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

2015 Final Crab SAFE

Compiled by

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of the Bering Sea and Aleutian Islands

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September 2015

North Pacific Fishery Management Council
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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.

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

The Crab Plan Team (CPT) annually assembles the SAFE report with contributions from ADF&G and the NMFS. This SAFE report is presented to the North Pacific Fishery Management Council (NPFMC) and is available to the public on the NPFMC web page at: http://fakr.noaa.gov/npfmc/membership/plan_teams/CRAB_team.htm. Under a process approved in 2008 for revised overfishing level (OFL) determinations, and annual catch limit (ACL) requirements in 2011, the CPT reviews one assessment in January (Norton Sound red king crab), three assessments in May to provide recommendations on OFL, acceptable biological catch (ABC) and stock status specifications for review by the NPFMC Science and Statistical Committee (SSC) in February and June. In September, the CPT reviews the remaining assessments and provides final OFL and ABC recommendations and stock status determinations. Additional information on the OFL and ABC determination process is contained in this report.

The CPT met from September 14-17, 2015 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 2015 Crab SAFE report contains all recommendations for all 10 stocks including those whose OFL and ABC were previously determined in February and June 2015. This SAFE report will be presented to the NPFMC in October for their annual review of the status of BSAI Crab stocks. Members of the team who participated in this review include the following: Bob Foy (Chair), Karla Bush (Vice-Chair), Laura Stichert, Heather Fitch, Brian Garber-Yonts, Ginny Eckert, Jason Gasper, Doug Pengilly André Punt, Buck Stockhausen, Martin Dorn, Shareef Siddeek, Jack Turnock and Diana Stram.

Stock Status Definitions

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

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

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

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

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

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

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

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

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

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

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

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

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

Status Determination Criteria

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

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

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

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

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

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

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

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

For each crab fishery, the optimum yield range is 0 to < OFL catch. For crab stocks, the OFL is the annualized MSY and is derived through the annual assessment process, under the framework of the tier system. Recognizing the relatively volatile reproductive potential of crab stocks, the cooperative management structure of the FMP, and the past practice of restricting or even prohibiting directed harvests of some stocks out of ecological considerations, this optimum yield range is intended to facilitate the achievement of the biological objectives and economic and social objectives of the FMP (see sections

7.2.1 and 7.2.2) under a variety of future biological and ecological conditions. It enables the SOA to determine the appropriate TAC levels below the OFL to prevent overfishing or address other biological concerns that may affect the reproductive potential of a stock but that are not reflected in the OFL itself. Under FMP section 8.2.2, the SOA establishes TACs at levels that maximize harvests, and associated economic and social benefits, when biological and ecological conditions warrant doing so.

Five-Tier System

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

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

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

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

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

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

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

Stock assessment documents shall:

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

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

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

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

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

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

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

Tiers 1 through 3

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

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

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

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

Overfishing would occur if, in any year, the sum of all three catch components exceeds the OFL.

Tier 4

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

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

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

Tier 5

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

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

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

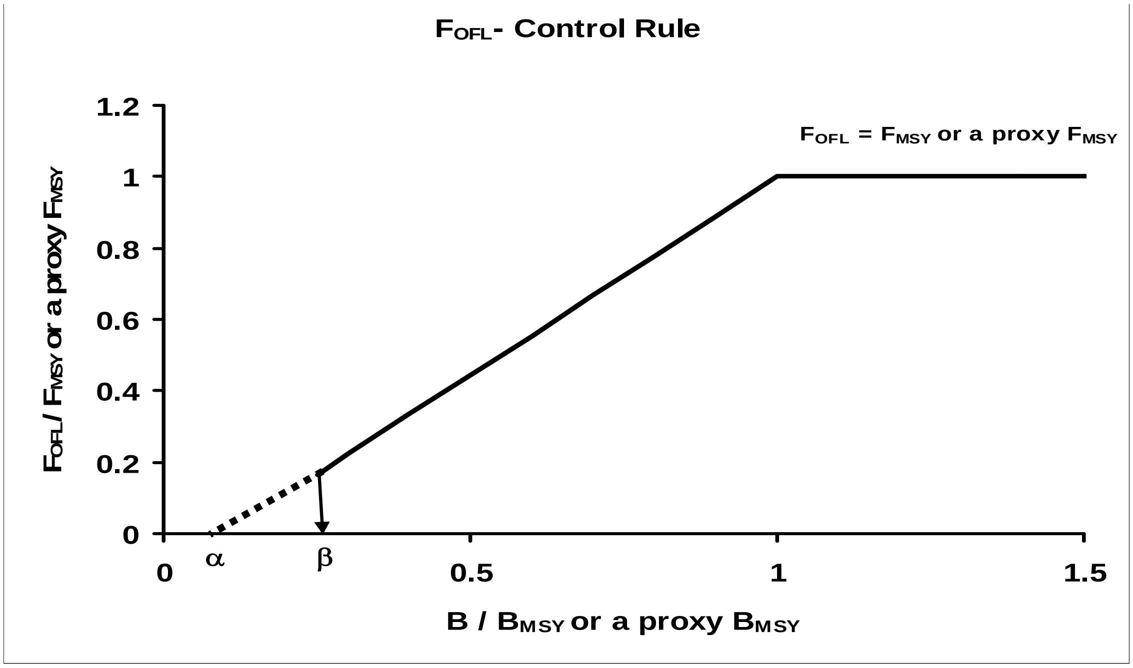

Table 1 Five-Tier System for setting overfishing limits (OFLs) and Acceptable Biological Catches (ABCs) for crab stocks. The tiers are listed in descending order of information availability. Table 2 contains a guide for understanding the five-tier system.

Information available	Tier	Stock status level	F_{OFL}	ABC control rule
B, B_{MSY}, F_{MSY}, and pdf of F_{MSY}	1	a. $\frac{B}{B_{msy}} > 1$	$F_{OFL} = \mu_A$ =arithmetic mean of the pdf	
		b. $\beta < \frac{B}{B_{msy}} \le 1$	$F_{OFL} = \mu_A \frac{B/B_{msy} - \alpha}{1-\alpha}$	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 2 A guide for understanding the five-tier system.

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

Crab Plan Team Recommendations

Table 3 lists the team’s recommendations for 2015/2016 on Tier assignments, model parameterizations, time periods for reference biomass estimation or appropriate catch averages, OFLs and ABCs. The team recommends three stocks be placed in Tier 3 (EBS snow crab, Bristol Bay red king crab and EBS Tanner crab), four stocks in Tier 4 (St. Matthew blue king crab, Pribilof Islands blue king crab, Pribilof Islands red king crab, and Norton Sound red king crab) and three stocks in Tier 5 (AI golden king crab, Pribilof Islands golden king crab, and Adak red king crab). Table 4 lists those stocks for which the team recommends an ABC less than the maximum permissible ABC for 2015/16. 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 1. EBS Tanner crab and Pribilof Islands red king crab are estimated to be above B_{MSY} for 2015/16 while snow crab, Bristol Bay red king crab, Saint Matthew blue king crab and Norton Sound red king crab are estimated below B_{MSY}. Pribilof Islands blue king crab stock remains overfished and estimated to be well below its MSST.

The CPT has general recommendations for all assessments and specific comments related to individual assessments. All recommendations are for consideration for the 2016 assessments. The general comments are listed below while the comments related to individual assessments are contained within the summary of CPT deliberations and recommendations contained in the stock specific summary section. Additional details regarding recommendations are contained in the Crab Plan Team Report (September 2015 CPT Report).

General recommendations for all assessments

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

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

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

Stock Status Summaries

1 Eastern Bering Sea Snow crab

Fishery information relative to OFL setting

Total catch mortality in 2014/15 was 34,300 t (with discard mortality rates applied), while the retained catch in the directed fishery was 30,820 t. This was below the 2014/15 OFL of 69,000 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 $B_{35\%}$ since 2010/11, but have generally declined recently. For 2015/16, projected MMB (147,200 t) fishing at the F_{OFL} is 93.3% of the $B_{35\%}$ value (157,800 t) used as the B_{MSY} proxy in this assessment.

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 2019 and 2010 BSFRF surveys. Updated data in the model include biomass and length frequency data from the 2015 NMFS Eastern Bering Sea trawl survey, retained and discard catch and length frequencies from the 2014/15 directed fishery, and discard catch and length frequencies from the 2014/15 groundfish fisheries.

The assessment author examined six model scenarios in this assessment. Model 0 was the September 2014 scenario, with the standard deviation parameter of the growth function fixed at an arbitrarily small value of 0.5. Model 1 changed: (1) the survey logistic curves from estimating size at 95%-selected to an offset from the size at 50% parameter; (2) survey q for the first time period to a probit scale; and (3) 2010 industry survey availability to a probit scale. Model 2 additionally removed a constraint on maturation probability, increased the weight on the smoothness for female maturity, and increased the weight on the trawl bycatch data. In Model 3 the length at 50% selected for female discards was changed from 4.2 to 4.4 (log scale), and the likelihood weight for growth data increased from 2.0 to 3.0. Model 4 removed a penalty on directed fishing mortality estimates for male crab after 1991. Model 5 removed a penalty on female fishing mortality estimates after 1991; potlift data are used to estimate pre-1992 fishing mortality for female discards.

The author selected Model 5 as the preferred model, because it removes the 1992–present fishing mortality penalties, which have been shown to result in bias. Model estimates of biomass, $F_{35\%}$, and $B_{35\%}$ were similar between Models 0 and 1, and moderately similar among Models 2–5, but there was insufficient information to fully understand the substantial change in estimates from Model 1 to 2. There were three potentially significant changes to the model between model 1 to Model 2 and it was unclear to the CPT which of these changes was affecting model results. Pending full understanding of the changes, the CPT recommends Model 0 as the preferred model, with current Model 5 as a potential target for future modeling.

Stock biomass and recruitment trends

Observed survey mature male biomass decreased from 167,400 t in 2011 to 96,100 t in 2013, increased to 156,900 t in 2014, then fell to 79,000 to in 2015. Similarly, the observed survey mature female biomass decreased from 280,000 t in 2011 to 195,100 t in 2013, increased to 212,500 t in 2014, then fell to 128,100 t in 2015. The 2015 model estimates of mature male biomass showed similar trends as survey biomass during 2011–2014, but failed to match the substantial survey decline observed in 2015. Model estimates of mature female biomass have generally increased since 2010 in contrast to a general decline in survey biomass since 2011. Under the 2015 model, mature male biomass and mature female biomass are both under-predicted at the time of the survey for 2014 and substantially over-predicted in 2015. The model estimates are partly driven by a peak in estimated recruitment from the 2005 fertilization year. This recruitment has not been observed subsequent to the 2010 survey. Fits by the 2015 model to the size frequency data since about 2011 were poor; fitted size frequencies were lower than observed for females and higher than observed for males.

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

The CPT recommends that the EBS snow crab is a Tier 3 stock so the OFL will be determined by the $F_{35\%}$ control rule. The proxy for B_{MSY} ($B_{35\%}$) is the mature male biomass at mating (157.8 thousand t) based on average recruitment over 1978 to present. Consequently, the minimum stock size threshold (MSST) is 73.2 thousand t. The CPT recommends that the ABC be less than maximum permissible ABC. The extent of contradiction between the model and the data is more extreme than in previous years. The CPT recommends a 25% buffer for setting the 2015/16 ABC due to the model uncertainties and contradictions between model trends and survey and fishery observations.

Historical status and catch specifications for snow crab (thousand t).

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	77.3	165.2[A]	40.3	40.5	44.7	73.5	66.2
2012/13	77.1	170.1[A]	30.1	30.1	32.4	67.8	61.0
2013/14	71.5	126.5[A]	24.5	24.5	28.1	78.1	70.3
2014/15	78.9	168.0[A]	30.8	30.8	34.3	69.0	62.1
2015/16		147.2[B]				83.1	62.3

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

Historical status and catch specifications for snow crab (millions of lb).

