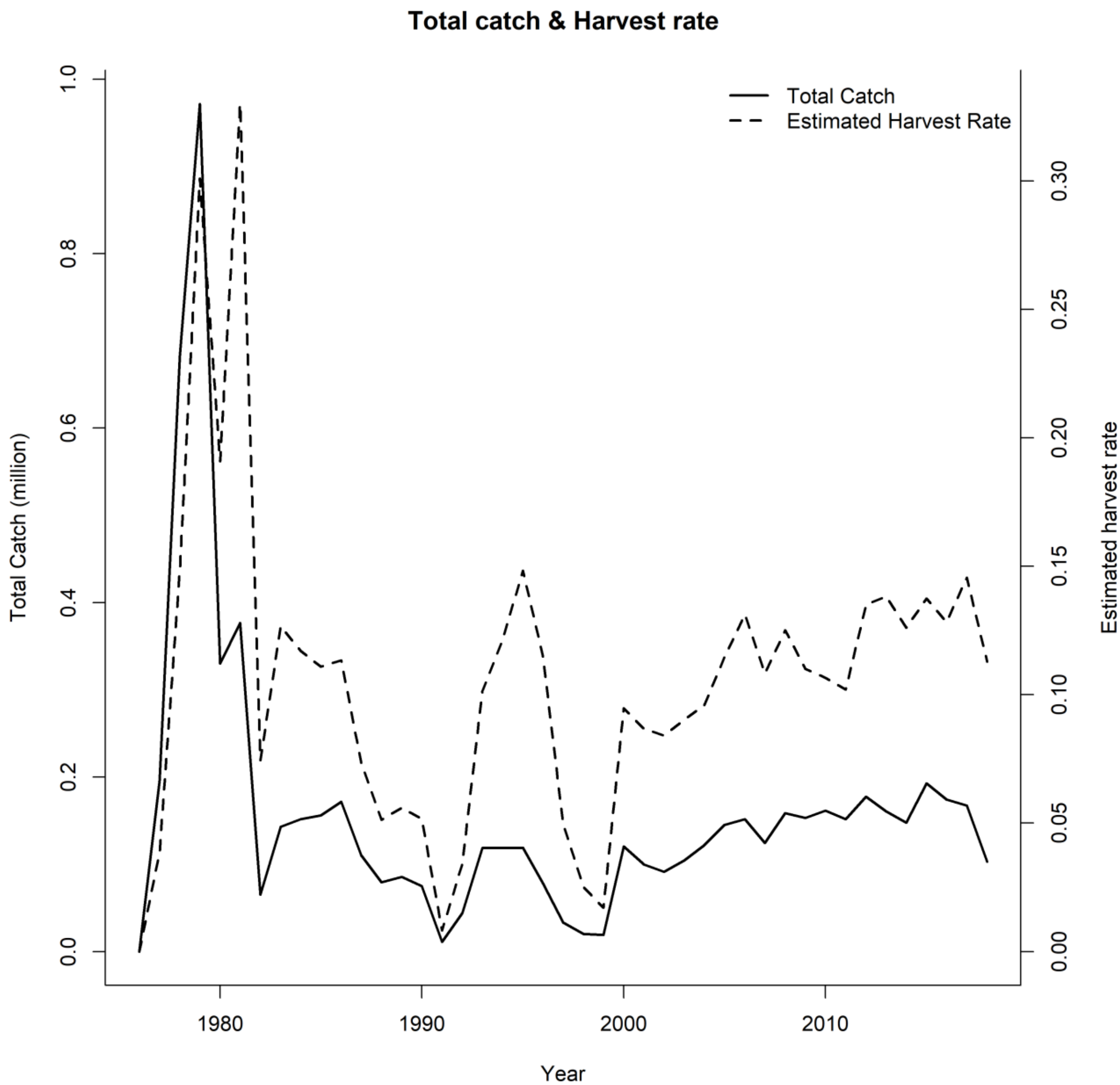


Figure C3-8. Total catch and estimated harvest rate 1976-2018.

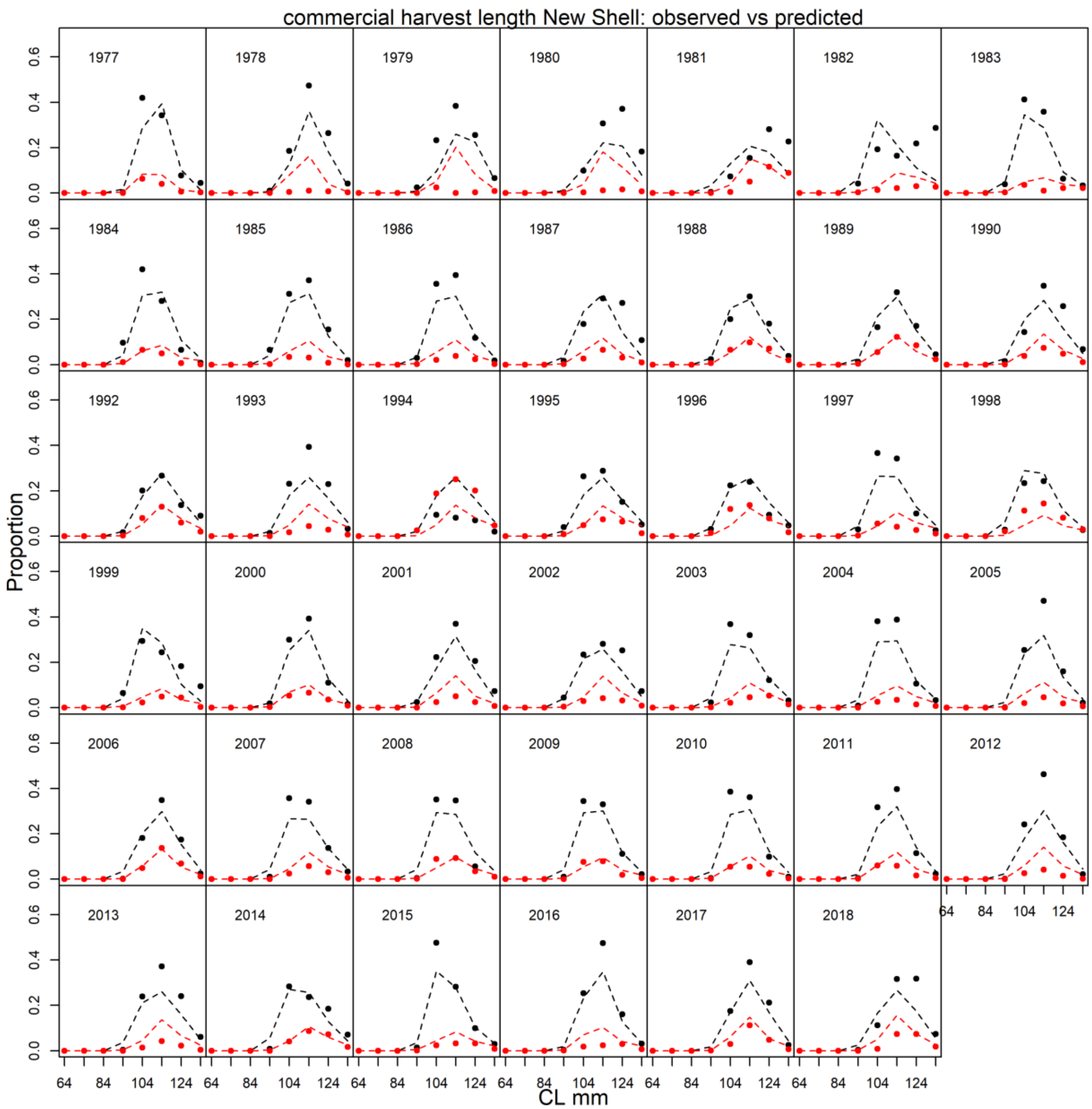


Figure C3-9. Predicted (dashed line) vs. observed (dots) length class proportions for commercial catch. Bladk: New Shell, Red: Old Shell

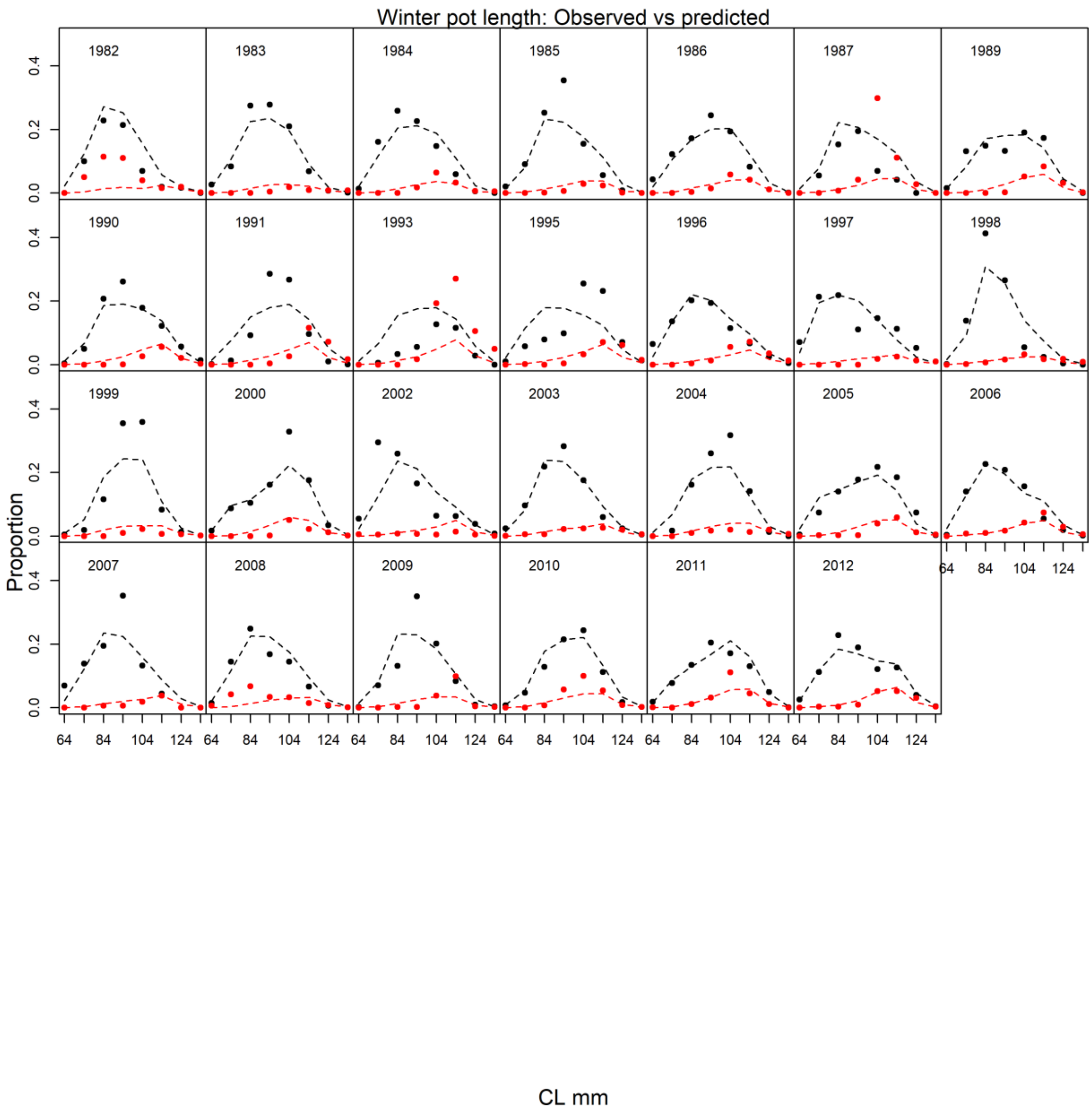
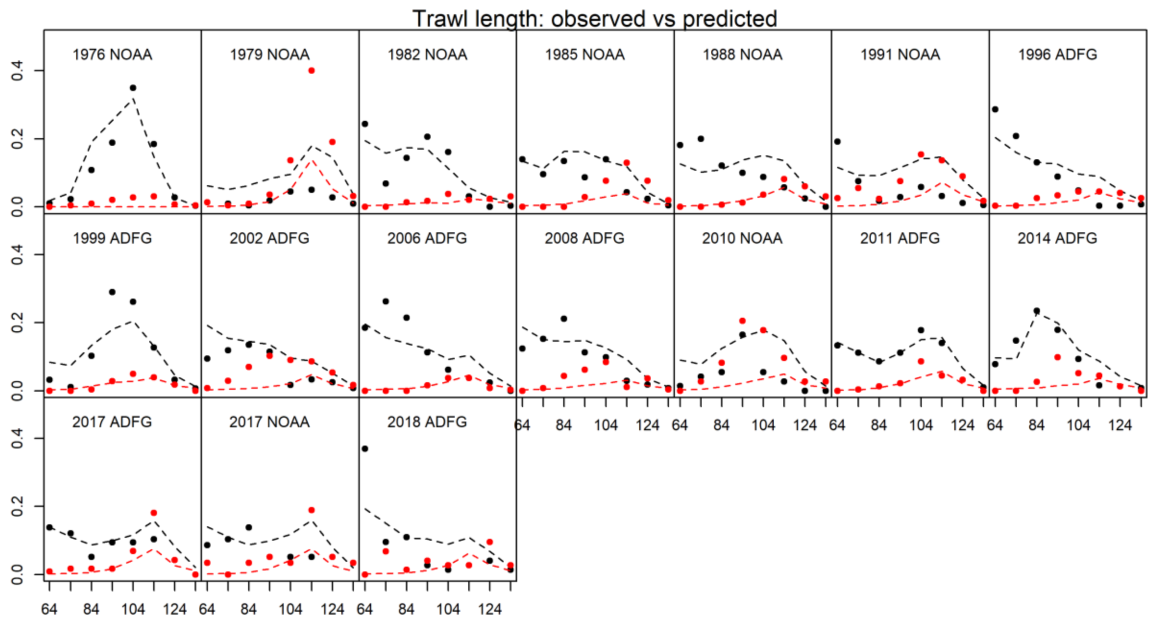
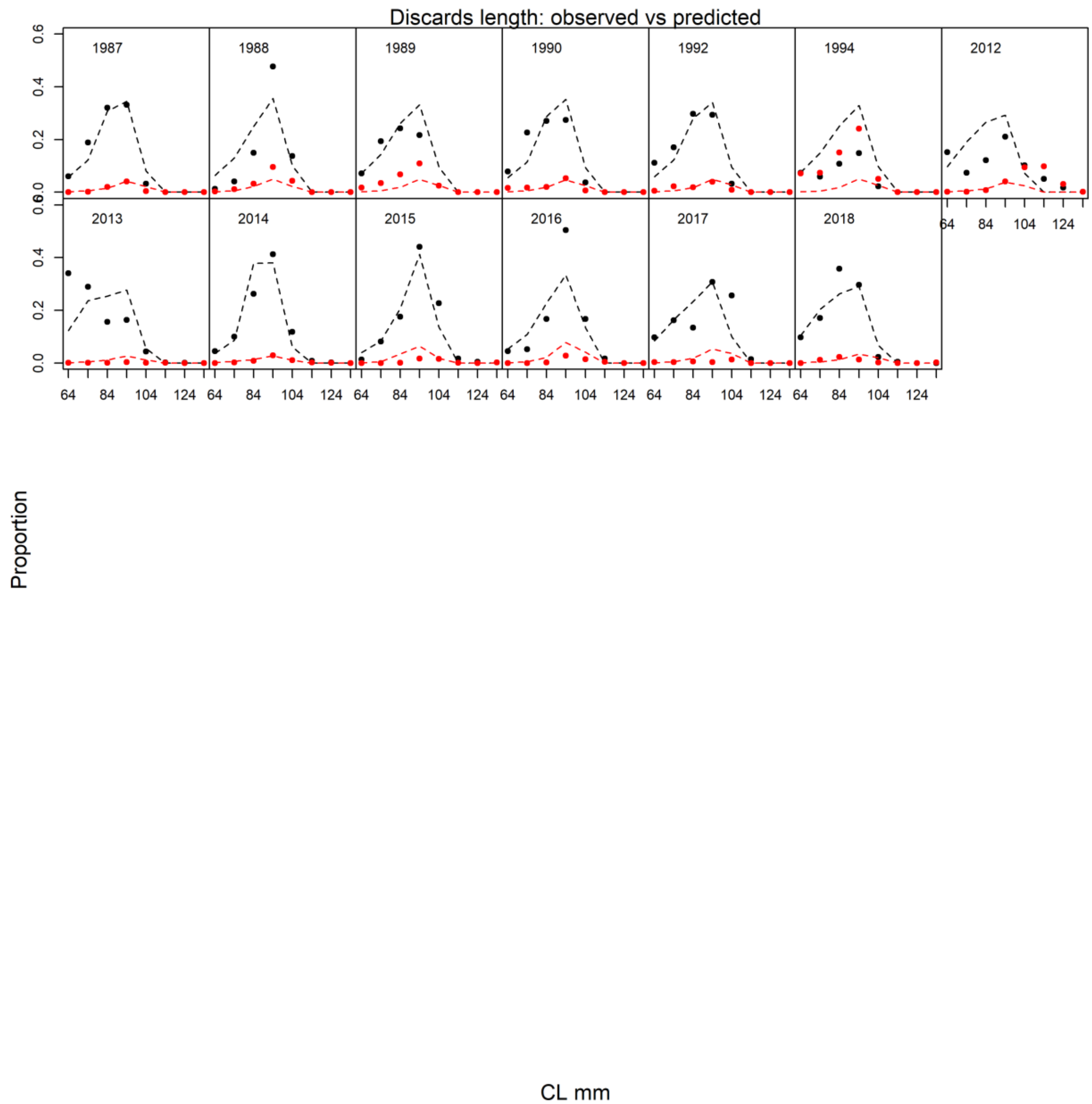


Figure C3-10. Predicted (dashed line) vs. observed (black dots) length class proportions for the winter and spring pot survey.


Trawl length: observed vs predicted
1976 NOAA
1979 NOAA
1982 NOAA
1985 NOAA
1988 NOAA
1991 NOAA
1996 ADFG
1999 ADFG
2002 ADFG
2006 ADFG
2008 ADFG
2010 NOAA
2011 ADFG
2014 ADFG
2017 ADFG
2017 NOAA
2018 ADFG
0.0
0.2
0.4
64
84
104
124


Discards length: observed vs predicted
1987
1988
1989
1990
1992
1994
2012
2013
2014
2015
2016
2017
2018
Proportion
CL mm

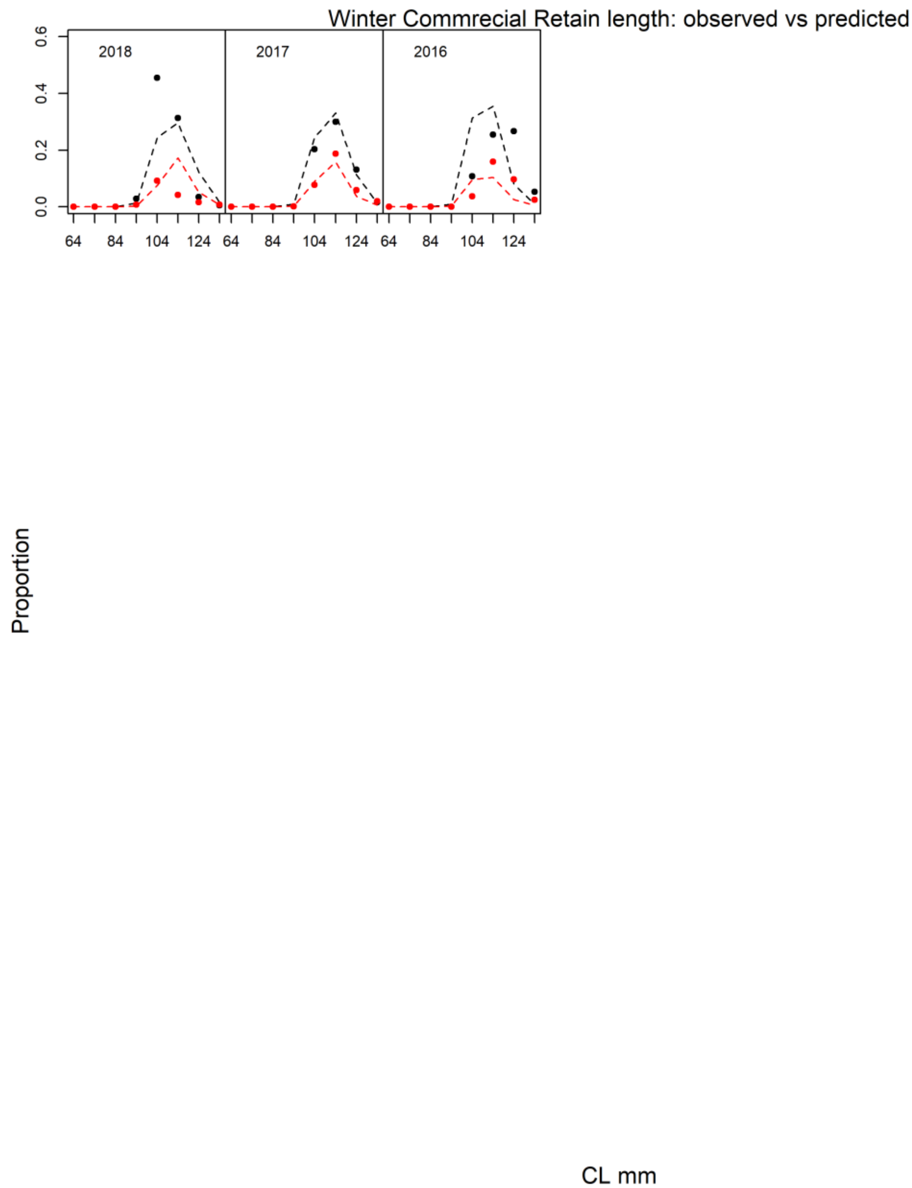


Figure C3-12. Predicted (dashed) vs. observed (dots) length class proportions for the observer survey.

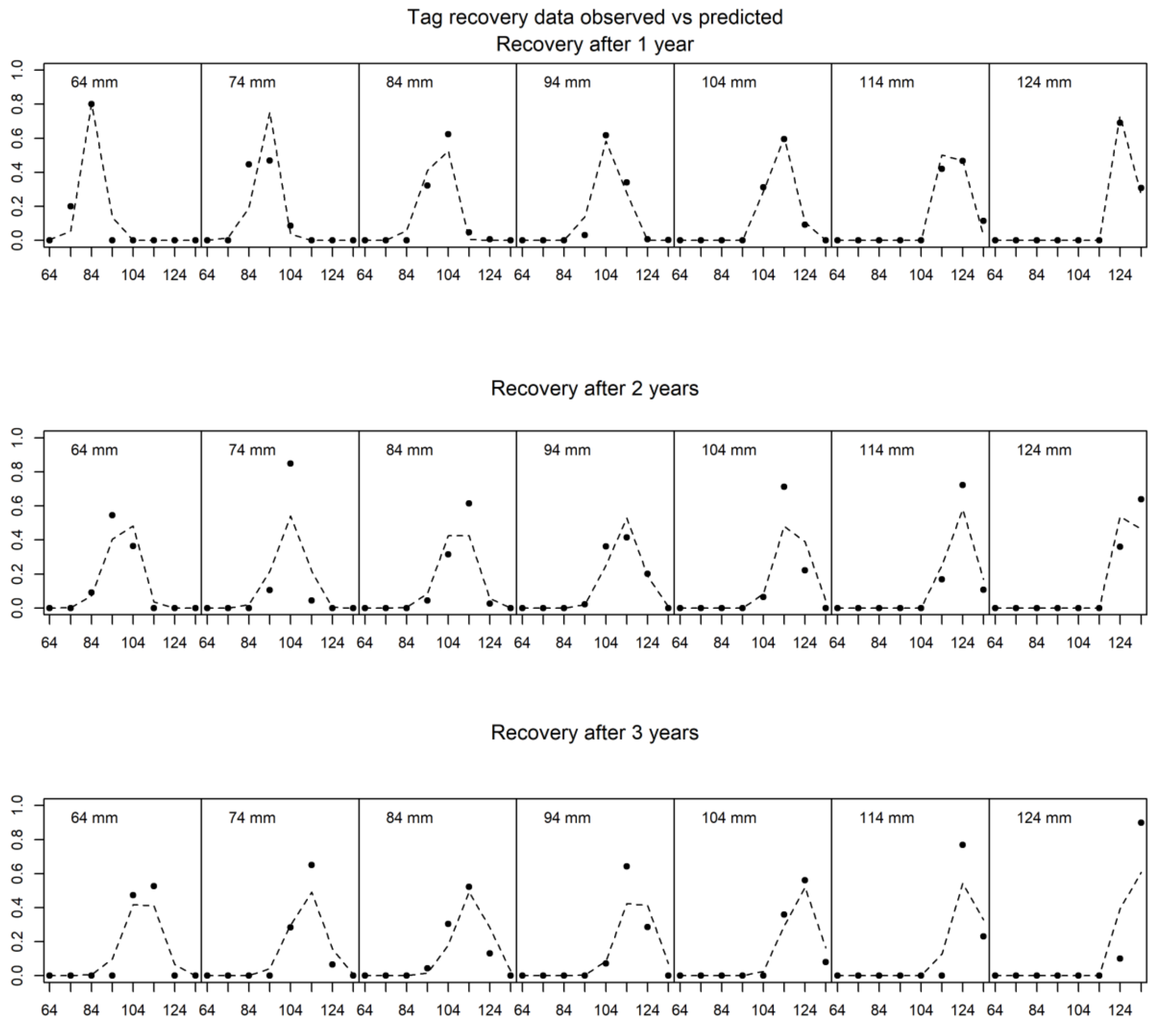


Figure C3-13. Predicted vs. observed length class proportions for tag recovery data.

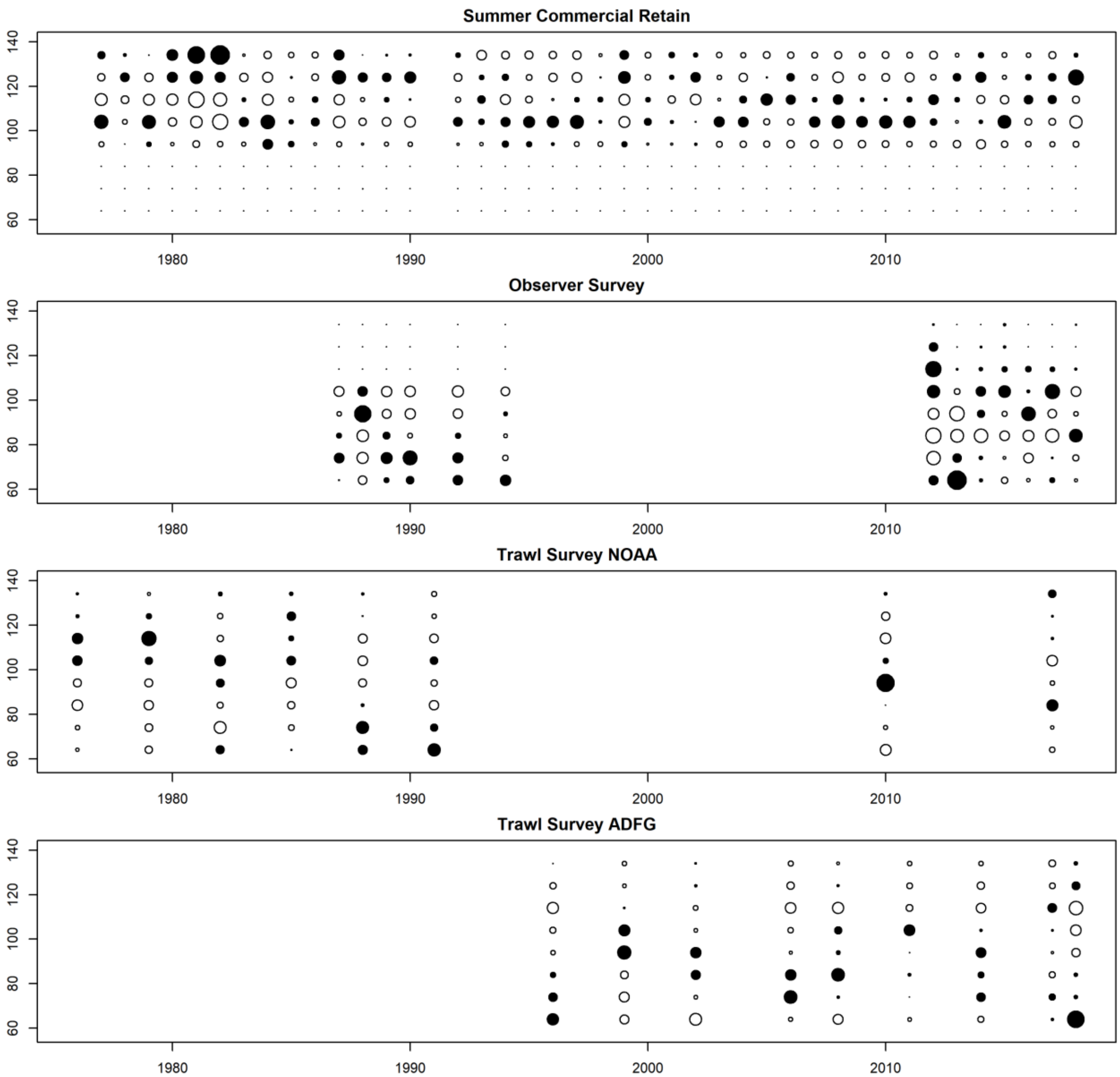


Figure C3-13. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

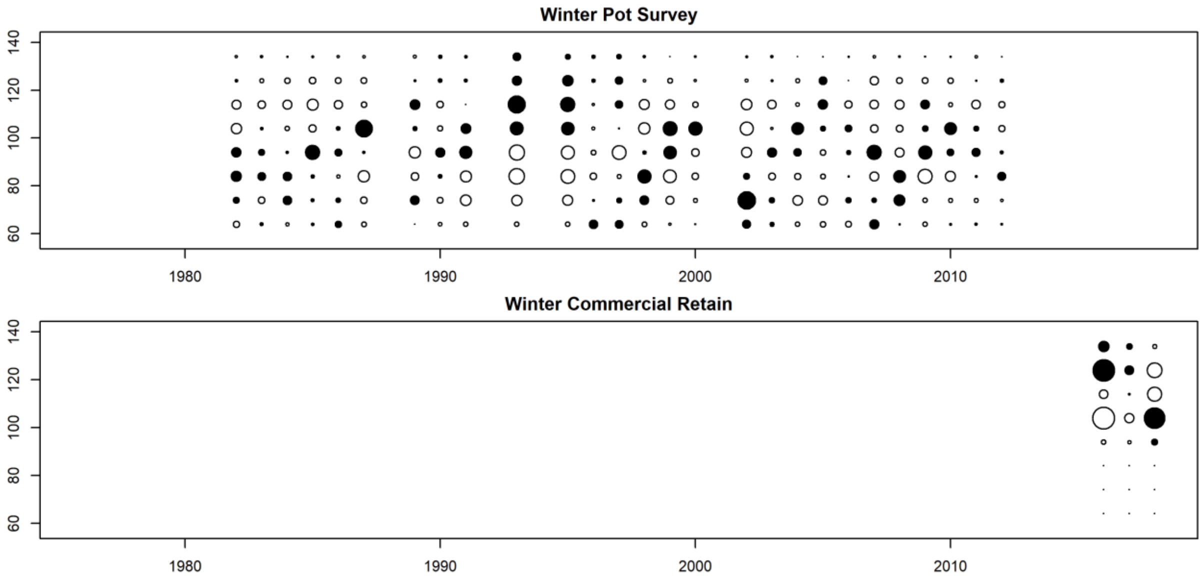


Figure C3-14. Bubble plots of predicted and observed length proportions.
Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicates degree of deviance (larger circle = larger deviance).

Table C3 . Summary of parameter estimates for a length-based stock synthesis population model of Norton Sound red king crab.

name	Estimate	std.dev
log_q_1	-6.967	0.168
log_q_2	-6.810	0.109
log_N_{76}	9.031	0.130
R_0	6.441	0.081
log_R_{76}	0.005	0.415
log_R_{77}	-0.542	0.369
log_R_{78}	-0.726	0.353
log_R_{79}	0.371	0.316
log_R_{80}	0.501	0.283
log_R_{81}	0.403	0.263
log_R_{82}	0.369	0.314
log_R_{83}	0.540	0.275
log_R_{84}	0.146	0.291
log_R_{85}	0.442	0.277
log_R_{86}	0.061	0.285
log_R_{87}	0.019	0.246
log_R_{88}	0.022	0.258
log_R_{89}	-0.332	0.279
log_R_{90}	-0.278	0.253
log_R_{91}	-0.530	0.286
log_R_{92}	-0.676	0.302
log_R_{93}	-0.583	0.289
log_R_{94}	-0.297	0.257
log_R_{95}	-0.066	0.225
log_R_{96}	0.569	0.218
log_R_{97}	-0.018	0.293
log_R_{98}	-0.629	0.320
log_R_{99}	-0.015	0.310
log_R_{00}	0.306	0.263
log_R_{01}	0.383	0.241
log_R_{02}	-0.011	0.314
log_R_{03}	-0.285	0.330
log_R_{04}	0.296	0.241
log_R_{05}	0.424	0.222
log_R_{06}	0.475	0.243

name	Estimate	std.dev
log_R_{07}	0.539	0.232
log_R_{08}	0.136	0.288
log_R_{09}	-0.364	0.294
log_R_{10}	0.003	0.253
log_R_{11}	0.281	0.273
log_R_{12}	0.839	0.187
log_R_{13}	-0.232	0.282
log_R_{14}	-0.503	0.288
log_R_{15}	-0.651	0.263
log_R_{16}	-0.378	0.226
log_R_{17}	-0.014	0.275
a_1	1.482	4.554
a_2	2.267	4.238
a_3	3.788	4.040
a_4	4.077	4.025
a_5	4.302	4.016
a_6	3.528	4.046
a_7	2.095	4.313
r1	10.000	0.890
r2	9.680	0.907
log_a	-2.670	0.089
log_b	4.831	0.015
log_ϕ_{st1}	-5.000	0.104
log_ϕ_{wa}	-2.219	0.311
log_ϕ_{wb}	4.797	0.033
Sw1	0.072	0.035
Sw2	0.488	0.124
log_ϕ_1	5.462	4490.400
log_awr	-0.827	0.603
log_bwr	4.666	0.033
w^2_t	0.053	0.017
q	0.766	0.131
σ	3.917	0.214
β_1	12.441	0.700
β_2	7.656	0.173
ms78	3.186	0.272

Aleutian Islands Golden King Crab Model-Based Stock Assessment

May 2018 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 commercial fishery has been prosecuted since 1981/82 and opened every year since then. 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 1,225 t (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 acronym changed from GHL to TAC (Total Allowable Catch) since crab rationalization in 2005/06. The TACs were further 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.

   Catches have been steady since the introduction of GHL/TAC and the fishery has harvested close to TAC levels since 1996/97. These TAC levels were 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. 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 on 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. In addition to the retained catch that is allotted as TAC, there was retained catch in a cost-recovery fishery towards a $300,000 goal in 2013/14 and 2014/15, and towards a $500,000 goal in 2015/16 and 2016/17.

   Catch per pot lift (CPUE) of retained legal males decreased from the 1980s into the mid-1990s, but increased steadily after 1994/95 and increased markedly at the initiation of the

Crab Rationalization program in 2005/06. Although CPUE for the two areas showed similar trends through 2010/11, during 2011/12–2014/1 5 CPUE trends have diverged (increasing EAG and decreasing WAG). Total retained catch in 2016/17 was 2,593 t (5,716,180 lb): 1,578 t (3,479,529 lb) from the EAG fishery, which included cost-recovery catch, 1,015 t (2,236,651 lb) from the WAG fishery. Discarded (non-retained) catch occurs mainly during the directed fishery. Although low levels of discarded catch can occur during other crab fisheries, there have been no such fisheries prosecuted since 2004/05, except as surveys for red king crab conducted under a commissioner's permit (and there were none 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 2016/17 was 138 t (303,832 lb) for EAG and 92 t (202,815 lb) for WAG. Discarded catch also occurs during fixed-gear and trawl groundfish fisheries, but is small relative to that during the directed fishery and the groundfish fisheries are a minor contributor to total fishery mortality. Estimated bycatch mortality during groundfish fisheries in 2016/17 was 3 t (6,245 lb) for EAG and 3 t (6,800 lb) for WAG. A cooperative golden king crab survey was performed by the Aleutian Islands King Crab Foundation (an industry group) and ADF&G during the EAG fishery in August 2016, by vessels that were simultaneously 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 2016/17, it was assumed that bycatch mortality that occurred during the survey was accounted for by reported discards for the 2016/17 EAG fishery. The cooperative survey was also conducted in August 2017 during the 2017/18 EAG fishery.

3. *Stock biomass*

Estimated mature male biomass (MMB) for EAG under all scenarios decreased from high levels during the 1990s, then systematically increased during the 2000s and 2010s. Estimated MMB for WAG decreased during the late 1980s and 1990s, systematically increased during the 2000s, and decreased for a number of years since 2009. The low levels of MMB for EAG were observed in 1995–1997 and in 1990s for WAG. Slightly increasing trends in MMB were observed since 2014 in both regions. 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, the model recruitment was high in 1987, 1988, 2008, 2015, 2017, and highest in 2014; and lowest in 1986. An increasing trend in recruitment was observed since the early-1990s in EAG. The model recruitment for WAG was high during 1983 to 1987 and highest in 2015; and lowest in 2011. After 1983 to 1987 peaks, the recruitment trend was low except the 2015 highest recruitment.

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. The CPT in May 2017 and SSC in June 2017 accepted author's 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. Following last year's approach, we added OFLs and ABCs by area to calculate OFL and ABC for the entire stock. We could add them together without any modification because the stock status in the two areas after 2016/17 fishery was similar.

Among the six common scenarios for EAG and WAG, we recommend three scenarios (17_0 (base), 17_0d (three catchability and total selectivity), and 17_0e (McAllister and Ianelli method of re-weighting) for consideration and provide the status and catch specifications for the AIGKC stock. Scenario 17_0 is the base scenario with an updated *M* of 0.21yr^{-1} and the addition of 2016/17 data. The model formulation is the same as that was accepted in 2017. Scenario 17_0d fits the recent three years' CPUE indices well for EAG, but the OFL and ABC are very low among the three selected scenarios. Scenario 17_0e is an alternative to the base scenario with McAllister and Ianelli method of size composition data weighting instead of Francis' method of reweighting. The OFL and ABC differences between 17_0e and 17_0 are small. The rest of the scenarios have some shortcomings either on adequacy of data or on model diagnostics; hence, are not considered. All scenarios assume the knife-edge maturity selection.

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]**
2013/14	N/A	N/A	2.853	2.894	3.192	5.69	5.12
2014/15	N/A	N/A	2.853	2.771	3.088	5.69	4.26
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]	6.046	17.952				5.514	4.136
2018/19[d]	5.898	14.665				3.963	2.972
2018/19[e]	6.107	17.793				5.581	4.186

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. 17_0 base scenario with Francis method of re-weighting
d. 17_0d three catchability and total selectivity scenario with Francis method of re-weighting
e. 17_0e McAllister and Ianelli method of re-weighting

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]
2013/14	N/A	N/A	6.290	6.38	7.038	12.54	11.28
2014/15	N/A	N/A	6.290	6.11	6.807	12.53	9.40
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]	13.329	39.577				12.157	9.118
2018/19[d]	13.002	32.331				8.737	6.553
2018/19[e]	13.464	39.227				12.305	9.228

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. 17_0 base scenario with Francis method of re-weighting
d. 17_0d three catchability and total selectivity scenario with Francis method of re-weighting
e. 17_0e McAllister and Ianelli method of re-weighting

Since the 2017/18 total catch of 2,942 t (6.487 million lb) is below the OFL catch of 6,048 t (13.333 million lb), "overfishing" did not occur in the Aleutian Islands golden king crab fishery in 2017/18.

6. Basis for the OFL

The length-based model developed for the Tier 3 analysis estimated MMB on February 15 each year for the period 1986 through 2016 and projected to February 15, 2018 for OFL and ABC determination. 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} derived from the combined data was used.

We provide the OFL and ABC estimates for EAG, WAG, and the two regions pooled together (i.e., for the entire Aleutian Islands, AI) for seven scenarios [17_0, 17_0a, 17_0b, 17_0c, 17_0d, 17_0e, and 17_0f (the last is only for EAG)] in the following six tables. As per September 2017 CPT suggestion, we also provide estimates for May 2017 CPT accepted scenario 9 (modified as 9** for WAG) in these tables. We treat scenario 17_0 as the base scenario for EAG and WAG. **We provide three options of OFL and ABC estimates based on scenarios 17_0, 17_0d, and 17_0e for CPT consideration and selection. Since the OFL and ABC have been set for the entire AI before, we suggest implementing the combined OFL and ABC for AI.**

EAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in millions of pounds. Current MMB = MMB on 15 Feb. 2018. Current MMB for May2017Sc9 =MMB on 15 Feb. 2017.

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)
EAG17_0	3a	15.332	25.474	1.66	0.64	1987–2012	0.64	8.637	8.601	6.478
EAG17_0a	3a	15.570	25.645	1.65	0.62	1987–2012	0.62	8.729	8.683	6.547
EAG17_0b	3a	14.979	22.949	1.53	0.65	1987–2012	0.65	7.529	7.492	5.646
EAG17_0c	3a	15.633	25.869	1.65	0.62	1987–2012	0.62	8.920	8.872	6.690
EAG17_0d	3a	14.745	17.986	1.22	0.64	1987–2012	0.64	5.469	5.435	4.102
EAG17_0e	3a	15.462	25.045	1.62	0.64	1987–2012	0.64	8.761	8.725	6.570
EAG17_0f	3a	15.312	25.340	1.65	0.64	1987–2012	0.64	8.581	8.545	6.436
May2017Sc9	3a	15.539	20.515	1.32	0.75	1987–2012	0.75	9.890	9.852	7.417

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)
EAG17_0	3a	6.954	11.555	1.66	0.64	1987–2012	0.64	3,917.776	3,901.317	2,938.332
EAG17_0a	3a	7.063	11.633	1.65	0.62	1987–2012	0.62	3,959.351	3,938.754	2,969.513
EAG17_0b	3a	6.794	10.409	1.53	0.65	1987–2012	0.65	3,414.981	3,398.458	2,561.235
EAG17_0c	3a	7.091	11.734	1.65	0.62	1987–2012	0.62	4,046.121	4,024.483	3,034.590
EAG17_0d	3a	6.688	8.158	1.22	0.64	1987–2012	0.64	2,480.617	2,465.170	1,860.463
EAG17_0e	3a	7.014	11.360	1.62	0.64	1987–2012	0.64	3,973.77	3,957.468	2,980.334
EAG17_0f	3a	6.946	11.494	1.65	0.64	1987–2012	0.64	3,892.238	3,876.174	2,919.178
May2017Sc9	3a	7.048	9.306	1.32	0.75	1987–2012	0.75	4,486.052	4,468.684	3,364.539

WAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in millions of pounds. Current MMB= MMB on 15 Feb. 2018. Current MMB for May2017Sc9 =MMB on 15 Feb. 2017.

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)
WAG17_0	3a	11.327	14.103	1.25	0.60	1987–2012	0.60	3.520	3.505	2.640
WAG17_0a	3a	11.405	14.148	1.24	0.59	1987–2012	0.59	3.503	3.489	2.627
WAG17_0b	3a	11.252	13.391	1.19	0.60	1987–2012	0.60	3.289	3.270	2.466
WAG17_0c	3a	11.294	13.947	1.23	0.60	1987–2012	0.60	3.418	3.395	2.564
WAG17_0d	3a	11.260	14.345	1.27	0.68	1987–2012	0.68	3.268	3.248	2.451
WAG17_0e	3a	11.466	14.182	1.24	0.59	1987–2012	0.59	3.544	3.529	2.658
May2017Sc9	3a	9.937	10.800	1.09	0.68	1993–1997	0.68	3.443	3.428	2.582

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)
WAG17_0	3a	5.138	6.397	1.25	0.60	1987–2012	0.60	1,596.535	1,589.834	1,197.401
WAG17_0a	3a	5.173	6.417	1.24	0.59	1987–2012	0.59	1,588.903	1,582.813	1,191.677
WAG17_0b	3a	5.104	6.074	1.19	0.60	1987–2012	0.60	1,491.700	1,483.331	1,118.775
WAG17_0c	3a	5.123	6.326	1.23	0.60	1987–2012	0.60	1,550.509	1,540.027	1,162.882
WAG17_0d	3a	5.108	6.507	1.27	0.68	1987–2012	0.68	1,482.383	1,473.365	1,111.787
WAG17_0e	3a	5.201	6.433	1.24	0.59	1987–2012	0.59	1,607.523	1,600.637	1,205.642
May2017Sc9	3a	4.507	4.899	1..09	0.68	1993–1997	0.68	1,561.668	1,554.794	1,171.251

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)
17_0	12.157	12.106	9.118
17_0a	12.232	12.172	9.174
17_0b	10.818	10.762	8.112
17_0c	12.338	12.267	9.254
17_0d	8.737	8.683	6.553
17_0e	12.305	12.254	9.228
May2017Sc9	13.333	13.280	9.999

Aleutian Islands (AI)
Total OFL and ABC for the next fishing season in t.

Scenario	OFL	ABC (P*=0.49)	ABC (0.75*OFL)
17_0	5,514.311	5,491.151	4,135.733
17_0a	5,548.254	5,521.567	4,161.190
17_0b	4,906.681	4,881.789	3,680.010
17_0c	5,596.630	5,564.510	4,197.472
17_0d	3,963.000	3,938.535	2,972.250
17_0e	5,581.293	5,558.105	4,185.976
May2017Sc9	6,047.720	6,023.478	4,535.790

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% buffer on the OFL; i.e., ABC = (1.0 - x/100)*OFL. We considered x = 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 ADF&G Area Management report (Leon et al., 2017) and most recent fish ticket data. Fishery data has been updated with the catches during 2016/17: 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 (1981/82–2016/17), total catch (1990/91–2016/17), and groundfish bycatch (1989/90–2016/17) biomass and size compositions.
   - Fish ticket retained CPUE were standardized by the 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 generalized linear model (GLM) with the negative binomial link function with variable selection by R square criterion and CAIC (modified AIC), separately for 1995/96–2004/05 and 2005/06–2015/16 periods.
   - For scenario 17_0a, observer data were standardized by VAST. The work is still preliminary.
   - For scenario 17_0f for EAG, independent pot survey data from 2015 to 2017 were standardized by GLM and a likelihood component with this set of indices was added.
   - Chela height with carapace length data from ADFG (1991) and NMFS (1984) surveys were analyzed outside the assessment model to determine the knife-edge maturity for mature male biomass calculation.
3. *Changes to assessment methodology*
   - The equilibrium initial population and Tier 3 MMB_{MSY} reference point estimation procedures used the mean number of recruits for 1987–2012.

- Francis re-weighting method was used to update the input effective sample sizes for length composition data for most scenarios, including *M* profiling and retrospective analysis except scenario 17_0e in which we applied the McAllister and Ianelli re-weighting method (McAllister and Ianelli, 1997; Siddeek et al. 2016c, 2017).
- We also added a stock projection part (Appendix F) to assess the viability of the stock under Tier 3 OFL and ABC control rule and a dynamic B0 analysis part (Appendix H) to assess the biomass dynamics under no fishery.

4. *Changes to assessment results*
   Expectedly, addition of one more year data changed the OFL and ABC estimates, but no dramatic changes were observed.

B. Response to September 2017 CPT comments

Comment 1: The CPT recommended moving forward with the modeling convention adopted by the Groundfish Plan Teams. Naming conventions in groundfish SAFE guidelines:
When a model constituting a "major change" from the original version of the base model is introduced, it is given a label of the form "Model *yy.j*," where *yy* is the year (designated by the last two digits) that the model was introduced, and *j* is an integer distinguishing this particular "major change" model from other "major change" models introduced in the same year.

When a model constituting only a "minor change" from the original version of the base model is introduced, it is given a label of the form "Model *yy.jx*," where "*x*" is a letter distinguishing this particular "minor change" model from other "minor change" models derived from the original version of the same base model.

The distinction between "major" and "minor" model changes is determined subjectively by the author on the basis of qualitative differences in model

Response:
We followed this naming convention in labeling model scenarios: 17_0 refers to model was established in 2017 and carried forward to 2018; no major changes occurred in 2018 and remain at the 0-level. 17_0a refers to a minor change to 17_0; for example, CPUE indices were determined by spatio-temporal delta generalized linear mixed model (deltaGLMM) instead of GLM in this case.

Comment 2: a) Reconsider what crabs are mature vs immature via breakpoint analysis; b) Repeat the breakpoint analysis using log (CH/CL) vs CL, rather than the logCH vs. logCL; c) Because it was based on an inappropriate analysis, there is no need to show models with a logistic maturity curve, unless an improved approach can be found.

Response:
As suggested by Steve Martel, we used the log(CH/CL) vs. CL plot to get a better delineation of points for breakpoint analysis (see Appendix C figures). We used the breakpoint 50% maturity length for maturity determination in all scenarios. Sizes ≥ 111 mm CL were treated as mature and below this breakpoint immature.

Comment 3: It is appropriate to use only the equilibrium abundance as a starting point.

Response:
We used the equilibrium starting point in 1960 in all scenarios.

Comment 4: Moving forward, do not look at the core data.

Response:
We are not using the core data, but we have analyzed the independent pot survey data to estimate CPUE indices and incorporated them in a separate model scenario (17_0f). In the future we intend to use a spatio-temporal model to analyze the independent pot survey data.

Comment 5: Continue analysis of spatio-temporal variation of the fishery using a program like VAST.

Response:
We did a preliminary analysis of observer data using a spatio-temporal deltaGLMM (VAST, Thorson et al. 2015) and estimated an additional set of CPUE indices (see Appendix B) for scenario 17_0a. VAST requires spatially explicit catch data and some measure of 'area fished'. This type of information is available from the observer data, which include soak time, lat. and long., and depth. The necessary data for a spatio-temporal detlaGLMM are not available from dock side sampling; therefore, observer data are more suitable (see West coast SSC's March 2017 groundfish subcommittee report on the review of assessment methodologies proposed for use in 2017 groundfish assessments).

However, unlike the open West Coast Sea or Bering Sea, the Aleutian Islands areas provide additional constraints for spatial analysis due to the edge effects from the many islands. More work is needed to improve the use of spatio-temporal models in this region.

Comment 6: Show a scenario with the McAllister and Ianelli re-weighting for comparison when choosing preferred model.

Response:
We provide scenario 17_0e, which considers McAllister and Ianelli method of re-weighting (see Appendix D for detail).

Comment 7: Consider interaction terms, specifically area x year interaction for CPUE standardization.

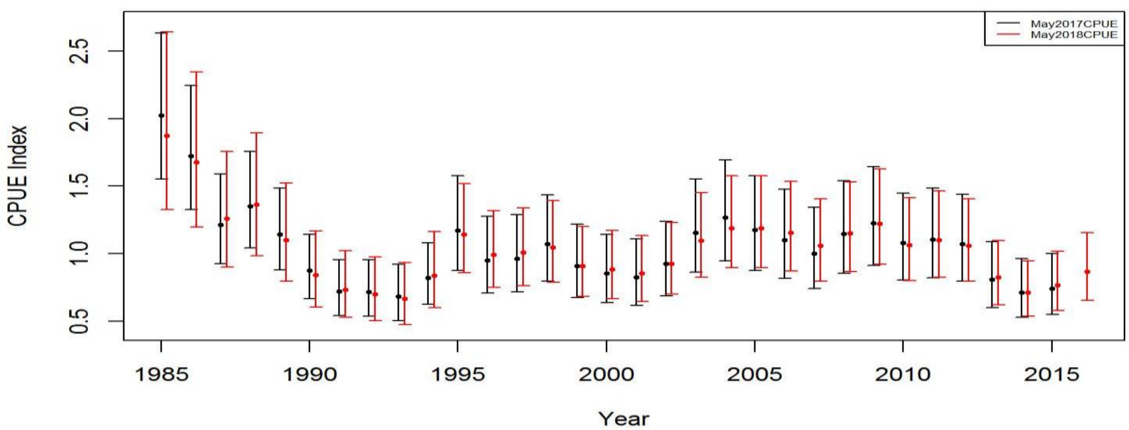
Response:
We standardized the CPUE considering the year: area interaction for scenario 17_0c (see Appendix B for details). The problem with this interaction analysis is that a lot of NAs occurred for many missing factor levels over the years. Anyway, we used the resulting CPUE indices in scenario 17_0c.

Comment 8: Consider scenarios with catchability and/or total selectivity breaking at a third point in 2010 (or a better year).

Response:
We considered scenario 17_0d with different sets of catchability and total selectivity for 1985/86–2004/05; 2005/06–2012/13; and 2013/14–2016/17.

Comment 9: Provide a comparison between the previous CPUE standardization and any new standardization methods that are applied.

Response:



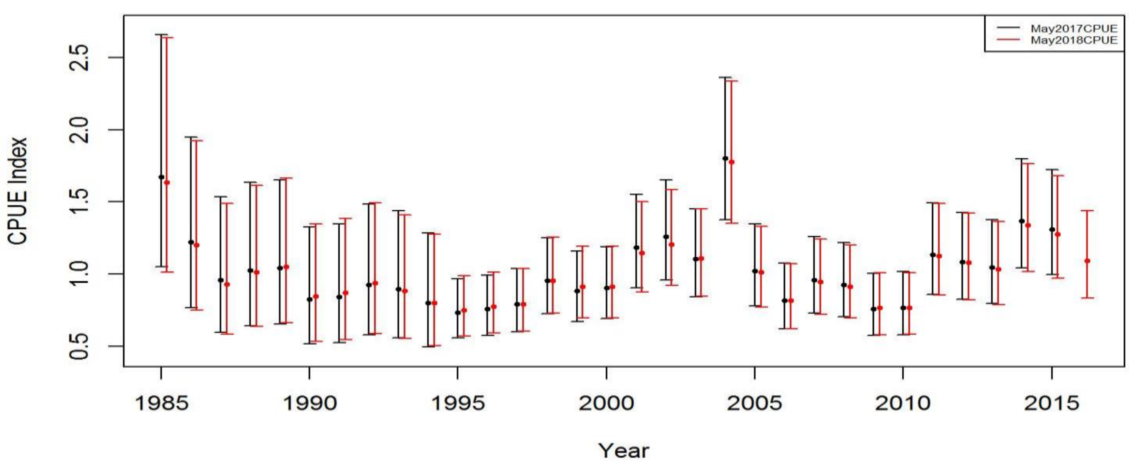


Figure Comm.9. Comparison between May 2017 and May 2018 CPUE indices (top: WAG, bottom: EAG). In 2017 we categorized the area broadly into 10 longitudinally separated regions whereas in 2018 we used individual ADFG coded statistical area. The confidence intervals are +/- 2SE. Model estimated additional standard error was added to each input standard error.

Comment 10: Include last year's model as a scenario for consideration.

Response:
We have included last year's model as scenario May17Sc9 to reflect scenario 9 with knife-edge maturity selectivity, which was accepted last year.

Comment 11: Overall model recommendation for May 2018: base model from last year (equilibrium initial abundance, knife edge maturity, both CPUE analyses with any significant interaction terms).

Response:
Done.

Response to October 2017 SSC comments

Comment 1: The SSC appreciates the CPT's consideration of model number convention and their recommendation to move forward with the modelling convention adopted by the Groundfish Plan Teams.

Response:
Done.

Comment 2: Although the use of chela height-carapace size regression lines has been validated for *Chionoecetes* crabs (snow, Tanner), the SSC expressed concern that the use of this approach to determine maturity may not be appropriate for lithodid (king) crabs. The SSC recommends that efforts be made to verify this relationship in lab or field experiments, as well as to review the available literature and application of this approach for other non-*Chionoecetes* species.

Response:

After analyzing a number of lithodid (king) crab stocks for size at maturity, Somerton and Otto (1986) observed that golden king crab provided a better separation of chela height growth at the onset of maturity than either red or blue king crabs (see Appendix C). We have also provided a literature review on king crab maturity determination in Appendix C, which supports the breakpoint type of analysis for male 50% maturity determination.

Comment 3: The SSC supports the exploration of the VAST geospatial model for investigation of fishery catch rate data, but cautions that the nonrandom nature of fisheries data adds an additional challenge to the standard assumptions of independence between the underlying density and the process of observation beyond that of standard statistically-designed survey programs.

Response:
We did a preliminary run of VAST for observer CPUE standardization and described its advantage and limitation (see response to CPT comment 5).

Comment 4: The SSC encourages the author to explore observer data and to discuss with the participants in the fishery potential changes in fisher behavior that may influence the relationship between fishery catch rates and crab abundance.

Response:
This is an ongoing process. We continue to explore this with the industry input and external experts.

Comment 5:The SSC reiterates previous concerns that this stock assessment relies solely on fishery data, and therefore carries a higher degree of uncertainty than other model-based assessments for crab stocks. The SSC encourages recent and future efforts by the industry to include survey pots in their fishing activity in order to generate additional data to inform this analysis. The SSC extends its appreciation to the industry for their generous cooperative research efforts on this important crab stock.

Response:
We recognized the higher degree of uncertainty in the assessment and therefore set the ABC using 25% buffer level. For the first time, we used the independent pot survey data in the model even though the time series is short (2015 to 2017).

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 2). 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 3), 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 4). 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 5).

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 4 and 5) 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 6) 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, 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 1996/97–2016/17 the annual retained catch during commercial fishing (including cost-recovery fishing that occurred during 2013/14–2016/17) has averaged 2% below the annual GHL/TACs. During 1996/97–2016/17, 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 SOA fishery regulations and management actions pertaining to the Aleutian Islands golden king crab fishery is provided below:

Beginning in 2005/06 the Aleutian Islands golden king crab fishery has been prosecuted under the Crab Rationalization Program. Accompanying the implementation of the Crab Rationalization program was implementation of a community development quota (CDQ) fishery for golden king crab in the eastern Aleutians (i.e., 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 5 AAC 34.050). Pots used to fish for golden king crab in the Aleutian Islands Area must be operated from a shellfish longline and, since 1996, must have at least four escape rings of five and one-half inches minimum inside diameter installed on the vertical plane or at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized golden king crab (5 AAC 34.625 (b)). Prior to the regulation requiring an escape mechanism on pots, some participants in the Aleutian Islands golden king crab fishery voluntarily sewed escape rings (typically 139 mm or 5.5 inches) into their gear or, more rarely, included panels with escape mesh (Beers 1992). With regard to the gear used since the establishment of 5 AAC 34.625 (b) in 1996, Linda Kozak, a representative of the industry, reported in a 19 September 2008 email to the Crab Plan Team that, "… the golden king crab fleet has modified their gear to allow for small crab sorting," and provided a written statement from Lance Nylander, of Dungeness Gear Works in Seattle, who "believes he makes all the gear for the golden king crab harvesting fleet," saying that, "Since 1999, DGW has installed 9[-inch] escape web on the door of over 95% of Golden Crab pot orders we manufactured." A study to estimate the contact-selection curve for male golden king crab that was conducted aboard one vessel commercial fishing for golden king crab during the 2012/13 season showed that gear and fishing practices used by that vessel 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 required on catcher-processors at all times 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 SOA 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 that 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 7 to 9 provide the 1985/86–2016/17 time series of catches, CPUE, and the geographic distribution of catch during the 2016/17 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, July 1, 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 2011/12–2016/17 (an increasing trend in EAG and a decreasing trend in WAG).

6. **Brief description of the annual ADF&G harvest strategy:**
The annual TAC is set by state regulation, 5 AAC 34.612 (Harvest Levels for Golden King Crab in Registration Area O), as approved by the BOF in March 2012:

(a) Until the Aleutian Islands golden king crab stock assessment model and a state regulatory harvest strategy are established, the harvest levels for the Registration Area O golden king crab fishery are as follows:

(1) east of 174° W long. (EAG): 3.31 million pounds; and
(2) west of 174° W long. (WAG): 2.98 million pounds;

(b) The department may reduce the harvest levels based on the best scientific information available and considering the reliability of estimates and performance measures, sources of uncertainty as necessary to avoid overfishing, and any other factors necessary to be consistent with sustained yield principles.

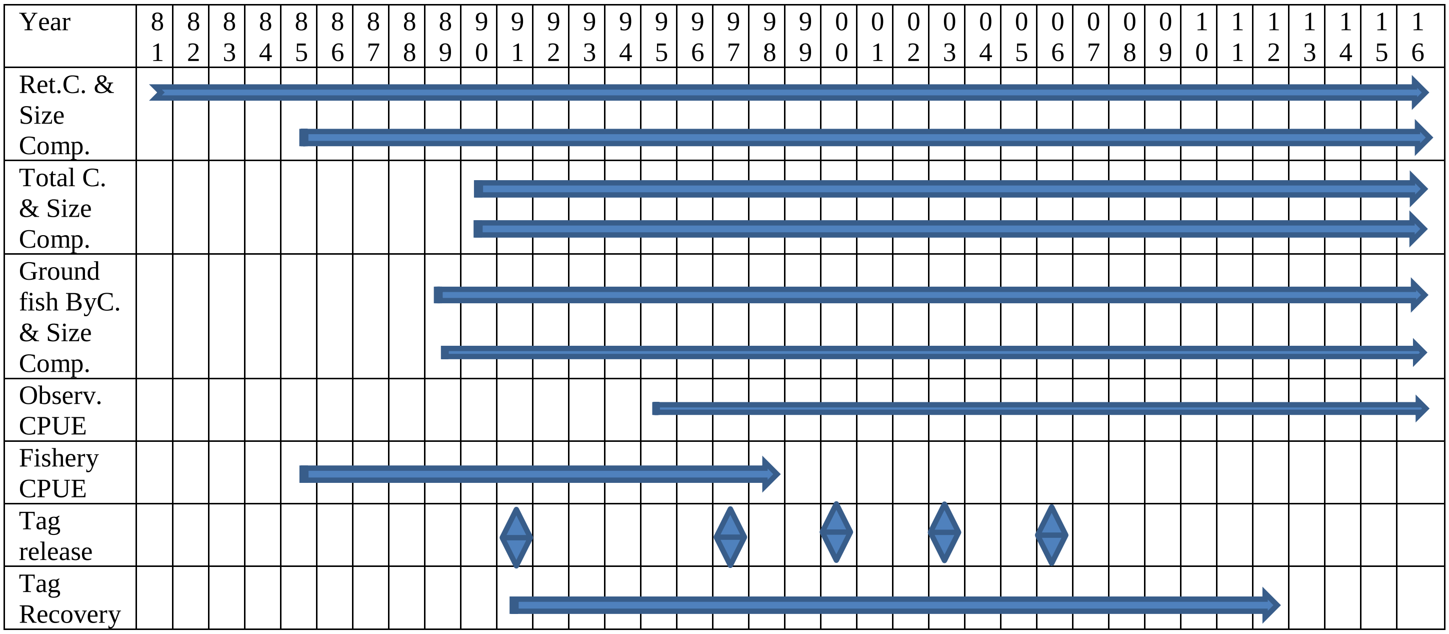
In addition to the retained catch that is limited by the TAC established by ADF&G under 5 AAC 34.612, ADF&G also has authority to annually receive receipts of $500,000 through cost-recovery fishing on Aleutian Islands golden king crab. The retained catch from that cost-recovery fishing is not counted against attainment of the annually-established TAC.
At the March 2018 meeting, The BOF decided to amend the phrase “may reduce to “may modify” in (b).

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, commercial fishery CPUE index, and tag-recapture data were updated to include 2016/17 information. The details are given in the pictorial table 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 1981/82–2016/17 (Table 1). Estimated total catch weight for 1990/91–2016/17 (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 1981/82–2016/17 (Table 2). Crab fishery discards are available after observer sampling was established in 1988/89. Some observer data exists 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 1991/92–2016/17 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 1985/86–2016/17 (Table 3).

- Estimated commercial fishery CPUE index with coefficient of variation (Table 4 for EAG and Table 22 for WAG). The estimation methods, CPUE fits and diagnostic plots are described in Appendixes B and G.

d. Catch-at-length:

Information on length compositions (Figures 11 to 13 for length compositions for EAG; and 29 to 31 for length compositions 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 model.
- **Weight-at-length**: Male length-weight relationship: $W = aL^b$ where a = $3.7255*10^{-4}$, b = 3.0896 (updated estimates).
- **Natural mortality**: Model estimated fixed natural mortality value 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 recapture data from these surveys were used.

E. Analytic Approach

1. History of modeling approaches for this stock:

A size structured assessment model based on only fisheries data has been under development for several years for the EAG and WAG golden king crab stocks. The model was accepted in 2016 for OFL and ABC setting for the 2017/18 season. The CPT in January 2017 and SSC in February 2017 recommended to using the Tier 3 procedure to set the OFL and ABC. They also suggested to using the maturity data to estimate MMB. We followed these suggestions in this report. This is the second fishing season we are proposing to use the model-based OFL and ABC setting.

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 male mature biomass (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). As a first attempt, we used VAST to estimate a separate set of observer CPUE indices for the model scenario 17_0a and also used the 2015-2017 fishery independent pot survey CPUE indices for the model scenario 17_0f.
There were significant changes in fishing practice due to changes in management regulations (e.g., constant TAC since 1996/97 and crab rationalization since 2005/06), pot configuration (escape web on the pot door increased to 9-inch since 1999), and improved observer recording in Aleutian Islands golden king crab fisheries since 1998. These changes prompted us to consider two sets of catchability and total selectivity parameters with only one set of retention parameters for the periods 1985/86–2004/05 and 2005/06–2016/17. However, in order to respond to the September 2017 CPT comment, we considered three catchabilities, three sets of total selectivity, and one set of retention curves in one scenario (scenario 17_0d).

We fitted the observer and commercial fishery CPUE indices with estimated (by GLM or VAST) standard errors and an additional model estimated constant variance. The assessment model predicted total and retained CPUEs. However, we compared only the predicted retained CPUE with the observer legal size crab CPUE indices in the likelihood function because observer recordings of legal size crabs are reliable.

The data series ranges used for the WAG are the same as those for EAG.

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

c.–f. Details are given in Appendix A.

g. **Critical assumptions and consequences of assumption failures**:
Because of the lack of an annual stock survey, we relied heavily on standardized CPUE indices (Appendix B) and catch and size composition information to determine the stock abundance trends in both regions. We assumed that the observer and fish ticket CPUE indices are linearly related to exploitable abundance. We kept *M* constant at 0.21 yr^{-1}. The *M* value was the combined estimates for EAG and WAG (Figure 1). 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 code is available from the authors.

3. Model Selection and Evaluation

a. Description of alternative model configurations:

We considered 7 scenarios for EAG and 6 scenarios for 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 17_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 1995/96–2016/17.

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 and McAllister and Ianelli methods (Appendix D).

v) Two catchability and two sets of logistic total selectivity for the periods 1985/86–2004/05 and 2005/06–2016/17, 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.

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 are 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.

As per CPT and SSC requests, initial parameter values for scenario 17_0 were jittered to confirm model global convergence. The results indicated that global convergence was achieved for almost all the runs (Appendix E).

Table T1. Features of model scenarios. Initial condition was estimated by the equilibrium condition for all scenarios. Changes from scenario 17_0 specifications are highlighted by the light blue shade.

Scenario	**Size-composition weighting**	**Catchability and logistic total selectivity sets**	**Maturity**	**Standardized CPUE data type**	**Treatment of *M* and Tier 3 MMB_{MSY} reference points**	**Natural mortality (*M* yr^{-1})**
0b	Stage-1:Number of boat_days/trips Stage-2: Francis method	2	Knife-edge, 111 mm CL	Observer from 1995/96–2016/17 & Fish Ticket from 1985/86–1998/99; GLM variable selection by R square criterion	Estimate a common *M* using the combined EAG and WAG data without an *M* prior	0.2254; Individual component's estimate: EAG: 0.2142 WAG: 0.2142
17_0	Stage-1:Number of boat_days/trips Stage-2: Francis method	2	Knife-edge, 111 mm CL	Observer from 1995/96–2016/17 & Fish Ticket from 1985/86–1998/99; GLM variable selection by R square criterion	Single *M* from combined EAG and WAG data; Tier 3 MMB_{MSY} reference points based on average recruitment from 1987–2012	0.21
17_0a	Stage-1:Number of boat_days/trips Stage-2: Francis method	2	Knife-edge, 111 mm CL	Observer CPUE by VAST & Fish Ticket CPUE by GLM; GLM variable selection by R square criterion	Single *M* from combined EAG and WAG data; Tier 3 MMB_{MSY} reference points based on average recruitment from 1987–2012	0.21
17_0b	Stage-1:Number of boat_days/trips Stage-2: Francis method	2	Knife-edge, 111 mm CL	Observer & Fish Ticket CPUE by GLM; GLM variable selection by CAIC	Single *M* from combined EAG and WAG data; Tier 3 MMB_{MSY} reference points based on average recruitment from 1987–2012	0.21

17_0c	Stage-1:Number of boat_days/trips Stage-2: Francis method	2	Knife-edge, 111 mm CL	Observer & Fish Ticket CPUE standardization considering Year:Area interaction; GLM variable selection by R square criterion	Single *M* from combined EAG and WAG data; Tier 3 MMB_{MSY} reference points based on average recruitment from 1987–2012	0.21
17_0d	Stage-1:Number of boat_days/trips Stage-2: Francis method	3	Knife-edge, 111 mm CL	Observer & Fish ticket; GLM variable selection by R square criterion	Three different total selectivity curves and catchability coefficients for 1985–2004, 2005–2012, and 2013–2016; single *M* from combined EAG and WAG data; Tier 3 MMB_{MSY} reference points based on average recruitment from 1987–2012	0.21
17_0e	Stage-1:Number of boat_days/trips Stage-2: McAllister and Ianelli method	2	Knife-edge, 111 mm CL	Observer & Fish ticket; GLM variable selection by R square criterion	Single *M* from combined EAG and WAG data; Tier 3 MMB_{MSY} reference points based on average recruitment from 1987–2012	0.21
17_0f (only for EAG)	Stage-1:Number of boat_days/trips Stage-2: Francis method	2	Knife-edge, 111 mm CL	Observer, Fish ticket, & fishery independent pot survey (2015–2016) in EAG; GLM variable selection by R square criterion	Fishery independent pot survey standardized CPUE are considered as a separate likelihood component for EAG; single *M* from combined EAG and WAG data; Tier 3 MMB_{MSY} reference points based on average recruitment from 1987–2012	0.21

b. **Progression of results:**
The OFL and ABC estimates are similar to those estimated by the 2017 model.

c. **Label the approved model from the previous year as model 0:**
Following the September CPT suggestion we used the notation 17_0 for the base model which came from the previous assessment.

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 a number of 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 seven scenarios also considered different configuration of parameters to select parsimonious models. The detailed results of the seven scenarios are provided in tables and figures. The total catch OFLs and the reduction in terminal (2016) MMB from the initial condition (i.e., virgin MMB in 1960) for all scenarios for EAG and WAG are provided in Table 38. We also included the results of the accepted 2017 model scenario, Sc9, in this table for comparison. The reduction in terminal MMB from the initial condition is higher for WAG than EAG.

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 and McAllister and Ianelli method (McAllister and Ianelli, 1997) (Appendix D).

We provide the initial input sample sizes (Stage-1) and Stage-2 effective sample sizes for scenarios 17_0 to 17_0f in Tables 5 to 11 for EAG and Tables 23 to 28 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) and details are in Appendix D.

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 a number of 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 a number of 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 11 for EAG and Tables 23 to 28 for WAG. The weights for different data sets are provided in Table A2 for various scenarios, respectively, for EAG and WAG (Appendix A). 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 to a large value (500.0) because retained catches are more reliable than any other data sets. We scaled the total catch biomass in accordance with the observer annual sample sizes 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. 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 12 and 13 for EAG and 29 and 30 for WAG for all scenarios. The numbers of estimable parameters are listed in Table A1 of Appendix A. The weights with the corresponding coefficient of variations specifications are detailed in Tables A2 of Appendix A for EAG and WAG.

2. **Include tables showing differences in likelihood:**
   Tables 21 and 37 list the total and component negative log likelihood values and their differences between scenarios of similar sample sizes and free parameters 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 12 and 13 for EAG and 29 and 30 for WAG. 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 14 to 20 for EAG and Tables 31 to 36 for WAG.

   d. The recruitment estimates for those scenarios are summarized in Tables 14 to 20 for EAG and Tables 31 to 36 for WAG.

   e. The negative log-likelihood component values and total negative log-likelihood values for all scenarios are summarized in Table 21 for EAG and Table 37 for WAG. Scenario 17_0d has the minimum total negative log likelihood for EAG whereas scenario 17_0e has the minimum for WAG. Among the scenarios with equal data components (base) and number of free parameters, scenario 17_0e has the lowest total negative log likelihoods for both EAG and WAG. Thus, we chose scenarios 17_0 (base), 17_0d, and 17_0e for OFL and ABC options for consideration.

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 14 for EAG and Figure 32 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 13 and 31 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 nine (a subset of 11) scenarios are depicted in Figures 28 and 46 for EAG and WAG, respectively. Mature male biomass tracked the CPUE trends well for all scenarios for EAG and WAG. The biomass variance was estimated using 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 $MMB_{35\%}$ calculation under Tier 3 approach.

c. **Fishing mortality**:
The full selection pot fishery F over time for all scenarios is shown in Figures 27 and 45 for EAG and WAG, respectively. The F peaked in late 1980s and early to mid-1990s and systematically declined in the EAG. On the other hand, the F in the WAG peaked in late 1980s, 1990s and early 2000s, then declined in late 2000s and slightly increased since 2010. The increase in F in recent years may be due to a decline in abundance under constant high harvest allocation to WAG.

d. **F vs. MMB:**
We provide these plots for scenarios 17_0 and 17_0d for EAG and WAG in Figure 47.

e. **Stock-Recruitment relationship:** None.

f. **Recruitment**:
The temporal changes in total number of recruits to the modeled population for all scenarios are illustrated in Figure 16 for EAG and in Figure 34 for WAG. The recruitment distribution to the model size group (101–185 mm CL) is shown in Figures 17 and 35 for EAG and WAG, respectively for all scenarios.

5. Evaluation of the fit to the data:

g. **Fits to catches:**
The fishery retained, total, and groundfish bycatch (observed vs. estimated) plots for all scenarios are illustrated in Figures 19 and 37 for EAG and WAG, respectively. The 1981/82–1984//85 retained catch plots for all scenarios are depicted in Figures 20 and 38 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 predicted vs. input CPUE indices for all scenarios are shown in Figure 26 for EAG and Figure 44 for WAG. Scenario 17_0d fit the recent three years' CPUE indices well for EAG; on the other hand, scenario 17_0c did not fit the post rationalization period CPUE indices well for WAG. The CPUE variance was estimated using 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 recaptures are depicted in Figure 15 for EAG and Figure 33 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 all scenarios are depicted in Figures 18 and 36 for EAG and WAG, respectively. The fits appear to be satisfactory.

l. **Fit to catch size compositions:**
Retained, total, and groundfish discard length compositions are shown in Figures 11 to 13 for EAG and 29 to 31 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 21 and 23 for EAG, and 39 and 41 for WAG) and for total catch (Figures 22 and 24 for EAG, and 40 and 42 for WAG) for two scenarios (17_0 and 17_0d). The retained catch bubble plots appear random 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, but provided the estimated values in Tables 5 to 11 for EAG and in Tables 23 to 28 for WAG, respectively.

o. **Tables of RMSEs for the indices:**
We did not provide this table in this report.

p. **Quantile-quantile (Q–Q) plots:**
We did not provide these plots for model fits in this report. However, we provided these plots in a separate Appendix F for CPUE standardization diagnostic.

6. **Retrospective and historical analysis:**
The retrospective fits for scenarios 17_0 and 17_0d are shown in Figure 25 for EAG and in Figure 43 for WAG. The retrospective fits were prepared for the whole time series 1961 to 2017. The retrospective patterns did not show severe departure when four terminal years' data were removed systematically, especially for WAG and

hence the current formulation of the model appears stable. The Mohn rho values are also given in the figures, which indicate no severe model misspecification (i.e., small rho) (Mohn, 1999; Deroba, 2014). 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.

   - We also determined likelihood values at different *M* and plotted component negative likelihood against *M* (Figure 1).

8. **Conduct 'jitter analysis':**
   We conducted the (random) jitter analysis on scenario 17_0 (base) model fitted parameters. This analysis indicated that the base model achieved the global convergence (details in Appendix E).

F. Calculation of the OFL

1. Specification of the Tier level:

Aleutian Islands golden king crab has been elevated to Tier 3 level in 2017 for OFL and ABC determination. In the following section, we provide the method to determine OFL and ABC

2. List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan:

The critical assumptions for $MMBB_{MSY}$ reference point estimation 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 2005/06–2016/17 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 2007/08 – 2016/17 (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 2013/14–2015/16 in the table below do not include landings towards a cost-recovery fishery goal, but the catches towards cost-recovery fishing in 2013/14–2014/15 are included in the retained and total catch.

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]
2013/14	N/A	N/A	2.853	2.894	3.192	5.69	5.12
2014/15	N/A	N/A	2.853	2.771	3.088	5.69	4.26
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]	6.046	17.952				5.514	4.136
2018/19[d]	5.898	14.665				3.963	2.972
2018/19[e]	6.107	17.793				5.581	4.186

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. 17_0 base scenario with Francis method of re-weighting
d. 17_0d three catchability and total selectivity scenario with Francis method of re-weighting
e. 17_0e McAllister and Ianelli method of re-weighting

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]
2013/14	N/A	N/A	6.290	6.38	7.038	12.54	11.28
2014/15	N/A	N/A	6.290	6.11	6.807	12.53	9.40
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			13.333	10.000
2018/19[c]	13.329	39.577				12.157	9.118
2018/19[d]	13.002	32.331				8.737	6.553
2018/19[e]	13.464	39.227				12.305	9.228

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. 17_0 base scenario with Francis method of re-weighting
d. 17_0d three catchability and total selectivity scenario with Francis method of re-weighting
e. 17_0e McAllister and Ianelli method of re-weighting

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) stock were calculated for the three recommended scenario options (17_0, 17_0d, and 17_0e):

Scenario 17_0:
EAG: 3,756 t (8.280 million lb)
WAG: 1,473 t (3.248 million lb)
AI: 5,229 t (11.528 million lb).

Scenario 17_0d:
EAG: 2,355 t (5.191 million lb)
WAG: 1,375 t (3.031 million lb)
AI: 3,730 t (8.222 million lb).

Scenario 17_0e:
EAG: 3,817 t (8.415 million lb)
WAG: 1,484 t (3.271 million lb)
AI: 5,301 t (11.686 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 additional buffer by setting ABC =0.75*OFL
   We provide the ABC estimates with the 25% buffer for EAG, WAG, and AI considering scenarios 17_0, 17_0d, and 17_0e:

   Scenario 17_0:
   EAG: ABC = 2,938 t (6.478 million lb)
   WAG: ABC = 1,197 t (2.640 million lb)
   AI: ABC = 4,136 t (9.118 million lb).

   Scenario 17_0d:
   EAG: ABC = 1,860 t (4.102 million lb)
   WAG: ABC = 1,112 t (2.451 million lb)
   AI: ABC = 2,972 t (6.553 million lb).

   Scenario 17_0e:
   EAG: ABC = 2,980 t (6.570 million lb)
   WAG: ABC = 1,206 t (2.658 million lb)
   AI: ABC = 4,186 t (9.228 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 was estimated in the model and independent estimate is not available.
   - 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 in during 1981/82–1989/90 were not available.

3. **List of additional uncertainties for alternative sigma-b.**
   We recommended a large buffer of 25% to account for additional uncertainties.

4. **Author recommended ABC:**
   Authors recommended three ABC options based on 25% buffer on the OFL under scenarios 17_0, 17_0d, and 17_0e.

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. Extensive tagging experiments or resource surveys are needed to investigate stock distributions.
2. We estimated M in the model. However, an independent estimate of M is needed for comparison, which could be achieved with tagging experiments.
3. An extensive tagging study 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. The Aleutian King Crab Research Foundation program can help us to update this relationship by collecting new length weight information.
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 recent data are needed.
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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Table 1. Commercial fishery history for the Aleutian Islands golden king crab fishery1981/82–2015/16: 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 2005/06–2016/17, 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 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]

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 – 2016/17, 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.