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	170.4	364.2 [A]	88.8	89.3	98.5	162.0	145.9
2012/13	170.0	375.0 [A]	66.4	66.4	71.4	149.5	134.5
2013/14	157.6	279.0[A]	54.0	54.0	62.0	172.2	155.0
2014/15	173.9	370.4[A]	67.9	67.9	75.4	152.1	137.0
2015/16		324.8[B]				183.2	137.4

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

2 Bristol Bay Red King Crab

Fishery information relative to OFL setting.

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

The current SOA harvest strategy allows a maximum harvest rate of 15% of mature-sized (≥120 mm CL) males, but also incorporates a maximum harvest rate of 50% of legal males and a threshold of 8.4 million mature-sized (≥90 mm CL) females and 14.5 million lb (6.6 thousand t) of effective spawning biomass (ESB), to prosecute a fishery. Annual non-retained catch of female and sublegal male RKC during the fishery averaged less than 3.9 million lb (8.6 thousand t) since data collection began in 1990. Total catch (retained and bycatch mortality) increased from 16.9 million lb (7.6 thousand t) in 2005/06 to 23.4 million lb (10.6 thousand t) in 2007/08, but has decreased since then; retained catch in 2014/15 was 10.01 million lb (4.54 thousand t) and total catch was 11.99 million lb (5.44 thousand t).

Data and assessment methodology

The stock assessment model is a sex- and size-structured population dynamics model incorporating data from the NMFS eastern Bering Sea trawl survey, the Bering Sea Fisheries Research Foundation (BSFRF) trawl survey, landings of commercial catch, at-sea observers, and dockside samplers. In the model recommended by the CPT, annual stock abundance was estimated for male and female crabs ≥ 65-mm carapace length from 1975 to the time of the 2015 survey and mature male (males ≥120 mm CL) biomass was projected to 15 February 2016. Catch data (retained catch numbers, retained catch weight, and pot lifts by statistical area and landing date) from the directed fishery, which targets males ≥ 135 mm (6.5 in carapace length), were obtained from ADF&G fish tickets and reports, red king crab and Tanner crab fisheries bycatch data from the ADF&G observer database, and groundfish trawl bycatch data from the NMFS trawl observer database. NMFS trawl survey data were updated with the newly re-estimated time series provided by NMFS in 2015; catch and bycatch data were updated with data from the 2014/15 crab fishery year.

Three alternative models were evaluated: the accepted model for the 2014 assessment, which served as the base model (model scenario 1); and two variants of the base model (model scenarios 1a and 1b) that explored alternative ways to model the dependence of trawl survey catchability on bottom temperature. Both approaches to modeling a temperature-catchability relationship suggested that there was a weakly positive relationship between temperature and trawl survey catchability, but the relationship was not statistically significant, and had almost no impact on model results. Therefore the author recommended model scenario 1 for use in the 2015 stock assessment. The CPT also selected model scenario 1 as its recommended model as the basis for status determination and OFL setting.

Stock biomass and recruitment trends

Model (scenario 1) estimates of total survey biomass increased from 247.1 thousand t in 1975 to 349.5 thousand t in 1978, fell to 34.5 thousand t in 1985, generally increased to 93.9 thousand t in 2007, and subsequently declined to 70.8 thousand t in 2015. Estimated recruitment was high during the 1970s and early 1980s and has been generally low since 1985. The near-term outlook for this stock is a continued gradual declining trend. Recruitment has been poor (less than the mean from 1984-2015) since 2006. The 2011 survey produced a high catch of juvenile males and females <65 mm CL in one survey tow but that catch did not track into the 2012−2015 surveys. The survey area-swept estimates for abundance and biomass in 2015 were more consistent with previous surveys, in comparison to 2014, when the estimates were anomalously high.

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

Bristol Bay red king crab is in Tier 3. Based on the author's discussion regarding an apparent reduction in stock productivity associated with the well-known 1976/77 climate regime shift in the EBS, the CPT continues to recommend computing average recruitment based on model recruitment using the time period 1984 (corresponding to fertilization in 1977) to the last year of the assessment. The estimated $B_{35\%}$ is 26.1 thousand t). MMB projected for 2015/16 is 24.7 thousand t, 95% of $B_{35\%}$. Consequently, the BBRKC stock is in Tier 3b in 2015/16.

The team recommends that the OFL for 2015/16 be set according to model scenario 1, for which the calculated OFL is 6.73 thousand t (14.84 million lb). The team recommends that the ABC for 2015/16 be set below the maximum permissible ABC. The team recommends that a 10% buffer from the OFL be used to set the ABC at 6.06 thousand t (13.36 million lb).

MMB for 2014/15 was estimated to be 27.3 thousand t and above MSST (13.03 thousand t); hence the stock was not overfished in 2014/15. The total catch in 2014/15 (5.44 thousand t) was less than the 2014/15 OFL (6.82 thousand t); hence overfishing did not occur in 2014/15. The stock at 2015/16 time of mating is projected to be above the MSST and 95% of $B_{35\%}$ (see above); hence the stock is not projected to be in overfished condition in 2015/16.

Status and catch specifications (thousand t) for Bristol Bay red king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	13.77	30.88[A]	3.55	3.61	4.09	8.80	7.92
2012/13	13.19	29.05[A]	3.56	3.62	3.90	7.96	7.17
2013/14	12.85	27.12[A]	3.90	3.99	4.56	7.07	6.36
2014/15	13.03	27.25[A]	4.49	4.54	5.44	6.82	6.14
2015/16		24.69[B]				6.73	6.06

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

Status and catch specifications (millions of lb) for Bristol Bay red king crab

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	30.4	68.1 [A]	7.83	7.95	9.01	19.39	17.46
2012/13	29.1	64.0 [A]	7.85	7.98	8.59	17.55	15.80
2013/14	28.3	59.9 [A]	8.60	8.80	10.05	15.58	14.02
2014/15	28.7	60.1[A]	9.99	10.01	11.99	15.04	13.53
2015/16		54.4[B]				14.84	13.36

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

3 Eastern Bering Sea Tanner crab

Fishery information relative to OFL setting.

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

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

Data and assessment methodology

The SSC accepted the stock assessment model for use in harvest specifications in 2012 and classified the EBS Tanner stock as a Tier 3 stock. The current model structure, based on crab size, sex, shell condition, and maturity, is the same as in the 2014 assessment. The model uses available data on the magnitude and size-composition from: the NMFS trawl survey; landings and discards by the directed fishery; bycatch in the Bristol Bay red king crab, EBS snow crab, and groundfish fisheries. The model includes prior distributions on parameters related to natural mortality and catchability, and penalties on changes in recruitment and in the proportion maturing. New input data were added to the time series for the 2015 assessment and updates or corrections to previously used data were made: the current “standard” dataset for crab from the NMFS EBS trawl survey, 1975−2015, with use of current standard NMFS estimator for weight-from-width; a correction to the 2013/14 fishery data used in the 2014 assessment; the retained catch, bycatch, and size composition data from the 2014/15 crab fisheries; and data on Tanner crab bycatch in the groundfish fisheries in 2014/15.

Stock biomass and recruitment trends

The MMB at the time of mating is estimated to have been highest early in the early 1970s (approximately 300 thousand t), with secondary peaks in 1989 (60 thousand t) and 2008 – 2009 (57 – 58 thousand t). The estimated MMB at time of mating in 2015 is 72 thousand t and the projection for the 2016 time of mating is 54 thousand t. Estimates of recruitment since 1999 have been generally low relative to the peaks estimated for the period prior to 1990 and estimates of recruitment in the last four years are below the 1982 – 2015 average.

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

The team recommends the OFL for this stock be based on the Tier 3 control rule. Application of the Tier 3 control rule requires a set of years for defining R_{MSY}, the mean recruitment corresponding to B_{MSY} under prevailing environmental conditions. The recommended time period for defining R_{MSY} is 1982 – 2015; 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 2016, the stock is at Tier 3 level a. The F_{MSY} proxy ($F_{35\%}$) is 0.58 yr^{-1}, and the 2015/16 F_{OFL} is 0.58 yr^{-1} under the Tier 3 OFL Control Rule, which results in a total male and female OFL of 27.19 thousand t (59.94 million lb). The CPT recommends a 20% buffer to account for model uncertainty and stock productivity uncertainty be applied to the OFL, to set ABC = 21.75 thousand t (47.95 million lb). The 2015/16 OFL is estimated from the same model that was used to estimate the 2014/15 OFL and the 20% buffer is the same that the SSC recommended for determination of the 2014/15 ABC.

Status and catch specifications (1000 t) for eastern Bering Sea Tanner crab.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2011/12	11.40	58.59[A]	0	0	1.24	2.75	2.48
2012/13	16.77	59.35[A]	0	0	0.71	19.02	8.17
2013/14	16.98	72.70[A]	1.41	1.26	2.78	25.35	17.82
2014/15	13.40	71.57[A]	6.85	6.16	9.16	31.48	25.18
2015/16		53.70[B]				27.19	21.75

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

Status and catch specifications (million lb) for eastern Bering Sea Tanner crab.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2011/12	25.13	129.17 [A]	0.00	0.00	2.73	6.06	5.47
2012/13	36.97	130.84 [A]	0.00	0.00	1.57	41.93	18.01
2013/14	37.43	160.28[A]	3.12	2.78	6.13	55.89	39.29
2014/15	29.53	157.78 [A]	15.10	13.58	20.19	69.40	55.51
2015/16		118.38[B]				59.94	47.95

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

4 Pribilof Islands red king crab

Fishery information relative to OFL setting

The Pribilof Islands red king crab fishery began in 1973 as bycatch during the blue king crab fishery. In 1993 and 1994 the red king crab fishery was open to directed fishing and blue king crab was closed. From 1995 through 1998, combined Pribilof Islands red and blue king crab GHLs were used. Declines in crab abundance of both red and blue king crab stocks from 1996 to 1998 resulted in poor fishery performance with annual harvests below the GHLs. The Pribilof red king crab fishery has been closed since 1999 due to uncertainty in estimated red king crab abundance and concerns for bycatch mortality of blue king crab, which is overfished and severely depressed. Fishery closures near the Pribilof Islands have resulted in low bycatch, recent catches have been well below the OFL, ranging from 0.002 to 0.029 t (1.06 to 13.1 million pounds; 2011/12–2014/15).

Data and assessment methodology

The 2015 assessment is based on trends in male mature biomass (MMB) at the time of mating inferred from NMFS bottom trawl survey from 1975-2015 and commercial catch and observer data from 1973/74 to 2014/15. Two assessment methods were presented for evaluation: one calculated an annual index of MMB derived as the 3-yr running average using inverse variance weighting; the second was an integrated length-based assessment model which was first presented in the spring of 2014. While the integrated assessment model appeared to fit survey length frequency composition data, it was rejected by the CPT because it did not fit the survey data. Natural mortality was used as a proxy for F_{MSY} and a proxy for B_{MSY} was calculated by averaging MMB from the 1991/92 through the current season.

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. Male crab were observed at 9 of 35 stations in the Pribilof District during the 2015 NMFS survey and female crab were found in 5 stations; most crab were caught in one station. The centers of distribution for both males and females have moved within a 40 nm by 40 nm region around St. Paul Island.

Recruitment for this stock is episodic, and has been low in recent years. Numbers at length vary dramatically from year to year; however, two (possibly three) cohorts can be seen moving through the length frequencies over time. MMB_{mating} increased over 2011 to 2015. Estimates for the 3-year moving average for MMB_{mating} have recently returned to levels exceeding those estimated during the early 1990s, peaking in 2015 at 13,685 t (30.2 million pounds).

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

The assessment included the status quo approach (a 3-year inverse-variance running average) as well as multiple scenarios using an integrated length-based assessment model. The CPT recommended using the 3-year inverse-variance running average assessment, and to remain in Tier 4 for stock status level determination. For 2015/16 the B_{MSY} = 5,649 t derived as the mean MMB_{mating} from 1991/92 to 2014/15. Male mature biomass at the time of mating for 2015/16 was estimated at 13,685 t. The B/ B_{MSY} = 2.42 and F_{OFL}=0.18. $B/ B_{MSY\ Proxy}$ is > 1, therefore the stock status level is *a*. For the 2015/16 fishery, the OFL is 2,119 t (4.7 million lb).

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

Status and catch specifications (t) of Pribilof Islands red king crab

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	2,571	2,775^{A*}	0	0	5.4	393	307
2012/13	2,609	4,025^{A**}	0	0	13.1	569	455
2013/14	2,582	4,679^{A**}	0	0	2.25	903	718
2014/15	2,871	8,894^{A**}	0	0	1.06	1,359	1,019
2015/16	2,825	13,685^{B**}				2,119	1,467

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.
*Estimate based on 3 year running average
**Estimates based on weighted 3 year running average using inverse variance

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	5.67	6.12^{A*}	0	0	0.011	0.87	0.68
2012/13	5.75	8.87^{A**}	0	0	0.029	1.25	1.00
2013/14	5.66	10.32 ^{A**}	0	0	0.005	1.99	1.58
2014/15	6.33	19.61 ^{A**}	0	0	0.002	3.00	2.25
2015/16	6.23	30.17				4.67	3.23

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.
*Estimate based on 3 year running average
**Estimates based on weighted 3 year running average using inverse variance

The stock is above MSST in 2015/16 and is hence not overfished. Overfishing did not occur during the 2014/15 fishing year.

5 Pribilof Islands blue king crab

Fishery information relative to OFL setting.

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

The stock was declared overfished in 2002 and a rebuilding plan implemented in 2003. 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 January 2015. 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.

Data and assessment methodology

The calculation of the 2015/16 survey biomass uses the stock area definition established in 2012/13 that includes an additional 20 nm strip east of the Pribilof District. This assessment changes the method used to project MMB and calculate B_{MSY}. Prior to this assessment, MMB for the current year was estimated from the NMFS EBS bottom trawl survey using a three-year running average weighted by the inverse of the variance of the area-swept estimate. The CPT recommended a new method to calculate MMB and B_{MSY} that uses a random effects model to smooth the survey time series. This model smooths the MMB estimates without low abundance estimates having undue influence. Differences in abundance estimates from the two methods were largest during periods of high inter-annual variability. Differences between the methods were small in recent years. Results from this method are shown in the 2014/15 MMB and 2015/2016 projected MMB.

In 2014/2015, nearly all the female and male bycatch mortality in the groundfish fishery (0.07 t) occurred in the hook-and-line fishery for Pacific cod. No bycatch was recorded in the pot or trawl fisheries.

Stock biomass and recruitment trends

The 2015/16 MMB at mating is projected to be 344 t, which is 8% 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 4,109 t (9.06 million pounds).

Because the projected 2015/16 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 2015/16 is 1.16 t (0.003 million lb).

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

Status and catch specifications (t) of Pribilof Islands blue king crab in recent years.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	2,247	365[A]	Closed	0	0.36	1.16	1.04
2012/13	1,994	579[A]	Closed	0	0.61	1.16	1.04
2013/14	2,001	225[A]	Closed	0	0.03	1.16	1.04
2014/15	2,055	344[A]	Closed	0	0.07	1.16	0.87
2015/16		455[B]				1.16	0.87

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

Status and catch specifications (million lb) of Pribilof Islands blue king crab in recent years.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	4.95	0.80[A]	Closed	0	0.0008	0.003	0.002
2012/13	4.39	1.28[A]	Closed	0	0.0013	0.003	0.002
2013/14	4.41	0.50[A]	Closed	0	0.0001	0.003	0.002
2014/15	4.53	0.76[A]	Closed	0	0.0002	0.003	0.002
2015/16		1.00[B]				0.003	0.002

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

The total catch for 2014/15 (0.07 t, 0.0002 million lb) was less than the 2014/15 OFL (1.16 t, 0.003 million lb) so overfishing did not occur during 2014/15. The 2015/16 projected MMB estimate of 455 t (0.70 million lb) is below the proxy for MSST (MMB/B_{MSY} = 0.05) so the stock continues 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 9.454 million lb were landed by 164 vessels. Harvest was fairly stable from 1986/87 to 1990/91, averaging 1.252 million lb annually. Harvest increased to a mean catch of 3.297 million lb during the 1991/92 to 1998/99 seasons until the fishery was declared overfished and closed in 1999 when the stock size estimate was below the MSST. In November of 2000, Amendment 15 to the FMP was approved to implement a rebuilding plan for the St. Matthew Island blue king crab stock. The rebuilding plan included a harvest strategy established in regulation by the Alaska Board of Fisheries, an area closure to control bycatch, and gear modifications. In 2008/09 and 2009/10, the MMB was estimated to be above B_{MSY} for two years and the stock declared rebuilt in 2009.

The fishery re-opened in 2009/10 with a TAC of 1.167 million lb and 0.461 million lb of retained catch were harvested. The 2010/11 TAC was 1.600 million lb and the fishery reported a retained catch of 1.264 million lb. The 2011/12 harvest of 1.881 million lb represented 80% of the 2.539 million lb TAC. In 2012/13, by contrast, harvesters landed 99% (1.616 million lb) of a reduced TAC of 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 0.655 million pounds, but the fishery performance was relatively poor with the retained catch of 0.309 million pounds. Bycatch of non-retained blue king crab has been observed in the St. Matthew blue king crab fishery, the eastern Bering Sea snow crab fishery, and trawl and fixed-gear groundfish fisheries. Based on limited observer data, bycatch of sublegal male and female crabs in the directed blue king crab fishery off St. Matthew Island was relatively high when the fishery was prosecuted in the 1990s, and total bycatch (in terms of number of crabs captured) was often twice as high or higher than total catch of legal crabs.

Data and assessment methodology

A three-stage catch-survey analysis (CSA) is used to assess the male crab ≥90 mm CL. The three size categories are: 90–104 mm CL; 105–119 mm CL; and ≥120 mm CL. Males ≥ 105 are used as a proxy to identify mature males, and males ≥ 120 mm CL are used as a proxy to identify legal males. The CSA incorporates the following data: (1) commercial catch data from 1978/79 -1998/99, 2009/10- 2012/13, 2014/15; (2) annual trawl survey data from 1978 to 2015; (3) triennial pot survey data from 1995 to 2015; (4) bycatch data in the groundfish trawl and groundfish fixed-gear fisheries from 1991 to 2014; and (5) ADF&G crab-observer composition data for the years 1990/91–1998/99, 2009/10–2012/13, 2014/15.

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

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

Stock biomass and recruitment trends

Following a period of low numbers after the stock was declared overfished in 1999, trawl-survey indices of SMBKC stock abundance and biomass generally increased in subsequent years, with survey estimated mature male biomass reaching 20.98 million pounds in 2011, the second highest in the 37-year time series used in this assessment. Survey mature male biomass then declined to 12.46 million pounds in 2012 and to 4.459 million pounds in 2013 before going back up to 12.06 million pounds in 2014 and 11.32 million pounds in 2015.

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 2013 trawl-survey area-swept estimate of 0.335 million male SMBKC in this size class marked a three-year decline and was the lowest since 2005. That decline reversed in 2014 with an estimate of 0.723 million. The survey recruitment is 0.992 million in 2015, but the majority of crab came from one tow resulting in a high estimate of uncertainty.

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

The stock assessment examines 20 model configurations: 1) the base model (Model T) used previously; 2) scenario 0: effective sample sizes are determined differently from scenario T; 3) scenario 00: scenario 0 plus reduction of penalty weights for groundfish fisheries bycatch fishing mortality; 4) scenario 1: scenario 00 plus changes in the effective sample sizes for pot fishery observer length composition data and use of pot fishery discarded biomass (please refer to the assessment report for definition of other scenarios). In scenario 9, authors consider two time blocks, pre-2000 and post-2000, for two separate selectivity and molt probability estimation. Authors recommend scenario 10-4 to be used for stock status determination in 2015. This scenario considers a reduction factor of 0.3751 for R24 abundance estimation. The CPT expressed concerns about this approach and instead recommended to stratify station R24 and to use a pot survey based variance scaled by density for that stratum, which then could be added to survey variance. The CPT observed that scenarios above scenario 1 were not sufficiently justified and concern was expressed regarding the estimation of additional variance term for the pot survey only. The CPT recommends the use of scenario 1 for stock status determination.

This stock is in Tier 4. The CPT-recommended model uses the full assessment period (1978/79-2014/15) to define the proxy for B_{MSY} in terms of average estimated MMB_{mating}. The MMB estimated for 2015/16 under the recommended model is 5.40 million lb (2,450 t) and the F_{MSY} proxy is the natural mortality rate (0.18^{-1} year), resulting in a mature male biomass OFL of 0.620 million lb (280 t). The author recommended and the CPT concurred with a 20% buffer on the OFL for the ABC which was consistent with the approach used last year. The ABC based on this buffer is 0.490 million lb (220 t).

Status and catch specifications of St. Matthew blue king crab (1,000 t):

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Male Catch	OFL	ABC
2011/12	1.50	5.03^{A}	1.15	0.85	0.95	1.70	1.54
2012/13	1.80	2.85^{A}	0.74	0.73	0.82	1.02	0.92
2013/14	1.50	3.01^{A}	0	0	0.0003	0.56	0.45
2014/15	1.86	2.48^{A}	0.30	0.14	0.15	0.43	0.34
2015/16		2.45^{B}				0.28	0.22

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

Status and catch specifications of St. Matthew blue king crab (million lb):

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Male Catch	OFL	ABC
2011/12	3.4	11.09^{A}	2.539	1.881	2.10	3.74	3.40
2012/13	4.0	6.29^{A}	1.630	1.616	1.81	2.24	2.02
2013/14	3.4	6.64^{A}	0	0	0.0006	1.24	0.99
2014/15	4.1	5.47^{A}	0.655	0.309	0.329	0.94	0.75
2015/16		5.40^{B}				0.62	0.49

A - Estimated biomass at the time of mating for the year concerned. Note this represents a revised estimate from the projection the previous year.
B - Projected biomass from the current stock assessment. This value will be updated next year.

The stock was above MSST in 2014/15 and is hence not overfished. The total catch was less than OFL in 2014/15 and hence overfishing did not occur.

Additional Plan Team recommendations

The CPT requested further investigation on appropriate way to handle R24 high abundance in total abundance estimation.

7 Norton Sound Red King Crab

Fishery information relative to OFL setting

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

Data and assessment methodology

Four types of surveys have occurred periodically during the last three decades: summer trawl, summer pot, winter pot, and preseason summer pot, but none of these surveys have been conducted every year. To improve abundance estimates, a male-only length-based model of male crab abundance was previously developed that combines multiple sources of data. A maximum likelihood approach was used to estimate abundance, recruitment, and selectivity and catchability of the commercial pot gear. The model has been updated to include the following data: 1980–2012 winter pot survey; 2013/2014 winter commercial and subsistence catches; revised commercial catch CPUE for 1977-2014; and the 1976–2014 triennial trawl survey data. The current model assumes a constant $M=0.18yr^{-1}$, except for a fixed value of $0.648yr^{-1}$ for the largest length class. Logistic functions are used to describe fishery and survey selectivities, except for a dome-shaped function examined for the winter pot fishery. The model timeline was also revised to have the assessment year start February 1.

The author summarized six model run alternatives, with the base model (Model 0) and alternatives originating from the 2014 modeling workshop. The CPT selected Model 6 as the recommended configuration based on several attributes: one selectivity for the NMFS and ADF&G trawl surveys and one selectivity for all commercial fisheries; inclusion of winter survey data as a means of informing the winter fishery harvest (this had negligible impact on model results); and estimation of a growth matrix inside the model (separated for newshell and oldshell crab).

Stock biomass and recruitment trends

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

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

The team recommended Tier 4, stock status a, for Norton Sound red king crab. The CPT recommended the authors recommendation of Model 6 for use in estimating retained catch. Model-based total catch estimates were provided; however, these estimates were model-generated from limited observer data and the team did not recommend their use in generating a total catch OFL. Thus the OFL and ABC are based on retained catch only.