<table>
<tr><th></th><th colspan="2"></th><th colspan="4">Bycatch Mortality by Fishery Type (t)</th><th colspan="3"></th></tr>
<tr><th></th><th colspan="2">Retained Catch (t)</th><th colspan="2">Crab</th><th colspan="2">Groundfish</th><th colspan="3">Total Fishery Mortality (t)</th></tr>
<tr><th>Season</th><th>EAG</th><th>WAG</th><th>EAG</th><th>WAG</th><th>EAG</th><th>WAG</th><th>EAG</th><th>WAG</th><th>Entire AI</th></tr>
<tr><td>1981/82</td><td>490</td><td>95</td><td></td><td></td><td colspan="2"></td><td></td><td></td><td>585</td></tr>
<tr><td>1982/83</td><td>1,260</td><td>2,655</td><td></td><td></td><td colspan="2"></td><td></td><td></td><td>3,914</td></tr>
<tr><td>1983/84</td><td>1,554</td><td>2,991</td><td></td><td></td><td colspan="2"></td><td></td><td></td><td>4,545</td></tr>
<tr><td>1984/85</td><td>1,839</td><td>424</td><td></td><td></td><td colspan="2"></td><td></td><td></td><td>2,263</td></tr>
<tr><td>1985/86</td><td>2,677</td><td>1,996</td><td></td><td></td><td colspan="2"></td><td></td><td></td><td>4,673</td></tr>
<tr><td>1986/87</td><td>2,798</td><td>4,200</td><td></td><td></td><td colspan="2"></td><td></td><td></td><td>6,998</td></tr>
<tr><td>1987/88</td><td>1,882</td><td>2,496</td><td></td><td></td><td colspan="2"></td><td></td><td></td><td>4,379</td></tr>
<tr><td>1988/89</td><td>2,382</td><td>2,441</td><td></td><td></td><td colspan="2"></td><td></td><td></td><td>4,823</td></tr>
<tr><td>1989/90</td><td>2,738</td><td>3,028</td><td></td><td></td><td colspan="2"></td><td></td><td></td><td>5,766</td></tr>
<tr><td>1990/91</td><td>1,623</td><td>1,621</td><td></td><td></td><td colspan="2"></td><td></td><td></td><td>3,244</td></tr>
<tr><td>1991/92</td><td>2,035</td><td>1,397</td><td>515</td><td>344</td><td colspan="2">0</td><td></td><td></td><td>4,291</td></tr>
<tr><td>1992/93</td><td>2,112</td><td>1,025</td><td>1,206</td><td>373</td><td colspan="2">0</td><td></td><td></td><td>4,716</td></tr>
<tr><td>1993/94</td><td>1,439</td><td>686</td><td>383</td><td>258</td><td colspan="2">4</td><td></td><td></td><td>2,770</td></tr>
<tr><td>1994/95</td><td>2,044</td><td>1,540</td><td>687</td><td>823</td><td colspan="2">1</td><td></td><td></td><td>5,095</td></tr>
<tr><td>1995/96</td><td>2,259</td><td>1,203</td><td>725</td><td>530</td><td colspan="2">2</td><td></td><td></td><td>4,719</td></tr>
<tr><td>1996/97</td><td>1,738</td><td>1,259</td><td>485</td><td>439</td><td colspan="2">5</td><td></td><td></td><td>3,926</td></tr>
<tr><td>1997/98</td><td>1,588</td><td>1,083</td><td>441</td><td>343</td><td colspan="2">1</td><td></td><td></td><td>3,455</td></tr>
<tr><td>1998/99</td><td>1,473</td><td>955</td><td>434</td><td>285</td><td colspan="2">1</td><td></td><td></td><td>3,149</td></tr>
<tr><td>1999/00</td><td>1,392</td><td>1,222</td><td>313</td><td>385</td><td colspan="2">3</td><td></td><td></td><td>3,316</td></tr>
<tr><td>2000/01</td><td>1,422</td><td>1,342</td><td>82</td><td>437</td><td colspan="2">2</td><td></td><td></td><td>3,285</td></tr>
<tr><td>2001/02</td><td>1,442</td><td>1,243</td><td>74</td><td>387</td><td colspan="2">0</td><td></td><td></td><td>3,146</td></tr>
<tr><td>2002/03</td><td>1,280</td><td>1,198</td><td>52</td><td>303</td><td colspan="2">18</td><td></td><td></td><td>2,850</td></tr>
<tr><td>2003/04</td><td>1,350</td><td>1,220</td><td>53</td><td>148</td><td colspan="2">20</td><td></td><td></td><td>2,792</td></tr>
<tr><td>2004/05</td><td>1,309</td><td>1,219</td><td>41</td><td>143</td><td colspan="2">1</td><td></td><td></td><td>2,715</td></tr>
<tr><td>2005/06</td><td>1,300</td><td>1,204</td><td>22</td><td>73</td><td colspan="2">2</td><td></td><td></td><td>2,601</td></tr>
<tr><td>2006/07</td><td>1,357</td><td>1,022</td><td>28</td><td>81</td><td colspan="2">18</td><td></td><td></td><td>2,506</td></tr>
<tr><td>2007/08</td><td>1,356</td><td>1,142</td><td>24</td><td>114</td><td colspan="2">59</td><td></td><td></td><td>2,695</td></tr>
<tr><td>2008/09</td><td>1,426</td><td>1,150</td><td>61</td><td>102</td><td colspan="2">33</td><td></td><td></td><td>2,772</td></tr>
<tr><td>2009/10</td><td>1,429</td><td>1,253</td><td>111</td><td>108</td><td>18</td><td>5</td><td>1,558</td><td>1,366</td><td>2,923</td></tr>
<tr><td>2010/11</td><td>1,428</td><td>1,279</td><td>123</td><td>124</td><td>49</td><td>3</td><td>1,600</td><td>1,407</td><td>3,006</td></tr>
<tr><td>2011/12</td><td>1,429</td><td>1,276</td><td>106</td><td>117</td><td>25</td><td>4</td><td>1,560</td><td>1,398</td><td>2,957</td></tr>
<tr><td>2012/13</td><td>1,504</td><td>1,339</td><td>118</td><td>145</td><td>9</td><td>6</td><td>1,631</td><td>1,491</td><td>3,122</td></tr>
</table>

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

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 (1990/91–2016/17). The crab weights are for the size range ≥ 101mm CL and 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	3,672	3,736
1991/92	3,946	2,275
1992/93	5,570	1,500
1993/94	NA	2,800
1994/95	2,020	4,945
1995/96	3,724	2,125
1996/97	2,035	1,766
1997/98	2,534	1,794
1998/99	2,797	1,083
1999/00	2,272	2,085
2000/01	2,551	2,225
2001/02	2,107	2,131
2002/03	1,796	1,889
2003/04	1,819	1,853
2004/05	1,618	1,873
2005/06	1,713	1,786
2006/07	1,621	1,542
2007/08	1,790	1,602
2008/09	1,796	1,719
2009/10	1,750	1,667
2010/11	1,719	1,580
2011/12	1,736	1,504
2012/13	1,927	1,811
2013/14	1,818	1,890
2014/15	1,939	1,583
2015/16	2,104	1,547
2016/17	2,104	1,425

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 the EAG and WAG golden king crab stocks, 1985/86–2016/17. Observer retained CPUE includes retained and non-retained legal size crabs.

Year	Pot Fishery Nominal Retained CPUE		Obs. Nominal Retained CPUE		Obs. Nominal Total CPUE		Pot Fishery Effort (no.pot lifts)		Obs. Sample Size (no.pot lifts)		Obs. CPUE Index	
	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG	EAG	WAG
1985/86	11.90	11.90					117,718	118,563				
1986/87	8.42	7.32					155,240	277,780				
1987/88	7.03	7.15					146,501	160,229				
1988/89	7.52	7.93					155,518	166,409				
1989/90	8.49	7.83					155,262	202,541				
1990/91	8.90	7.00	6.84	8.00	33.60	27.04	106,281	108,533	138	340		
1991/92	8.20	7.40	8.11	6.83	24.69	17.01	133,428	101,429	377	857		
1992/93	8.40	5.90	10.42	6.35	38.46	16.64	133,778	69,443	199	690		
1993/94	7.80	4.40	5.07	6.51	20.81	17.14	106,890	127,764	31	174		
1994/95	5.90	4.10	2.54	6.71	12.91	19.25	191,455	195,138	127	1,270		
1995/96	5.90	4.70	5.03	4.96	16.94	14.26	177,773	115,248	6,388	5,598	0.75	1.14
1996/97	6.50	6.10	5.11	5.43	13.65	13.56	113,460	99,267	8,360	7,194	0.77	0.99
1997/98	7.30	6.60	7.11	6.53	18.15	15.03	106,403	86,811	4,670	3,985	0.79	1.01
1998/99	8.90	11.40	9.10	9.41	25.76	23.05	83,378	35,975	3,616	1,876	0.96	1.05
1999/00	9.00	6.30	9.21	5.92	20.70	14.47	79,129	107,040	3,851	4,523	0.91	0.91
2000/01	9.90	7.00	9.90	6.39	25.35	16.63	71,551	101,239	5,043	4,740	0.91	0.89
2001/02	11.70	6.50	11.19	5.99	22.59	14.64	62,639	105,512	4,626	4,454	1.15	0.86
2002/03	12.40	8.40	11.94	7.47	22.54	17.37	52,042	78,979	3,980	2,509	1.21	0.93
2003/04	10.90	10.20	11.03	9.28	19.46	18.15	58,883	66,236	3,960	3,334	1.11	1.10
2004/05	18.30	12.10	17.71	11.13	28.47	22.43	34,848	56,846	2,206	2,619	1.78	1.19
2005/06	25.40	21.20	29.44	23.89	38.47	36.23	24,569	30,116	1,193	1,365	1.01	1.19
2006/07	24.80	19.60	25.21	24.01	33.52	33.47	26,195	26,870	1,098	1,183	0.82	1.16
2007/08	28.00	20.00	31.09	21.07	40.37	32.48	22,653	29,950	998	1,082	0.95	1.06
2008/09	27.30	22.40	29.92	24.54	38.36	38.12	24,466	26,200	613	979	0.92	1.15
2009/10	25.90	23.70	26.64	26.54	35.89	34.07	26,298	26,489	408	892	0.77	1.22
2010/11	26.00	20.90	26.05	22.35	36.76	29.05	25,851	29,994	436	867	0.77	1.06
2011/12	37.30	23.40	38.79	23.76	51.69	31.09	17,915	26,326	361	837	1.13	1.10
2012/13	33.02	20.57	38.00	22.81	47.74	30.73	20,827	32,716	438	1,109	1.08	1.06
2013/14	33.67	16.42	35.83	16.93	46.16	24.95	21,388	41,835	499	1,223	1.04	0.83
2014/15	42.29	15.29	46.96	15.28	60.00	22.67	17,002	41,548	376	1,137	1.34	0.71
2015/16	39.41	14.97	43.17	15.75	58.81	22.13	19,376	41,108	478	1,296	1.28	0.77
2016/17	32.45	14.29	37.01	16.63	52.78	24.25	24,470	38,118	617	1,060	1.09	0.87

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. GLM predictor variables selected by R square criteria.

Year	**CPUE Index**	**CV**
1985/86	1.63	0.05
1986/87	1.20	0.05
1987/88	0.93	0.06
1988/89	1.02	0.05
1989/90	1.05	0.04
1990/91	0.85	0.06
1991/92	0.87	0.06
1992/93	0.94	0.06
1993/94	0.89	0.06
1994/95	0.80	0.06
1995/96	0.77	0.07
1996/97	0.82	0.07
1997/98	1.19	0.05
1998/99	1.39	0.05

Table 5. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_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	48				
1986/87	11	9				
1987/88	61	51				
1988/89	352	293				
1989/90	792	660			9	4
1990/91	163	136	22	11	13	6
1991/92	140	117	48	24	NA	NA
1992/93	49	41	41	21	2	1
1993/94	340	283	NA	NA	2	1
1994/95	319	266	34	17	4	2
1995/96	879	733	1,117	568	5	2
1996/97	547	456	509	259	4	2
1997/98	538	449	711	362	8	4
1998/99	541	451	574	292	15	7
1999/00	463	386	607	309	14	6
2000/01	436	363	495	252	16	7
2001/02	488	407	510	259	13	6
2002/03	406	338	438	223	15	7
2003/04	405	338	416	212	17	8
2004/05	280	233	299	152	10	4
2005/06	266	222	232	118	12	5
2006/07	234	195	143	73	14	6
2007/08	199	166	134	68	17	8
2008/09	197	164	113	57	15	7
2009/10	170	142	95	48	16	7
2010/11	183	153	108	55	26	12
2011/12	160	133	107	54	13	6
2012/13	187	156	99	50	18	8
2013/14	193	161	122	62	17	8
2014/15	168	140	99	50	16	7
2015/16	190	158	125	64	10	4
2016/17	223	186	155	79	12	5

Table 6. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_0a 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	48				
1986/87	11	9				
1987/88	61	51				
1988/89	352	294				
1989/90	792	661			9	4
1990/91	163	136	22	12	13	6
1991/92	140	117	48	26	NA	NA
1992/93	49	41	41	22	2	1
1993/94	340	284	NA	NA	2	1
1994/95	319	266	34	18	4	2
1995/96	879	733	1,117	598	5	2
1996/97	547	456	509	272	4	2
1997/98	538	449	711	380	8	4
1998/99	541	451	574	307	15	7
1999/00	463	386	607	325	14	6
2000/01	436	364	495	265	16	7
2001/02	488	407	510	273	13	6
2002/03	406	339	438	234	15	7
2003/04	405	338	416	223	17	8
2004/05	280	234	299	160	10	4
2005/06	266	222	232	124	12	5
2006/07	234	195	143	76	14	6
2007/08	199	166	134	72	17	8
2008/09	197	164	113	60	15	7
2009/10	170	142	95	51	16	7
2010/11	183	153	108	58	26	12
2011/12	160	133	107	57	13	6
2012/13	187	156	99	53	18	8
2013/14	193	161	122	65	17	8
2014/15	168	140	99	53	16	7
2015/16	190	158	125	67	10	4
2016/17	223	186	155	83	12	5

Table 7. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_0b 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	48				
1986/87	11	9				
1987/88	61	51				
1988/89	352	294				
1989/90	792	662			9	4
1990/91	163	136	22	11	13	6
1991/92	140	117	48	24	NA	NA
1992/93	49	41	41	21	2	1
1993/94	340	284	NA	NA	2	1
1994/95	319	266	34	17	4	2
1995/96	879	734	1,117	566	5	2
1996/97	547	457	509	258	4	2
1997/98	538	449	711	360	8	4
1998/99	541	452	574	291	15	7
1999/00	463	387	607	307	14	6
2000/01	436	364	495	251	16	7
2001/02	488	408	510	258	13	6
2002/03	406	339	438	222	15	7
2003/04	405	338	416	211	17	8
2004/05	280	234	299	151	10	4
2005/06	266	222	232	118	12	5
2006/07	234	195	143	72	14	6
2007/08	199	166	134	68	17	8
2008/09	197	165	113	57	15	7
2009/10	170	142	95	48	16	7
2010/11	183	153	108	55	26	12
2011/12	160	134	107	54	13	6
2012/13	187	156	99	50	18	8
2013/14	193	161	122	62	17	8
2014/15	168	140	99	50	16	7
2015/16	190	159	125	63	10	4
2016/17	223	186	155	79	12	5

Table 8. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_0c 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	50				
1988/89	352	288				
1989/90	792	648			9	4
1990/91	163	133	22	12	13	6
1991/92	140	115	48	26	NA	NA
1992/93	49	40	41	22	2	1
1993/94	340	278	NA	NA	2	1
1994/95	319	261	34	18	4	2
1995/96	879	719	1,117	602	5	2
1996/97	547	447	509	274	4	2
1997/98	538	440	711	383	8	4
1998/99	541	443	574	309	15	7
1999/00	463	379	607	327	14	6
2000/01	436	357	495	267	16	7
2001/02	488	399	510	275	13	6
2002/03	406	332	438	236	15	7
2003/04	405	331	416	224	17	8
2004/05	280	229	299	161	10	4
2005/06	266	218	232	125	12	5
2006/07	234	191	143	77	14	6
2007/08	199	163	134	72	17	8
2008/09	197	161	113	61	15	7
2009/10	170	139	95	51	16	7
2010/11	183	150	108	58	26	12
2011/12	160	131	107	58	13	6
2012/13	187	153	99	53	18	8
2013/14	193	158	122	66	17	8
2014/15	168	137	99	53	16	7
2015/16	190	155	125	67	10	4
2016/17	223	182	155	84	12	5

Table 9. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_0d 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	48				
1986/87	11	9				
1987/88	61	52				
1988/89	352	298				
1989/90	792	669			9	4
1990/91	163	138	22	12	13	6
1991/92	140	118	48	25	NA	NA
1992/93	49	41	41	22	2	1
1993/94	340	287	NA	NA	2	1
1994/95	319	270	34	18	4	2
1995/96	879	743	1,117	593	5	2
1996/97	547	462	509	270	4	2
1997/98	538	455	711	378	8	4
1998/99	541	457	574	305	15	7
1999/00	463	391	607	322	14	6
2000/01	436	369	495	263	16	7
2001/02	488	412	510	271	13	6
2002/03	406	343	438	233	15	7
2003/04	405	342	416	221	17	8
2004/05	280	237	299	159	10	4
2005/06	266	225	232	123	12	5
2006/07	234	198	143	76	14	6
2007/08	199	168	134	71	17	8
2008/09	197	167	113	60	15	7
2009/10	170	144	95	50	16	7
2010/11	183	155	108	57	26	12
2011/12	160	135	107	57	13	6
2012/13	187	158	99	53	18	8
2013/14	193	163	122	65	17	8
2014/15	168	142	99	53	16	7
2015/16	190	161	125	66	10	4
2016/17	223	188	155	82	12	5

Table 10. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by McAllister and Ianelli method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_0e 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	72				
1986/87	11	14				
1987/88	61	77				
1988/89	352	443				
1989/90	792	997			9	7
1990/91	163	205	22	8	13	10
1991/92	140	176	48	18	NA	NA
1992/93	49	62	41	16	2	1
1993/94	340	428	NA	NA	2	1
1994/95	319	402	34	13	4	3
1995/96	879	1,106	1,117	424	5	4
1996/97	547	689	509	193	4	3
1997/98	538	677	711	270	8	6
1998/99	541	681	574	218	15	11
1999/00	463	583	607	230	14	10
2000/01	436	549	495	188	16	12
2001/02	488	614	510	194	13	10
2002/03	406	511	438	166	15	11
2003/04	405	510	416	158	17	13
2004/05	280	352	299	113	10	7
2005/06	266	335	232	88	12	9
2006/07	234	295	143	54	14	10
2007/08	199	250	134	51	17	13
2008/09	197	248	113	43	15	11
2009/10	170	214	95	36	16	12
2010/11	183	230	108	41	26	19
2011/12	160	201	107	41	13	10
2012/13	187	235	99	38	18	13
2013/14	193	243	122	46	17	13
2014/15	168	211	99	38	16	12
2015/16	190	239	125	47	10	7
2016/17	223	281	155	59	12	9

Table 11. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_0f 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	48				
1986/87	11	9				
1987/88	61	51				
1988/89	352	294				
1989/90	792	661			9	4
1990/91	163	136	22	11	13	6
1991/92	140	117	48	24	NA	NA
1992/93	49	41	41	21	2	1
1993/94	340	284	NA	NA	2	1
1994/95	319	266	34	17	4	2
1995/96	879	734	1,117	569	5	2
1996/97	547	457	509	259	4	2
1997/98	538	449	711	362	8	4
1998/99	541	452	574	292	15	7
1999/00	463	386	607	309	14	6
2000/01	436	364	495	252	16	7
2001/02	488	407	510	260	13	6
2002/03	406	339	438	223	15	7
2003/04	405	338	416	212	17	8
2004/05	280	234	299	152	10	4
2005/06	266	222	232	118	12	5
2006/07	234	195	143	73	14	6
2007/08	199	166	134	68	17	8
2008/09	197	164	113	58	15	7
2009/10	170	142	95	48	16	7
2010/11	183	153	108	55	26	12
2011/12	160	134	107	55	13	6
2012/13	187	156	99	50	18	8
2013/14	193	161	122	62	17	8
2014/15	168	140	99	50	16	7
2015/16	190	159	125	64	10	4
2016/17	223	186	155	79	12	5

Table 12. Parameter estimates and coefficient of variations (CV) with the 2016 MMB (MMB on 15 Feb 2017) for scenarios 17_0, 17_0a, 17_0b, and 17_0c for the golden king crab data from the EAG, 1985/86–2016/17. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 17_0		**Scenario 17_0a**		**Scenario 17_0b**		**Scenario 17_0c**		
Parameter	Estimate	CV	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	2.54	0.006	1.0, 4.5
ω_2 (growth incr. slope)	-8.20	0.21	-8.22	0.21	-8.22	0.21	-8.26	0.21	-12.0,-5.0
log_a (molt prob. slope)	-2.50	0.02	-2.48	0.02	-2.50	0.02	-2.48	0.02	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.00	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	3.68	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.38	0.020	3.38	0.02	3.37	0.020	3.38	0.019	0.,4.4
log_ total sel deltaθ, 2005–16	2.97	0.030	2.93	0.030	2.98	0.030	2.92	0.031	0.,4.4
log_ ret. sel deltaθ, 1985–16	1.85	0.023	1.85	0.023	1.85	0.0234	1.85	0.0233	0.,4.4
log_tot sel θ_{50}, 1985–04	4.83	0.003	4.84	0.003	4.83	0.003	4.84	0.003	4.0,5.0
log_tot sel θ_{50}, 2005–16	4.92	0.002	4.91	0.002	4.92	0.0021	4.91	0.0019	4.0,5.0
log_ret. sel θ_{50}, 1985–16	4.91	0.0003	4.91	0.00	4.91	0.0003	4.91	0.0003	4.0,5.0
log_β_r (rec.distribution par.)	-1.09	0.18	-1.08	0.18	-1.09	0.18	-1.06	0.18	-12.0, 12.0
logq2 (catchability 1995–04)	-0.59	0.12	-0.61	0.13	-0.57	0.13	-0.69	0.15	-9.0, 2.25
logq3 (catchability 2005–16)	-0.97	0.13	-1.06	0.13	-0.89	0.15	-1.09	0.13	-9.0, 2.25
log_mean_rec (mean rec.)	0.874	0.05	0.890	0.05	0.855	0.05	0.893	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-1.060	0.06	-1.108	0.06	-1.032	0.07	-1.119	0.07	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.244	0.09	-9.278	0.09	-9.210	0.09	-9.289	0.09	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.018	0.37	0.029	0.43	0.032	0.39	0.031	0.47	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.051	0.43	0.051	0.44	0.040	0.432	0.173	0.58	0.0,1.0
2016 MMB	13,455	0.17	13,579	0.20	11,842	0.19	13,767	0.21	

Table 13. Parameter estimates and coefficient of variations (CV) with the 2016 MMB (MMB on 15 Feb 2017) for scenarios 17_0d, 17_0e, and 17_0f for the golden king crab data from the EAG, 1985/86–2016/17. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 17_0d		**Scenario 17_0e**		**Scenario 17_0f**		
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	0.21	-7.94	0.21	-8.20	0.21	-12.0,-5.0
log_a (molt prob. slope)	-2.50	0.02	-2.51	0.02	-2.50	0.02	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.001	4.95	0.00	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	3.34	0.02	3.38	0.02	0.,4.4
log_ total sel deltaθ, 2005–12	2.93	0.04			2.97	0.03	0.,4.4
log_ total sel deltaθ, 2013–16 or 2005–16	3.02	0.05	2.96	0.03	1.85	0.02	0.,4.4
log_ ret. sel deltaθ, 1985–16	1.85	0.02	1.85	0.02	4.83	0.003	0.,4.4
log_tot sel θ_{50}, 1985–04	4.83	0.002	4.83	0.002	4.92	0.002	4.0,5.0
log_tot sel θ_{50}, 2005–12	4.92	0.002			4.91	0.0003	4.0,5.0
log_tot sel θ_{50}, 2013–16 or 2005–16	4.92	0.004	4.92	0.002	-1.09	0.18	4.0,5.0
log_ret. sel θ_{50}, 1985–16	4.91	0.0003	4.91	0.0003	-0.59	0.12	4.0,5.0
log_β_r (rec.distribution par.)	-1.08	0.18	-1.15	0.17	-0.97	0.13	-12.0, 12.0
Logq1 (catchability 1985–04)	-0.60	0.12	-0.60	0.12	0.873	0.05	-9.0, 2.25
Logq3 (catchability 2005–12)	-0.99	0.11			-1.060	0.06	-9.0, 2.25
Logq2 (catchability 2013–16 or 2005–16)	-0.57	0.36	-1.01	0.12	-9.242	0.09	-9.0, 2.25
log_mean_rec (mean rec.)	0.83	0.06	0.872	0.05	0.018	0.38	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-1.02	0.07	-1.080	0.06	0.051	0.43	-15.0, -0.01
log_mean_Fground (GF byc. F)	-9.18	0.09	-9.259	0.09	2.54	0.006	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.02	0.36	0.018	0.37	-8.20	0.21	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.05	0.43	0.052	0.42	-2.50	0.02	0.0,1.0
σ_e^2 (survey CPUE additional var)					0.0000003	1001.0	0.0,1.0
2016 MMB	8,833	0.23	13,440	0.17	13,368	0.17	

Table 14. 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 17_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 2017 are restricted to 1985–2017. 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} =23,950 $MMB_{35\%}$=6,954			
1985	1.67			9,618	0.05
1986	1.00	9,534	0.04	8,147	0.04
1987	4.12	7,286	0.04	6,353	0.04
1988	3.77	6,652	0.05	5,274	0.05
1989	2.20	6,706	0.05	4,698	0.07
1990	2.71	5,973	0.06	4,287	0.07
1991	3.52	6,078	0.05	4,647	0.06
1992	2.27	6,116	0.04	4,466	0.05
1993	2.13	6,058	0.04	4,471	0.05
1994	2.45	6,195	0.03	4,889	0.04
1995	2.29	5,716	0.04	4,442	0.04
1996	2.25	5,139	0.04	3,850	0.04
1997	3.03	5,253	0.04	3,987	0.05
1998	2.78	5,529	0.05	4,100	0.05
1999	2.96	6,118	0.05	4,542	0.05
2000	2.78	6,811	0.05	5,202	0.06
2001	2.11	7,463	0.06	5,847	0.06
2002	2.70	7,848	0.06	6,414	0.06
2003	2.26	8,179	0.06	6,787	0.07
2004	1.95	8,507	0.07	7,089	0.07
2005	2.95	8,577	0.07	7,304	0.07
2006	2.25	8,649	0.07	7,233	0.08
2007	2.17	8,903	0.08	7,390	0.08
2008	3.52	8,910	0.08	7,543	0.08
2009	2.39	9,127	0.08	7,509	0.09
2010	2.19	9,630	0.08	7,914	0.09
2011	2.82	9,685	0.08	8,235	0.08
2012	2.74	9,708	0.08	8,229	0.09
2013	2.36	9,885	0.09	8,273	0.09
2014	5.63	9,913	0.10	8,368	0.10
2015	4.76	10,626	0.11	8,432	0.11
2016	2.59	12,484	0.14	9,623	0.13
2017	4.70	13,455	0.17		

Table 15. 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 17_0a 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 1985–2017. 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} =24,335 *$MMB_{35\%}$*=7,063			
1985	1.67			9,713	0.05
1986	1.01	9,594	0.04	8,206	0.04
1987	4.14	7,331	0.04	6,389	0.04
1988	3.75	6,696	0.05	5,303	0.05
1989	2.20	6,751	0.05	4,732	0.07
1990	2.70	6,013	0.06	4,321	0.07
1991	3.51	6,116	0.05	4,678	0.06
1992	2.23	6,146	0.04	4,492	0.05
1993	2.11	6,069	0.04	4,488	0.05
1994	2.49	6,179	0.03	4,881	0.04
1995	2.36	5,695	0.04	4,414	0.04
1996	2.32	5,152	0.04	3,836	0.04
1997	3.17	5,321	0.05	4,016	0.05
1998	2.94	5,673	0.05	4,185	0.05
1999	3.12	6,369	0.05	4,711	0.06
2000	2.97	7,180	0.06	5,476	0.06
2001	2.26	7,954	0.06	6,231	0.06
2002	2.83	8,457	0.07	6,914	0.07
2003	2.35	8,870	0.07	7,381	0.07
2004	2.02	9,248	0.08	7,747	0.08
2005	2.96	9,328	0.08	7,988	0.08
2006	2.41	9,369	0.08	7,907	0.09
2007	2.32	9,594	0.08	8,018	0.09
2008	3.46	9,635	0.08	8,168	0.09
2009	2.27	9,840	0.09	8,162	0.09
2010	2.23	10,218	0.09	8,513	0.09
2011	2.81	10,143	0.09	8,698	0.10
2012	2.68	10,095	0.10	8,594	0.10
2013	2.42	10,186	0.11	8,567	0.11
2014	5.58	10,143	0.13	8,582	0.13
2015	4.78	10,821	0.15	8,606	0.15
2016	2.63	12,627	0.18	9,754	0.18
2017	4.70	13,579	0.20		

Table 16. 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 17_0b 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 1985–2017. 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
		MMBeq =23,449 MMB35%=6,794			
1985	1.68			9,583	0.06
1986	1.00	9,536	0.04	8,138	0.04
1987	4.17	7,300	0.04	6,364	0.04
1988	3.73	6,683	0.05	5,295	0.05
1989	2.13	6,751	0.05	4,738	0.07
1990	2.72	5,991	0.06	4,325	0.07
1991	3.54	6,066	0.05	4,652	0.06
1992	2.28	6,107	0.04	4,455	0.05
1993	2.15	6,060	0.04	4,466	0.05
1994	2.43	6,209	0.03	4,896	0.04
1995	2.27	5,735	0.04	4,462	0.04
1996	2.23	5,145	0.04	3,864	0.04
1997	3.01	5,242	0.04	3,987	0.05
1998	2.74	5,498	0.05	4,082	0.05
1999	2.90	6,064	0.05	4,506	0.05
2000	2.71	6,720	0.06	5,140	0.06
2001	2.05	7,327	0.06	5,747	0.06
2002	2.60	7,667	0.07	6,270	0.07
2003	2.24	7,946	0.07	6,601	0.07
2004	1.92	8,231	0.07	6,852	0.08
2005	2.92	8,294	0.08	7,044	0.08
2006	2.27	8,364	0.08	6,971	0.08
2007	2.17	8,633	0.08	7,133	0.09
2008	3.32	8,676	0.08	7,313	0.09
2009	2.20	8,873	0.08	7,306	0.09
2010	2.08	9,261	0.08	7,650	0.09
2011	2.59	9,207	0.08	7,855	0.08
2012	2.45	9,126	0.08	7,753	0.09
2013	2.18	9,143	0.09	7,678	0.09
2014	4.97	9,019	0.11	7,618	0.11
2015	4.39	9,511	0.13	7,548	0.12
2016	2.54	11,020	0.16	8,450	0.16
2017	4.70	11,842	0.19		

Table 17. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with coefficient of variation (CV) for scenario 17_0c 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 1985–2017. 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} =24,526 $MMB_{35\%}$=7,091			
1985	1.59			9,750	0.06
1986	0.98	9,598	0.04	8,236	0.04
1987	3.98	7,282	0.04	6,372	0.04
1988	3.99	6,587	0.05	5,241	0.05
1989	2.18	6,625	0.06	4,601	0.07
1990	2.73	5,964	0.06	4,239	0.07
1991	3.52	6,080	0.05	4,634	0.06
1992	2.22	6,136	0.04	4,474	0.05
1993	2.09	6,069	0.04	4,487	0.05
1994	2.48	6,175	0.03	4,884	0.04
1995	2.35	5,682	0.04	4,409	0.04
1996	2.34	5,129	0.04	3,820	0.05
1997	3.24	5,300	0.05	3,995	0.05
1998	3.02	5,684	0.05	4,176	0.06
1999	3.15	6,445	0.06	4,749	0.06
2000	3.00	7,314	0.06	5,577	0.07
2001	2.27	8,117	0.07	6,375	0.07
2002	2.85	8,630	0.07	7,075	0.08
2003	2.38	9,044	0.08	7,545	0.08
2004	2.04	9,420	0.08	7,908	0.09
2005	3.03	9,502	0.09	8,147	0.09
2006	2.38	9,561	0.09	8,070	0.09
2007	2.30	9,795	0.09	8,202	0.10
2008	3.52	9,803	0.09	8,342	0.10
2009	2.37	9,997	0.09	8,307	0.10
2010	2.22	10,407	0.10	8,662	0.10
2011	2.81	10,360	0.10	8,886	0.10
2012	2.72	10,295	0.11	8,788	0.11
2013	2.41	10,377	0.12	8,745	0.12
2014	5.59	10,332	0.14	8,758	0.14
2015	4.85	10,995	0.16	8,773	0.16
2016	2.65	12,801	0.18	9,910	0.18
2017	4.70	13,767	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 17_0d 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 1985–2017. 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} =23,043 $MMB_{35\%}$=6,688			
1985	1.66			9,599	0.06
1986	0.99	9,538	0.04	8,146	0.04
1987	4.14	7,286	0.04	6,356	0.04
1988	3.79	6,653	0.05	5,272	0.05
1989	2.18	6,719	0.05	4,698	0.07
1990	2.70	5,989	0.06	4,296	0.07
1991	3.53	6,087	0.05	4,654	0.06
1992	2.26	6,126	0.04	4,470	0.05
1993	2.13	6,067	0.04	4,475	0.05
1994	2.46	6,200	0.03	4,890	0.04
1995	2.30	5,721	0.04	4,442	0.04
1996	2.26	5,150	0.04	3,853	0.04
1997	3.04	5,271	0.04	3,997	0.05
1998	2.79	5,553	0.05	4,115	0.05
1999	2.97	6,149	0.05	4,562	0.05
2000	2.79	6,849	0.05	5,229	0.06
2001	2.12	7,504	0.06	5,879	0.06
2002	2.69	7,894	0.06	6,449	0.06
2003	2.23	8,224	0.06	6,824	0.07
2004	1.92	8,539	0.07	7,123	0.07
2005	2.89	8,584	0.07	7,319	0.07
2006	2.16	8,619	0.07	7,221	0.07
2007	2.06	8,813	0.07	7,334	0.08
2008	3.21	8,743	0.07	7,424	0.08
2009	2.04	8,824	0.07	7,307	0.08
2010	1.78	9,087	0.08	7,538	0.08
2011	2.15	8,861	0.08	7,617	0.08
2012	2.11	8,518	0.09	7,326	0.09
2013	1.82	8,233	0.10	6,976	0.11
2014	3.58	7,848	0.12	6,651	0.12
2015	3.43	7,832	0.15	6,312	0.15
2016	2.42	8,486	0.19	6,546	0.19
2017	4.70	8,833	0.23		

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 17_0e 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 1985–2017. Equilibrium MMB_{eq} and $MMB_{35\%}$ are also listed.

Year	Recruits to the Model ($\geq$ 101 mm CL)	Mature Male Biomass ($\geq$ 111 mm CL)	CV	Legal Size Male Biomass ($\geq$ 136 mm CL)	CV
		MMB_{eq} =24,217 $MMB_{35\%}$=7,014			
1985	1.75			9,489	0.05
1986	0.99	9,601	0.04	8,137	0.04
1987	4.25	7,417	0.04	6,449	0.04
1988	3.36	6,806	0.04	5,406	0.04
1989	2.38	6,813	0.05	4,854	0.06
1990	2.63	5,974	0.05	4,325	0.06
1991	3.69	6,109	0.04	4,662	0.06
1992	2.26	6,148	0.04	4,471	0.04
1993	2.07	6,158	0.04	4,522	0.04
1994	2.37	6,286	0.03	4,977	0.03
1995	2.28	5,760	0.03	4,514	0.03
1996	2.22	5,130	0.04	3,860	0.04
1997	3.05	5,218	0.04	3,961	0.04
1998	2.69	5,473	0.05	4,048	0.05
1999	2.99	6,042	0.05	4,479	0.05
2000	2.88	6,701	0.05	5,105	0.06
2001	2.06	7,391	0.06	5,747	0.06
2002	2.87	7,821	0.06	6,364	0.06
2003	2.41	8,181	0.06	6,759	0.07
2004	1.92	8,631	0.07	7,136	0.07
2005	3.12	8,776	0.07	7,458	0.07
2006	2.40	8,879	0.07	7,426	0.08
2007	2.11	9,240	0.07	7,645	0.08
2008	3.84	9,295	0.08	7,886	0.08
2009	2.17	9,547	0.08	7,862	0.08
2010	2.26	10,114	0.08	8,353	0.08
2011	2.99	10,069	0.08	8,635	0.08
2012	2.77	10,108	0.08	8,581	0.09
2013	2.27	10,327	0.09	8,653	0.09
2014	5.75	10,317	0.10	8,764	0.10
2015	4.33	10,957	0.11	8,763	0.11
2016	2.55	12,709	0.14	9,910	0.13
2017	2.39	13,440	0.17		

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 17_0f 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 1985–2017. 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} =23,924 $MMB_{35\%}$=6,946			
1985	1.67			9,618	0.05
1986	1.00	9,534	0.04	8,146	0.04
1987	4.12	7,286	0.04	6,353	0.04
1988	3.77	6,652	0.05	5,274	0.05
1989	2.20	6,706	0.05	4,698	0.07
1990	2.71	5,973	0.06	4,287	0.07
1991	3.52	6,078	0.05	4,647	0.06
1992	2.27	6,116	0.04	4,466	0.05
1993	2.13	6,058	0.04	4,471	0.05
1994	2.45	6,195	0.03	4,889	0.04
1995	2.29	5,716	0.04	4,442	0.04
1996	2.25	5,139	0.04	3,849	0.04
1997	3.04	5,253	0.04	3,987	0.05
1998	2.78	5,530	0.05	4,100	0.05
1999	2.96	6,120	0.05	4,543	0.05
2000	2.78	6,814	0.05	5,204	0.06
2001	2.11	7,466	0.06	5,850	0.06
2002	2.70	7,853	0.06	6,417	0.06
2003	2.26	8,183	0.06	6,791	0.07
2004	1.95	8,511	0.07	7,093	0.07
2005	2.95	8,581	0.07	7,307	0.07
2006	2.25	8,653	0.07	7,237	0.08
2007	2.17	8,907	0.08	7,394	0.08
2008	3.51	8,914	0.08	7,547	0.08
2009	2.38	9,128	0.08	7,513	0.09
2010	2.18	9,625	0.08	7,913	0.09
2011	2.80	9,670	0.08	8,226	0.08
2012	2.70	9,683	0.08	8,212	0.09
2013	2.34	9,841	0.09	8,243	0.09
2014	5.66	9,845	0.10	8,317	0.10
2015	4.71	10,553	0.11	8,362	0.11
2016	2.59	12,415	0.13	9,560	0.13
2017	4.70	13,368	0.17		

Table 21. Negative log-likelihood values of the fits for scenarios (Sc) 17_0 (base), 17_0a (observer CPUE by VAST), 17_0b (observer and fishtick CPUE variable selection by CAIC), 17_0c (Year:Area interaction for observer and fishtick CPUE), 17_0d (three total selectivity and catchability for 1985–04, 2005–12, and 2013–16 time periods), 17_0e (Stage 2 effective sample sizes by McAllister and Ianelli method), and 17_0f (independent pot survey CPUE as an additional likelihood component) for golden king crab in the EAG. Differences in likelihood values are given for scenarios with the same number of data points (base) and free parameters. Likelihood components with zero entry in the entire rows are omitted. RetdcatchB= retained catch biomass.

Likelihood Component	**Sc 17_0**	**Sc 17_0a**	**Sc 17_0b**	**Sc 17_0c**	**Sc 17_0d**	**Sc 17_0e**	**Sc 17_0f**	**Sc17_0a– Sc 17_0**	**Sc 17_0b – Sc 17_0**	**Sc 17_0c – Sc 17_0**	**Sc 17_0e – Sc 17_0**
Number of free parameters	140	140	140	140	143	140	141				
Data	Base	Base	Base	Base	Base	Base					
Retlencomp	-1177.540	-1177.110	-1178.030	-1174.470	-1180.060	-1235.080	-1177.740	0.43	-0.490	3.070	-57.540
Totallencomp	-1249.120	-1260.300	-1248.190	-1261.890	-1258.200	-1192.770	-1249.490	-11.18	0.930	-12.770	56.350
Observer cpue	-12.551	-5.466	-6.545	-3.945	-12.776	-12.429	-12.364	7.085	6.006	8.606	0.122
RetdcatchB	7.502	8.109	7.283	8.009	7.581	7.034	7.501	0.607	-0.219	0.507	-0.468
TotalcatchB	18.260	18.609	18.199	18.611	18.419	17.723	18.267	0.349	-0.061	0.351	-0.537
GdiscdcatchB	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0	0	0	0
Rec_dev	7.571	7.435	6.880	7.804	5.937	7.966	7.552	-0.136	-0.691	0.233	0.395
Pot F_dev	0.013	0.014	0.013	0.015	0.013	0.013	0.013	0.001	0	0.002	0
Gbyc_F_dev	0.026	0.026	0.026	0.026	0.028	0.026	0.026	0	0	0	0
Tag	2692.200	2691.860	2692.350	2691.730	2692.220	2692.450	2692.200	-0.34	0.150	-0.470	0.250
Fishery cpue	-0.460	-0.565	-2.206	10.74300	-0.461	-0.347	-0.463	-0.105	-1.745	11.203	0.113
RetcatchN	0.007999	0.007584	0.007019	0.007569	0.005034	0.010917	0.0079	-0.00042	-0.00098	-0.00043	0.002918
Total	285.910	282.618	289.789	296.634	272.703	284.602	285.765	-3.292	3.879	10.724	-1.308

Table 22. 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	1.87	0.03
1986/87	1.68	0.03
1987/88	1.26	0.04
1988/89	1.37	0.03
1989/90	1.10	0.03
1990/91	0.84	0.04
1991/92	0.73	0.06
1992/93	0.70	0.06
1993/94	0.67	0.08
1994/95	0.84	0.05
1995/96	0.87	0.05
1996/97	0.85	0.04
1997/98	0.84	0.04
1998/99	1.12	0.03

Table 23. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_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	23				
1986/87	23	12				
1987/88	8	4				
1988/89	286	148				
1989/90	513	265			7	5
1990/91	205	106	190	89	6	5
1991/92	102	53	104	49	1	1
1992/93	76	39	94	44	3	2
1993/94	378	196	62	29	NA	NA
1994/95	367	190	119	56	2	2
1995/96	705	365	907	426	5	4
1996/97	817	423	1,061	498	8	6
1997/98	984	509	1,116	524	6	5
1998/99	613	317	638	300	14	11
1999/00	915	473	1,155	542	18	14
2000/01	1,029	532	1,205	566	11	8
2001/02	898	464	975	458	11	8
2002/03	628	325	675	317	16	12
2003/04	688	356	700	329	8	6
2004/05	449	232	488	229	9	7
2005/06	337	174	220	103	6	5
2006/07	337	174	321	151	14	11
2007/08	276	143	257	121	17	13
2008/09	318	164	258	121	19	14
2009/10	362	187	292	137	24	18
2010/11	328	170	222	104	13	10
2011/12	295	153	252	118	14	11
2012/13	288	149	241	113	18	14
2013/14	327	169	236	111	17	13
2014/15	305	158	219	103	18	14
2015/16	287	148	243	114	10	8
2016/17	392	203	253	119	12	9

Table 24. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_0a 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	23				
1986/87	23	12				
1987/88	8	4				
1988/89	286	148				
1989/90	513	266			7	5
1990/91	205	106	190	89	6	5
1991/92	102	53	104	49	1	1
1992/93	76	39	94	44	3	2
1993/94	378	196	62	29	NA	NA
1994/95	367	190	119	56	2	2
1995/96	705	365	907	427	5	4
1996/97	817	423	1,061	499	8	6
1997/98	984	510	1,116	525	6	5
1998/99	613	318	638	300	14	11
1999/00	915	474	1,155	543	18	14
2000/01	1,029	533	1,205	567	11	8
2001/02	898	465	975	459	11	8
2002/03	628	325	675	318	16	12
2003/04	688	357	700	329	8	6
2004/05	449	233	488	230	9	7
2005/06	337	175	220	104	6	5
2006/07	337	175	321	151	14	11
2007/08	276	143	257	121	17	13
2008/09	318	165	258	121	19	14
2009/10	362	188	292	137	24	18
2010/11	328	170	222	104	13	10
2011/12	295	153	252	119	14	11
2012/13	288	149	241	113	18	14
2013/14	327	169	236	111	17	13
2014/15	305	158	219	103	18	14
2015/16	287	149	243	114	10	8
2016/17	392	203	253	119	12	9

Table 25. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_0b 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	23				
1986/87	23	12				
1987/88	8	4				
1988/89	286	145				
1989/90	513	261			7	5
1990/91	205	104	190	92	6	5
1991/92	102	52	104	50	1	1
1992/93	76	39	94	45	3	2
1993/94	378	192	62	30	NA	NA
1994/95	367	187	119	57	2	2
1995/96	705	358	907	438	5	4
1996/97	817	415	1,061	513	8	6
1997/98	984	500	1,116	539	6	5
1998/99	613	312	638	308	14	11
1999/00	915	465	1,155	558	18	14
2000/01	1,029	523	1,205	582	11	8
2001/02	898	456	975	471	11	8
2002/03	628	319	675	326	16	12
2003/04	688	350	700	338	8	6
2004/05	449	228	488	236	9	7
2005/06	337	171	220	106	6	5
2006/07	337	171	321	155	14	11
2007/08	276	140	257	124	17	13
2008/09	318	162	258	125	19	15
2009/10	362	184	292	141	24	18
2010/11	328	167	222	107	13	10
2011/12	295	150	252	122	14	11
2012/13	288	146	241	116	18	14
2013/14	327	166	236	114	17	13
2014/15	305	155	219	106	18	14
2015/16	287	146	243	117	10	8
2016/17	392	199	253	122	12	9

Table 26. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_0c model fit to WAG data. NA: not available.

Year	Initial Input Retained Vessel-Days Sample Size (no)	Stage-2 Retained Effective Sample Size (no)	Initial Input Total Vessel-Days Sample Size (no)	Stage-2 Total Effective Sample Size (no)	Initial Input Groundfish Trip Sample Size (no)	Stage-2 Groundfish Effective Sample Size (no)
1985/86	45	22				
1986/87	23	11				
1987/88	8	4				
1988/89	286	142				
1989/90	513	255			7	5
1990/91	205	102	190	91	6	5
1991/92	102	51	104	50	1	1
1992/93	76	38	94	45	3	2
1993/94	378	188	62	30	NA	NA
1994/95	367	183	119	57	2	2
1995/96	705	351	907	433	5	4
1996/97	817	407	1,061	506	8	6
1997/98	984	490	1,116	533	6	5
1998/99	613	305	638	305	14	11
1999/00	915	456	1,155	551	18	14
2000/01	1,029	512	1,205	575	11	8
2001/02	898	447	975	465	11	8
2002/03	628	313	675	322	16	12
2003/04	688	343	700	334	8	6
2004/05	449	224	488	233	9	7
2005/06	337	168	220	105	6	5
2006/07	337	168	321	153	14	11
2007/08	276	137	257	123	17	13
2008/09	318	158	258	123	19	14
2009/10	362	180	292	139	24	18
2010/11	328	163	222	106	13	10
2011/12	295	147	252	120	14	11
2012/13	288	143	241	115	18	14
2013/14	327	163	236	113	17	13
2014/15	305	152	219	105	18	14
2015/16	287	143	243	116	10	8
2016/17	392	195	253	121	12	9

Table 27. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_0d 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	25				
1986/87	23	13				
1987/88	8	4				
1988/89	286	160				
1989/90	513	286			7	5
1990/91	205	114	190	92	6	5
1991/92	102	57	104	50	1	1
1992/93	76	42	94	45	3	2
1993/94	378	211	62	30	NA	NA
1994/95	367	205	119	57	2	2
1995/96	705	393	907	438	5	4
1996/97	817	456	1,061	512	8	6
1997/98	984	549	1,116	539	6	5
1998/99	613	342	638	308	14	11
1999/00	915	510	1,155	557	18	14
2000/01	1,029	574	1,205	582	11	8
2001/02	898	501	975	471	11	8
2002/03	628	350	675	326	16	12
2003/04	688	384	700	338	8	6
2004/05	449	250	488	236	9	7
2005/06	337	188	220	106	6	5
2006/07	337	188	321	155	14	11
2007/08	276	154	257	124	17	13
2008/09	318	177	258	125	19	14
2009/10	362	202	292	141	24	18
2010/11	328	183	222	107	13	10
2011/12	295	165	252	122	14	11
2012/13	288	161	241	116	18	14
2013/14	327	182	236	114	17	13
2014/15	305	170	219	106	18	14
2015/16	287	160	243	117	10	8
2016/17	392	219	253	122	12	9

Table 28. The initial input number of vessel-days/trips and Stage-2 effective sample sizes iteratively estimated by McAllister and Ianelli method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 17_0e 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	45				
1986/87	23	23				
1987/88	8	8				
1988/89	286	285				
1989/90	513	512			7	5
1990/91	205	204	190	82	6	4
1991/92	102	102	104	45	1	1
1992/93	76	76	94	41	3	2
1993/94	378	377	62	27	NA	NA
1994/95	367	366	119	51	2	1
1995/96	705	703	907	392	5	3
1996/97	817	815	1,061	459	8	6
1997/98	984	981	1,116	483	6	4
1998/99	613	611	638	276	14	10
1999/00	915	913	1,155	500	18	13
2000/01	1,029	1,026	1,205	521	11	8
2001/02	898	896	975	422	11	8
2002/03	628	626	675	292	16	11
2003/04	688	686	700	303	8	6
2004/05	449	448	488	211	9	6
2005/06	337	336	220	95	6	4
2006/07	337	336	321	139	14	10
2007/08	276	275	257	111	17	12
2008/09	318	317	258	112	19	13
2009/10	362	361	292	126	24	17
2010/11	328	327	222	96	13	9
2011/12	295	294	252	109	14	10
2012/13	288	287	241	104	18	13
2013/14	327	326	236	102	17	12
2014/15	305	304	219	95	18	13
2015/16	287	286	243	105	10	7
2016/17	392	391	253	109	12	8

Table 29. Parameter estimates and coefficient of variations (CV) with the 2016 MMB (MMB on 15 Feb 2017) for scenarios 17_0, 17_0a, 17_0b, and 17_0c for the golden king crab data from the WAG, 1985/86–2016/17. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 17_0		Scenario 17_0a		Scenario 17_0b		Scenario 17_0c		
Parameter	Estimate	CV	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	2.54	0.006	1.0, 4.5
ω_2 (growth incr. slope)	-7.81	0.22	-7.84	0.22	-7.74	0.22	-7.74	0.22	-12.0,-5.0
log_a (molt prob. slope)	-2.61	0.03	-2.61	0.03	-2.61	0.03	-2.61	0.03	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.00	4.95	0.001	4.95	0.001	3.869,5.05
σ (growth variability std)	3.69	0.03	3.68	0.03	3.69	0.03	3.69	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.40	0.02	3.40	0.02	3.40	0.01	3.40	0.01	0.,4.4
log_ total sel deltaθ, 2005–16	2.90	0.02	2.89	0.02	2.89	0.02	2.89	0.02	0.,4.4
log_ ret. sel deltaθ, 1985–16	1.78	0.02	1.77	0.02	1.78	0.02	1.78	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.86	0.002	4.86	0.002	4.87	0.002	4.87	0.002	4.0,5.0
log_tot sel θ_{50}, 2005–16	4.90	0.002	4.90	0.002	4.90	0.002	4.90	0.002	4.0,5.0
log_ret. sel θ_{50}, 1985–16	4.92	0.0002	4.92	0.00	4.92	0.0002	4.92	0.0002	4.0,5.0
log_β_r (rec.distribution par.)	-1.05	0.16	-1.06	0.16	-1.05	0.16	-1.05	0.16	-12.0, 12.0
logq2 (catchability 1995–04)	-0.06	1.18	-0.06	1.16	-0.09	0.75	-0.09	0.75	-9.0, 2.25
logq3 (catchability 2005–16)	-0.38	0.24	-0.39	0.22	-0.37	0.29	-0.37	0.29	-9.0, 2.25
log_mean_rec (mean rec.)	0.725	0.06	0.727	0.06	0.720	0.06	0.720	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.699	0.09	-0.709	0.09	-0.692	0.09	-0.692	0.09	-15.0, -0.01
log_mean_Fground (GF byc. F)	-8.371	0.10	-8.376	0.10	-8.364	0.10	-8.364	0.10	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.019	0.38	0.012	0.47	0.054	0.34	0.054	0.34	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.025	0.60	0.025	0.62	0.013	0.58	0.013	0.58	0.0,1.0
2016 MMB	6,269	0.17	6,280	0.16	5,884	0.22	5,884	0.22	

Table 30. Parameter estimates and coefficient of variations (CV) with the 2016 MMB (MMB on 15 Feb 2017) for scenarios 17_0d and 17_0e for the golden king crab data from the WAG, 1985/86–2016/17. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

	Scenario 17_0d		**Scenario 17_0e**		
Parameter	Estimate	CV	Estimate	CV	Limits
log_ω_1 (growth incr. intercept)	2.54	0.006	2.54	0.006	1.0, 4.5
ω_2 (growth incr. slope)	-7.74	0.22	-7.29	0.23	-12.0,-5.0
log_a (molt prob. slope)	-2.62	0.03	-2.67	0.02	-4.61,-1.39
log_b (molt prob. L50)	4.95	0.001	4.95	0.00	3.869,5.05
σ (growth variability std)	3.68	0.03	3.69	0.03	0.1,12.0
log_total sel deltaθ, 1985–04	3.39	0.01	3.36	0.01	0.,4.4
log_ total sel deltaθ, 2005–12	2.90	0.03			0.,4.4
log_ total sel deltaθ, 2013–16 or 2005–16	2.92	0.03	2.89	0.02	0.,4.4
log_ ret. sel deltaθ, 1985–16	1.78	0.02	1.78	0.02	0.,4.4
log_tot sel θ_{50}, 1985–04	4.87	0.002	4.87	0.002	4.0,5.0
log_tot sel θ_{50}, 2005–12	4.89	0.002			4.0,5.0
log_tot sel θ_{50}, 2013–16 or 2005–16	4.92	0.003	4.90	0.002	4.0,5.0
log_ret. sel θ_{50}, 1985–16	4.92	0.00	4.92	0.00	4.0,5.0
log_β_r (rec.distribution par.)	-1.06	0.15	-1.10	0.15	-12.0, 12.0
Logq1 (catchability 1985–04)	-0.067	1.02	-0.04	1.62	-9.0, 2.25
Logq3 (catchability 2005–12)	-0.424	0.21			-9.0, 2.25
Logq2 (catchability 2013–16 or 2005–16)	-0.098	1.80	-0.41	0.20	-9.0, 2.25
log_mean_rec (mean rec.)	0.719	0.06	0.717	0.06	0.01, 5.0
log_mean_Fpot (Pot fishery F)	-0.681	0.09	-0.710	0.08	-15.0, -0.01
log_mean_Fground (GF byc. F)	-8.364	0.10	-8.390	0.10	-15.0, -1.6
σ_e^2 (observer CPUE additional var)	0.023	0.38	0.020	0.39	0.0, 0.15
σ_e^2 (fishery CPUE additional var)	0.026	0.57	0.037	0.53	0.0,1.0
2016 MMB	6,136	0.23	6,355	0.17	

Table 31. 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 17_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 1985–2017. 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} =17,827 $MMB_{35\%}$=5,138			
1985	3.75			8,812	0.11
1986	3.41	10,641	0.05	8,387	0.08
1987	2.69	8,164	0.05	5,971	0.06
1988	1.92	7,496	0.04	5,553	0.05
1989	2.55	6,432	0.04	4,896	0.04
1990	1.85	4,468	0.05	3,106	0.06
1991	1.56	4,172	0.05	2,870	0.05
1992	2.07	3,906	0.05	2,810	0.05
1993	1.60	4,025	0.04	2,923	0.05
1994	1.96	4,613	0.03	3,493	0.03
1995	1.88	3,924	0.03	2,833	0.04
1996	1.72	3,925	0.04	2,785	0.04
1997	1.84	3,934	0.04	2,828	0.04
1998	1.90	4,002	0.04	2,909	0.04
1999	2.23	4,318	0.04	3,184	0.04
2000	2.49	4,351	0.04	3,122	0.04
2001	2.54	4,507	0.04	3,129	0.04
2002	2.48	4,943	0.05	3,451	0.05
2003	1.78	5,489	0.05	3,961	0.05
2004	2.27	5,810	0.06	4,442	0.06
2005	2.29	5,913	0.06	4,626	0.06
2006	2.41	6,194	0.06	4,797	0.06
2007	1.71	6,698	0.06	5,224	0.06
2008	1.48	6,863	0.05	5,502	0.06
2009	1.89	6,658	0.05	5,539	0.05
2010	1.59	6,263	0.05	5,173	0.05
2011	1.14	5,972	0.05	4,864	0.05
2012	1.80	5,465	0.05	4,521	0.05
2013	2.29	4,850	0.05	3,903	0.05
2014	1.59	4,627	0.07	3,421	0.07
2015	3.63	4,719	0.09	3,491	0.08
2016	2.23	5,204	0.13	3,650	0.12
2017	2.06	6,269	0.17		

Table 32. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) CV for scenario 17_0a 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 1985–2017. 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**
		MMBeq =17,862 *MMB35%*=5,173			
1985	3.76			8,815	0.11
1986	3.41	10,646	0.05	8,388	0.08
1987	2.69	8,170	0.05	5,974	0.06
1988	1.92	7,499	0.04	5,556	0.05
1989	2.55	6,435	0.04	4,898	0.04
1990	1.85	4,471	0.04	3,108	0.06
1991	1.56	4,175	0.05	2,873	0.05
1992	2.06	3,908	0.05	2,812	0.05
1993	1.60	4,022	0.04	2,924	0.05
1994	1.99	4,605	0.03	3,487	0.03
1995	1.89	3,921	0.03	2,826	0.04
1996	1.72	3,940	0.04	2,791	0.04
1997	1.85	3,957	0.04	2,846	0.04
1998	1.91	4,026	0.04	2,931	0.04
1999	2.23	4,344	0.04	3,206	0.04
2000	2.54	4,379	0.04	3,147	0.04
2001	2.59	4,544	0.04	3,154	0.04
2002	2.50	5,013	0.05	3,495	0.05
2003	1.81	5,592	0.05	4,038	0.05
2004	2.26	5,932	0.05	4,543	0.05
2005	2.21	6,044	0.06	4,744	0.06
2006	2.42	6,295	0.06	4,913	0.06
2007	1.69	6,755	0.05	5,299	0.06
2008	1.48	6,898	0.05	5,545	0.06
2009	1.91	6,668	0.05	5,557	0.05
2010	1.61	6,268	0.05	5,175	0.05
2011	1.13	5,987	0.05	4,867	0.05
2012	1.81	5,488	0.05	4,536	0.05
2013	2.28	4,872	0.05	3,922	0.05
2014	1.59	4,650	0.06	3,443	0.06
2015	3.62	4,739	0.08	3,510	0.08
2016	2.23	5,218	0.11	3,666	0.10
2017	2.07	6,280	0.16		

Table 33. 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 17_0b 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 1985–2017. 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
		MMBeq =17,730 $MMB_{35\%}$=5,104			
1985	3.89			8,932	0.09
1986	3.57	10,650	0.05	8,419	0.07
1987	2.65	8,254	0.05	5,995	0.06
1988	1.80	7,644	0.04	5,650	0.04
1989	2.36	6,540	0.04	5,019	0.04
1990	1.84	4,474	0.04	3,175	0.05
1991	1.65	4,091	0.05	2,841	0.05
1992	2.08	3,828	0.05	2,725	0.05
1993	1.56	3,985	0.04	2,857	0.05
1994	1.97	4,575	0.03	3,451	0.03
1995	1.87	3,879	0.03	2,792	0.03
1996	1.73	3,885	0.03	2,745	0.03
1997	1.85	3,895	0.04	2,787	0.04
1998	1.91	3,974	0.04	2,874	0.04
1999	2.25	4,301	0.04	3,158	0.04
2000	2.51	4,346	0.04	3,107	0.04
2001	2.55	4,519	0.04	3,126	0.04
2002	2.48	4,971	0.05	3,463	0.05
2003	1.76	5,525	0.05	3,985	0.05
2004	2.29	5,840	0.06	4,468	0.06
2005	2.33	5,937	0.06	4,645	0.06
2006	2.42	6,235	0.06	4,818	0.07
2007	1.70	6,758	0.06	5,264	0.06
2008	1.47	6,918	0.05	5,551	0.06
2009	1.85	6,698	0.05	5,581	0.05
2010	1.58	6,282	0.05	5,201	0.05
2011	1.13	5,965	0.05	4,867	0.05
2012	1.78	5,444	0.05	4,503	0.05
2013	2.16	4,817	0.06	3,876	0.06
2014	1.48	4,546	0.08	3,377	0.08
2015	3.43	4,547	0.12	3,382	0.11
2016	2.19	4,921	0.17	3,455	0.16
2017	2.05	5,884	0.22		

Table 34. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) CV for scenario 17_0c 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 1985–2017. 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} =17,720 $MMB_{35\%}$=5,123			
1985	3.03			8,932	0.09
1986	3.64	10,650	0.05	8,419	0.07
1987	2.56	8,254	0.05	5,995	0.06
1988	1.87	7,644	0.04	5,650	0.04
1989	2.59	6,540	0.04	5,019	0.04
1990	1.87	4,474	0.04	3,175	0.05
1991	1.57	4,091	0.05	2,841	0.05
1992	1.86	3,828	0.05	2,725	0.05
1993	1.57	3,985	0.04	2,857	0.05
1994	1.97	4,575	0.03	3,451	0.03
1995	1.85	3,879	0.03	2,792	0.03
1996	1.71	3,885	0.03	2,745	0.03
1997	1.87	3,895	0.04	2,787	0.04
1998	1.89	3,974	0.04	2,874	0.04
1999	2.23	4,301	0.04	3,158	0.04
2000	2.48	4,346	0.04	3,107	0.04
2001	2.52	4,519	0.04	3,126	0.04
2002	2.45	4,971	0.05	3,463	0.05
2003	1.75	5,525	0.05	3,985	0.05
2004	2.32	5,840	0.06	4,468	0.06
2005	2.40	5,937	0.06	4,645	0.06
2006	2.37	6,235	0.06	4,818	0.07
2007	1.71	6,758	0.06	5,264	0.06
2008	1.49	6,918	0.05	5,551	0.06
2009	1.84	6,698	0.05	5,581	0.05
2010	1.61	6,282	0.05	5,201	0.05
2011	1.18	5,965	0.05	4,867	0.05
2012	1.80	5,444	0.05	4,503	0.05
2013	2.20	4,817	0.06	3,876	0.06
2014	1.55	4,546	0.08	3,377	0.08
2015	3.60	4,547	0.12	3,382	0.11
2016	2.23	4,921	0.17	3,455	0.16
2017	2.08	5,884	0.22		

Table 35. 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 17_0d 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 1985–2017. 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
		MMBeq =17,710 $MMB_{35\%}$=5,108			
1985	3.68			8,888	0.10
1986	3.43	10,707	0.05	8,462	0.07
1987	2.68	8,202	0.05	6,010	0.06
1988	1.91	7,530	0.04	5,574	0.05
1989	2.56	6,457	0.04	4,911	0.04
1990	1.85	4,489	0.04	3,116	0.06
1991	1.56	4,198	0.04	2,882	0.05
1992	2.05	3,934	0.05	2,826	0.05
1993	1.58	4,047	0.04	2,941	0.05
1994	1.97	4,619	0.03	3,501	0.03
1995	1.89	3,920	0.03	2,828	0.03
1996	1.74	3,922	0.04	2,774	0.04
1997	1.86	3,936	0.04	2,818	0.04
1998	1.91	4,012	0.04	2,906	0.04
1999	2.26	4,336	0.04	3,188	0.04
2000	2.54	4,382	0.04	3,135	0.04
2001	2.62	4,564	0.04	3,156	0.04
2002	2.60	5,042	0.05	3,506	0.05
2003	1.83	5,654	0.05	4,061	0.05
2004	2.30	6,040	0.06	4,608	0.06
2005	2.21	6,171	0.06	4,843	0.06
2006	2.40	6,428	0.06	5,029	0.06
2007	1.64	6,871	0.05	5,411	0.06
2008	1.39	6,979	0.05	5,634	0.05
2009	1.71	6,688	0.05	5,606	0.05
2010	1.37	6,176	0.04	5,154	0.05
2011	1.08	5,723	0.04	4,720	0.05
2012	1.80	5,082	0.05	4,224	0.05
2013	2.09	4,424	0.06	3,513	0.06
2014	1.57	4,169	0.08	3,014	0.08
2015	4.05	4,211	0.11	3,039	0.11
2016	2.26	4,829	0.18	3,195	0.16
2017	2.05	6,136	0.23		

Table 36. 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 17_0e 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 1985–2017. 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
		MMBeq =18,001 *MMB35%*=5,201			
1985	3.33			9,215	0.08
1986	3.56	10,884	0.04	8,762	0.06
1987	2.62	8,250	0.04	6,106	0.04
1988	1.91	7,581	0.04	5,590	0.04
1989	2.68	6,476	0.04	4,903	0.04
1990	1.89	4,534	0.04	3,106	0.05
1991	1.54	4,296	0.04	2,908	0.05
1992	2.00	4,046	0.04	2,895	0.05
1993	1.54	4,139	0.04	3,022	0.04
1994	1.90	4,675	0.03	3,558	0.03
1995	1.86	3,931	0.03	2,848	0.03
1996	1.86	3,884	0.03	2,743	0.03
1997	1.77	3,906	0.04	2,753	0.03
1998	1.88	4,003	0.03	2,865	0.03
1999	2.20	4,285	0.03	3,140	0.03
2000	2.51	4,297	0.04	3,057	0.04
2001	2.67	4,437	0.04	3,035	0.04
2002	2.76	4,905	0.05	3,347	0.05
2003	1.95	5,573	0.05	3,907	0.05
2004	2.34	6,071	0.05	4,531	0.06
2005	2.25	6,289	0.05	4,875	0.06
2006	2.30	6,598	0.05	5,137	0.06
2007	1.65	7,039	0.05	5,561	0.05
2008	1.44	7,104	0.05	5,758	0.05
2009	1.86	6,820	0.04	5,710	0.05
2010	1.66	6,363	0.04	5,277	0.05
2011	1.02	6,048	0.04	4,914	0.04
2012	1.90	5,522	0.04	4,563	0.04
2013	2.48	4,868	0.05	3,910	0.05
2014	1.58	4,714	0.06	3,426	0.06
2015	3.58	4,878	0.09	3,561	0.08
2016	2.21	5,336	0.13	3,756	0.12
2017	2.05	6,355	0.17		

Table 37. Negative log-likelihood values of the fits for scenarios (Sc) 17_0 (base), 17_0a (observer CPUE by VAST), 17_0b (observer and fishtick CPUE variable selection by CAIC), 17_0c (Year:Area interaction for observer and fishtick CPUE), 17_0d (three total selectivity and catchability for 1985–04, 2005–12, and 2013–16 time periods), and 17_0e (Stage 2 effective sample sizes by McAllister and Ianelli method) for golden king crab in the WAG. Differences in likelihood values are given for scenarios with the same number of data points (base) and free parameters. Likelihood components with zero entry in the entire rows are omitted. RetdcatchB= retained catch biomass.

Likelihood Component	**Sc 17_0**	**Sc 17_0a**	**Sc 17_0b**	**Sc 17_0c**	**Sc 17_0d**	**Sc 17_0e**	**Sc17_0a– Sc 17_0**	**Sc 17_0b – Sc 17_0**	**Sc 17_0c – Sc 17_0**	**Sc 17_0e – Sc 17_0**
Number of free parameters	140	140	140	140	143	140				
Data	Base	Base	Base	Base	Base	Base				
Retlencomp	-1146.700	-1147.140	-1143.350	-1142.310	-1161.250	-1243.980	-0.440	3.350	4.390	-97.280
Totallencomp	-1389.720	-1389.680	-1395.850	-1396.210	-1396.220	-1370.230	0.040	-6.130	-6.490	19.490
Observer cpue	-11.773	-14.747	-0.680	15.078	-10.040	-11.199	-2.974	11.093	26.851	0.574
RetdcatchB	4.721	4.854	4.853	5.858	4.846	4.956	0.133	0.132	1.137	0.235
TotalcatchB	43.783	43.745	43.936	44.348	43.849	47.086	-0.038	0.153	0.565	3.303
GdiscdcatchB	0.001	0.001	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000
Rec_dev	5.243	5.248	5.254	4.797	6.091	6.103	0.005	0.011	-0.446	0.860
Pot F_dev	0.026	0.026	0.026	0.027	0.027	0.026	0.000	0.000	0.001	0.000
Gbyc_F_dev	0.037	0.037	0.037	0.037	0.038	0.037	0.000	0.000	0.000	0.000
Tag	2693.630	2693.450	2693.710	2693.780	2693.910	2695.840	-0.180	0.080	0.150	2.210
Fishery cpue	-5.155	-5.207	-9.456	17.685	-5.004	-2.783	-0.052	-4.301	22.840	2.371
RetcatchN	0.002129	0.002068	0.001757	0.000874	0.002098	0.005553	-0.000061	-0.000372	-0.001255	0.003424
Total	194.090	190.591	198.490	243.086	176.255	125.863	-3.499	4.400	48.996	-68.227

Table 38. Predicted total catch OFL (t), $MMB_{35\%}$, and terminal MMB ratio for various scenarios for EAG and WAG, respectively. Sc = scenario; MMB_{2016}/ $MMB_{initial}$ = ratio of terminal MMB relative to initial MMB (= MMB_{1960}). Note: MMB_{2016} is estimated on Feb 15, 2017.

	EAG			WAG				
Sc	**Tier 3 Total Catch OFL (t)**	***$MMB_{35\%}$* (t)**	**MMB_{2016} / $MMB_{initial}$**	**Tier 3 Total Catch OFL (t)**	***$MMB_{35\%}$* (t)**	**MMB_{2016} / $MMB_{initial}$**	***M* yr^{-1}**	**Remarks**
17_0	3,918	6,954	0.68	1,597	5,138	0.42	0.21	Base scenario: 1960 equilibrium initial size composition, 1995/96–2016/17 observer CPUE, 1985/86–1998/99 Fishery CPUE, time period for mean R calculation for equilibrium initial abundance and MMB_{MSY} reference point calculations 1987–2012, knife-edge maturity≥111 mm CL, Francis re-weighting,
17_0a	3,959	7,063	0.67	1,589	5,173	0.42	0.21	Observer CPUE standardization by VAST
17_0b	3,415	6,794	0.61	1,492	5,104	0.40	0.21	Variable selection for CPUE standardization by CAIC
17_0c	4,046	7,091	0.67	1,551	5,123	0.40	0.21	Year:Area interaction for CPUE standardization
17_0d	2,481	6,688	0.46	1,482	5,108	0.42	0.21	Three catchability and asymptotic total selectivity for 1985/86–2004/05, 2005/06–2012/13, and 2013/14–2016/17
17_0e	3,974	7,014	0.67	1,608	5,201	0.43	0.21	McAllister and Ianelli method of re-weighting
17_0f	3,892	6,946	0.67				0.21	EAG fishery independent pot survey (2015/16-2016/17) CPUE indices as an additional likelihood component.
May 2017 Sc9	4,486	7,048	0.60	1,562	4,507	0.34	0.224	2017 assessment. Knife-edge maturity ≥111 mm CL

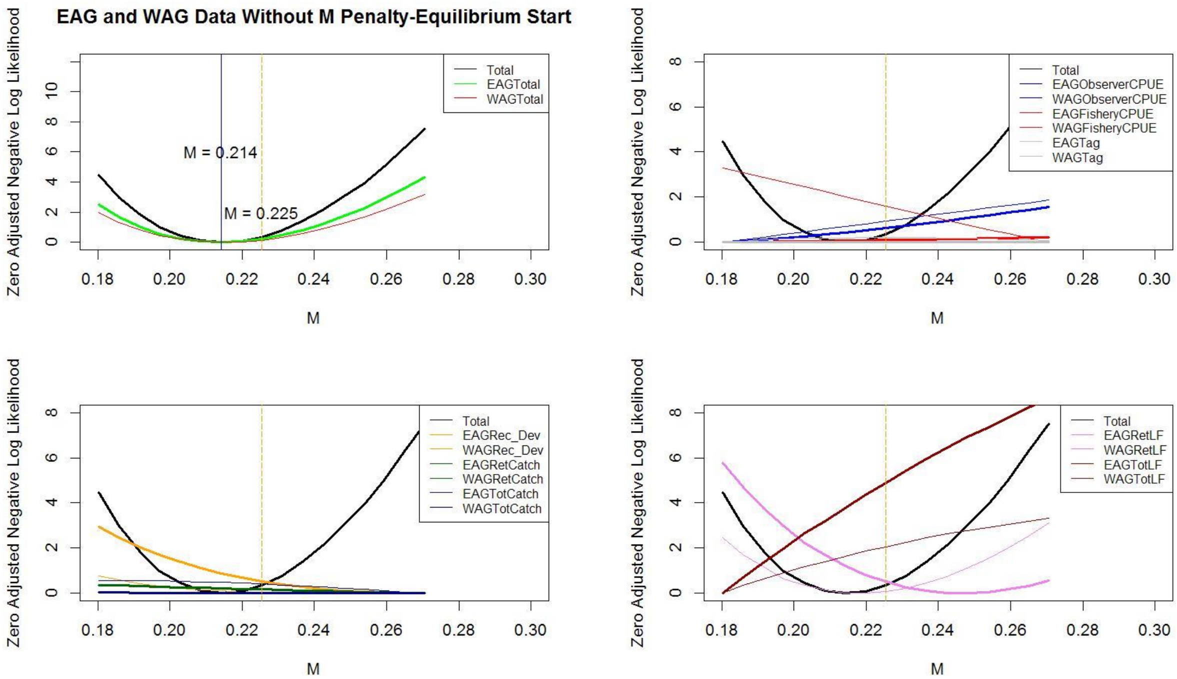


Figure 1. Total and components negative log-likelihoods vs. *M* for **scenario 0b** model fit for EAG and WAG combined data. The *M* estimate was obtained without any *M* penalty. The *M* estimate was 0.2254 yr^{-1} ($\pm$ 0.0199 yr^{-1}). The negative log likelihood values were estimated for fixed proportions of estimated *M* without using an *M* penalty and they were zero adjusted. The *M* profile indicates an *M* value of 0.2142 yr^{-1} at the minima of negative total likelihood for combined data as well as individual date sets. Hence an *M* value of 0.21 yr^{-1} was used in all scenarios.

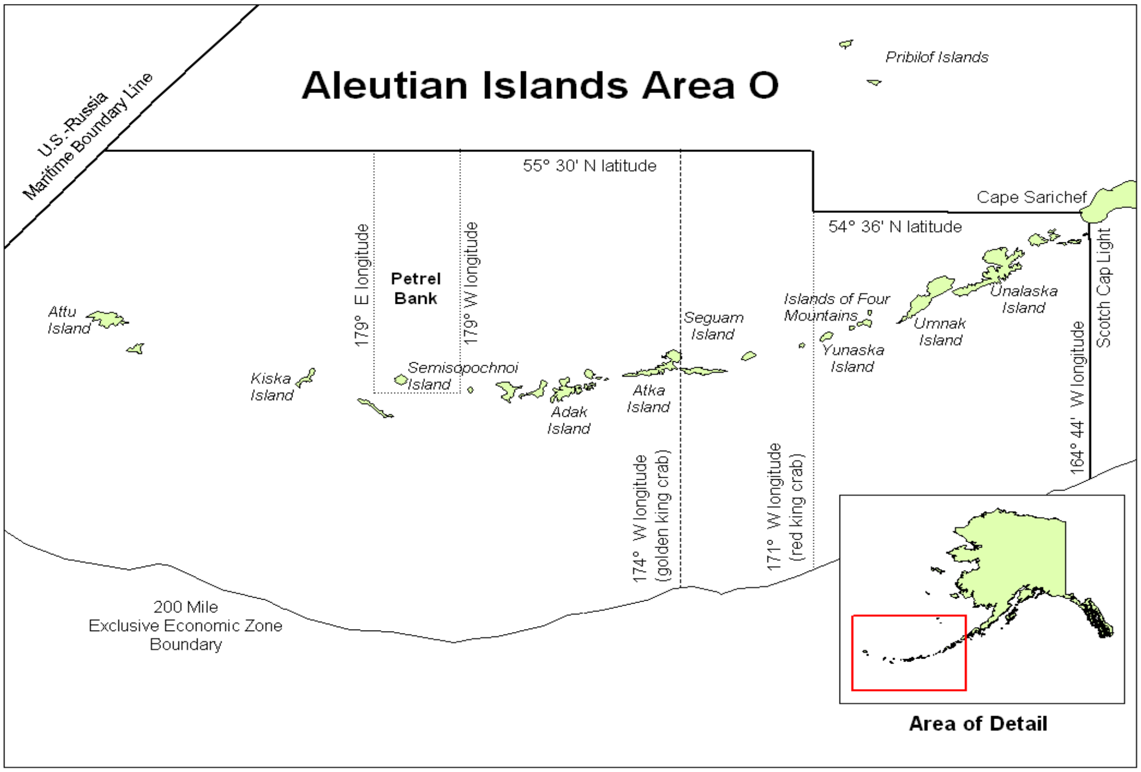


Figure 2. Aleutian Islands, Area O, red and golden king crab management area (from Leon et al. 2017).

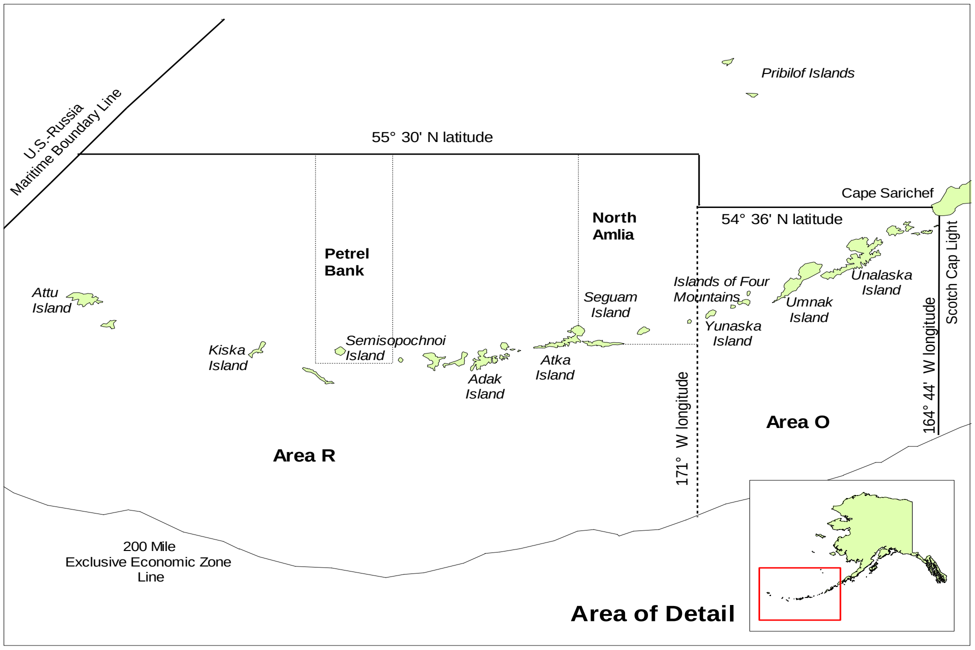


Figure 3. Adak (Area R) and Dutch Harbor (Area O) king crab registration area and districts, 1984/85–1995/96 seasons (Leon et al., 2017).

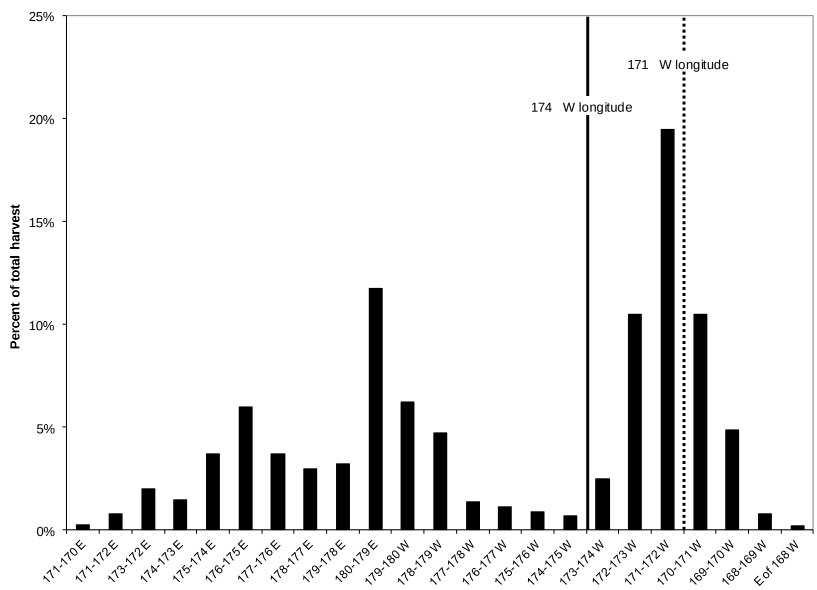


Figure 4. Percent of total 1981/82–1995/96 golden king crab retained catch weight (harvest) from one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor 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).

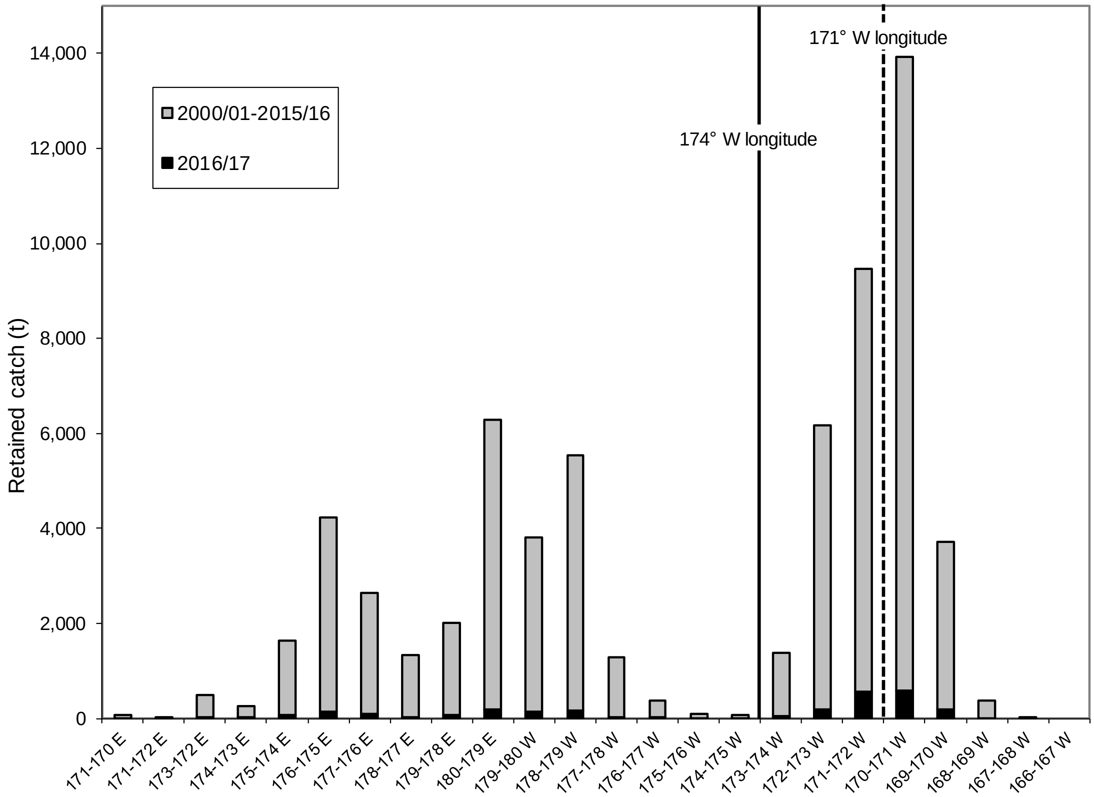


Figure 5. Retained catch (t) of golden king crab within one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2016/17commercial fishery seasons; solid line denotes the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden king 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).

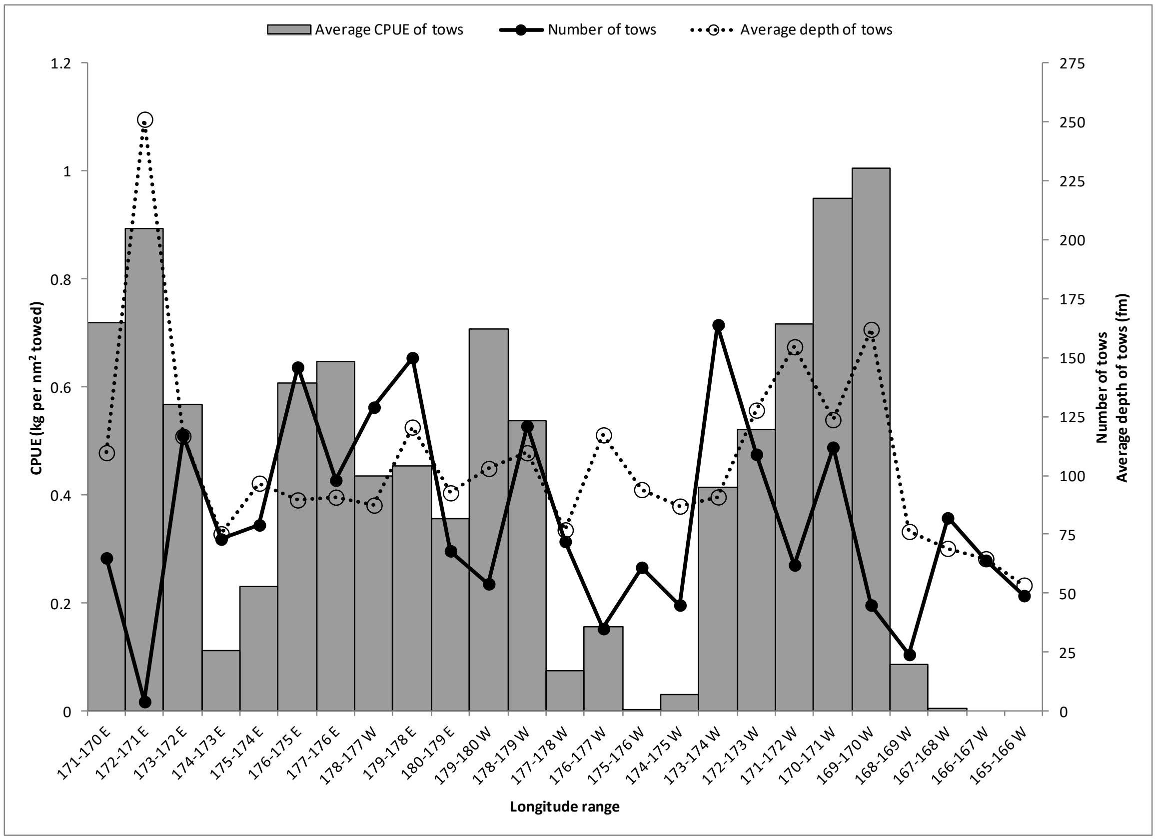


Figure 6. Average golden king crab CPUE (kg/nm2) for tows, number of tows, and average depth of tows from one-degree longitude intervals during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys; preliminary summary of data obtained on 1 April 2013 from http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm.

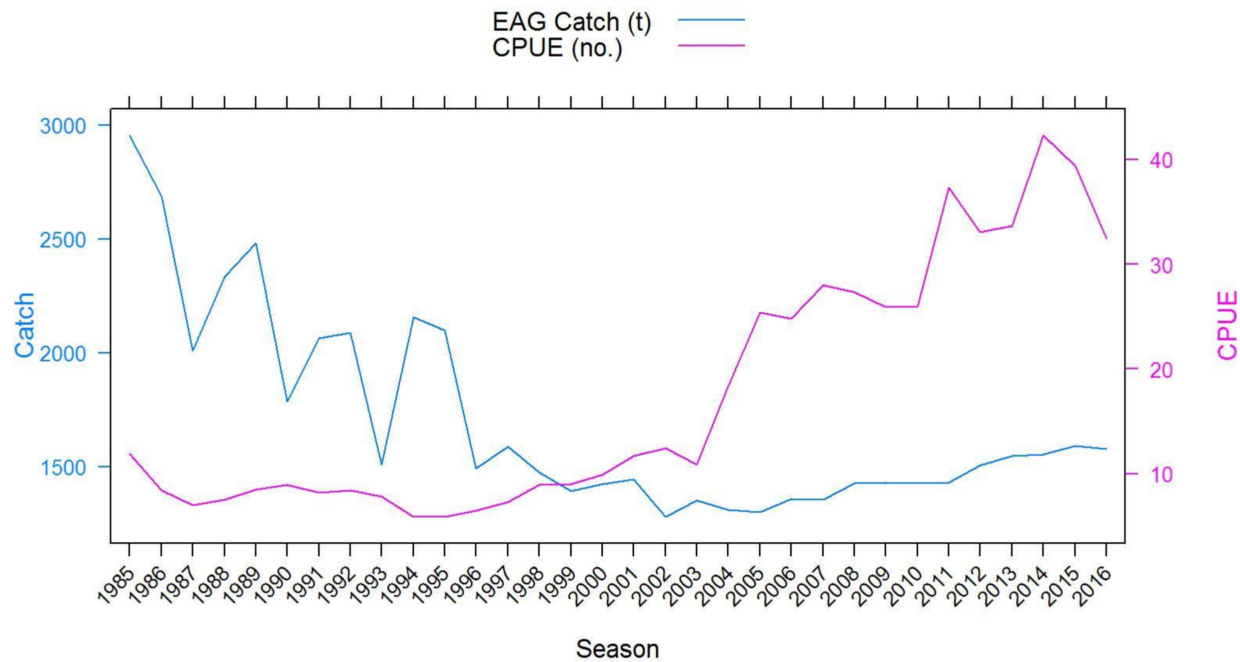


Figure 7. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the EAG, 1985/86–2016/17 fisheries (note: 1985 refers to the 1985/86 fishing year).

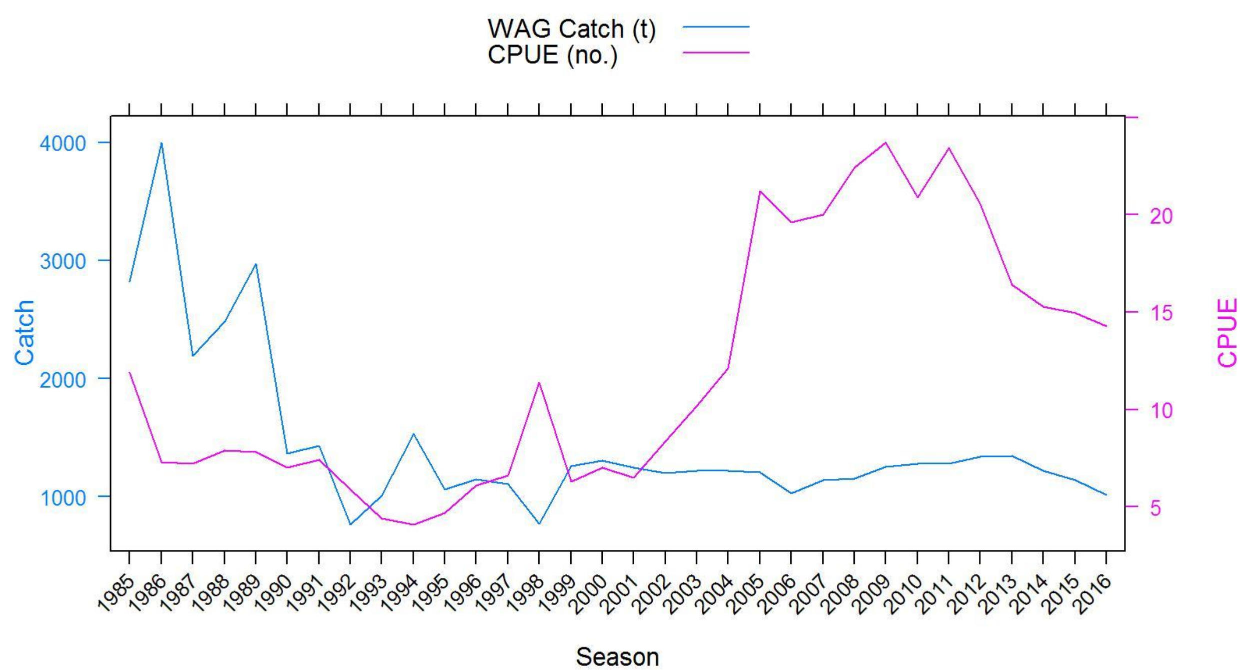


Figure 8. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the WAG, 1985/86–2016/17 fisheries (note: 1985 refers to the 1985/86 fishing year).

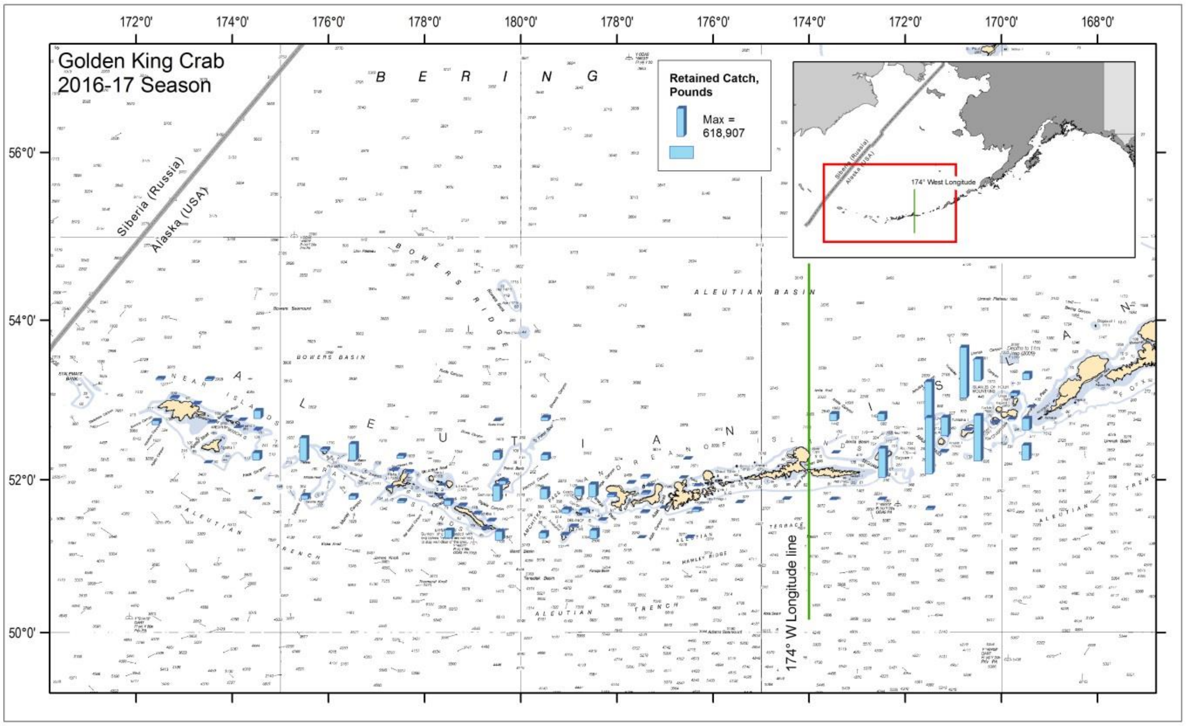


Figure 9. Catch distribution by statistical area.in 2016/17.

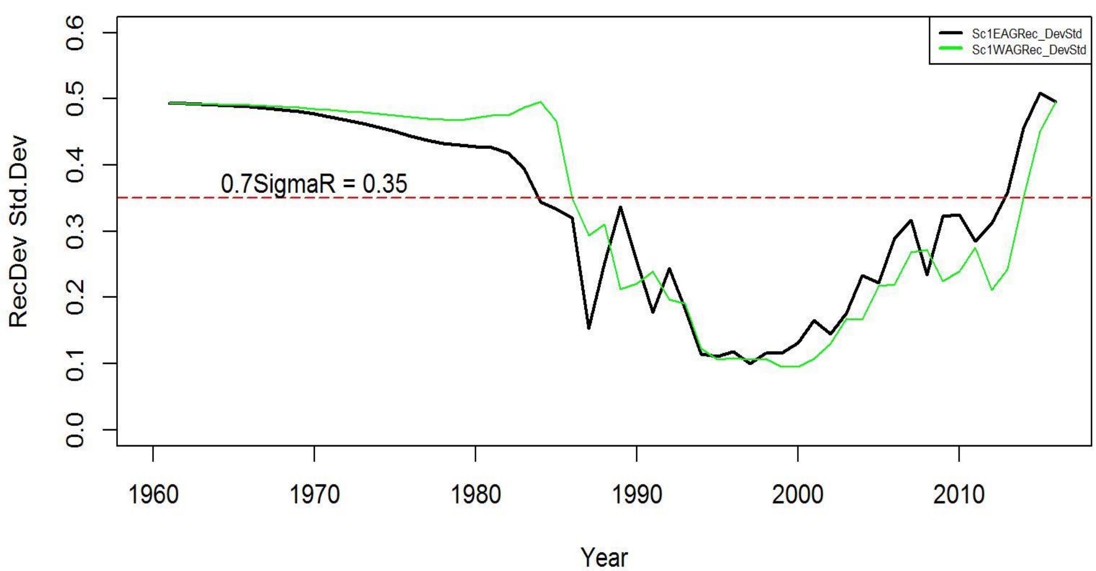


Figure 10. Standard deviation of recruit_dev plot for EAG and WAG. The mean recruit for years with standard deviation less than 0.7 sigma R was used to initialize model. We selected the 1987–2012 period for mean recruit estimation.

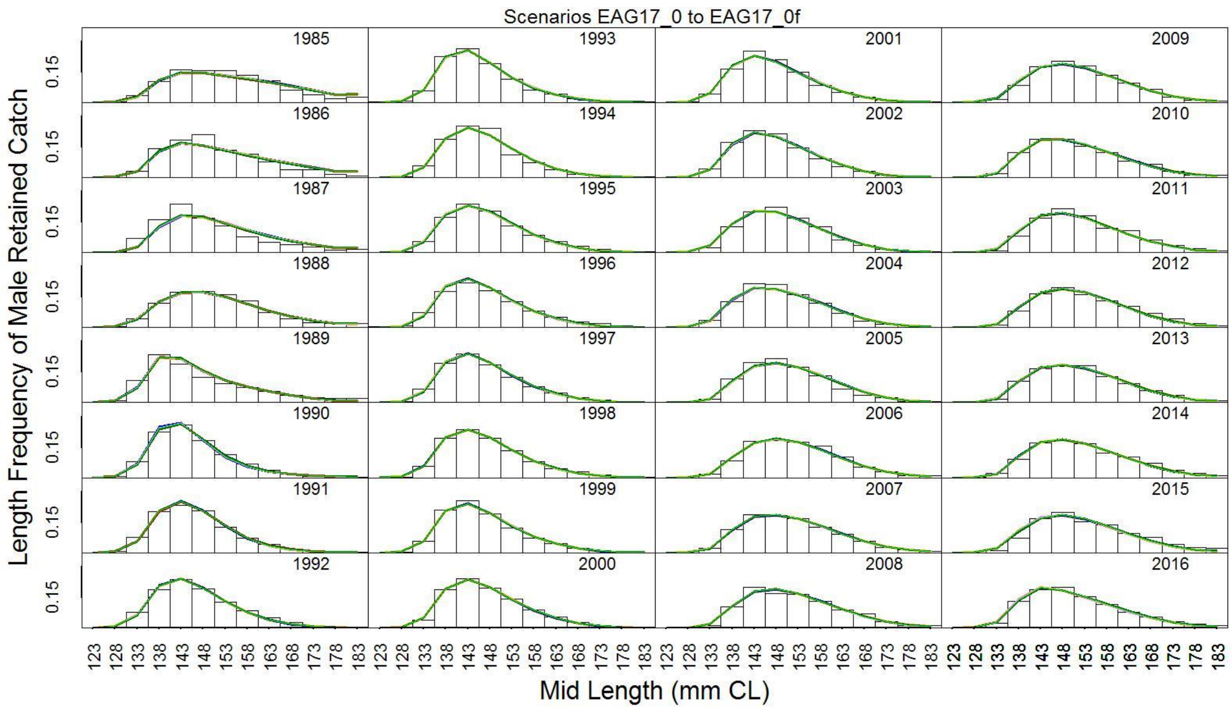


Figure 11. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions under scenarios 17_0 (black line), 17_0a (orange line), 17_0b (red line), 17_0c (blue line), 17_0d (violet line), 17_0e (dark green line), and 17_0f (green line) for golden king crab in the EAG, 1985/86 to 2016/17. This color scheme is used in all other graphs.

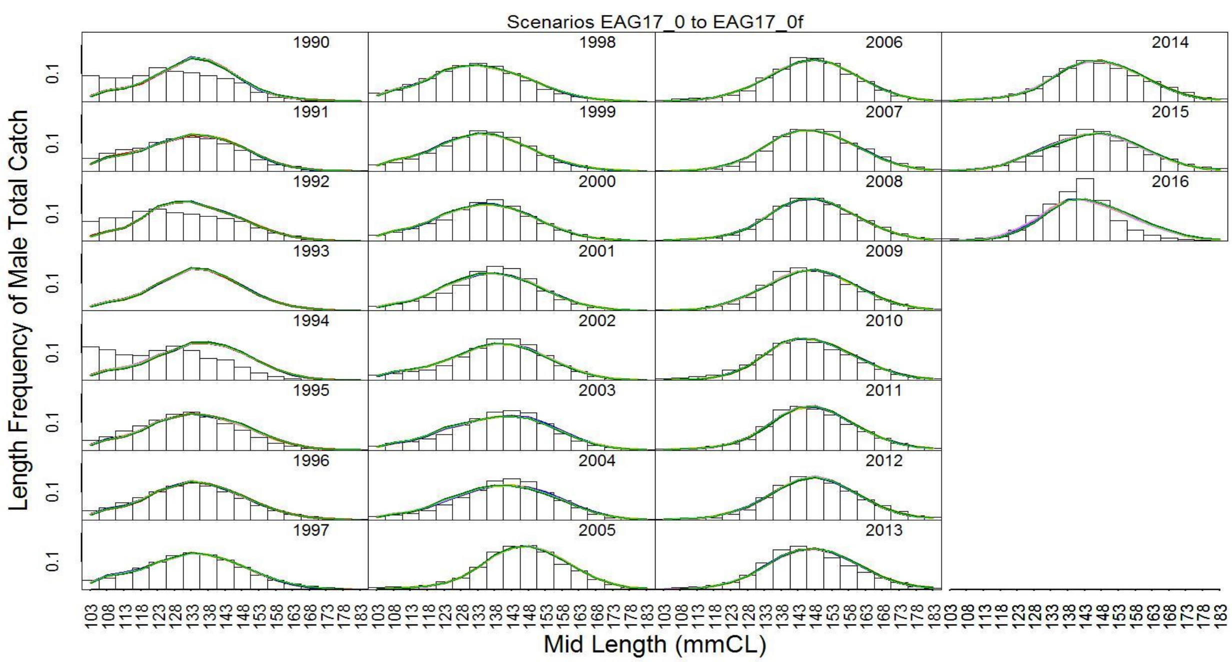


Figure 12. Predicted (line) vs. observed (bar) total catch relative length frequency distributions under scenarios 17_0 to 17_0f for golden king crab in the EAG, 1990/91 to 2016/17.

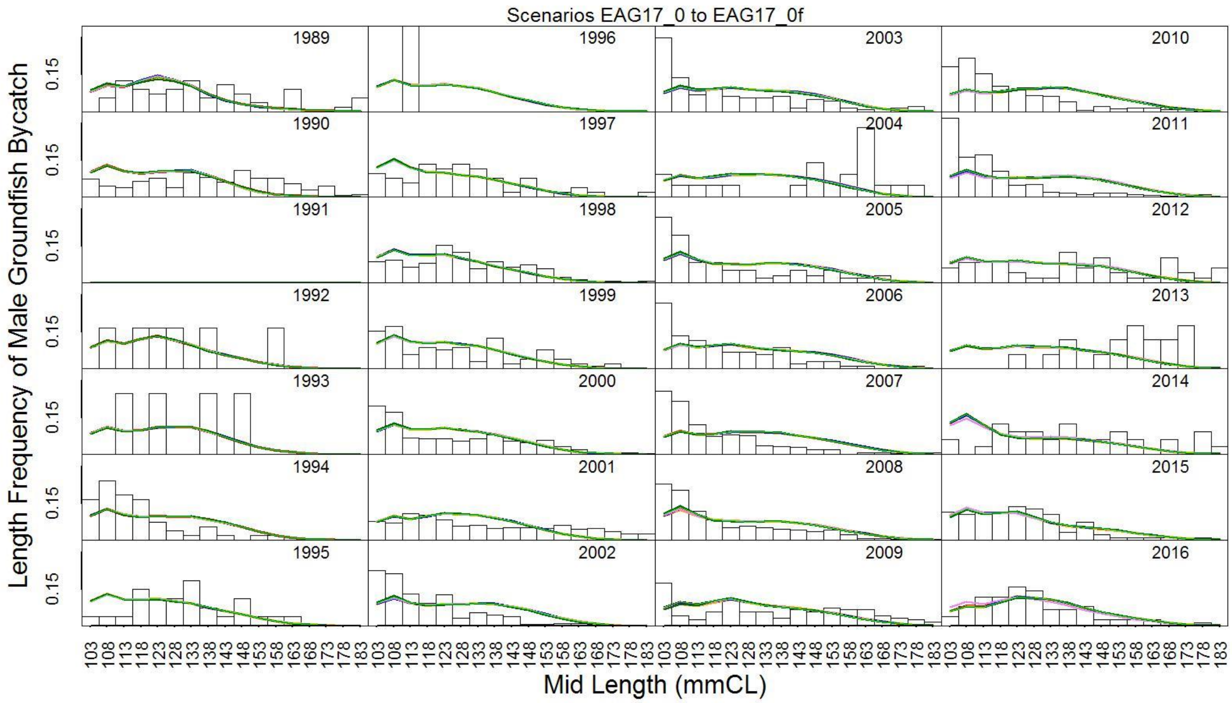
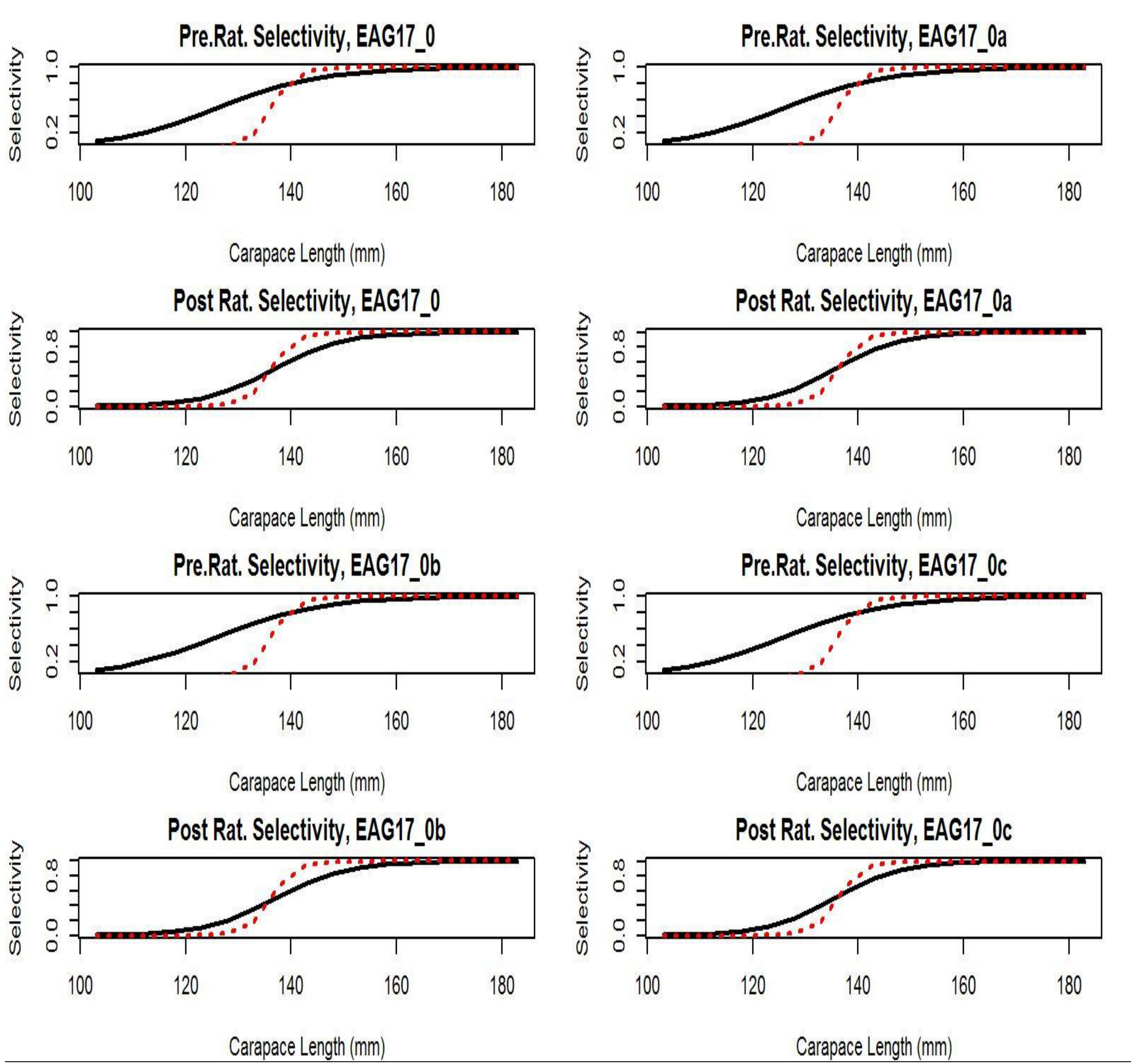
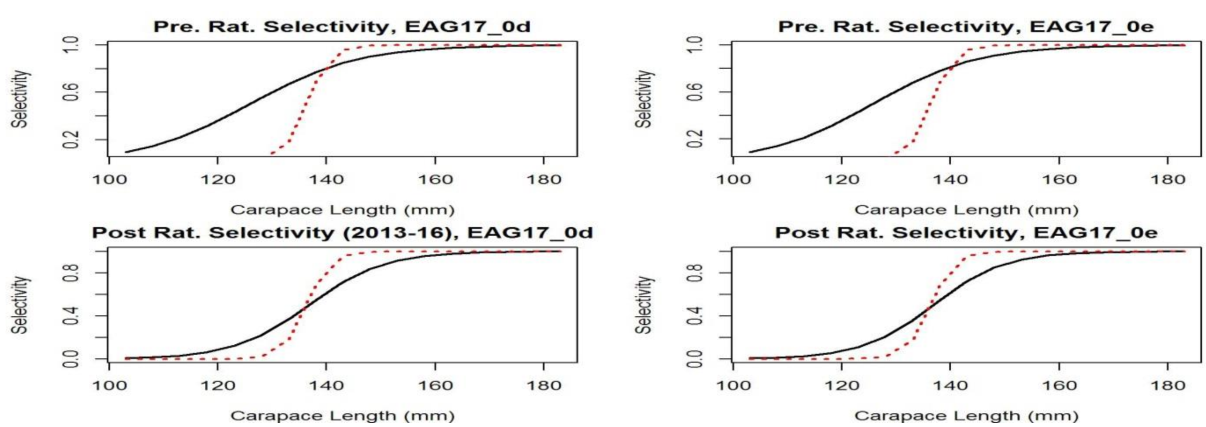


Figure 13. Predicted (line) vs. observed (bar) groundfish (or trawl) discarded bycatch relative length frequency distributions under scenarios 17_0 to 17_0f for golden king crab in the EAG, 1989/90 to 2016/17. Note that this data set was not used in the model fitting.


Pre.Rat. Selectivity, EAG17_0
Pre.Rat. Selectivity, EAG17_0a
Post Rat. Selectivity, EAG17_0
Post Rat. Selectivity, EAG17_0a
Pre.Rat. Selectivity, EAG17_0b
Pre.Rat. Selectivity, EAG17_0c
Post Rat. Selectivity, EAG17_0b
Post Rat. Selectivity, EAG17_0c
Selectivity
Carapace Length (mm)


Pre. Rat. Selectivity, EAG17_0d
Pre. Rat. Selectivity, EAG17_0e
Post Rat. Selectivity (2013-16), EAG17_0d
Post Rat. Selectivity, EAG17_0e
Selectivity
Carapace Length (mm)

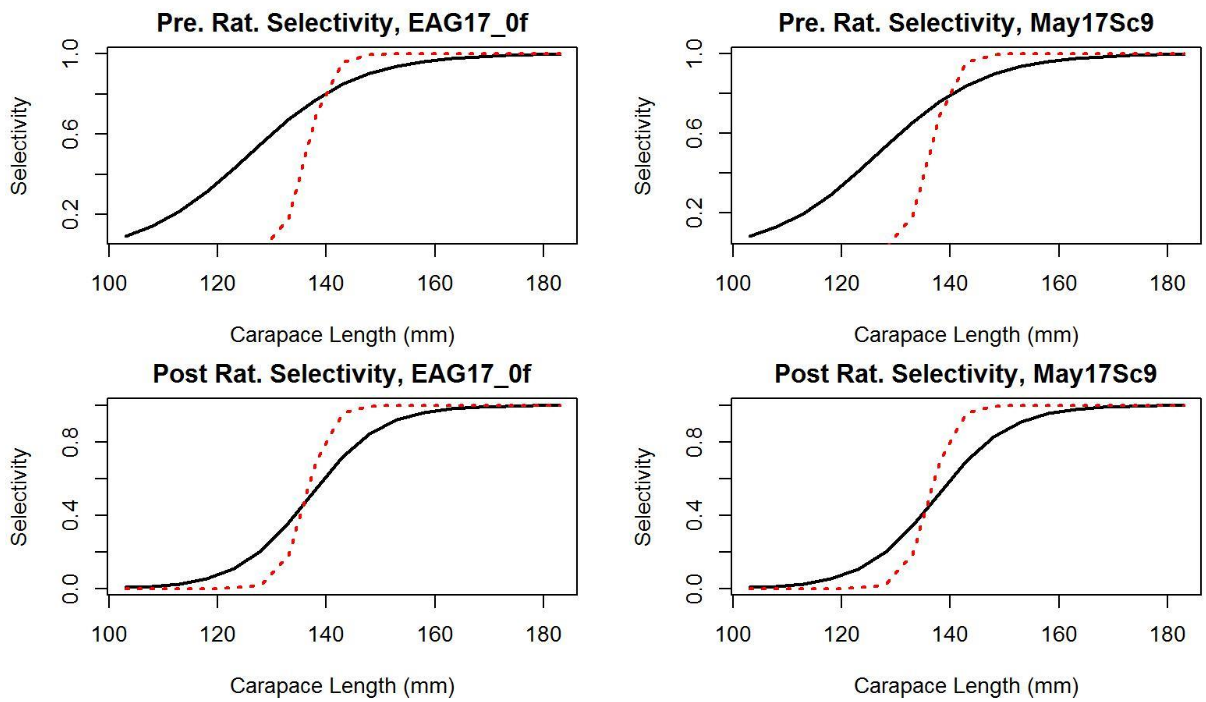


Figure 14. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios 17_0 to May 2017 Sc9 model fits to golden king crab data in the EAG.

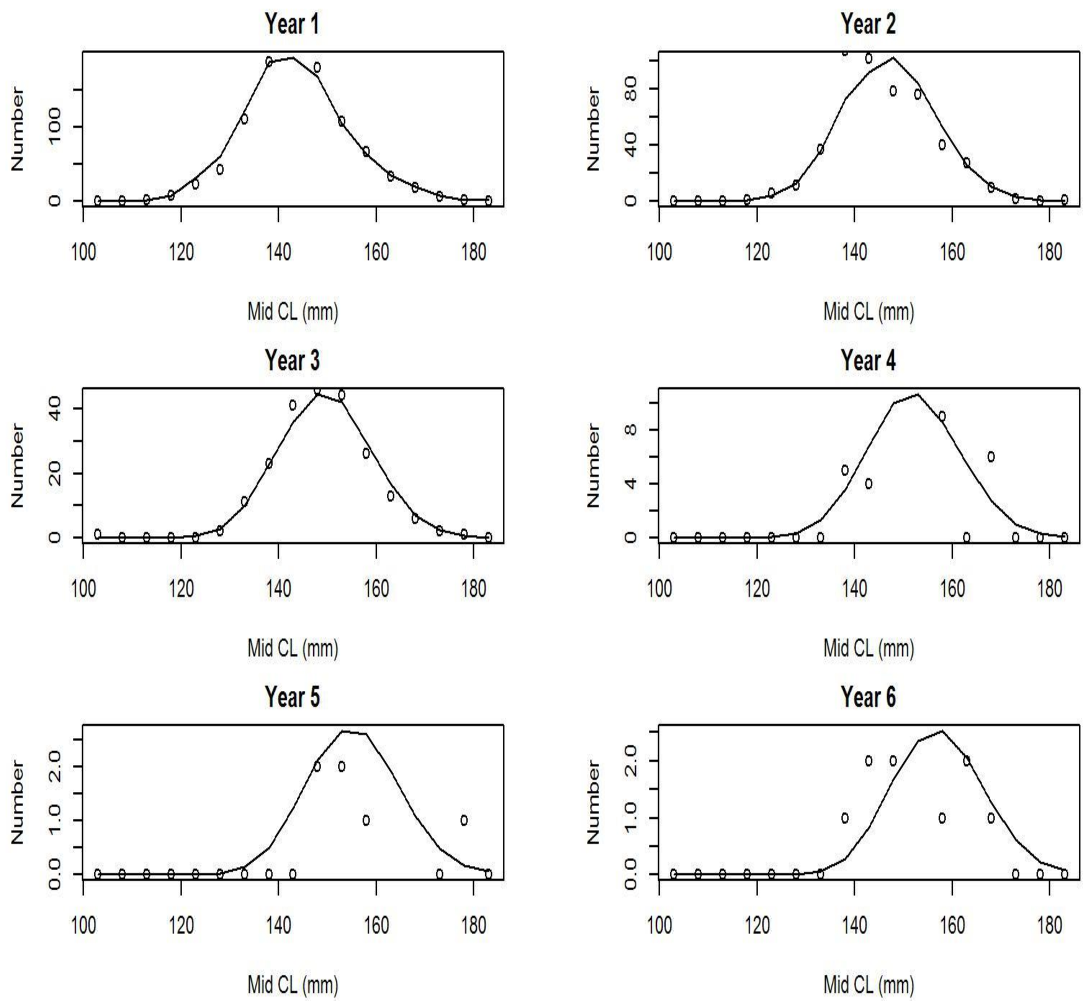


Figure 15. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 recaptures under scenario 17_0 for EAG golden king crab.

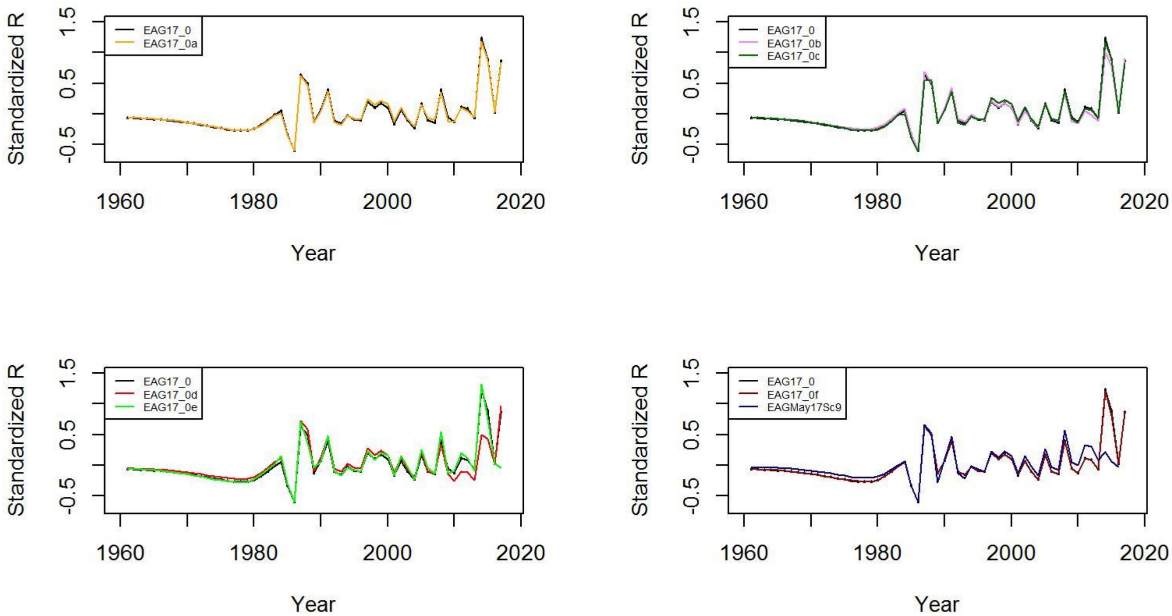


Figure 16. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under scenarios (Sc) 17_0 to May 2017 Sc9 for EAG golden king crab data, 1961–2017. Top left: scenarios 17_0 and 17_0a; top right: scenarios 17_0, 17_0b, and 17_0c; bottom left: scenarios 17_0, 17_0d, and 17_0e; and bottom right: scenarios 17_0, 17_0f, and May 2017 Sc9. This grouping scheme was used in a number of subsequent figures. The number of recruits are centralized using (R-mean R)/mean R for comparing different scenarios' results.

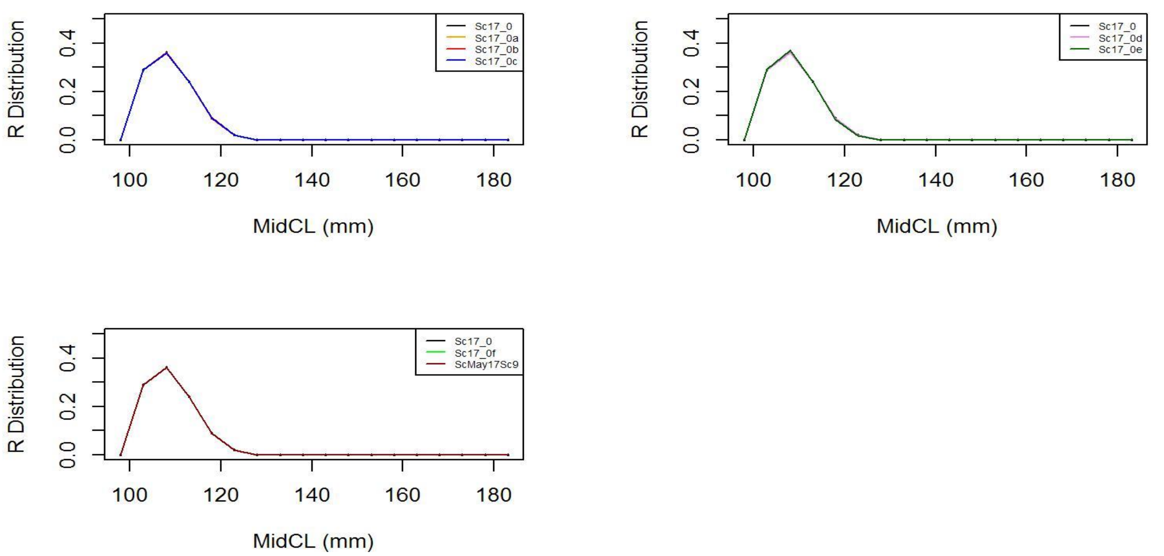


Figure 17. Recruit size distribution to the assessment model under scenarios (Sc) 17_0 to May 2017 Sc9 for EAG golden king crab.

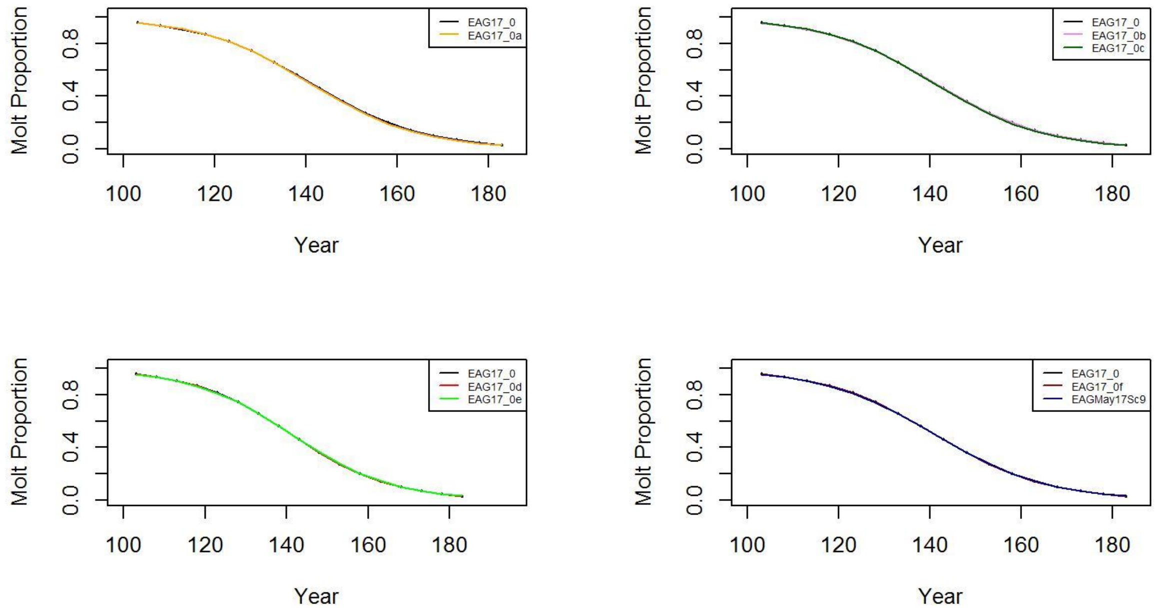
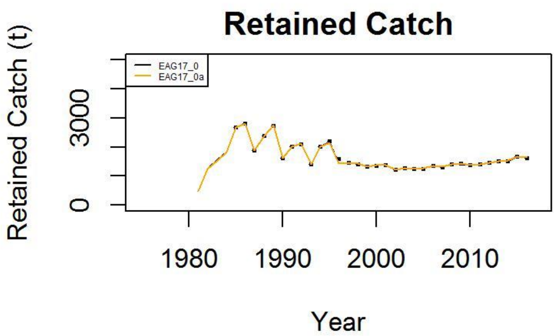
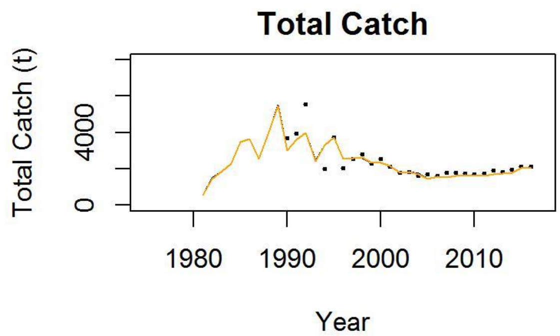
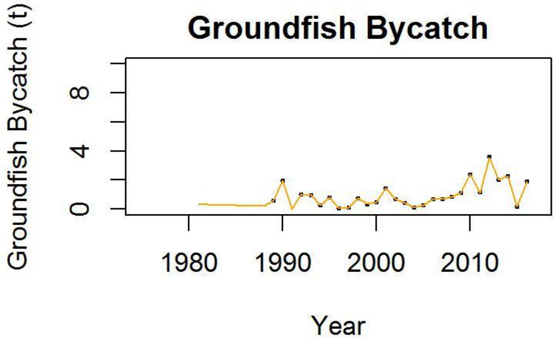
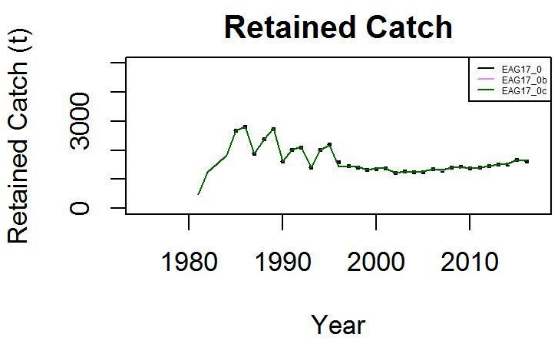


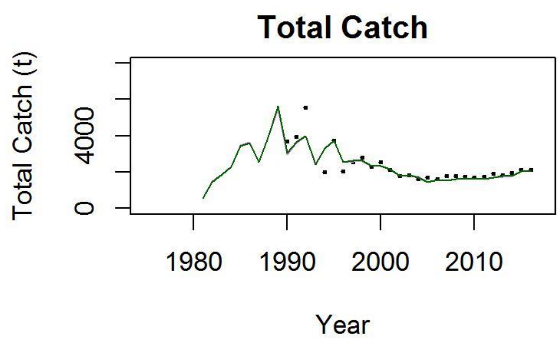
Figure 18. Estimated molt probability vs. carapace length of golden king crab for scenarios 17_0 to May 2017 Sc9 in the EAG.

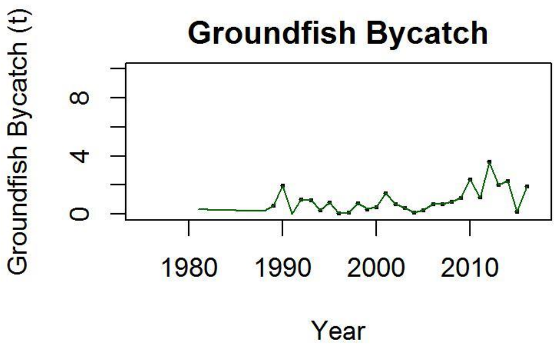

Retained Catch
EAG17_0
EAG17_0a
Retained Catch (t)
0
3000
1980
1990
2000
2010
Year


Total Catch
Total Catch (t)
0
4000
1980
1990
2000
2010
Year


Groundfish Bycatch
Groundfish Bycatch (t)
0
4
8
1980
1990
2000
2010
Year


Retained Catch
EAG17_0
EAG17_0b
EAG17_0c
Retained Catch (t)
0
3000
1980
1990
2000
2010
Year


Total Catch
Total Catch (t)
0
4000
1980
1990
2000
2010
Year


Groundfish Bycatch
Groundfish Bycatch (t)
0
4
8
1980
1990
2000
2010
Year

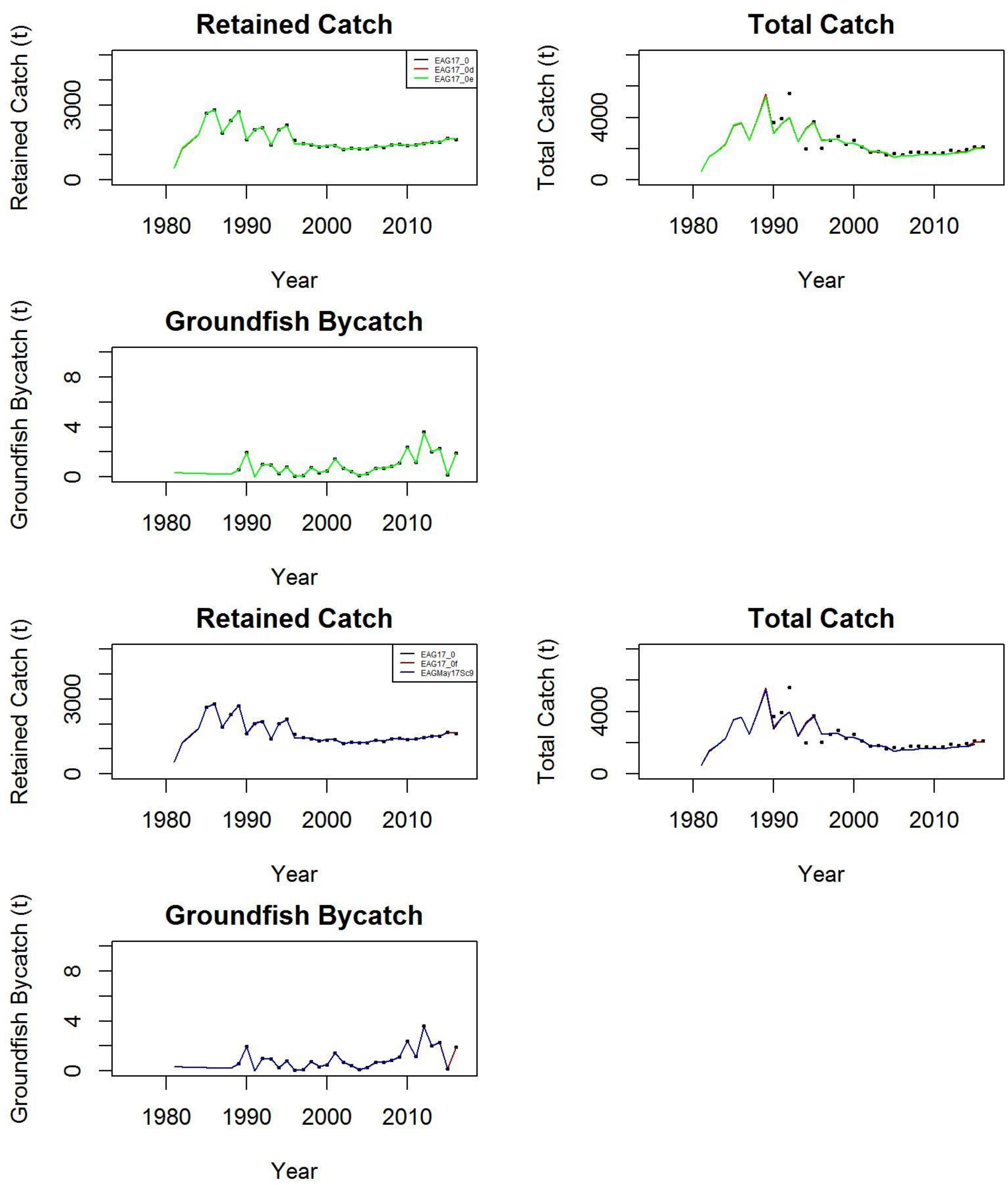


Figure 19. Observed (open circle) vs. predicted (solid line) retained catch (top left in each scenario set), total catch (top right in each scenario set), and groundfish bycatch (bottom left in each scenario set) of golden king crab for scenarios 17_0 to May 2017 Sc9, in EAG, 1981/82–2016/17.

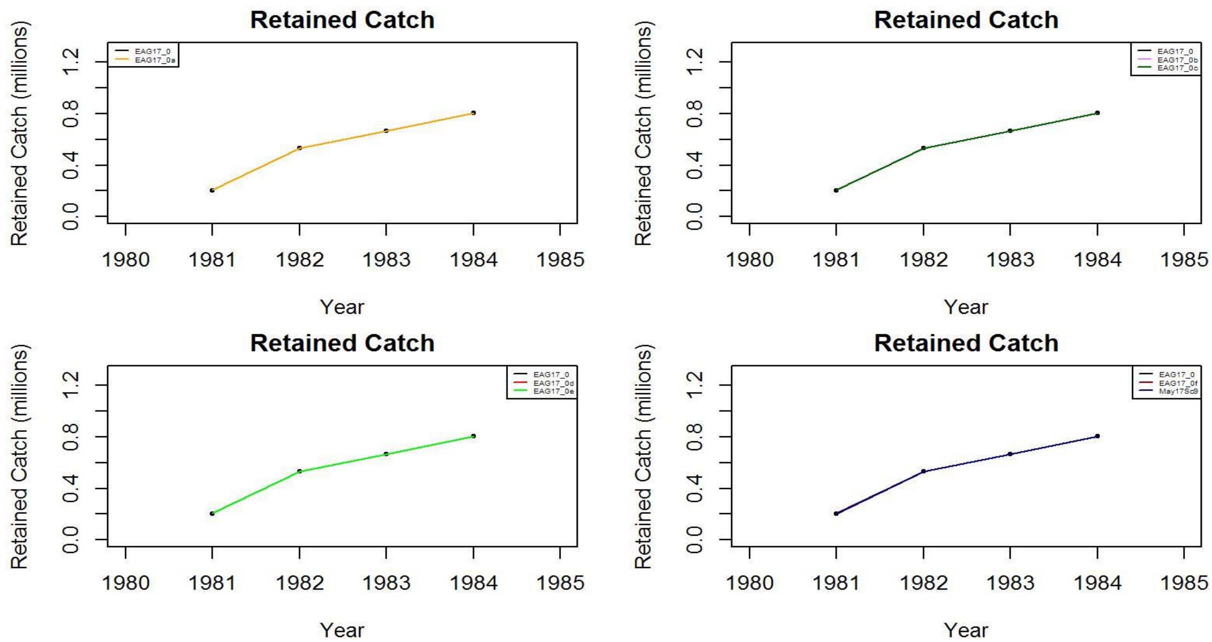


Figure 20. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios 17_0 to May 2017 Sc9 fits in the EAG, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period were in number of crabs.

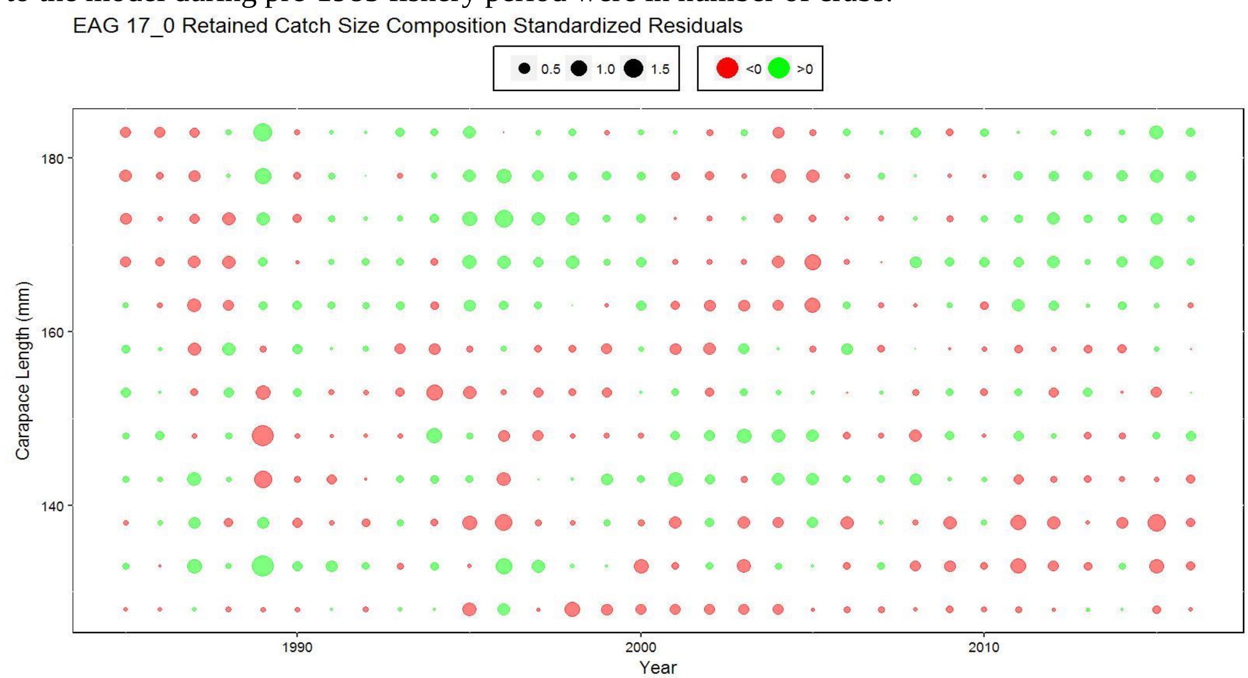


Figure 21. Bubble plot of standardized residuals of retained catch length composition for scenario 17_0 fit for EAG golden king crab, 1985/86–2016/17. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

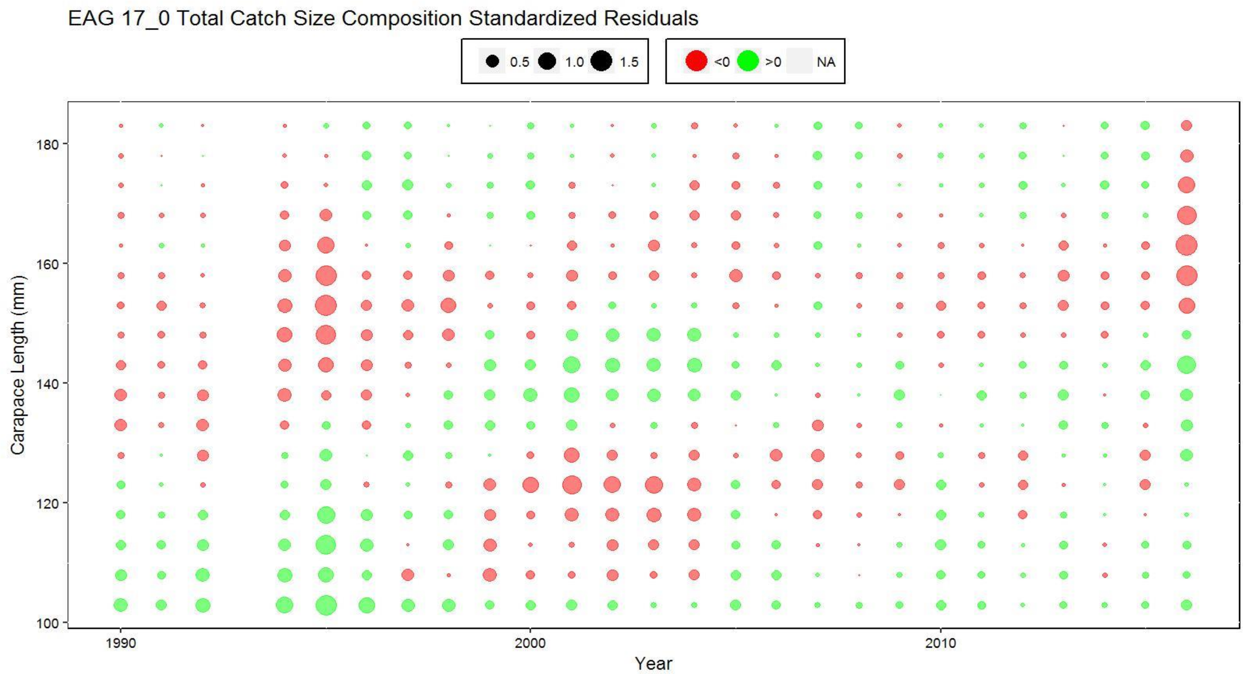


Figure 22. Bubble plot of standardized residuals of total catch length composition for scenario 17_0 fit for EAG golden king crab, 1990/91–2016/17. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

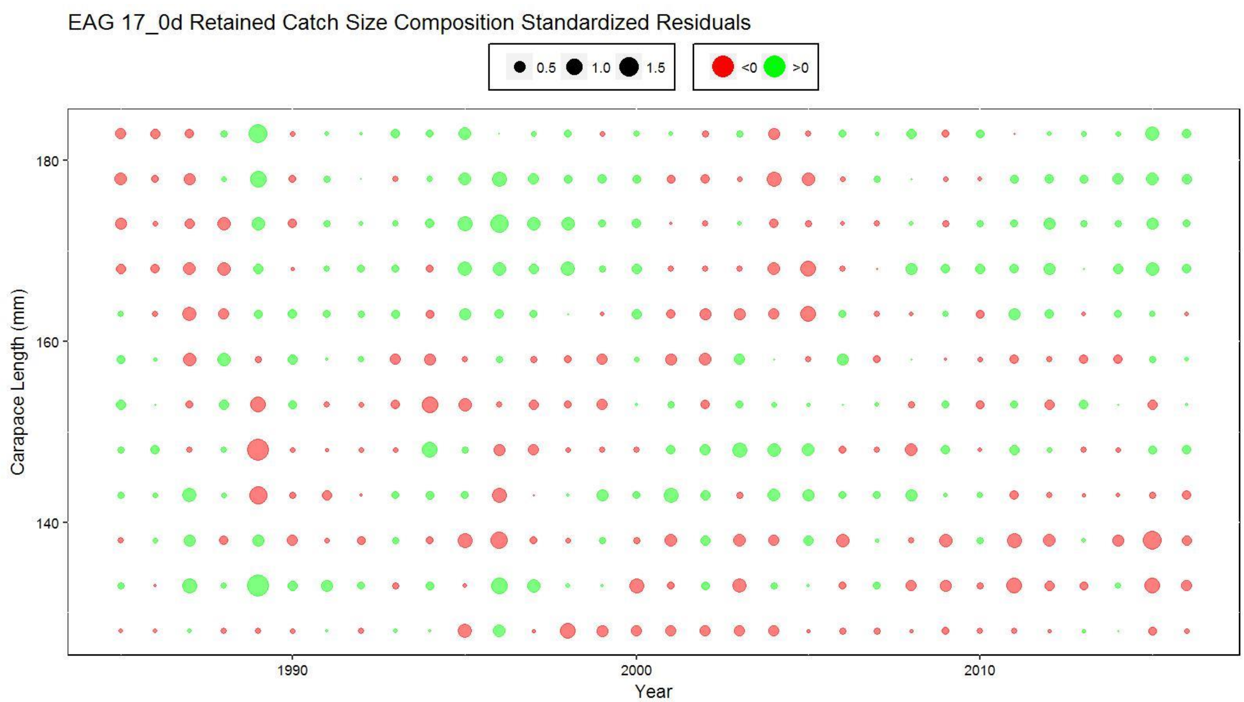


Figure 23. Bubble plot of standardized residuals of retained catch length composition for scenario 17_0d fit for EAG golden king crab, 1985/86–2015/16. Blue circles are the positive and

pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

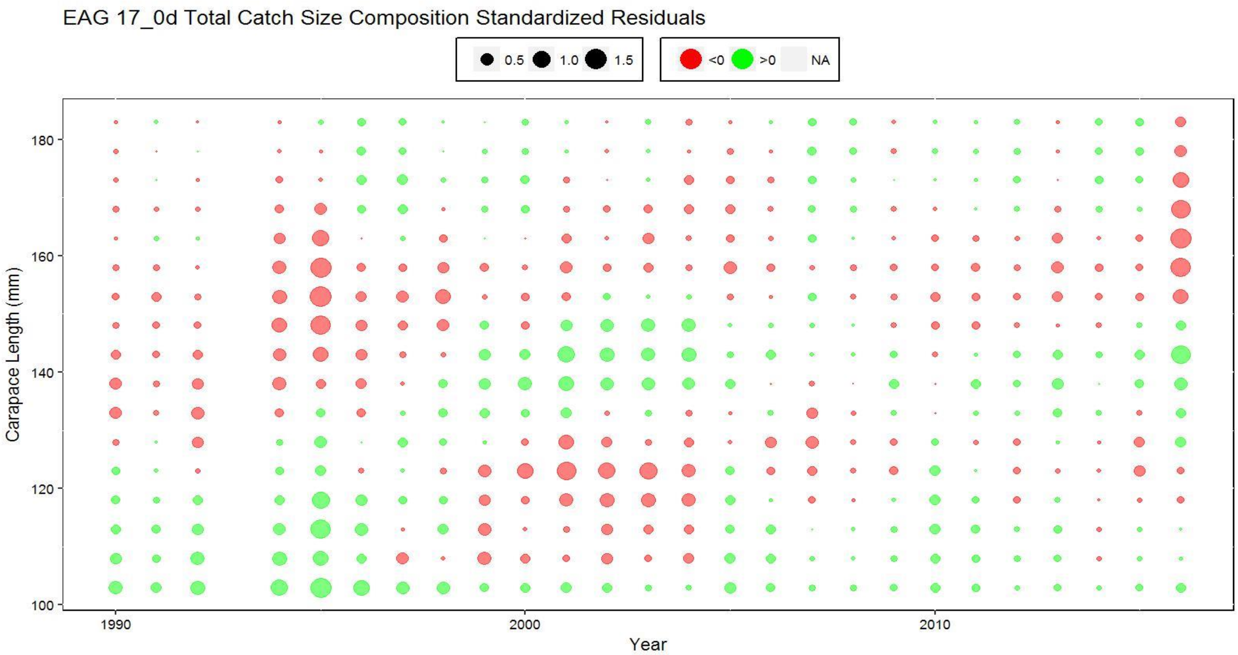
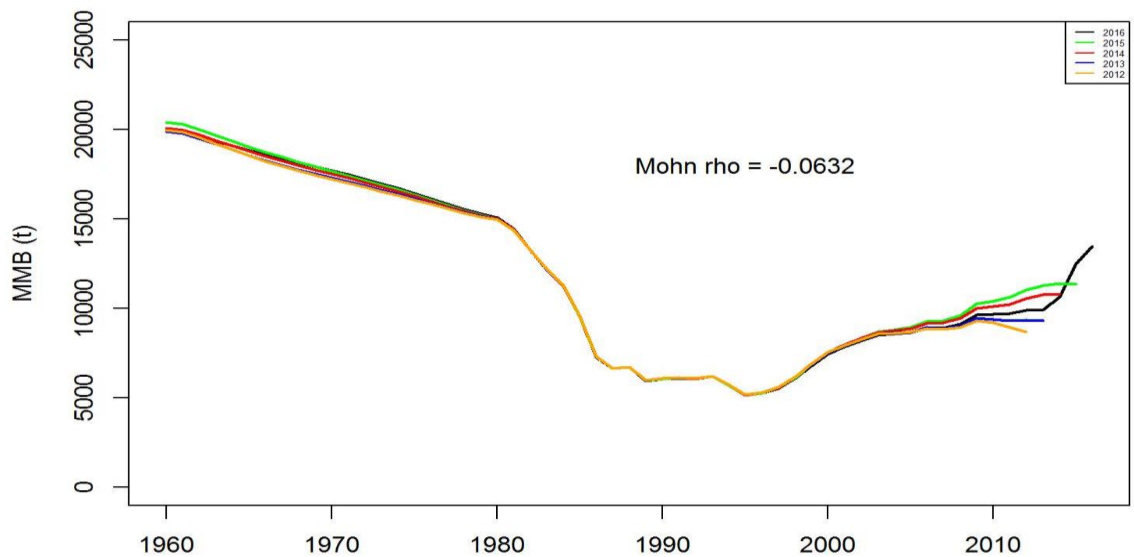


Figure 24. Bubble plot of standardized residuals of total catch length composition for scenario 9 fit for EAG golden king crab, 1990/91–2015/16. Blue circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.



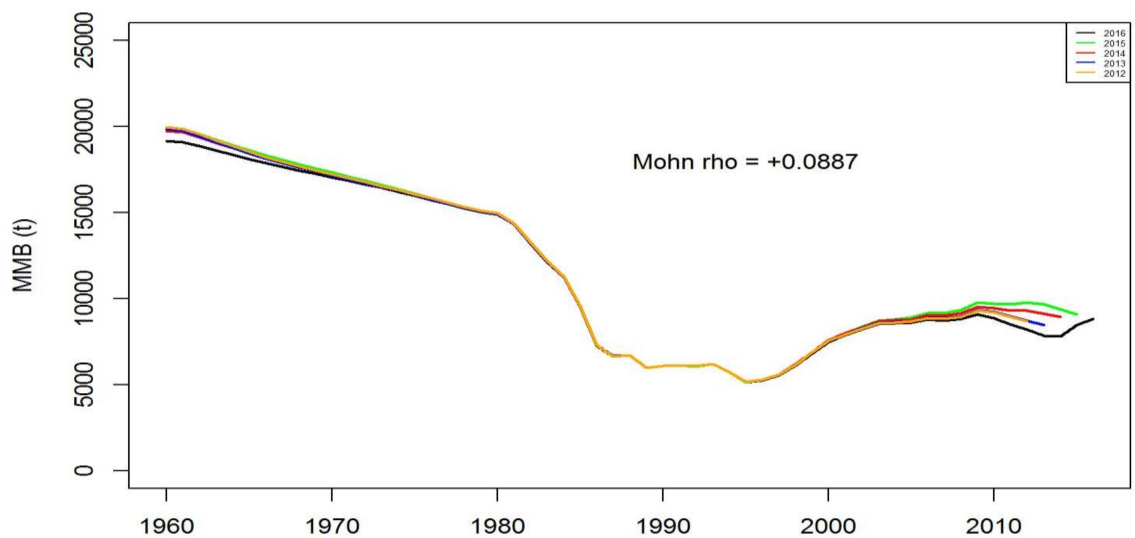


Figure 25. Retrospective fits of MMB by the model following removal of terminal year data under scenarios 17_0 (top) and 17_0d (bottom) for golden king crab in the EAG, 1960/61–2016/17.

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 four peels (x=4) and our T =2016.

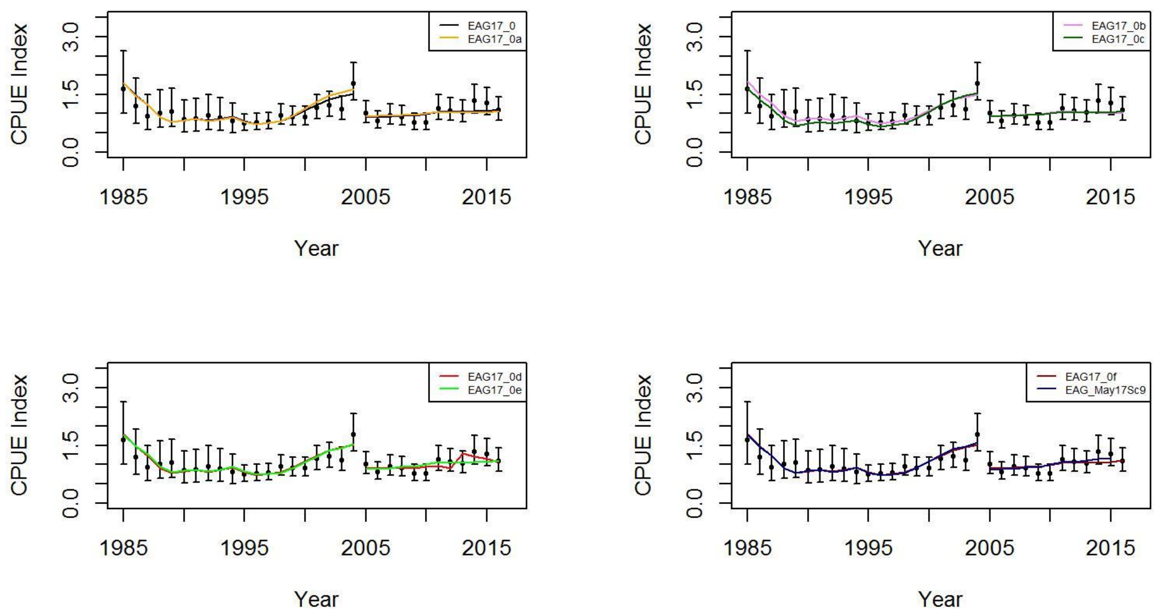


Figure 26. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) under scenarios 17_0 to May 2017 Sc9 for EAG golden king crab data, 1985/86–2016/17. Model estimated additional standard error was added to each input standard error.

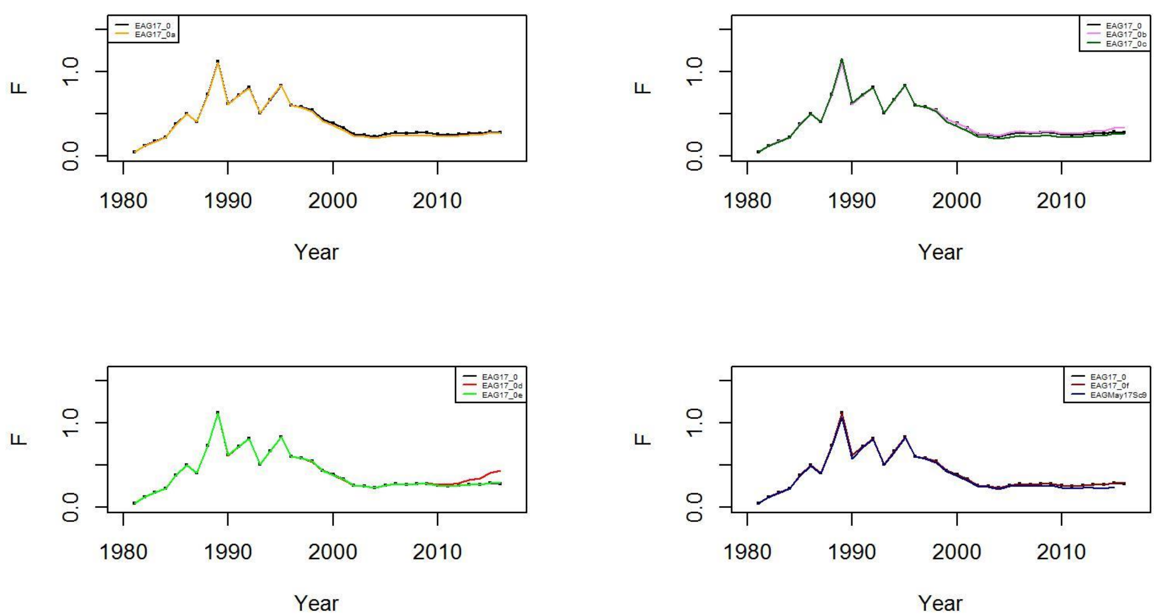


Figure 27. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios 17_0 to May 2017 Sc9 model fits in the EAG, 1981/82–2016/17.

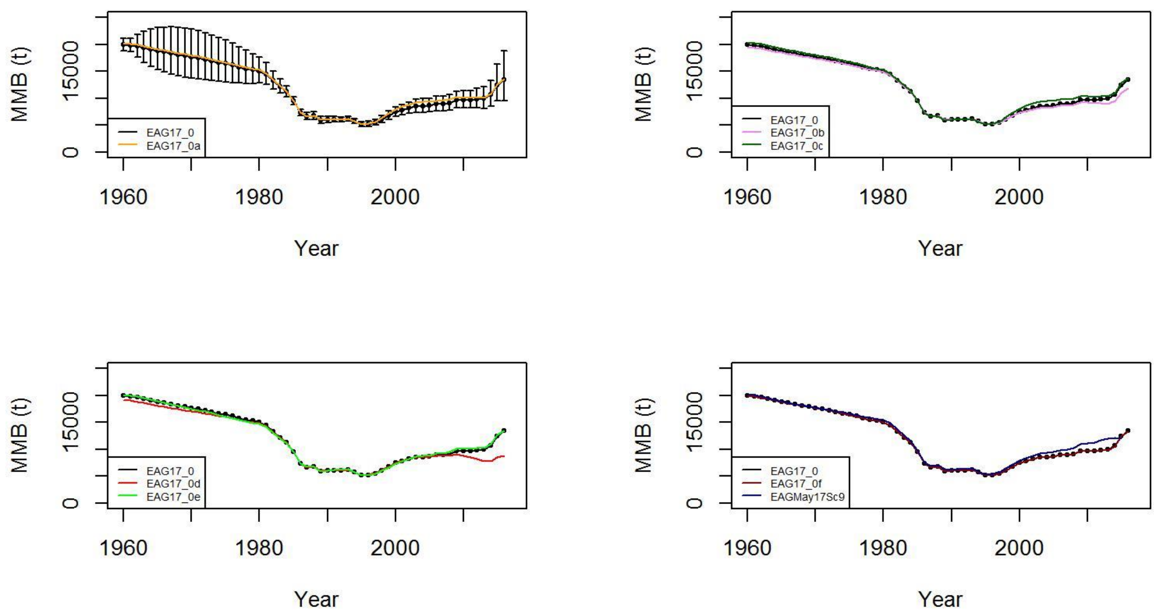


Figure 28. Trends in golden king crab mature male biomass for scenarios 17_0 to May 2017 Sc9 fits in the EAG, 1960/61–2016/17. Scenario 17_0 estimates have two standard errors confidence limits.