The estimated abundance and biomass in 2015 using Model 6 are:
Mature male biomass: 5.13 million lb with a standard deviation of 0.87 million lb.

The $B_{MSY\ \mathrm{proxy}}$, calculated as the average of mature male biomass during 1980-2015, was $B_{MSY\ \mathrm{proxy}}$ = 4.81

million lb. The $F_{MSY\ \mathrm{proxy}}$ is M =0.18 yr^{-1} and the F_{OFL}=0.18yr^{-1}, because the 2015 mature male biomass is larger than $B_{MSY\ \mathrm{proxy}}$ with the CPT choosing the default of gamma =1.0.

The maximum permissible ABC would be 0.721 million lb, based on retained catch. The CPT recommended an ABC less than the maximum permissible due to concerns with model specification, lack of bycatch data as well as issues noted with the M employed for the largest length group. The CPT recommended an ABC = 80% of the OFL (20% buffer) of 0.577 million lb.

Status and catch specifications (1000 t) of Norton Sound red king crab

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2010/11	0.71	2.47[A]	0.18	0.19	0.22	0.33	
2011/12	0.57	2.13[A]	0.16	0.18	0.20	0.30	0.27
2012/13	0.80	2.08[A]	0.21	0.21	0.21	0.24	0.22
2013/14	0.93	2.27[A]	0.23	0.16	0.16	0.26	0.24
2014/15	1.09	2.33[B]	TBD	TBD	TBD	0.33	0.26

Status and catch specifications (million lb) of Norton Sound red king crab

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2010/11	1.56	5.44[A]	0.40	0.42	0.46	0.73	
2011/12	1.25	4.70[A]	0.36	0.40	0.43	0.66	0.59
2012/13	1.76	4.59[A]	0.47	0.47	0.47	0.53	0.48
2013/14	2.06	5.00[A]	0.50	0.35	0.35	0.58	0.52
2014/15	2.41	5.13[B]	TBD	TBD	TBD	0.72	0.58

A – Estimated biomass in May for the year concerned.
B – Estimated biomass on February 1.

Total catch in 2014/15 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:

- more comprehensive description of the survey data;
- trawl survey CPUE standardization method needs to be explained.

8 Aleutian Islands Golden King Crab

Fishery information relative to OFL setting

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

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

Data and assessment methodology

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

Stock biomass and recruitment trends

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

Summary of major changes

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

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

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

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

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

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

where,

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

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

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

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

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

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

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

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

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

Additional Plan Team recommendations

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

9 Pribilof District Golden King Crab

Fishery information relative to OFL setting

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

Data and assessment methodology

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

Stock biomass and recruitment trends

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

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

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

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

where,

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

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

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

N/A = not available

Conf. = confidential

TBA = to be announced

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

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

N/A = not available

Conf. = confidential

TBA = to be announced

10 Western Aleutian Islands red king crab

Fishery information relative to OFL and ABC setting

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

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

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

Data and assessment methodology

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

Stock biomass and recruitment trends

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

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

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

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

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

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch[a]	OFL	ABC
2011/12	N/A	N/A	Closed	0	1	56	12
2012/13	N/A	N/A	Closed	0	<1	56	34
2013/14	N/A	N/A	Closed	0	<1	56	34
2014/15	N/A	N/A	Closed	0	<1	56	34
2015/16	N/A	N/A	Closed			54	32

a. Includes bycatch mortality of discarded bycatch.

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

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

a. Includes bycatch mortality of discarded bycatch.

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

Figures and Tables

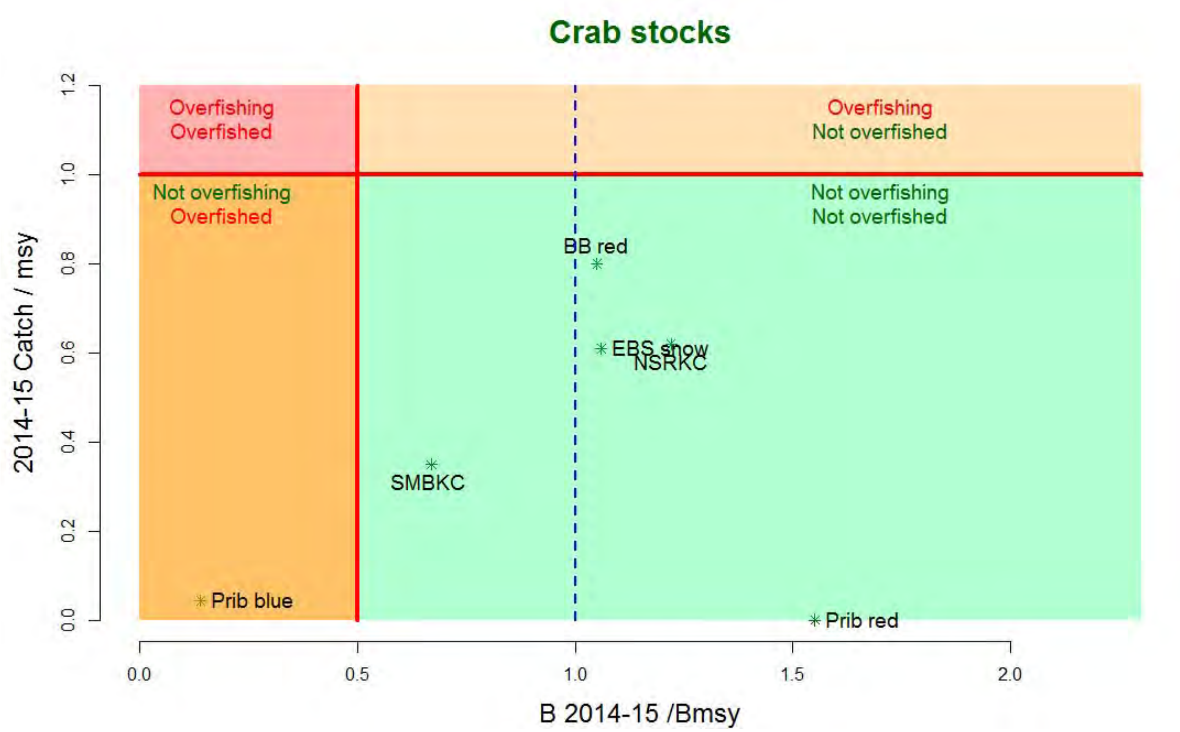

Figure 1. Status of 7 Bering Sea crab stocks in relation to status determination criteria (B_{MSY}, MSST, overfishing). Note that information is insufficient to assess Tier 5 stocks according to these criteria (WAIRKC, AIGKC, PIGKC).

Table 3 Crab Plan Team recommendations for September 2015 (stocks 1-6). Note that recommendations for stocks 7,8,9, 10 represent those final values recommended by the SSC in April and June 2015. Note diagonal fill indicates parameters are not applicable for that tier

Chapter	Stock	Tier	Status (a,b,c)	F_{OFL}	B_{MSY} or $B_{MSYproxy}$	Years[1] (biomass or catch)	2015/16[2 3] MMB	2015 MMB / MMB_{MSY}	γ	Mortality (M)	2015/16 OFL	2015/16 ABC	ABC buffer (%)
1	EBS snow crab	3	b	1.32	157.8	1979-current [recruitment]	147.2	0.93		0.23(females) 0.386 (imm) 0.2613 (mat males)	83.1	62.3	25%
2	BB red king crab	3	b	0.27	26.1	1984-current [recruitment]	24.1	0.92		0.18 default Estimated[4]	6.73	6.06	10%
3	EBS Tanner crab	3	a	0.58	26.8	1982-current [recruitment]	71.6	2.67		0.34 (females), 0.25 (mat male), 0.247 (imm males and females)	27.18	21.75	20%
4	Pribilof Islands red king crab	4	a	0.18	5.65	1991-current	13.7	2.42	1.0	0.18	1.36	1.02	25%
5	Pribilof Islands blue king crab	4	c	0.18	4.1	1980-1984 1990-1997	0.034	0.06	1.0	0.18	1.16	0.87	25%
6	St. Matthew Island blue king crab	4	b	0.18	3.72	1978-current	2.45	0.65	1.0	0.18	0.28	0.22	20%
7	Norton Sound red king crab	4	b	0.157	1.9	1980-current [model estimate]	1.68	0.88	1.0	0.18 0.68 (>123 mm)	0.21	0.19	10%
8	Aleutian Islands golden king crab	5				See intro chapter					5.69	4.26	25%
9	Pribilof Islands golden king crab	5				See intro chapter					0.09	0.07	25%
10	Adak red king crab	5				1995/96–2007/08					0.05	0.03	40%

1 For Tiers 3 and 4 where B_{MSY} or $B_{MSYproxy}$ is estimable, the years refer to the time period over which the estimate is made. For Tier 5 stocks it is the years upon which the catch average for OFL is obtained.
2 MMB as projected for 2/15/2016 at time of mating.
3 Model mature biomass on 7/1/2013.
4 Additional mortality males: two periods-1980-1985; 1968-1979 and 1986-2013. Females three periods: 1980-1984; 1976-1979; 1985 to 1993 and 1968-1975; 1994-2013. See assessment for mortality rates associated with these time periods.

Table 4 Maximum permissible ABCs for 2015/16 and Crab Plan Team recommended ABCs for those stocks where the Plan Team recommendation is below the maximum permissible ABC as defined by Amendment 38 to the Crab FMP. Note that the rationale is provided in the individual introduction chapters for recommending an ABC less than the maximum permissible for these stocks.

Stock	Tier	2015/16 *Max*ABC (1000 t)	2015/16 ABC (1000 t)
EBS Snow Crab	3	82.7	62.3
Bristol Bay red king crab	3		6.06
EBS Tanner Crab	3		21.75
Pribilof Islands red king crab	4		
Pribilof Islands blue king crab	4		0.87
Saint Matthew blue king crab	4		0.34
Norton Sound red king crab	4		0.24
Aleutian Islands golden king crab	5	5.12	4.26
Pribilof Islands golden king crab [1]	5	0.08	0.07
WAI red king crab	5	0.05	0.03

1 for Pribilof Islands golden king crab this is for the 2016 calendar year instead of the 2015-2016 crab fishing year.

Table 5. Stock status in relation to status determination criteria 2014/15. (Note diagonal fill indicates parameters not applicable for this tier level).

Chapter	Stock	Tier	MSST	B_{MSY} or $B_{MSYproxy}$	2014/15[1] MMB	2014/15 MMB / MMB_{MSY}	2014/15 OFL 1000 t	2014/15 Total catch	Rebuilding Status
1	EBS snow crab	3	78.9	157.8	168.0	1.06	73.5	44.7	
2	BB red king crab	3	13.03	26.06	27.25	1.05	6.82	5.44	
3	EBS Tanner crab	3	13.40	26.80	71.57	2.67	31.48	9.16	
4	Pribilof Islands red king crab	4	2.87	5.74	8.89	1.55	1.36	.001	
5	Pribilof Islands blue king crab	4	2.06	4.12	0.3	0.14	.00016	.000007	overfished
6	St. Matthew Island blue king crab	4	1.86	3.72	2.48	0.67	0.43	0.15	
7	Norton Sound red king crab	4	0.93	1.86	2.27	1.22	0.26	0.16	
8	Aleutian Islands golden king crab	5					5.69	3.19	
9	Pribilof Islands golden king crab	5					0.09	Conf.	
10	Adak red king crab	5					0.054	0.001	

1 MMB as estimated during this assessment for 2014/15 as of 2/15/2015.

Stock Assessment of eastern Bering Sea snow crab

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National Marine Fisheries Service
September 20, 2015

EXECUTIVE SUMMARY

1. Stock: species/area.

A size based model was developed for eastern Bering Sea snow crab (*Chionoecetes opilio*) to estimate population biomass and harvest levels.