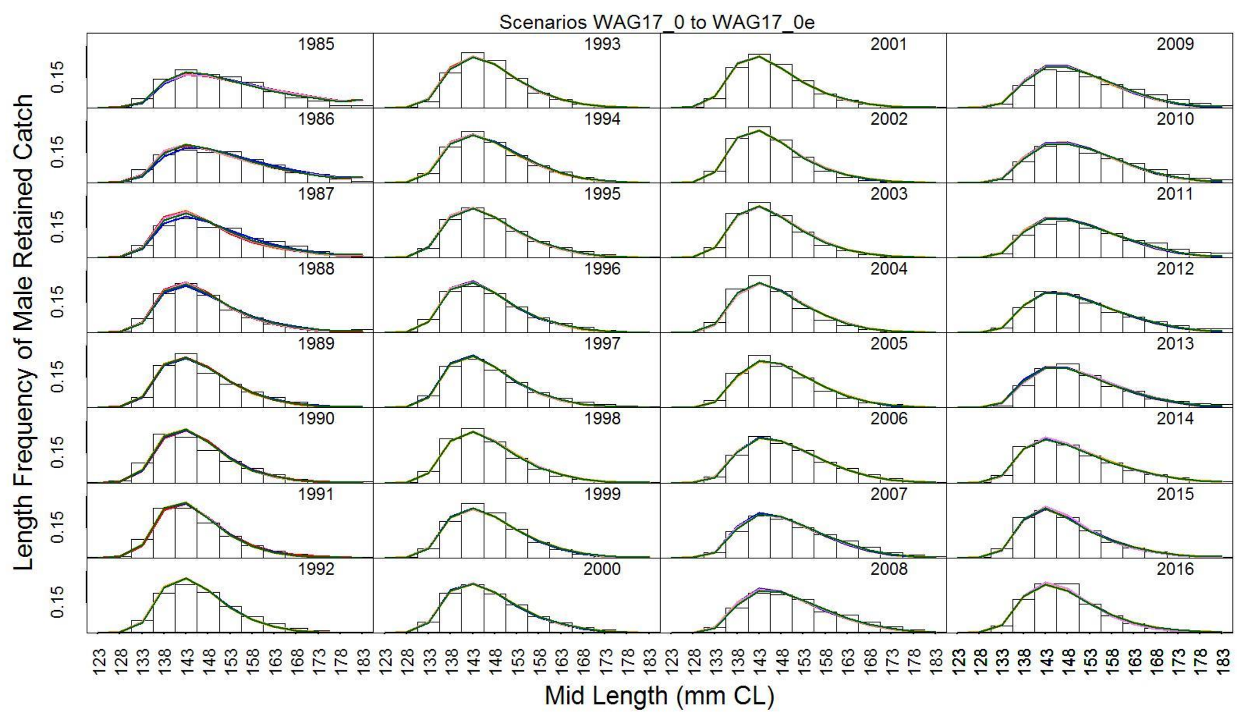


Figure 29. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions under scenarios 17_0 (black line), 17_0a (orange line), 17_0b (red line), 17_0c (blue line), 17_0d (violet line), and 17_0e (dark green line) for golden king crab in the WAG, 1985/86 to 2016/17. This color scheme is used in all other graphs.

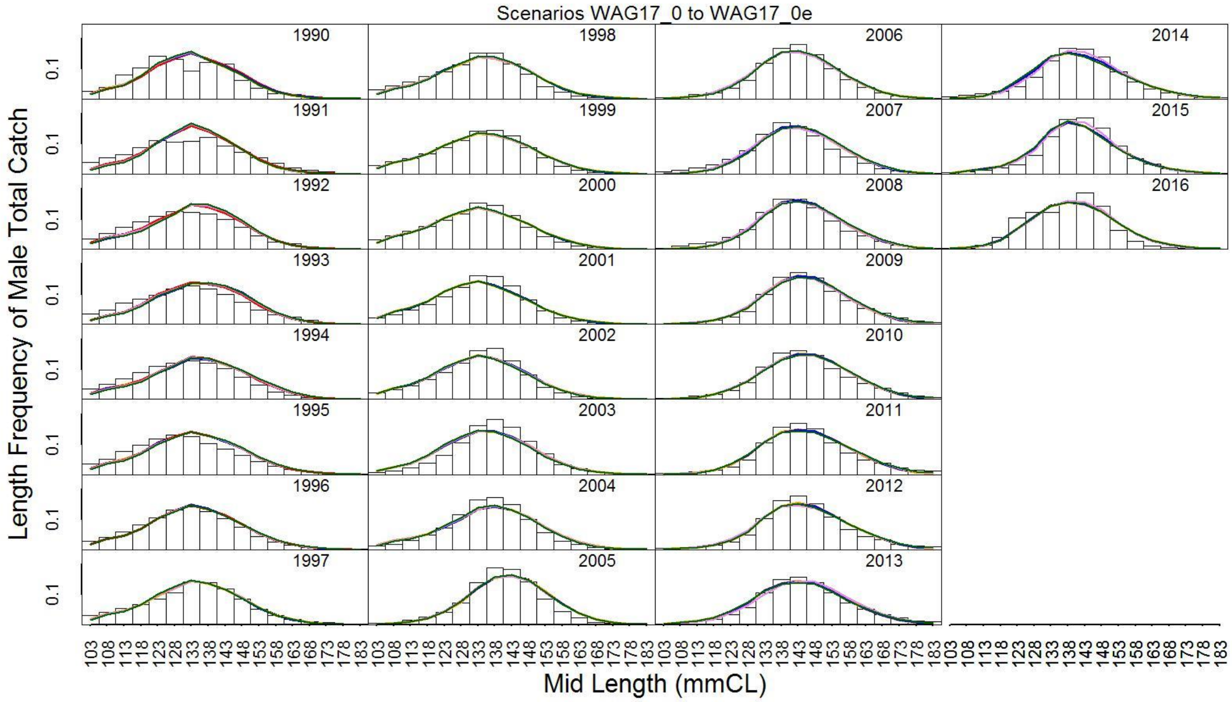


Figure 30. Predicted (line) vs. observed (bar) total catch relative length frequency distributions under scenarios 17_0 to 17_0e for golden king crab in the WAG, 1990/91 to 2016/17.

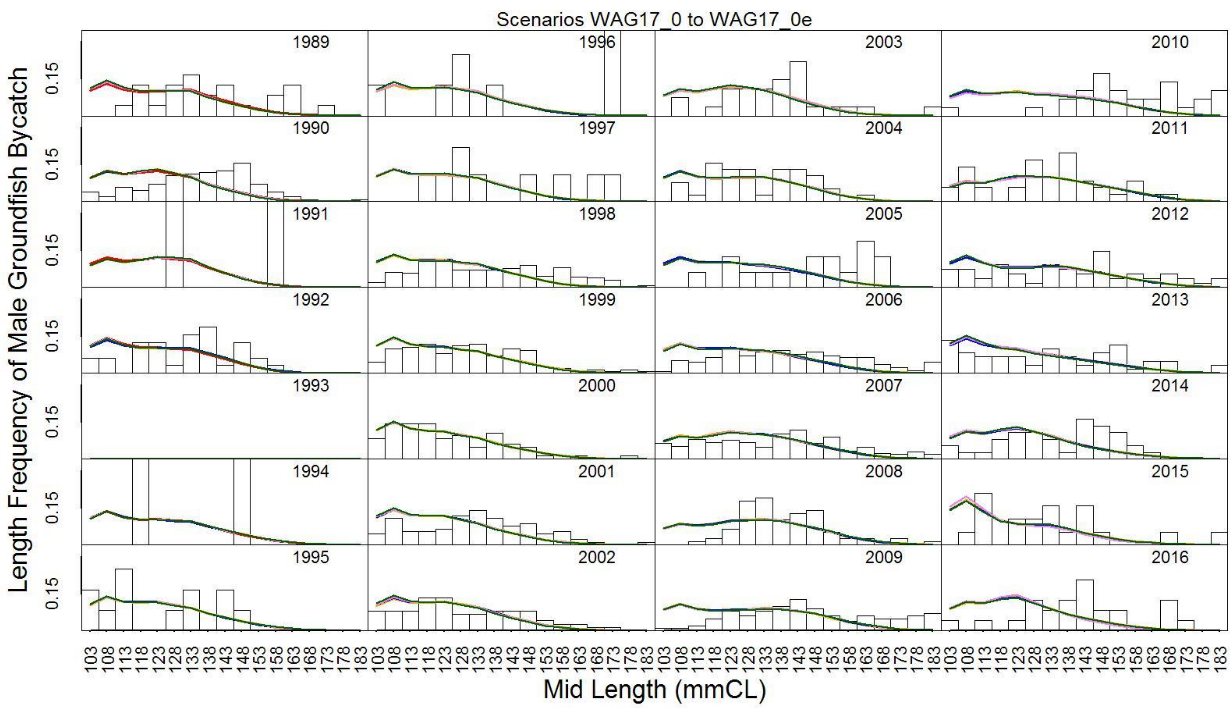
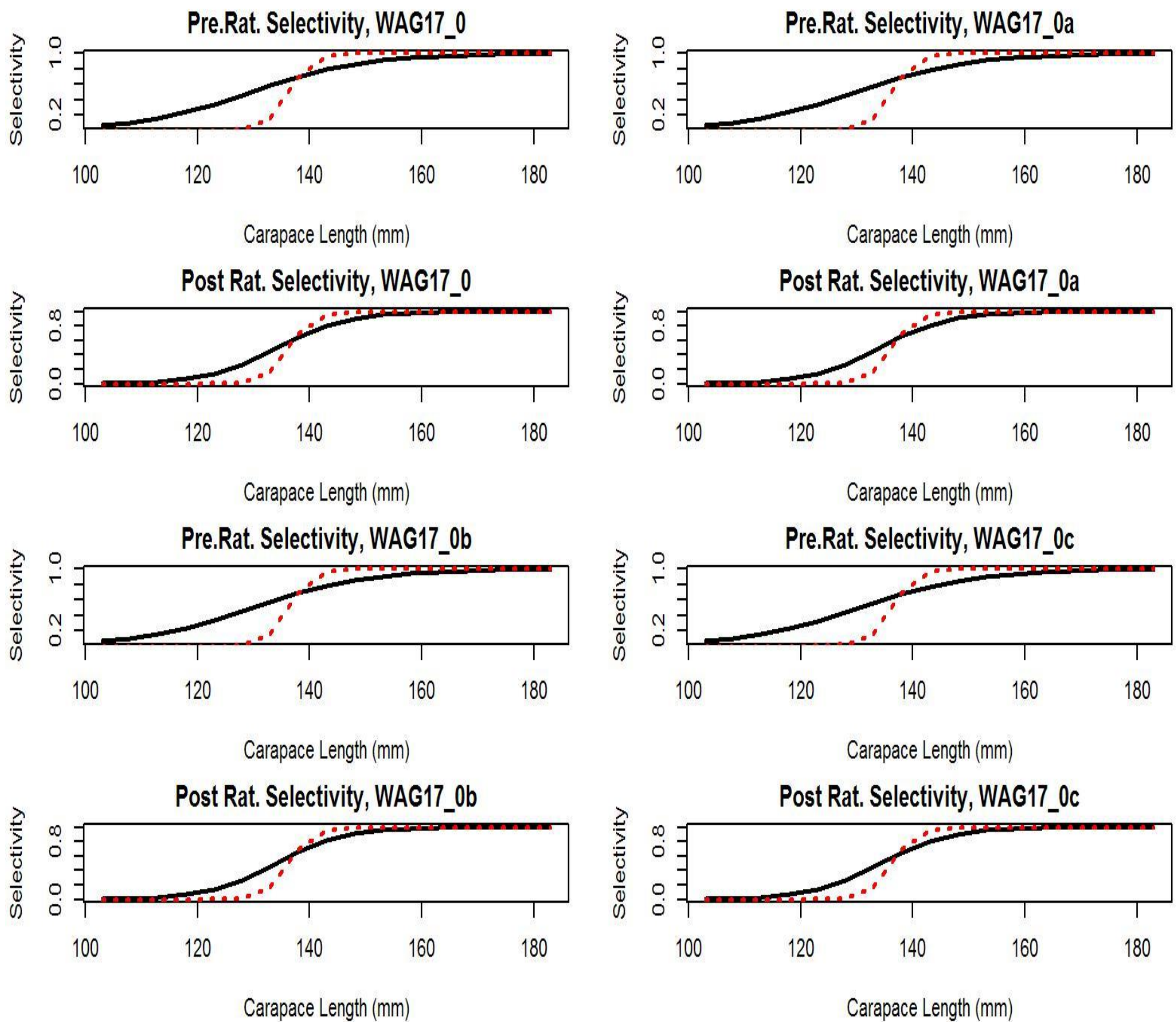


Figure 31. Predicted (line) vs. observed (bar) groundfish (or trawl) discarded bycatch relative length frequency distributions under scenarios 17_0 to 17_0e for golden king crab in the WAG, 1989/90 to 2016/17. Note that this data set was not used in the model fitting.


Pre.Rat. Selectivity, WAG17_0
Pre.Rat. Selectivity, WAG17_0a
Post Rat. Selectivity, WAG17_0
Post Rat. Selectivity, WAG17_0a
Pre.Rat. Selectivity, WAG17_0b
Pre.Rat. Selectivity, WAG17_0c
Post Rat. Selectivity, WAG17_0b
Post Rat. Selectivity, WAG17_0c
Selectivity
Carapace Length (mm)
100
120
140
160
180
0.2
1.0
0.0
0.8

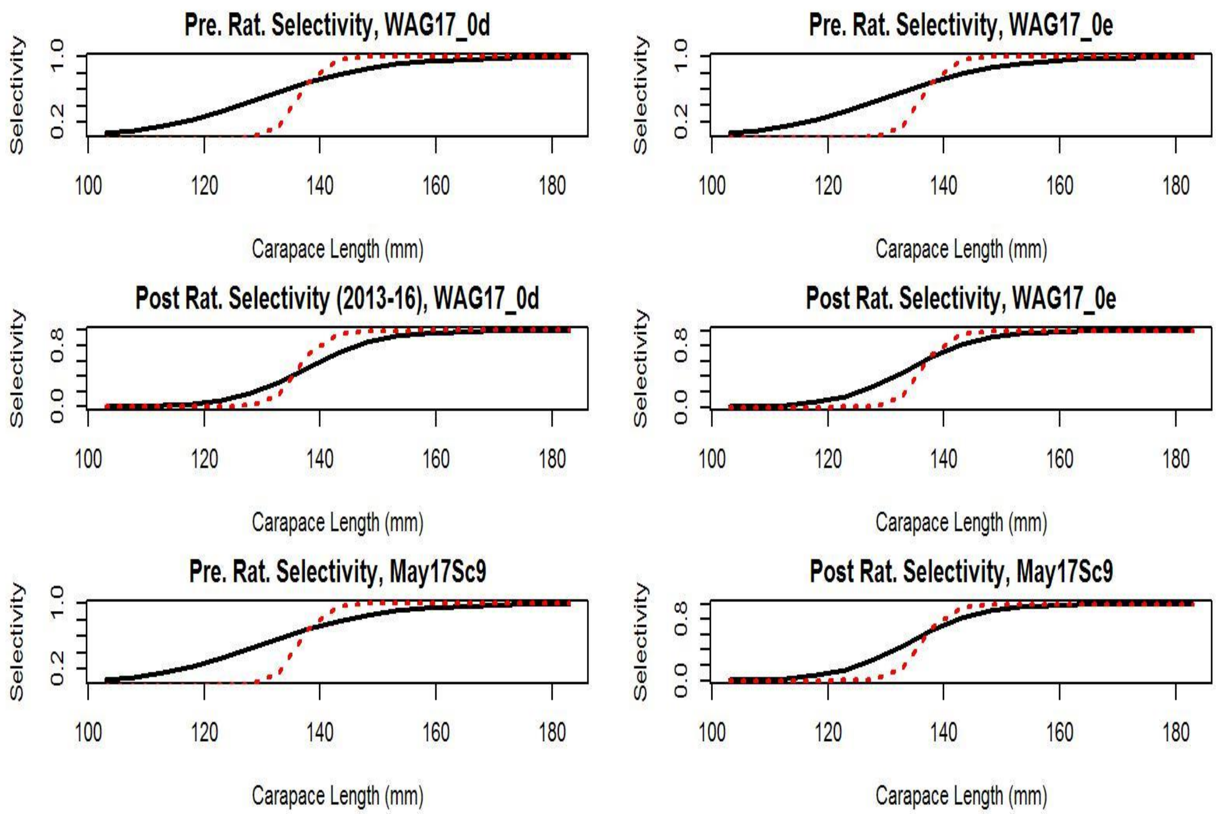


Figure 32. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios 17_0 to May 2017 Sc9 fits to golden king crab data in the WAG.

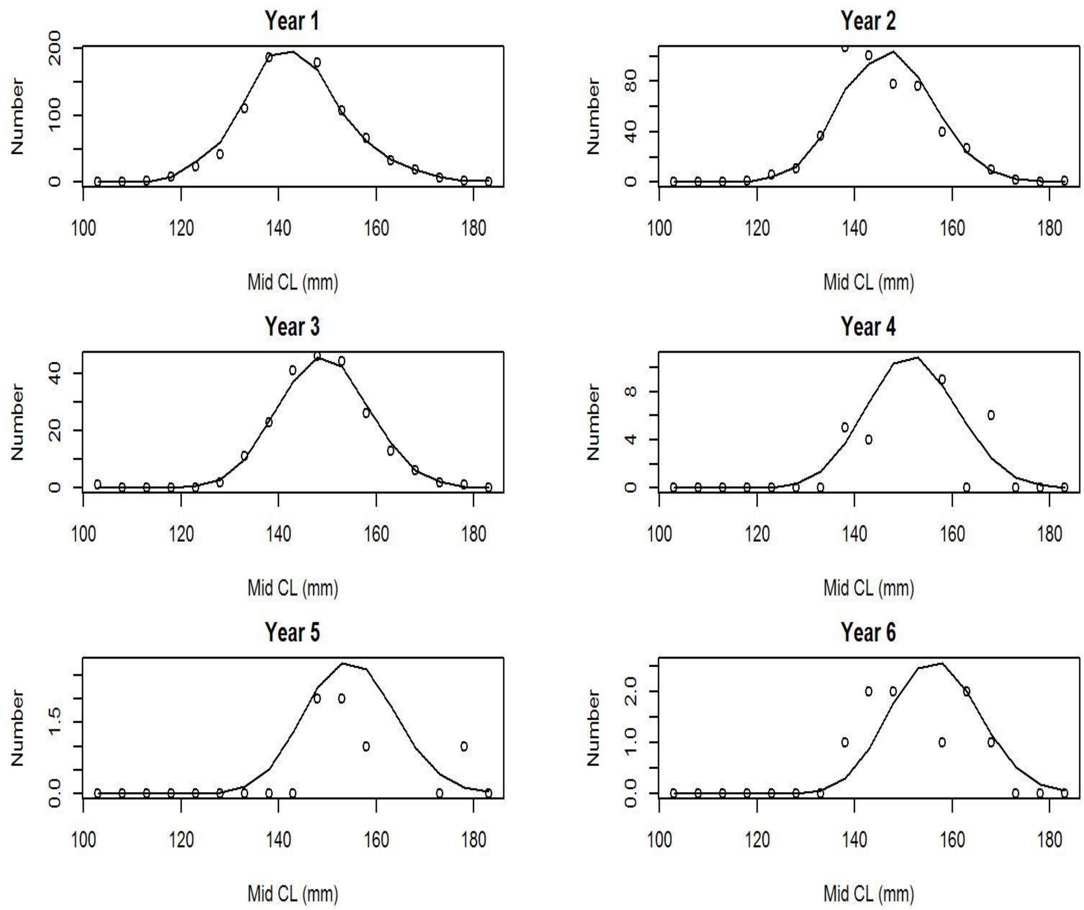


Figure 33. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 recaptures under scenario 17_0 for WAG golden king crab.

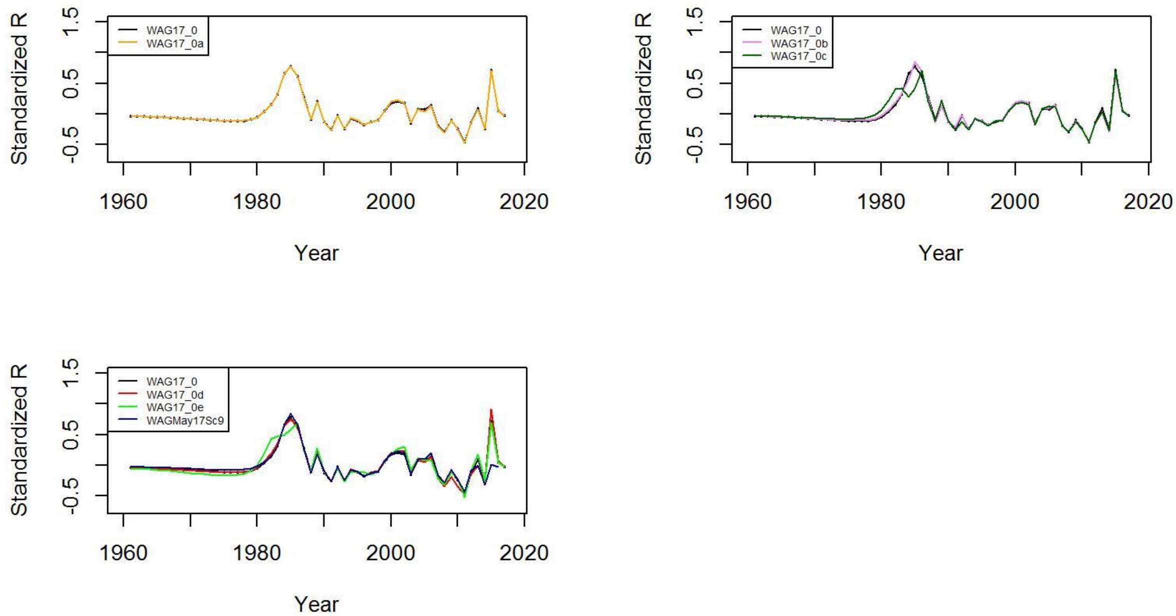


Figure 34. Estimated number of male recruits (crab size ≥ 101 mm CL) to the assessment model under scenarios 17_0 to May 2017 Sc9 for WAG golden king crab data, 1961–2017. Top left: scenarios 17_0 and 17_0a; top right: scenarios 17_0, 17_0b, and 17_0c; and bottom left: scenarios 17_0, 17_0d, and 17_0e and May 2017 Sc9. The number of recruits are centralized using (R-mean R)/mean R for comparing different scenarios' results.

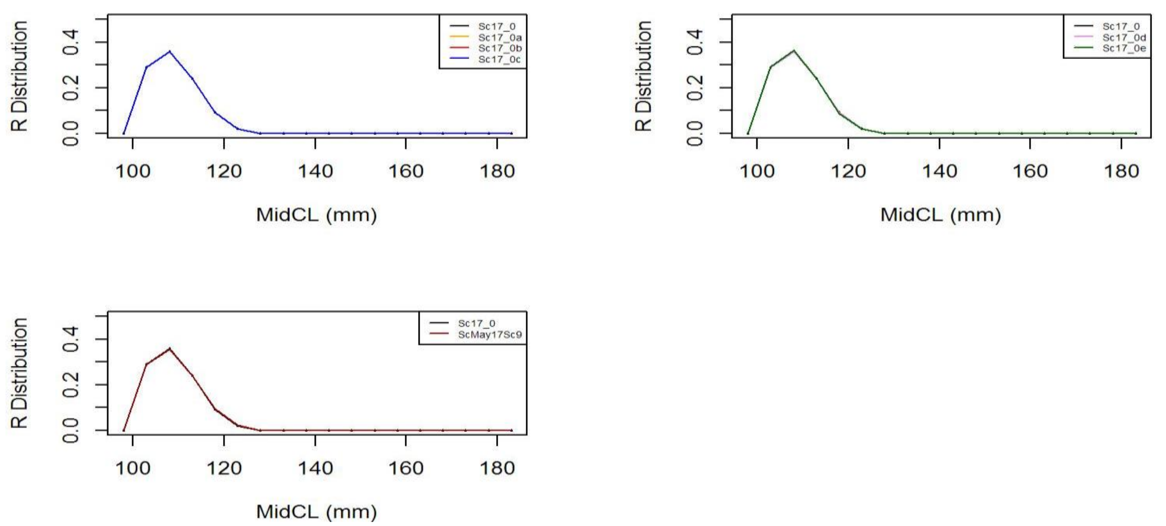


Figure 35. Recruit size distribution to the assessment model under scenarios (Sc) 17_0 to May 2017 Sc9 for WAG golden king crab.

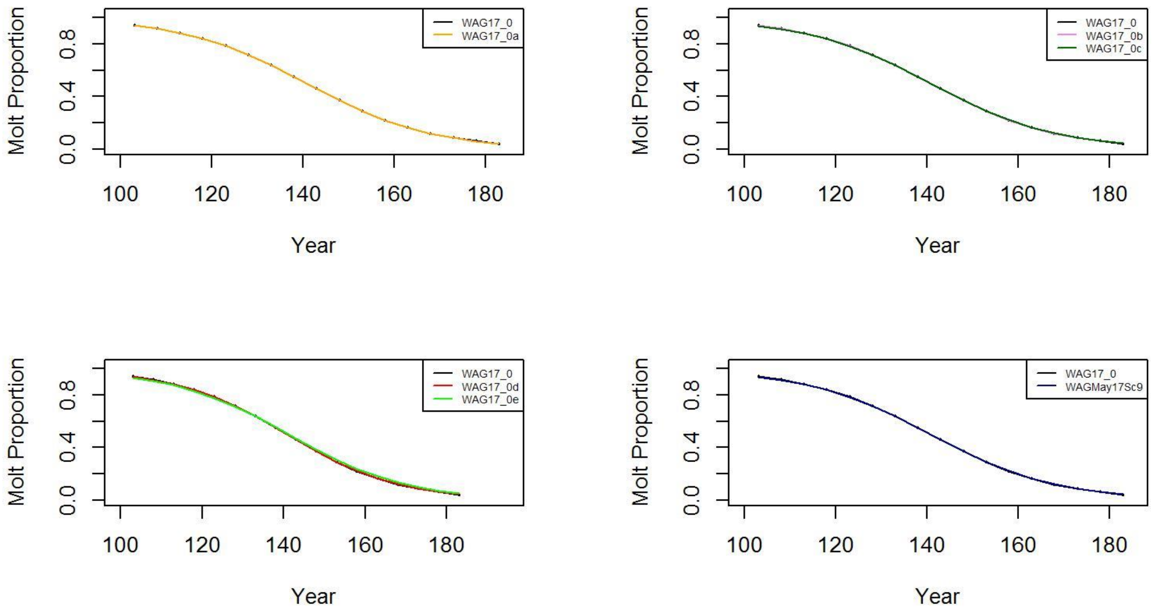
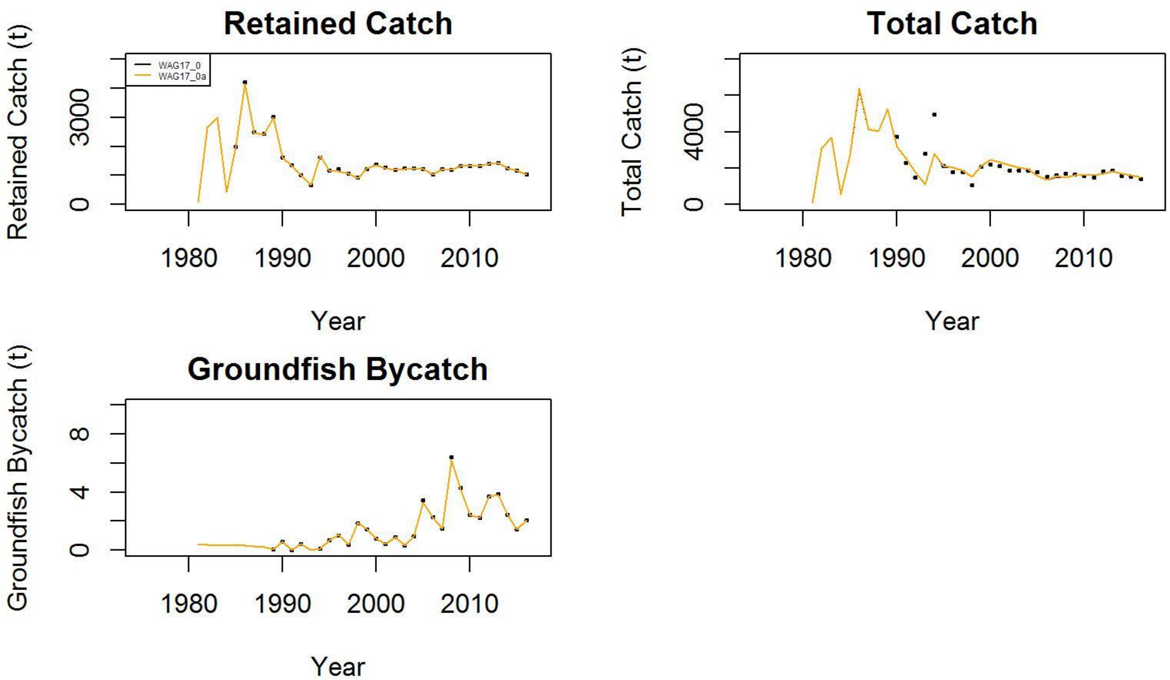
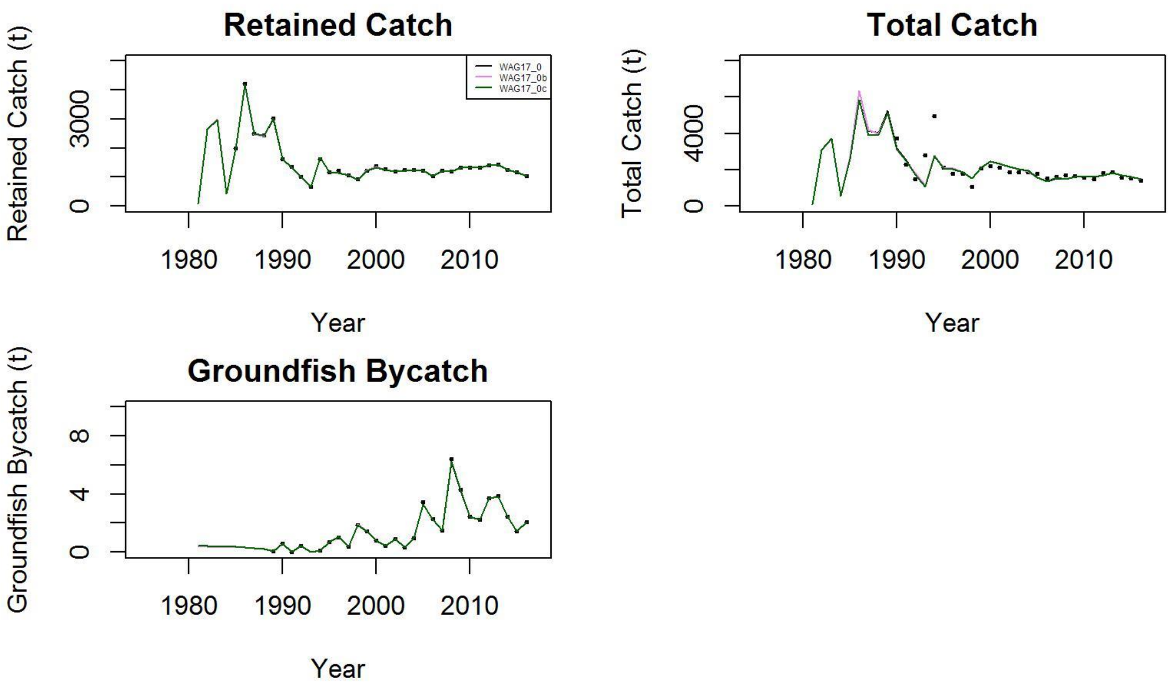


Figure 36. Estimated molt probability vs. carapace length of golden king crab for scenarios 17_0 to May 2017 Sc9 in the WAG.


Retained Catch
WAG17_0
WAG17_0a
Retained Catch (t)
0
3000
1980
1990
2000
2010
Year
Total Catch
Total Catch (t)
0
4000
1980
1990
2000
2010
Year
Groundfish Bycatch
Groundfish Bycatch (t)
0
4
8
1980
1990
2000
2010
Year


Retained Catch
WAG17_0
WAG17_0b
WAG17_0c
Retained Catch (t)
0
3000
1980
1990
2000
2010
Year
Total Catch
Total Catch (t)
0
4000
1980
1990
2000
2010
Year
Groundfish Bycatch
Groundfish Bycatch (t)
0
4
8
1980
1990
2000
2010
Year

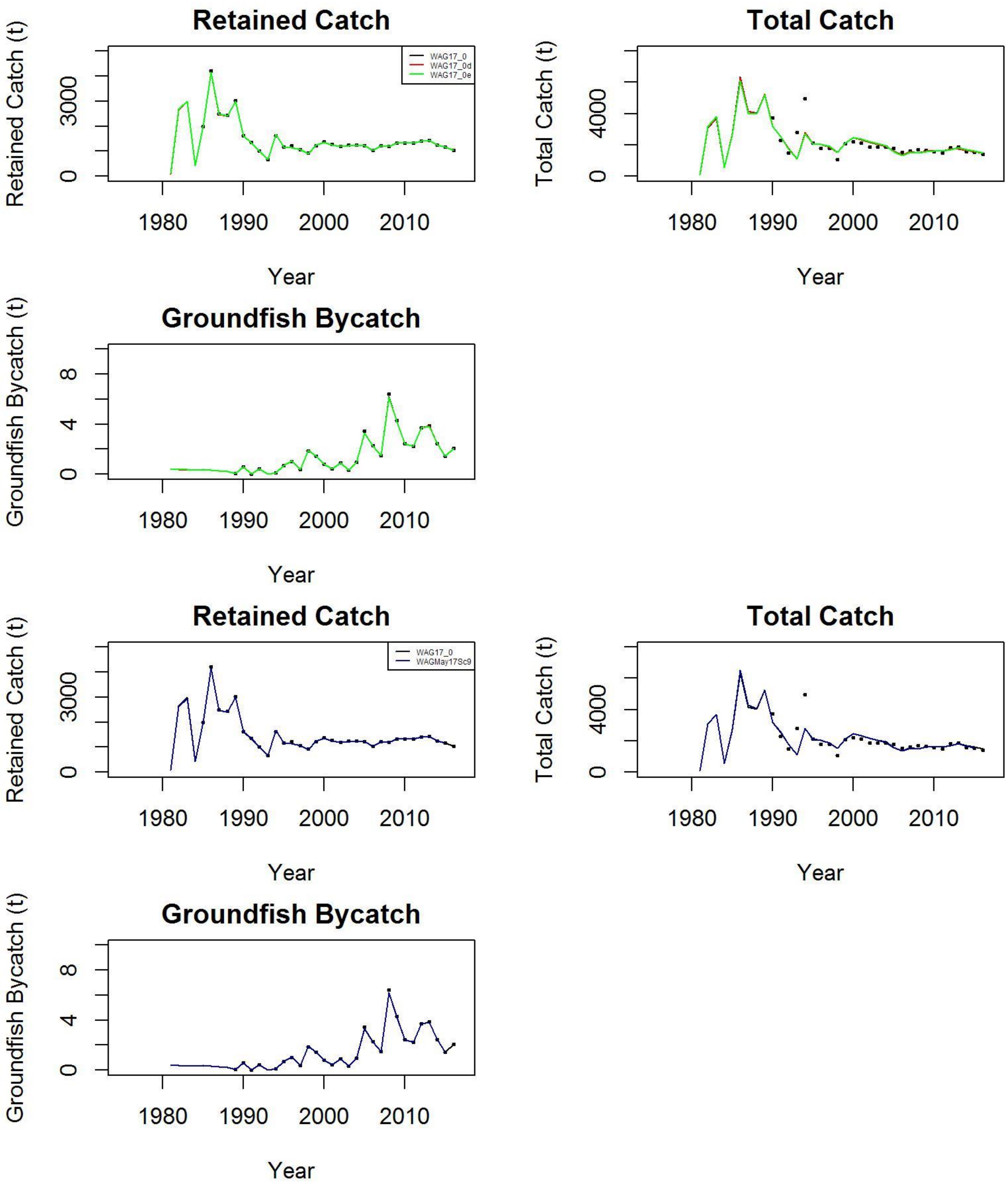


Figure 37. Observed (open circle) vs. predicted (solid line) retained catch (top left in each scenario set), total catch (top right in each scenario set), and groundfish bycatch (bottom left in each scenario set) of golden king crab for scenarios 17_0 to May 2017 Sc9 fits in the WAG, 1981/82–2016/17.

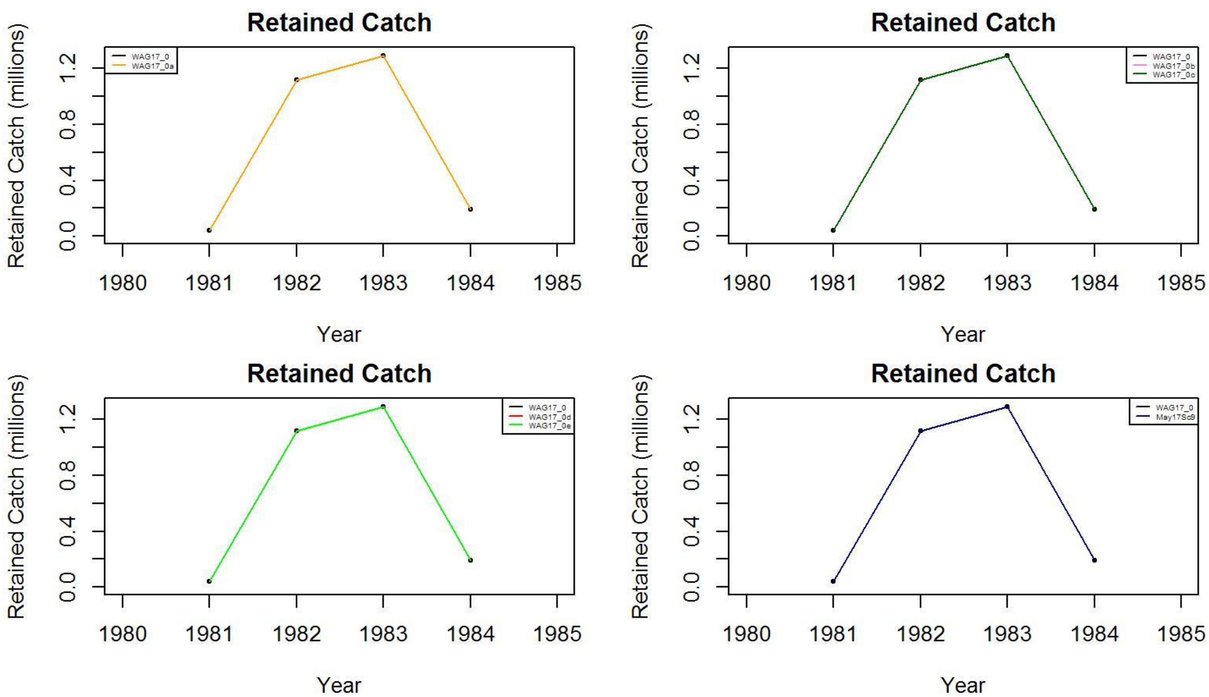


Figure 38. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios 17_0 to May 2017 Sc9 fits in the WAG, 1981/82–1984/85. Note: Input retained catches to the model during pre-1985 fishery period were in number of crabs.

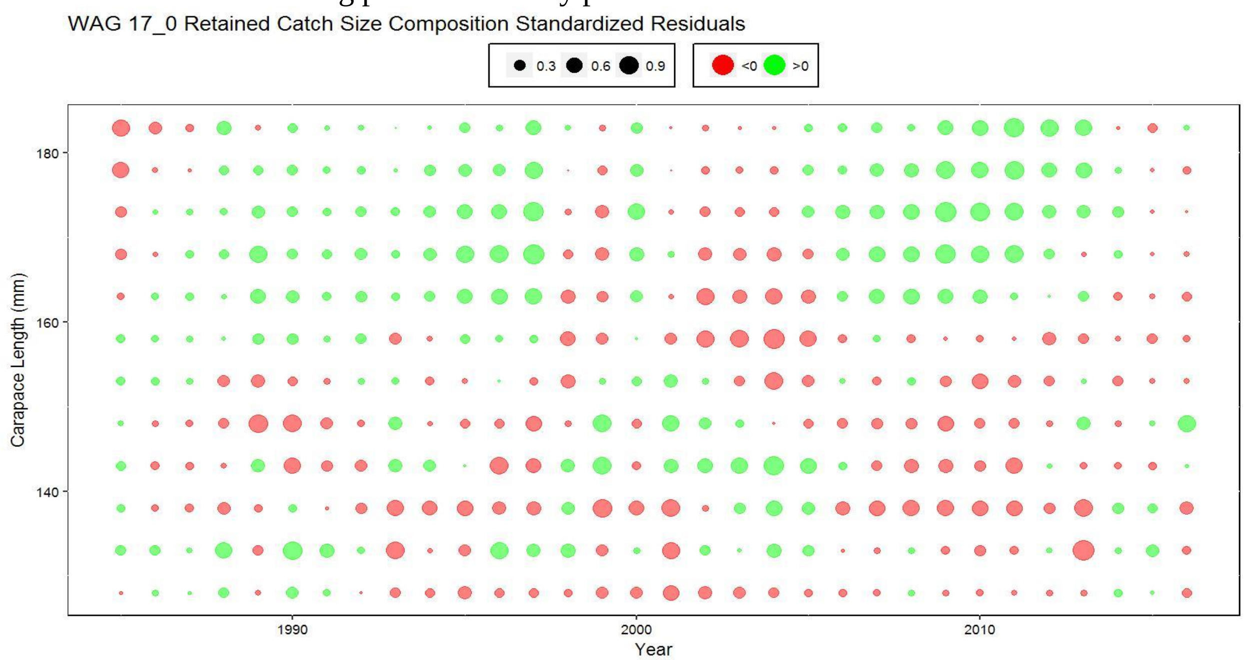


Figure 39. Bubble plot of standardized residuals of retained catch length composition for scenario 17_0 fit for WAG golden king crab, 1985/86–2016/17. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

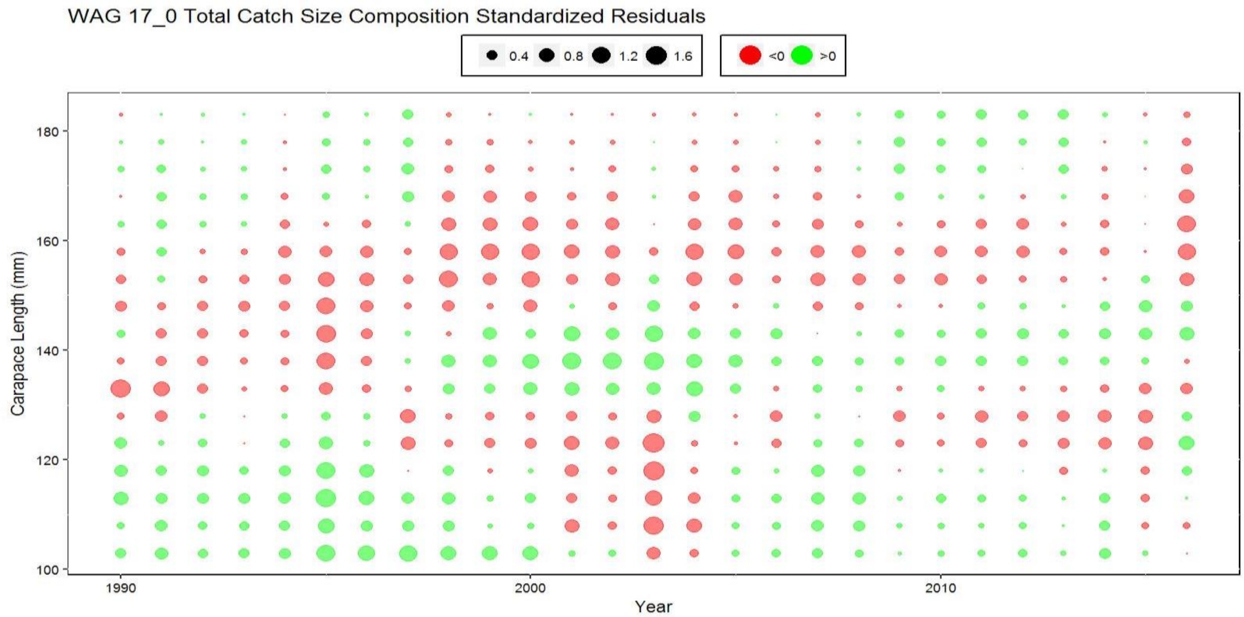


Figure 40. Bubble plot of standardized residuals of total catch length composition for scenario 17_0 fit for WAG golden king crab, 1990/91–2016/17. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

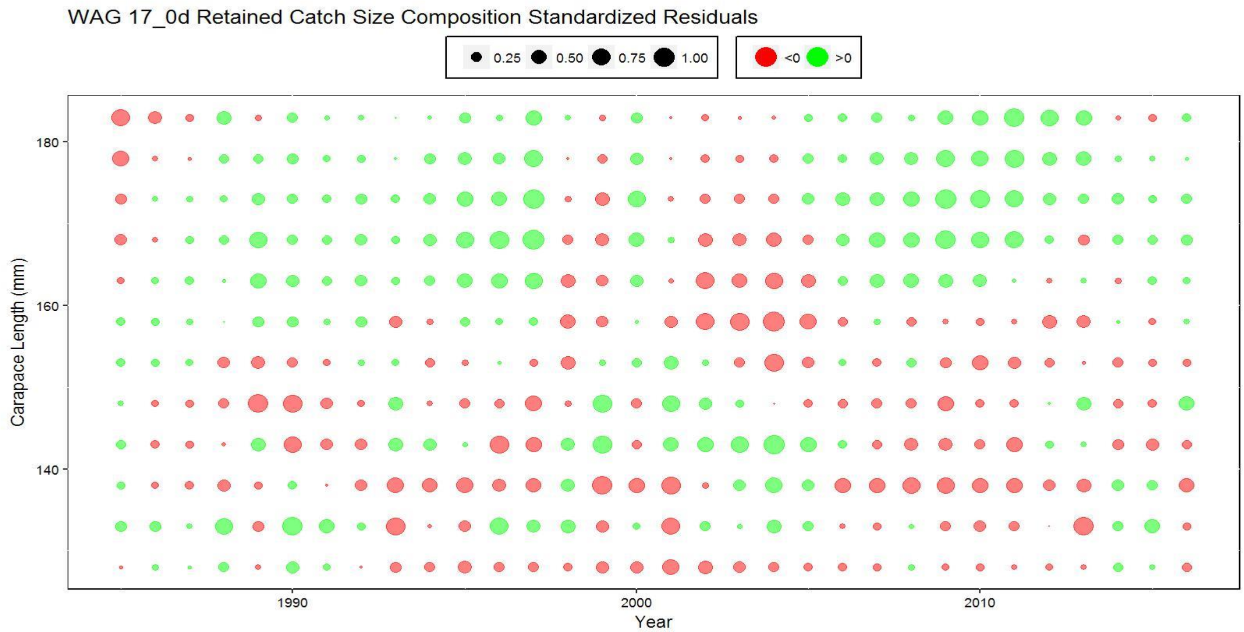


Figure 41. Bubble plot of standardized residuals of retained catch length composition for scenario 17_0d fit for WAG golden king crab, 1985/86–2016/17. Blue circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

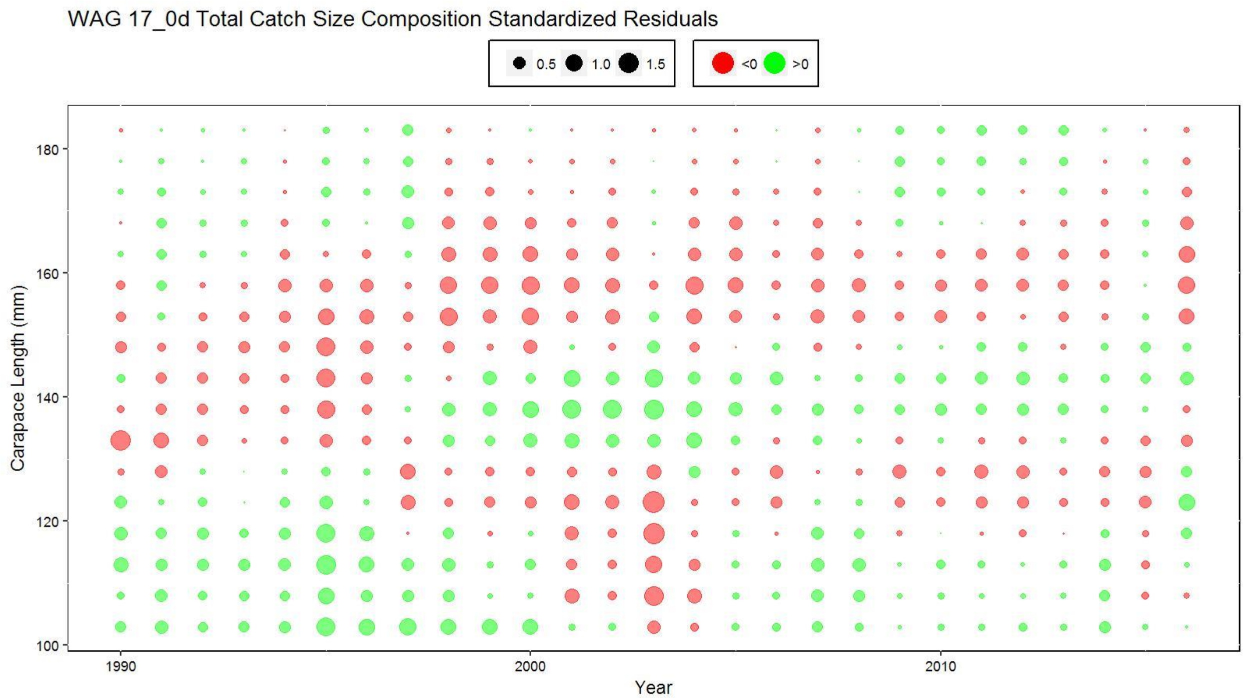


Figure 42. Bubble plot of standardized residuals of total catch length composition for scenario 17_0d fit for WAG golden king crab, 1990/91–2016/17. Blue circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

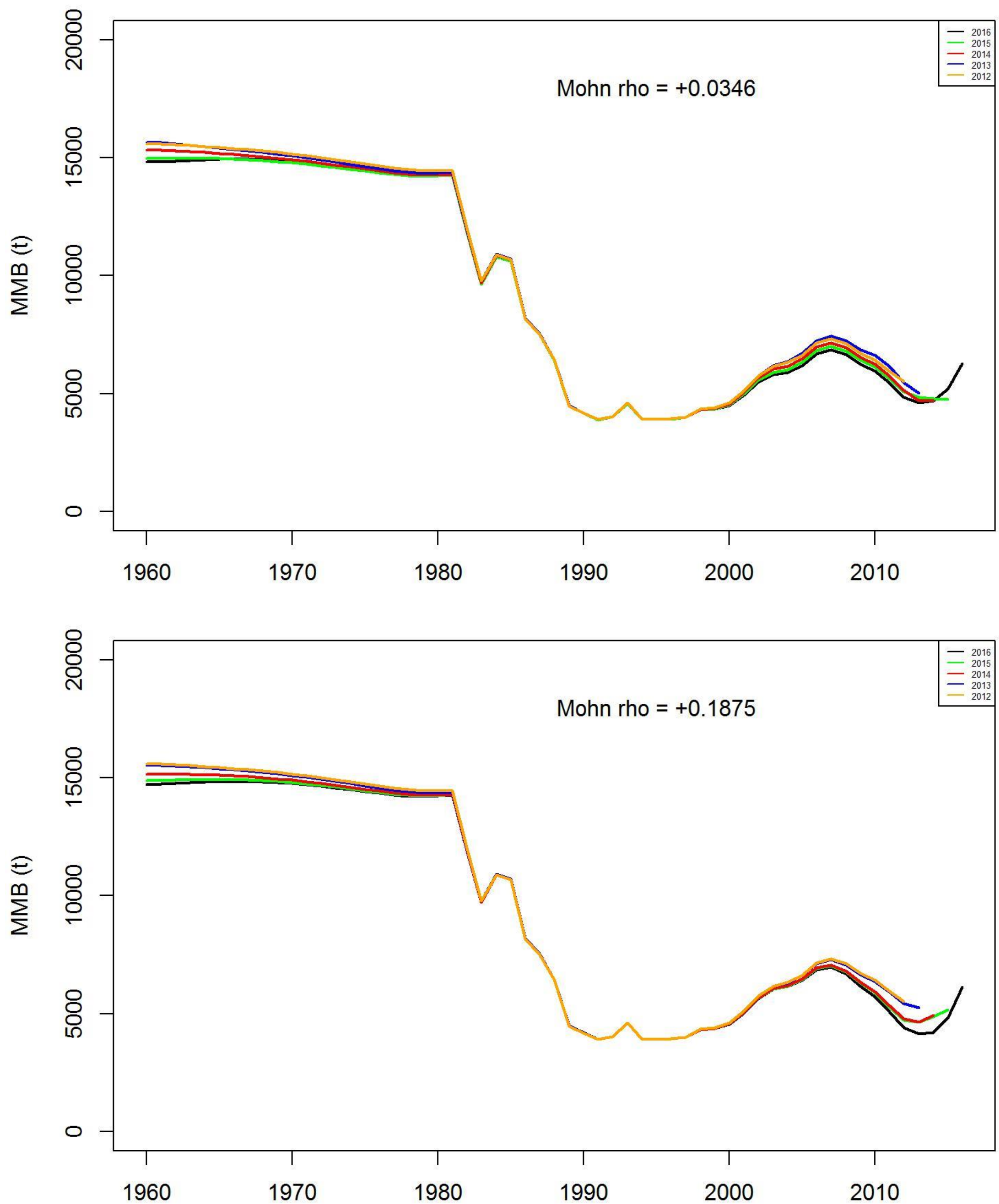


Figure 43. Retrospective fits of MMB by the model following removal of terminal year data under scenarios 17_0 (top) and 17_0d (bottom) for golden king crab in the WAG, 1960/61–2016/17.

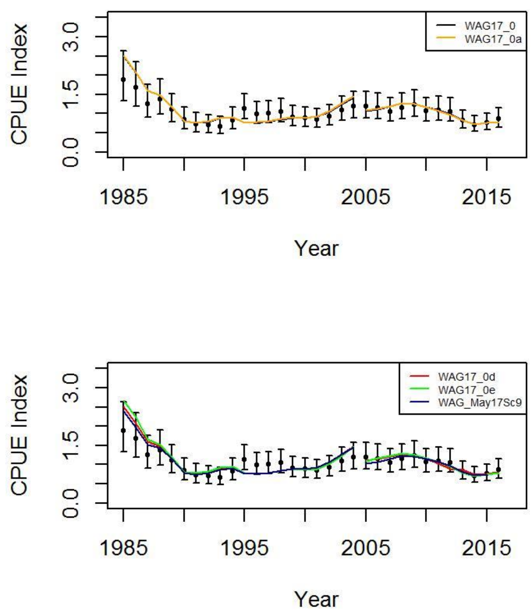


Figure 44. Comparison of input CPUE indices (open circles with +/- 2 SE) with predicted CPUE indices (colored solid lines) under scenarios 17_0 to May 2017 Sc9 for WAG golden king crab data, 1985/86–2016/17. Model estimated additional standard error was added to each input standard error.

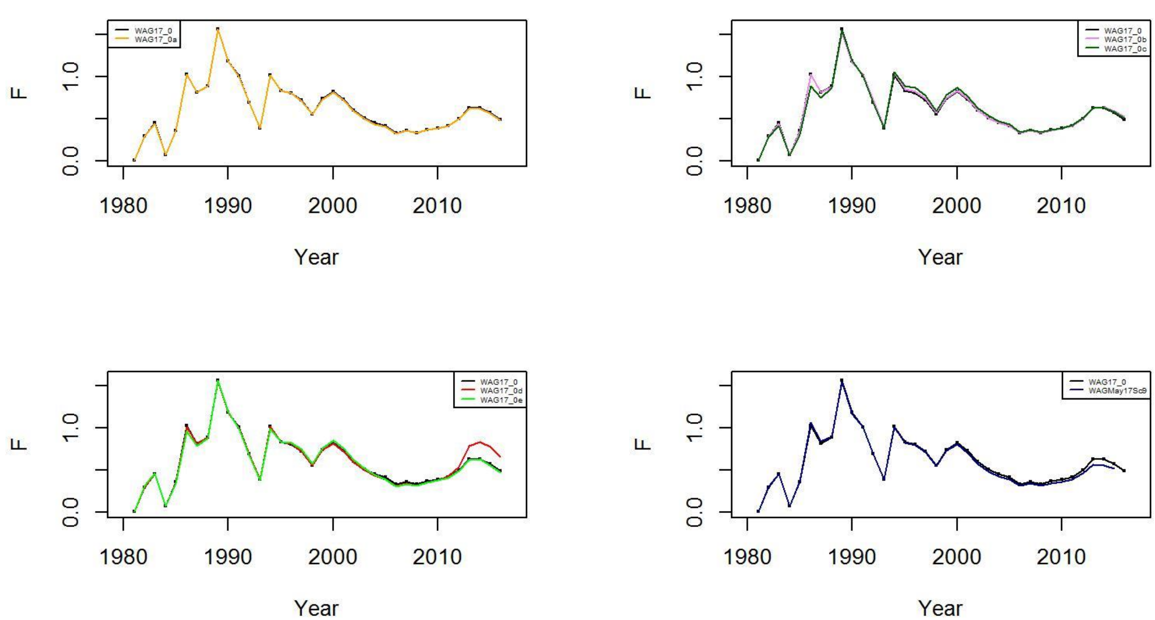


Figure 45. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios 17_0 to May 2017 Sc9 model fits in the WAG, 1981/82–2016/17.

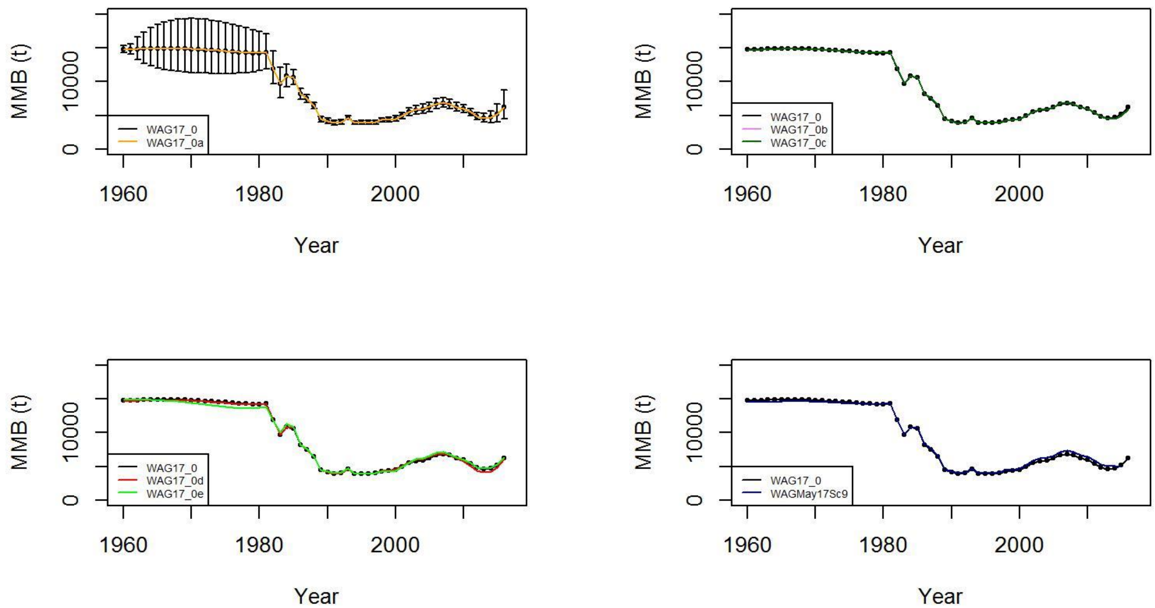


Figure 46. Trends in golden king crab mature male biomass for scenarios 17_0 to May 2017 Sc9 model fits in the WAG, 1960/61–2016/17. Scenario 17_0 estimates have two standard errors confidence limits.

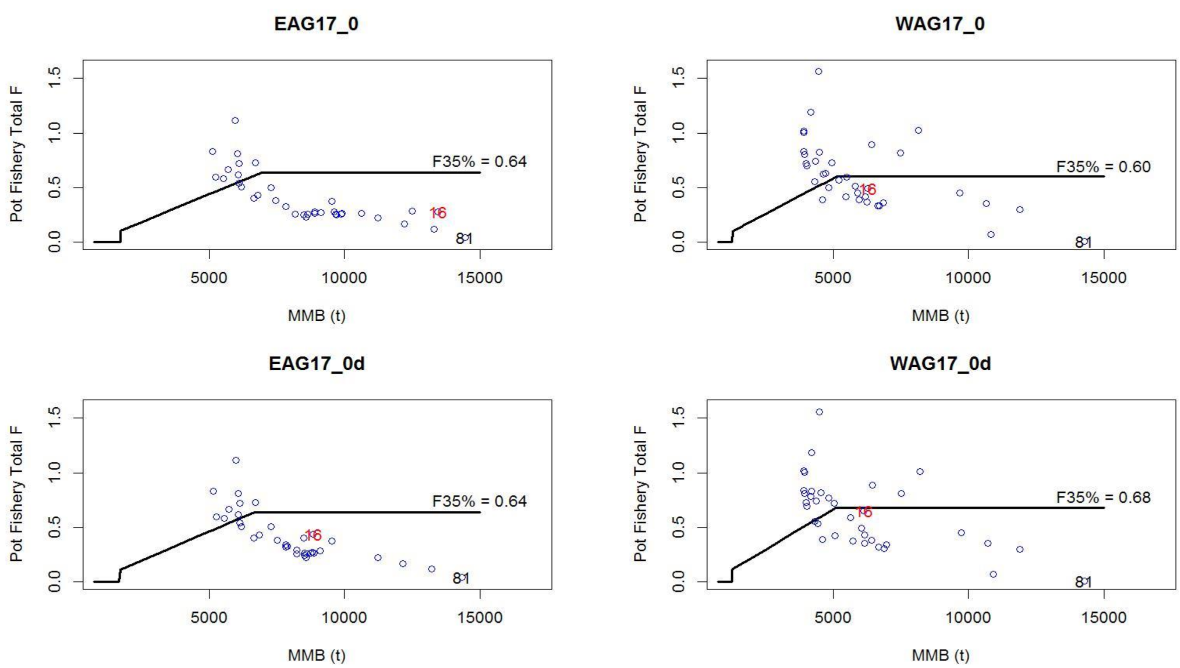


Figure 47. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1985/86–2016/17 under scenarios 17_0 and 17_0d for EAG and WAG. Average recruitment from 1987 to 2012 was used to estimate $MMB_{35\%}$. Pot and groundfish handling mortality rates were assumed to be 0.2 and 0.65, respectively.

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 $\widehat{Tr}_{t,i}$ are respectively the predicted fishery retained, pot fishery discard dead, and groundfish fishery discard dead catches in length class *i* during year *t*; $\widehat{D}_{t,i}$ is estimated from the intermediate total ($\widehat{T}_{t,i\ temp}$) catch and the retained ($\hat{C}_{t,i}$) catch by Equation A.2c. $X_{i,j}$ is the probability of length-class *i* growing into length-class *j* during the year; y_t is elapsed time period from 1 July to the mid –point of fishing period in year *t*; *M* is instantaneous rate of natural mortality; and $R_{t+1,j}$ recruitment to length class *j* in year *t+1*.

The catches are predicted using the equations

$$\widehat{T}_{t,j,temp} = \frac{F_t s_{t,j}^T}{Z_{t,j}} N_{t,j}e^{-y_tM}(1 - e^{-Z_{t,j}}) \qquad \text{(A.2a)}$$

$$\hat{C}_{t,j} = \frac{F_t s_{t,j}^T s_{t,j}^r}{Z_{t,j}} N_{t,j}e^{-y_tM}(1 - e^{-Z_{t,j}}) \qquad \text{(A.2b)}$$

$$\widehat{D}_{t,j} = 0.2(\widehat{T}_{t,j,temp} - \hat{C}_{t,j}) \qquad \text{(A.2c)}$$

$$\widehat{Tr}_{t,j} = 0.65\frac{F_t^{Tr} s_j^{Tr}}{Z_{t,j}} N_{t,j}e^{-y_tM}(1 - e^{-Z_{t,j}}) \qquad \text{(A.2d)}$$

$$\widehat{T}_{t,j} = \hat{C}_{t,j} + \widehat{D}_{t,j} \qquad \text{(A.2e)}$$

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

$$N = X.S.N + R \qquad \text{(A.4)}$$

The equilibrium abundance in 1960, N_{1960} , is

$$\underline{N}_{1960} = (I - XS)^{-1}\underline{R} \qquad \text{(A.5)}$$

where X is the growth matrix, S is a matrix with diagonal elements given by e^{-M} , I is the identity matrix, and $\underline{R}$ is the product of average recruitment and relative proportion of total recruitment to each size-class.

We used the mean number of recruits from 1987 to 2012 in equation (A.5) to obtain the equilibrium solution under only natural mortality in year 1960, and then projected the equilibrium abundance under natural mortality with recruitment estimated for each year after 1960 up to 1985 with removal of retained catches during 1981/82 to 1984/85.

Growth Matrix

The growth matrix X is modeled as follows:

$$X_{i,j} = \begin{cases} 0 & if\ j < i \\ P_{i,j} + (1 - m_i) & if\ j = i \\ P_{i,j} & if\ j > i \end{cases} \qquad \text{(A.6)}$$

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:

$$\mu_i = \omega_1 + \omega_2 * \bar{L}_i. \qquad \text{(A.7)}$$

ω_1 , ω_2 , and σ are estimable parameters, and j_1 and j_2 are the lower and upper limits of the receiving length-class j (in mm CL), and $\bar{L}_i$ is the mid-point of the contributing length interval i. The quantity m_i is the molt probability for size-class i:

$$m_i = \frac{1}{1+e^{c(\tau_i-d)}} \quad \text{(A.8)}$$

where τ_i is the mid-length of the *i*-th length-class, *c* and *d* are parameters.

Selectivity and retention

Selectivity and retention are both assumed to be logistic functions of length. Selectivity depends on the fishing period for the pot fishery:

$$S_i = \frac{1}{1+e^{\left[-ln(19)\frac{\tau_i-\theta_{50}}{\theta_{95}-\theta_{50}}\right]}} \quad \text{(A.9)}$$

where θ_{95} and θ_{50} are the parameters of the selectivity/ retention pattern (Mark Maunder, unpublished generic crab model). In the program, we re-parameterized the denominator (θ_{95} - θ_{50}) to $log(delta\theta)$ so that the difference is always positive and transformed θ_{50} to $log(\theta_{50})$ to keep the estimate always positive.

Recruitment

Recruitment to length–class i during year *t* is modeled as $R_{t,i} = \bar{R}e^{\epsilon_i}\Omega_i$ where Ω_i is a normalized gamma function

$$gamma(x|\alpha_r,\beta_r) = \frac{x^{\alpha_r-1}e^{\frac{x}{\beta_r}}}{{\beta_r}^{\alpha_r}\Gamma_{(\alpha_r)}} \quad \text{(A.10)}$$

with α_r and β_r (restricted to the first five length classes).

Parameter estimation

Table A1 lists the parameters of the model indicating which are estimated and which are pre-specified. The objective function includes contributions related to the fit of the model to the available data and penalties (priors on various parameters).

Tables A2 lists parameter values (with the corresponding coefficient of variations in parentheses) used to weight the components of the objective functions for EAG and WAG.

Likelihood components

Catches

The contribution of the catch data (retained, total, and groundfish discarded) to the objective function is given by:

$$LL_r^{catch} = \lambda_r \sum_t \{\ln(\sum_j \hat{C}_{t,j}w_j + c) - \ln(\sum_j C_{t,j}w_j + c)\}^2 \quad \text{(A.11a)}$$

$$LL_T^{catch} = \lambda_T \sum_t \{ln(\sum_j \hat{T}_{t,j}w_j + c) - ln(\sum_j T_{t,j}w_j + c)\}^2 \quad \text{(A.11b)}$$

$$LL_{GD}^{catch} = \lambda_{GD} \sum_t \{ln(\sum_j \widehat{Tr}_{t,j}w_j + c) - ln(\sum_j Tr_{t,j}w_j + c)\}^2 \quad \text{(A.11c)}$$

where λ_r, λ_T, and λ_{GD} are weights assigned to likelihood components for the retained, pot total, and groundfish discard catches; w_j is the average mass of a crab is length-class j; $C_{t,j}$, $T_{t,j}$, and $Tr_{t,j}$ are, respectively, the observed numbers of crab in size class j for retained, pot total, and groundfish fishery discarded crab during year t, and c is a small constant value. We assumed c = 0.001.

An additional retained catch likelihood (using Equation A.11a without w) for the retained catch in number of crabs during 1981/82 to 1984/85 was also considered in all scenarios.

Catch-rate indices

The catch-rate indices are assumed to be lognormally distributed about the model prediction. Account is taken of variation in addition to that related to sampling variation:

$$LL_r^{CPUE} = \lambda_{r,CPUE}\left\{0.5\sum_t ln\left[2\pi\left(\sigma_{r,t}^2 + \sigma_e^2\right)\right] + \sum_t \frac{\left(ln(CPUE_t^r + c) - ln(\widehat{CPUE}_t^r + c)\right)^2}{2\left(\sigma_{r,t}^2 + \sigma_e^2\right)}\right\} \quad \text{(A.12)}$$

where $CPUE_t^r$ is the standardized retain catch-rate index for year t, $\sigma_{r,t}$ is standard error of the logarithm of $CPUE_t^r$, and $\widehat{CPUE}_t^r$ is the model-estimate of $CPUE_t^r$:

$$\widehat{CPUE}_t^r = q_k \sum_j S_j^T S_j^r \left(N_{t,j} - 0.5\left[\widehat{C_{t,J}} + \widehat{D_{t,J}} + \widehat{Tr_{t,J}}\right]\right)e^{-y_t M} \quad \text{(A.13)}$$

in which q_k is the catchability coefficient during the k-th time period (e.g., pre- and post-rationalization time periods), σ_e is the extent of over-dispersion, c is a small constant to prevent zero values (we assumed c = 0.001), and $\lambda_{r,CPUE}$ is the weight assigned to the catch-rate data. We used the same likelihood formula (A.12) for fish ticket retained catch rate indices.

Following Burnham et al. (1987), we computed the ln(CPUE) variance by:

$$\sigma_{r,t}^2 = \ln(1 + CV_{r,t}^2) \quad \text{(A.14)}$$

Length-composition data

The length-composition data are included in the likelihood function using the robust normal for proportions likelihood, i.e., generically:

$$LL_r^{LF} = 0.5\sum_t\sum_j \ln(2\pi\sigma_{t,j}^2) - \sum_t\sum_j \ln\left[\exp\left(-\frac{(P_{t,j} - \hat{P}_{t,j})^2}{2\sigma_{t,j}^2}\right) + 0.01\right] \quad \text{(A.15)}$$

where $P_{t,j}$ is the observed proportion of crabs in length-class j in the catch during year t, $\hat{P}_{t,j}$ is the model-estimate corresponding to $P_{t,j}$, i.e.:

$$\hat{L}_{t,j}^r = \frac{\hat{C}_{t,j}}{\sum_j^n \hat{C}_{t,j}}$$

$$\hat{L}_{t,j}^T = \frac{\hat{T}_{t,j}}{\sum_j^n \hat{T}_{t,j}}$$

$$\hat{L}^{GF}_{t,j} = \frac{\widehat{Tr}_{t,j}}{\sum_j^n \widehat{Tr}_{t,j}} \qquad (A.16)$$

$\sigma^2_{t,j}$ is the variance of $P_{t,j}$:

$$\sigma^2_{t,j} = \left[(1-P_{t,j})P_{t,j} + \frac{0.1}{n}\right] / S_t \qquad (A.17)$$

and S_t is the effective sample size for year *t* and *n* is the number of size classes.

Note: The likelihood calculation for retained length composition starts from length-class 6 (mid length 128 mm CL) because the length-classes 1 to 5 mostly contain zero data.

Tagging data

Let $V_{j,t,y}$ be the number of tagged male crab that were released during year *t* that were in size-class *j* when they were released and were recaptured after *y* years, and $\underline{\rho}_{j,t,y}$ be the vector of recaptures by size-class from the males that were released in year *t* that were in size-class *j* when they were released and were recaptured after *y* years. The log-likelihood corresponding to the multinomial distribution for the tagging data is then:

$$lnL = \lambda_{y,tag} \sum_j \sum_t \sum_y \sum_i \rho_{j,t,y,i} ln\hat{\rho}_{j,t,y,i} \qquad (A18)$$

where $\lambda_{y,tag}$ is the weight assigned to the tagging data for recapture year *y*, $\hat{\rho}_{j,t,y,i}$ is the proportion in size-class *i* of the recaptures of males that were released during year *t* that were in size-class *j* when they were released and were recaptured after *y* years:

$$\underline{\hat{\rho}}_{j,t,y} \propto \underline{s}^T [\mathbf{X}]^y \underline{Z}^{(j)} \qquad (A19)$$

where $Z^{(j)}$ is a vector with $V_{j,t,y}$ at element *j* and 0 otherwise, and S^T is the vector of total selectivities 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):

$$P_1 = \lambda_F \sum_t (\ln F_t - \ln \bar{F})^2 \qquad (A.20)$$

$$P_2 = \lambda_{F^{Tr}} \sum_t (\ln F_t^{Tr} - \ln \bar{F}^{Tr})^2$$

(A.21)

$$P_3 = \lambda_R \sum_t (\ln \varepsilon_t)^2 \tag{A.22}$$

$$P_5 = \lambda_{posfn} * \text{fpen} \tag{A.23}$$

Standardized Residual of Length Composition

$$\text{Std.Res}_{t,j} = \frac{P_{t,j} - \widehat{P_{t,j}}}{\sqrt{2\sigma^2_{t,j}}} \tag{A.24}$$

Output Quantities

Harvest rate

Total pot fishery harvest rate:

$$E_t = \frac{\sum_{j=1}^{n} (\hat{C}_{j,t} + \hat{D}_{j,t})}{\sum_{j=1}^{n} N_{j,t}} \tag{A.25}$$

Exploited legal male biomass at the start of year t:

$$LMB_t = \sum_{j=legal\ size}^{n} s_j^T s_j^r N_{j,t}\ w_j \tag{A.26}$$

where w_j is the weight of an animal in length-class j.

Mature male biomass on 15 February spawning time (NPFMC 2007) in the following year:

$$MMB_t = \sum_{j=mature\ size}^{n} \{N_{j,t} e^{-y'M} - (\hat{C}_{j,t} + \hat{D}_{j,t} + \widehat{Tr}_{j,t}) e^{(y_t - y')M}\} w_j \tag{A.27}$$

where y' is the elapsed time from 1 July to 15 February in the following year.

For estimating the next year limit harvest levels from current year stock abundances, a F_{OFL} value is needed. Current crab management plan specifies five different Tier formulas for different stocks depending on the strength of information available for a stock, for computing F_{OFL} (NPFMC 2007). For the golden king crab, the following Tier 3 formula is applied to compute F_{OFL}:

If,
$MMB_{current} > MMB_{35\%}, F_{OFL} = F_{35\%}$

If,
$MMB_{current} \leq MMB_{35\%}$ *and* $MMB_{current} > 0.25 MMB_{35\%}$,

$$F_{OFL} = F_{35\%} \frac{\left(\frac{MMB_{current}}{MMB_{35\%}} - \alpha\right)}{(1-\alpha)} \tag{A.28}$$

If,

$MMB_{current} \leq 0.25 MMB_{35\%}$,

$F_{OFL} = 0.$

where α is a parameter, $\mathrm{MMB_{current}}$ is the mature male biomass in the current year and $MMB_{35\%}$ is the proxy MMB_{MSY} for Tier 3 stocks. We assumed $\alpha = 0.1$.
Because projected $\mathrm{MMB_t}$ (i.e., $\mathrm{MMB_{current}}$) depends on the intervening retained and discard catch (i.e., $\mathrm{MMB_t}$ 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
Initial conditions:	
Length specific equilibrium abundance	17 (estimated)
Fishing mortalities:	
Pot fishery, F_t	1981–2016 (estimated)
Mean pot fishery fishing mortality, $\bar{F}$	1 (estimated)
Groundfish fishery, F_t^{Tr}	1989–2016 (the mean F for 1989 to 1994 was used to estimate groundfish discards back to 1981 (estimated)
Mean groundfish fishery fishing mortality, $\bar{F}^{Tr}$	1 (estimated)
Selectivity and retention:	
Pot fishery total selectivity, θ_{50}^{T}	2 (1981–2004; 2005+) or 3 (1981–2004, 2005–2012, 2013+) (estimated)
Pot fishery total selectivity difference, deltaθ^{T}	2 (1981–2004; 2005+) or 3 (1981–2004; 2005–2012; 2013+) (estimated)
Pot fishery retention, θ_{50}^{r}	1 (1981+) (estimated)
Pot fishery retention selectivity difference, deltaθ^{r}	1 (1981+) (estimated)
Groundfish fishery selectivity	fixed at 1 for all size-classes
Growth:	
Expected growth increment, ω_1, ω_2	2 (estimated)
Variability in growth increment, σ	1 (estimated)
Molt probability (size transition matrix with tag data), a	1 (estimated)
Molt probability (size transition matrix with tag data), b	1 (estimated)
Natural mortality, *M*	1 (pre-specified, 0.21$\mathrm{yr^{-1}}$)
Recruitment:	
Number of recruiting length-classes	5 (pre-specified)
Mean recruit length	1 (pre-specified, 110 mmCL)
Distribution to length-class, β_r	1 (estimated)
Median recruitment, $\bar{R}$	1 (estimated)
Recruitment deviations, ε_t	57 (1961–2017) (estimated)

Fishery catchability, q	2 (1985–2004; 2005+) or 3 (1981–2004; 2005–2012; 2013+) (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. select. phase = selectivity phase. Scenario 17_0f is for the independent survey and applicable only to EAG.

Weight	Value Scenario 17_0	Scenario 17_0a	Scenario 17_0b	Scenario 17_0c	Scenario 17_0d	Scenario 17_0e	Scenario 17_0f
Catch:							
Retained catch for 1981–1984 and/or 1985–2016, λ_r	500 (0.032)	500	500	500	500	500	500
Total catch for 1990–2016, 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	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	Number of sampled pots scaled to a max 250
Groundfish bycatch for 1989 –2016, λ_{GD}	0.2 (3.344)	0.2	0.2	0.2	0.2	0.2	0.2
Catch-rate:							
Observer legal size crab catch-rate for 1995–2016, $\lambda_{r,CPUE}$	1(0.805)	1	1	1	1	1	1
Independent survey catch-rate for 2015–2017, $\lambda_{r,CPUE}$							1(0.805)
Fish ticket retained crab catch-rate for 1985–1998 , $\lambda_{r,CPUE}$	1(0.805)	1	1	1	1	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	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	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	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	Initially 1000, relaxed to 0.001 at phases ≥ select. phase
Recruitment, λ_R	2 (0.533)	2	2	2	2	2	2
Posfunction (to keep abundance estimates always positive), λ_{posfn}	1000 (0.022)	1000	1000	1000	1000	1000	1000

Tagging likelihood	EAG individual tag returns	EAG tag data	EAG tag data	EAG tag data	EAG tag data	EAG tag data	EAG tag data

$*$ Coefficient of Variation, $\mathrm{CV} = \sqrt{\exp[\frac{1}{2\mathrm{W}}] - 1}$, 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:

$$\sum_{j=1}^{k} C_j \frac{LF_{j,i}}{\sum_{i=1}^{n} LF_{j,i}} \tag{B.1}$$

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 1990/91–2016/17 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 1995/96–2016/17. The 1990/91–2016/17 observer database consists of 112,510 records and that of 1995/96–2016/17 contains 108,231 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 –2016/17.

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 2005/06–2016/17, 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 previous to 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 26).

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.

Most scenarios used CPUE indices estimated by the GLM method. One scenario (17_0a) used the deltaGLMM spatio-temporal method (VAST, Thorson et al., 2015) to estimate observer CPUE indices. We describe both below:

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. Therefore, we assumed the null model to be

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year}_{\mathrm{y_i}} \tag{B.2}$$

where Year is a factorial variable.

The maximum set of model terms offered to the stepwise selection procedure was:

$$\ln(\mathrm{CPUE_I}) = \mathrm{Year}_{\mathrm{y_i}} + \mathrm{ns}(\mathrm{Soak_{si}}, \mathrm{df}) + \mathrm{Month}_{\mathrm{m_i}} + \mathrm{Vessel_{vi}} + \mathrm{Captain_{ci}} + \mathrm{Area_{ai}} + \mathrm{Gear_{gi}} + \mathrm{ns}(\mathrm{Depth_{di}}, \mathrm{df}) + \mathrm{ns}(\mathrm{VesSoak_{vsi}}, \mathrm{df}) \;, \tag{B.3}$$

where Soak is in unit of days and is numeric; Month, Area code, Vessel code, Captain code, and Gear code are factorial variables; Depth in fathom is a numeric variable; VesSoak is a numeric variable computed as annual number of vessels times annual mean soak days (to account for other vessels' effect on CPUE); ns=cubic spline, and df = degree of freedom.

We used a log link function and a dispersion parameter (θ) in the GLM fitting process. We used the R^2 criterion for predictor variable selection (Siddeek *et al*. 2016b).

The R^2 formula for explanatory variable selection is as follows:

$$R^2 = \frac{(null\ model\ deviance - added\ parameter\ model\ deviance)}{null\ model\ deviance} \quad \text{(B.4)}$$

An arbitrary R^2 minimum increment of 0.01 was set to select the model terms.

First we determined the dispersion parameter (θ) by a grid search method (Fox and Weisberg, 2011). The best θ value was obtained at the minimum AIC:

Table B.1. Dispersion parameter search.

	Time Period	**θ**	**AIC**
EAG	1995/96–2004/05	1.37	223,933
	2005/06–2016/17	2.30	59,284
WAG	1995/96–2004/05	1.00	196,290
	2005/06–2016/17	1.17	94,190

Then we used the optimized dispersion parameter value in the GLM model for individual predictor variable fit to determine appropriate df value based on the minimum AIC:

Table B.2. Predictor variable degree of freedom search.

	Time Period	**Predictor Variable**	**Df**	**AIC**
EAG	1995/96–2004/05	Soak	4	235,222
		Depth	2	237,098
		VesSoak	9	232,152
	2005/06–2016/17	Soak	11	59,988
		Depth	6	60,215
		VesSoak	4	59,982
WAG	1995/96–2004/05	Soak	10	201,755
		Depth	9	205,398
		VesSoak	7	204,841
	2005/06–2016/17	Soak	5	95,181
		Depth	2	95,202
		VesSoak	4	94,954

We also used the "stepAIC" package (R Core Team, 2018) for forward selection of predictor variables for CPUE standardization for scenarios EAG17_0b and WAG17_0b, respectively. Instead of using the traditional AIC (-2log_likelihood+2p) we used CAIC {-2log_likelihood+[ln(n)+1]p} for variable selection, where n=number of observations and p= number of parameters to be estimated.

The final main effect models for EAG were:

Under R square selection criteria:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{Area} + \mathrm{ns}(\mathrm{Soak}, 4)$ (B.5)
for the 1995/96–2004/05 period [θ=1.37, $R^2 = 0.2473$, AIC=223,933]

Under CAIC selection criteria:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{ns}(\mathrm{Soak}, 4) + \mathrm{Month} + \mathrm{Area}$ (B.6)
for the 1995/96–2004/05 period [θ=1.37, $R^2 = 0.2563$, AIC=224,707]

Under R square selection criteria:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 11)$ (B.7)
for the 2005/06–2016/17 period ($\theta = 2.30$, $R^2 = 0.1177, \mathrm{AIC} = 59{,}284$).

Under CAIC selection criteria:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Vessel} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 11)$ (B.8)
for the 2005/06–2016/17 period ($\theta = 2.30$, $R^2 = 0.1143, \mathrm{AIC} = 59{,}610$).

The final models for WAG were:

Under R square selection criteria:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 10) + \mathrm{Area}$ (B.9)
for the 1995/96–2004/05 period [θ=1.00, $R^2 = 0.2031$, AIC=196,290]

Under CAIC selection criteria:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 10) + \mathrm{Month} + \mathrm{Vessel} + \mathrm{ns}(\mathrm{Depth}, 9)$ (B.10)
for the 1995/96–2004/05 period [θ=1.00, $R^2 = 0.1948$, AIC=197,640]

Under R square selection criteria:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Area} + \mathrm{Gear} + \mathrm{ns}(\mathrm{Soak}, 5)$ (B.11)
for the 2005/06–2016/17 period
[θ=1.17, $R^2 = 0.0831, \mathrm{AIC} = 94{,}190$ with $\mathrm{ns}(\mathrm{Soak}, 5)$ forced in]

Under CAIC selection criteria:
$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Vessel} + \mathrm{ns}(\mathrm{Depth}, 2) + \mathrm{Month} + \mathrm{ns}(\mathrm{Soak}, 5)$ (B.12)
for the 2005/06–2016/17 period
[θ=1.17, $R^2 = 0.0684, \mathrm{AIC} = 94{,}699$ with $\mathrm{ns}(\mathrm{Soak}, 5)$ forced in]

The final model after adding the Year:Area interaction term in the scope of variables for EAG were:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Gear} + \mathrm{Captain} + \mathrm{Area} + \mathrm{Year{:}\,Area} + \mathrm{ns(Soak, 4)} \qquad \text{(B.13)}$$

for the 1995/96–2004/05 period
[θ=1.37, $R^2 = 0.2684$, AIC=223,164 with $\mathrm{ns(Soak, 4)}$ forced in]

Note: A number of indeterminate parameter values for interaction factors were observed. However, as per January 2018 CPT request, we used the resulting CPUE indices in scenario EAG17_0c.

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns(Soak, 11)} \qquad \text{(B.14)}$$

for the 2005/06–2016/17 period [$\theta = 2.30,\ R^2 = 0.1177, \mathrm{AIC} = 59{,}284$].

Note: The Year:Area interaction term was not selected.

The final model after adding Year:Area interaction term in the scope of variables for WAG were:

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Captain} + \mathrm{Gear} + \mathrm{ns(Soak, 10)} + \mathrm{Area} \qquad \text{(B.15)}$$

for the 1995/96–2004/05 period [θ=1.00, $R^2 = 0.2031$, AIC=196,290]

Note: The Year:Area interaction term was not selected.

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{Area} + \mathrm{Year{:}\,Area} + \mathrm{ns(Soak, 5)} \qquad \text{(B.16)}$$

for the 2005/06–2016/17 period
[θ=1.17, $R^2 = 0.1356, \mathrm{AIC} = 94{,}273$ with $\mathrm{ns(Soak, 5)}$ forced in]

Note: A number of indeterminate parameter values for interaction factors were observed. However, as per January 2018 CPT request, we used the resulting CPUE indices in scenario WAG17_0c.

Figures B.1 to B.4 depict the trends in nominal and standardized CPUE indices for the two CPUE time series for EAG and WAG, respectively.

b. *Fishery independent survey CPUE index by GLM*:

The fishing industry and ADF&G cooperative fishery independent surveys have been conducted during the first month of each fishing season (i.e., August) for the last three years, 2015-2017 in the EAG, and this project is expected to continue. The sampling procedure is different from the observer sampling design. Fishing operations are conducted in a randomly selected grids (2km X 2km) and five pots per string are sampled for fishery and biological data collection (e.g., date, vessel, captain, soak time, depth, Lat. Long., pot number, string number, species, sex, size, legal status, catch, etc.). There are 7294 records for EAG golden king crab. 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.

The GLM followed the same procedure as that for observer data for standardizing CPUE. Only R^2 criterion was used for variable selection. The null model was

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year_{y_i}} \tag{B.17}$$

where Year is a factorial variable.

The maximum set of model terms offered to the stepwise selection procedure was:

$$\ln(\mathrm{CPUE_i}) = \mathrm{Year_{y_i}} + \mathrm{ns}(\mathrm{Soak_{si}}, \mathrm{df}) + \mathrm{Vessel_{vi}} + \mathrm{Captain_{ci}} + \mathrm{VesStrPot_{Si}} + Lat_i + \mathrm{Long}Long_i + \mathrm{ns}(\mathrm{Depth_{di}}, \mathrm{df})$$

(B.18)

where Soak is in unit of days and is numeric; Depth in fathom is a numeric variable; Vessel code, Captain code, VesStrPot , Lat, and Long are factorial variables; ns=cubic spline, and df = degree of freedom. To make a unique factor level for vessel, string, and pot, we concatenated the Vessel code, string ID, and PotID (VesStrPot)..

The final model was

$$\ln(\mathrm{CPUE}) = \mathrm{Year} + \mathrm{VesStrPot} + \mathrm{Lat} + \mathrm{ns}(\mathrm{Soak}, 11) \tag{B.19}$$

for the 2015/16–2017/18 period

$[\theta = 2.30,\ R^2 = 0.55695, \mathrm{AIC} = 30{,}481 \text{ with } \mathrm{ns}(\mathrm{Soak}, 11) \text{ forced in}]$.

Because the assessment model considered fisheries data up to 2016/17, we used CPUE indices for 2015/16 – 2016/17 in the fitting of scenario EAG17_0f.

Figure B.5 shows the trends in nominal and standardized CPUE indices for the two CPUE time series for the independent survey in EAG.

c. *Observer CPUE index by VAST*:

We used a spatio-temporal deltaGLMM (Thorson et al., 2015; Thorson et al., 2017; Thorson and Barnett, 2017) to develop separate sets of CPUE indices based on the observer data for the pre- (1995/96–2004/05) and post- rationalization (2005/06–2016/17) periods. This is a two-stage model that first estimates the probability of presence (B.20) then estimates positive catch rates in the second stage (B.21). To account for the spatial dependence of crab density within the model, spatial and spatio-temporal autocorrelation are incorporated into the model as random effects. Positive catch rates in the model are a function of area fished. Since area swept is difficult to define for a pot gear, we used soak time as the area fished proxy. The number of knots is user defined and derived over the spatial domain based on the relative sampling density. Based on the fishing locations recorded during 1995/96-2016/17, one hundred knots were selected for each of EAG and WAG (Thorson et al., 2015; Runnebaum et al., 2017) (Figure B.6).

The final models applied to each period for EAG and WAG data are:

$$P_i = logit^{-1}\,[d^{(p)}_{T_{(i)}} + r^{(p)}_{v_i} + \omega^{(p)}_{J_{(i)}} + \varepsilon^{(p)}_{J_{(i)},T_{(i)}}\ ] \tag{B.20}$$

$$\lambda_i = w_i exp[d^{(\lambda)}_{T_{(i)}} + r^{(\lambda)}_{v_i} + \omega^{(\lambda)}_{J_{(i)}} + \varepsilon^{(\lambda)}_{J_{(i)},T_{(i)}}\ ] \tag{B.21}$$

where
P_i and λ_i are the expected probabilities of an occupied habitat and positive catches given occupied habitat for sample i at a given location; $d_{T_{(i)}}$ is the average annual density in year $T_{(i)}$; J_i is the nearest knot to sample i; w_i is the soak time for sample i; $\omega_{J_{(i)}}$ is a random field accounting for spatially correlated variability at knot $J_{(i)}$ that is persistent among years; $\varepsilon_{J_{(i)},T_{(i)}}$ is the random field accounting for spatio-temporal correlation at knot $J_{(i)}$ in year $T_{(i)}$; and r_{v_i} is a random effect accounting for differences in catch between vessels.

Figure B.7 compares the CPUE index trends between GLM and deltaGLMM estimates for EAG and WAG. The CPUE trends are similar, in particular during the post rationalization period. The confidence intervals for deltaGLMM estimated CPUE indices are wider than those of GLM estimated CPUE indices. Spatio-temporal models have been shown to provide more precision compared to design sampling of stock distribution because they are able to account for the spatial variation in density, thereby minimizing unexplained variability (Thorson et al., 2015). However, this was not the case when using a spatio-temporal deltaGLMM for golden king crab along the Aleutian Islands. There are likely two contributing factors to the increased variability in CPUE estimates. 1) Currently the VAST modeling framework is not able to account for an ‘edge effect’ when extrapolating species density to a given grid cell. In essence, there is no recognition of a land existing between density distributions, it appears density estimates from a given knot are being extrapolated over land. 2) Standard abundance surveys use a pre-designed grid and sample all grid cells consistently; on the other hand, commercial fishery samples the stock area opportunistically. Consequently, there are some years where there are large gaps in coverage, resulting in large areas being assigned density estimates with no direct observations for that area. This is leading to likely uncertainty in the spatial variability in density estimates. These are the two likely causes of increased variability in standard error estimates when using the deltaGLMM for Aleutian Islands golden king crab.

Fish Ticket CPUE index:

We also fitted the lognormal GLM for the fish ticket retained CPUE time series 1985/86–1998/99 offering Year, Month, Vessel, Captain, and Area as explanatory variables. The fitting procedure was similar to that followed for observer data analysis. There were 20,435 records for 1985/86 –2016/17. The number of records was reduced by considering only those for 1985/86 – 1998/99, positive catches, and Vessels with five trips per year for at least three years.

The final model for EAG was:

Under R square selection criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Area} + \text{Vessel} + \text{Month},\ R^2 = 0.5037, \text{AIC} = 4{,}957 \quad \text{(B.22)}$$

Under CAIC selection criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Vessel} + \text{Month},\ R^2 = 0.3700,\ \text{AIC} = 5{,}345 \quad \text{(B.23)}$$

and those for WAG was:

Under R square selection criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Vessel} + \text{Area},\ R^2 = 0.4971,\ \text{AIC} = 9{,}923 \quad \text{(B.24)}$$

Under CAIC selection criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Vessel},\ R^2 = 0.3679,\ \text{AIC} = 10{,}670 \quad \text{(B.25)}$$

The final model after adding the Year:Area interaction term in the scope of variables for EAG were:

Under R square selection criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Area} + \text{Vessel} + \text{Month} + \text{Year:Area},\ R^2 = 0.6086,\ \text{AIC} = 4{,}783 \quad \text{(B.26)}$$

The final model after adding the Year:Area interaction term in the scope of variables for WAG were:

Under R square selection criteria:

$$\ln(\text{CPUE}) = \text{Year} + \text{Captain} + \text{Vessel} + \text{Area} + \text{Year:Area},\ R^2 = 0.6105,\ \text{AIC} = 9{,}802 \quad \text{(B.27)}$$

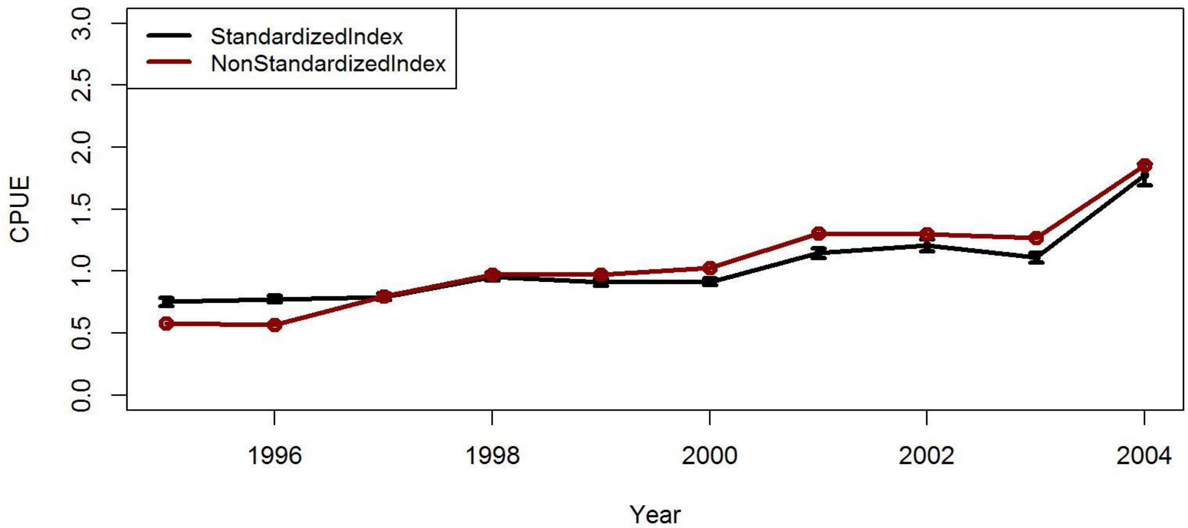
Note:

1. A number of indeterminate parameter values for Year:Area interaction factors were observed. However, as per January 2018 CPT request, we used the resulting CPUE indices in scenarios EAG17_0c and WAG17_0c.

2. The R^2 values for the fish ticket data fits are much higher compared to that for observer data fits.

Figures B.8 and B.9 depict the trends in nominal and standardized CPUE indices for the 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.



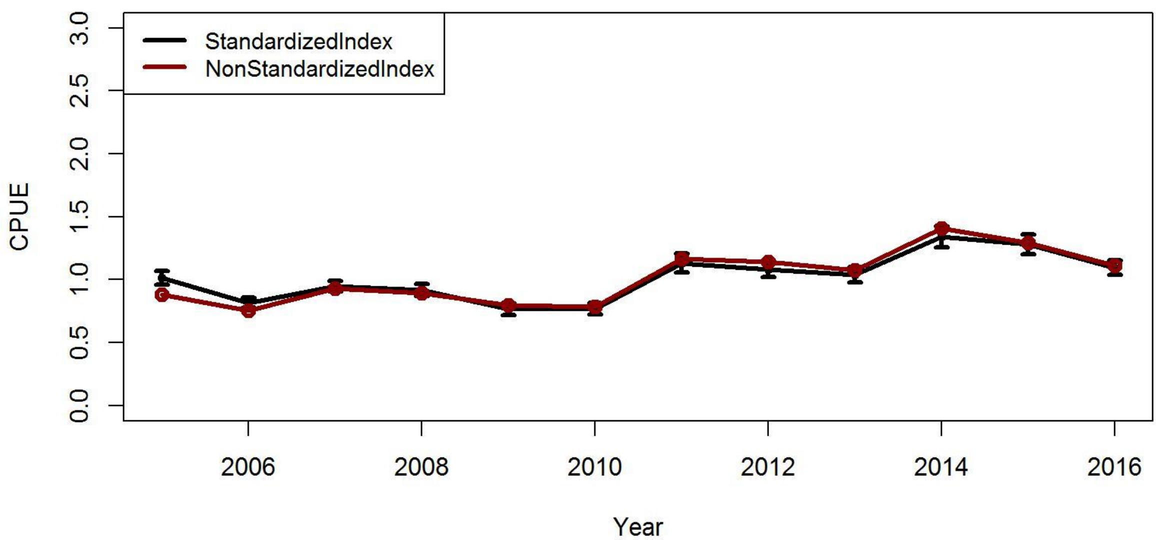
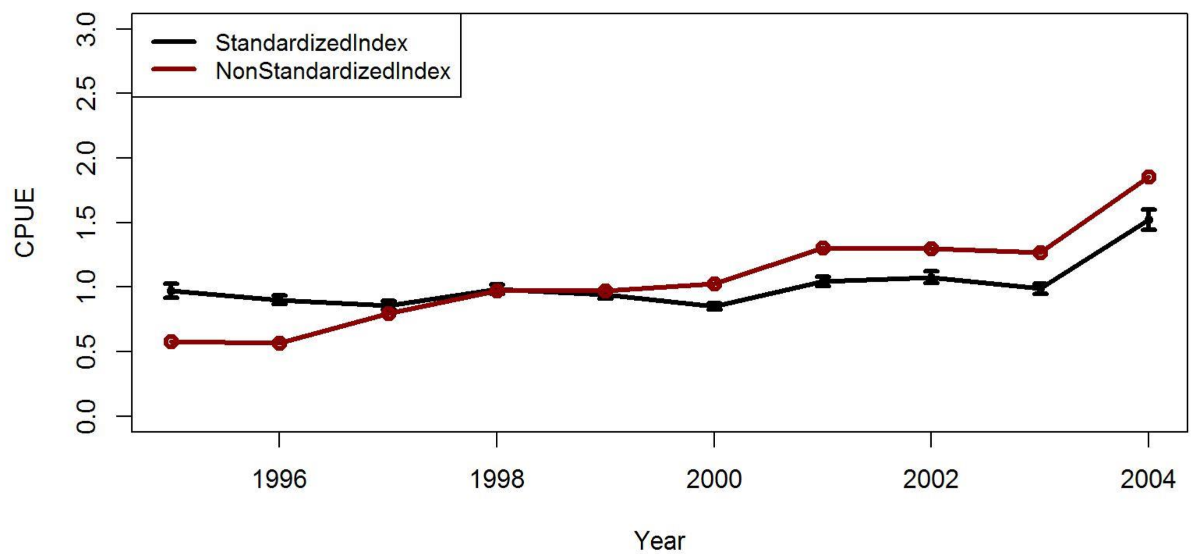


Figure B.1. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from EAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05, and bottom panel: 2005/06–2016/17. Standardized indices: black line and non-standardized indices: red line. Variable selection by R^2 criteria.



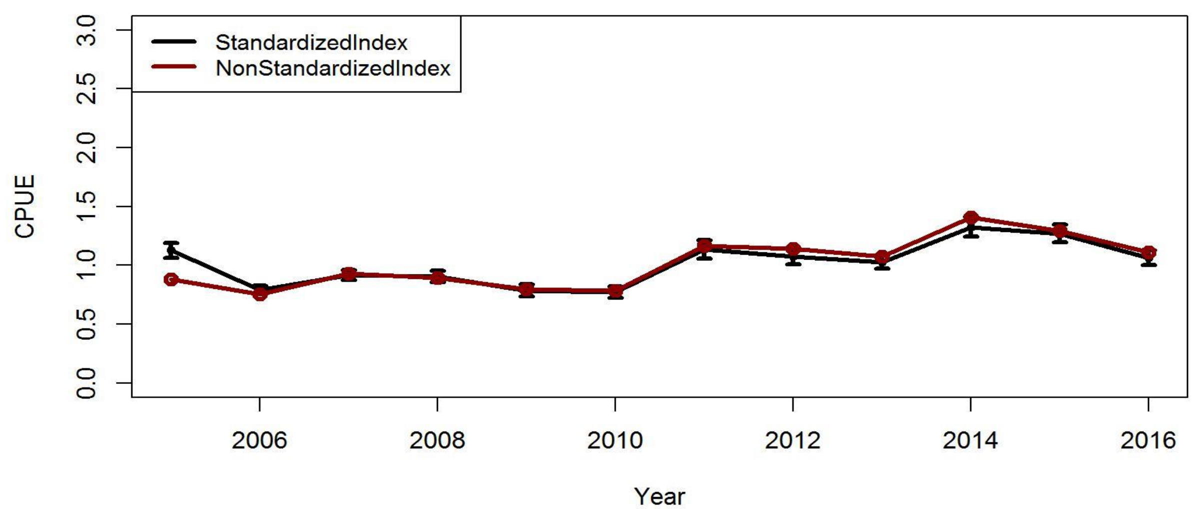


Figure B.2. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from EAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05, and bottom panel: 2005/06–2016/17. Standardized indices: black line and non-standardized indices: red line. Variable selection by CAIC criteria.

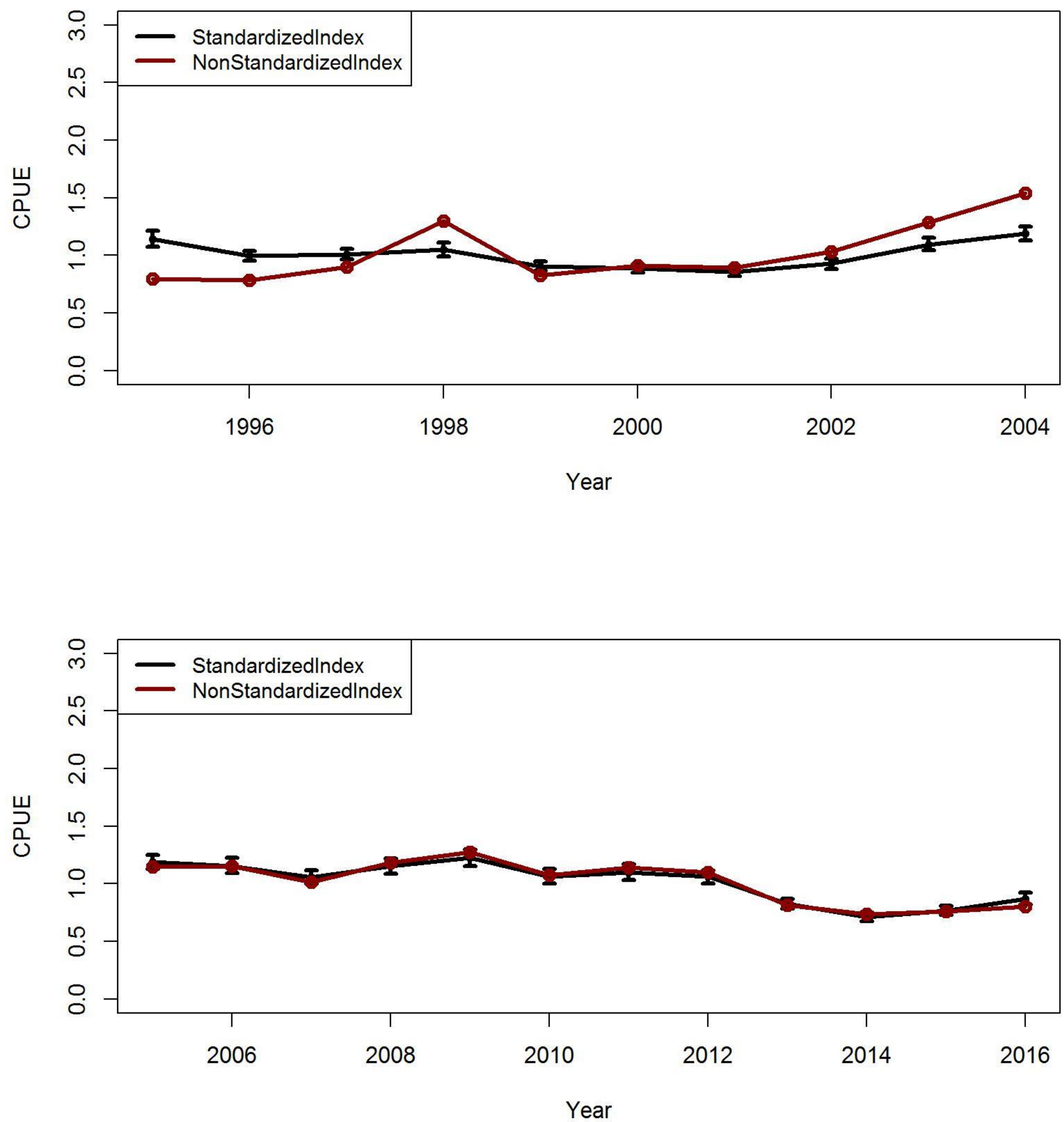


Figure B.3. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from WAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05, and bottom panel: 2005/06–2016/17. Standardized indices: black line and non-standardized indices: red line. Variable selection by R^2 criteria.

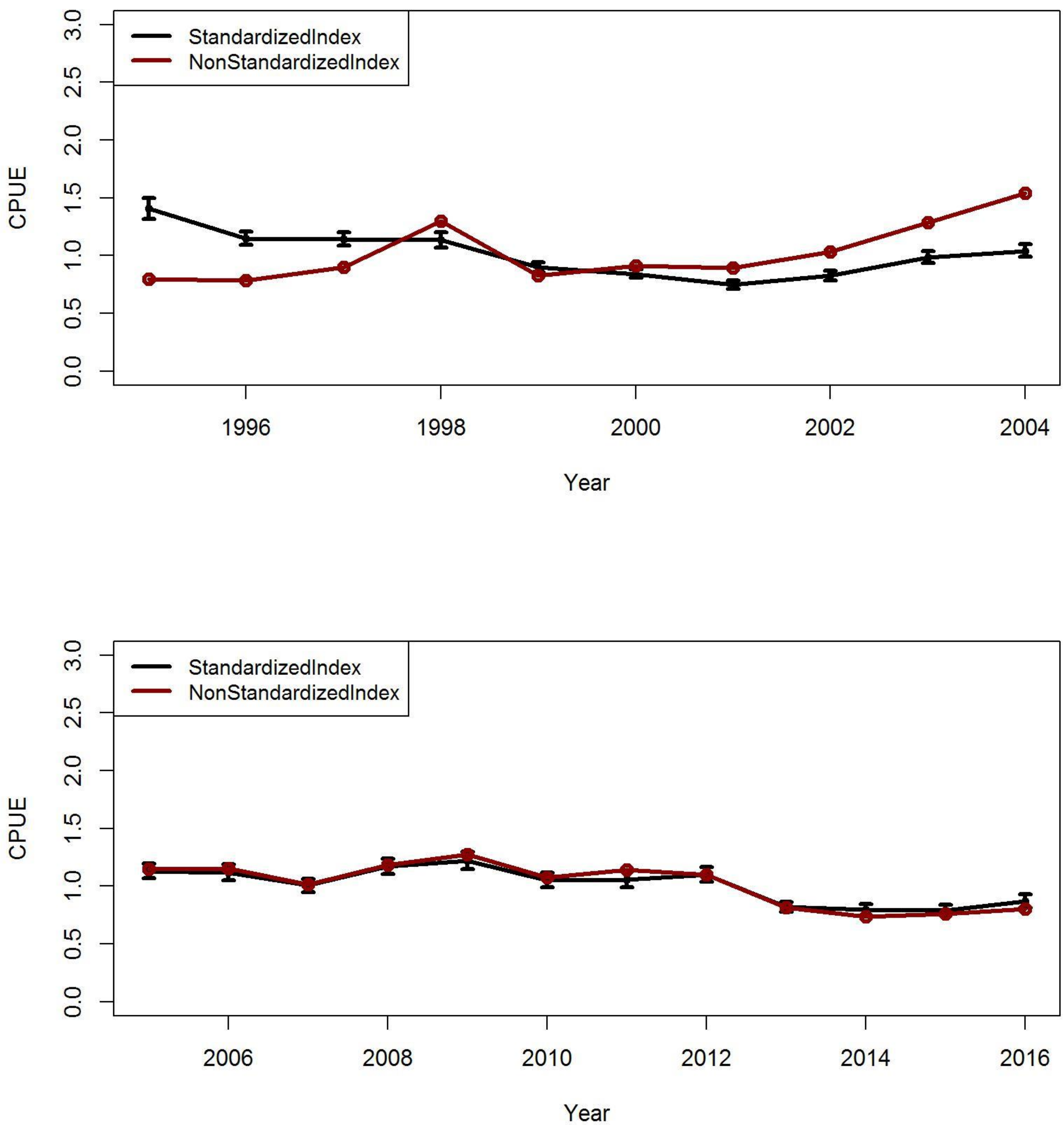


Figure B.4. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from WAG (east of 174 ° W longitude). Top panel: 1995/96–2004/05, and bottom panel: 2005/06–2016/17. Standardized indices: black line and non-standardized indices: red line. Variable selection by CAIC criteria.

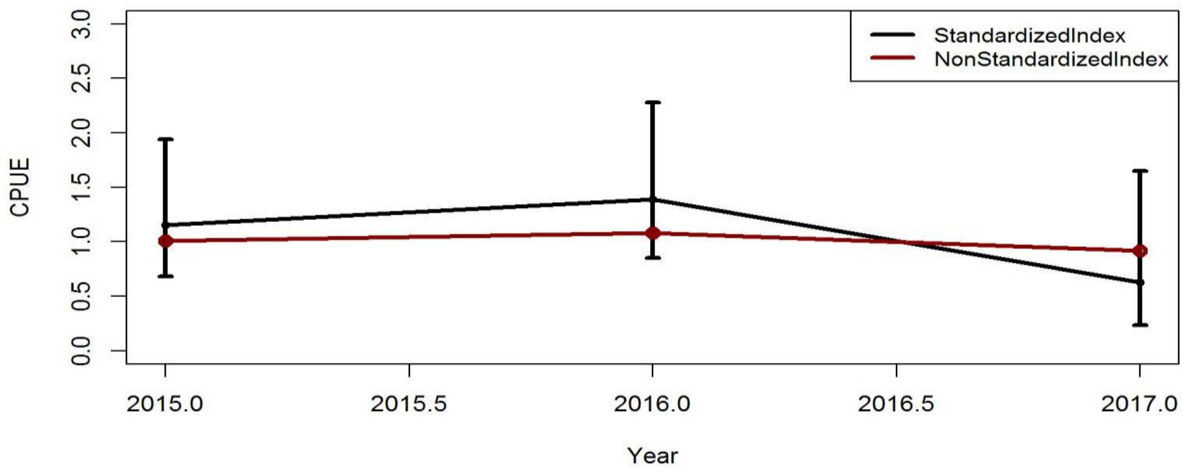


Figure B.5. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab independent survey data from EAG (east of 174 ° W longitude) during 2015–2017. Standardized indices: black line and non-standardized indices: red line. Variable selection by R^2 criteria.

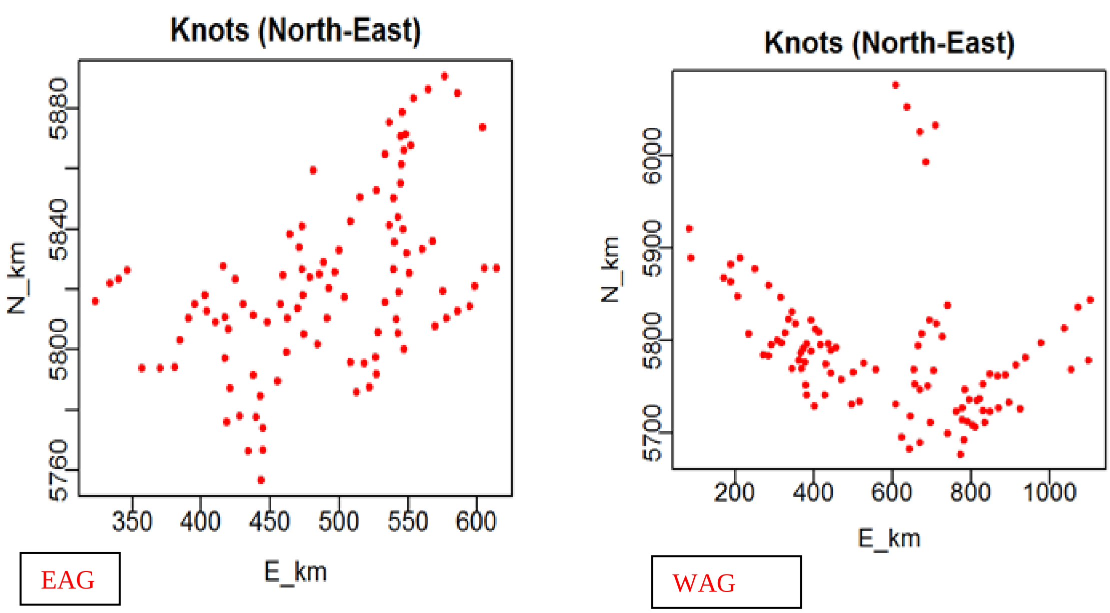
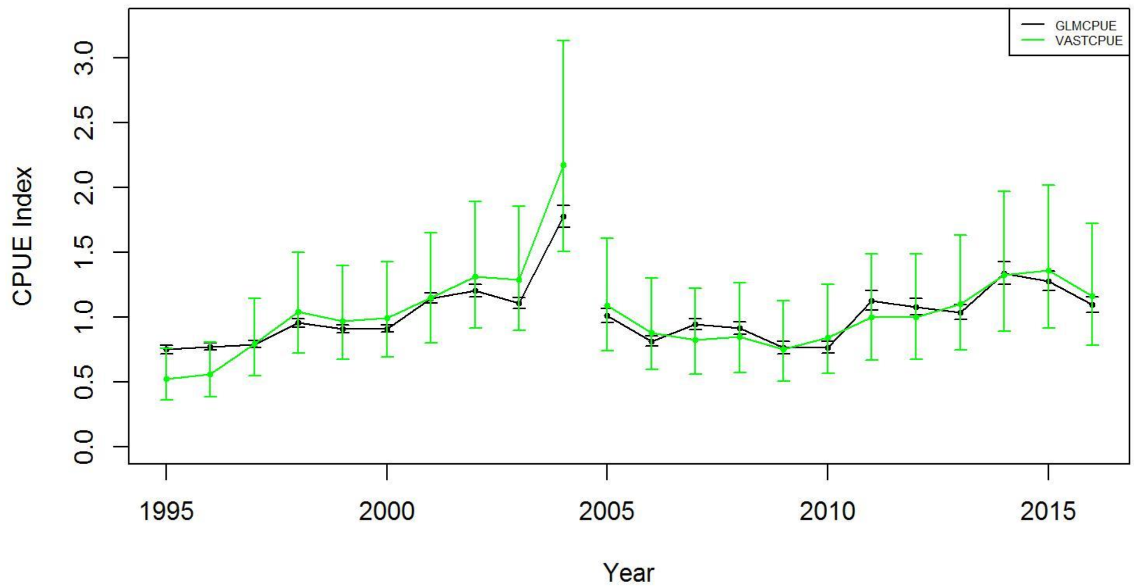


Figure B6. One hundred knots selected each for EAG (left panel) and WAG (right panel) for spatio-temporal delta GLMM model fitting for CPUE indices estimation.



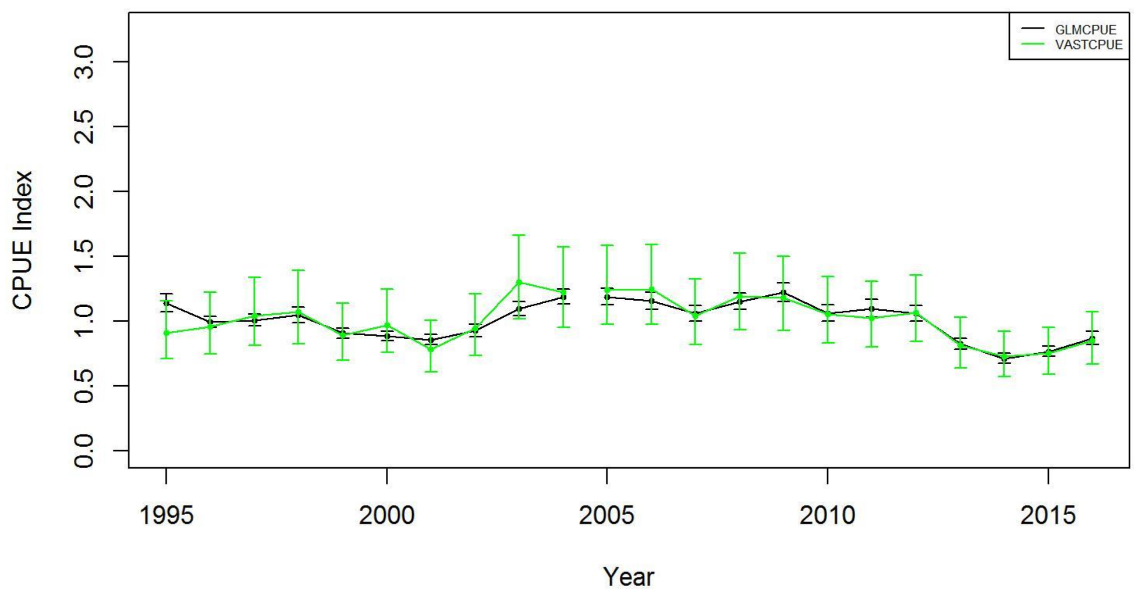
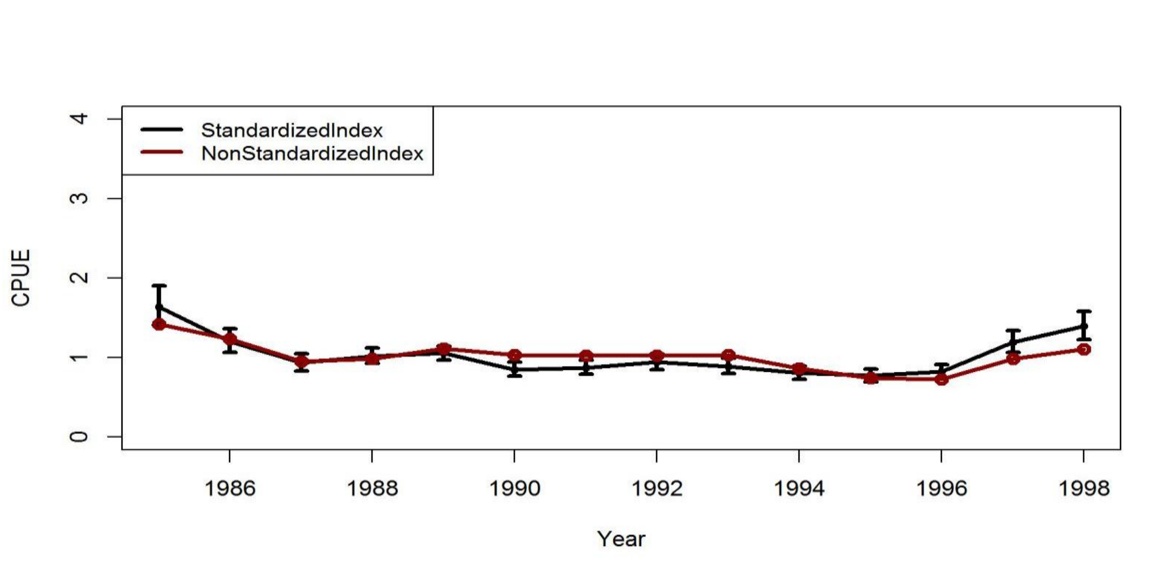


Figure B.7. Comparison of GLM (black) and VAST (green) estimated CPUE indices with +/- 2 SE for Aleutian Islands golden king crab in EAG (top panel) and WAG (bottom panel) for 1995/96–2016/17. GLM variable selection by R^2 criteria.



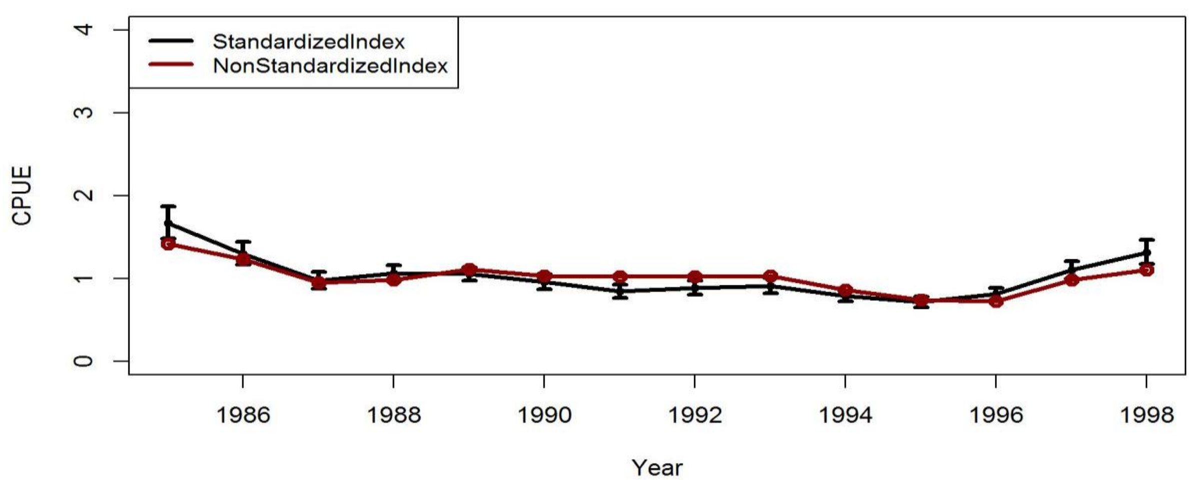
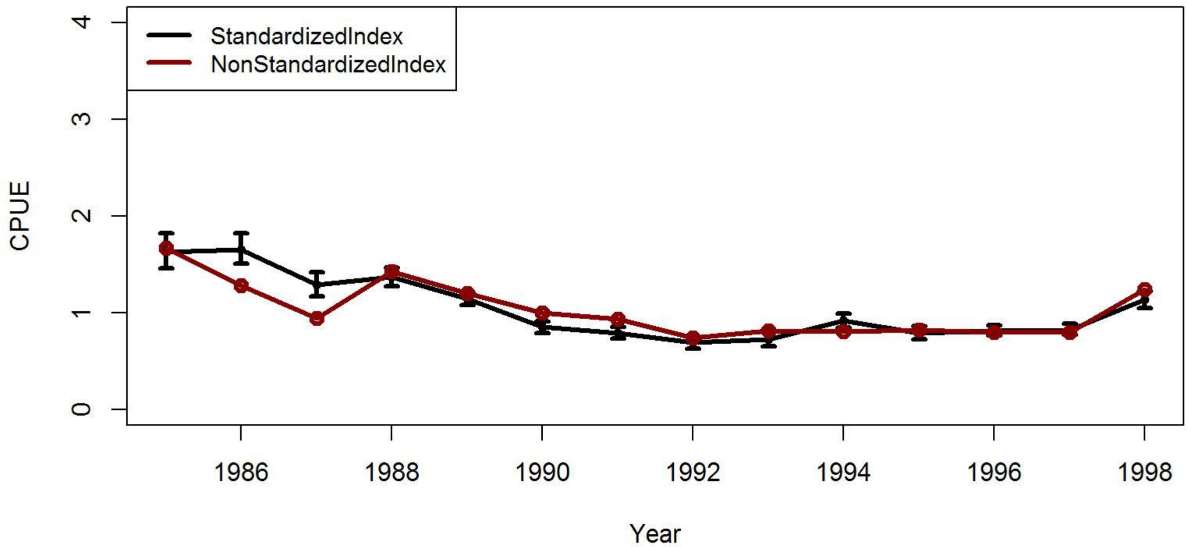


Figure B.8. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG. The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line. Top panel: variable selection by R^2 criteria; bottom panel: variable selection by CAIC square criteria.



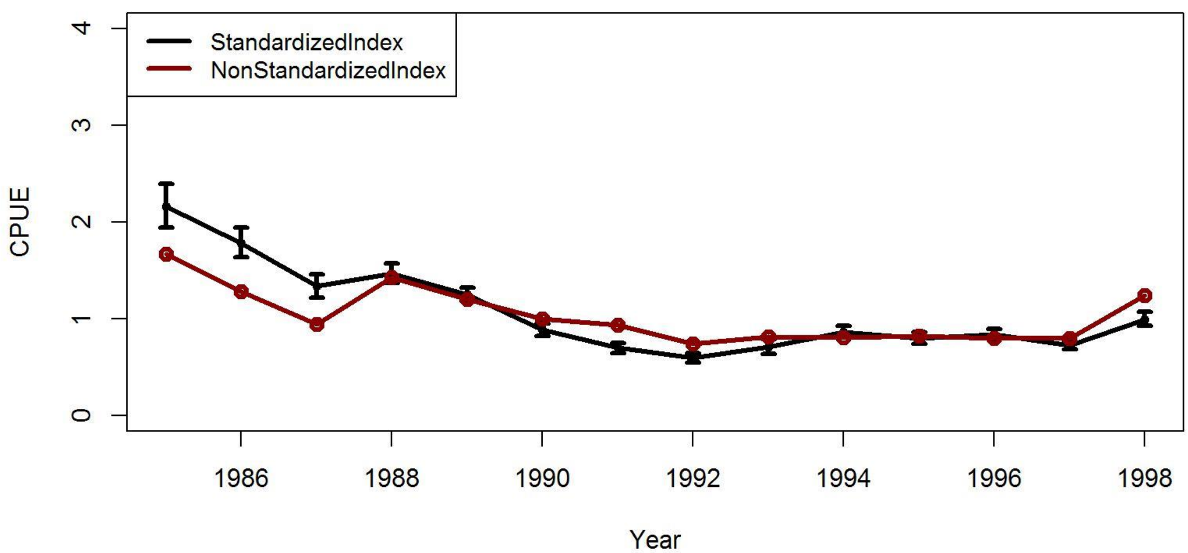


Figure B.9. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG. The 1985/86–1998/99 fish ticket data set was used. Standardized indices: black line and non-standardized indices: red line. Top panel: variable selection by R^2 criteria; bottom panel: variable selection by CAIC criteria.

Appendix C: Male maturity

Male maturity:

Method:
We used the 1991 EAG pot survey collected 2457 carapace length (mm CL) and chela height (up to one-tenth of a mm CH) measurements in the EAG and NMFS survey collected 508 same measurements in Bowers Ridge, WAG for male 50% maturity length determination. We determined the 50% maturity length outside the assessment model using the 'segmented regression' package available in R (R Core Team 2017). We used the 50% maturity length as the break point for categorizing immature and mature crab for mature male biomass (MMB) determination for EAG and WAG.

First we fitted a linear regression model to the data pair using the R package as follows:

$$\ln(CH/CL) = \beta_0 + \beta_1 CL \qquad \text{(C.1)}$$

where β_0 and β_1 are regression parameters

The procedure of 'segmented regression' uses maximum likelihood to fit a somewhat different parameterization of the linear model. It can be approximated as

$$\ln(CH/CL) = \beta_0 + \beta_1 CL + \beta_2[\mathrm{CL} - c] + \gamma I[\mathrm{CL} > c] \qquad \text{(C.2)}$$

where β_2 is a regression parameter and c is the break point. $\gamma I[\mathrm{CL} > c]$ is a dummy variable. When CL < c, the model reduces to,

$$\ln(CH/CL) = \beta_0 + \beta_1 CL + \beta_2[\mathrm{CL} - c] \qquad \text{(C.3)}$$

The γ term is a measure of the distance between the end of the first segment and the beginning of the next. The model converges when γ is minimized, thus this method constrains the segments to be (nearly) continuous.

Results:
Table C1. Breakpoint analysis results for EAG:

Breakpoint Estimate, CL:	107.015	Standard Error (SE):	1.916	
Meaningful coefficients of the linear terms:				
	Estimate	SE	t value	Pr(>|t|)
Intercept	-1.60175	0.02286	-70.05	<2e-16 ***
CL	0.00070	0.00026	2.72	0.00657 **
U1.CL	0.00424	0.00029	14.45	NA
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				
Adjusted R-squared: 0.4551, df = 2453				

Thus, the break point estimate of male CL (i.e., 50% maturity length) = 107.015 mm CL.

Table C2. Breakpoint analysis results for WAG:

Breakpoint Estimate, CL:	107.482	Standard Error (SE):	2.747	
Meaningful coefficients of the linear terms:				
	Estimate	SE	t value	Pr(>|t|)
Intercept	-1.63672	0.05592	-29.271	<2e-16 ***
CL	0.00086	0.00059	1.446	0.149
U1.CL	0.00441	0.00063	7.035	NA
Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1				
Adjusted R-squared: 0.7389, df=504				

Thus, the break point estimate of male CL (i.e., 50% maturity length) = 107.482 mm CL.

Figures C.1 and C.2 provide the segment regression fit to the log (CH/CL) vs. CL data pair for EAG and WAG, respectively:

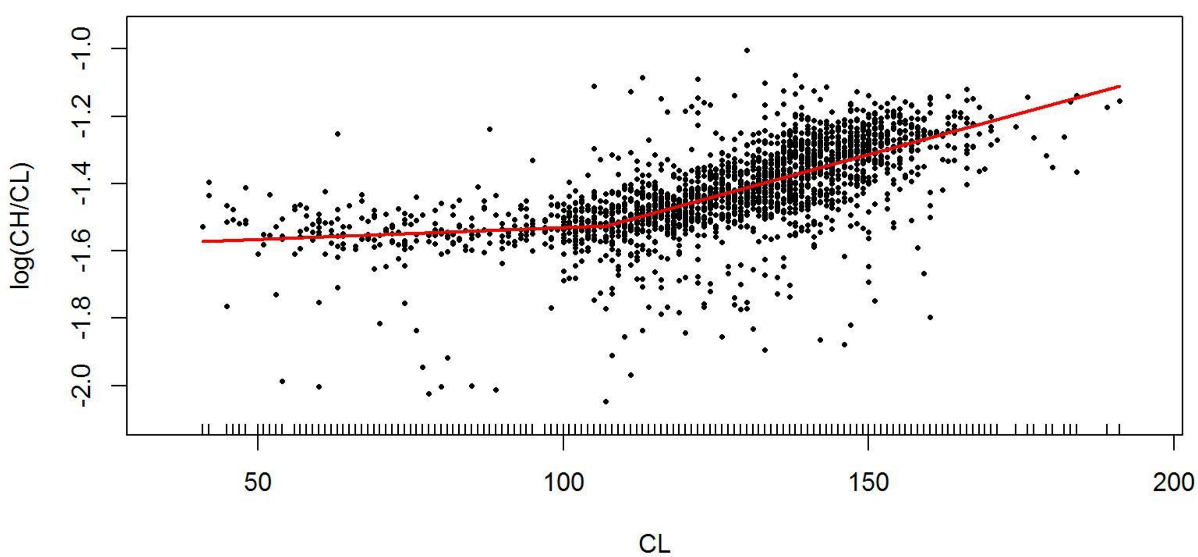


Figure C.1. Segmented linear regression fit to ln(CH/CL) vs. CL data of male golden king crab in EAG.

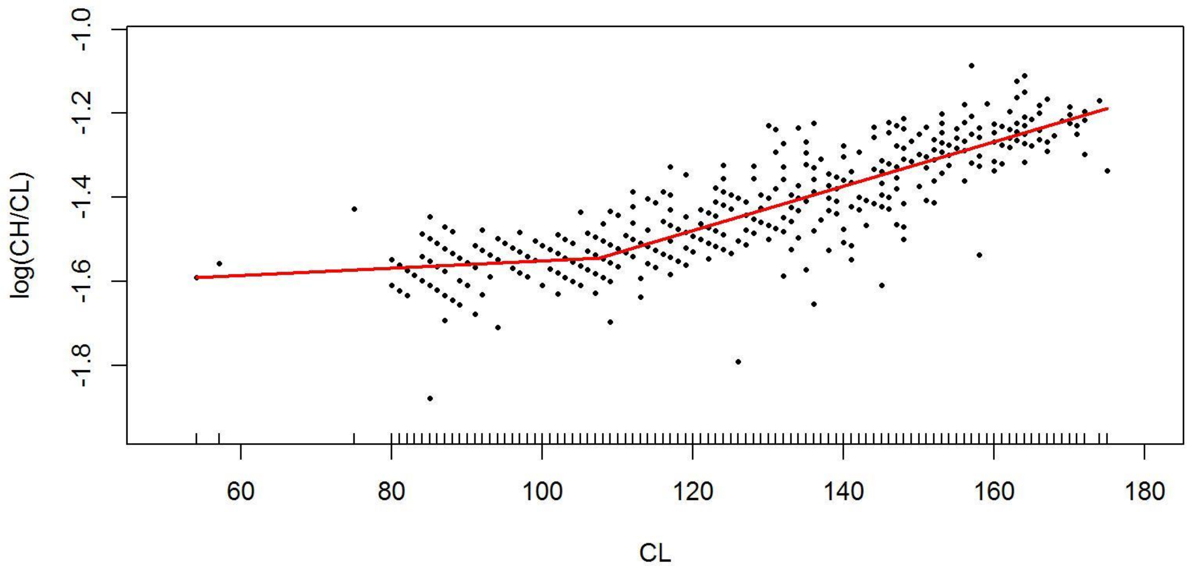


Figure C.2. Segmented linear regression fit to ln(CH/CL) vs. CL data of male golden king crab in WAG.

Bootstrap estimate of breakpoint with 95% confidence limits:

We created 1000 bootstrap samples of the ln(CH/CL) and CL pair and fitted the segmented regression to each sample [ln(CH/CL) vs CL] and estimated the median and the 95% confidence interval (2.5% and 97.5% percentiles of CL of the breakpoints) for EAG and WAG.

Table C.3. Median and 95% confidence limits of 1000 bootstrap estimates of male maturity by breakpoint analysis of chela height and carapace length data of golden king crab in EAG (1991 data) and WAG (1984 data).

Males	Median	Lower 95% Limit	Upper 95% Limit
EAG			
Maturity Breakpoint (mm CL)	107.02	85.12	111.02
WAG			
Maturity Breakpoint (mm CL)	107.85	103.46	126.03

We considered one bin above the median maturity size falling bin as the knife edge breakpoint of maturity. Thus all sizes equal and above 111 mmCL were considered to be fully mature and below this size immature for MMB calculation.

Essential R steps:

```
# Segmented regression:
# fit a single linear regression first then apply segmented
  library(segmented)
 singleline.mod<- lm(log(CH/CL)~CL)
 segmented.mod<- segmented(singleline.mod,seg.Z=~CL)
```

Review of king crab male maturity:

Chelae allometry has been used to determine morphometric male size-at-maturity among a number of king crab (*Lithodidae*) stocks. Golden king crab provides a better discrimination of chelae height against size at the onset of maturity than other king crab stocks (Somerton and Otto, 1986). Table C.4 lists the literature reported estimates of size-at-maturity of males and females of different king crab stocks in the northern hemisphere including golden king crab. Breakpoint analysis has been used to estimate maturity on king crabs in majority of cases (Table C.4 and Webb, 2014).

Table C.4. Review of estimates of male and female size-at-maturity of golden (*Lithodes aequispins*), blue (*Paralithodes platypus*), and red (*Paralithodes camtschatica*) king crabs by area and stocks. Numbers in parentheses are standard deviations estimated by the bootstrap sampling method.

Species	**Sex**	**Size-at-Maturity (mm CL)**	**Method**	**Area**	**Sources**
Lithodes aequispins	Male	114 (11.4)	Breakpoint analysis on log(chela height) vs. log(carapace length)	British Columbia, Canada	Jewett *et al*., 1985
		92 (2.4) 107 (4.6) 130 (4.0)	Breakpoint analysis on log(chela height) vs. log(carapace length)	St. Matthew Is. District Pribilof Is District Eastern Aleutian Is	Somerton and Otto, 1986
		117.9 to 158.0	Breakpoint analysis on log(chela height) vs. log(carapace length)	Various water inlets in southeast Alaska	Olson, 2016
		108.6 (2.6) 120.8 (2.9)	Breakpoint analysis on log(chela height) vs. log(carapace length)	Bowers Ridge Seguam Pass	Otto and Cummiskey, 1985
		107.8 (5.2) 107.0 (6.2)	Breakpoint analysis on log (chela height/carapace length) vs. carapace length; median estimates	Bowers Ridge Seguam Pass	Current analysis
		110	Minimum size of successful mating (lab observation)	Prince William Sound	Paul and Paul, 2001
	Female	105.5 (0.7)	Size at 50% ovigerity – logistic regression	British Columbia, Canada	Jewett *et al*., 1985

Species	**Sex**	**Size-at-Maturity (mm CL)**	**Method**	**Area**	**Sources**
		97.7 (0.5) 99.9 (0.2) 110.7 (0.8)	Size at 50% ovigerity – logistic regression	St. Matthew Is. District, Pribilof Is District, Eastern Aleutian Is	Somerton and Otto, 1986
		106.4 (0.5) 113.2 (0.3) 102.2 (0.3)	Size at 50% ovigerity – logistic regression	Bowers Ridge Seguam Pass Petrel Bank	Otto and Cummiskey, 1985
Paralithodes platypus	Male	77 (9.8) 108 (12.8) 87 (7.2) 93 (13.9)	Breakpoint analysis on log(chela height) vs. log(carapace length)	St. Matthew Is. Pribilof Is. Olga Bay Prince William Sound	Somerton and MacIntosh, 1983
		~100	Lab study: Asymptote of the spermatophore diameter vs. carapace length	St. Matthew Is.	Paul *et al.*, 1991
	Female	80.6 (0.6) 96.3 (0.3) 93.7 (0.4) 87.4 (0.5)	Size at 50% ovigerity – logistic regression	St. Matthew Is. Pribilof Is. Olga Bay Prince William Sound	Somerton and MacIntosh, 1983
Paralithodes camtschatica	Male	102.8	Breakpoint analysis on log(chela height) vs. log(carapace length)	Eastern Bering Sea	Somerton, D.A., 1980
		120	Smallest male grasping female (in situ observation on mating pairs)	Kodiak	Powell *et al.*, 2002
		104.3	Breakpoint analysis on log(chela height) vs. log(carapace length)	Barents Sea, Norway	Rafter *et al.*, 1996
		105	Lab study: Asymptote of the spermatophore diameter vs. carapace length	Bristol Bay	Paul *et al.*, 1991
	Female	101.9	Breakpoint analysis on log(chela height) vs. log(carapace length)	Eastern Bering Sea	Somerton, D.A., 1980
		88.8 (0.5)	Size at 50% ovigerity – logistic regression	Bristol Bay	Otto *et al.*, 1990
		89 (1.3)	Size at 50% ovigerity – logistic regression	Adak Island	Blau *et al.*, 1990

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Appendix D: Francis and McAllister and Ianelli re-weighting methods

Stage-1 effective sample size:

We considered number of vessel-days as the initial input annual effective sample sizes (i.e., Stage-1) for retained and total size compositions and number of trips for groundfish discard catch size composition without enforcing any upper limit. The number of vessel-days was calculated using,

$$Vessel - days_t \; = \; mean\; trip\; day_t \; \times number\; of\; trips\; made\; by\; all\; vessels_t \qquad \text{(D.1)}$$

The groundfish bycatch of golden king crab comes from bottom trawlers, fish pot, and longlines. Vessel-days are difficult to calculate for the groundfish bycatch and hence we used annual number of trips as the Stage-1 effective sample size. Please note that we did not use the groundfish discard size compositions in any of the scenario's optimization although the predicted effective sample sizes were produced as a byproduct. We refer to the Stage-1 effective samples sizes for the size-composition of the retained catch, total catch, and the groundfish crab bycatch for year t as $\tau^{r}_{1,t}, \tau^{T}_{1,t}$, and $\tau^{Tr}_{1,t}$ respectively.

We estimated the Stage-2 effective sample sizes iteratively from Stage-1 input effective sample sizes. The reiterated effective sample sizes' subscripts replace 1 by 2.

Francis' method:

The Francis' (2011) mean length based method [i.e., Francis TA1.8 method, Punt (2017)] uses the following formulas:

Observed mean length for year *t*,

$$\overline{l_t} \; = \; \sum_{i=1}^{n} l_{t,i} \times \; P_{t,i} \qquad \text{(D.2)}$$

Predicted mean length for year *t*,

$$\hat{\bar{l}}_t \; = \; \sum_{i=1}^{n} l_{t,i} \times \; \hat{P}_{t,i} \qquad \text{(D.3)}$$

Variance of the predicted mean length in year *t*,

$$var\left(\hat{\bar{l}}_t\right) = \; \frac{\sum_{i=1}^{n} \hat{P}_{t,i}\left(l_{t,i} - \hat{\bar{l}}_t\right)^2}{S_t} \qquad \text{(D.4)}$$

Francis' re-weighting parameter *W*,

$$W \; = \; \frac{1}{var\left\{\dfrac{\bar{l}_t - \hat{\bar{l}}_t}{\sqrt{var\left(\hat{\bar{l}}_t\right)}}\right\}} \qquad \text{(D.5)}$$

where $\widehat{P}_{t,i}$ and $P_{t,i}$ are the estimated and observed proportions of the catch during year t in length-class i, $l_{t,i}$ is the mid length of the length-class i during year t, S_t is the effective sample size in year t, $\hat{\bar{l}}_t$ and $\bar{l}_t$ are predicted and observed mean lengths of the catch during year t, n is the number of length bins, and W is the re-weighting multiplier of Stage-1 sample sizes.

Francis (2017) suggested that a good stopping criterion for the iteration process is when there are no appreciable changes in the key outputs. Hence, we considered a stopping criterion of no appreciable change (<0.01%) in W and terminal year MMB (Equation A.27).

S_t is related to the initial input (Stage-1) effective sample size according to:

$$S_{t,i} = W_i \tau_{1,t} \tag{D.6}$$

where $S_{t,i}$ is the effective sample size for year t in iteration i and W_i is the Francis weight calculated using Equation D.5 during iteration i.

We did the re-weighting for combined data (for *M* estimation), individual scenarios, and MMB profiles. For brevity, we provide the iteration process for Francis Stage-2 weight calculation for individual scenarios for EAG and WAG respectively in Table D.1.

McAllister's and Ianelli's method:

Based on the assumption that the size-composition data are a multinomial sample, McAllister and Ianelli (1997) provided an estimator for the Stage-2 effective sample sizes based on the ratio of the theoretical variance of expected proportions to the actual variance of proportions,

$$\tau_{2,t} = \frac{\sum_l \hat{P}_{t,l}(1-\hat{P}_{t,l})}{\sum_l (P_{t,l}-\hat{P}_{t,l})^2} \tag{D.7}$$

McAllister and Ianelli (1997) set the effective sample size for each size-composition data set for eastern Bering Sea yellowfin sole (*Limanda aspera*) as the arithmetic mean of $\tau_{2,t}$ over years *t* (i.e., a year-invariant effective sample size) and iterated the model fitting, updating the effective sample sizes, until convergence occurred. Equation D.7 ignores correlation among the residuals for the catch proportions so likely overestimates effective sample sizes (Francis, 2011). Punt (2015) suggests using the harmonic mean of $\tau_{2,t}$ if the McAllister and Ianelli formula is used. A harmonic mean (constant) multiplier was consequently used to update the effective sample sizes at each iteration of model fitting until convergence occurred; i.e.

$$\tau_{2,t,i} = \left\{ \frac{1}{n_t} \sum_t \left[\frac{\dot{\tau}_{2,t,i-1}}{\tau_{2,t,i-1}} \right]^{-1} \right\}^{-1} \tau_{2,t,i-1} \tag{D.8}$$

where $\tau_{2,t,i}$ is the Stage-2 effective sample size for year *t* in iteration *i* ($\tau_{2,t,0} = \tau_{1,t}$) and $\dot{\tau}_{2,t,i}$ is the result of applying Equation D.7. Convergence of the process of setting the Stage-2 effective sample sizes using Equation D.8 was assessed similar to Francis' procedure, but the weight (*W*) at the final iteration was allowed to reach 1. We considered this re-weighting process for scenarios EAG17_0e and WAG17_0e (Table D.1).

Table D.1. Iteration process for Stage-2 effective sample size re-weighting multiplier, *W*, by Francis' (scenarios 17b0, 17_0, 17_0a, 17_0b, 17_0c, 17_0d, and 17_0f) and McAllister and Ianelli (scenario 17_0e) methods for retained, total, and groundfish discard catch size compositions of golden king crab for EAG and WAG. Sc. =scenario. Note: For certain scenarios we have done over six iterations, but we provide only the last three iteration results.

Area	Sc.	Iteration No.	Retained Catch Size Comp Effective Sample Size Multiplier (W)	Total Catch Size Comp Effective Sample Size Multiplier (W)	Groundfish Discard Catch Size Comp Effective Sample Size Multiplier (W)	Terminal MMB (t)	*M* yr^{-1}
EAGpart	17b0	1	0.8384	0.5053	0.4469	14,342	0.2274
		2	0.8384	0.5066	0.4458	14,142	0.2254
		3	0.8384	0.5053	0.4469	14,141	0.2254
WAGpart	17b0	1	0.5176	0.4685	0.7542	6,646	0.2274
		2	0.5175	0.4684	0.7584	6,603	0.2254
		3	0.5176	0.4685	0.7542	6,603	0.2254
EAG	17_0	1	0.8343	0.5084	0.4476	13,455	0.21
		2	0.8339	0.5086	0.4476	13,455	
		3	0.8338	0.5086	0.4476	13,455	
WAG	17_0	1	0.5171	0.4698	0.7596	6,269	0.21
		2	0.5172	0.4697	0.7598	6,269	
		3	0.5173	0.4697	0.7597	6,269	
EAG	17_0a	1	0.8343	0.5349	0.4488	13,579	0.21
		2	0.8340	0.5349	0.4487	13,579	
		3	0.8340	0.5349	0.4488	13,579	
WAG	17_0a	1	0.5180	0.4707	0.7625	6,280	0.21
		2	0.5183	0.4706	0.7627	6,280	
		3	0.5183	0.4705	0.7627	6,280	
EAG	17_0b	1	0.8351	0.5066	0.4498	11,842	0.21
		2	0.8353	0.5066	0.4497	11,842	
		3	0.8354	0.5065	0.4497	11,842	
WAG	17_0b	1	0.5084	0.4831	0.7643	5,884	0.21
		2	0.5083	0.4831	0.7643	5,884	
		3	0.5082	0.4832	0.7642	5,884	
EAG	17_0c	1	0.8182	0.5387	0.4468	13,766	0.21
		2	0.8181	0.5388	0.4467	13,767	
		3	0.8181	0.5388	0.4467	13,767	
WAG	17_0c	1	0.4979	0.4774	0.7581	6,154	0.21
		2	0.4979	0.4774	0.7579	6,154	
		3	0.4979	0.4774	0.7581	6,154	
EAG	17_0d	1	0.8450	0.5311	0.4495	8,833	0.21
		2	0.8452	0.5310	0.4495	8,833	
		3	0.8452	0.5310	0.4495	8,833	

WAG	17_0d	1	0.5582	0.4830	0.7604	6,136	0.21
		2	0.5578	0.4826	0.7611	6,136	
		3	0.5577	0.4826	0.7610	6,136	
EAG	17_0e	1	1.4025	0.7873	1.6475	13,453	0.21
		2	1.0640	0.9582	1.0022	13,444	
		3	1.0100	0.9908	1.0001	13,440	
WAG	17_0e	1	1.1639	0.9202	0.9948	6,348	0.21
		2	1.0384	0.9526	0.9989	6,353	
		3	1.0097	0.9817	0.9997	6,355	
EAG	17_0f	1	0.8396	0.5065	0.4487	12,484	0.21
		2	0.8410	0.5060	0.4488	12,485	
		3	0.8411	0.5060	0.4488	12,485	

Appendix E: Jittering

Jittering of scenario 17_0 parameter estimates:
We followed the Stock Synthesis approach to do 100 jitter runs of scenarios EAG17_0 and WAG17_0 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 found 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:

$$temp = 0.5 * rdev * Jitterfactor * \ln\left(\frac{P_{\max} - P_{\min} + 0.0000002}{P_{val} - P_{\min} + 0.0000001} - 1\right), \qquad \text{(E.1)}$$

with the final jittered initial parameter value back transformed as:

$$P_{new} = P_{\min} + \frac{P_{\max} - P_{\min}}{1.0 + \exp(-2.0\, temp)}, \qquad \text{(E.2)}$$

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 scenario 17_0 in Tables E.1 and E.2 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 produced smaller objective function values compared to the base estimate (run 0). However, those fits predicted extremely large groundfish bycatches in certain years, consequently we ignored those runs. Thus we selected scenario 17_0 as the base scenario for EAG and WAG.

Table E.1. Results from 100 jitter runs for scenario 17_0 for EAG. Jitter run 0 corresponds to the original optimized estimates. Note: B_{MSY} reference points were based on average recruitment for 1986–2016.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**285.91650**	**0.0000222934**	**6,954.48**	**3,917.74**	**11,554.70**
1	285.91650	0.0000174504	6,954.48	3,917.74	11,554.70
2	285.91650	0.0001631845	6,954.48	3,917.74	11,554.70
3	285.91650	0.0000062988	6,954.48	3,917.74	11,554.70
4	285.91650	0.0002805318	6,954.48	3,917.74	11,554.70
5	285.91650	0.0001137684	6,954.48	3,917.74	11,554.70
6	285.91650	0.0001572297	6,954.48	3,917.74	11,554.70
7	285.91650	0.0001488496	6,954.48	3,917.74	11,554.70
8	285.91650	0.0003391617	6,954.48	3,917.74	11,554.70
9	285.91650	0.0001285458	6,954.48	3,917.74	11,554.70

10	285.91650	0.0000977588	6,954.48	3,917.74	11,554.70
11	285.91650	0.0001231468	6,954.48	3,917.74	11,554.70
12	285.91650	0.0000890800	6,954.48	3,917.74	11,554.70
13	285.91650	0.0000399059	6,954.48	3,917.74	11,554.70
14	285.91650	0.0002567647	6,954.48	3,917.74	11,554.70
15	285.91650	0.0000064600	6,954.48	3,917.74	11,554.70
16	285.91650	0.0002346045	6,954.48	3,917.74	11,554.70
17	285.91650	0.0002820026	6,954.48	3,917.74	11,554.70
18	285.91650	0.0000241932	6,954.48	3,917.74	11,554.70
19	285.91650	0.0000365975	6,954.48	3,917.74	11,554.70
20	285.91650	0.0003771734	6,954.48	3,917.74	11,554.70
21	285.91650	0.0001375338	6,954.48	3,917.74	11,554.70
22	285.91650	0.0001120951	6,954.48	3,917.74	11,554.70
23	285.91650	0.0000285661	6,954.48	3,917.74	11,554.70
24	285.91650	0.0006714663	6,954.48	3,917.74	11,554.70
25	285.91650	0.0001187696	6,954.48	3,917.74	11,554.70
26	285.91650	0.0000138714	6,954.48	3,917.74	11,554.70
27	285.91650	0.0000495531	6,954.48	3,917.74	11,554.70
28	285.91650	0.0005756958	6,954.48	3,917.74	11,554.70
29	285.91650	0.0000373670	6,954.48	3,917.74	11,554.70
30	285.91650	0.0001517096	6,954.48	3,917.74	11,554.70
31	285.91650	0.0003618456	6,954.48	3,917.74	11,554.70
32	285.91650	0.0013670960	6,954.48	3,917.74	11,554.70
33	285.91650	0.0000539773	6,954.48	3,917.74	11,554.70
34	285.91650	0.0000154992	6,954.48	3,917.74	11,554.70
35	285.91650	0.0000760394	6,954.48	3,917.74	11,554.70
36	285.91650	0.0000046526	6,954.48	3,917.74	11,554.70
37	285.91650	0.0002455134	6,954.48	3,917.74	11,554.70
38	285.91650	0.0001081487	6,954.48	3,917.74	11,554.70
39	285.91650	0.0001221035	6,954.48	3,917.74	11,554.70
40	285.91650	0.0001775793	6,954.48	3,917.74	11,554.70
41	285.91650	0.0000850537	6,954.48	3,917.74	11,554.70
42	285.91650	0.0000655746	6,954.48	3,917.74	11,554.70
43	285.91650	0.0001097075	6,954.48	3,917.74	11,554.70
44	285.91650	0.0005359162	6,954.48	3,917.74	11,554.70
45	285.91650	0.0000582206	6,954.48	3,917.74	11,554.70
46	285.91650	0.0001263718	6,954.48	3,917.74	11,554.70
47	285.91650	0.0001669157	6,954.48	3,917.74	11,554.70
48	285.91650	0.0001184376	6,954.48	3,917.74	11,554.70
49	285.91650	0.0001850153	6,954.48	3,917.74	11,554.70
50	285.91650	0.0001171299	6,954.48	3,917.74	11,554.70
51	285.91650	0.0000927041	6,954.48	3,917.74	11,554.70
52	285.91650	0.0001977530	6,954.48	3,917.74	11,554.70

53	285.91650	0.0000502208	6,954.48	3,917.74	11,554.70
54	285.91650	0.0002810899	6,954.48	3,917.74	11,554.70
55	285.91650	0.0002931756	6,954.48	3,917.74	11,554.70
56	285.91650	0.0001466994	6,954.48	3,917.74	11,554.70
57	285.91650	0.0001492200	6,954.48	3,917.74	11,554.70
58	285.91650	0.0000375202	6,954.48	3,917.74	11,554.70
59	285.91650	0.0004659215	6,954.48	3,917.74	11,554.70
60	285.91650	0.0000479571	6,954.48	3,917.74	11,554.70
61	285.91650	0.0000159505	6,954.48	3,917.74	11,554.70
62	285.91650	0.0000466713	6,954.48	3,917.74	11,554.70
63	285.91650	0.0001467107	6,954.48	3,917.74	11,554.70
64	285.91650	0.0003362615	6,954.48	3,917.74	11,554.70
65	285.91650	0.0003528916	6,954.48	3,917.74	11,554.70
66	285.91650	0.0001518528	6,954.48	3,917.74	11,554.70
67	285.91650	0.0000965183	6,954.48	3,917.74	11,554.70
68	285.91650	0.0001700814	6,954.48	3,917.74	11,554.70
69	285.91650	0.0001150075	6,954.48	3,917.74	11,554.70
70	285.91650	0.0001708935	6,954.48	3,917.74	11,554.70
71	285.91650	0.0000843366	6,954.48	3,917.74	11,554.70
72	285.91650	0.0000147518	6,954.48	3,917.74	11,554.70
73	285.91650	0.0000711309	6,954.48	3,917.74	11,554.70
74	285.91650	0.0000831972	6,954.48	3,917.74	11,554.70
75	285.91650	0.0001249322	6,954.48	3,917.74	11,554.70
76	285.91650	0.0000950038	6,954.48	3,917.74	11,554.70
77	285.91650	0.0000930142	6,954.48	3,917.74	11,554.70
78	285.91650	0.0005069687	6,954.48	3,917.74	11,554.70
79	285.91650	0.0001041060	6,954.48	3,917.74	11,554.70
80	285.91650	0.0000268403	6,954.48	3,917.74	11,554.70
81	285.91650	0.0001235642	6,954.48	3,917.74	11,554.70
82	285.91650	0.0001945769	6,954.48	3,917.74	11,554.70
83	285.91650	0.0004412037	6,954.48	3,917.74	11,554.70
84	285.91650	0.0000976698	6,954.48	3,917.74	11,554.70
85	285.91650	0.0000551057	6,954.48	3,917.74	11,554.70
86	285.91650	0.0000495026	6,954.48	3,917.74	11,554.70
87	285.91650	0.0005078082	6,954.48	3,917.74	11,554.70
88	285.91650	0.0001855834	6,954.48	3,917.74	11,554.70
89	285.91650	0.0001687559	6,954.48	3,917.74	11,554.70
90	285.91650	0.0000065286	6,954.48	3,917.74	11,554.70
91	285.91650	0.0000599673	6,954.48	3,917.74	11,554.70
92	285.91650	0.0003389603	6,954.48	3,917.74	11,554.70
93	285.91650	0.0000402791	6,954.48	3,917.74	11,554.70
94	285.91650	0.0002217916	6,954.48	3,917.74	11,554.70
95	285.91650	0.0000923698	6,954.48	3,917.74	11,554.70

96	285.91650	0.0000245177	6,954.48	3,917.74	11,554.70
97	285.91650	0.0001364416	6,954.48	3,917.74	11,554.70
98	285.91650	0.0001427303	6,954.48	3,917.74	11,554.70
99	285.91650	0.0000980820	6,954.48	3,917.74	11,554.70
100	285.91650	0.0000929987	6,954.48	3,917.74	11,554.70

Table E.2. Results from 100 jitter runs for scenario 17_0 for WAG. Jitter run 0 corresponds to the original optimized estimates. Since there were differences in the objective function estimates, we sorted out the jitter results from lowest to the highest objective function values. Note: B_{MSY} reference points were based on average recruitment for 1986–2017.