2. Catches: trends and current levels

Catch trends historically followed survey abundance estimates of large males, as the survey estimates were the basis for calculating the Guideline Harvest Level (GHL) for retained catch. The TAC is currently set (starting in 2009) by Alaska Department of Fish and Game (ADFG) using the ADFG harvest strategy. Retained catches increased from about 3,040 t at the beginning of the directed fishery in 1973 to a peak of 149,110 t in 1991, declined thereafter, then increased to another peak of 110,410 t in 1998. Retained catch in the 1999/2000 fishery was reduced to 15,200 t due to the low abundance estimated by the 1999 survey. A harvest strategy (Zheng et al. 2002) was developed using an earlier generation simulation model that pre-dated the current stock assessment model. This early generation model has been used to set the GHL (TAC since 2009) since the 2000/01 fishery. Retained catch in the 2014/15 fishery increased to 30,820 t from the 2013/14 fishery retained catch of 24,480 t. The total catch in the 2014/15 fishery was estimated at 34,300 t (30% mortality on directed discards) and was well below the OFL of 69,000 t. Discard in the directed fishery was 11,700 t (no mortality applied) in 2014/15, similar to the 10,880 t (no mortality applied) in 2013/14.

Estimated discard mortality (mostly undersized males and old shell males) in the directed pot fishery has averaged about 31% (no mortality applied) of the retained catch biomass since 1992 when observers were first placed on crab vessels. Discards prior to 1992 were estimated based on fishery selectivities estimated for the period with observer data and the full selection fishing mortality estimated using the retained catch and retained fishery selectivities.

3. Stock Biomass:

Model estimates of total mature biomass of snow crab increased from the early 1980's to a peak in 1990 of about 1,019,600 t. The total mature biomass includes all sizes of mature females and morphometrically mature males. The stock was declared overfished in 1999 due to the survey estimate of total mature biomass (149,900 t) being below the minimum stock size threshold (MSST = 208,710 t). A rebuilding plan was implemented in 2000. During the 10 year rebuilding period, the assessment model structure was changed and the currency for estimating B_{MSY} was changed from total mature survey biomass to model estimated mature male biomass at mating (MMB). Using the revised definitions for estimating B_{MSY}, MMB at mating was above $B_{35\%}$ in 2010/11 and the stock was declared rebuilt in 2011. Furthermore, the total mature biomass observed in the 2011 survey was 447,400 t which was also above the old B_{MSY} (418,150 t) in place under the rebuilding plan implemented in 2000. The increase in total mature biomass was mainly due to an increase in observed female mature biomass in 2011.

Observed survey mature male biomass increased from 96,100 t in 2013 to 156,900 t in 2014, then decreased to 79,000 t in 2015. Observed survey mature female biomass also increased from 195,100 t in 2013 to 212,500 t in 2014, then decreased to 128,100 t in 2015. The estimate of males greater than 101 mm increased from 73.6 million in 2013 to 138.5 million in 2014, then decreased to 57,200 t in 2015.

Base model estimates of mature male biomass at mating increased from 100,600 t in 2012/13 to 108,300 t in 2013/14, and to 129,300 t in 2014/15 (84% of $B_{35\%}$ =146,357 t).

4. Recruitment

Recruitment was near average in 2005 (lag 5 years) and just below average in 2006 to 2009. Survey length frequency data in 2015 indicate a possible large recruitment, although estimated with high uncertainty, in 2010 (5 year lag).

5. Management

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	77.3	165.2[A]	40.3	40.5	42.0	73.5	66.2[E]
2012/13	77.1	170.1[B]	30.1	30.1	32.4	67.8	61.0[E]
2013/14	71.5	126.5[C]	24.5	24.5	27.7	78.1	70.3[E]
2014/15	73.2	129.3[D]	30.8	30.8	34.3	69.0	62.1[E]
2015/16		123.5[D]				61.5	55.4[E]

Historical status and catch specifications for snow crab (millions of lb.).

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	170.4	364.2 [A]	88.8	89.3	92.4	162.0	145.8[E]
2012/13	169.9	374.9 [B]	66.3	66.3	71.2	149.5	134.5 [E]
2013/14	157.7	279.0[C]	54.0	54.0	61.0	172.1	154.9 [E]
2014/15	161.0	284.5 [D]	67.9	67.9	75.5	152.1	136.9 [E]
2015/16		271.7 [D]				135.3	121.8 [E]

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2012
B– Calculated from the assessment reviewed by the Crab Plan Team in September 2013
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2014
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2015
E – 10% Buffer recommended by SSC

6. Basis for the OFL

The OFL for 2015/16 for the Base model was 61,500 t fishing at F_{OFL} = 1.26, a decrease from the 2014/15 OFL of 69,000 t. The MMB at mating projected for 2015/16 when fishing at the $F_{35\%}$ control rule (OFL) was 84.4% of $B_{35\%}$.

7. Probability Density Function of the OFL

   The ABC (P*=.49) was estimated from the PDF of the OFL with a cv = 0.10 on beginning biomass estimated from the Hessian. The description of the projection model used to estimate the PDF is included later in this assessment.

8. Basis for ABC

The Annual Catch Limit (ACL) was estimated at 61,200 t using a p*=0.49. The total catch estimated at 90% of OFL (the ACL recommended by the SSC for 2013/14) was 55,400 t. The MMB projected for 2015/16 when fishing at 90% of the OFL catch was 87.1% of $B_{35\%}$. $B_{35\%}$ for the Base model was estimated at 146,357 t and $F_{35\%}$ was estimated at 1.53. MMB at mating for 2014/15 was estimated at 129,300 t above the estimated MMST of 73,180 t.

A. Summary of Major Changes

Changes to the Data

Data added to the assessment included: 2015 Bering Sea survey biomass and length frequency data; 2014/15 directed fishery retained and discard catch and length frequencies for retained and discard catch; and groundfish discard length frequency and discard catch from 2014/15. The 2013/14 discard length composition was corrected. The observer total catch length frequency was input incorrectly where the observer discard length frequency should have been input.

Changes to the Assessment Methodology

Six model scenarios are presented in this assessment following recommendations by the CPT in May 2015. Model 0 is the September 2014 model with the standard deviation parameter of the growth function fixed at a small value (0.5). Models 1 changes the parameterization of the survey logistic curves from estimating a size at 95% selected to an offset from the size at 50% parameter. Also, the survey q for the first time period and the survey availability for the industry survey in 2010 was changed to a probit scale to allow estimation of a variance when q is estimated at 1.0. Model 2 is Model 1 with the constraint on the probability of maturing removed, the weight on the smoothness constraint on the female probability of maturing increased and the weight on fit to the trawl discard catch increased by 4 times. In Model 3 the fixed size at 50% selected for female discard length data was changed from 4.2 to 4.4 (log scale) to better fit the length data. Model 3 also increased the weight on the likelihood for the fit to the growth data from 2.0 to 3.0. Model 4 removes the penalty on the directed fishing mortality estimates (male crab) from 1992 to present. Model 5 removes the penalty on female fishing mortality estimates from 1992 to present; potlift data are used to estimate pre-1992 fishing mortality for female discard.

Model 5 was selected as the base model as all fishing mortality penalties, which have been shown to result in bias, were removed from 1992 to the present.

Changes to Assessment Results
See above

CPT May 2015 Recommendations for next assessment:

Run the 2014 assessment model (Model 0) fixing the standard deviation of the cumulative normal distribution of the growth function to a small value for both male and female growth functions.
Keep the F penalties for pre 1992/93 as in Model 0 and remove them for post 1991/92. Do separate scenarios changing the F penalties for males and then adding the change in F penalties for female discards. (The CPT was concerned about the way pre 1992/93 effort data and post 1992/93 catchability estimate were used to regularize pre 1992/93 F to overcome the effect of F penalty removal.).
Do not consider a separate selectivity curve for 2013/14 to correct under fitting of the final year (2014) survey biomass.
Run model scenarios from Model 0 (2014 assessment) to Model 1 with one change per scenario so that the effect of each change can be evaluated.

Authors response

Model scenarios include all CPT recommended models (6 models from Model 0 to Model 5).

SSC Recommendations June 2015:

No specific recommendations in SSC minutes.

Authors response

Model scenarios include all CPT recommended models.

INTRODUCTION

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 common at depths less than about 200 meters. 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.

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. Retained catch in the domestic fishery increased in the late 1980s to a high of about 149,110 t in 1991, declined to 29,820 t in 1996, increased to 110,410 t in 1998 then declined to 15,200 t in the 1999/2000 fishery (Table 1, Figure 1). Due to low abundance and a reduced harvest rate, retained catches from 2000/01 to 2006/07 ranged from a low of about 10,860 t to 16,780 t. In the 2014/15 fishery retained catch was 30,820 t and total catch was estimated at 34,300 t (0.30 mortality for pot fishery discard and 0.80 mortality for groundfish discard). Total catch in the 2013/14 fishery was 27,700 t.

Discard from the directed pot fishery was estimated from observer data since 1992 and ranged from 11% to 64% (average 33%) of the retained catch of male crab biomass (Table 1). Discard of male crab in the directed fishery increased in the last two years to 44% (2013/14) and 38% (2014/15) of the retained catch (no mortality applied). Female discard catch is very low compared to male discard catch and not a significant source of mortality. In 1991/92 trawl discard was about 1,950 t (no mortality applied), increased to about 3,550 t in 1994/95, then declined and ranged between 900 t and 1,500 t until 1998/99. Trawl bycatch in 2012/13 and 2013/14 was 220 t and 120 t respectively. Discard of snow crab in groundfish fisheries from highest to lowest is the yellowfin sole trawl fishery, flathead sole trawl fishery, Pacific cod bottom trawl fishery, rock sole trawl fishery, and the Pacific cod hook-and-line and pot fisheries.

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).

The average size of retained crabs has remained fairly constant over time ranging between 105 mm and 118 mm Carapace Width (CW), and most recently about 110 mm to 111 mm CW. The percent new shell animals in the catch has varied between 69% (2002 fishery) to 98% (1999), and was 87% for the 2005/6 fishery and 93% in the 2007/8 fishery. In the 2007/8 fishery 94% of the new shell males >101mm CW were retained, while 78% of the old shell males >101mm CW were retained. Only 3% of crab were retained between 78mm and 101 mm CW. The average weight of retained crab has varied between 0.5 kg (1983-1984) and 0.73 kg (1979), and 0.59 kg in the recent fisheries.

Several modifications to pot gear have been introduced to reduce bycatch mortality. In the 1978/79 season, pots used in the snow crab fishery first contained escape panels 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 to prevent ghost fishing 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 had to contain not less than 5 inches stretched mesh webbing or have no less than four circular rings of no less than 3 3/4 inches inside diameter. In the 2001 season the escapement for undersize crab was increased to at least eight escape rings of no less than 4 inches placed within one mesh measurement from the bottom of the pot, with four escape rings on each side of the two sides of a four-sided pot, or one-half of one side of the pot must have a side panel composed of not less than 5 1/4 inch stretched mesh webbing.

Harvest rates

The harvest rate used to set the Guideline Harvest Level (GHL) of retained crab only previous to 2000 was 58% of the number of male crab over 101 mm CW estimated from the survey. The minimum legal size limit for snow crab is 78 mm, however, the snow crab market generally accepts animals greater than 101 mm. In 2000, due to the decline in abundance and the declaration of the stock as overfished, the harvest rate for calculation of the GHL was reduced to 20% of male crab over 101 mm. After 2000, a rebuilding strategy was developed based on simulations by Zheng (2002).

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% (Figure 2). The exploitation rate for total catch divided by mature male biomass ranged from 6% to 46% and was estimated at 21% in 2014/15 (Table 6 and Figure 2).

Prior to adoption of Amendment 24, B_{MSY} (921.6 million lbs (418,150 t)) was defined as the average total mature biomass (males and females) estimated from the survey for the years 1983 to 1997 (NPFMC 1998). MSST was defined as 50% of the B_{MSY} value (MSST=460 million lbs of total mature biomass (209,074 t)). The harvest strategy since 2000/01 used a retained crab harvest rate on the mature male biomass of 0.10 on levels of total mature biomass greater than ½ MSST (230 million lbs), increasing linearly to 0.225 when biomass is equal to or greater than B_{MSY} (921.6 million lbs) (Zheng et al. 2002). The GHL was actually set as the number of retained crab allowed in the harvest, calculated by dividing the GHL in lbs by the average weight of a male crab > 101 mm. If the GHL in numbers was 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 GHL is capped at 58%. If natural mortality is 0.2, then this actually results in a realized exploitation rate cap for the retained catch of 66% at the time of the fishery, occurring approximately 7 months after the survey (if survey Q=1). The fishing mortality rate that results from this harvest strategy depends on the relationship between mature male numbers less than 101 mm compared to greater than 101 mm.