Jitter Run	Objective Function	Maximum Gradient	$B_{35\%}$ (t)	OFL (t)	Current MMB (t)
0	**194.09019**	**0.0001417655**	**5,137.94**	**1,596.46**	**6,397.24**
3	188.28830	0.0000977034	5,711.55	1,730.50	6,854.65
76	188.28830	0.0000794244	5,711.55	1,730.50	6,854.65
98	188.28830	0.0002341052	5,711.55	1,730.49	6,854.65
16	190.76970	0.0005141899	5,715.07	1,694.36	6,775.36
18	190.76970	0.0001464585	5,715.07	1,694.36	6,775.36
32	190.76970	0.0000894627	5,715.07	1,694.36	6,775.36
39	190.76970	0.0000800169	5,715.07	1,694.36	6,775.36
62	190.76970	0.0002638217	5,715.07	1,694.36	6,775.36
90	190.76970	0.0004216969	5,715.07	1,694.36	6,775.36
84	193.67430	0.0002215062	5,684.40	1,708.01	6,745.06
1	194.09020	0.0000999658	5,137.94	1,596.46	6,397.24
2	194.09020	0.0001227291	5,137.94	1,596.46	6,397.24
4	194.09020	0.0000671676	5,137.94	1,596.46	6,397.24
5	194.09020	0.0001882438	5,137.94	1,596.46	6,397.24
6	194.09020	0.0000723657	5,137.94	1,596.46	6,397.24
7	194.09020	0.0000858417	5,137.94	1,596.46	6,397.24
8	194.09020	0.0001479368	5,137.94	1,596.46	6,397.24
9	194.09020	0.0000540315	5,137.94	1,596.46	6,397.24
10	194.09020	0.0002584561	5,137.94	1,596.46	6,397.24
11	194.09020	0.0001629403	5,137.94	1,596.46	6,397.24
12	194.09020	0.0000882497	5,137.94	1,596.46	6,397.24
13	194.09020	0.0003632097	5,137.94	1,596.46	6,397.24
14	194.09020	0.0001908709	5,137.94	1,596.46	6,397.24
15	194.09020	0.0000972293	5,137.94	1,596.46	6,397.24
17	194.09020	0.0000796912	5,137.94	1,596.46	6,397.24
19	194.09020	0.0000362523	5,137.94	1,596.46	6,397.24
20	194.09020	0.0000699955	5,137.94	1,596.46	6,397.24
21	194.09020	0.0000281890	5,137.94	1,596.46	6,397.24

22	194.09020	0.0001078193	5,137.94	1,596.46	6,397.24
23	194.09020	0.0002701639	5,137.94	1,596.46	6,397.24
24	194.09020	0.0004094629	5,137.94	1,596.46	6,397.24
25	194.09020	0.0001398647	5,137.94	1,596.46	6,397.24
26	194.09020	0.0001581441	5,137.94	1,596.46	6,397.24
27	194.09020	0.0000172173	5,137.94	1,596.46	6,397.24
28	194.09020	0.0002431567	5,137.94	1,596.46	6,397.24
29	194.09020	0.0001333304	5,137.94	1,596.46	6,397.24
30	194.09020	0.0001117535	5,137.94	1,596.46	6,397.24
31	194.09020	0.0001606068	5,137.94	1,596.46	6,397.24
33	194.09020	0.0004427428	5,137.94	1,596.46	6,397.24
34	194.09020	0.0001611413	5,137.94	1,596.46	6,397.24
35	194.09020	0.0000631701	5,137.94	1,596.46	6,397.24
36	194.09020	0.0000459606	5,137.94	1,596.46	6,397.24
37	194.09020	0.0001064168	5,137.94	1,596.46	6,397.24
38	194.09020	0.0000172059	5,137.94	1,596.46	6,397.24
40	194.09020	0.0000038408	5,137.94	1,596.46	6,397.24
41	194.09020	0.0000859666	5,137.94	1,596.46	6,397.24
42	194.09020	0.0000537521	5,137.94	1,596.46	6,397.24
43	194.09020	0.0001620099	5,137.94	1,596.46	6,397.24
44	194.09020	0.0000315661	5,137.94	1,596.46	6,397.24
45	194.09020	0.0000738932	5,137.94	1,596.46	6,397.24
46	194.09020	0.0001887252	5,137.94	1,596.46	6,397.24
47	194.09020	0.0000429643	5,137.94	1,596.46	6,397.24
48	194.09020	0.0000776832	5,137.94	1,596.46	6,397.24
49	194.09020	0.0003267544	5,137.94	1,596.46	6,397.24
50	194.09020	0.0003924007	5,137.94	1,596.46	6,397.24
51	194.09020	0.0001833688	5,137.94	1,596.46	6,397.24
52	194.09020	0.0002360240	5,137.94	1,596.46	6,397.24
53	194.09020	0.0000717775	5,137.94	1,596.46	6,397.24
54	194.09020	0.0001178624	5,137.94	1,596.46	6,397.24
55	194.09020	0.0002562605	5,137.94	1,596.46	6,397.24
56	194.09020	0.0001003891	5,137.94	1,596.46	6,397.24
57	194.09020	0.0002306516	5,137.94	1,596.46	6,397.24
58	194.09020	0.0001687052	5,137.94	1,596.46	6,397.24
59	194.09020	0.0001481354	5,137.94	1,596.46	6,397.24
60	194.09020	0.0000907526	5,137.94	1,596.46	6,397.24
61	194.09020	0.0002972557	5,137.94	1,596.46	6,397.24
63	194.09020	0.0001718722	5,137.94	1,596.46	6,397.24
64	194.09020	0.0000443092	5,137.94	1,596.46	6,397.24
65	194.09020	0.0004282920	5,137.94	1,596.46	6,397.24
66	194.09020	0.0000609887	5,137.94	1,596.46	6,397.24
69	194.09020	0.0000496104	5,137.94	1,596.46	6,397.24

70	194.09020	0.0001474220	5,137.94	1,596.46	6,397.24
71	194.09020	0.0000817530	5,137.94	1,596.46	6,397.24
72	194.09020	0.0002925135	5,137.94	1,596.46	6,397.24
74	194.09020	0.0000172826	5,137.94	1,596.46	6,397.24
75	194.09020	0.0001158849	5,137.94	1,596.46	6,397.24
77	194.09020	0.0000685658	5,137.94	1,596.46	6,397.24
78	194.09020	0.0000642759	5,137.94	1,596.46	6,397.24
79	194.09020	0.0002103009	5,137.94	1,596.46	6,397.24
80	194.09020	0.0000927951	5,137.94	1,596.46	6,397.24
82	194.09020	0.0000092932	5,137.94	1,596.46	6,397.24
83	194.09020	0.0002106457	5,137.94	1,596.46	6,397.24
85	194.09020	0.0002154777	5,137.94	1,596.46	6,397.24
86	194.09020	0.0002772188	5,137.94	1,596.46	6,397.24
87	194.09020	0.0000738715	5,137.94	1,596.46	6,397.24
88	194.09020	0.0000222923	5,137.94	1,596.46	6,397.24
89	194.09020	0.0000501345	5,137.94	1,596.46	6,397.24
91	194.09020	0.0004448138	5,137.94	1,596.46	6,397.24
92	194.09020	0.0000542747	5,137.94	1,596.46	6,397.24
93	194.09020	0.0002043152	5,137.94	1,596.46	6,397.24
94	194.09020	0.0000163931	5,137.94	1,596.46	6,397.24
95	194.09020	0.0001567686	5,137.94	1,596.46	6,397.24
97	194.09020	0.0000887919	5,137.94	1,596.46	6,397.24
99	194.09020	0.0001385326	5,137.94	1,596.46	6,397.24
100	194.09020	0.0004455103	5,137.94	1,596.46	6,397.24
68	194.56190	0.0002346658	5,667.26	1,710.85	6,808.70
96	1575.75000	8813.9550000000	11,642.10	5,338.79	18,099.20
67	1755.93500	7572.1610000000	112,920.00	185,340.00	446,363.00
73	1783.22200	2679.4760000000	6,571.68	1,390.86	6,177.96
81	2018.62300	5380.9700000000	11,434.00	7,879.87	29,661.80

Appendix F: Projection

Simulations on future projection and outlook of Aleutian Islands golden king crab under Tier 3 harvest control rule

Simulation Method

We simulated the future male abundances from the 2018 model scenarios 17_0 and 17_0d estimated abundances by length-class and recruitment. We projected the abundances for 30 years with 100 random replicates and estimated various management parameters: legal male biomass (LMB), mature male biomass (MMB), OFL (total) catch, retained catch, CPUE indices, and probability of overfishing under federal overfishing control rule. Future population projections primarily depend on future recruitment, but crab recruitment is difficult to predict. Therefore, annual recruitment for the projections was selected by a random selection from estimated recruitments during 1987– 2012 (CPT and SSC agreed time period, Siddeek et al., 2017). Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2016 (terminal year). The estimated recruitments were randomly selected using a uniform random distribution whereas the 2016 abundance was randomized by a lognormal random error.

The simulation steps are as follows:

1) Run the assessment model scenario 17_0 and 17_0d from the start year to the terminal year of the data (1981/82 - 2016/17 fishing seasons). Model equations are provided in Appendix A.

2) After estimating the abundances and parameters, run the forecast function (at the standard deviation phase of the ADMB optimization).

a) Randomize the recruitment:

Random selection of model estimated recruits for 1987 to 2012 was done as follows:

$$R_i = e^{[logMeanRec \ + rec_{dev(1987+uniform\ random\ error\ selected\ year\ incrment)}]} \qquad (F.1)$$

where i = 2 to 30 years

b) Randomize the abundance:

The lognormal random error to abundance is added in the following steps:

We first scaled the standard error based on the terminal year abundance (number of crabs) on its standard error (i.e., CV= $\frac{Std.Error\ of\ terminal\ year\ mature\ male\ abundance}{terminal\ year\ mature\ male\ abundance}$). Then we added the lognormal random error to abundance as follows:

$$N_i = N_i e^{\varepsilon_i - \frac{\sigma_\varepsilon^2}{2}} \qquad (F.2)$$

where $\sigma_\varepsilon = \frac{Std.Error\ of\ terminal\ year\ mature\ male\ abundance}{terminal\ year\ mature\ male\ abundance}$

N = abundance, and *i* = projection year.

The scaled standard error estimates (CV) are:

Scenario 17_0:

WAG: σ_ε = 0.18108
EAG: σ_ε = 0.18726

Scenario 17_0d:

WAG: σ_ε = 0.23771
EAG: σ_ε = 0.23674

3. Projection.

Two scenarios of fishing mortality for the directed pot fishery were used in the projections under Tier 3 control rule (i.e., Federal overfishing control rule):

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

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

The groundfish bycatch mortality was kept constant at the last 10-year mean fishing mortality level.

Each scenario was replicated 100 times and projections made over 30 years beginning in 2016

At each time step in the future:

a) Calculated legal male biomass (LMB) and mature male biomass (MMB).

b) Calculated the overfishing level total catch (OFL), acceptable biological catch (ABC), retained catch (RETC), and catch-per-unit effort (CPUE) indices using the Tier 3 OFL control rule.

c) Implemented the fishery under Tier 3 OFL control rule and removed the OFL catch from the simulated population.

d) Drew new recruitment numbers from historical distribution.

e) Updated the number-at-length.

4) Repeated step-3 for 30 years into the future.

5) Repeated steps 3 and 4 for 100s of Monte Carlo trials, randomizing recruitment and abundance.

6) Used the annual distribution of simulated OFL catch, ABC catch, RETC, CPUE, LMB, and MMB to calculate performance statistics:

a) Median and mean annual MMB, LMB, OFL, ABC, RETC, and CPUE with standard errors and 95% confidence limits (by Efron's and Tibshirani's (1986) method: 2.5% and 97.5% percentile points).

b) Probability that the median MMB remains above the threshold reference points ($0.25MMB_{35\%,2016}$), median ABC and median OFL exceeding ABC_{2016} and OFL_{2016} respectively during the 30-yr projection period. The subscript 2016 refers to estimates by the respective assessment model scenarios.

The state harvest control rule simulation procedures are under development; therefore, we are not presenting any results of the state harvest strategy in this report.

Results

The simulations compared the projection outputs for 17_0 and 17_0d scenarios and also investigated the probability of the stock being overfished (median $MMB<0.25MMB_{35\%,2016}$) and overfishing occurred [i.e., median OFL catch (i.e., median total catch under F_{OFL}) exceeded OFL_{2016} or ABC_{2016} estimates] during the 30yr projection time horizon. The standard deviation of the total catch (OFL), retained catch (RETC), and CPUE are provided to assess the variability of the harvest under Tier 3 control rule.

We provide the results in the subsequent tables for the Tier 3 control rule for both scenarios. Tables F.1 and F.2 compare the 30-yr projected OFL catches with that of the model estimated OFL and ABC and provide the probability of overfishing and overfished under Tier 3 control rule for 17_0 and 17_0d scenarios for EAG and WAG, respectively. Subsequent tables (Tables F.3 to F.14) provide the mean, median, standard deviation, and 95% confidence intervals for projected OFL, ABC, RETC, CPUE, LMB, and MMB during time horizon. We can make the following general conclusion from the simulation results:

If the Tier 3 control rule were directly applied as the harvest strategy, the probability of median MMB declining below the threshold (overfished) would be zero for both scenarios for EAG and WAG. However, probability of median OFL (total) catch exceeding ABC would be 0.067 for scenario 17_0, but zero for scenario 17_0d for EAG. On the other hand, probability of median OFL exceeding ABC would be 1.0 for both scenarios (17_0 and 17_0d) for WAG (Tables F.1 and F.2).

Reference

Efron, B., and Tibshirani, R. 1986. Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. Statistical Science, 1(1): 54-75.

M.S.M. Siddeek, J. Zheng, C. Siddon, B. Daly. 2017. Aleutian Islands golden king crab (*Lithodes aequispinus*) model-based stock assessment in Spring 2017. Draft report for the May 2017 CPT meeting, Juneau.

Table F.1. Comparison of projected median OFL (i.e., total catch under Tire 3 F_{OFL}) with OFL_{2016} and ABC_{2016} in metric tons (t) for scenario (Sc) 17_0 and 17_0d with $F=F_{35\%}$ ($0.64 yr^{-1}$) and F=0 for EAG. Probability of projected median OFL exceeding OFL_{2016} and ABC_{2016} and projected median MMB (t) depleting below the threshold MMB_{2016} are also listed. $Thresh_{2016}$= threshold MMB in 2016.

Projection Year	Sc17_0			Sc 17_0, F=0			Sc 17_0, $F=F_{35\%}$			Sc17_0d			Sc 17_0d, F=0			Sc 17_0d, $F=F_{35\%}$		
	OFL_{2016}	ABC_{2016}	$Thresh_{2016}$	OFL	ABC	MMB	OFL	ABC	MMB	OFL_{2016}	ABC_{2016}	$Thresh_{2016}$	OFL	ABC	MMB	OFL	ABC	MMB
2016	3,918	2,938	1738.615	1.974	1.480	14,832	3,359	2,519	11,445	2,481	1,860	1672.03	1.672	1.254	10,201	2,262	1,696	7,922
2017				2.157	1.618	16,281	3,194	2,395	10,017				1.911	1.434	11,708	2,170	1,628	7,470
2018				2.252	1.689	17,228	2,909	2,182	8,790				2.090	1.567	13,021	2,074	1,555	7,191
2019				2.361	1.771	17,851	2,559	1,919	7,889				2.272	1.704	13,957	1,975	1,481	6,957
2020				2.407	1.805	18,401	2,256	1,692	7,416				2.376	1.782	15,000	1,907	1,430	6,804
2021				2.460	1.845	18,660	2,073	1,555	7,092				2.506	1.879	15,573	1,884	1,413	6,716
2022				2.471	1.854	18,959	1,951	1,463	7,064				2.598	1.949	16,324	1,832	1,374	6,736
2023				2.507	1.880	19,082	1,937	1,453	7,014				2.674	2.005	16,848	1,831	1,373	6,747
2024				2.548	1.911	19,380	1,899	1,424	7,019				2.763	2.072	17,381	1,819	1,365	6,705
2025				2.547	1.910	19,483	1,904	1,428	6,877				2.805	2.104	17,715	1,835	1,376	6,667
2026				2.544	1.908	19,434	1,893	1,420	6,884				2.844	2.133	17,969	1,831	1,373	6,653
2027				2.560	1.920	19,527	1,877	1,407	6,881				2.877	2.158	18,051	1,814	1,361	6,675
2028				2.587	1.940	19,632	1,871	1,403	6,828				2.923	2.192	18,398	1,813	1,360	6,723
2029				2.563	1.923	19,701	1,872	1,404	6,882				2.930	2.198	18,507	1,817	1,363	6,657
2030				2.571	1.928	19,630	1,883	1,413	6,930				2.947	2.210	18,649	1,818	1,363	6,743
2031				2.576	1.932	19,694	1,883	1,412	6,881				2.962	2.221	18,770	1,814	1,360	6,604
2032				2.564	1.923	19,639	1,889	1,417	6,845				2.968	2.226	18,733	1,836	1,377	6,656
2033				2.577	1.933	19,657	1,882	1,411	6,913				2.974	2.231	18,869	1,814	1,360	6,682
2034				2.571	1.928	19,676	1,875	1,406	6,945				2.978	2.233	18,846	1,818	1,364	6,674
2035				2.585	1.939	19,709	1,885	1,414	6,921				2.991	2.243	18,909	1,816	1,362	6,664
2036				2.582	1.936	19,710	1,881	1,411	6,920				2.985	2.239	19,008	1,806	1,355	6,690
2037				2.595	1.947	19,715	1,885	1,413	6,895				3.002	2.252	18,942	1,838	1,378	6,644
2038				2.596	1.947	19,804	1,880	1,410	6,983				3.017	2.262	19,059	1,812	1,359	6,768
2039				2.615	1.962	19,894	1,896	1,422	7,008				3.048	2.286	19,206	1,823	1,367	6,823
2040				2.617	1.962	19,979	1,905	1,429	7,025				3.038	2.278	19,305	1,831	1,374	6,870
2041				2.629	1.972	20,013	1,924	1,443	7,098				3.065	2.299	19,363	1,856	1,392	6,856
2042				2.623	1.967	20,115	1,915	1,436	6,976				3.045	2.284	19,400	1,857	1,393	6,716
2043				2.613	1.959	20,005	1,925	1,444	6,861				3.060	2.295	19,346	1,851	1,389	6,685
2044				2.605	1.953	19,920	1,898	1,423	6,871				3.060	2.295	19,359	1,842	1,381	6,695
2045				2.606	1.955	19,945	1,871	1,404	6,876				3.045	2.284	19,300	1,810	1,358	6,653
Prob OFL> ABC_{2016}				0			0.067						0			0		
Prob OFL> OFL_{2016}				0			0						0			0		
Prob MMB< $Thresh_{2016}$						0			0						0			0

Table F.2. Comparison of projected median OFL (i.e., total catch under Tire 3 F_{OFL}) with OFL_{2016} and ABC_{2016} in metric tons (t) for scenario (Sc) 17_0 and 17_0d with F=$F_{35\%}$ (0.6yr^{-1} and 0.68yr^{-1} for Sc 17_0 and Sc 17_0d, respectively) and F=0 for WAG. Probability of projected median OFL exceeding OFL_{2016} and ABC_{2016} and projected median MMB (t) depleting below the threshold MMB_{2016} are also listed. $Thresh_{2016}$= threshold MMB in 2016.

Projection Year	Sc17_0			Sc 17_0, F=0			Sc 17_0, F=$F_{35\%}$			Sc17_0d			Sc 17_0d, F=0			Sc 17_0d, F=$F_{35\%}$		
	OFL_{2016}	ABC_{2016}	$Thresh_{2016}$	OFL	ABC	MMB	OFL	ABC	MMB	OFL_{2016}	ABC_{2016}	$Thresh_{2016}$	OFL	ABC	MMB	OFL	ABC	MMB
2016	1,597	1,197	1,284.485	3.367	2.526	7,243	1,297	973	5,934	1,482	1,112	1,276.905	3.434	2.576	7,015	1,119	840	5,886
2017				3.955	2.966	8,745	1,489	1,116	6,057				4.065	3.048	8,565	1,416	1,062	6,132
2018				4.335	3.251	9,814	1,614	1,211	5,778				4.491	3.368	9,717	1,625	1,219	5,811
2019				4.765	3.574	10,647	1,605	1,204	5,550				4.945	3.709	10,565	1,636	1,227	5,584
2020				5.091	3.818	11,457	1,525	1,143	5,425				5.298	3.973	11,415	1,548	1,161	5,475
2021				5.369	4.027	12,153	1,475	1,106	5,229				5.581	4.186	12,089	1,483	1,113	5,243
2022				5.566	4.174	12,666	1,443	1,082	5,195				5.811	4.358	12,637	1,449	1,087	5,138
2023				5.786	4.339	13,127	1,407	1,055	5,175				6.032	4.524	13,059	1,406	1,055	5,131
2024				5.883	4.413	13,532	1,404	1,053	5,277				6.121	4.591	13,437	1,394	1,045	5,238
2025				5.999	4.499	13,725	1,410	1,057	5,272				6.266	4.699	13,633	1,398	1,048	5,214
2026				6.074	4.555	13,941	1,410	1,057	5,192				6.326	4.745	13,888	1,409	1,057	5,152
2027				6.136	4.602	14,080	1,415	1,061	5,145				6.400	4.800	14,001	1,411	1,058	5,122
2028				6.179	4.634	14,154	1,395	1,047	5,121				6.447	4.835	14,104	1,391	1,043	5,111
2029				6.216	4.662	14,253	1,381	1,036	5,136				6.470	4.853	14,194	1,384	1,038	5,117
2030				6.234	4.676	14,348	1,384	1,038	5,117				6.500	4.875	14,230	1,386	1,039	5,106
2031				6.318	4.738	14,406	1,391	1,043	5,148				6.608	4.956	14,359	1,381	1,036	5,102
2032				6.333	4.749	14,574	1,389	1,041	5,244				6.602	4.952	14,512	1,384	1,038	5,207
2033				6.330	4.747	14,570	1,402	1,051	5,189				6.611	4.958	14,461	1,393	1,045	5,189
2034				6.389	4.791	14,631	1,406	1,054	5,204				6.650	4.987	14,508	1,409	1,057	5,234
2035				6.412	4.809	14,695	1,406	1,054	5,213				6.676	5.007	14,590	1,401	1,051	5,201
2036				6.410	4.808	14,774	1,401	1,051	5,273				6.709	5.032	14,728	1,408	1,056	5,256
2037				6.452	4.839	14,750	1,411	1,058	5,174				6.724	5.043	14,711	1,413	1,059	5,146
2038				6.468	4.851	14,872	1,403	1,052	5,177				6.714	5.035	14,802	1,406	1,055	5,135
2039				6.424	4.818	14,825	1,407	1,055	5,188				6.674	5.005	14,730	1,395	1,046	5,110
2040				6.431	4.823	14,754	1,399	1,049	5,160				6.696	5.022	14,647	1,392	1,044	5,151
2041				6.428	4.821	14,756	1,390	1,043	5,180				6.698	5.023	14,659	1,392	1,044	5,121
2042				6.430	4.823	14,814	1,393	1,045	5,150				6.691	5.018	14,745	1,394	1,046	5,164
2043				6.458	4.843	14,766	1,392	1,044	5,212				6.716	5.037	14,703	1,390	1,043	5,223
2044				6.467	4.850	14,828	1,391	1,043	5,266				6.770	5.078	14,726	1,394	1,045	5,223
2045				6.507	4.880	14,951	1,407	1,056	5,274				6.795	5.096	14,871	1,408	1,056	5,229
Prob OFL> ABC_{2016}				0			1.000						0			1.000		
Prob OFL> OFL_{2016}				0			0.067						0			0.133		
Prob MMB< $Thresh_{2016}$						0			0						0			0

Table F.3. Projected mean, median, and standard deviation (SD) of legal male (LMB) and mature male (MMB) biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0 for EAG, 2016–2045. The top table provides a base projection scenario with no directed fishery.

No Directed Fishery										
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	9,433	9,400	1,737	6,595	13,218	14,883	14,832	2,740	10,405	20,855
2017	12,587	12,543	2,317	8,800	17,637	16,313	16,281	2,879	11,472	22,419
2018	14,564	14,507	2,665	10,191	20,352	17,318	17,228	2,765	12,462	22,966
2019	15,658	15,592	2,660	11,087	21,174	17,972	17,851	2,547	13,564	23,105
2020	16,274	16,134	2,483	11,898	21,322	18,445	18,401	2,267	14,667	22,953
2021	16,686	16,579	2,208	12,937	21,095	18,764	18,660	2,036	15,385	22,643
2022	16,951	16,865	1,936	13,656	20,784	19,051	18,959	1,885	16,157	22,485
2023	17,171	17,116	1,753	14,400	20,388	19,259	19,082	1,742	16,473	22,652
2024	17,366	17,243	1,618	14,781	20,347	19,375	19,380	1,619	16,511	22,420
2025	17,493	17,327	1,513	14,933	20,420	19,432	19,483	1,497	16,608	22,483
2026	17,553	17,605	1,405	14,934	20,344	19,470	19,434	1,389	16,841	22,141
2027	17,573	17,560	1,309	15,118	20,291	19,532	19,527	1,273	17,123	21,747
2028	17,600	17,568	1,213	15,298	19,926	19,598	19,632	1,168	17,154	21,722
2029	17,654	17,645	1,103	15,492	19,590	19,630	19,701	1,132	17,275	21,915
2030	17,699	17,785	1,037	15,537	19,733	19,643	19,630	1,088	17,308	21,718
2031	17,718	17,723	1,013	15,618	19,809	19,658	19,694	1,027	17,590	21,531
2032	17,724	17,743	963	15,725	19,467	19,674	19,639	1,006	17,599	21,354
2033	17,738	17,788	922	15,861	19,497	19,713	19,657	998	17,616	21,727
2034	17,746	17,646	914	15,906	19,499	19,778	19,676	1,015	17,712	21,734
2035	17,810	17,732	923	15,948	19,565	19,789	19,709	1,037	17,929	21,948
2036	17,838	17,778	945	16,047	19,809	19,818	19,710	1,088	17,836	21,972
2037	17,864	17,785	978	16,167	19,867	19,833	19,715	1,110	17,931	22,094
2038	17,875	17,752	1,027	15,999	19,970	19,870	19,804	1,100	17,973	22,222
2039	17,901	17,835	1,021	16,166	19,971	19,898	19,894	1,152	17,873	22,330
2040	17,928	17,902	1,033	16,176	20,238	19,951	19,979	1,214	18,010	22,393
2041	17,961	17,984	1,092	16,044	20,048	20,007	20,013	1,207	18,006	22,526
2042	18,018	18,011	1,128	16,214	20,399	20,012	20,115	1,153	17,988	22,093
2043	18,053	18,078	1,099	16,200	20,182	19,987	20,005	1,115	17,941	22,148
2044	18,042	18,095	1,051	16,167	20,096	19,952	19,920	1,100	18,168	21,959
2045	18,012	18,009	1,020	16,199	19,887	19,941	19,945	1,114	18,181	22,370

	$F_{35\%}$ (0.64yr^{-1})									
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	9,433	9,400	1,737	6,595	13,218	11,485	11,445	2,114	8,029	16,093
2017	9,210	9,178	1,696	6,439	12,905	10,054	10,017	1,731	7,096	13,655
2018	8,346	8,309	1,518	5,842	11,637	8,841	8,790	1,261	6,536	11,281
2019	7,275	7,264	1,135	5,304	9,522	7,968	7,889	885	6,497	9,837
2020	6,435	6,374	795	5,123	8,085	7,466	7,416	677	6,471	8,855
2021	5,943	5,923	561	5,148	7,087	7,180	7,092	592	6,206	8,342
2022	5,665	5,570	445	5,095	6,591	7,095	7,064	643	6,092	8,546
2023	5,563	5,509	438	4,915	6,516	7,063	7,014	658	6,042	8,493
2024	5,548	5,415	473	4,884	6,721	7,005	7,019	649	5,976	8,352
2025	5,526	5,456	459	4,870	6,508	6,939	6,877	635	5,932	8,313
2026	5,481	5,417	453	4,832	6,552	6,901	6,884	594	5,933	8,260
2027	5,434	5,383	431	4,826	6,452	6,919	6,881	562	6,129	8,227
2028	5,421	5,350	416	4,823	6,491	6,955	6,828	543	6,123	7,865
2029	5,449	5,348	388	4,909	6,390	6,957	6,882	555	6,067	8,016
2030	5,466	5,402	388	4,929	6,245	6,939	6,930	511	6,098	7,974
2031	5,455	5,383	385	4,874	6,272	6,931	6,881	471	6,104	7,756
2032	5,439	5,407	329	4,925	6,037	6,933	6,845	539	6,057	8,148
2033	5,446	5,388	348	4,928	6,245	6,964	6,913	582	6,030	8,224
2034	5,447	5,365	406	4,875	6,442	7,020	6,945	611	6,111	8,336
2035	5,500	5,377	428	4,924	6,437	7,007	6,921	614	6,049	8,323
2036	5,503	5,378	446	4,933	6,486	7,011	6,920	626	6,025	8,452
2037	5,507	5,386	441	4,901	6,459	7,005	6,895	634	6,041	8,437
2038	5,498	5,376	456	4,859	6,683	7,026	6,983	618	6,101	8,368
2039	5,507	5,430	450	4,875	6,508	7,038	7,008	630	6,076	8,276
2040	5,520	5,453	432	4,927	6,452	7,074	7,025	679	6,090	8,398
2041	5,536	5,493	474	4,887	6,436	7,109	7,098	665	6,100	8,294
2042	5,570	5,488	492	4,881	6,509	7,083	6,976	628	6,086	8,478
2043	5,571	5,505	465	4,884	6,562	7,027	6,861	622	6,085	8,636
2044	5,534	5,426	452	4,899	6,669	6,982	6,871	612	6,077	8,428
2045	5,498	5,358	448	4,919	6,586	6,978	6,876	605	6,036	8,197

Table F.4. Projected mean, median, and standard deviation (SD) of total catch (OFL) and retained catch (RETC) in biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0 for EAG, 2016–2045.

No Directed Fishery										
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	1.981	1.974	0.365	1.385	2.775	0	0	0	0	0
2017	2.163	2.157	0.363	1.533	2.907	0	0	0	0	0
2018	2.279	2.252	0.349	1.667	2.995	0	0	0	0	0
2019	2.367	2.361	0.316	1.841	2.993	0	0	0	0	0
2020	2.419	2.407	0.283	1.932	2.973	0	0	0	0	0
2021	2.466	2.460	0.262	2.048	2.943	0	0	0	0	0
2022	2.501	2.471	0.239	2.127	2.955	0	0	0	0	0
2023	2.523	2.507	0.223	2.157	2.959	0	0	0	0	0
2024	2.536	2.548	0.205	2.158	2.930	0	0	0	0	0
2025	2.542	2.547	0.190	2.177	2.951	0	0	0	0	0
2026	2.550	2.544	0.176	2.218	2.878	0	0	0	0	0
2027	2.560	2.560	0.159	2.240	2.837	0	0	0	0	0
2028	2.566	2.587	0.151	2.246	2.852	0	0	0	0	0
2029	2.569	2.563	0.147	2.263	2.862	0	0	0	0	0
2030	2.570	2.571	0.138	2.284	2.818	0	0	0	0	0
2031	2.574	2.576	0.134	2.296	2.829	0	0	0	0	0
2032	2.574	2.564	0.130	2.295	2.833	0	0	0	0	0
2033	2.587	2.577	0.131	2.319	2.832	0	0	0	0	0
2034	2.586	2.571	0.132	2.325	2.870	0	0	0	0	0
2035	2.592	2.585	0.137	2.352	2.859	0	0	0	0	0
2036	2.593	2.582	0.145	2.334	2.881	0	0	0	0	0
2037	2.598	2.595	0.140	2.344	2.879	0	0	0	0	0
2038	2.601	2.596	0.145	2.347	2.915	0	0	0	0	0
2039	2.606	2.615	0.155	2.331	2.901	0	0	0	0	0
2040	2.615	2.617	0.158	2.367	2.952	0	0	0	0	0
2041	2.619	2.629	0.152	2.356	2.922	0	0	0	0	0
2042	2.616	2.623	0.147	2.357	2.909	0	0	0	0	0
2043	2.614	2.613	0.143	2.358	2.862	0	0	0	0	0
2044	2.609	2.605	0.144	2.385	2.930	0	0	0	0	0
2045	2.614	2.606	0.147	2.383	2.909	0	0	0	0	0

	$F_{35\%}$ (0.64yr^{-1})									
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	3,371	3,359	621	2,357	4,723	3,198	3,187	589	2,236	4,481
2017	3,205	3,194	589	2,241	4,488	3,051	3,042	564	2,134	4,278
2018	2,925	2,909	526	2,052	4,058	2,796	2,788	517	1,878	3,906
2019	2,566	2,559	401	1,877	3,372	2,447	2,449	405	1,714	3,247
2020	2,274	2,256	281	1,801	2,856	2,154	2,143	292	1,657	2,734
2021	2,092	2,073	196	1,813	2,500	1,964	1,964	213	1,641	2,390
2022	1,991	1,951	153	1,802	2,312	1,853	1,823	177	1,571	2,201
2023	1,949	1,937	145	1,740	2,266	1,806	1,791	170	1,504	2,137
2024	1,939	1,899	155	1,720	2,321	1,792	1,776	185	1,494	2,202
2025	1,931	1,904	152	1,718	2,268	1,781	1,781	184	1,469	2,142
2026	1,917	1,893	149	1,704	2,257	1,769	1,741	179	1,455	2,138
2027	1,902	1,877	142	1,700	2,231	1,758	1,753	165	1,493	2,108
2028	1,896	1,871	135	1,708	2,250	1,753	1,738	156	1,529	2,119
2029	1,904	1,872	127	1,732	2,219	1,760	1,734	151	1,504	2,097
2030	1,909	1,883	126	1,733	2,158	1,768	1,743	152	1,508	2,036
2031	1,906	1,883	125	1,720	2,172	1,766	1,756	149	1,510	2,060
2032	1,901	1,889	108	1,734	2,123	1,757	1,747	131	1,504	2,006
2033	1,903	1,882	112	1,737	2,156	1,759	1,741	136	1,529	2,031
2034	1,905	1,875	130	1,723	2,224	1,763	1,733	153	1,509	2,110
2035	1,919	1,885	140	1,730	2,230	1,777	1,752	163	1,496	2,108
2036	1,923	1,881	146	1,732	2,254	1,779	1,749	171	1,489	2,135
2037	1,924	1,885	146	1,728	2,243	1,780	1,773	170	1,507	2,128
2038	1,922	1,880	149	1,716	2,314	1,780	1,749	173	1,503	2,192
2039	1,924	1,896	148	1,720	2,253	1,779	1,763	174	1,503	2,133
2040	1,929	1,905	144	1,732	2,247	1,785	1,782	172	1,518	2,138
2041	1,935	1,924	154	1,729	2,230	1,793	1,808	178	1,522	2,105
2042	1,944	1,915	161	1,728	2,258	1,805	1,784	183	1,511	2,141
2043	1,945	1,925	154	1,726	2,263	1,803	1,782	177	1,515	2,135
2044	1,934	1,898	149	1,733	2,300	1,790	1,761	171	1,516	2,175
2045	1,922	1,871	147	1,731	2,289	1,777	1,749	170	1,518	2,174

Table F.5. Projected mean, median, and standard deviation (SD) of retained CPUE indices with 95% confidence limits under $F_{35\%}$ harvest control rule for scenario 17_0 for EAG, 2016–2045.

	$F_{35\%}$ (0.64yr^{-1})				
Year	Mean CPUE	Median CPUE	SD CPUE	95% Lower Limit	95% Upper Limit
2016	0.997	0.993	0.183	0.697	1.396
2017	0.977	0.974	0.180	0.683	1.369
2018	0.894	0.890	0.162	0.631	1.245
2019	0.781	0.779	0.121	0.573	1.023
2020	0.691	0.684	0.084	0.553	0.866
2021	0.638	0.636	0.059	0.555	0.759
2022	0.609	0.597	0.046	0.549	0.705
2023	0.598	0.592	0.045	0.533	0.697
2024	0.597	0.586	0.049	0.533	0.719
2025	0.595	0.588	0.047	0.528	0.699
2026	0.591	0.585	0.047	0.524	0.701
2027	0.585	0.579	0.045	0.524	0.692
2028	0.584	0.578	0.043	0.524	0.697
2029	0.587	0.578	0.040	0.533	0.685
2030	0.589	0.580	0.040	0.536	0.669
2031	0.587	0.579	0.040	0.529	0.673
2032	0.586	0.583	0.034	0.533	0.649
2033	0.587	0.580	0.036	0.534	0.667
2034	0.587	0.578	0.042	0.528	0.691
2035	0.592	0.580	0.044	0.533	0.690
2036	0.593	0.579	0.046	0.537	0.697
2037	0.593	0.580	0.046	0.533	0.693
2038	0.592	0.577	0.047	0.527	0.716
2039	0.593	0.584	0.047	0.529	0.697
2040	0.595	0.587	0.045	0.535	0.694
2041	0.596	0.589	0.049	0.528	0.690
2042	0.599	0.590	0.051	0.527	0.699
2043	0.600	0.593	0.048	0.531	0.702
2044	0.596	0.586	0.047	0.529	0.713
2045	0.592	0.578	0.047	0.533	0.707

Table F.6. Projected mean, median, and standard deviation (SD) of legal male (LMB) and mature male (MMB) biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0d for EAG, 2016–2045. The top table provides a base projection scenario with no directed fishery.

No Directed Fishery										
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	6,380	6,317	1,492	4,036	9,720	10,303	10,201	2,410	6,517	15,696
2017	8,560	8,476	2,002	5,415	13,042	11,798	11,708	2,604	7,590	17,467
2018	10,234	10,117	2,373	6,490	15,526	13,110	13,021	2,533	8,872	18,403
2019	11,540	11,427	2,419	7,551	16,666	14,156	13,957	2,346	10,271	19,084
2020	12,560	12,405	2,290	8,730	17,353	15,033	15,000	2,094	11,533	19,428
2021	13,400	13,345	2,041	10,045	17,723	15,743	15,573	1,905	12,803	19,627
2022	14,066	14,004	1,804	11,079	17,776	16,385	16,324	1,787	13,789	19,940
2023	14,643	14,507	1,655	12,140	17,967	16,917	16,848	1,679	14,335	20,394
2024	15,150	15,076	1,552	12,825	18,258	17,331	17,381	1,587	14,705	20,452
2025	15,560	15,517	1,476	13,189	18,526	17,647	17,715	1,498	15,057	20,612
2026	15,873	15,903	1,395	13,550	18,569	17,894	17,969	1,422	15,326	20,455
2027	16,102	16,185	1,329	13,784	18,564	18,129	18,051	1,321	15,632	20,465
2028	16,296	16,311	1,255	13,967	18,635	18,336	18,398	1,228	15,841	20,412
2029	16,487	16,473	1,160	14,221	18,403	18,480	18,507	1,194	16,107	20,815
2030	16,641	16,671	1,097	14,440	18,678	18,578	18,649	1,160	16,190	20,835
2031	16,743	16,802	1,078	14,591	18,980	18,666	18,770	1,112	16,481	20,835
2032	16,812	16,905	1,036	14,719	18,805	18,749	18,733	1,090	16,680	20,769
2033	16,886	16,976	1,003	14,950	18,922	18,836	18,869	1,067	16,746	20,946
2034	16,944	16,978	987	15,039	18,916	18,942	18,846	1,063	16,902	20,851
2035	17,043	17,010	977	15,185	18,859	18,999	18,909	1,073	16,939	20,976
2036	17,109	17,018	981	15,220	19,041	19,056	19,008	1,139	16,994	21,238
2037	17,171	17,079	1,016	15,281	19,027	19,088	18,942	1,177	17,131	21,443
2038	17,196	17,107	1,080	15,291	19,465	19,154	19,059	1,177	17,201	21,705
2039	17,242	17,141	1,091	15,448	19,480	19,194	19,206	1,225	17,118	21,872
2040	17,289	17,194	1,105	15,403	19,809	19,250	19,305	1,296	17,135	21,839
2041	17,325	17,357	1,160	15,458	19,682	19,324	19,363	1,305	17,086	22,242
2042	17,391	17,377	1,210	15,319	20,080	19,337	19,400	1,249	17,209	21,814
2043	17,437	17,530	1,190	15,452	19,940	19,323	19,346	1,189	17,243	21,651
2044	17,433	17,426	1,134	15,472	19,561	19,314	19,359	1,145	17,356	21,601
2045	17,418	17,423	1,073	15,548	19,448	19,332	19,300	1,148	17,505	21,690

	$F_{35\%}$ ($0.64yr^{-1}$)									
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	6,380	6,317	1,492	4,036	9,720	8,001	7,922	1,871	5,061	12,189
2017	6,314	6,215	1,418	4,237	9,563	7,556	7,470	1,585	5,035	10,977
2018	6,068	5,930	1,305	4,234	9,084	7,254	7,191	1,184	5,386	9,669
2019	5,783	5,651	1,010	4,299	7,907	7,004	6,957	846	5,772	8,950
2020	5,550	5,422	732	4,538	7,199	6,865	6,804	656	5,887	8,205
2021	5,416	5,374	517	4,682	6,620	6,773	6,716	594	5,751	7,937
2022	5,323	5,245	425	4,730	6,200	6,783	6,736	666	5,800	8,264
2023	5,306	5,228	446	4,636	6,330	6,802	6,747	684	5,760	8,404
2024	5,331	5,189	497	4,684	6,583	6,787	6,705	669	5,685	8,226
2025	5,336	5,258	482	4,651	6,458	6,746	6,667	665	5,727	8,092
2026	5,318	5,239	473	4,619	6,401	6,709	6,653	649	5,673	8,157
2027	5,281	5,158	464	4,650	6,293	6,723	6,675	618	5,769	8,189
2028	5,264	5,184	458	4,611	6,434	6,751	6,723	599	5,782	7,855
2029	5,287	5,208	433	4,702	6,286	6,742	6,657	606	5,749	7,852
2030	5,298	5,204	428	4,684	6,199	6,711	6,743	561	5,785	7,775
2031	5,279	5,185	422	4,662	6,178	6,698	6,604	523	5,814	7,689
2032	5,254	5,244	369	4,705	5,924	6,707	6,656	571	5,745	8,044
2033	5,261	5,190	384	4,667	6,165	6,734	6,682	607	5,869	8,116
2034	5,264	5,189	427	4,652	6,382	6,789	6,674	646	5,798	8,073
2035	5,315	5,201	452	4,724	6,296	6,789	6,664	657	5,794	8,084
2036	5,324	5,182	477	4,695	6,315	6,791	6,690	685	5,817	8,413
2037	5,336	5,261	481	4,697	6,379	6,776	6,644	695	5,809	8,323
2038	5,318	5,170	502	4,691	6,679	6,808	6,768	672	5,760	8,295
2039	5,328	5,229	498	4,696	6,487	6,815	6,823	669	5,771	8,214
2040	5,345	5,271	470	4,662	6,455	6,839	6,870	720	5,662	8,357
2041	5,352	5,314	498	4,647	6,415	6,883	6,856	719	5,749	8,302
2042	5,386	5,327	530	4,601	6,494	6,858	6,716	669	5,847	8,387
2043	5,391	5,273	507	4,664	6,545	6,806	6,685	646	5,932	8,428
2044	5,352	5,257	483	4,721	6,534	6,778	6,695	636	5,862	8,344
2045	5,322	5,185	469	4,755	6,561	6,794	6,653	634	5,820	8,047

Table F.7. Projected mean, median, and standard deviation (SD) of total catch (OFL) and retained catch (RETC) in biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0d for EAG, 2016–2045.

No Directed Fishery										
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	1.689	1.672	0.395	1.068	2.573	0	0	0	0	0
2017	1.929	1.911	0.397	1.267	2.758	0	0	0	0	0
2018	2.115	2.090	0.386	1.473	2.933	0	0	0	0	0
2019	2.278	2.272	0.350	1.707	3.016	0	0	0	0	0
2020	2.403	2.376	0.317	1.882	3.051	0	0	0	0	0
2021	2.517	2.506	0.297	2.057	3.099	0	0	0	0	0
2022	2.613	2.598	0.275	2.206	3.175	0	0	0	0	0
2023	2.690	2.674	0.261	2.277	3.222	0	0	0	0	0
2024	2.750	2.763	0.244	2.346	3.218	0	0	0	0	0
2025	2.795	2.805	0.232	2.402	3.244	0	0	0	0	0
2026	2.836	2.844	0.218	2.429	3.250	0	0	0	0	0
2027	2.874	2.877	0.200	2.472	3.203	0	0	0	0	0
2028	2.902	2.923	0.191	2.527	3.248	0	0	0	0	0
2029	2.921	2.930	0.187	2.544	3.296	0	0	0	0	0
2030	2.936	2.947	0.179	2.569	3.262	0	0	0	0	0
2031	2.953	2.962	0.175	2.614	3.300	0	0	0	0	0
2032	2.962	2.968	0.170	2.623	3.298	0	0	0	0	0
2033	2.984	2.974	0.167	2.664	3.285	0	0	0	0	0
2034	2.991	2.978	0.165	2.668	3.318	0	0	0	0	0
2035	3.005	2.991	0.172	2.686	3.309	0	0	0	0	0
2036	3.007	2.985	0.184	2.676	3.382	0	0	0	0	0
2037	3.019	3.002	0.181	2.726	3.379	0	0	0	0	0
2038	3.026	3.017	0.186	2.708	3.450	0	0	0	0	0
2039	3.032	3.048	0.199	2.714	3.429	0	0	0	0	0
2040	3.046	3.038	0.205	2.696	3.501	0	0	0	0	0
2041	3.052	3.065	0.199	2.701	3.484	0	0	0	0	0
2042	3.050	3.045	0.192	2.719	3.433	0	0	0	0	0
2043	3.050	3.060	0.182	2.726	3.389	0	0	0	0	0
2044	3.049	3.060	0.181	2.744	3.421	0	0	0	0	0
2045	3.059	3.045	0.182	2.782	3.474	0	0	0	0	0

	$F_{35\%}$ (0.64yr^{-1})									
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	2,284	2,262	534	1,445	3,480	2,124	2,137	556	1,116	3,289
2017	2,206	2,170	493	1,487	3,336	2,046	2,052	519	1,148	3,157
2018	2,126	2,074	446	1,500	3,154	1,981	1,966	467	1,209	3,012
2019	2,027	1,975	351	1,521	2,782	1,887	1,855	373	1,299	2,657
2020	1,947	1,907	254	1,595	2,523	1,809	1,778	276	1,406	2,397
2021	1,897	1,884	178	1,652	2,316	1,756	1,752	201	1,459	2,206
2022	1,865	1,832	144	1,675	2,154	1,721	1,709	169	1,441	2,043
2023	1,857	1,831	147	1,641	2,195	1,712	1,691	170	1,424	2,068
2024	1,863	1,819	162	1,647	2,268	1,717	1,686	187	1,429	2,134
2025	1,864	1,835	159	1,645	2,244	1,715	1,703	188	1,401	2,105
2026	1,859	1,831	156	1,634	2,227	1,710	1,688	185	1,400	2,106
2027	1,848	1,814	153	1,641	2,165	1,704	1,676	177	1,407	2,034
2028	1,842	1,813	149	1,636	2,227	1,699	1,689	171	1,418	2,102
2029	1,847	1,817	142	1,652	2,193	1,702	1,686	166	1,425	2,073
2030	1,851	1,818	140	1,650	2,151	1,708	1,695	167	1,406	2,021
2031	1,846	1,814	137	1,641	2,136	1,703	1,691	161	1,409	2,018
2032	1,838	1,836	121	1,653	2,076	1,695	1,683	143	1,434	1,952
2033	1,839	1,814	124	1,658	2,128	1,694	1,678	145	1,429	2,008
2034	1,842	1,818	137	1,645	2,199	1,698	1,677	159	1,454	2,081
2035	1,856	1,816	147	1,667	2,176	1,712	1,687	169	1,439	2,049
2036	1,861	1,806	157	1,652	2,191	1,716	1,673	182	1,420	2,066
2037	1,864	1,838	160	1,655	2,217	1,717	1,706	183	1,431	2,081
2038	1,861	1,812	166	1,653	2,313	1,718	1,690	187	1,424	2,182
2039	1,862	1,823	164	1,649	2,244	1,717	1,691	188	1,403	2,118
2040	1,868	1,831	156	1,640	2,238	1,721	1,706	185	1,422	2,115
2041	1,872	1,856	163	1,645	2,213	1,728	1,741	187	1,405	2,086
2042	1,881	1,857	173	1,624	2,255	1,741	1,730	192	1,422	2,125
2043	1,882	1,851	168	1,644	2,254	1,742	1,721	187	1,458	2,126
2044	1,871	1,842	159	1,666	2,258	1,729	1,702	177	1,478	2,139
2045	1,861	1,810	155	1,678	2,254	1,719	1,685	173	1,464	2,134

Table F.8. Projected mean, median, and standard deviation (SD) of retained CPUE indices with 95% confidence limits under $F_{35\%}$ harvest control rule for scenario 17_0d for EAG, 2016–2045.

	$F_{35\%}$ ($0.64yr^{-1}$)				
Year	Mean CPUE	Median CPUE	SD CPUE	95% Lower Limit	95% Upper Limit
2016	0.661	0.652	0.151	0.432	1.004
2017	0.657	0.644	0.144	0.455	0.991
2018	0.636	0.619	0.134	0.455	0.947
2019	0.606	0.591	0.104	0.457	0.829
2020	0.583	0.571	0.075	0.477	0.753
2021	0.568	0.565	0.053	0.497	0.692
2022	0.559	0.551	0.043	0.498	0.649
2023	0.557	0.549	0.045	0.491	0.662
2024	0.560	0.545	0.050	0.495	0.687
2025	0.561	0.553	0.049	0.492	0.676
2026	0.559	0.551	0.048	0.490	0.670
2027	0.555	0.544	0.047	0.493	0.657
2028	0.553	0.546	0.047	0.487	0.673
2029	0.556	0.548	0.044	0.494	0.660
2030	0.557	0.546	0.043	0.498	0.647
2031	0.555	0.545	0.043	0.494	0.646
2032	0.552	0.551	0.037	0.497	0.622
2033	0.553	0.546	0.039	0.493	0.643
2034	0.553	0.545	0.043	0.494	0.668
2035	0.558	0.546	0.046	0.500	0.658
2036	0.560	0.544	0.048	0.498	0.662
2037	0.561	0.552	0.049	0.495	0.667
2038	0.559	0.544	0.051	0.494	0.699
2039	0.560	0.549	0.050	0.496	0.678
2040	0.562	0.555	0.047	0.497	0.676
2041	0.562	0.559	0.050	0.491	0.671
2042	0.565	0.558	0.054	0.488	0.680
2043	0.566	0.555	0.052	0.492	0.684
2044	0.563	0.552	0.049	0.499	0.684
2045	0.559	0.544	0.048	0.503	0.685

Table F.9. Projected mean, median, and standard deviation (SD) of legal male (LMB) and mature male (MMB) biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0 for WAG, 2016–2045. The top table provides a base projection scenario with no directed fishery.

No Directed Fishery										
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	3,581	3,571	637	2,534	4,964	7,263	7,243	1,292	5,141	10,070
2017	5,526	5,511	983	3,911	7,662	8,749	8,745	1,452	6,428	11,840
2018	7,292	7,253	1,284	5,191	10,074	9,898	9,814	1,403	7,709	12,874
2019	8,572	8,561	1,349	6,452	11,405	10,815	10,647	1,312	8,797	13,603
2020	9,502	9,311	1,277	7,554	12,218	11,541	11,457	1,222	9,518	13,945
2021	10,211	10,095	1,167	8,321	12,665	12,115	12,153	1,130	10,264	14,185
2022	10,752	10,731	1,074	8,956	12,782	12,602	12,666	1,035	10,879	14,553
2023	11,195	11,267	979	9,618	13,002	13,025	13,127	967	11,284	14,629
2024	11,567	11,645	900	9,982	13,232	13,398	13,532	893	11,684	14,808
2025	11,909	12,028	843	10,346	13,211	13,681	13,725	799	12,083	15,031
2026	12,192	12,286	768	10,682	13,403	13,902	13,941	730	12,413	15,167
2027	12,408	12,481	691	10,977	13,601	14,076	14,080	703	12,709	15,225
2028	12,574	12,550	639	11,283	13,678	14,210	14,154	717	12,847	15,469
2029	12,702	12,659	636	11,495	13,806	14,306	14,253	706	13,035	15,594
2030	12,796	12,752	658	11,545	13,971	14,382	14,348	683	13,082	15,585
2031	12,863	12,834	635	11,773	14,045	14,471	14,406	722	12,990	15,833
2032	12,923	12,862	644	11,715	14,092	14,561	14,574	733	13,329	15,953
2033	13,004	12,980	669	11,654	14,311	14,612	14,570	704	13,303	16,015
2034	13,066	13,072	670	11,871	14,304	14,655	14,631	672	13,403	16,083
2035	13,107	13,078	630	11,950	14,389	14,705	14,695	656	13,459	16,069
2036	13,143	13,138	610	11,963	14,475	14,745	14,774	647	13,540	15,999
2037	13,187	13,209	593	12,086	14,331	14,761	14,750	656	13,465	15,747
2038	13,208	13,203	597	12,045	14,247	14,780	14,872	667	13,502	16,029
2039	13,225	13,255	607	12,032	14,221	14,778	14,825	709	13,322	16,210
2040	13,232	13,300	626	11,973	14,443	14,775	14,754	765	13,298	15,976
2041	13,225	13,223	675	11,890	14,471	14,773	14,756	780	13,281	16,113
2042	13,223	13,198	711	11,855	14,335	14,764	14,814	784	13,091	16,148
2043	13,214	13,227	720	11,735	14,536	14,784	14,766	785	13,351	16,114
2044	13,214	13,261	724	11,863	14,509	14,828	14,828	776	13,538	16,103
2045	13,240	13,274	716	12,022	14,462	14,880	14,951	782	13,420	16,134

	$F_{35\%}$ ($0.6yr^{-1}$)									
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	3,581	3,571	637	2,534	4,964	5,951	5,934	1,059	4,212	8,251
2017	4,237	4,208	727	3,117	5,851	6,061	6,057	961	4,582	8,101
2018	4,619	4,575	777	3,445	6,341	5,849	5,778	713	4,731	7,379
2019	4,546	4,531	623	3,646	5,907	5,597	5,550	543	4,544	6,679
2020	4,334	4,262	451	3,635	5,246	5,395	5,425	473	4,472	6,244
2021	4,160	4,135	346	3,554	4,858	5,258	5,229	420	4,438	6,005
2022	4,031	4,030	306	3,503	4,611	5,205	5,195	396	4,405	5,872
2023	3,967	3,937	268	3,506	4,459	5,209	5,175	415	4,496	5,911
2024	3,949	3,907	271	3,476	4,438	5,246	5,277	393	4,567	5,888
2025	3,973	3,951	283	3,499	4,516	5,243	5,272	345	4,581	5,859
2026	3,983	3,962	253	3,595	4,442	5,222	5,192	335	4,663	5,945
2027	3,971	3,962	230	3,554	4,500	5,200	5,145	389	4,550	6,031
2028	3,960	3,924	239	3,621	4,446	5,183	5,121	445	4,389	6,116
2029	3,954	3,890	283	3,524	4,622	5,164	5,136	427	4,373	5,867
2030	3,943	3,891	300	3,456	4,542	5,152	5,117	414	4,408	5,930
2031	3,927	3,895	271	3,468	4,454	5,174	5,148	440	4,240	5,997
2032	3,925	3,888	288	3,405	4,485	5,210	5,244	415	4,376	5,993
2033	3,952	3,945	291	3,470	4,554	5,204	5,189	373	4,586	5,960
2034	3,959	3,927	272	3,472	4,525	5,197	5,204	369	4,446	5,865
2035	3,952	3,927	244	3,529	4,457	5,207	5,213	371	4,465	5,907
2036	3,949	3,930	247	3,510	4,430	5,214	5,273	397	4,454	5,873
2037	3,965	3,955	254	3,490	4,399	5,200	5,174	422	4,448	6,031
2038	3,960	3,946	278	3,523	4,475	5,198	5,177	420	4,457	6,055
2039	3,956	3,939	288	3,494	4,571	5,179	5,188	432	4,323	6,002
2040	3,950	3,926	281	3,486	4,617	5,167	5,160	452	4,271	6,004
2041	3,938	3,885	295	3,426	4,539	5,164	5,180	442	4,300	5,915
2042	3,938	3,907	299	3,402	4,543	5,157	5,150	438	4,283	5,912
2043	3,930	3,901	292	3,442	4,486	5,180	5,212	420	4,404	5,889
2044	3,932	3,892	290	3,381	4,477	5,226	5,266	403	4,436	5,911
2045	3,954	3,947	274	3,536	4,410	5,266	5,274	415	4,412	6,051

Table F.10. Projected mean, median, and standard deviation (SD) of total catch (OFL) and retained catch (RETC) in biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0 for WAG, 2016–2045.

No Directed Fishery										
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	3.377	3.367	0.601	2.390	4.682	0	0	0	0	0
2017	3.949	3.955	0.603	2.998	5.223	0	0	0	0	0
2018	4.416	4.335	0.585	3.520	5.656	0	0	0	0	0
2019	4.796	4.765	0.549	3.902	5.943	0	0	0	0	0
2020	5.085	5.091	0.517	4.241	6.051	0	0	0	0	0
2021	5.332	5.369	0.472	4.555	6.220	0	0	0	0	0
2022	5.532	5.566	0.439	4.785	6.356	0	0	0	0	0
2023	5.721	5.786	0.411	4.977	6.388	0	0	0	0	0
2024	5.864	5.883	0.369	5.149	6.482	0	0	0	0	0
2025	5.978	5.999	0.335	5.307	6.557	0	0	0	0	0
2026	6.068	6.074	0.312	5.459	6.595	0	0	0	0	0
2027	6.139	6.136	0.308	5.537	6.676	0	0	0	0	0
2028	6.192	6.179	0.314	5.605	6.735	0	0	0	0	0
2029	6.230	6.216	0.289	5.684	6.787	0	0	0	0	0
2030	6.265	6.234	0.306	5.680	6.822	0	0	0	0	0
2031	6.314	6.318	0.314	5.726	6.919	0	0	0	0	0
2032	6.339	6.333	0.315	5.761	6.896	0	0	0	0	0
2033	6.361	6.330	0.293	5.847	6.993	0	0	0	0	0
2034	6.381	6.389	0.291	5.811	6.992	0	0	0	0	0
2035	6.407	6.412	0.280	5.893	6.942	0	0	0	0	0
2036	6.412	6.410	0.283	5.859	6.905	0	0	0	0	0
2037	6.426	6.452	0.282	5.864	6.882	0	0	0	0	0
2038	6.429	6.468	0.292	5.831	6.993	0	0	0	0	0
2039	6.426	6.424	0.321	5.789	7.014	0	0	0	0	0
2040	6.430	6.431	0.333	5.803	6.972	0	0	0	0	0
2041	6.422	6.428	0.335	5.748	7.030	0	0	0	0	0
2042	6.425	6.430	0.340	5.775	7.013	0	0	0	0	0
2043	6.440	6.458	0.336	5.825	7.002	0	0	0	0	0
2044	6.462	6.467	0.336	5.872	7.017	0	0	0	0	0
2045	6.480	6.507	0.341	5.858	7.031	0	0	0	0	0

				$F_{35\%}$ ($0.6yr^{-1}$)						
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	1,301	1,297	232	921	1,804	1,177	1,188	235	726	1,652
2017	1,500	1,489	256	1,106	2,069	1,372	1,371	251	939	1,906
2018	1,629	1,614	267	1,232	2,219	1,514	1,506	264	1,116	2,087
2019	1,614	1,605	218	1,303	2,091	1,505	1,500	223	1,165	1,977
2020	1,546	1,525	158	1,301	1,864	1,433	1,412	171	1,136	1,767
2021	1,485	1,475	121	1,271	1,725	1,372	1,374	137	1,112	1,623
2022	1,440	1,443	104	1,264	1,636	1,325	1,336	120	1,080	1,538
2023	1,417	1,407	91	1,261	1,591	1,300	1,298	107	1,079	1,487
2024	1,411	1,404	92	1,254	1,577	1,296	1,281	105	1,115	1,474
2025	1,417	1,410	95	1,265	1,597	1,306	1,309	106	1,118	1,497
2026	1,420	1,410	86	1,288	1,572	1,310	1,314	96	1,144	1,465
2027	1,416	1,415	78	1,282	1,592	1,300	1,297	89	1,153	1,485
2028	1,413	1,395	82	1,300	1,587	1,291	1,269	100	1,127	1,482
2029	1,410	1,381	96	1,266	1,641	1,289	1,271	115	1,076	1,535
2030	1,407	1,384	101	1,246	1,606	1,286	1,272	118	1,076	1,512
2031	1,402	1,391	93	1,249	1,580	1,282	1,276	112	1,070	1,471
2032	1,402	1,389	97	1,238	1,593	1,285	1,283	113	1,074	1,488
2033	1,409	1,402	98	1,248	1,623	1,295	1,291	110	1,083	1,514
2034	1,412	1,406	91	1,255	1,595	1,297	1,296	106	1,111	1,492
2035	1,410	1,406	82	1,265	1,582	1,296	1,294	98	1,099	1,481
2036	1,409	1,401	83	1,264	1,575	1,293	1,293	101	1,092	1,468
2037	1,413	1,411	86	1,256	1,565	1,295	1,302	104	1,088	1,464
2038	1,413	1,403	93	1,268	1,595	1,297	1,302	110	1,091	1,488
2039	1,411	1,407	97	1,263	1,615	1,292	1,296	116	1,084	1,511
2040	1,409	1,399	96	1,253	1,631	1,288	1,296	118	1,053	1,528
2041	1,405	1,390	99	1,233	1,606	1,284	1,277	119	1,035	1,496
2042	1,405	1,393	101	1,222	1,611	1,283	1,284	121	1,067	1,511
2043	1,403	1,392	99	1,239	1,593	1,283	1,279	117	1,041	1,488
2044	1,404	1,391	98	1,220	1,595	1,289	1,284	113	1,097	1,490
2045	1,411	1,407	93	1,270	1,570	1,298	1,307	108	1,083	1,469

Table F.11. Projected mean, median, and standard deviation (SD) of retained CPUE indices with 95% confidence limits under $F_{35\%}$ harvest control rule for scenario 17_0 for WAG, 2016–2045.

	$F_{35\%}$ $(0.6yr^{-1})$				
Year	Mean CPUE	Median CPUE	SD CPUE	95% Lower Limit	95% Upper Limit
2016	0.753	0.749	0.131	0.546	1.041
2017	0.887	0.880	0.151	0.661	1.223
2018	0.970	0.960	0.161	0.725	1.328
2019	0.954	0.950	0.129	0.766	1.237
2020	0.908	0.893	0.092	0.772	1.095
2021	0.871	0.864	0.070	0.753	1.015
2022	0.844	0.845	0.062	0.738	0.964
2023	0.831	0.823	0.055	0.739	0.935
2024	0.827	0.818	0.056	0.727	0.927
2025	0.832	0.825	0.058	0.733	0.944
2026	0.834	0.829	0.052	0.754	0.930
2027	0.833	0.831	0.048	0.744	0.942
2028	0.831	0.823	0.049	0.759	0.932
2029	0.830	0.818	0.058	0.742	0.968
2030	0.827	0.819	0.062	0.728	0.949
2031	0.824	0.819	0.055	0.728	0.932
2032	0.823	0.814	0.059	0.717	0.939
2033	0.828	0.825	0.060	0.723	0.953
2034	0.830	0.823	0.056	0.724	0.945
2035	0.828	0.822	0.050	0.746	0.933
2036	0.828	0.822	0.050	0.739	0.928
2037	0.831	0.827	0.052	0.739	0.920
2038	0.831	0.829	0.057	0.736	0.937
2039	0.830	0.824	0.059	0.739	0.957
2040	0.829	0.825	0.057	0.738	0.966
2041	0.826	0.819	0.060	0.723	0.951
2042	0.826	0.819	0.061	0.725	0.949
2043	0.824	0.820	0.060	0.719	0.939
2044	0.824	0.818	0.060	0.710	0.936
2045	0.829	0.827	0.056	0.740	0.924

Table F.12. Projected mean, median, and standard deviation (SD) of legal male (LMB) and mature male (MMB) biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0d for WAG, 2016–2045. The top table provides a base projection scenario with no directed fishery.

No Directed Fishery										
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	3,114	3,082	731	1,966	4,751	7,086	7,015	1,664	4,473	10,813
2017	5,231	5,179	1,229	3,302	7,982	8,653	8,565	1,897	5,747	12,848
2018	7,156	7,068	1,664	4,553	10,877	9,840	9,717	1,837	7,101	13,857
2019	8,514	8,461	1,771	5,843	12,382	10,778	10,565	1,706	8,248	14,532
2020	9,472	9,275	1,675	7,021	13,147	11,512	11,415	1,567	9,062	14,823
2021	10,190	10,001	1,513	7,874	13,523	12,083	12,089	1,431	9,855	14,907
2022	10,729	10,690	1,369	8,596	13,491	12,560	12,637	1,291	10,420	15,125
2023	11,162	11,189	1,228	9,209	13,492	12,975	13,059	1,184	10,983	15,295
2024	11,522	11,572	1,108	9,640	13,807	13,346	13,437	1,076	11,528	15,238
2025	11,857	11,918	1,017	10,115	13,710	13,624	13,633	955	11,823	15,302
2026	12,137	12,211	917	10,487	13,766	13,836	13,888	857	12,253	15,430
2027	12,347	12,367	815	10,812	13,810	14,005	14,001	801	12,511	15,313
2028	12,506	12,515	738	11,145	13,852	14,133	14,104	790	12,770	15,557
2029	12,629	12,587	712	11,343	13,832	14,222	14,194	758	12,864	15,647
2030	12,717	12,676	713	11,442	14,008	14,292	14,230	735	12,931	15,650
2031	12,778	12,765	679	11,586	14,050	14,379	14,359	782	12,929	15,883
2032	12,834	12,767	694	11,589	14,120	14,468	14,512	796	13,067	15,984
2033	12,913	12,933	725	11,546	14,342	14,515	14,461	770	13,146	16,056
2034	12,974	12,993	729	11,661	14,334	14,556	14,508	736	13,248	16,009
2035	13,012	13,001	690	11,836	14,390	14,604	14,590	721	13,224	15,910
2036	13,046	13,041	669	11,811	14,325	14,641	14,728	711	13,185	15,965
2037	13,088	13,120	652	11,800	14,262	14,651	14,711	724	13,144	15,807
2038	13,105	13,213	656	11,753	14,196	14,669	14,802	736	13,219	16,065
2039	13,119	13,203	669	11,748	14,269	14,661	14,730	785	13,079	16,111
2040	13,123	13,196	691	11,762	14,479	14,651	14,647	852	12,886	15,926
2041	13,110	13,122	750	11,557	14,376	14,651	14,659	867	12,829	16,081
2042	13,106	13,115	792	11,440	14,339	14,645	14,745	867	12,909	16,137
2043	13,098	13,171	799	11,350	14,481	14,666	14,703	859	13,009	16,142
2044	13,100	13,192	796	11,517	14,491	14,717	14,726	847	13,374	16,156
2045	13,130	13,179	781	11,737	14,429	14,775	14,871	857	13,271	16,112

$F_{35\%}$ $(0.68yr^{-1})$										
Year	Mean LMB	Median LMB	SD LMB	95% Lower Limit	95% Upper Limit	Mean MMB	Median MMB	SD MMB	95% Lower Limit	95% Upper Limit
2016	3,114	3,082	731	1,966	4,751	5,946	5,886	1,396	3,754	9,073
2017	4,116	4,051	930	2,738	6,244	6,187	6,132	1,300	4,262	9,067
2018	4,701	4,611	1,042	3,189	7,086	5,966	5,811	947	4,567	8,085
2019	4,652	4,571	843	3,482	6,545	5,664	5,584	669	4,407	6,948
2020	4,397	4,288	579	3,525	5,678	5,419	5,475	536	4,391	6,376
2021	4,182	4,150	406	3,466	4,969	5,251	5,243	464	4,352	6,075
2022	4,024	4,011	341	3,435	4,678	5,177	5,138	435	4,300	5,925
2023	3,944	3,903	294	3,435	4,487	5,174	5,131	459	4,381	6,014
2024	3,918	3,848	299	3,404	4,495	5,218	5,238	439	4,455	5,938
2025	3,943	3,909	315	3,432	4,541	5,218	5,214	388	4,486	5,899
2026	3,957	3,928	285	3,513	4,462	5,193	5,152	379	4,499	5,995
2027	3,945	3,925	259	3,484	4,507	5,170	5,122	429	4,479	6,055
2028	3,931	3,889	269	3,524	4,472	5,151	5,111	480	4,259	6,153
2029	3,924	3,871	308	3,475	4,666	5,129	5,117	465	4,251	5,881
2030	3,911	3,871	323	3,370	4,562	5,116	5,106	463	4,242	5,997
2031	3,895	3,842	297	3,380	4,463	5,140	5,102	490	4,156	6,064
2032	3,893	3,829	323	3,311	4,529	5,178	5,207	460	4,287	6,095
2033	3,922	3,897	324	3,390	4,561	5,173	5,189	419	4,478	6,009
2034	3,931	3,906	303	3,404	4,535	5,166	5,234	408	4,309	5,858
2035	3,923	3,903	270	3,450	4,443	5,175	5,201	408	4,258	5,849
2036	3,919	3,919	271	3,415	4,394	5,179	5,256	438	4,300	5,880
2037	3,934	3,941	278	3,407	4,371	5,162	5,146	476	4,329	6,099
2038	3,928	3,924	308	3,423	4,483	5,161	5,135	476	4,299	6,101
2039	3,923	3,892	326	3,413	4,608	5,138	5,110	487	4,100	6,016
2040	3,917	3,876	317	3,374	4,628	5,122	5,151	508	4,073	6,076
2041	3,901	3,857	331	3,290	4,587	5,125	5,121	489	4,151	5,903
2042	3,900	3,881	331	3,273	4,568	5,122	5,164	481	4,130	5,994
2043	3,896	3,880	320	3,330	4,481	5,148	5,223	458	4,316	5,948
2044	3,900	3,877	316	3,294	4,511	5,199	5,223	446	4,346	5,975
2045	3,924	3,918	302	3,465	4,446	5,244	5,229	461	4,336	6,093

Table F.13. Projected mean, median, and standard deviation (SD) of total catch (OFL) and retained catch (RETC) in biomass (t) with 95% confidence limits under no directed fishery (top) and under $F_{35\%}$ (bottom) harvest control rule for scenario 17_0d for WAG, 2016–2045.

No Directed Fishery										
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	3.469	3.434	0.815	2.190	5.293	0	0	0	0	0
2017	4.094	4.065	0.825	2.846	5.883	0	0	0	0	0
2018	4.599	4.491	0.798	3.423	6.348	0	0	0	0	0
2019	5.006	4.945	0.742	3.853	6.633	0	0	0	0	0
2020	5.311	5.298	0.692	4.228	6.737	0	0	0	0	0
2021	5.568	5.581	0.624	4.560	6.782	0	0	0	0	0
2022	5.773	5.811	0.571	4.831	6.990	0	0	0	0	0
2023	5.970	6.032	0.523	5.072	6.943	0	0	0	0	0
2024	6.119	6.121	0.467	5.242	6.949	0	0	0	0	0
2025	6.233	6.266	0.417	5.471	6.978	0	0	0	0	0
2026	6.325	6.326	0.379	5.633	7.010	0	0	0	0	0
2027	6.398	6.400	0.364	5.747	7.011	0	0	0	0	0
2028	6.450	6.447	0.358	5.810	7.071	0	0	0	0	0
2029	6.487	6.470	0.326	5.877	7.147	0	0	0	0	0
2030	6.522	6.500	0.347	5.872	7.152	0	0	0	0	0
2031	6.572	6.608	0.357	5.945	7.276	0	0	0	0	0
2032	6.597	6.602	0.360	5.931	7.239	0	0	0	0	0
2033	6.618	6.611	0.336	6.046	7.321	0	0	0	0	0
2034	6.638	6.650	0.334	6.005	7.264	0	0	0	0	0
2035	6.665	6.676	0.323	6.041	7.233	0	0	0	0	0
2036	6.667	6.709	0.327	6.019	7.245	0	0	0	0	0
2037	6.681	6.724	0.326	6.004	7.246	0	0	0	0	0
2038	6.683	6.714	0.337	6.003	7.328	0	0	0	0	0
2039	6.674	6.674	0.375	5.930	7.320	0	0	0	0	0
2040	6.680	6.696	0.388	5.880	7.305	0	0	0	0	0
2041	6.673	6.698	0.390	5.819	7.354	0	0	0	0	0
2042	6.676	6.691	0.391	5.871	7.341	0	0	0	0	0
2043	6.693	6.716	0.384	6.008	7.317	0	0	0	0	0
2044	6.719	6.770	0.384	6.074	7.328	0	0	0	0	0
2045	6.741	6.795	0.393	6.020	7.378	0	0	0	0	0

$F_{35\%}$ ($0.68yr^{-1}$)										
Year	Mean OFL	Median OFL	SD OFL	95% Lower Limit	95% Upper Limit	Mean RETC	Median RETC	SD RETC	95% Lower Limit	95% Upper Limit
2016	1,131	1,119	266	714	1,725	1,017	1,029	275	516	1,586
2017	1,440	1,416	323	964	2,181	1,322	1,314	321	784	2,025
2018	1,656	1,625	360	1,143	2,480	1,553	1,532	358	1,028	2,356
2019	1,664	1,636	302	1,250	2,342	1,569	1,557	308	1,131	2,240
2020	1,584	1,548	211	1,281	2,066	1,487	1,457	225	1,129	1,978
2021	1,508	1,483	146	1,255	1,805	1,410	1,399	164	1,108	1,729
2022	1,452	1,449	118	1,249	1,684	1,350	1,351	135	1,062	1,601
2023	1,421	1,406	101	1,240	1,610	1,316	1,300	119	1,068	1,525
2024	1,410	1,394	100	1,238	1,607	1,309	1,299	116	1,092	1,517
2025	1,416	1,398	105	1,254	1,618	1,319	1,307	119	1,111	1,534
2026	1,420	1,409	97	1,269	1,588	1,323	1,322	109	1,123	1,502
2027	1,417	1,411	88	1,263	1,599	1,314	1,305	101	1,135	1,510
2028	1,413	1,391	91	1,278	1,603	1,305	1,276	111	1,119	1,509
2029	1,410	1,384	103	1,269	1,658	1,302	1,286	126	1,072	1,568
2030	1,406	1,386	108	1,231	1,628	1,298	1,284	130	1,070	1,551
2031	1,401	1,381	101	1,234	1,598	1,294	1,300	124	1,068	1,506
2032	1,400	1,384	107	1,220	1,620	1,296	1,293	125	1,071	1,531
2033	1,408	1,393	109	1,230	1,635	1,306	1,300	124	1,087	1,547
2034	1,412	1,409	102	1,238	1,624	1,310	1,314	120	1,114	1,539
2035	1,410	1,401	91	1,260	1,584	1,309	1,318	110	1,086	1,502
2036	1,409	1,408	90	1,244	1,568	1,305	1,302	113	1,072	1,484
2037	1,413	1,413	93	1,234	1,565	1,306	1,318	116	1,075	1,482
2038	1,412	1,406	102	1,240	1,604	1,307	1,310	123	1,061	1,508
2039	1,410	1,395	110	1,239	1,638	1,302	1,300	133	1,033	1,554
2040	1,408	1,392	108	1,224	1,644	1,298	1,303	135	1,011	1,559
2041	1,403	1,392	111	1,199	1,626	1,294	1,284	134	1,006	1,535
2042	1,402	1,394	111	1,195	1,634	1,293	1,292	135	1,048	1,548
2043	1,401	1,390	108	1,216	1,599	1,294	1,287	129	1,032	1,509
2044	1,402	1,394	106	1,204	1,622	1,301	1,304	124	1,099	1,536
2045	1,410	1,408	102	1,258	1,590	1,310	1,326	120	1,084	1,509

Table F.14. Projected mean, median, and standard deviation (SD) of retained CPUE indices with 95% confidence limits under $F_{35\%}$ harvest control rule for scenario 17_0d for WAG, 2016–2045.

	$F_{35\%}$ (0.68yr^{-1})				
Year	Mean CPUE	Median CPUE	SD CPUE	95% Lower Limit	95% Upper Limit
2016	0.562	0.554	0.128	0.369	0.855
2017	0.733	0.719	0.163	0.499	1.109
2018	0.846	0.828	0.185	0.576	1.272
2019	0.841	0.825	0.152	0.628	1.184
2020	0.795	0.778	0.104	0.645	1.029
2021	0.755	0.746	0.071	0.638	0.894
2022	0.726	0.723	0.059	0.628	0.843
2023	0.711	0.706	0.051	0.622	0.808
2024	0.706	0.697	0.052	0.613	0.805
2025	0.710	0.703	0.055	0.621	0.815
2026	0.713	0.707	0.050	0.634	0.801
2027	0.712	0.709	0.045	0.635	0.808
2028	0.710	0.703	0.046	0.643	0.807
2029	0.708	0.697	0.052	0.635	0.839
2030	0.706	0.695	0.056	0.614	0.820
2031	0.703	0.693	0.051	0.615	0.801
2032	0.702	0.693	0.056	0.607	0.813
2033	0.707	0.703	0.057	0.608	0.820
2034	0.709	0.705	0.053	0.611	0.813
2035	0.707	0.702	0.047	0.629	0.797
2036	0.707	0.704	0.046	0.622	0.787
2037	0.710	0.706	0.047	0.616	0.786
2038	0.709	0.708	0.053	0.621	0.804
2039	0.708	0.701	0.056	0.619	0.826
2040	0.707	0.699	0.054	0.625	0.831
2041	0.705	0.698	0.057	0.602	0.822
2042	0.704	0.700	0.057	0.605	0.821
2043	0.703	0.698	0.055	0.599	0.805
2044	0.703	0.701	0.055	0.597	0.814
2045	0.707	0.707	0.052	0.626	0.799

Appendix H. 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 base assessment model 17_0 and setting all directed and bycatch fishing mortality to zero. Figure H.1 compares the time series of estimated B0 and MMB with fishing and MMB ratio (MMB/B0) for scenario 17_0 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.

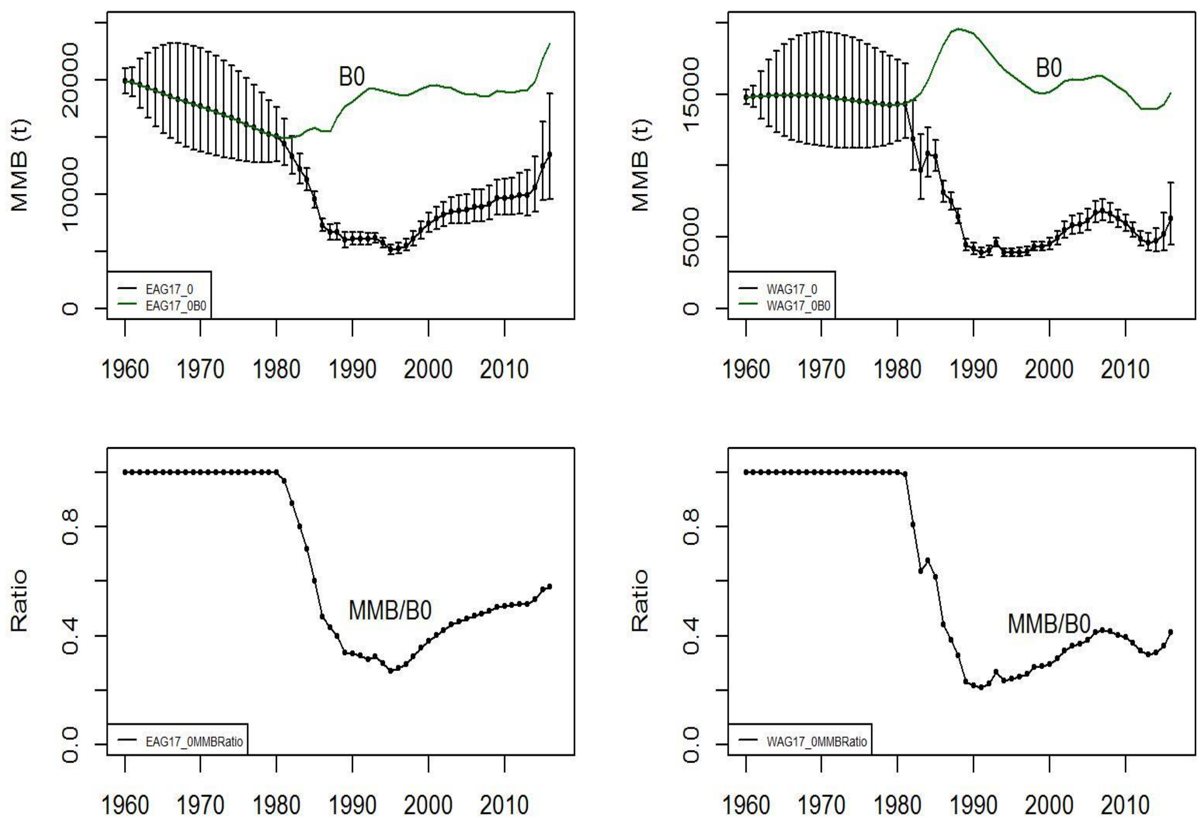

Figure H.1. Estimated B0 (t) (dark green curve) and MMB (t) with fishing (black curve with +/- 2SE) (top panel); and MMB/B0 ratio (bottom panel) from 1960 to 2016 for scenario 17_0 for Aleutian Islands golden king crab in EAG (left) and WAG (right). (Note: 2016 MMB= MMB estimated on 15 February 2017).

9. Assessment of Pribilof Islands Golden King Crab (PIGKC) [2017]

Benjamin Daly, ADF&G, Kodiak
Alaska Department of Fish and Game
Division of Commercial Fisheries

[NOTE: In accordance with the approved schedule, no assessment was conducted for this stock 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 specifications]

Summary of Results

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

Calendar Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2014	N/A	N/A	68	Conf.	Conf.	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	Conf.	Conf.	93	70
2018	N/A	N/A				93	70
2019	N/A	N/A				93	70
2020	N/A	N/A				93	70

N/A = not available

Conf. = confidential

TBA = to be announced

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

Calendar Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2014	N/A	N/A	150,000	Conf.	Conf.	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	Conf.	Conf.	0.20	0.15
2018	N/A	N/A				0.20	0.15
2019	N/A	N/A				0.20	0.15
2020	N/A	N/A				0.20	0.15

N/A = not available

Conf. = confidential

TBA = to be announced

Pribilof Islands Golden King Crab

– 2017 Tier 5 Assessment

2017 Crab SAFE Report Chapter (September 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, 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 2001–2016 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 2016. Estimates of annual fishery mortality during 1991/92–2016 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. <u>Stock biomass</u>:
Stock biomass (all sizes, both sexes) of golden king crab have been estimated for the Pribilof Canyon area using the area-swept technique applied to data obtained from the biennial eastern Bering Sea upper continental slope trawl survey performed by NMFS-AFSC in 2002, 2004, 2008, 2010, 2012, and 2016 (Hoff and Britt 2003, 2005, 2009, 2011; Hoff 2013, 2016). See Appendix A1 for summaries of the slope survey as they pertain to data on and estimates of Pribilof Island golden king crab stock biomass. Complete data on size-sex composition of survey catch are available only from the 2008–2016 biennial surveys (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. <u>Recruitment</u>:
Estimated from size-sex composition data from the eastern Bering Sea upper continental slope trawl survey, mature male biomass in the entire survey area increased slightly from 812 t (1,790,154 lb) in 2012 to 897 t (1,977,546 lb) in 2016, and from 256 t (564,383 lb) in 2012 to 475 t (1,047,196 lb) in 2016 in the Pribilof canyon.

5. <u>Management performance</u>:
No overfished determination (i.e., MSST) has been made for this stock, although approaches to using data from the biennial NMFS-AFSC eastern Bering Sea upper continental slope surveys have been presented to, and considered by, the Crab Plan Team (Gaeuman 2013a, 2013b; Pengilly 2015, Pengilly and Daly 2017; Appendix A1). 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	N/A	N/A				0.20	0.15

a. Guideline harvest level.
b. Total retained catch plus estimated bycatch mortality of discarded catch during crab fisheries and 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. **Basis for the ABC recommendation:** A 25% buffer on the OFL, the default; i.e., ABC = (1-0.25)·OFL. This is a data-poor stock.

9. **A summary of the results of any rebuilding analyses:** Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. **Changes to the management of the fishery:** Fishery continues to be managed under authority of an ADF&G commissioner's permit; guideline harvest level (GHL) was reduced from 68 t (150,000 lb) to 59 t (130,000 lb) in 2015 to account for bycatch mortality in the directed fishery, non-directed crab fisheries, and groundfish fisheries, and to avoid exceeding the ABC. The GHL remained at 59 t (130,000 lb) 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 used in previous assessments due to rounding.

B. Responses to SSC and CPT Comments

- **Responses to the most recent two sets of SSC and CPT comments 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 participation in the 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 re-ran the model with 2016 slope survey data and presents results in an associated discussion paper. However, the author does not present this in relation to a Tier 4 or modified Tier 5 assessment.
- 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, and are frequently found on coral (NMFS 2004, pages 3–43).

The Pribilof District is part of king crab Registration Area Q (Figure 1). Leon et al. (2017) define those boundaries:

> The Bering Sea king crab Registration Area Q southern boundary is a line from 54°36′N lat, 168°W long, to 54°36′N lat, 171°W long, to 55°30′N lat, 171°W long, to 55°30′N lat, 173°30′E long. The northern boundary is the latitude of Point Hope (68°21′N lat). The eastern boundary is a line from 54°36′N lat, 168°W long, to 58°39′N lat, 168°W long, to Cape Newenham (58°39′N lat). The western boundary is the United States-Russia Maritime Boundary Line of 1990 (Figure 2-4). Area Q is divided into 2 districts: the Pribilof District, which includes waters south of Cape Newenham; and the Northern District, which includes all waters north of Cape Newenham.

The NMFS-AFSC conducted an eastern Bering Sea continental slope trawl survey on a biennial schedule during 2002–2016 (the 2014 survey was cancelled). Biomass estimates from the 2016 slope survey have not been presented to the Crab Plan Team prior to this document. Results of this survey from 2002–2016 show that the biomass, number, and density (in number per area and in weight per area) of golden king crab on the eastern Bering Sea continental slope are higher in the southern areas than in the northern areas (Gaeuman 2013a, 2013b; Haaga et al. 2009; Hoff 2013, 2016; Hoff and Britt 2003, 2005, 2009, 2011; Pengilly 2015; Pengilly and Daly 2017). Of the six survey subareas (see Figure 1 in Hoff 2016), biomass and abundance of golden king crab were estimated through 2016 to be highest in the Pribilof Canyon area (survey subarea 2), and most of the commercial fishery catches for golden king crab have occurred there (Neufeld and Barnard 2003; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006; Leon et al. 2017).

Results of the 2002–2016 biennial NMFS-AFSC eastern Bering Sea continental slope trawl surveys showed that a majority of golden king crab on the eastern Bering Sea continental slope occurred in the 200–400 m and 400–600 m depth ranges (Hoff and Britt 2003, 2005, 2009, 2011; Haaga et al. 2009; Hoff 2013, 2016). Commercial fishing for golden king crab in the Bering Sea typically occurs at depths of 100–300 fathoms (183–549 m; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006; Gaeuman 2011, 2013c, 2014; Neufeld and Barnard 2003); average depth of pots fished in the 2002 Pribilof District golden king crab fishery (the most recently prosecuted fishery for which fishery observer data are not confidential) was 214 fathoms (391 m).

3. **<u>Evidence of stock structure</u>:**

Although highest densities of golden king crab are found in the deep canyons of the eastern Bering Sea continental slope, golden king crab occur sporadically on the surveyed slope at locations between those canyons in the eastern Bering Sea (Hoff and Britt 2003, 2005, 2009, 2011; Gaeuman 2013b, 2014; Hoff 2013, 2016). Stock structure within the Pribilof District has not been evaluated. Fishery and slope survey data suggest that areas at the northern and southern border of the Pribilof District are largely devoid of golden king crab (Pengilly 2015, Pengilly and Daly 2017; Appendix A1), but the stock relationship between golden king crab within and outside of the Pribilof District has not been evaluated.

4. **Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology):**

The following review of molt timing and reproductive cycle of golden king crab is adapted from Watson et al. (2002):

> Unlike red king crab, golden king crab may have an asynchronous molting cycle (McBride et al. 1982; Otto and Cummiskey 1985; Sloan 1985; Blau and Pengilly 1994). In a sample of male golden king crab 95–155-mm CL and female golden king crab 104–157-mm CL collected from Prince William Sound and held in seawater tanks, Paul and Paul (2000) observed molting in every month of the year, although the highest frequency of molting occurred during May–October. Watson et al. (2002) estimated that only 50% of 139-mm CL male golden king crab in the eastern Aleutian Islands molt annually and that the intermolt period for males ≥150-mm CL averages >1 year.
>
> Female lithodids molt before copulation and egg extrusion (Nyblade 1987). From observations on embryo development in golden king crab, Otto and Cummiskey (1985) suggested that time between successive ovipositions was roughly twice that of embryo development and that spawning and molting of mature females occurs approximately every two years. Sloan (1985) also suggested a reproductive cycle >1 year with a protracted barren phase for female golden king crab. Data from tagging studies on female golden king crab in the Aleutian Islands are generally consistent with a molt period for mature females of two years or less and that females carry embryos for less than two years with a prolonged period in which they remain in barren condition (Watson et al. 2002). From laboratory studies of golden king crab collected from Prince William Sound, Paul and Paul (2001b) estimated a 20-month reproductive cycle with a 12-month clutch brooding period.
>
> Numerous observations on clutch and embryo condition of mature female golden king crab captured during surveys have been consistent with asynchronous, aseasonal reproduction (Otto and Cummiskey 1985; Hiramoto 1985; Sloan 1985; Somerton and Otto 1986; Blau and Pengilly 1994; Blau et al. 1998; Watson et al. 2002). Based on data from Japan (Hiramoto and Sato 1970), McBride et al. (1982) suggested that spawning of golden king crab in the Bering Sea and Aleutian Islands occurs predominately during the summer and fall.

The success of asynchronous and aseasonal spawning of golden king crab may be facilitated by fully lecithoatrophic larval development (i.e., the larvae can develop successfully to juvenile crab without eating; Shirley and Zhou 1997).

Current knowledge of reproductive biology and maturity of male and female golden king crab was reviewed by Webb (2014).

Note that asynchronous, aseasonal molting and the prolonged intermolt period (>1 year) of mature female and the larger mature male golden king crab likely makes scoring shell conditions very difficult and especially difficult to relate to "time post-molt," posing problems for inclusion of shell condition data into assessment models.

5. <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, one vessel fished in each of 2010 and 2012–2014, and two 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)). 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 Appendix A1 for biomass estimates of mature male golden king crab using data from the 2002–2016 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey.

e. ***Survey catch at length:*** Survey catch at length data are not used in a Tier 5 assessment. However, see Appendix A1 for size data composition by sex of golden king crab during the 2002–2016 Bering Sea upper continental slope trawl surveys.

f. ***Other data time series:*** None.

3. Data which may be aggregated over time:

a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):

The author is not aware of data on growth per molt collected from golden king crab in the Pribilof District. Growth per molt of juvenile golden king crab, 2–35 mm CL, collected from Prince William Sound have been observed in a laboratory setting and equations describing the increase in CL and intermolt period were estimated from those observations (Paul and Paul 2001a); those results are not provided here. Growth per molt has also been estimated from golden king crab with CL ≥90 mm that were tagged in the Aleutian Islands and recovered during subsequent commercial fisheries (Watson et al. 2002); those results are not presented here because growth-per-molt information does not enter into a Tier 5 assessment.

See section **C.4** for discussion of evidence that mature female and the larger male golden king crab exhibit asynchronous, aseasonal molting and a prolonged intermolt period (>1 year).

b. Weight-at length or weight-at-age (by sex):

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female golden king crab according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007) are: A = 0.0002988 and B = 3.135 for males and A = 0.0014240 and B = 2.781 for females.

c. Natural mortality rate:

The default natural mortality rate assumed for king crab species by NPFMC (2007) is M=0.18. Note, however, natural mortality was not used for OFL estimation because this stock 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 Appendix A1, 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. 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, and 2011 OFLs, but those time periods were rejected by the CPT and the SSC. Hence the period for calculating the retained-catch portion of the Tier 5 total-catch OFL for this stock has been firmly established by the CPT and SSC at 1993–1998 (the CPT said “this freezes the time frame...”). For the 2012 and the 2013 OFLs, the CPT and SSC recommended the period 2001–2010 for calculating the ratio-based estimate of the bycatch mortality during the 1993–1998 directed fishery, the period 1994–1998 for calculating the estimated bycatch mortality due to non-directed crab fisheries during 1993–1998, and the period 1992/93–1998/99 for calculating the estimated bycatch mortality due to groundfish fisheries during 1993–1998.

Two alternative approaches for determination of the 2013 OFL were presented to the CPT and SSC in May–June 2013. Alternative 1 was the status quo approach (i.e., the approach used to establish the 2012 total-catch OFL). Alternative 2 was the same as Alternative 1 except that it used updated discarded catch data from crab fisheries in 2011. Alternative 2 was presented specifically to allow the CPT and the SSC to clarify whether the 2013 and subsequent OFLs should be computed using data collected after 2010, or if the time periods for data used to calculate the 2013 and subsequent OFLs should be “frozen” at the years used to calculate the 2012 OFL. The CPT and the SSC both recommended Alternative 1, clarifying that Tier 5 OFLs for future years should be computed using only data collected through 2010. Following that recommendation from CPT and the SSC, only one alternative was presented for computing the 2014–2017 Tier 5 OFLs (i.e., the Alternative 1 that was presented in 2013). The 2018 Tier 5 OFL recommended here uses the same approach as used for the 2013–2017 Tier 5 OFLs.

3. Model Selection and Evaluation:

a. *Description of alternative model configurations*

The recommended OFL is set as a total-catch OFL using 1993–1998 to compute average annual retained catch, an estimate of the ratio of bycatch mortality to retained catch during the directed fishery, an estimate of the average annual bycatch mortality due to the non-directed crab fisheries during 1994–1998, and an estimate of average annual bycatch mortality due to the groundfish fisheries during 1992/93–1998/99; i.e.,

$$OFL_{2018} = (1+R_{2001–2010})*RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,92/93–98/99},$$

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).

There are no discarded catch data available for the non-directed fisheries during 1993, thus 1994–1998 is used to estimate average annual bycatch mortality in non-directed fisheries.

The estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99 is used to estimate the average annual bycatch mortality in groundfish fisheries during 1993–1998 because 1992/93–1998/99 is the shortest time period of crab fishery years that encompasses calendar years 1993–1998.

Statistics on the data and estimates used to calculate $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$ are provided in Table 5; the column means in Table 5 are the calculated values of $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$. Using the calculated values of $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$, the calculated value of OFL_{2018} is,

$$OFL_{2018} = (1+0.052)*78.80 \text{ t} + 6.09 \text{ t} + 3.79 \text{ t} = 93 \text{ t } (204{,}527 \text{ lbs}).$$

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>*** 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. Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring: See table below. No vessels participated in the 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 and Daly (2017). 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.

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Appendix A1: EBS slope survey data on Pribilof Islands golden king crab and draft Pribilof Island golden king crab stock structure template (from Pengilly and Daly May 2017 report to Crab Plan Team).

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)			Total
	Fixed	Trawl	Total	Mortality
1991/92	0.05	6.11	6.16	4.91
1992/93	3.49	8.87	12.35	8.84
1993/94	0.51	9.64	10.14	7.96
1994/95	0.25	3.22	3.47	2.70
1995/96	0.41	1.90	2.31	1.72
1996/97	0.02	0.87	0.89	0.71
1997/98	1.34	0.49	1.83	1.06
1998/99	6.77	0.18	6.95	3.53
1999/00	4.79	0.65	5.43	2.91
2000/01	1.63	1.88	3.50	2.31
2001/02	1.50	0.36	1.85	1.03
2002/03	0.55	0.21	0.77	0.45
2003/04	0.23	0.18	0.41	0.26
2004/05	0.16	0.39	0.55	0.39
2005/06	0.09	0.06	0.15	0.09
2006/07	1.32	0.12	1.44	0.75
2007/08	8.47	0.16	8.63	4.36
2008/09	3.99	1.56	5.55	3.24
2009	2.67	2.55	5.22	3.38
2010	2.13	1.01	3.14	1.87
2011	0.85	1.33	2.18	1.49
2012	0.73	0.82	1.55	1.02
2013	0.50	2.49	2.99	2.24
2014	0.60	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 $BM_{GF,92/93\text{-}98/99}$.

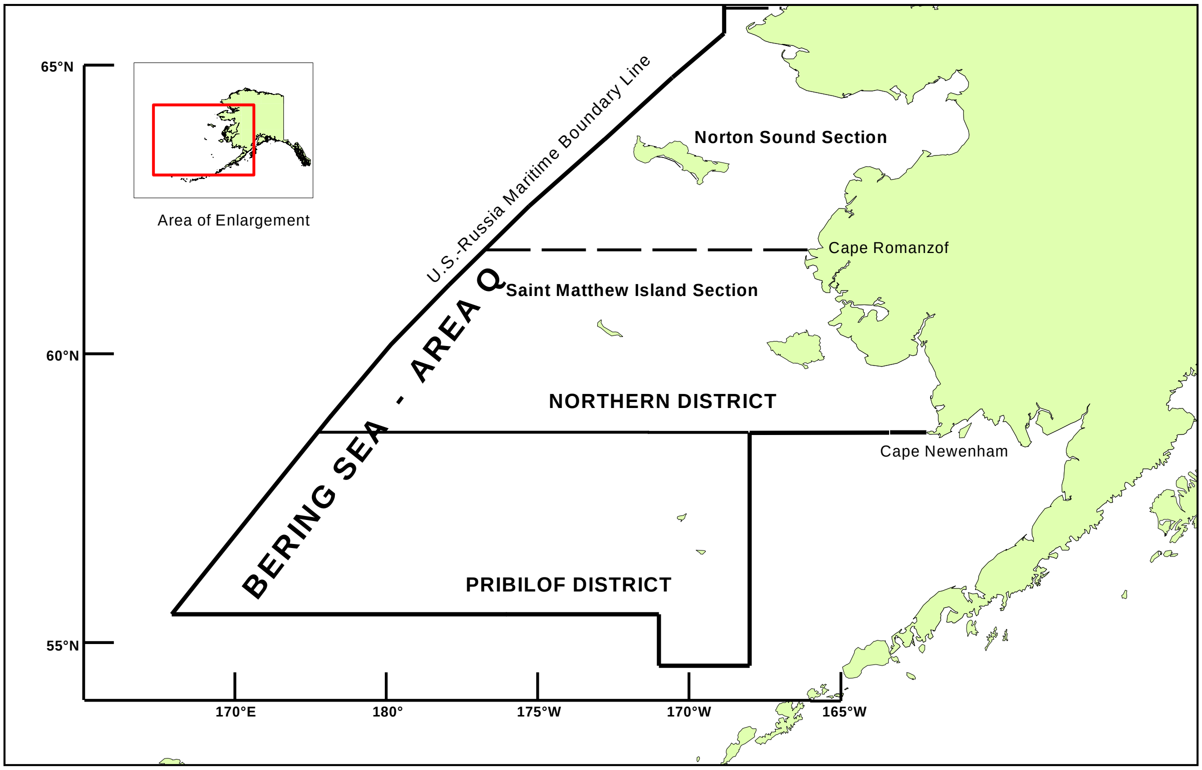

Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District (from Figure 2-4 *in* Leon et al. 2017).

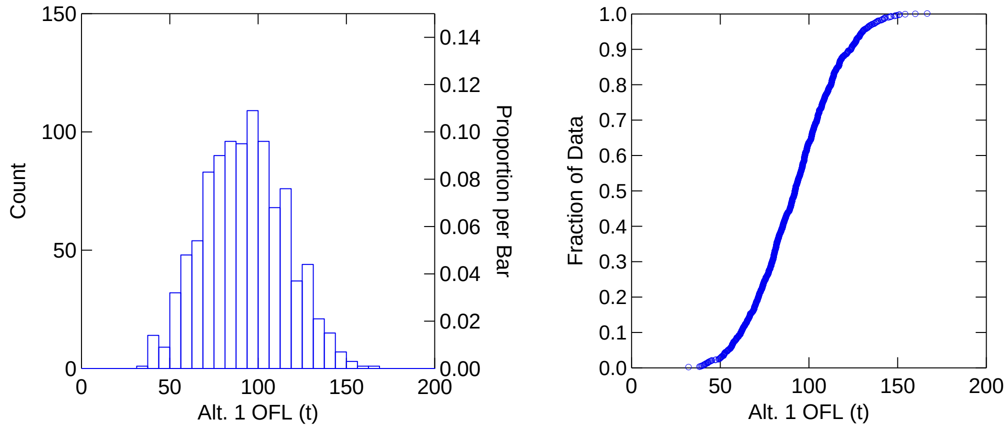

Figure 2. Bootstrapped estimates of the sampling distribution of the 2017 Alternative 1 Tier 5 OFL (total catch, t) for the Pribilof Islands golden king crab stock; histogram on left, quantile plot on right.

Appendix A1: EBS slope survey data on Pribilof Islands golden king crab and draft Pribilof Island golden king crab stock structure template (from Pengilly and Daly May 2017 report to Crab Plan Team).

Updated discussion paper for May 2017 Crab Plan Team meeting:
Random effects approach to modeling NMFS EBS slope survey area-swept biomass estimates for Pribilof Islands golden king crab.

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Introduction.

The Pribilof Islands golden king crab stock has been defined by the geographic borders of the Pribilof District (Figure 1) and has been managed as a Tier 5 stock (i.e., no reliable estimates of biomass and only historical catch data available) for determination of federal overfishing limits and annual catch limits (Pengilly 2014). Since 2011, the Council's Crab Plan Team (CPT) and the Scientific and Statistical Committee (SSC) have expressed interest in utilizing data collected during NMFS eastern Bering Sea (EBS) upper continental slope surveys (Hoff 2013) to establish an annual overfishing limit (OFL) and acceptable biological catch (ABC) on the basis of biomass estimates as an alternative to the standard Tier 5 historical-catch approach (see: reports of the June 2011, June 2012, June 2013, and October 2013 SSC meetings; reports of the May 2013 and September 2013 CPT meetings). Reviews of the EBS slope survey relative to the data collected on golden king crab, summaries of those data, and area-swept biomass estimates (Pengilly 2012, Gaeuman 2013a, 2013b), a Tier 4 approach to establishing OFL and ABC (Gaeuman 2013b), and "modified Tier 5" approach to establishing OFL and ABC (Gaeuman 2013a) have been presented to the CPT and SSC. Cancellation of the EBS biennial slope survey scheduled for 2014 precluded application of Gaeuman's (2013a) approach to establishment of OFL and ABC (see: report of the May 2015 CPT meeting; report of the June 2015 SSC meeting); however, the completion of the 2016 slope survey allows opportunity to revisit this approach.

In May 2015 the CPT recommended that, "*a preliminary Tier 4 assessment be brought to the September 2015 meeting using available slope survey data and applying a Kalman filter approach (e.g., the program developed by Jim Ianelli for groundfish stock assessments)*" (report of May 2015 CPT meeting). In June 2015, the SSC supported "*the CPT recommendation that a preliminary Tier 4 assessment be brought to the September 2015 meeting, using existing slope data and applying a Kalman filter approach*" (report of the June 2015 SSC meeting). The SSC also requested that the assessment include "*a discussion … of what stock delineation was chosen (what slope data were used) and the reason for that delineation*," and that "*a Stock Structure Template be completed for PI GKC*" (report of the June 2015 SSC meeting). In September 2016 the CPT "*recommends the random effects model be re-evaluated after results from the 2016* *slope survey are available.*" The SSC confirmed that request: *"The SSC concurs with the CPT recommendation"* ["*that the random effects model be re-evaluated after results from the 2016 slope survey are available*"].

This report provides: results of applying the program developed for groundfish stock assessments to the slope survey area-swept biomass estimates of golden king crab; a discussion of the stock delineation chosen (what slope data were used and why); and a Stock Structure Template for Pribilof Islands golden king crab (Appendix C) that was prepared with the guidance of Spencer et al. (2010).

This report does not provide a Tier 4 assessment, however (i.e., no OFLs or ABCs are computed from the results of this exercise). Prior to computation of an OFL or ABC, the author would like to review the biomass estimates with the CPT so that the CPT can evaluate the results relative to the Tier 4 and Tier 5 criteria (i.e., Do the biomass estimates meet the "reliability" criterion for removing the stock from Tier 5? Do the results meet the Tier 4 criterion of having sufficient information for simulation modeling that captures the essential population dynamics of the stock?). Additionally, the term "Tier 4 assessment" in application to this stock since 2013 has lost its clarity, making it unclear if the requested assessment was to be made according to Tier 4 as defined in the FMP, according to the "modified Tier 5" approach of Gaeuman (2013a,b), or according to some modification to a Tier 4 assessment. Dependent on the evaluation of results and after clarification of the assessment approach, the computations of OFL and ABC can be performed with the results presented here.

The NMFS EBS slope survey.
Only data from NMFS EBS slope trawl surveys performed in 2002 and later are used here. Although a pilot slope survey was also performed in 2000 and triennial surveys using a variety of nets, methods, vessels, and sampling locations were performed during 1979–1991, authors noted that, "Comparisons between the post-2000 surveys and those conducted from 1979–1991 remain confounded due to differences in sampling gear, survey design, sampling methodology, and species identification" (Hoff and Britt 2011). Starting in 2002, the slope survey was nominally a biennial survey, but no survey was performed in 2006 or 2014. Details on the methods and survey gear used in the 2002, 2004, 2008, 2010, 2012, and 2016 NMFS EBS slope surveys are provided in Hoff and Britt (2003, 2005, 2009, 2011) and Hoff (2013, 2016), respectively. Those methods and the applicability of the slope survey data to golden king crab abundance and biomass estimation have also been summarized by Pengilly (2012) and Gaeuman (2013a,b).

Briefly, the survey samples from an area of 32,723 km^2 in the 200–1,200 m depth zone. The surveyed area is divided into six subareas (Figure 2). Each subarea is divided into strata defined by 200 m depth zones and tows are performed at randomly-selected locations within each stratum, with target sampling density within strata proportional to the area in each subarea and stratum. Number of stations towed per survey ranged from 156 in 2002 to 231 in 2004; mean sampling density within strata ranged from approximately one tow per 162 km^2 in 2004 to approximately one tow per 255 km^2 in 2002. With regard to survey catchability of golden king crab by size and sex, the survey uses a Poly Nor'eastern high-opening bottom trawl equipped with mud-sweeper roller gear. ASFC scientists conveyed their opinion to the CPT during the May meeting that, with respect to golden king crab, "… the catchability of the slope net is less than 1.0 and probably considerably lower than the shelf net due to the differences in the foot rope and surveyed habitat" (report of the May 2013 CPT meeting).

Methods.

Data available by survey. Data on golden king crab that are available from the 2002, 2004, 2006, 2008, 20010, 2012 and 2016 NMFS EBS slope surveys are summarized in Table 1.

Although the CPT and SSC both suggested that NMFS would "*provide the author with slope survey CPUE data based on State statistical areas or other stratification instead of the entire slope survey area because the entire survey extends beyond the Pribilof management area*" (reports of the May 2015 CPT meeting and June 2015 SSC meeting), the author did not find it necessary or useful for this exercise to receive the data stratified by State statistical area or by any other stratification besides that defined by the survey design.

Data summarization: area-swept biomass estimates. Area-swept estimates of total (male and female, all sizes) biomass and variances of estimates within strata within survey subarea for 2002, 2004, 2008, 2010, and 2012 were obtained directly from the tables presented in Hoff and Britt (2003; 2005; 2009; 2011) and Hoff (2013). For area-swept biomass estimation of mature males and legal males from the 2008, 2010, 2012, and 2016 survey data, 107 mm CL was used as a proxy for size at maturity (Somerton and Otto 1986) and 124 mm CL was used as a proxy for the 5.5 in carapace width (including spines) legal size (NPFMC 2007); weight of males was estimated from the CL measured during the survey by weight (g) = $(0.0002988)\text{x}(CL)^{3.135}$ (NPFMC 2007). An area-swept estimate of biomass and of the variance of the biomass estimate was computed for each stratum within a survey subarea and summed over strata within the subarea to obtain area-swept estimates of biomass within a subarea and of the variance of that biomass estimate; estimates of the biomass and associated variances within subareas were summed over subareas to obtain biomass estimates in aggregates of subareas and of the variances of those estimates.

Model estimates of biomass and projections to 2018.[1] The program "re.exe" was used to estimate biomass from the area-swept estimates in surveyed years and to project biomass estimates for unsurveyed years into 2018 via a state-space random walk plus noise model. The state-space random walk plus noise is formulated as a random effect model. The random effects model considers the process errors as "random effects" (i.e., drawn from an underlying distribution) and integrated out of the likelihood. The method was developed by the NPFMC groundfish plan team's survey averaging working group as a smoothing technique similar to the Kalman Filter, but which provides more flexibility with non-linear processes and non-normal error structures.

Stock delineation chosen (what slope data were used). The author followed the guidance provided by the SSC in June 2013 (report of the June 2013 SSC meeting):

[1] The author acknowledges help from Martin Dorn, Jim Ianelli, and Paul Spencer, AFSC, in getting this paragraph completed.

> "*Because the stock structure is unknown, the SSC recommends that the authors examine maps of catch-per-unit-effort by survey year to identify natural breaks in the spatial distribution of golden king crab along the slope. If no obvious breaks exist, the SSC recommends that the authors bring forward biomass estimates for the Pribilof canyon region and for the slope as a whole. However, we note that the Pribilof Canyon stations do not encompass the historical catches, which occurred inside and to the north of Pribilof Canyon. Therefore, the authors should consider a biomass estimate for an area that encompasses the majority of historical catches*."

Figures 3–8 show CPUE (kg km^{-2}) of golden king crab (males and females, all sizes) by tow and survey subarea during the 2002, 2004, 2008, 2010, 2012, and 2016 NMFS EBS slope surveys relative to the boundaries of the Pribilof District. Highest survey CPUE occurs at tows within survey subareas 2–4 (particularly in subarea 2; i.e., Pribilof Canyon). Tows performed in the portion of subarea 5 that lie within the Pribilof District have produced little or no catch of golden king crab, indicating a gap in golden king crab distribution between subarea 4 and the portion of the surveyed area north of the Pribilof District boundary (i.e., the portion of subarea 5 that is north of the Pribilof District boundary and all of subarea 6). Tows performed in subarea 1 that are within the Pribilof District have produced little or no catch of golden king crab, indicating a gap in distribution between Pribilof Canyon and the area east of the Pribilof District within subarea 1. It appears that the areas of subareas 1 and 5 that lie within the Pribilof District support limited densities of golden king crab. Subarea 3 appears to support only low-to-moderate densities of golden king crab relative to subarea 4 and – especially – subarea 2; tows with catch of golden king crab occurred sporadically within subarea 3, with highest densities occurring near the border of subarea 4 in 2010 and 2012 and near the border of subarea 2 in 2002.

Figure 9 shows the distribution of all 6,104 pot lifts sampled by observers with locations recorded during 1992–2014 Bering Sea golden king crab fisheries (including the Saint Matthew section of the Northern District, which is north of the Pribilof District) relative to the borders of the Pribilof District and of the survey subareas. Only one of those locations is within the portion of subarea 5 that is within the Pribilof District, none are within the portion of subarea 1 that is within the Pribilof District, and none are within subarea 3.

Figure 10 shows the 26 statistical areas with reported catch during the 1985–2014 Pribilof District golden king crab fisheries relative to the borders of the Pribilof District and of the survey subareas: one (accounting for 0.7% of the 1985–2014 total catch) lies largely in subarea 4, but extends into subarea 5; four (2.9% of the total catch) include portions of subarea 4; six (1.5% of total catch) include portions of subarea 3; one (8.9% of total catch) includes portions of subareas 3 and 2; four (83.9% of total catch) are in or extend into subarea 2; one (0.7% of total catch) includes portions of subareas 2 and 1; one (<0.1% of total catch) is largely within subarea 1; and eight (1.4% of total catch) are outside of the survey area (some of those may be errors in recording of statistical area).

This review of survey distribution and fishery catch and effort distribution shows that golden king crab in the Bering Sea and the fishery for golden king crab in the Bering Sea are concentrated in the Pribilof Canyon area (survey subarea 2). Nonetheless, golden king crab do occur more sporadically and at lower densities in survey subareas 3 and 4 and there has been some limited catch and effort during Pribilof District fisheries within survey subareas 3 and 4. Portions of survey subareas 1 and 5 that lie within the Pribilof District appear to be largely devoid of golden king crab, have received little or no fishery effort during the Pribilof District fishy, and thus have produced little or no catch. The golden king crab that occur in survey subarea 6 are exploited by the Saint Matthew section fishery when it is prosecuted. Accordingly, the following analyses to estimate trends in the Pribilof District stock were performed using survey data from only survey subareas 2, 3, and 4. Data summaries and analyses were also performed using data only from survey Subarea 2 due to the high concentration of fishery effort and fishery catch in Pribilof Canyon and the high CPUE of golden king crab within Pribilof Canyon during the slope surveys,.

Results.

Size frequency distributions of golden king crab captured within subareas 2, 3, and 4 during the 2008, 2010, 2012, 2016 NMFS EBS slope surveys are shown in Figures 11–14.

Area-swept biomass estimates by survey subarea, for the total surveyed area (pooled subareas 1–6), and for pooled subareas 2–4 for 2002, 2004, 2008, 2010, 2012 and 2016 are in Table 2.

Estimates and projections through 2018 of total, mature male, and legal male biomass in survey subareas 2-4 and survey subarea 2 from the state-space random walk plus noise model are plotted in Figures 15 and 16, respectively. More detailed results produced by re.exe are provided in Appendices A and B.

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Table 1. Data on golden king crab recorded during the 2002, 2004, 2008, 2010, 2012, and NMFS EBS slope surveys.

Survey	Weight in tow	Count in tow	Sex/CL/shell con/fem repro	Individual weights
2002	YES	YES	NO	NO
2004	YES	YES	NO	NO
2008	YES	YES	YES	285 of 416 meas'd
2010	YES	YES	YES	NO
2012	YES	YES	YES[a]	495 of 899 meas'd
2016	YES	YES	YES[b]	NO

a. Golden king crab <100 mm CL were subsampled for data recording at one tow in subarea 4 during the 2012 survey.
b. Golden king crab were subsampled for data recording at one tow in subarea 2 during the 2016 survey.

Table 2. Area-swept biomass (t) estimates of total (sexes combined), mature-sized males, and legal male golden king crab computed from 2002, 2004, 2008, 2010, 2012, and 2016 NMFS eastern Bering Sea slope survey data, by survey subarea, and with coefficients of variation (CV = standard error of estimate divided by the estimate).

		Total (males and females)		Mature males (males ≥ 107 mm CL)		Legal males (males ≥ 124 mm CL)	
Survey Year	Subarea	Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV
2002	1	131	0.39	–	–	–	–
2002	2	682	0.22	–	–	–	–
2002	3	81	0.40	–	–	–	–
2002	4	53	0.40	–	–	–	–
2002	5	19	0.86	–	–	–	–
2002	6	44	0.69	–	–	–	–
2002	1–6	1,010	0.16	–	–	–	–
2002	2–4	816	0.19	–	–	–	–
2004	1	65	0.22	–	–	–	–
2004	2	817	0.38	–	–	–	–
2004	3	51	0.41	–	–	–	–
2004	4	121	0.36	–	–	–	–
2004	5	20	0.73	–	–	–	–
2004	6	24	0.73	–	–	–	–
2004	1–6	1,098	0.29	–	–	–	–
2004	2–4	989	0.32	–	–	–	–
2008	1	146	0.40	47	0.35	11	0.70
2008	2	920	0.32	490	0.36	294	0.29
2008	3	91	0.44	64	0.44	28	0.54
2008	4	205	0.46	85	0.53	78	0.52
2008	5	2	1.00	22	1.00	22	1.00
2008	6	66	0.50	30	0.63	19	0.61
2008	1–6	1,431	0.22	737	0.25	452	0.22
2008	2–4	1,216	0.26	638	0.29	401	0.24
2010	1	363	0.20	168	0.20	145	0.23
2010	2	1,614	0.31	440	0.24	349	0.25
2010	3	89	0.63	79	0.72	71	0.75
2010	4	72	0.41	46	0.47	44	0.50
2010	5	37	0.45	10	0.76	7	1.00
2010	6	122	0.43	25	0.51	12	1.00
2010	1–6	2,298	0.22	768	0.17	628	0.18
2010	2–4	1,776	0.29	565	0.22	464	0.23
2012	1	421	0.37	328	0.45	280	0.50
2012	2	778	0.45	256	0.32	207	0.34
2012	3	172	0.75	146	0.83	131	0.81
2012	4	494	0.69	26	0.48	8	1.00
2012	5	12	0.43	6	0.74	4	1.00
2012	6	149	0.40	49	0.33	40	0.38
2012	1–6	2,025	0.26	812	0.26	670	0.28
2012	2–4	1,444	0.35	429	0.34	346	0.37
2016	1	217	0.35	116	0.37	98	0.40
2016	2	1060	0.27	475	0.30	336	0.30
2016	3	100	0.34	74	0.42	65	0.47
2016	4	304	0.79	191	0.77	165	0.73
2016	5	23	0.48	10	0.72	4	1.00
2016	6	50	0.30	31	0.46	18	0.75
2016	1–6	1,754	0.22	897	0.24	685	0.24
2016	2–4	1,464	0.26	740	0.28	565	0.28

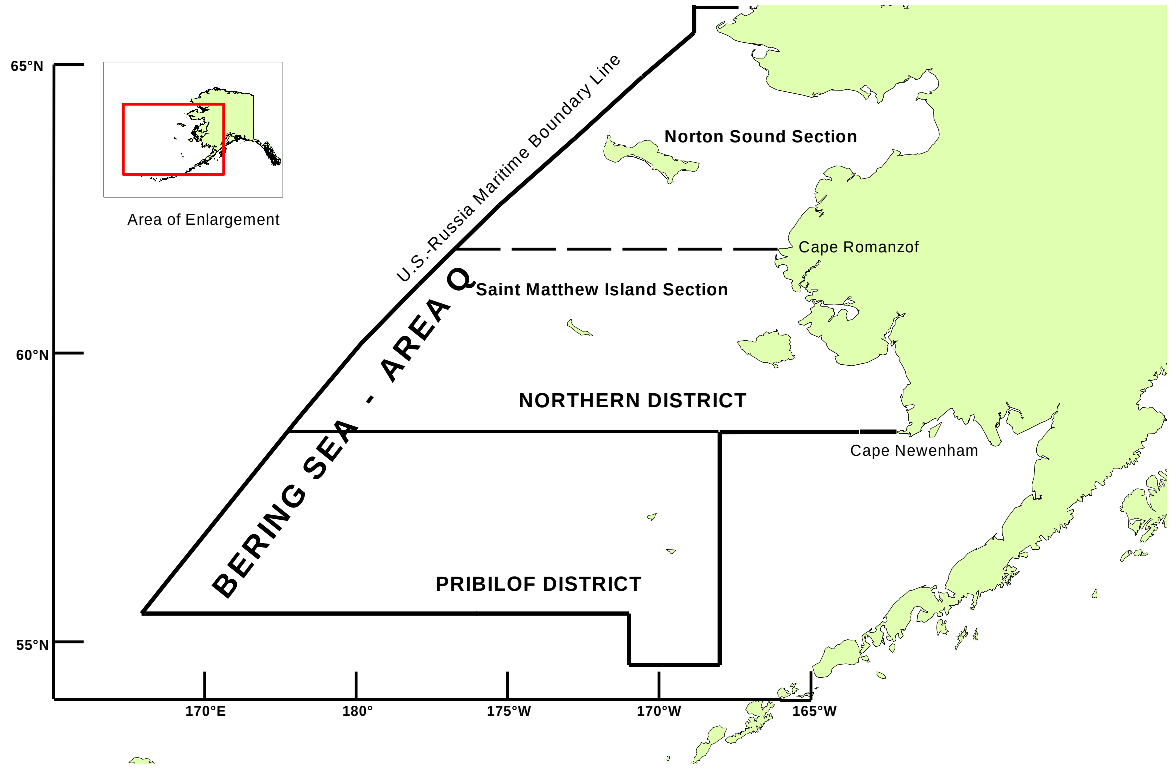


Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District.

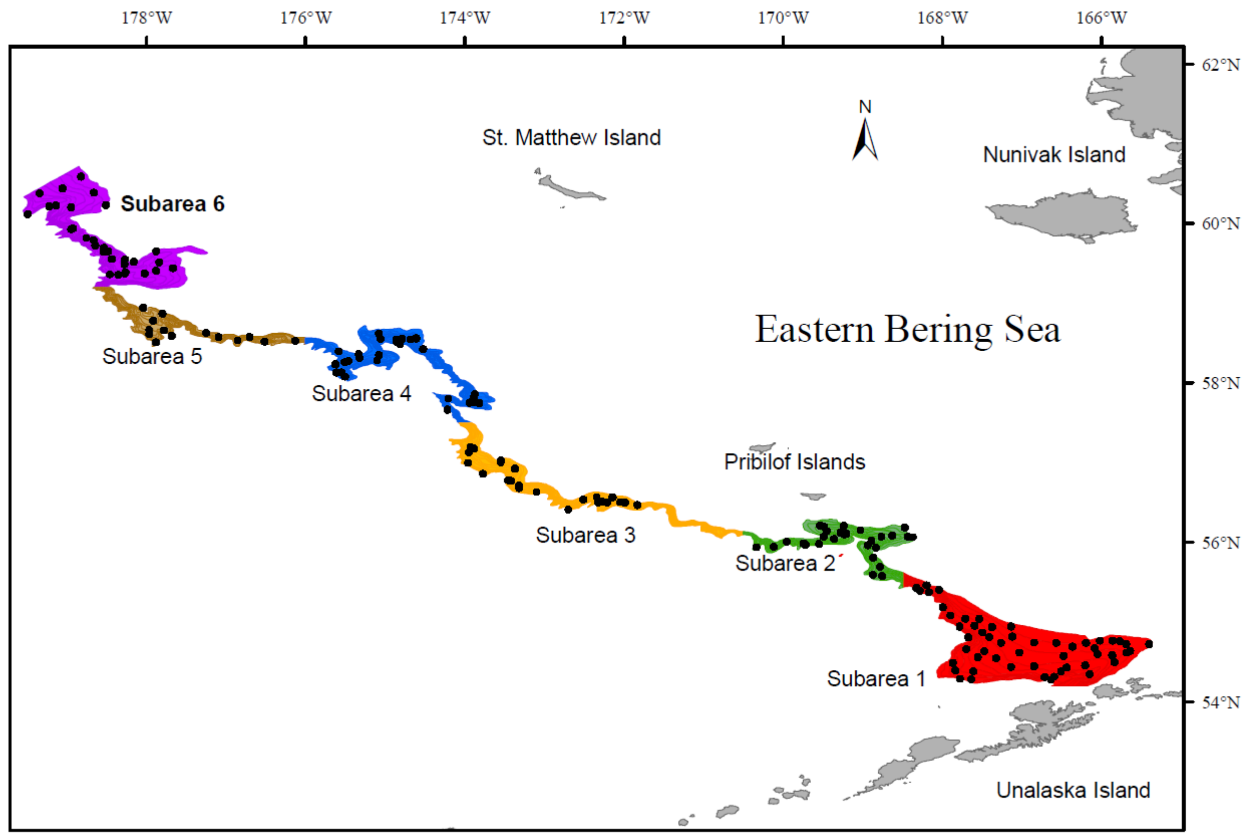


Figure 2. Map of standard survey area and the six subareas. Indicated are the 175 successful trawl stations (black dots) completed during the 2016 EBSS survey (taken from Hoff 2016).

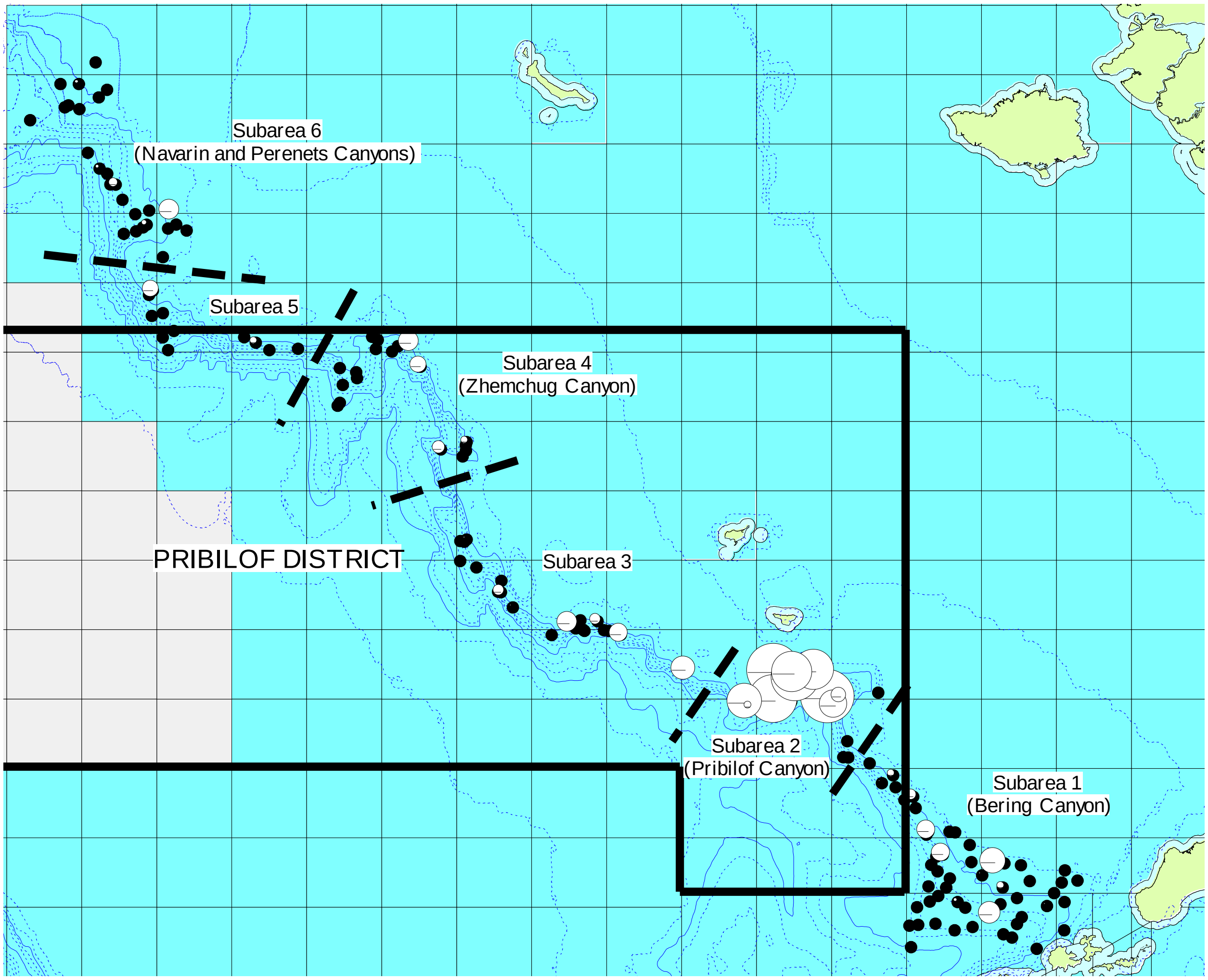


Figure 3. 2002 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 510 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

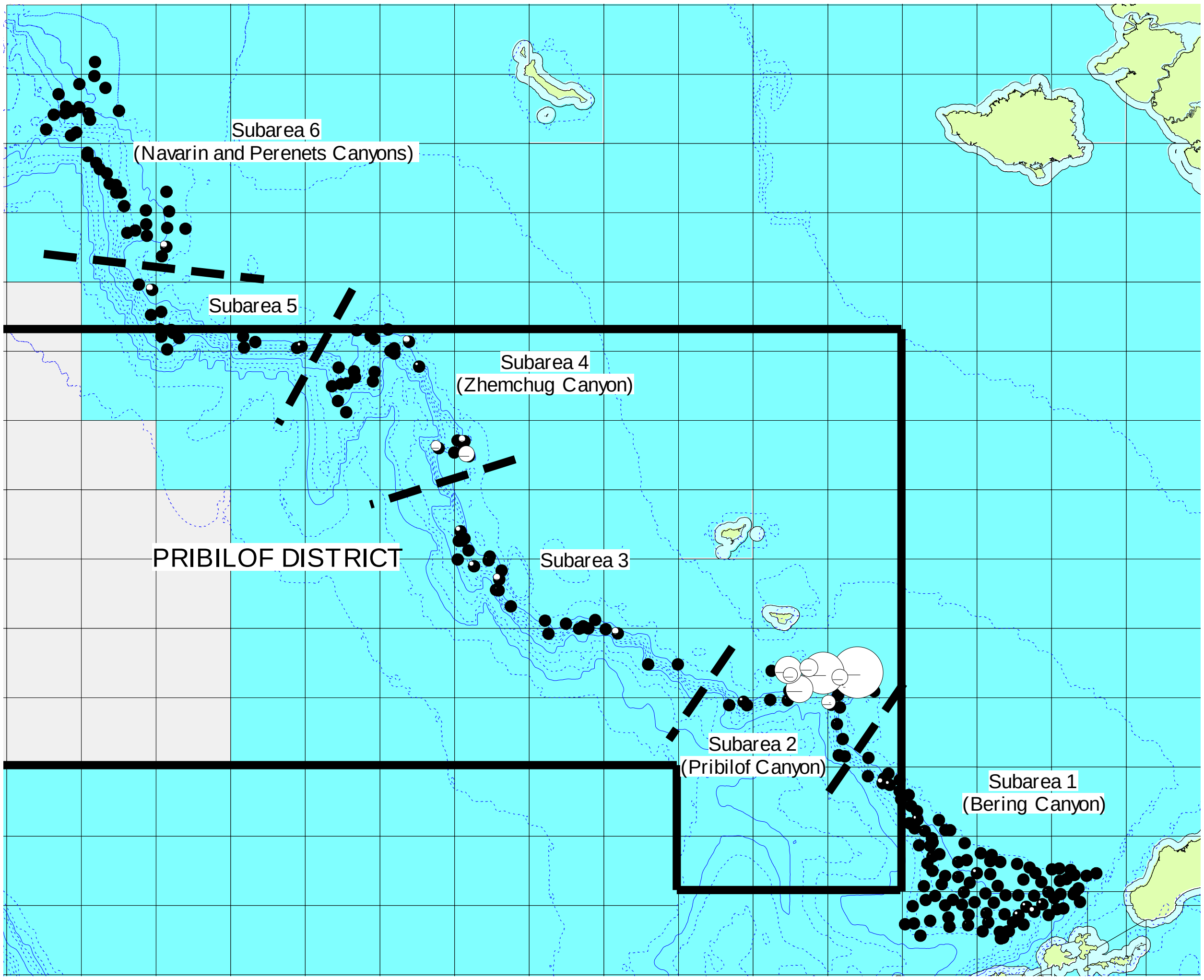


Figure 4. 2004 slope survey tow locations (black circles) and golden king crab CPUE (kg/sq-km; white circles; largest circle = 2,300 kg/sq-km); squares are 1° longitude x 30' latitude State statistical areas.

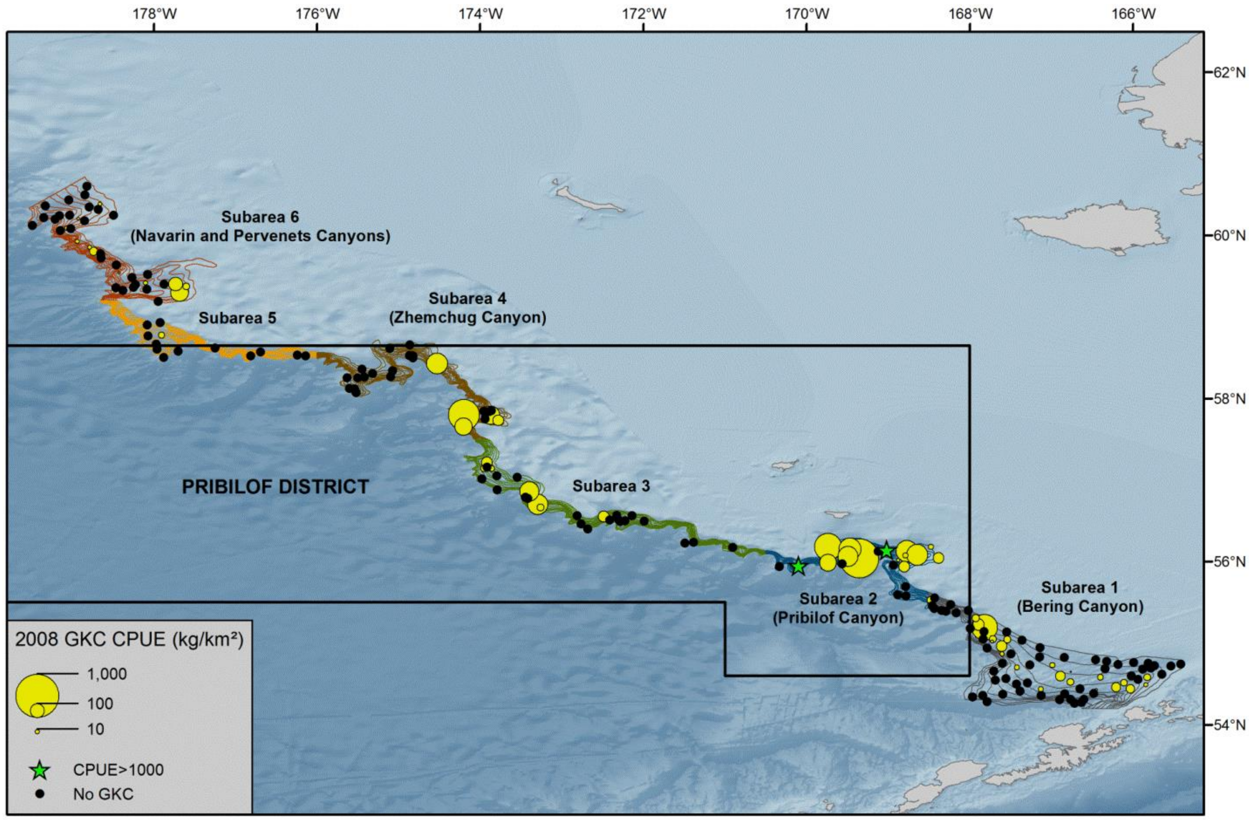


Figure 5. 2008 slope survey tow locations (black circles) and golden king crab CPUE (kg km^{-2}; yellow circles, green stars indicate values outside the normal range).

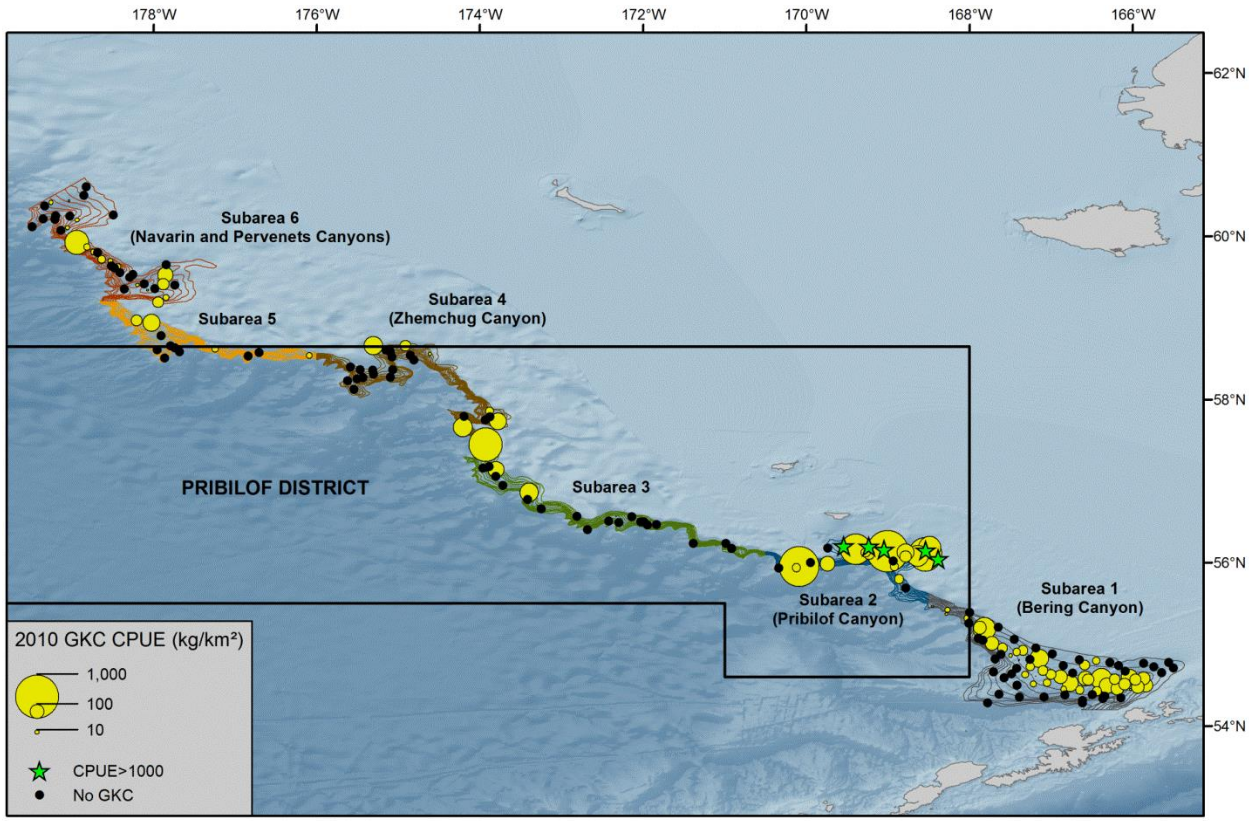


Figure 6. 2010 slope survey tow locations (black circles) and golden king crab CPUE (kg km^{-2}; yellow circles, green stars indicate values outside the normal range).

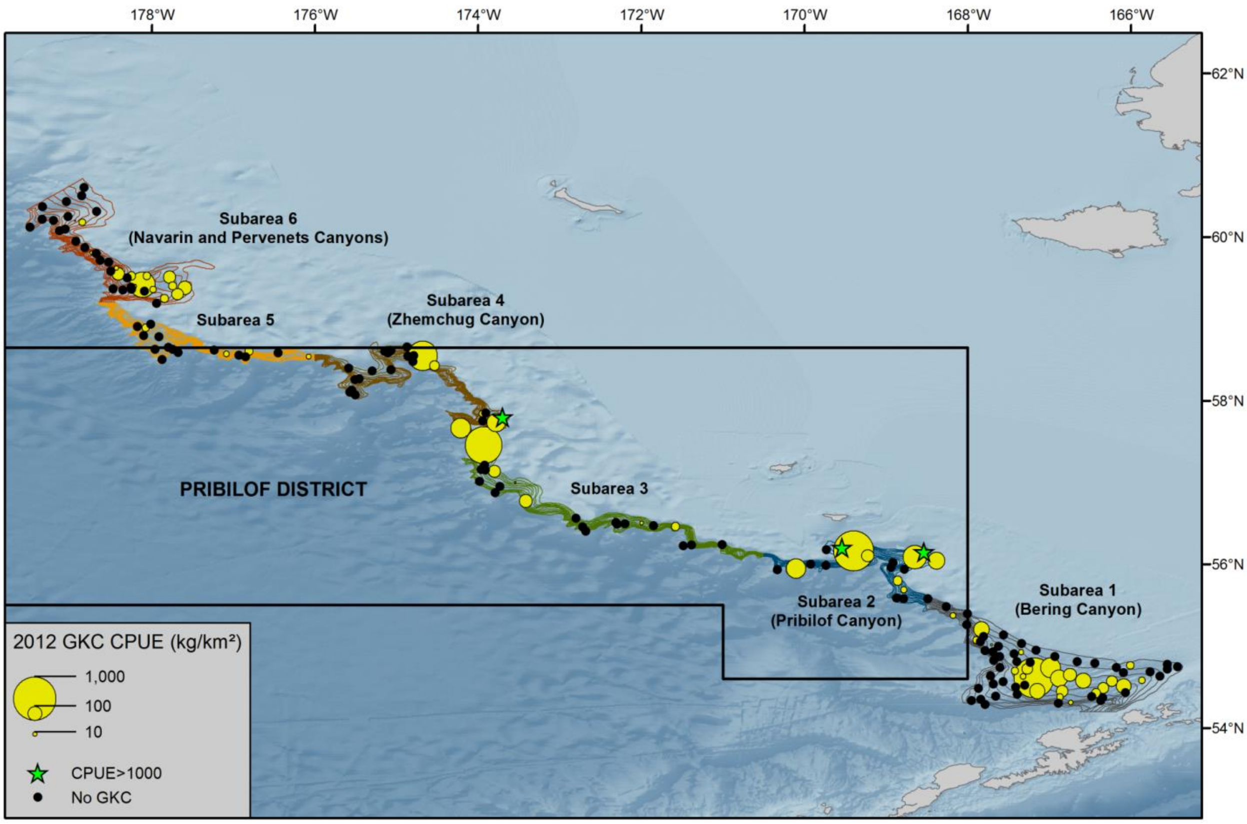


Figure 7. 2012 slope survey tow locations (black circles) and golden king crab CPUE (kg km^{-2}; yellow circles, green stars indicate values outside the normal range).

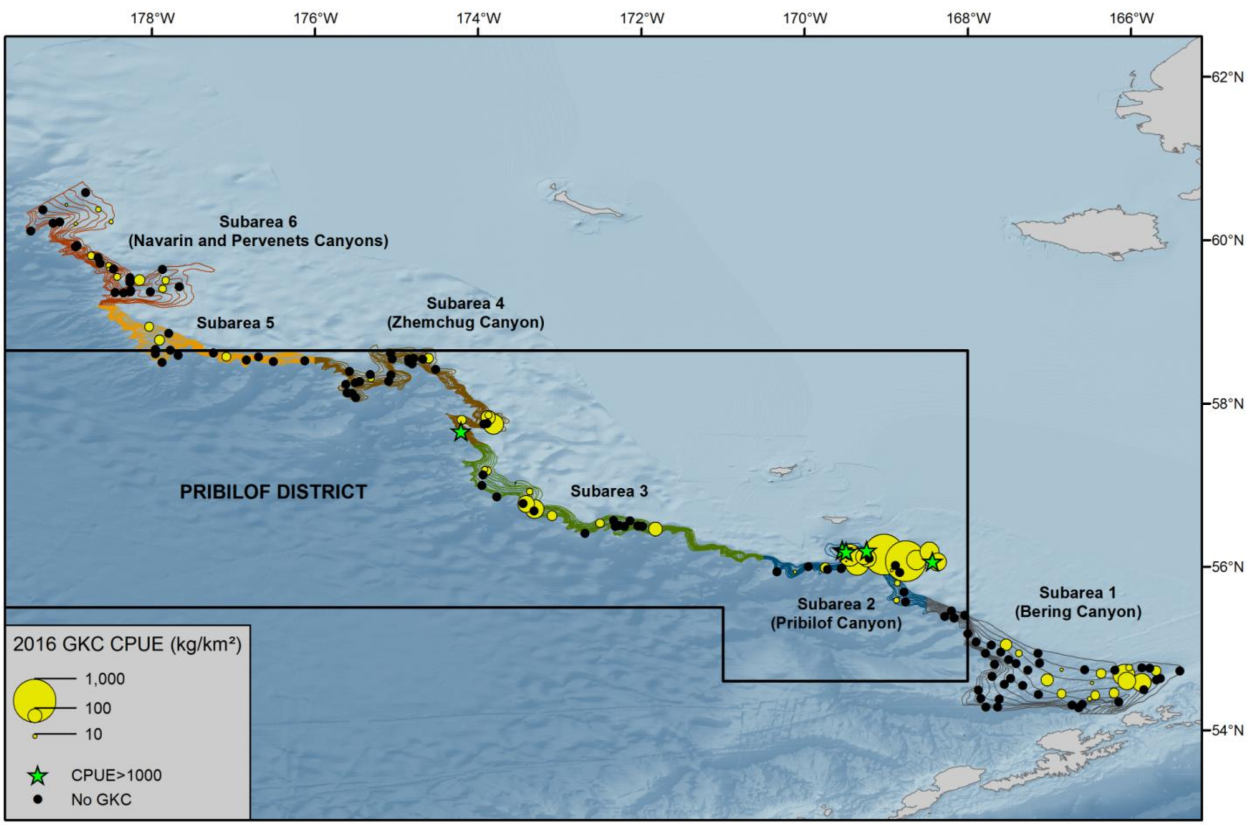


Figure 8. 2016 slope survey tow locations (black circles) and golden king crab CPUE (kg km^{-2}; yellow circles, green stars indicate values outside the normal range).

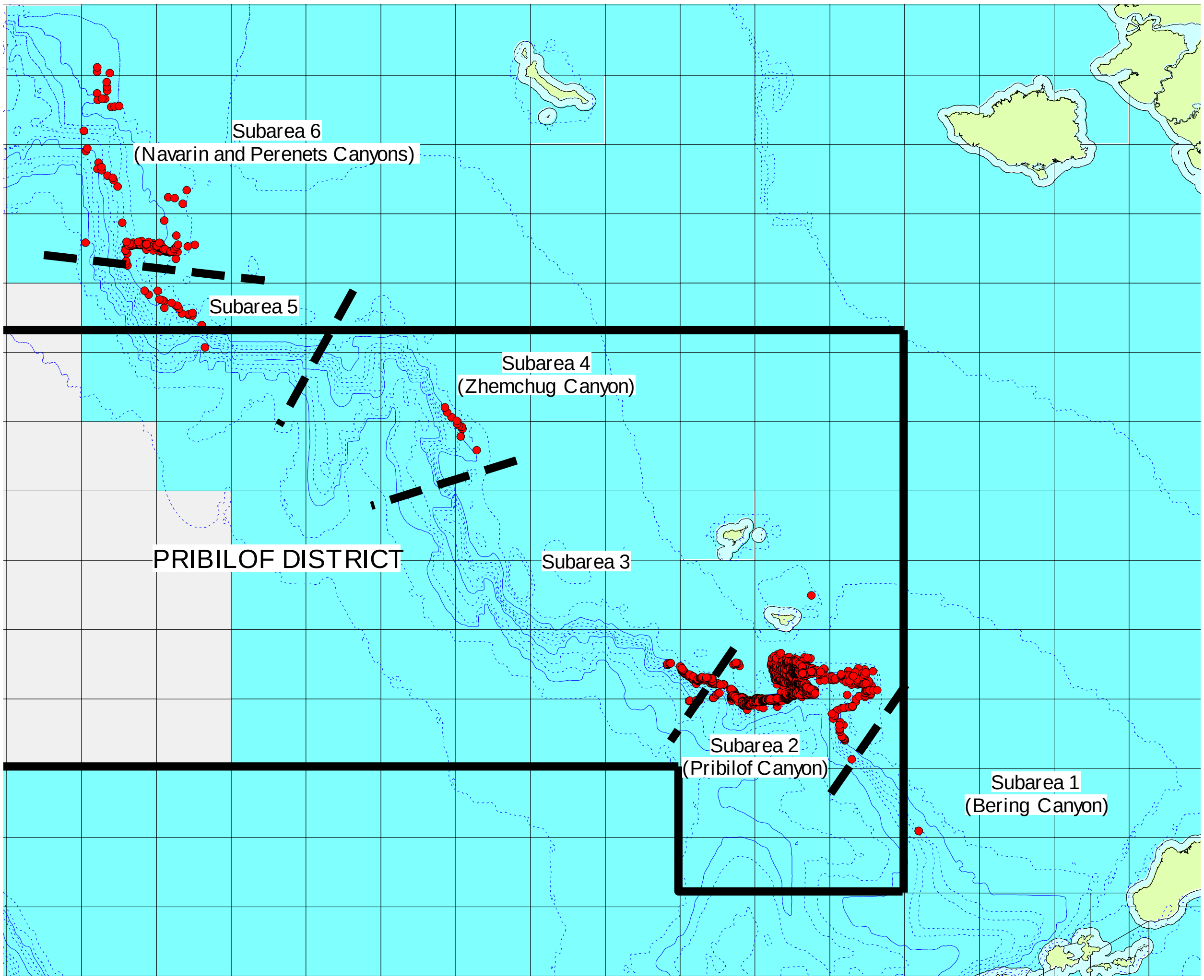


Figure 9. Locations of all pots sampled by observers during Bering Sea golden king crab fisheries (n = 6,104), 1992–2014; pots north of the Pribilof District northern boundary were fished during the Northern District – Saint Matthew Island Section fishery; squares are 1° longitude x 30' latitude State statistical areas.

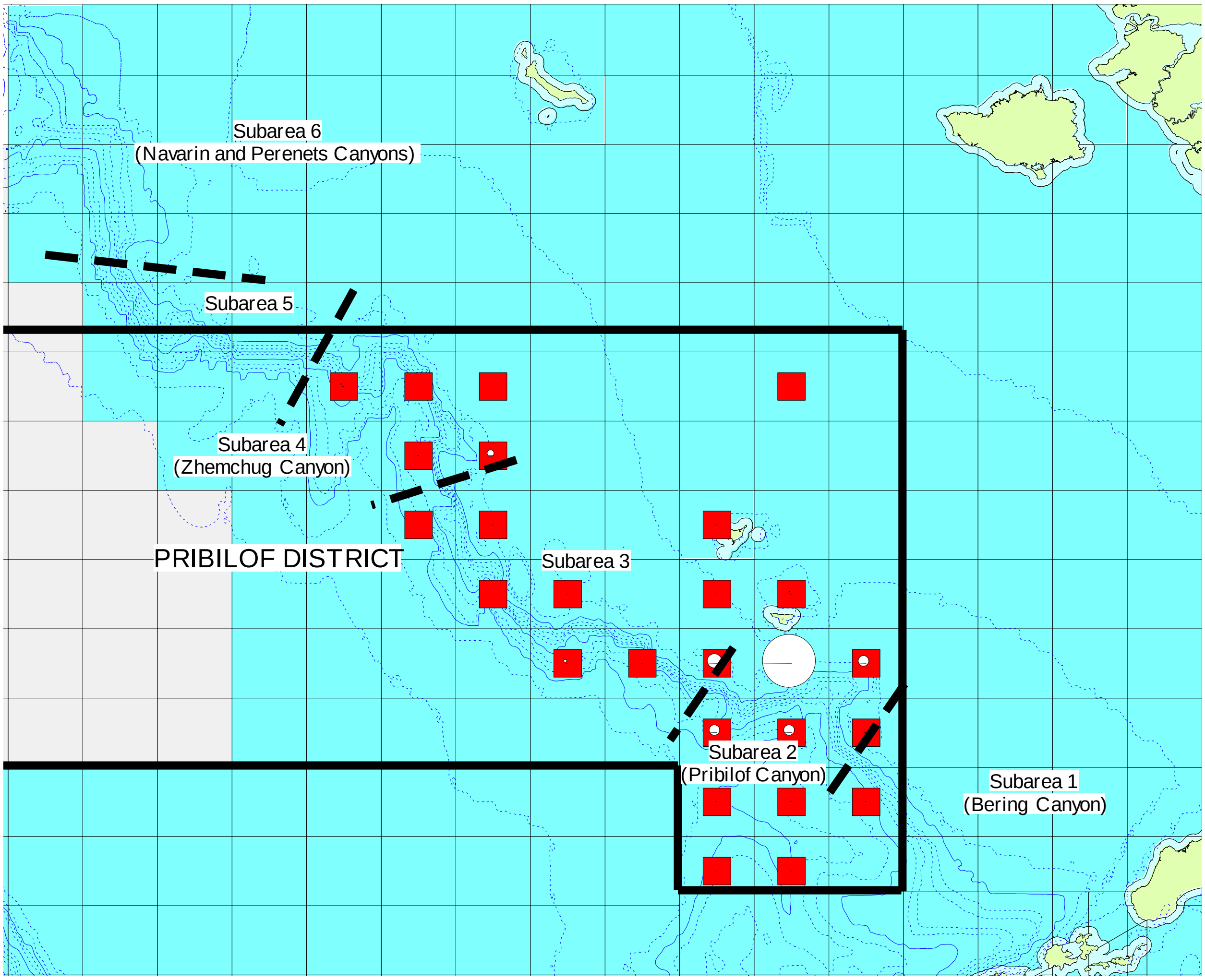


Figure 10. Statistical areas with reported catch during the 1985–2014 Pribilof District golden king crab fisheries: filled red squares denote statistical areas with reported catch; size of overlain white circles are proportional to the percentage of the total 1985–2014 catch reported from statistical area (biggest circle = 68% of total); squares are 1° longitude x 30' latitude State statistical areas.

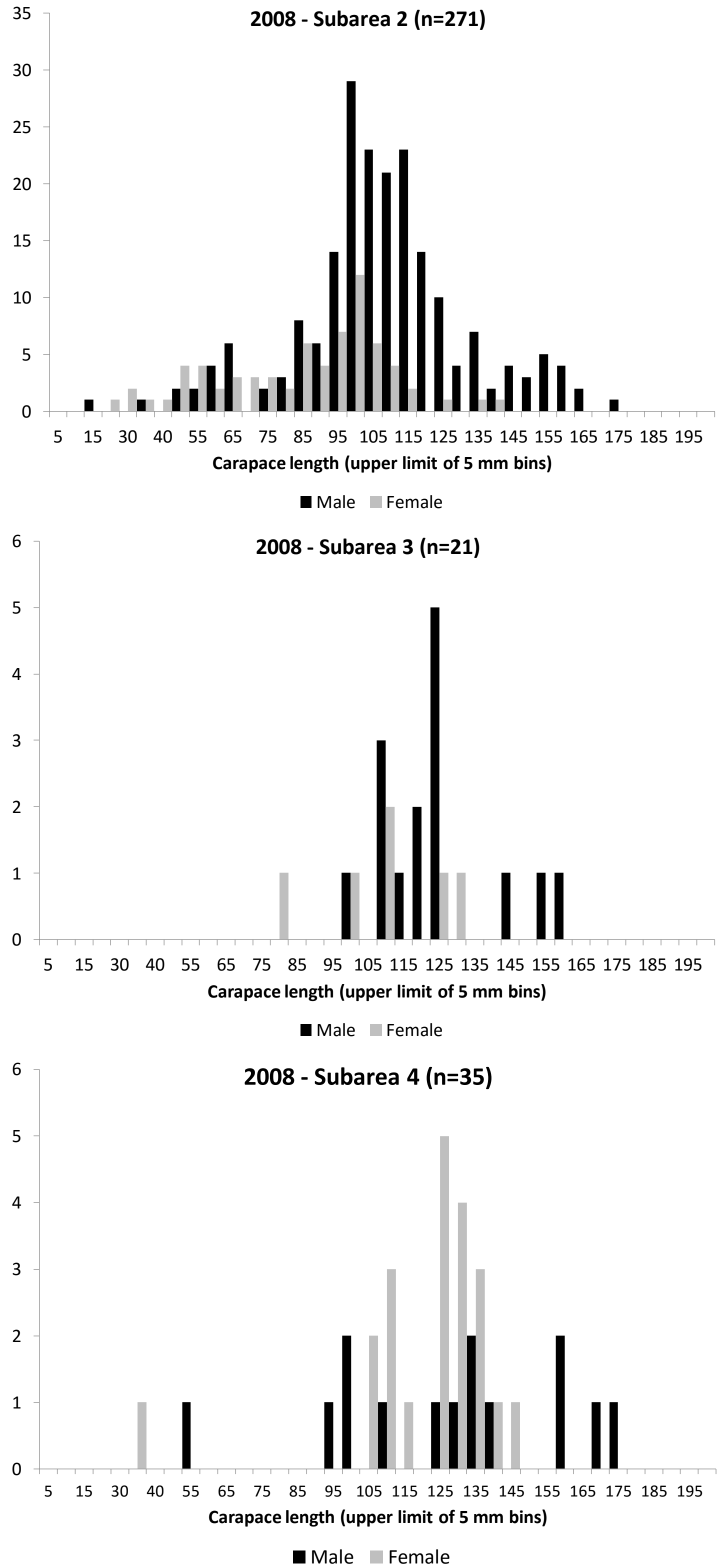


Figure 11. Size distribution of measured golden king crab during the 2008 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

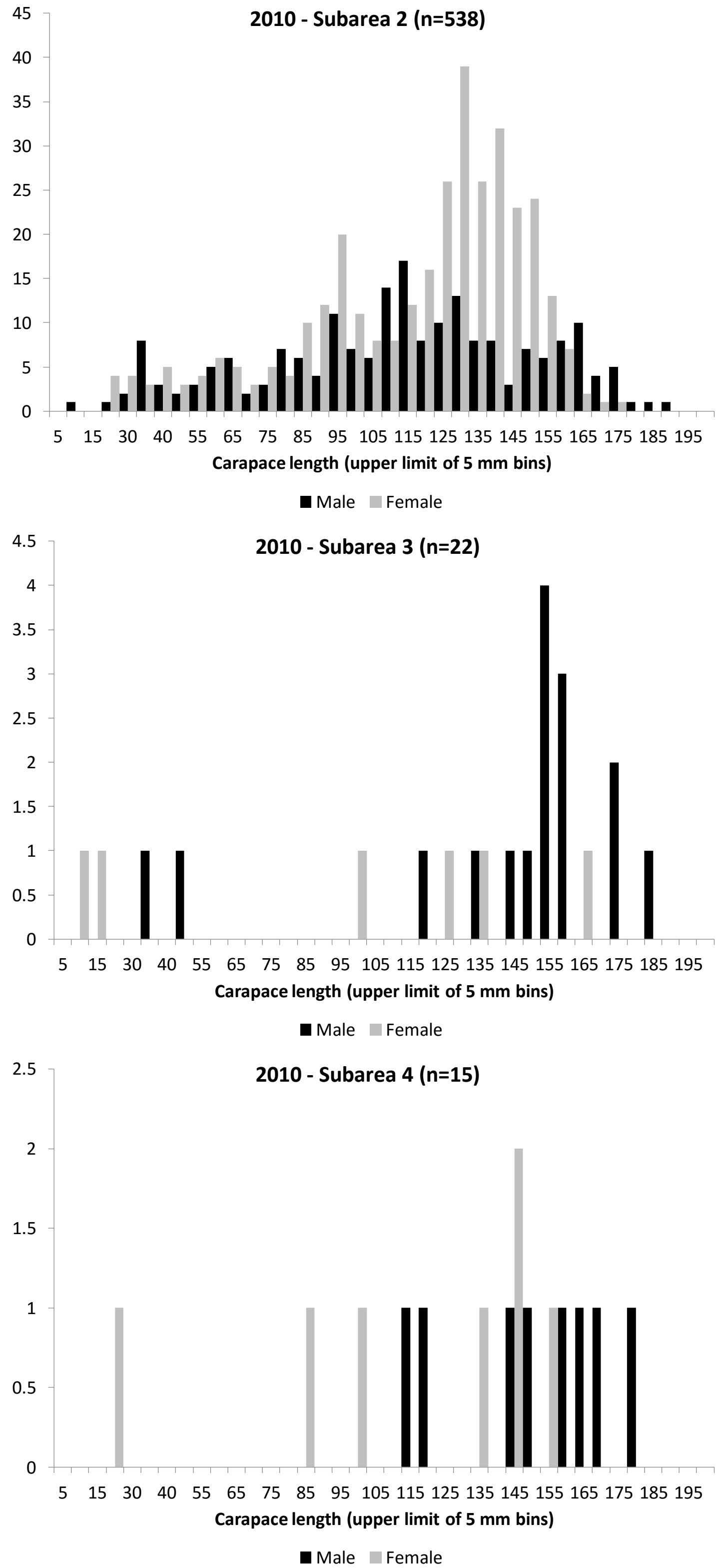


Figure 12. Size distribution of measured golden king crab during the 2010 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

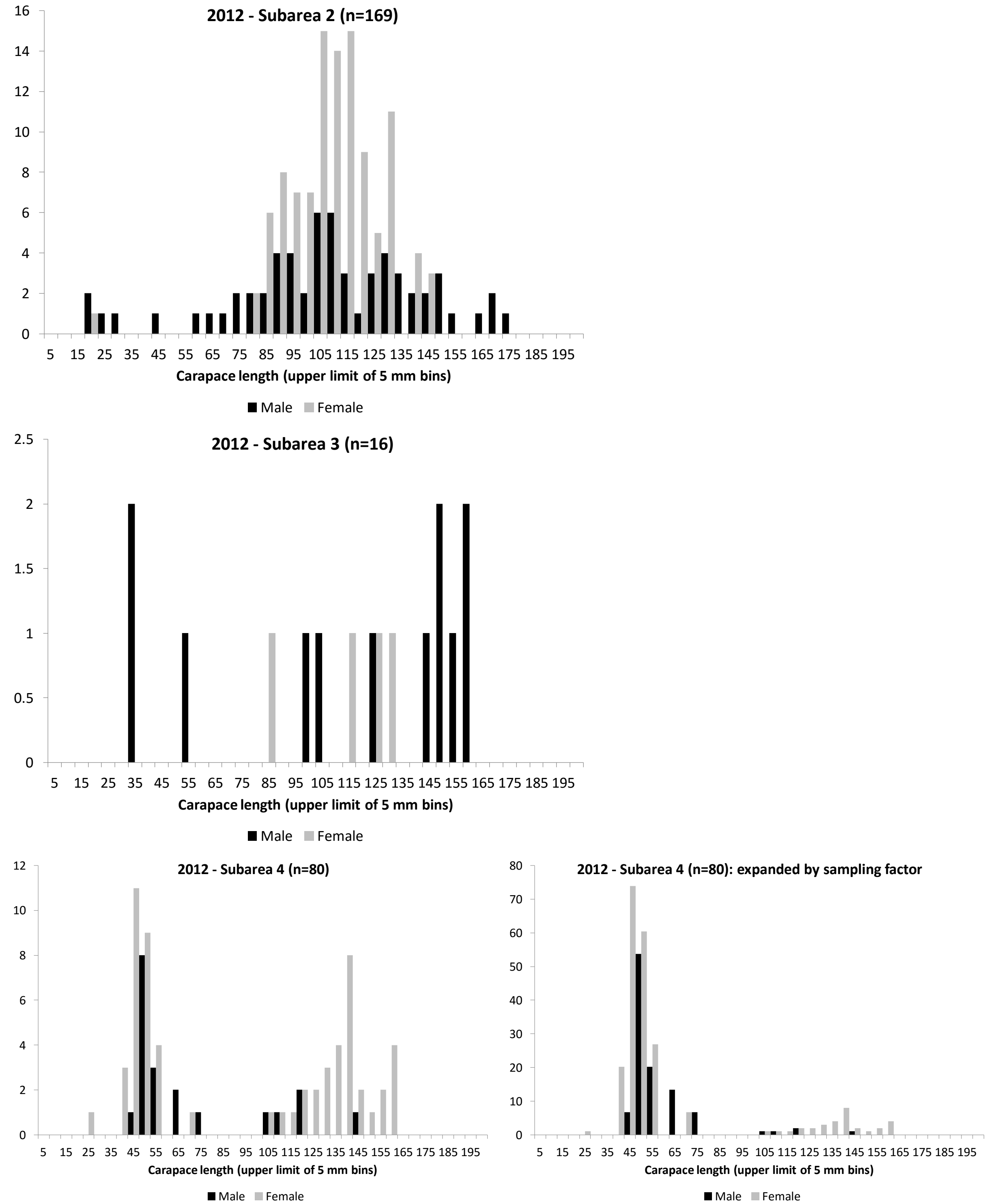
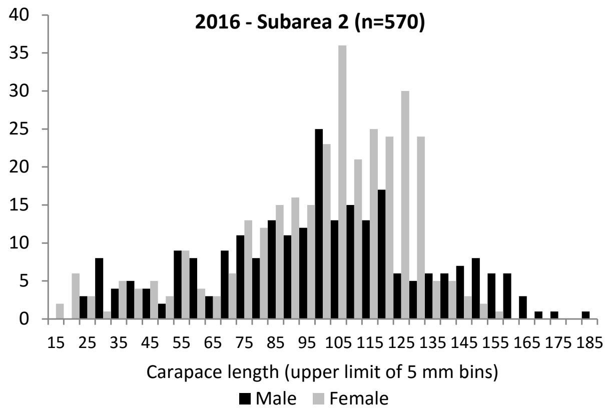
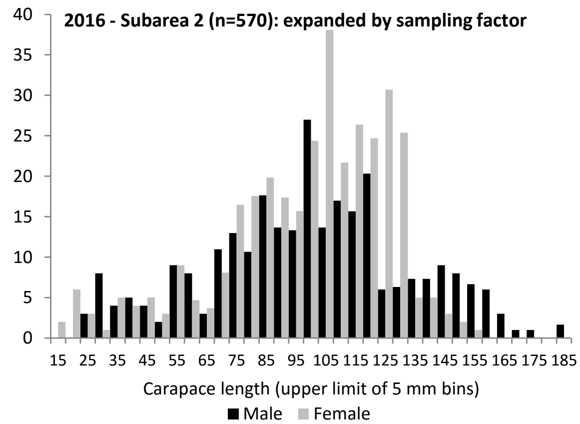
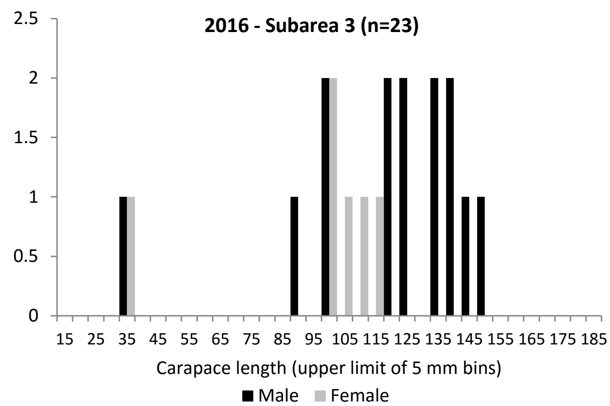


Figure 13. Size distribution of measured golden king crab during the 2012 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.