DATA

Data Sources

Catch data and size frequencies of retained crab from the directed snow crab pot fishery from 1978/79 to the 2014/15 season were used in this analysis. Observers were placed on directed crab fishery vessels starting in 1990. Size frequency data on the total catch (retained plus discarded) in the directed crab fishery were available from 1992/93 to 2014/15. Total discarded catch was estimated from observer data from 1992 to 2014/15 (Table 1). The discarded male catch was estimated for 1978 to 1991 in the model using the estimated fishery selectivities based on the observer data for the period 1992 to 2014/15. The discard catch estimate was multiplied by the assumed mortality of discards from the pot fishery. The mortality of discarded crab was 30% for all model scenarios. This estimate differs from the current rebuilding harvest strategy used since 2001 to the present by ADFG to set the TAC, which assumes a discard mortality of 25% (Zheng, et al. 2002). The discards prior to 1992 may be underestimated due to the lack of escape mechanisms for undersized crab in the pots before 1997.

The following table contains the various data components used in the model,

Data component	Years
Retained male crab pot fishery size frequency by shell condition	1978/79-2014/15
Discarded male and female crab pot fishery size frequency	1992/3-2014/15
Trawl fishery bycatch size frequencies by sex	1991-2014/2015
Survey size frequencies by sex and shell condition	1978-2015
Retained catch estimates	1978/79-2014/15
Discard catch estimates from snow crab pot fishery	1992/93-2014/15 from observer data
Trawl bycatch estimates	1973-2014/15
Total survey biomass estimates and coefficients of variation	1978-2015
2009 study area biomass estimates and coefficients of variation and length frequencies for BSFRF and NMFS tows	2009
2010 study area biomass estimates and coefficients of variation and length frequencies for BSFRF and NMFS tows	2010

Survey Biomass

Abundance is estimated from the annual eastern Bering Sea (EBS) bottom trawl survey conducted by NMFS (see Rugolo et al. 2003 for design and methods). Since 1989, the survey has sampled stations farther north than previous years (61.2^{o} N previous to 1989). In 1982 the survey net was changed resulting in a change in catchability. Juvenile crabs tend to occupy more inshore northern regions (up to about 63^{o} N) and mature crabs deeper areas to the south of the juveniles (Zheng et al. 2001).

All survey data in this assessment use measured net widths instead of the fixed 50 ft net width used in the September 2009 snow crab assessment (variable net width data were shown for comparison in the September 2009 assessment). Snow crab assessments prior to and including September 2009 used survey biomass estimates for all crab based on an assumed 50 ft net width. In 2009, Chilton et al. (2009) provided new survey estimates based on measured net width. The average measured net width for all tows in the 2009 survey was 17.08 meters which is about 112% of 50ft (15.24 meters) (Chilton et al. 2009). The 2009 mature male survey biomass was 162,890 t using the fixed 50 ft net width and 141,300 t using the measured net width for each tow. The difference between the survey male mature biomass estimates calculated with the fixed 50 ft width and the measured net width is small in the early part of the time series, and then is an average ratio of 0.86 (range 0.81 to 0.90) from 1998 to 2009.

The total mature biomass (all sizes of morphometrically mature males and females) estimated from the survey declined to a low of 82,100 t in 1985, increased to a high of 809,600 t in 1991 (includes northern stations after 1989), then declined to 140,900 t in 1999, when the stock was declared overfished (Table 3 and Figure 4). The mature biomass increased in 2000 and 2001, mainly due to a few large catches of mature females. The survey estimate of total mature biomass increased from 291,200 t in 2013 to 369,400 t in 2014, then declined to 207,100 t in 2015.

Survey mature male biomass increased from 96,100 t in 2013 to 156,900 t in 2014, then declined to 79,000 t in 2015. The observed survey estimate of males greater than 101 mm increased from 73.6 million in 2013 to 138.9 million in 2014, then declined to 57.2 million in 2015 (Table 3). Survey mature female biomass increased from 195,100 t in 2013 to 212,500 t in 2014, then declined to 128,100 t in 2015.

The term mature for male snow crab in this assessment means morphometrically mature. Morphometric maturity for males refers to a marked change in chelae size (thereafter termed “large claw”), after which males are assumed to be effective at mating. Males are functionally mature at smaller sizes than when they become morphometrically mature, although the contribution of these “small-clawed” males to annual reproductive output is negligible. The minimum legal size limit for the snow crab fishery is 78 mm, however the size for males that are generally accepted by the fishery is >101mm. The historical quotas were based on the survey abundance of large males (>101mm).

Survey Size Composition

Carapace width is measured on snow crab and shell condition recorded in the survey and the fishery. Snow crab cannot be aged at present (except by radiometric aging of the shell since last molt) however, shell condition has been used as a proxy for age. Based on protocols adopted in the NMFS EBS trawl survey, shell condition class and presumptive age are as follows: soft shell (SC1) (less than three months from molting), new shell (SC2) (three months to less than one year from molting), old shell (SC3) (two years to three years from molting), very old shell (SC4) (three years to four years form molting), and very very old shell (SC5) (four years or longer from molting). Radiometric aging of shells from terminal molt male crabs (after the last molt of their lifetime) elucidated the relationship between shell condition and presumptive age, which will be discussed in a later section (Nevissi et al. 1995).

Survey abundance by size for males and females indicate a moderate level of recruitment moving through the stock and resulting in the small increase in abundance in 2015 (Figures 6 - 8). In 2009 small crab (<50mm) increased in abundance relative to 2008. The 2010 length frequency data showed high abundance in the 40 to 50 mm range. The recruitment progressed into the mature female abundance in 2011 and also can be seen in male abundance in the 50-65mm range in 2011(Figure 8). However, in 2012 and 2013, the progress of the recruitment is not evident. High numbers of small crab in the late 1970's survey data did not follow through the population to the mid-1980's. The high numbers of small crab in the late 1980's resulted in the high biomass levels of the early 1990's and subsequent high catches. Moderate increase in numbers can also be seen in the mid 1990's. The 2015 survey length composition data indicate a possible large recruitment to the model in 2015 (2010 lag 5 years to fertilization year).

Spatial distribution of catch and survey abundance

The majority of the fishery catch occurs south of 58.5^{o} N., even in years when ice cover did not restrict the fishery moving farther north. In past years, most of the fishery catch occurred in the southern portion of the snow crab range possibly due to ice cover and proximity to port and practical constraints of meeting delivery schedules. The directed fishery catch in 2012/13 is shown in Figure 9 showing some catch from east of the Pribilof Islands, however, the majority of catch is west and north of the Pribilof Islands. The majority of catch in 2014/15 has shifted to east of the Pribilof Islands (Figure 11).

CPUE of survey catch by tow for 2014 to 2015 are shown in Figures 12 through 25. Immature female and small male (<78mm) distributions in 2014 and 2015 were farther south than in previous years with higher tows just north of the Pribilof Islands (Figures 12, 15, 20 and 22). Legal males (>77mm) and large males (>101mm) are distributed farther south and east of the Pribilof Islands than in previous years (Figures 13, 14, 19, and 21). Mature females with less than or equal to half clutch of eggs were mostly in the northern part of the survey area above 58 ^{o} N (Figures 18 and 24).

The difference between the summer survey distribution of large males and the fishery catch distribution indicates that survey catchability may be less than 1.0 and/or some movement occurs between the summer survey and the winter fishery. However, the exploitation rate on males south of 58.5^{o} N latitude may exceed the target rate, possibly resulting in localized depletion of males from the southern part of their range. Snow crab larvae probably drift north and east after hatching in spring. Snow crab appear to move south and west as they age, however, no tagging studies have been conducted to fully characterize the ontogenetic or annual migration patterns of this stock(Murphy et al. 2010). High exploitation rates in the southern area may have resulted in a northward shift in snow crab distribution. The last few years of survey data indicate a shift to the south in distribution of snow crab, which reverses the trends seen in early 2000s.

Ernst, et al. (2005) found the centroids of survey summer distributions have moved to the north over time (Figures 26 and 27). In the early 1980's the centroids of mature female distribution were near 58.5 ^{o} N, in the 1990s the centroids were about 59.5 ^{o} N. The centroids of old shell male distribution was south of 58 ^{o} N in the early 1980s, moved north in the late 1980s and early 1990s then shifted back to the south in the late 1990s. The distribution of males>101 mm was about at 58 ^{o} N in the early 1980s, then was farther north (58.5 to 59 ^{o} N) in the late 1980s and early 1990s, went back south in 1996 and 1997 then has moved north with the centroid of the distribution in 2001 just north of 59 ^{o} N.. The centroids of the catch are generally south of 58 ^{o} N, except in 1987. The centroids of catch also moved north in the late 1980s and most of the 1990s. The centroids of the catch were about at 56.5 ^{o} N in 1997 and 1998, then moved north to above 58.5 ^{o} in 2002.

2009 and 2010 Study Area Data Additional survey data

Bering Sea Fisheries Research Foundation (BSFRF) conducted a survey of 108 tows in 27 survey stations (10,827 nm^2, hereafter referred to as the "study area") in the Bering Sea in summer 2009 (Figure 28, see Somerton et al 2010 for more details). The abundance estimated by the BSFRF survey in the study area was 66.9 million male crab >=100 mm compared to 36.7 million for the NMFS tows (Table 4). The NMFS abundance of females >=50mm (121.5 million) was greater than the BSFRF abundance estimate in the study area (113.6 million) (Table 4).

The abundance of male crab in the entire Bering Sea survey for 2009 was greatest in the 30 – 60mm size range (Figures 29 and 30). The abundance of crab in the 35 to 60mm size range for the BSFRF net in the study area was very low compared to the abundance of the same size range for the NMFS entire Bering Sea survey. The differences in abundance by size for the NMFS entire Bering Sea survey and the BSFRF study area were due to availability of crab in the study area as well as capture probability. While the abundance of larger male crab for the NMFS net in the study area is less than for the BSFRF, the abundance of females >45 mm is greater for the NMFS net than the BSFRF (Figure 29). This difference may be due to different towing locations for the two nets within the study area, or to higher catchability of females possibly due to aggregation behavior. The ratio of abundance of the NMFS net and BSFRF net in the study area are quite different for males and females (Figure 31). The ratio of abundance indicates a catchability for mature females (mainly 45 – 65 mm) that is greater than 1.0 for the NMFS net.

The largest tows for small (<78mm) male crab in the entire Bering Sea area were north of the study area near St. Matthew Island (Figure 12 and 20). Some higher tows for large males (>=100mm) and for mature females occurred in the study area as well as outside the study areas (Figures 5-18 and 22-24). These distributions indicate that availability of crab of different sizes and sex varies spatial throughout the Bering Sea. The numbers by length and mature biomass by sex for the BSFRF tows and the NMFS tows within the study area were added to the model as an additional survey.

The 2009 estimated snow crab abundance by length in the study area had very low numbers of both male and female crab in the 35 mm to 70 mm range than observed in the Bering sea wide survey(Figures 29 and 30). The ratio of abundance (NMFS/BSFRF) by length for 2009 was 0.2 at about 45 mm increasing gradually to 0.4 at 95mm then increasing steeply to 0.9 to 1.25 above 115 mm (Figure 31). The mean size of crab retained by the fishery is about 110 mm, with minimum size retained about 102mm. Ratios of abundance for female crab were above 1.0 from 45mm to 60mm then declined to 0.5 to 0.8 above 60mm to 80mm. There were very few female crab above 80mm in the population.