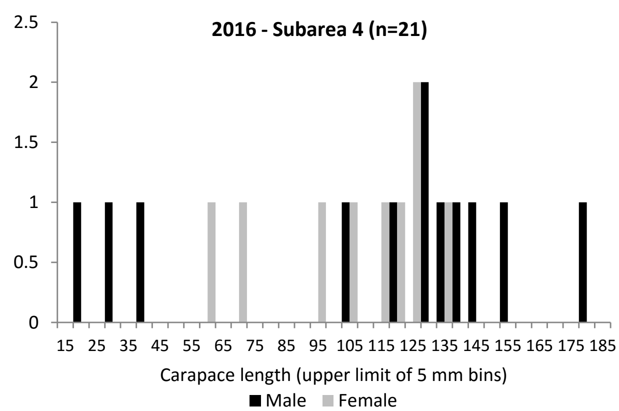


Figure 14. Size distribution of measured golden king crab during the 2016 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.

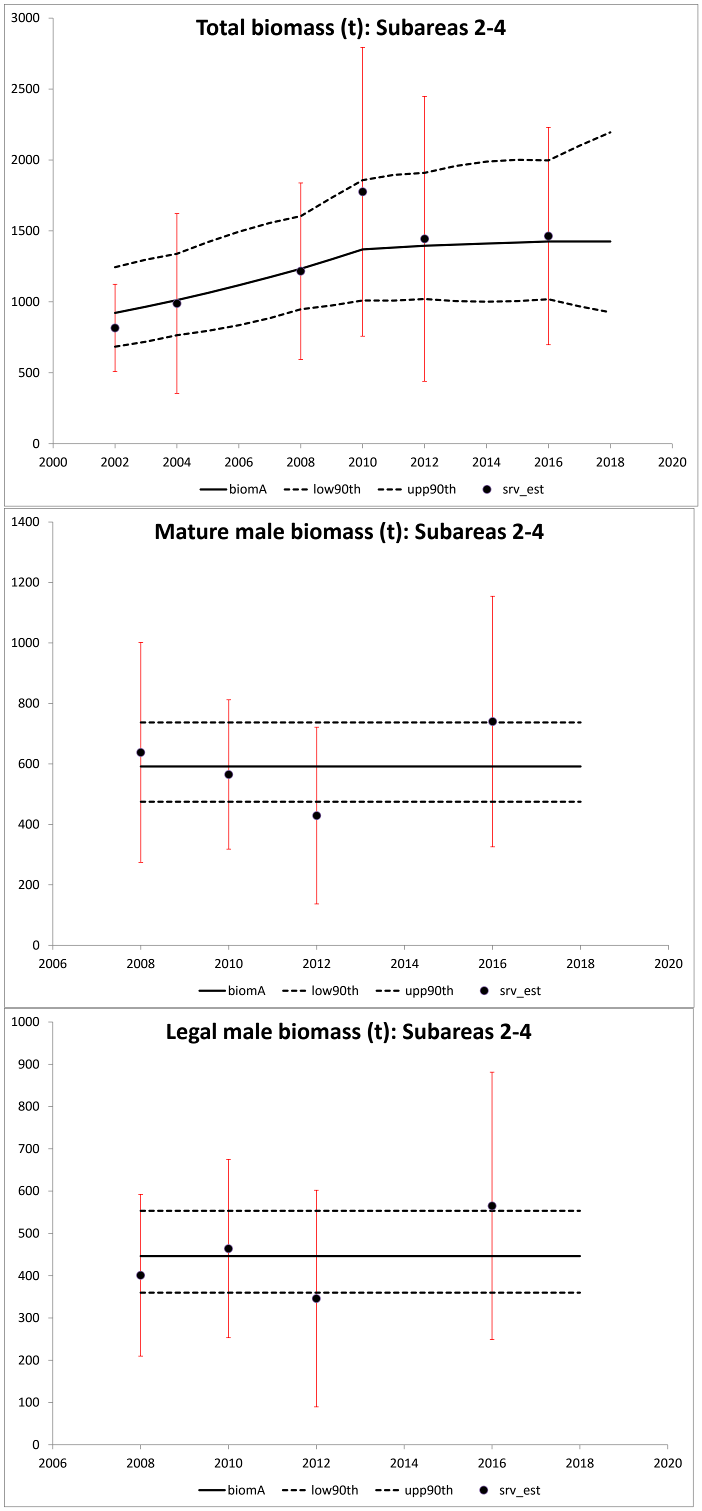


Figure 15. Plots of estimated and projected (into 2018) biomass of total, mature male, and legal male golden king crab in NMFS slope survey Subareas 2–4 with 90% confidence intervals and survey area-swept estimates; red bars are survey estimates ± 2 standard errors.

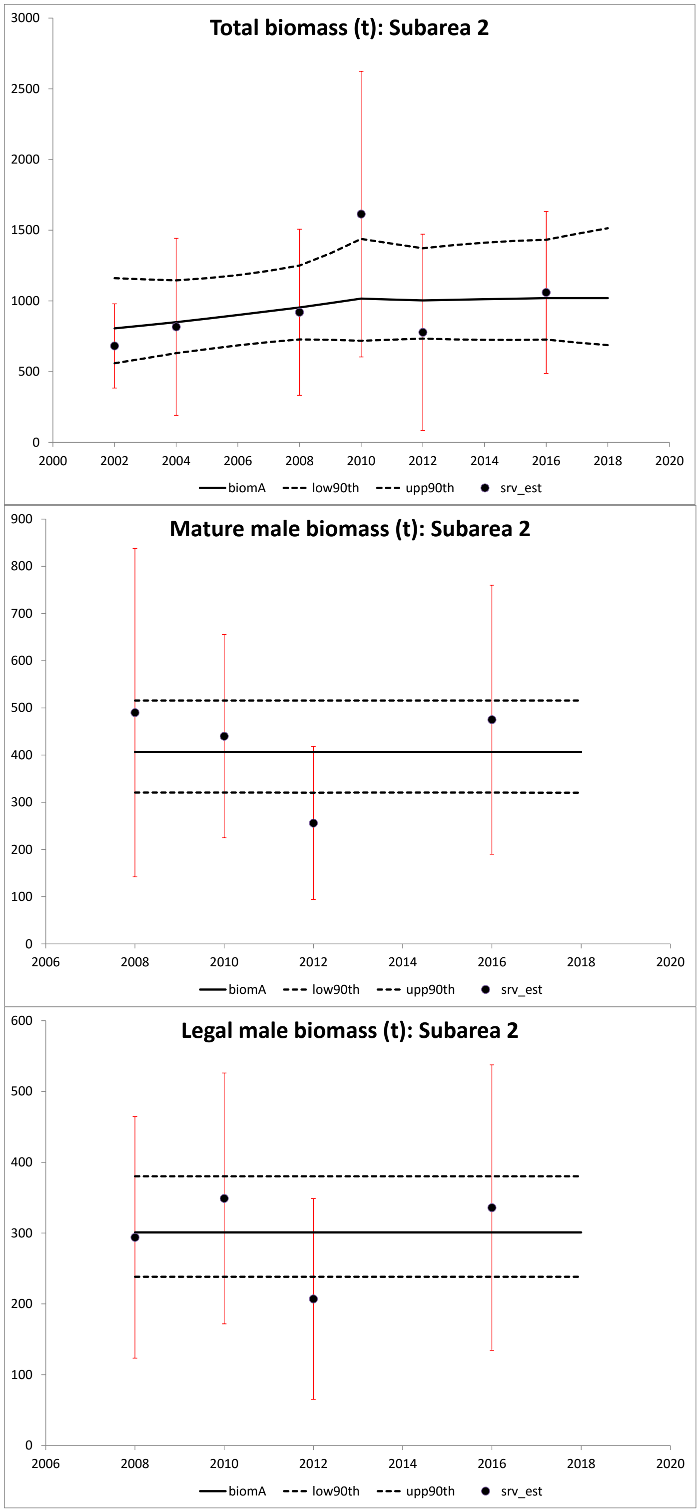


Figure 16. Plots of estimated and projected (into 2018) biomass of total, mature male, and legal male golden king crab in NMFS slope survey Subarea 2 with 90% confidence intervals and survey area-swept estimates; red bars are survey estimates ± 2 standard errors.

Appendix A1. Input file (re.dat) for total golden king crab biomass in NMFS EBS slope survey Subareas 2-4 and results file (rwout.rep) produced by re.exe.

re.dat file

2002	#Start year of model				
2018	#End year of model				
6	#number of survey estimates				
#Years of survey					
2002	2004	2008	2010	2012	2016
#Biomass estimates					
816	989	1216	1776	1444	1464
#Coefficients of variation for biomass estimates					
0.19	0.32	0.26	0.29	0.35	0.26

rwout.rep file

yrs_srv																	
	2002	2004	2008	2010	2012	2016											
srv_est																	
	816	989	1216	1776	1444	1464											
srv_sd																	
	0.188318	0.312233	0.25576	0.284166	0.339939	0.25576											
yrs																	
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI																	
	645.592	679.925	725.189	752.615	790.057	838.815	901.75	922.256	952.61	949.698	960.644	943.422	937.229	940.902	954.447	899.215	853.018
biomA																	
	922.492	966.221	1012.02	1063.35	1117.29	1173.96	1233.5	1299.86	1369.79	1382.64	1395.6	1403.14	1410.71	1418.33	1425.99	1425.99	1425.99
UCI																	
	1318.16	1373.07	1412.31	1502.39	1580.05	1643	1687.3	1832.06	1969.66	2012.94	2027.5	2086.87	2123.4	2138.02	2130.5	2261.36	2383.83
low90th																	
	683.706	719.43	765.09	795.604	835.309	885.377	948.313	974.552	1009.87	1008.79	1020.07	1005.57	1000.89	1005.05	1018.06	968.382	926.452
upp90th																	
	1244.67	1297.67	1338.66	1421.21	1494.45	1556.59	1604.45	1733.75	1857.98	1895.02	1909.38	1957.89	1988.34	2001.55	1997.37	2099.84	2194.87
biomsd																	
	6.82708	6.87339	6.91971	6.96918	7.01866	7.06813	7.11761	7.17001	7.22241	7.23175	7.24108	7.24647	7.25185	7.25724	7.26262	7.26262	7.26262
biomsd.sd																	
	0.182097	0.179291	0.170039	0.176341	0.176813	0.171502	0.159833	0.175096	0.185309	0.191634	0.19055	0.202527	0.208635	0.209386	0.204842	0.235255	0.262163

Appendix A2. Input file (re.dat) for mature male golden king crab biomass in NMFS EBS slope survey Subareas 2-4 and results file (rwout.rep) produced by re.exe.

re.dat file				
2008	#Start year of model			
2018	#End year of model			
4	#number of survey estimates			
#Years of survey				
2008	2010	2012	2016	
#Biomass estimates				
638	565	429	740	
#Coefficients of variation for biomass estimates				
0.29	0.22	0.34	0.28	

rwout.rep file											
yrs_srv											
	2008	2010	2012	2016							
srv_est											
	638	565	429	740							
srv_sd											
	0.284166	0.217406	0.330745	0.274733							
yrs											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI											
	455.113	455.114	455.115	455.114	455.114	455.115	455.113	455.109	455.103	455.099	455.095
biomA											
	591.486	591.485	591.484	591.484	591.485	591.486	591.488	591.49	591.492	591.492	591.492
UCI											
	768.721	768.718	768.715	768.716	768.718	768.721	768.728	768.74	768.756	768.762	768.768
low90th											
	474.693	474.694	474.694	474.694	474.693	474.694	474.693	474.69	474.684	474.681	474.678
upp90th											
	737.014	737.011	737.009	737.01	737.011	737.014	737.02	737.03	737.043	737.048	737.053
biomsd											
	6.38264	6.38264	6.38264	6.38264	6.38264	6.38264	6.38264	6.38265	6.38265	6.38265	6.38265
biomsd.sd											
	0.13372	0.133718	0.133717	0.133718	0.133718	0.133719	0.133722	0.133728	0.133737	0.133741	0.133745

Appendix A3. Input file (re.dat) for legal male golden king crab biomass in NMFS EBS slope survey Subareas 2-4 and results file (rwout.rep) produced by re.exe.

re.dat file

2008	#Start year of model		
2018	#End year of model		
4	#number of survey estimates		
#Years of survey			
2008	2010	2012	2016
#Biomass estimates			
401	464	346	565
#Coefficients of variation for biomass estimates			
0.24	0.23	0.37	0.28

rwout.rep file

yrs_srv											
	2008	2010	2012	2016							
srv_est											
	401	464	346	565							
srv_sd											
	0.236648	0.227042	0.358197	0.274733							
yrs											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI											
	345.148	345.153	345.158	345.158	345.158	345.156	345.151	345.143	345.132	345.129	345.126
biomA											
	446.173	446.174	446.175	446.176	446.177	446.178	446.18	446.182	446.184	446.184	446.184
UCI											
	576.768	576.762	576.758	576.759	576.761	576.769	576.781	576.799	576.822	576.828	576.834
low90th											
	359.687	359.692	359.696	359.696	359.696	359.695	359.691	359.684	359.675	359.672	359.669
upp90th											
	553.454	553.45	553.446	553.448	553.449	553.456	553.467	553.481	553.5	553.505	553.509
biomsd											
	6.10071	6.10071	6.10071	6.10071	6.10071	6.10072	6.10072	6.10073	6.10073	6.10073	6.10073
biomsd.sd											
	0.130986	0.13098	0.130975	0.130975	0.130976	0.130981	0.13099	0.131004	0.131022	0.131027	0.131032

Appendix B1. Input file (re.dat) for total golden king crab biomass in NMFS EBS slope survey Subarea 2 and results file (rwout.rep) produced by re.exe.

re.dat file					
2002	#Start year of model				
2018	#End year of model				
6	#number of survey estimates				
#Years of survey					
2002	2004	2008	2010	2012	2016
#Biomass estimates					
682	817	920	1614	778	1060
#Coefficients of variation for biomass estimates					
0.22	0.38	0.32	0.31	0.45	0.27

rwout.rep file																	
yrs_srv																	
	2002	2004	2008	2010	2012	2016											
srv_est																	
	682	817	920	1614	778	1060											
srv_sd																	
	0.217406	0.367261	0.312233	0.302917	0.429421	0.265265											
yrs																	
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI																	
	521.757	558.084	595.708	624.797	650.996	673.321	691.078	684.518	671.956	681.957	691.351	684.38	680.48	679.379	680.946	657.937	637.299
biomA																	
	805.904	827.675	850.035	874.937	900.568	926.95	954.105	984.827	1016.54	1010.12	1003.74	1007.86	1011.99	1016.14	1020.31	1020.31	1020.31
UCI																	
	1244.8	1227.5	1212.94	1225.22	1245.82	1276.12	1317.24	1416.89	1537.82	1496.2	1457.29	1484.23	1505.01	1519.84	1528.81	1582.27	1633.51
low90th																	
	559.517	594.576	630.736	659.541	685.85	708.818	727.844	725.728	718.182	726.402	734.044	728.306	725.297	724.789	726.67	706.005	687.371
upp90th																	
	1160.79	1152.16	1145.58	1160.68	1182.51	1212.21	1250.7	1336.43	1438.84	1404.65	1372.53	1394.72	1412.01	1424.62	1432.61	1474.54	1514.52
biomsd																	
	6.69196	6.71862	6.74528	6.77415	6.80303	6.8319	6.86077	6.89247	6.92416	6.91782	6.91149	6.91558	6.91968	6.92377	6.92786	6.92786	6.92786
biomsd.sd																	
	0.221818	0.201078	0.181392	0.171798	0.165572	0.163101	0.164552	0.185587	0.211207	0.200438	0.190226	0.197485	0.202489	0.205403	0.206316	0.223854	0.240114

Appendix B2. Input file (re.dat) for mature male golden king crab biomass in NMFS EBS slope survey Subarea 2 and results file (rwout.rep) produced by re.exe.

re.dat file

2008	#Start year of model			
2018	#End year of model			
4	#number of survey estimates			
#Years of survey				
2008	2010	2012	2016	
#Biomass estimates				
490	440	256	475	
#Coefficients of variation for biomass estimates				
0.36	0.24	0.32	0.3	

rwout.rep file

yrs_srv											
	2008	2010	2012	2016							
srv_est											
	490	440	256	475							
srv_sd											
	0.34909	0.236648	0.312233	0.29356							
yrs											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI											
	306.329	306.333	306.335	306.332	306.325	306.327	306.328	306.328	306.327	306.323	306.319
biomA											
	406.596	406.595	406.594	406.592	406.59	406.591	406.592	406.594	406.595	406.595	406.595
UCI											
	539.683	539.674	539.666	539.666	539.673	539.672	539.674	539.678	539.684	539.691	539.698
low90th											
	320.592	320.595	320.597	320.593	320.587	320.589	320.59	320.59	320.589	320.586	320.582
upp90th											
	515.674	515.666	515.66	515.659	515.664	515.664	515.665	515.669	515.674	515.68	515.685
biomsd											
	6.00782	6.00782	6.00782	6.00781	6.0078	6.00781	6.00781	6.00781	6.00782	6.00782	6.00782
biomsd.sd											
	0.14447	0.144463	0.144457	0.14446	0.144469	0.144466	0.144466	0.144468	0.144473	0.144479	0.144486

Appendix B3. Input file (re.dat) for legal male golden king crab biomass in NMFS EBS slope survey Subareas 2 and results file (rwout.rep) produced by re.exe.

re.dat file

2008	#Start year of model			
2018	#End year of model			
4	#number of survey estimates			
#Years of survey				
2008	2010	2012	2016	
#Biomass estimates				
294	349	207	336	
#Coefficients of variation for biomass estimates				
0.29	0.25	0.34	0.3	

rwout.rep file

yrs_srv											
	2008	2010	2012	2016							
srv_est											
	294	349	207	336							
srv_sd											
	0.284166	0.246221	0.330745	0.29356							
yrs											
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
LCI											
	227.905	227.906	227.907	227.906	227.905	227.905	227.905	227.904	227.903	227.902	227.901
biomA											
	301.019	301.02	301.02	301.019	301.018	301.019	301.019	301.019	301.02	301.02	301.02
UCI											
	397.589	397.588	397.587	397.587	397.587	397.588	397.59	397.592	397.594	397.596	397.599
low90th											
	238.328	238.329	238.33	238.329	238.328	238.328	238.327	238.327	238.326	238.325	238.324
upp90th											
	380.202	380.201	380.2	380.199	380.2	380.201	380.202	380.203	380.205	380.207	380.209
biomsd											
	5.70717	5.70718	5.70718	5.70717	5.70717	5.70717	5.70717	5.70718	5.70718	5.70718	5.70718
biomsd.sd											
	0.141961	0.14196	0.141958	0.141959	0.141961	0.141961	0.141963	0.141964	0.141966	0.14197	0.141973

Appendix C. Draft Pribilof Islands (Pribilof District) golden king crab stock structure template (adapted from Spencer et al. 2010). Page 1 of 2.

Factor and criterion	**Justification**
Harvest and trends	
Fishing mortality (5-year average percent of F_{abc} or F_{ofl})	F, F_{ABC}, and F_{OFL} are not estimated for Tier 5 stock. Total catch annual catch is confidential, but has been below the OFLs and ABCs established for season.
Spatial concentration of fishery relative to abundance (Fishing is focused in areas << management areas)	Fishery effort and catch is concentrated in Pribilof Canyon, a very small area of the Pribilof District, but also an area of concentrated golden king crab density (see EBS slope survey data).
Population trends (Different areas show different trend directions)	Uncertain. Standardized trawl surveys in the Pribilof District have only been performed in 2002, 2004, 2008, 2010, 2012, and 2016. Total biomass estimates generally increased from 2002 through 2012; with no substantial increase in 2016.
Barriers and phenotypic characters	
Generation time (e.g., >10 years)	Unknown, but likely >10 years.
Physical limitations (Clear physical inhibitors to movement)	Species occurs primarily in the 200-1000 m depth zone. No known physical barriers exist in the Pribilof District, although survey and fishery data suggest low densities in the 200-1000 m depth zone of the EBS slope between Pribilof Canyon and Zhemchug Canyon.
Growth differences (Significantly different LAA, WAA, or LW parameters)	No data for estimating size at age. Spatial differences in length-weight relationship within Pribilof District have not been investigated. Within the Bering Sea males at higher latitudes have been estimated to be heavier than equal-sized males at lower latitudes.
Age/size-structure (Significantly different size/age compositions)	Age structure data is lacking. Spatial trends within Pribilof District in size structure have not been investigated, but trend of latitudinal decrease in mean size may exist over the Bering Sea due to latitudinal decrease in size at maturity.
Spawning time differences (Significantly different mean time of spawning)	Species is known to exhibit an asynchronous reproductive cycle lacking distinct seasonal variation; mean spawning time within Pribilof District has not been estimated.

Factor and criterion	**Justification**
Maturity-at-age/length differences (Significantly different mean maturity-at-age/ length)	No data for estimating maturity at age. Spatial differences in size at maturity within Pribilof District have not been investigated. Within Bering Sea, estimates of size at maturity decrease south-to-north.
Morphometrics (Field identifiable characters)	Spatial trends within Pribilof District in morphometrics have not been investigated. Latitudinal trends in male morphometrics (chela size at length) may exist over the Bering Sea that are related to latitudinal trends in size at maturity.
Meristics (Minimally overlapping differences in counts)	N/A.
Behavior & movement	
Spawning site fidelity (Spawning individuals occur in same location consistently)	Not likely: ovigerous females tend to occur in the shallower depth zones at sites throughout the Pribilof District within the species depth distribution.
Mark-recapture data (Tagging data may show limited movement)	Mark-recapture data not available.
Natural tags (Acquired tags may show movement smaller than management areas)	Unknown.
Genetics	
Isolation by distance (Significant regression)	Unknown.
Dispersal distance (<<Management areas)	Unknown.
Pairwise genetic differences (Significant differences between geographically distinct collections)	Unknown.

10. Assessment of Western Aleutian Islands Red King Crab (WAIRKC)

[2017]

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Division of Commercial Fisheries

[NOTE: In accordance with the approved schedule, no assessment was conducted for this stock 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 specifications]

Summary of Results

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

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

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

Fishing Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2014/15	N/A	N/A	Closed	0	0.00047	0.12387	0.07432
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				0.12387	0.03097
2019/20	N/A	N/A				0.12387	0.03097

Western Aleutian Islands Red King Crab

– 2017 Tier 5 Assessment

2017 Crab SAFE Report Chapter (September 2017)

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Executive Summary

1. Stock:

Western Aleutian Islands (the Aleutian Islands, west of 171° W longitude) red king crab, *Paralithodes camtschaticus*

There are two districts for State management of commercial red king crab fisheries in waters of the Aleutian Islands west of 171º W longitude: the Adak District for waters east of 179º W longitude and the Petrel District for waters west of 179º W longitude. Although this stock has been referred to colloquially as the “Adak” stock, this report will refer to the stock as the “Western Aleutian Islands (WAI) red king crab” stock to avoid confusion with the Adak District.

2. Catches:

The domestic fishery has been prosecuted since 1960/61 and was opened every year through the 1995/96 crab fishing year. Peak retained catch occurred in 1964/65 at 9,613 t (21,193,000 lb). During the early years of the fishery through the late 1970s, most or all of the retained catch was harvested in the area between 172° W longitude and 179°15' W longitude. As the annual retained catch decreased into the mid-1970s and the early-1980s, the area west of 179°15' W longitude began to account for a larger portion of the retained catch. Retained catch during the 10-year period 1985/86–1994/95 averaged 428 t (942,940 lb), but the retained catch in 1995/96 was only 18 t (38,941 lb). The fishery has been opened only occasionally during 1996/97 to present. There was an exploratory fishery with a low guideline harvest level (GHL) in 1998/99, three commissioner’s permit fisheries in limited areas during 2000/01–2002/03 to allow for ADF&G-Industry surveys, and two commercial fisheries with a GHL of 227 t (500,000 lb) in 2002/03 and 2003/04. Most of the retained catch since 1990/91 was harvested in the Petrel Bank area (between 179° W longitude and 179° E longitude); in 2002/03 and 2003/04 the commercial fishery was opened only in the Petrel Bank area. Retained catch in the last two years with commercial fishing was 229 t (505,642 lb) in 2002/03 and 217 t (479,113 lb) in 2003/04. The fishery has been closed during 2004/05–2016/17. 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 1995/96–2016/17 averaged 1 t (1,902 lb). Estimated annual weight of bycatch mortality due to groundfish fisheries during 1993/94–2016/17 averaged 7 t (15,710 lb). Estimated weight of annual total fishery mortality during 1995/96–2016/17 averaged 34 t (74,890 lb); the average annual retained catch during that period was 26 t (57,278 lb). A cooperative red king crab survey was performed by the Aleutian Islands King Crab Foundation (an industry group) and ADF&G in the Petrel Bank area in November 2016 (Hilsinger and Siddon 2016b), which resulted in an estimated bycatch mortality of 0.03 t (59 lb). Estimated total fishery mortality in 2016/17 resulted from groundfish fisheries (0.13 t; 294 lb), the Aleutian Islands golden king crab fishery (0.05 t; 100 lb), and the cooperative survey (0.03 t; 59 lb).

3. Stock biomass:

Estimates of past or present stock biomass are not available for this Tier 5 assessment.

4. Recruitment:

Estimates of recruitment trends and current levels relative to virgin or historic levels are not available for this Tier 5 assessment.

5. Management performance:

Overfishing did not occur during 2016/17 because the estimated total catch (0.2 t; 454 lb) did not exceed the Tier 5 OFL established for 2016/17 (56 t; 123,867 lb). Additionally, the 2016/17 estimated total catch did not exceed the ABC established for 2016/17 (34 t; 74,320 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	<1	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	454	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 is lowered because 1) the industry has not expressed interest in a small test fishery during 2017/18, and 2) because the stock is severely depressed as indicated by the 2016 Petrel survey (CPT minutes for May 2017).

   At 14 t the ABC provides a 75% buffer on the OFL of 56 t; i.e., $(1.0\text{-}0.75)\cdot 56$ 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 2016/17 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 was opened only in the Petrel Bank area (i.e., between 179° W longitude and 179° E longitude; Baechler and Cook 2014) during the most recent two years that the fishery was prosecuted (2002/03 and 2003/04). Fishery effort during those two years typically occurred at depths of 60–90 fathoms (110–165 m); average depth of pots fished in the Aleutian Islands area during 2002/03 was 68 fathoms (124 m; Barnard and Burt 2004) and during 2003/04 was 82 fathoms (151 m; Burt and Barnard 2005). Depth was recorded for 578 pots out of the 580 pot lifts sampled by observers during the 1996/97–2006/07 Aleutian Islands golden king crab fishery that contained 1 or more red king crab (ADF&G observer database, Dutch Harbor, April 2008). Of those, the deepest recorded depth was 266 fathoms (486 m) and 90% of pot lifts had recorded depths of 100–200 fathoms (183–366 m); no red king crab were present in any of the 6,465 pot lifts sampled during the 1996/97–2006/07 Aleutian Islands golden king crab fishery with depths >266 fathoms (486 m).

In this chapter we will refer to the area west of 171° W longitude within the Aleutian Islands king crab Registration Area O as the “Western Aleutian Islands” (WAI). The Aleutian Islands king crab Registration Area O is described by Baechler and Cook (2014, page 7) as follows (see also Figure 1):

> "The Aleutian Islands king crab Registration Area O has as its eastern boundary the longitude of Scotch Cap Light (164° 44' W longitude), its northern boundary a line from Cape Sarichef (54° 36' N latitude) to 171° W longitude, north to 55° 30' N latitude, and as its western boundary the Maritime Boundary Agreement Line as that line is described in the text of and depicted in the annex to the Maritime Boundary Agreement between the United States and the Union of Soviet Socialist Republics signed in Washington, June 1, 1990. Area O encompasses both the waters of the Territorial Sea (0-3 nautical miles) and waters of the Exclusive Economic Zone (3-200 nautical miles)."

From 1984/85 until the March 1996 Alaska Board of Fisheries meeting, the Aleutian Islands king crab Registration Area O as currently defined had been subdivided at 171° W longitude into the historic Adak Registration Area R and the Dutch Harbor Registration Area O. The geographic boundaries of the WAI red king crab stock are defined here by the boundaries of the historic Adak Registration Area R (i.e., the current Aleutian Islands king crab Registration Area O, west of 171° W longitude). Note that in March 2014 the Alaska Board of Fisheries established two districts for management of commercial fisheries for red king crab in the waters of the Aleutian Islands west of 171° W longitude: 1) the Adak District, 171º to 179º W longitude; and the Petrel District, west of 179º W longitude.

3. <u>Evidence of stock structure</u>:

Seeb and Smith (2005) analyzed microsatellite DNA variability in nearly 1,800 individual red king crab originating from the Sea of Okhotsk to Southeast Alaska, including a sample 75 specimens collected during 2002 from the vicinity of Adak Island in the Aleutian Islands (51° 51' N latitude, 176° 39' W longitude), to evaluate the degree to which the established geographic boundaries between stocks in the BSAI reflect genetic stock divisions. Seeb and Smith (2005) concluded that, "There is significant divergence of the Aleutian Islands population (Adak sample) and the Norton Sound population from the southeastern Bering Sea population (Bristol Bay, Port Moller, and Pribilof Islands samples)." Recent analysis of patterns of genetic diversity among red king crab stocks in the western north Pacific (Asia), eastern North Pacific, and Bering Sea by multiple techniques (SNPs, allozymes, and mtDNA) also showed that red king crab sampled near Adak Island had greater genetic similarity to stocks in Asia rather than other stocks in Alaskan waters including Bristol Bay and the Gulf of Alaska (reviewed in Grant et al. 2014).

To date, population genetic studies of red king crab within the WAI have only grouped samples from within this region as one site (i.e., Adak Island) (Grant et al. 2014). Given the complexity of currents throughout the WAI and that canyons deeper than the depth restrictions of red king crab (>1,000 m) separate several islands, the possibility of fine scale genetic structuring exists, but remains uninvestigated. A summary of total retained catch by 1-degree longitude groupings during 1985/86–1995/96 (years for which state statistical area definitions allow for grouping by 1-degree longitude and for which catch distribution was not affected by area closures and openings; see Section C.5) shows that catch and, presumably, distribution of legal-sized male red king crab is not evenly distributed across the Aleutian Islands. Most catch during that period was from Petrel Bank, followed by the vicinity of Adak, Atka, and Amlia Islands (Figure 2). Note that the 1-degree longitude grouping of catch does not portray the spatial gaps in catch that are apparent upon a closer inspection of the 1985/86–1995/96 catch data by state statistical areas.

For example, no catch was reported during 1985/86–1995/96 from the two statistical areas (795102 and 795132) that include Amchitka Pass (Amchitka Pass lies between Petrel Bank and the Delarof Islands; see Figure 2).

McMullen and Yoshihara (1971) reported the following on male red king crab that were tagged in February 1970 on the Bering Sea and Pacific Ocean sides of Atka Island and recovered in the subsequent fishery:

> "Fishermen landing tagged crabs were questioned carefully concerning the location of recapture. In no instance did crabs migrate through ocean passes between the Pacific Ocean and Bering Sea."

4. **<u>Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology)</u>:**

Red king crab eggs are fertilized externally and the clutch of fertilized eggs (embryos) are carried under the female's abdominal flap until hatching. Male king crab fertilize eggs by passing spermatophores from the fifth periopods to the gonopores and coxae of the female's third periopods; the eggs are fertilized during ovulation and attach to the female's pleopodal setae (Nyblade 1987, McMullen 1967). Females are generally mated within hours after molting (Powell and Nickerson 1965), but may mate up to 13 days after molting (McMullen 1969). Males must wait at least 10 days after completing a molt before mating (Powell et al. 1973), but, unlike females, do not need to molt prior to mating (Powell and Nickerson 1965).

Wallace et al. (1949, page 23) described the "egg laying frequency" of red king crab:

> "Egg laying normally takes place once a year and only rarely are mature females found to have missed an egg laying cycle. The eggs are laid in the spring immediately following shedding [i.e., molting] and mating and are incubated for a period of nearly a year. Hatching of the eggs does not occur until the following spring just prior to moulting [i.e., molting] season."

McMullen and Yoshihara (1971) reported that from 804 female red king crab (79–109-mm CL) collected during the 1969/70 commercial fishery in the western Aleutians, "Female king crab in the western Aleutians appeared to begin mating at 83 millimeters carapace length and virtually all females appeared to be mature at 102 millimeters length." Blau (1990) estimated size at maturity for WAI red king crab females as the estimated CL at which 50% of females are mature (SM50; as evidenced by presence of clutches of eggs or empty) according to a logistic regression: 89-mm CL (SD = 2.6 mm). Size at maturity has not been estimated for WAI male red king crab. However, because the estimated SM50 for WAI red king crab females is the same as that estimated for Bristol Bay red king crab females (Otto et al. 1990), the estimated maturity schedule used for Bristol Bay red king crab males (see SAFE chapter on Bristol Bay red king crab) could be applied to males in the WAI stock as a proxy.

Few data are available on the molting and mating period for red king crab specifically in the WAI. Among the red king crab captured by ADF&G staff for tagging on the south side of Amlia Island (173° W longitude to 174° W longitude) in the first half of April 1971, males and females were molting, females were hatching embryos, and mating was occurring (McMullen and Yoshihara 1971). The spring mating period for red king crab is known to last for several months, however. For example, although mating activity in the Kodiak area apparently peaks in April, mating pairs in the Kodiak area have been documented from January through May (Powell et al. 2002). Due to the timing of the commercial fishery within a year, little data on reproductive condition of WAI red king crab females have been collected by at-sea fishery observers that can be used for evaluating the mating period. Most recently, of the 3,211 mature females that were examined during the 2002/03 and 2003/04 red king crab fisheries in the Petrel Bank area, which were prosecuted in late October, only 10 were scored as “hatching” (ADF&G observer database, Dutch Harbor, April 2008).

Data on mating pairs of red king crab collected from the Kodiak area during March–May of 1968 and 1969 showed that size of the females in the pairs increased from March to May, indicating that females tend to release their larvae and mate later in the mating season with increasing body size (Powell et al. 2002). Size of the males in those mating pairs did not increase with later sampling periods, but did show a decreasing trend in estimated time since last molt. In all the data on mating pairs collected from the Kodiak area during 1960–1984, the proportion of males that were estimated to have not recently molted prior to mating decreased monthly over the mating period (Powell et al. 2002). Those data also suggest that, for males, not molting early in the mating period provides the advantage of mating when primiparous and small, multiparous females tend to ovulate. Alternatively, males that do molt early in the mating period likely participate in mating later, and with larger females.

Current knowledge of red king crab reproductive biology, including male and female maturation, migration, mating dynamics, and potential effects of exploitation on reproductive potential, is summarized by Webb (2014).

5. <u>Brief summary of management history</u>:

A complete summary of the management history through 2011/12 is provided by Baechler and Cook (2014, pages 7–13). The domestic fishery for red king crab in the WAI began in 1960/61. Retained catch of red king crab in the Aleutians west of 172° W longitude averaged 5,259 t (11,595,068 lb) during 1960/61–1975/76, with a peak retained catch of 9,613 t (21,193,000 lb) in 1964/65 (Tables 1a and 1b, Figure 3). Guideline harvest levels (GHL; sometimes expressed as ranges, with an upper and lower GHL) for the fishery were established in most years since 1973/74. The fishery was closed in 1976/77 in the area west of 172º W longitude, but was reopened for each year during 1977/78–1995/96. Average retained catch during 1977/78–1995/96 (for the area west of 172º W longitude prior to 1984/85 and for the area west of 171º W longitude since 1984/85) was 470 t (1,036,659 lb); the peak retained catch during that period occurred in 1983/84 at 899 t (1,981,579 lb). During the mid-to-late 1980s, significant portions of the catch during the WAI red king crab fishery occurred west of 179º E longitude or east of 179º W longitude, whereas most of the retained catch was harvested from the Petrel Bank area (179° W longitude to 179° W longitude) during 1990/91–1994/95 (Figure 4). Retained catch and fishery CPUE (retained crab per pot lift) declined from 1993/94 to 1994/95 and 1995/96; retained catch in 1994/95 and, especially, 1995/96 was far below the lower GHL established. Due to concerns about the low stock level and poor recruitment indicated by results of the fishery in 1994/95–1995/96, the fishery was closed in 1996/97–1997/98. During 1998/99–2003/04 the fishery was opened only in restricted areas, either as an open fishery managed under a GHL or as an ADF&G-Industry survey conducted as a commissioner's permit fishery (Table 2); peak retained catch during that period was 229 t (505,642 lb) harvested from the Petrel Bank area in 2002/03. The fishery has been closed during 2004/05–2016/17.

Only males of a minimum legal size may be retained by the commercial red king crab fishery in the WAI. By State of Alaska regulation (**5 AAC 34.620 (a)**), the minimum legal size limit is 6.5-inches (165 mm) carapace width (CW), including spines. A carapace length (CL) ≥138 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007). Except for the years 1968–1970, the minimum size has been 6.5-inches CW since 1950; in 1968 there was a "first-season" minimum size of 6.5-inches CW and a "second-season" minimum size of 7.0-inches and in 1969–1970 the minimum size was 7.0-inches CW (Donaldson and Donaldson 1992).

Red king crab may be commercially fished only with king crab pots (as defined in **5 AAC 34.050**). Pots used to fish for red king crab in the WAI must, since 1996, have at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized red king crab and may not be longlined (**5 AAC 34.625 (e)**). The sidewall of the pot "…must contain an opening equal to or exceeding 18 inches in length... The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread." (**5 AAC 39.145(1)**).

The WAI red king crab fishery west of 179° W longitude has been managed since 2005/06 under the Crab Rationalization program (50 CFR Parts 679 and 680). The WAI red king crab fishery in the area east of 179° W longitude was not included in the Crab Rationalization program (Baechler and Cook 2014). In March 2014 the Alaska Board of Fisheries established two red king crab management districts in state regulations for the Aleutian Islands west of 171° W longitude (the Adak District, 171º to 179º W longitude; and the Petrel District, west of 179º W longitude) and some notable differences in regulations exist between the two districts. The red king crab commercial fishing season in the Adak District is August 1 to February 15, unless closed by emergency order (**5 AAC 34.610 (a) (1)**); the red king crab commercial fishing season in the Petrel is October 15 to February 15, unless closed by emergency order (**5 AAC 34.610 (a) (2)**). Only vessels 60 feet or less in overall length may participate in the commercial red king crab fishery within the state waters of the Adak District (**5 AAC 34.610 (d)**); no vessel size limit is established for federal waters in the Adak District or for state or federal waters in the Petrel District. Federal waters in the Adak District are opened to commercial red king crab fishing only if the season harvest level established by ADF&G for the Adak District is 250,000 lb or more (**5 AAC 34.616 (a) (2)**); there is no comparable regulation for the Petrel District. In the Adak District, pots commercially fished for red king crab may only be deployed and retrieved between 8:00 AM and 5:59 PM each day (**5 AAC 34.625 (g) (2)**) and the following pot limits pertain: 10 pots per vessel for vessels fishing within state waters (**5 AAC 34.625 (g) (1) (A)**); and 15 pots per vessel for vessels fishing in federal waters (**5 AAC 34.625 (g) (1) (B)**). In the Petrel District there is no regulation pertaining to periods for operation of gear and a pot limit of 250 pots per vessel (**5 AAC 34.625 (d)**). See also "6. Brief description of the annual ADF&G harvest strategy," below.

6. <u>Brief description of the annual ADF&G harvest strategy</u>:

Prior to the March 2014 Alaska Board of Fisheries meeting, when the board adopted a harvest strategy for the Adak District only, there was no harvest strategy in state regulation for WAI red king crab. Following results of the January/February and November 2001 ADF&G-Industry pot surveys for red king crab in the Petrel Bank area, which produced high catch rates of legal males (CPUE = 28), but low catches of females and sublegal males, ADF&G opened the fishery in 2002/03 and 2003/04 with a GHL of 227 t (500,000 lb); that GHL was established as the minimum GHL that could be managed inseason, given expected participation and effort (Baechler and Cook 2014). The fishery was closed in 2004/05 due to continued uncertainty on the status of pre-recruit legal males, a reduction in legal male CPUE from 18 in 2002/03 to 10 in 2003/04, and a strategy adopted by ADF&G to close the fishery before the CPUE of legal crab dropped below 10.

The harvest strategy for red king crab in the Adak District adopted by the Alaska Board of Fisheries in March 2014 is as follows:

> **5 AAC 34.616. Adak District red king crab harvest strategy.** (a) In the Adak District, based on the best scientific information available, if the department determines that there is a harvestable surplus of
>
> (1) red king crab available in the waters of Alaska in the Adak District, the commissioner may open, by emergency order, a commercial red king crab fishery only in the waters of Alaska in the Adak District under 5 AAC 34.610(a)(1);
>
> (2) at least 250,000 pounds of red king crab in the Adak District, the commissioner may open, by emergency order, a commercial red king crab fishery in the entire Adak District under 5 AAC 34.610(a)(1).
>
> (b) In the Adak District, during a season opened under 5 AAC 34.610(a)(1), the operator of a validly registered king crab fishing vessel shall
>
> (1) report each day to the department
>
> (A) the number of pot lifts;
>
> (B) the number of crab retained for the 24-hour fishing period preceding the report; and
>
> (C) any other information the commissioner determines is necessary for the management and conservation of the fishery, as specified in the vessel registration certificate issued under 5 AAC 34.020; and
>
> (2) complete and submit a logbook as prescribed and provided by the department.

7. <u>Summary of the history of B_{MSY}</u>: Not applicable for this Tier 5 stock.

D. Data

1. **Summary of new information:**
   - Retained catch data from the 2016/17 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 2016/17 Aleutian Islands golden king crab fishery and the 2016/17 groundfish fisheries in reporting areas 541, 542, and 543 (Figure 5).
   - Discarded catch during the cooperative industry-ADF&G survey in 2016. Data was available as number of crab caught per size/sex group (males: legal, sub-lagal, and females). Assumptions were made on the representative size (width) of each group, which were converted to length then weight. A bycatch mortality rate of 0.2 (as applied to crab fisheries) was applied to the estimated total weight caught.

2. **Data presented as time series:**

a. ***Total catch** and b. **Information on bycatch and discards**:*

- Annual retained catch weight for 1960/61–2016/17 (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 1995/96–2016/17 (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 2004/05–2016/17 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 1993/94–2016/17 (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 1993/94–2016/17 is also presented in Table 5.

- Annual estimated weight of total fishery mortality for 1995/96–2016/17, 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 1960/61–2016/17 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 1972/73–2016/17 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, 1988/89–2016/17 (ADF&G observer database).
   - Summary of data collected by ADF&G WAI red king crab fishery observers or surveys during 1969–1987 (Blau 1993).

E. Analytic Approach

1. **History of modeling approaches for this stock:** This is a Tier 5 assessment.
2. **Model Description:** Subsections a–i are not applicable to a Tier 5 assessment.

There is no regular survey of this stock. No assessment model for the WAI red king crab stock exists and none is in development. The SSC in June 2010 recommended that: the WAI red king crab stock be managed as a Tier 5 stock; the OFL be specified as a total-catch OFL; the total-catch OFL be established as the estimated average annual weight of the retained catch and bycatch mortality in crab and groundfish fisheries over the period 1995/96–2007/08; and the period used for computing the Tier 5 total-catch OFL be fixed at 1995/96–2007/08.

Given the strong recommendations from the SSC in June 2010, Tier 5 total-catch OFLs would change only if retained catch data and estimates of discarded catch for the period 1995/96–2007/08 or assumed values of bycatch mortality rates used in the 2010 SAFE were revised. Given that no need has been shown to revise either the retained catch data or the discarded catch estimates for the period 1995/96–2007/08 or assumed values of bycatch mortality rates used in the 2010 SAFE, the recommended approach for establishing the 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,

- $RET_{95/96-07/08}$ is the average annual retained catch in the directed crab fishery during 1995/96–2007/08
- $BM_{CF, 95/96-07/08}$ is the estimated average annual bycatch mortality in the directed and non-directed crab fisheries during 1995/96–2007/08, and
- $BM_{GF, 95/96-07/08}$ is the estimated average annual bycatch mortality in the groundfish fisheries during 1995/96–2007/08.

Given the June 2010 SSC recommendations, items ***E.2 a–i*** are not applicable.

3. Model Selection and Evaluation:

a. ***Description of alternative model configurations***
Not applicable; see section E.2.

b. ***Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed:*** None; see section A.4.

c. ***Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models:*** None; see the section A.4.

d. ***Convergence status and convergence criteria for the base-case model (or proposed base-case model):*** Not applicable.

e. ***Table (or plot) of the sample sizes assumed for the compositional data:*** Not applicable.

f. ***Do parameter estimates for all models make sense, are they credible?:***
Use of the 1995/96–2007/08 time period for estimating annual total fishery mortality and computing a Tier 5 OFL was established by the SSC in 2010.

g. ***Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty:*** Use of the 1995/96–2007/08 time period for estimating annual total fishery mortality and computing a Tier 5 OFL was established by the SSC in 2010.

h. ***Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach):*** Not applicable.

i. ***Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented:*** The model follows the June 2010 SSC recommendations to freeze the time period for estimation of the Tier 5 OFL.

4. Results (best model(s)):

a. ***List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties:*** Not applicable to a Tier 5 assessment.

b. ***Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons):*** See Table 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. **Specification of the Tier level and stock status level for computing the OFL:**
   - Recommended as Tier 5, total-catch OFL computed as the estimated average annual total catch over a specified period.
   - Recommended time period for computing retained-catch portion of the OFL: 1995/96–2007/08.
   - Recommended time period for computing bycatch mortality due to crab fisheries: 1995/96–2007/08.
   - Recommended time period for computing bycatch mortality due to groundfish fisheries: 1995/96–2007/08.
   - Recommended bycatch mortality rates: 0.2 for crab fisheries; 0.5 for fixed-gear groundfish fisheries; 0.8 for trawl groundfish fisheries.
   - Recommended OFL for 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,

$$OFL_{2017/18} = 43.97 \text{ t} + 1.36 \text{ t} + 10.86 \text{ t} = 56 \text{ t (123,867 lb).}$$

2. **List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan:** Not applicable to Tier 5 assessment.

3. **Specification of the OFL:**

a. ***Provide the equations (from Amendment 24) on which the OFL is to be based:***

From **Federal Register** / Vol. 73, No. 116, page 33926, "For stocks in Tier 5, the overfishing level is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information." Additionally, "For stocks where nontarget fishery removal data are available, catch includes all fishery removals, including retained catch and discard losses. Discard losses will be determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the overfishing level is set for and compared to the retained catch" (FR/Vol. 73, No. 116, 33926). That compares with the specification of NPFMC (2007) that the OFL "represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock."

b. ***Basis for projecting MMB to the time of mating:*** Not applicable to Tier 5 assessment.

c. ***Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring:*** See Management Performance tables, below. No vessels participated in the 2016/17 directed fishery and but some bycatch was observed in the Aleutian Islands golden king crab fishery in 2016/17. Total catch mortality in 2016/17 consists of what occurred during the Aleutian Islands golden king crab fishery and groundfish fisheries (0.18 t) and the cooperative industry-ADF&G survey (0.03 t). Overfishing did not occur in 2016/17. 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	0	<1	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	454	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 (30,967 lb). This is lower than the ABC that has been recommended by the author since the SSC recommended a 34 t (74,320 lb) ABC for 2012/13. The SSC's recommended ABC of 34 t for 2012/13 was determined as a value "sufficient to cover bycatch and the proposed test fishery catch" (June 2012 SSC meeting minutes, page 10). It provides a 40% buffer on the OFL of 56 t (123,867 lb). However, the industry has not expressed interest in conducting a test fishery for 2017/18. Further, the 2016 Petrel survey indicated the stock is severely depressed. Thus, the author and CPT recommend 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.

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Table 1a. Commercial fishery history for the western Aleutian Islands red king crab commercial fishery, 1960/61–2016/17: 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 2005/06–2016/17, 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
2004/05–2016/17	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, 1960/61–2016/17 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 2005/06–2016/17, 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
2004/05–2016/17	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) ○ 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
	  ○ 1 vessel
	  ○ Retained catch weight = 35 t (76,562 lb)
	  ○ 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
	  ○ 4 vessels
	  ○ Retained catch weight = 70 t (153,961 lb)
	  ○ 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)
	  ○ 33 vessels
	  ○ Retained catch weight = 229 t (505,642 lb)
	  ○ 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
	  ○ 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)
	  ○ 30 vessels
	  ○ Retained catch weight = 217 t (479,113) lb
	  ○ 10 retained crab per pot lift

2004/05–2016/17	• Fishery closed
	  ○ 2006 and 2009 ADF&G pot surveys on Petrel Bank
	  ○ 2015 exploratory/reconnaissance survey in Adak Island area.
	  ○ 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, 1995/96–2016/17.

Crab fishing	WAI red king crab fishery				AI golden king crab fishery			Total
		Discarded						
year	Retained	Legal male	Sublegal male	Female	Legal male	Sublegal male	Female	Discarded
1995/96	17.66	0.00	9.38	12.53	0.00	0.93	0.14	22.98
1996/97	0.00	0.00	0.00	0.00	1.49	0.92	0.30	2.71
1997/98	0.00	0.00	0.00	0.00	0.08	0.26	0.08	0.42
1998/99[a]	2.68	–[a]	–[a]	–[a]	0.34	0.06	0.08	–[a]
1999/00	0.00	0.00	0.00	0.00	0.07	0.34	0.04	0.46
2000/01	34.73	0.00	0.35	0.17	0.17	0.12	0.02	0.83
2001/02	69.84	0.08	2.98	3.80	9.07	0.00	0.17	16.09
2002/03	229.36	0.75	2.73	7.91	9.86	0.16	0.23	21.65
2003/04	217.32	0.29	2.99	3.61	4.28	2.88	3.03	17.08
2004/05	0.00	0.00	0.00	0.00	0.97	0.10	0.00	1.07
2005/06	0.00	0.00	0.00	0.00	0.09	0.00	0.02	0.11
2006/07	0.00	0.00	0.00	0.00	0.15	0.05	0.02	0.22
2007/08	0.00	0.00	0.00	0.00	0.28	0.83	0.25	1.36
2008/09	0.00	0.00	0.00	0.00	0.10	0.01	0.04	0.15
2009/10	0.00	0.00	0.00	0.00	0.26	0.11	0.02	0.39
2010/11	0.00	0.00	0.00	0.00	1.96	0.08	0.04	2.07
2011/12	0.00	0.00	0.00	0.00	0.43	0.01	0.04	0.49
2012/13	0.00	0.00	0.00	0.00	0.40	0.03	0.02	0.44
2013/14	0.00	0.00	0.00	0.00	1.34	0.05	0.08	1.46
2014/15	0.00	0.00	0.00	0.00	0.24	0.01	0.03	0.28
2015/16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2016/17	0.00	0.00	0.00	0.00	0.15	0.01	0.07	0.23
Average	25.98	0.05	0.88	1.33	1.49	0.33	0.22	4.31

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), 1993/94–2016/17 (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
2016/17	0.00	0.17	0.00	0.13	0.13
Average	2.45	8.80	1.23	7.03	8.25

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, 1993/94–2016/17.

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
2016/17	0.0000	0.0718	0.0950	0.1669
Average	4.7280	4.3656	2.1551	11.2488

Table 6. Estimated annual weight (**t**) of total fishery mortality to Western Aleutian Islands red king crab, 1995/96–2016/17, partitioned by source of mortality: retained catch, estimated bycatch mortality during crab fisheries, and estimated bycatch mortality during groundfish fisheries.

		Bycatch Mortality by Fishery Type		Total Estimated
Crab fishing year	Retained Catch	Crab	Groundfish	Fishery mortality
1995/96	17.66	4.60	6.86	29.12
1996/97	0.00	0.54	16.86	17.40
1997/98	0.00	0.08	5.12	5.20
1998/99[a]	2.68	0.70	18.82	22.19
1999/00	0.00	0.09	18.72	18.81
2000/01	34.73	0.17	5.65	40.54
2001/02	69.84	3.22	22.82	95.88
2002/03	229.36	4.33	29.06	262.75
2003/04	217.32	3.42	4.13	224.87
2004/05	0.00	0.21	4.87	5.08
2005/06	0.00	0.02	1.66	1.68
2006/07	0.00	0.04	1.76	1.81
2007/08	0.00	0.27	4.80	5.08
2008/09	0.00	0.03	6.18	6.21
2009/10	0.00	0.08	5.19	5.27
2010/11	0.00	0.41	1.61	2.02
2011/12	0.00	0.10	1.01	1.10
2012/13	0.00	0.09	0.19	0.28
2013/14	0.00	0.29	0.04	0.33
2014/15	0.00	0.06	0.09	0.15
2015/16	0.00	0.16	1.19	1.34
2016/17	0.00	0.07	0.13	0.21
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, 1995/96–2016/17	25.98	0.86	7.13	33.97
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
2016/17	0.00	0.23	0.00	0.17

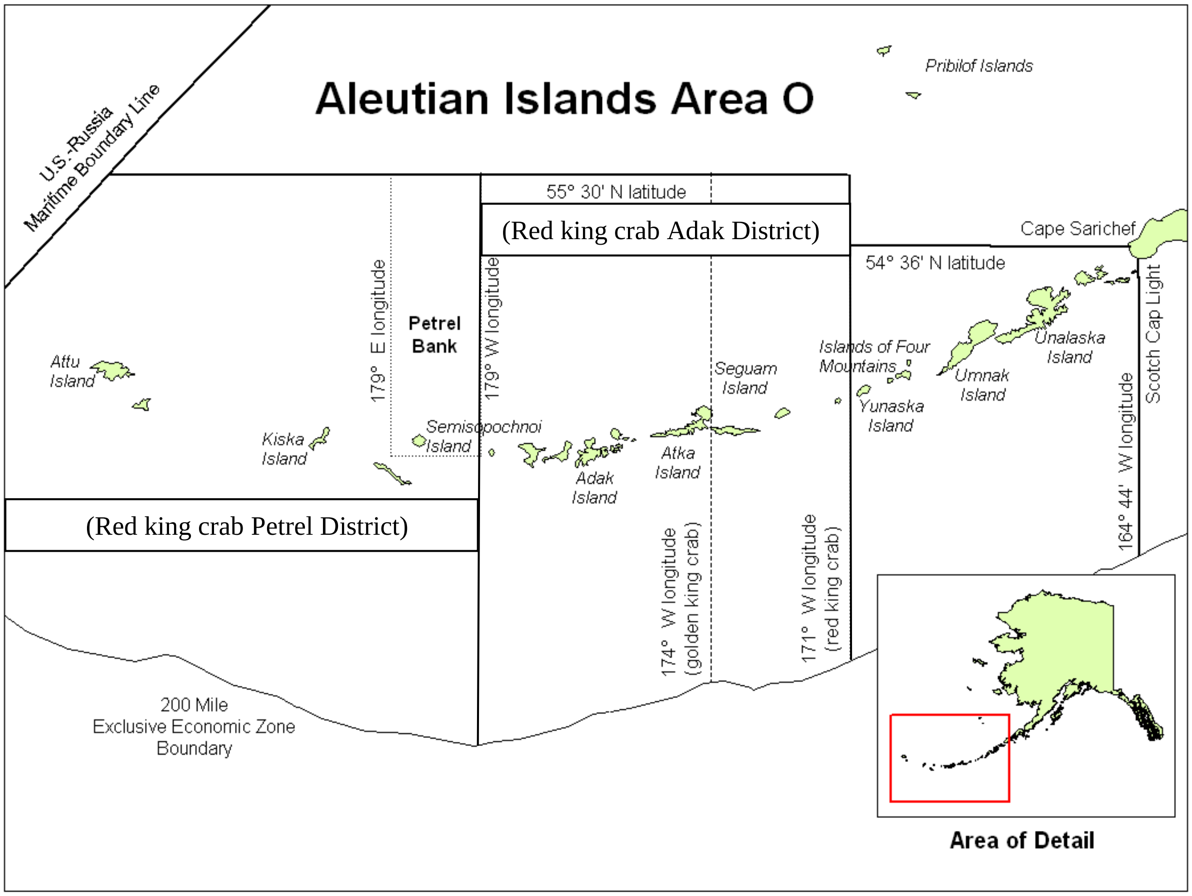

Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Baechler and Cook 2014, updated to show boundaries of the Adak and Petrel Districts for red king crab as established by the Alaska Board of Fisheries in March 2014).

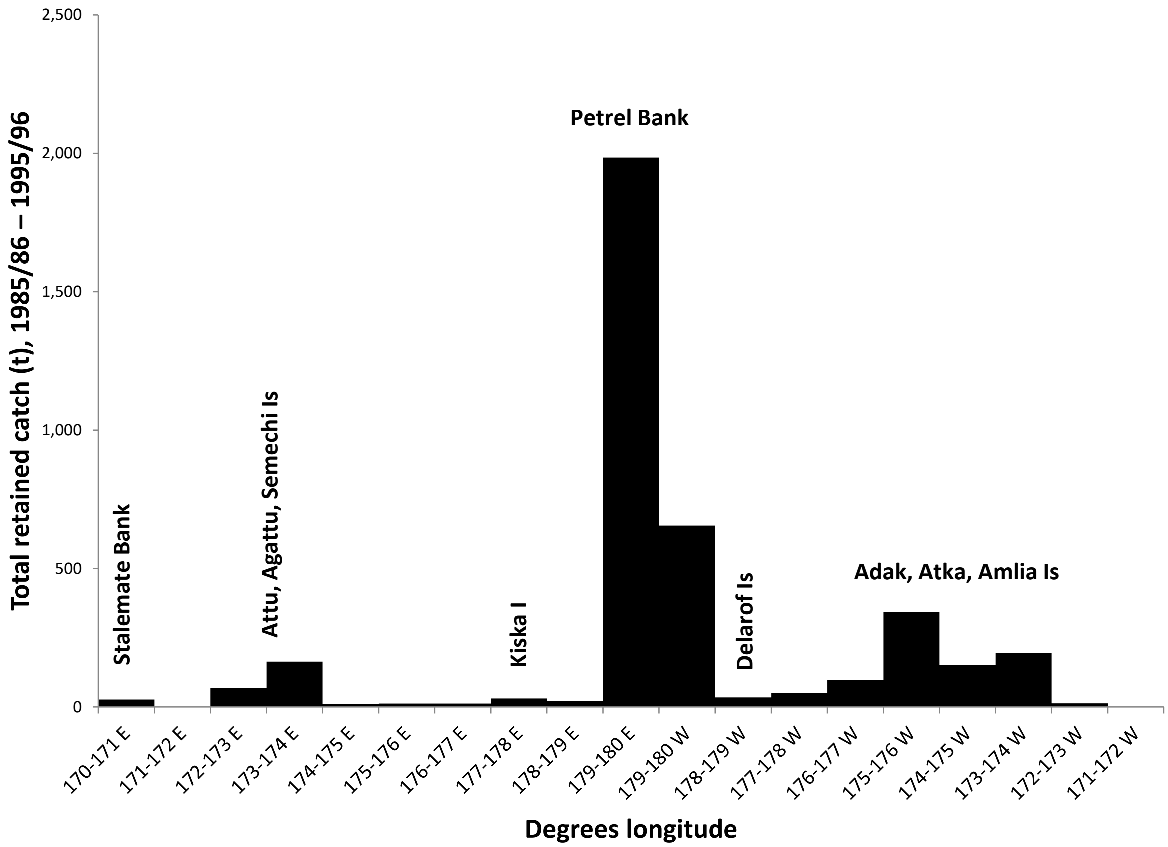

Figure 2. Retained catch (**t**) in the Western Aleutian Islands red king crab fishery, 1985/86–1995/96 by 1-degree longitude grouping, summarized from fish ticket catch by state statistical area landing data.

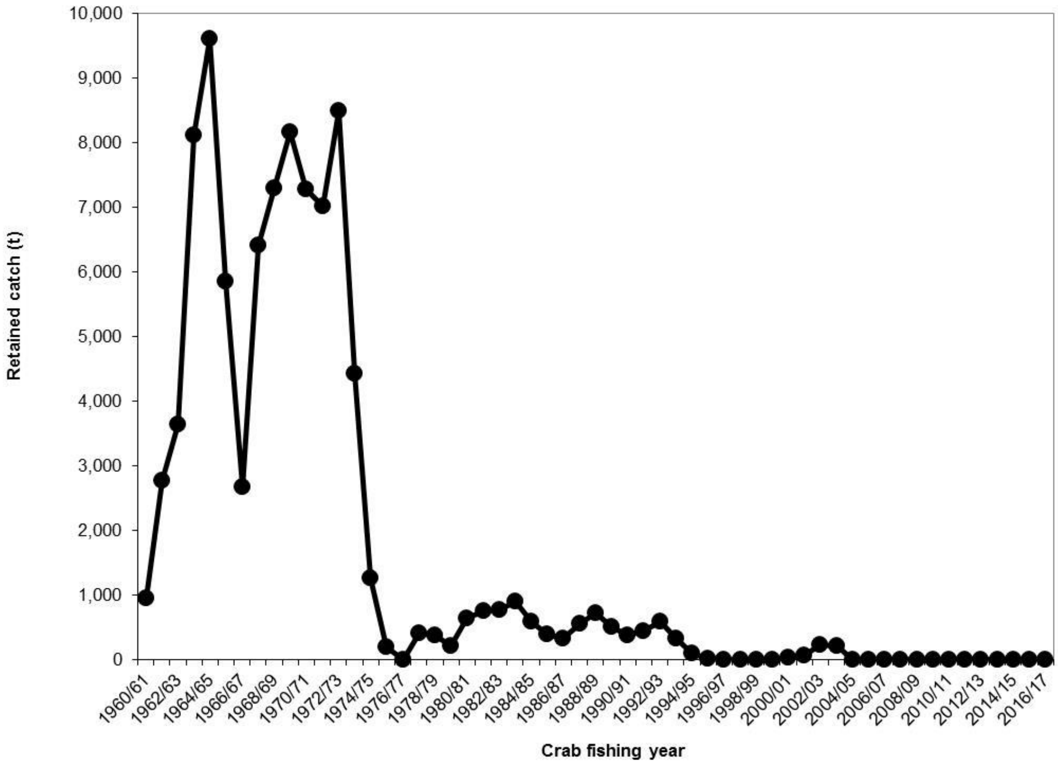

Figure 3. Retained catch (**t**) in the Western Aleutian Islands red king crab fishery, 1960/61–2016/17 (catch is for the area west of 172° W longitude during 1960/61–1983/84 and for the area west of 171° W longitude during 1984/85–2016/17; see Table 1a).

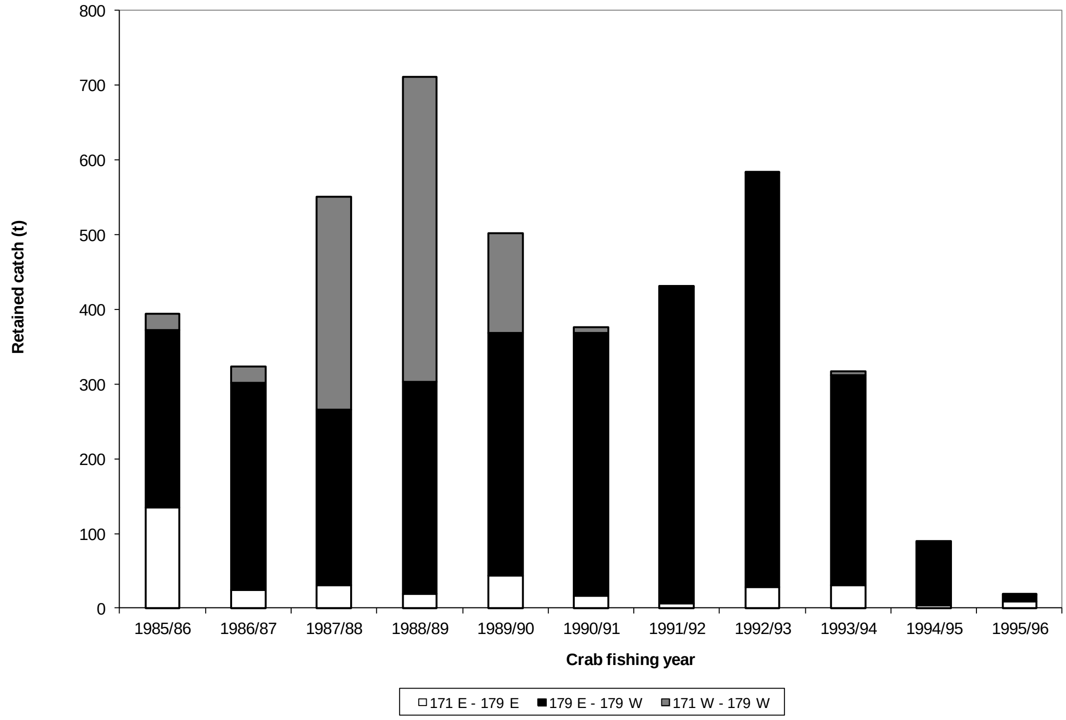

Figure 4. Annual retained catch (**t**) in the Western Aleutian Islands red king crab fishery during 1985/86–1995/96, partitioned into three longitudinal zones: 171º W longitude to 179º W longitude (white bars); 179º W longitude to 179º E longitude (black bars); and 179º E longitude to 171º E longitude.

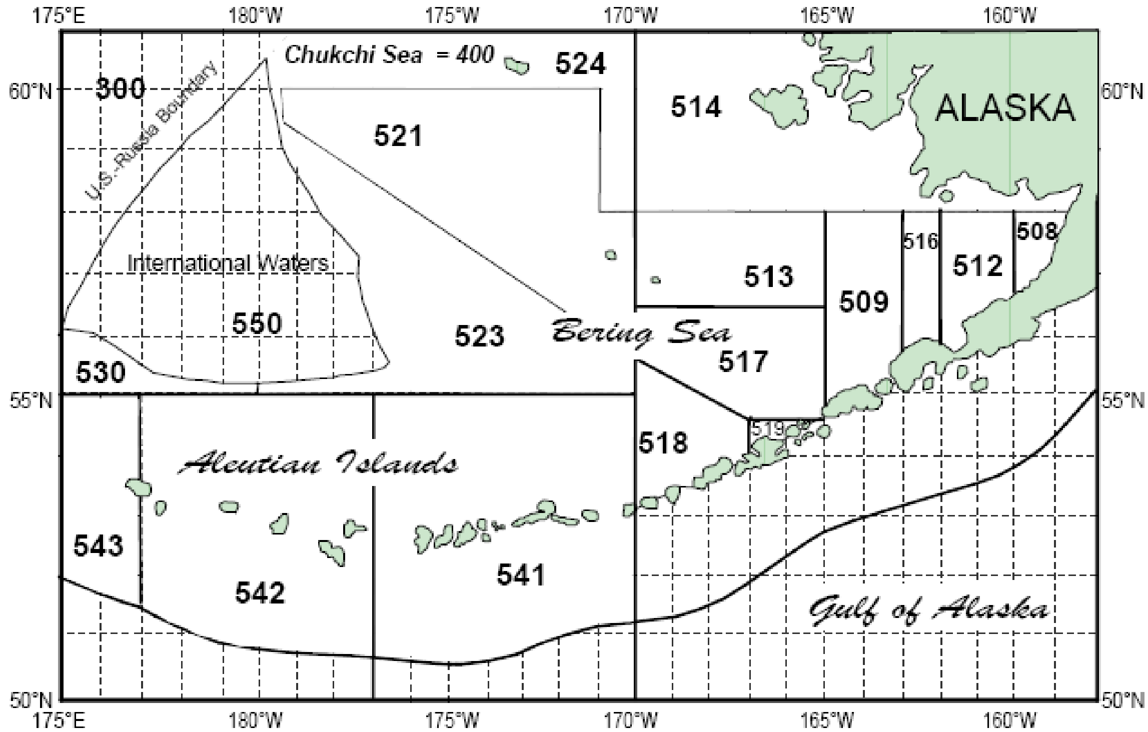

Figure 5. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands. Areas 541, 542, and 543 are used to obtain data on discarded catch of Western Aleutian Islands red king crab during groundfish fisheries (from http://www.alaskafisheries.noaa.gov/rr/figures/fig1.pdf).

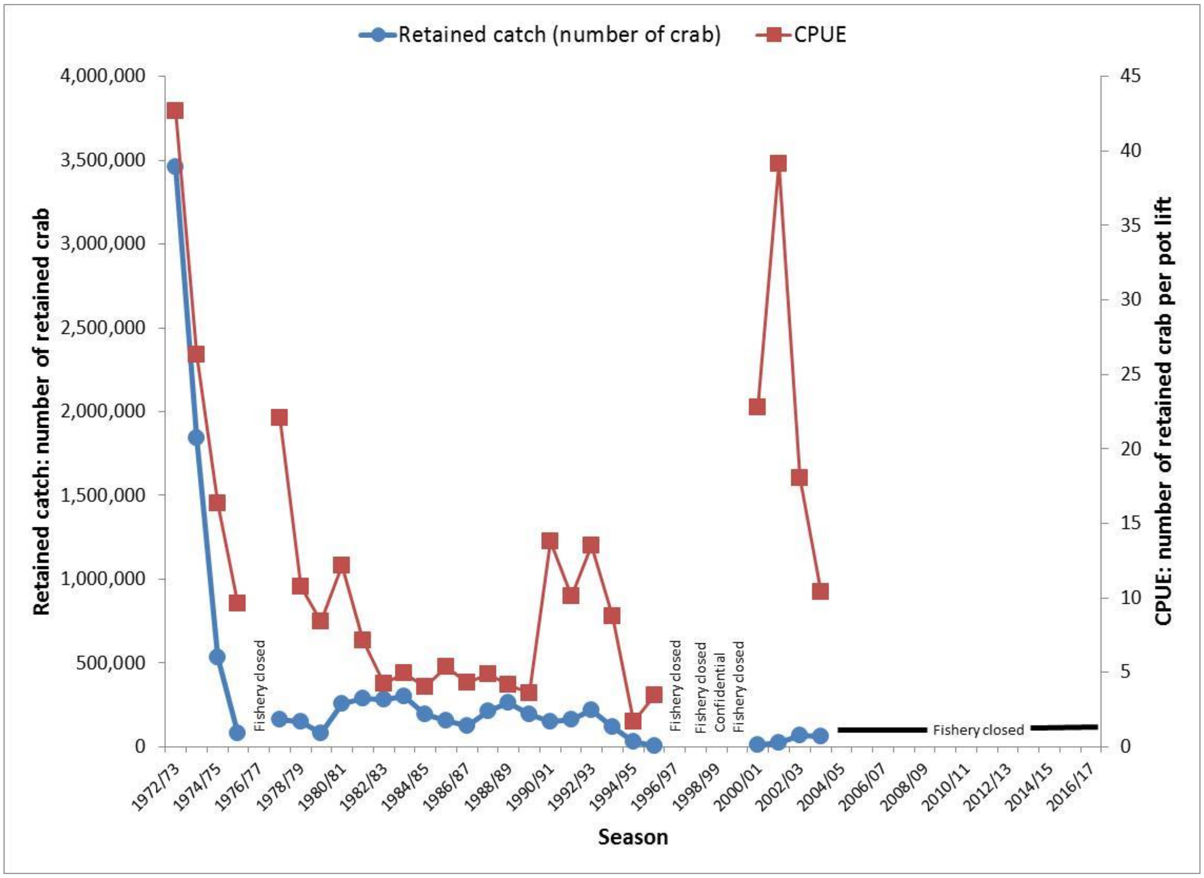

Figure 6. Retained catch (number of crab) and CPUE (number of retained crab per pot lift) in the western Aleutian Islands red king crab fishery, 1972/73–2016/17 (from Table 1a). Data for 1972/73–1983/84 are for the area west of 172° W longitude; data for 1984/85–1997/98, 1999/00, and 2004/05–2016/17 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.

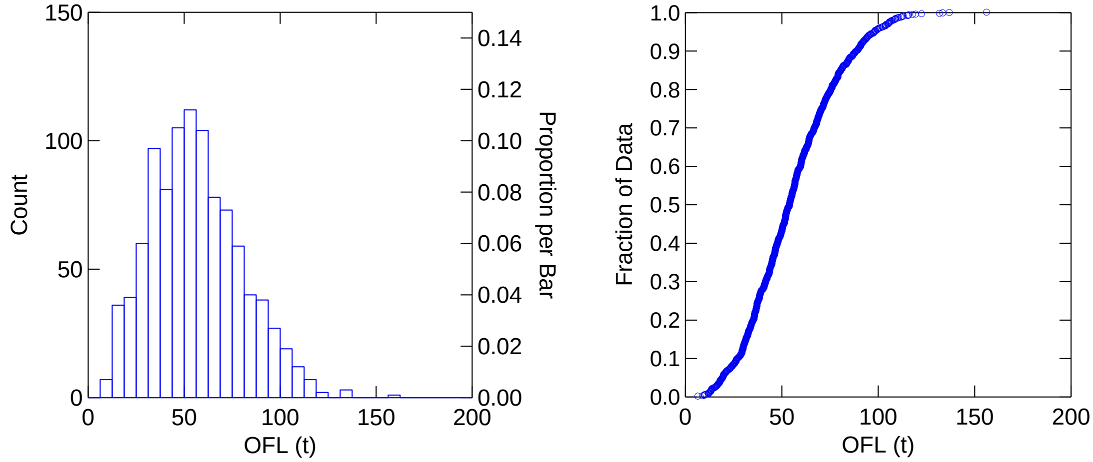

Figure 7. Bootstrapped estimate of the sampling distribution of the recommended 2016/2017 Tier 5 OFL (total-catch, t) for the Western Aleutian Islands red king crab stock; histogram in left column, cumulative distribution in right column.

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
2004/05−2016/17	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

Appendix A2. Page 2 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
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).