The 2010 study area covered a larger portion of the distribution of snow crab than the 2009 study area. The abundance by length for the 2010 study area is very different from the 2009 data, with higher abundance in 2010 of small crab (Figure 32). The expanded estimate (expanded to the study area) of male abundance from BSFRF data is higher than the Bering Sea wide abundance for length from 50mm to about 110mm. Female abundance shows a similar relationship (Figure 33). The ratio of male abundance by length (NMFS/BSFRF) in 2010 increased to 0.6 at 40mm then decreased to about 0.2 at 65-70mm then increased and ranged between 0.3 and 0.4 up to about 112mm (Figure 34). The ratios increased from 0.4 at 112 to about 0.7 at 122mm then to 1.55 at 132mm. The ratio of female abundance by length in 2010 was 0.6 at about 45mm and declined to 0.4 at about 67mm then declined below 0.1 above about 77mm.

Several processes influence net performance. Somerton et al. (2010) accounted for area swept, sediment type, depth and crab size. However, they did not correct for the probability of encountering crab. The 2010 study area data have a number of paired tows where BSFRF caught no crab (within a particular size bin) or where NMFS caught no crab. This creates problems with simply taking the ratio of catches since a number of ratios will be infinity (dividing by 0). This occurs because the paired tows although near in space were not fishing on the same density of crab. In addition, the BSFRF tow covered about 10% of the area of the NMFS tow, due to the narrower net width and the 5 minute tow duration compared to the 30 minute NMFS tow duration. To analyze these data, first the ratio of the “NMFS density” (numbers per nm^2) to the “sum of the density” of NMFS and BSFRF were calculated (Figure 35 males and Figure 38 females). These values range from 0 to 1.0. The simple mean of these values was estimated by length bin and then transformed to estimate mean catchability by length bin (Figure 39 males Figure 40 females). A value of 0.5 for the ratio of the “NMFS density” to the “sum of density” is equivalent to a catchability of 1.0, and a value of the ratio of 0.33 is equivalent to a catchability of 0.5. The size of the catch for each observation is plotted in Figure 36 (same data as Figure 35).

The BSFRF study provides a rich data set to evaluate net performance. In this survey the sample is the paired tows and the goal would be to evaluate net performance over a wide range of densities, sediment types and depths. Somerton et al. (February 2011 Modeling Workshop) used catch to weight observations for estimation of the selectivity curve. This assumes that trawl performance is influenced by local density of crab (an untested assumption). No weighting of the observations assumes that there is no relationship between catch and the selectivity of crab. If selectivity changes depending on whether catches are high or low, then further study and analysis is needed. Further analysis needs to be done on whether data should be weighted in the initial estimation of the selectivity curve. The unweighted mean values by length bin are higher than the values estimated by Somerton et al.. Somerton weights again by survey abundance and adjusts for depth and sediment type in a separate step in the analysis to estimate a Bering Sea wide survey selectivity. Simulation studies are needed to determine the influence of weighting (whether bias is introduced) and whether the distributional assumptions and likelihood equations used in the analysis of the paired tow data are correct and unbiased.

The overall distribution of the ratio of "NMFS density" to the "sum of the densities" is skewed with about 140 - 0.0 values and 110 - 1.0 values (Figure 41). The percentage of observations where NMFS caught crab and no crab were caught by the BSFRF tow increases by size bin for male crab (Figures 41 through 46).

Catches of male crab decrease with size simply because they are lower in abundance in the population. At sizes of male crab greater than about 90 mm the fraction of observations where the ratio of NMFS density to the sum of densities was 1.0 and 1 crab was caught in the net was about 10% to 30%. In other, words the majority of the tows involved more than 1 crab caught.

The mean values of the ratio of NMFS density to the sum of densities for female crab transformed to catchability increase from less than 0.1 at 25mm to about 0.5 at 55mm then decrease slightly above 70mm (Figures 38 and 40).

Weight - Size

The weight (kg) – size (mm) relationship was estimated from survey data, where weight = a* size^b. Juvenile female a= 0.00000253, b=2.56472. Mature female a=0.000675 b=2.943352, and males, a= 0.00000023, b=3.12948 (Figure 47).

Maturity

Maturity for females was determined by visual examination during the survey and used to determine the fraction of females mature by size for each year. Female maturity was determined by the shape of the abdomen, by the presence of brooded eggs or egg remnants. The average fraction mature for female snow crab is shown in Figure 48b, although this curve is not used in the model.

Morphometric maturity for males is determined by chela height measurements, which are available starting from the 1989 survey (Otto 1998). The number of males with chela height measurements has varied between about 3,000 and 7,000 per year. In this report a mature male refers to a morphometrically mature male.

One 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 (Figure 48c). The separation of mature and immature males by chela height at small widths 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 a new shell crab maturing was estimated in the model at a smooth function to move crab from immature to mature (Figure 48). The probability of maturing was estimated to match the observed fraction mature for all mature males and females observed in the survey data.

The probability of maturing by size for female crab was about 50% at about 48 mm and increased to 100% at 60mm (Figure 49). The probability of maturing for male crab was about 15% to 20% at 60 mm to 90mm and increased sharply to 50% at about 98mm, and 100% at 108 mm.

Natural Mortality

Natural mortality is a critical variable in population dynamic modeling, and may have a large influence on derived optimal harvest rates. Natural mortality rates estimated in a population dynamics model may have high uncertainty and may be correlated with other parameters, and therefore are usually fixed. The ability to estimate natural mortality in a population dynamics model depends on how the true value varies over time as well as other factors (Schnute and Richards 1995, Fu and Quinn 2000).

Nevissi, et al. (1995) used radiometric techniques to estimate shell age from last molt (Table 7). The total sample size was 21 male crabs (a combination of Tanner and snow crab) from a collection of 105 male crabs from various hauls in the 1992 and 1993 NMFS Bering Sea survey. Fishing mortality rates before and during the time period when these crab were collected were relatively high, and therefore maximum age would represent Z (total mortality) rather than M. 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. The range of ages was 2.70 to 6.85 years for those same crabs. 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. Radiometric ages estimated by Nevissi, et al. (1995) may 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 reveal 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.

We reasoned that in a virgin population of snow crab, longevity would be at least 20 years. Hence, we used 20 years as a proxy for longevity and assumed that this age would represent the 99^{th} percentile of the distribution of ages in an unexploited population if observable. Under negative exponential depletion, the 99^{th} percentile corresponding to age 20 of an unexploited population corresponds to a natural mortality rate of 0.23. Using Hoenig's (1983) method an M=0.23 corresponds to a maximum age of 18 years (Table 8). M=0.23 was used for all female crab in the model. Male natural mortality estimated in the model with a prior constraint of mean

M=0.23 with a se = 0.054 estimated from using the 95% CI of +-1.7 years on maximum age estimates from dactal wear and tag return analysis in Fonseca, et al. (2008).

Molting probability

Female and male snow crab have a terminal molt to maturity. Many papers have dealt with the question of terminal molt for Atlantic Ocean mature male snow crab (e.g., Dawe, et al. 1991). A laboratory study of morphometrically mature male Tanner crab, which were also believed to have a terminal molt, found all crabs molted after two years (Paul and Paul 1995). Bering Sea male snow crab appear to have a terminal molt based on data on hormone levels (Tamone et al. 2005) and findings from molt stage analysis via setagenesis. The models presented here assume a terminal molt for both males and females.

Male Tanner and 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 about 100 days from molting (Paul et al. 1995). Sainte-Marie et al. (2002) states 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. Animals that molt to maturity at a size smaller than what is acceptable to the fishery may be subjected to fishery mortality from being caught and discarded before they have a chance to mate. However, new shell males will be a mixture of crab less than 1 year from terminal molt and 1+ years from terminal molt due to the inaccuracy of shell condition as a measure of shell age.

Crabs in their first few years of life may molt more than once per year, however, the smallest crabs included in the model are approximately 3 to 4 years old and would be expected to molt annually. The growth transition matrix was applied to animals that grow, resulting in new shell animals. Those animals that don’t molt become old shell animals. Animals that are classified as new shell in the survey are assumed to have molted during the last year. The assumption is that shell condition (new and old) is an accurate measure of whether animals have molted during the previous year. The relationship between shell condition and time from last molt needs to be investigated further.

Mating ratio and reproductive success

Full clutches of unfertilized eggs may be extruded and appear normal to visual examination, and may be retained for several weeks or months by snow crab. Resorption of eggs may occur if not all eggs are extruded resulting in less than a full clutch. Female snow crab at the time of the survey may have a full clutch of eggs that are unfertilized, resulting in overestimation of reproductive potential. Male snow crab are sperm conservers, using less than 4% of their sperm at each mating. 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.

The fraction barren females and clutch fullness observed in the survey increased in the early 1990s then decreased in the mid- 1990s then increased again in the late 1990s (Figures 49 and 50). 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, the rate of production from the stock may have been reduced due to the spatial distribution of the catch and the resulting sex ratio in areas of highest reproductive potential. The percentage of barren females was low in 2006, increased in 2007, then declined in 2008 and 2009 to below 1 percent for new and old shell females and about 17% for very old females. Clutch fullness for new shell females declined slightly in 2009 relative to 2008, however, on average is about 70% compared to about 80% before 1997. Clutch fullness for old and very old shell females was high in 2006, declined in 2007, then was higher in 2009 (about 78% old shell and 60% very old).

The fraction of barren females in the 2003 and 2004 survey south of 58.5 ^{o} N latitude was generally higher than north of 58.5 ^{o} N latitude (Figures 51 and 52). In 2004 the fraction barren females south of 58.5 ^{o} N latitude was greater for all shell conditions. In 2003, the fraction barren was greater for new shell and very very old shell south of 58.5 ^{o} N latitude.

Laboratory analysis determined that female snow crab collected in waters colder than 1.5 ^{o} C from the Bering Sea were biennial spawners. Future recruitment may be affected by the fraction of biennial spawning females in the population as well as the estimated fecundity of females, which may depend on water temperature.

An index of reproductive potential for crab stocks needs to be defined that includes spawning biomass, fecundity, fertilization rates and frequency of spawning. In most animals, spawning biomass is a sufficient index of reproductive potential because it addresses size related impacts on fecundity, and because the fertilization rates and frequency of spawning are relatively constant over time. This is not the case for snow crab.

The centroids of the cold pool (<2.0 ^{o} C) were estimated from the summer survey data for 1982 to 2006 (Figure 53). The centroid is the average latitude and average longitude. In the 1980's the cold pool was farther south(about 58 to 59 ^{o} N latitude) except for 1987 when the centroid shifted to north of 60 ^{o} N latitude. The cold pool moved north from about 58 ^{o} N latitude in 1999 to about 60.5 ^{o} N latitude in 2003. The cold pool was farthest south in 1989, 1999 and 1982 and farthest north in 1987, 1998, 2002 and 2003. In 2005 the cold pool was north, then in 2006 back to the south. The years 2007, 2008 and 2009 have all been cold years.

The clutch fullness and fraction of unmated females however, may not account for the fraction of females that may have unfertilized eggs, since these cannot be detected by the naked eye at the time of the survey. The fraction of barren females observed in the survey may not be an accurate measure of fertilization success because females may retain unfertilized eggs for months after extrusion. To examine this hypothesis, RACE personnel sampled mature females from the

Bering Sea in winter and held them in tanks until their eggs hatched in March of the same year (Rugolo et al. 2005). All females then extruded a new clutch of eggs in the absence of males. All eggs were retained until the crabs were sacrificed near the end of August. Approximately 20% of the females had full clutches of unfertilized eggs. The unfertilized eggs could not be distinguished from fertilized eggs by visual inspection at the time they were sacrificed. Indices of fertilized females based on the visual inspection method of assessing clutch fullness and percent unmated females may overestimate fertilized females and not an accurate index of reproductive success.

McMullen and Yoshihara (1969) examined female red king crab around Kodiak Island in 1968 and found high percentages of females without eggs in areas of most intense fishing (up to 72%). Females that did not extrude eggs and mate were found to resorb their eggs in the ovaries over a period of several months. One trawl haul captured 651 post-molt females and nine male red king crab during the period April to May 1968. Seventy-six percent of the 651 females were not carrying eggs. Ten females were collected that were carrying eggs and had firm post-molt shells. The eggs were sampled 8 and 10 days after capture and were examined microscopically. All eggs examined were found to be infertile. This indicates that all ten females had extruded and held egg clutches without mating. Eggs of females sampled in October of 1968 appear to have been all fertile from a table of results in McMullen and Yoshihara(1969), however the results are not discussed in the text, so this is unclear. This may mean that extruded eggs that are unfertilized are lost between May and October.

ANALYTIC APPROACH

Model Structure

The model structure 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. This software provides the derivative calculations needed for finding the objective function via a quasi-Newton function minimization routine (e.g., Press et al. 1992). The model implementation language (ADModel Builder) gives simple and rapid access to these routines and provides the ability to estimate the variance-covariance matrix for all parameters of interest.

The model estimates the abundance by length bin and sex in the first year (1978) as parameters rather than estimating the recruitments previous to 1978. This results in 44 estimated parameters.

Recruitment is determined from the estimated mean recruitment, the yearly recruitment deviations and a gamma function that describes the proportion of recruits by length bin,

$$N_{t,1} = pr_l \, e^{R_0^l + \tau_t}$$

where,

R_0^l Log Mean recruitment

pr_l Proportion of recruits for each length bin

τ_t Recruitment deviations by year.

Recruitment is estimated equal for males and females in the model.

Crab were distributed into 5mm CW bins based on a pre-molt to post-molt transition matrix. For immature crab, the number of crabs in length bin *l* in year *t-1* that remain immature in year *t* is given by,

$$N_{t,l}^{s} = (1 - \phi_l^s) \sum_{l=l_1}^{l'} \psi_{l',l}^{s} \, e^{-Z_{l'}^{s}} N_{t-1,l'}^{s}$$

$\psi_{l',l}^{s}$	growth transition matrix by sex, pre-molt and post-molt length bins which defined the fraction of crab of sex *s* and pre-molt length bin *l'*, that moved to length bin *l* after molting,
$N_{t,l}^{s}$	abundance of immature crab in year *t*, sex *s* and length bin *l*,
$N_{t-1,l'}^{s}$	abundance of immature crab in year *t-1*, sex s and length bin *l'*,
$Z_{l'}^{s}$	total instantaneous mortality by sex *s* and length bin *l'*,
ϕ_l^s	fraction of immature crab that became mature for sex *s* and length bin *l*,
l'	pre-molt length bin,
l	post-molt length bin.

Growth

Very little information exists on growth for Bering Sea snow crab. A growth study was conducted in 2011 (Somerton 2013) that added new information that was used in the Base model of the current assessment. Tagging experiments were conducted on snow crab in 1980 with recoveries occurring in the Tanner crab (*Chionoecetes bairdi*) fishery in 1980 to 1982 (Mcbride 1982). All tagged crabs were males greater than 80mm CW and which were released in late May of 1980. Forty-nine tagged crabs were recovered in the Tanner crab fishery in the spring of 1981 of which only 5 had increased in carapace width. It is not known if the tags inhibited molting or resulted in mortality during molting, or the extent of tag retention. One crab was recovered after 15 days in the 1980 fishery, which apparently grew from 108 mm to 123 mm carapace width. One crab was recovered in 1982 after almost 2 years at sea that increased from 97 to 107 mm.

In the 2012 assessment and previous to 2012, growth data from 14 male crabs collected in March of 2003 that molted soon after being captured were used to estimate a linear function between premolt and postmolt width (Lou Rugolo unpublished data, Figure 54). The crabs were measured when shells were still soft because all died after molting, so measurements are probably underestimates of postmolt width (Rugolo, pers. com.). Growth appears to be greater than growth of some North Atlantic snow crab stocks (Sainte-Marie 1995). Growth from the 1980 tagging of snow crab was not used due to uncertainty about the effect of tagging on growth. Previous to the 2011 growth data collection that was used in the Base model and scenario 1, there were no growth measurements for Bering Sea snow crab females. North Atlantic growth data indicate growth is slightly less for females than males.

Somerton's (2013) estimates of growth for Bering sea snow crab combined several data sets as well as female and male data. The best model determined by Somerton(2013) included the following data :

1. Transit study; 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

Total sample size was 35 crab. Somerton(2013) excluded data from the NMFS Kodiak holding study where crab were held more than 30 days and also for the ADF&G Kodiak holding study where crab were collected during the summer survey and held until molting the next spring because growth was significantly lower than the above four data sets.

Some data points were excluded from 1, 2 and 3 above (35 was the final sample size). 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. Somerton fit each data set starting with (1) above and testing the next data set for significant difference. Two linear models were fit that joined at 36.1 mm (males and females combined, Figure 55),

For < =36.1mm
Postmolt = -4.0 + 1.46 * Premolt

>= 36.1 mm
Postmolt = 6.59 + 1.17 * Premolt

The postmolt size is 48.8 mm at premolt size of 36.1 mm.

The base model in the current assessment has growth modeled as two linear segments with a smooth transition recommended by the 2014 CIE review (Cadigan 2014),

$$f_i(x) = a_i + b_i\,x, \qquad i = 1{,}2\,,$$

$$a_2 = a_1 + (b_1 - b_2)\delta$$

$$f(x) = f_1(x)\left\{1 - \varphi\left(\frac{x-\delta}{s}\right)\right\} + f_2(x)\left\{\varphi\left(\frac{x-\delta}{s}\right)\right\}$$

Where φ is the cumulative distribution function for a standard normal random variable. δ constrains the breakpoint, and s is a scale parameter determining how smooth the transition is between equation segments. The cumd norm function was used in ADMB for the cumulative normal distribution. Separate parameters were estimated for male and female crab, except one s parameter was used both sexes and fixed at 0.5. The s = 0.5 results in a sharp transition between the lower and upper lines. This results in 4 estimated parameters per sex for a total of 8 estimated parameters.

Likelihood equations were added for the sum of squares fit with the new growth data by sex,

$$0.5\sum(g_i - \hat{g}_i)^2$$

Where g_i is post-molt size from growth data (Somerton 2013) and $\hat{g}_i$ is predicted post-molt size.

Crab were assigned to 5mm width bins using a two-parameter gamma distribution with mean equal to the growth increment by sex and length bin and a beta parameter (which determines the variance),

$$\psi^s_{l',l} = \int_{l-2.5}^{l+2.5} gamma(l/\alpha_{s,l'}, \beta_s)$$

where,

$\alpha_{s,l'}$ expected growth interval for sex s and size l' divided by the shape parameter β,

$\psi^s_{l',l}$ growth transition matrix for sex, s and length bin l' (pre-molt size), and post-molt size l.

The Gamma distribution was,

$$gamma(l/\alpha_{s,l}, \beta_s) = \frac{l^{\alpha_{s.l}-1} e^{-\frac{l}{\beta_s}}}{\beta^{\alpha_{s,l}} \Gamma(\alpha_{s,l})}$$

where l is the length bin, β for both males and females was set equal to 0.75, which was estimated from growth data on Bering Sea Tanner and King crab due to the small amount of growth data available for snow crab. The distribution was truncated at postmolt sizes greater 40mm above the premolt size due to problems in estimation of very small values in the growth transition matrix, and that crab would not be expected to have a larger molt increment than 40mm. There was no difference in the results of the model with the truncated growth matrix and without.

The probability of an immature crab becoming mature by size is applied to the post-molt size. Crab that mature and reach their terminal molt in year t then are mature new shell during their first year of maturity. The abundance of newly mature crab ($\Omega^s_{t,l}$) in year *t* is given by,

$$\Omega^s_{t,l} = \phi^s_l \sum_{L=l_1}^{l'} \psi^s_{l',l} \; e^{-Z^s_{l'}} N^s_{t-1,l'}$$

Crab that were mature SC2 in year *t-1* no longer molt and move to old shell mature crab (SC3+) in year *t* ($\Lambda^s_{t,l}$). Crab that are SC3+ in year *t-1* remained old shell mature for the rest of their lifespan. The total old shell mature abundance ($\Lambda^s_{t,l}$) in year *t* is the sum of old shell mature crab in year *t-1* plus previously new shell (SC2) mature crabs in year *t-1*,

$$\Lambda^s_{t,l} = e^{-Z^{s,old}_l} \Lambda^s_{t-1,l} + e^{-Z^{s,new}_l} \Omega^s_{t-1,l}$$

The fishery is prosecuted in early winter prior to growth in the spring. Crab that molted in year *t-1* remain as SC2 until after the spring molting season. Crab that molted to maturity in year *t-1* are SC2 through the fishery until the spring molting season after which they become old shell mature (SC3).

Mature male biomass (MMB) was calculated as the sum of all mature males at the time of mating multiplied by respective weight at length.

$$B_t = \sum_{L=1}^{lbins} (\Lambda^{males}_{tm,l} + \Omega^{males}_{tm,l}) \, W^{males}_l$$

tm	nominal time of mating after the fishery and before molting,
lbins	number of length bins in the model,
$\Lambda^{males}_{tm,l}$	abundance of mature old shell males at time of mating in length bin *l*,
$\Omega^{males}_{tm,l}$	abundance of mature new shell males at the time of mating in length bin *l*,
W_l	mean weight of a male crab in length bin *l*.

Catch of male snow crab was estimated as a pulse fishery 0.62 yr after the beginning of the assessment year (July 1),

$$catch = \sum_l (1 - e^{-(F * Sel_l + Ftrawl * TrawlSel_l)}) w_l N_l e^{-M * .62}$$

F	Full selection fishing mortality determined from the control rule using biomass including implementation error
$Sel_{,l}$	Fishery selectivity for length bin l for male crab

Ftrawl	Fishing mortality for trawl bycatch
$TrawlSel_l$	Trawl bycatch fishery selectivity by length bin l
W_l	weight by length bin l
N_l	Numbers by length for length bin l
M	Natural Mortality

Selectivity

The selectivity curve total catch, female discard and groundfish bycatch were estimated as two-parameter ascending logistic curves (Figure 56 and 67).

$$S_l = \frac{1}{1 + e^{-a(l-b)}}$$

The probability of retaining crabs by size with combined shell condition was estimated as an ascending logistic function. The selectivities for the retained catch were estimated by multiplying a two parameter logistic retention curve by the selectivities for the total catch.

$$S_{ret,l} = \frac{1}{1 + e^{-a(l-b)}} \frac{1}{1 + e^{-c_{ret}(l-d_{ret})}}$$

The selectivities for the survey were estimated with three-parameter (Q, L95% and L50%), ascending logistic functions (Survey selectivities in Figure 57).

$$Selectivity_l = \frac{Q}{1 + e^{\left\{\frac{-\ln(19)(l - l_{50\%})}{(l_{95\%} - l_{50\%})}\right\}}}$$

Separate survey selectivities were estimated for the period 1978 to 1981, 1982 to 1988, and 1989 to the present. Survey selectivities were estimated separately for males and females in the 1989 to present period. The maximum selectivity(Q) for each time period was estimated in the model for the Base Model. The separate selectivities were used due to the change in catchability in 1982 from the survey net change, and the addition of more survey stations to the north of the survey area after 1988. Survey selectivities have been estimated for Bering Sea snow crab from underbag trawl experiments (Somerton and Otto 1999). A bag underneath the regular trawl was used to catch animals that escaped under the footrope of the regular trawl, and was assumed to have selectivity equal to 1.0 for all sizes. The selectivity was estimated to be 50% at about 74 mm, 0.73 at 102 mm, and reached about 0.88 at the maximum size in the model of 135 mm.

Likelihood Equations

Weighting values (λ) for each likelihood equation are shown in Table 11.

Catch biomass is assumed to have a normal distribution,

$$\lambda \sum_{t=1}^{T} \left[C_{t,\, fishery, obs} - C_{t,\, fishery.pred} \right]^2$$

There are separate likelihood components for the retained and total catch.

The robust multinomial likelihood is used for length frequencies from the survey and the catch (retained and total) for the fraction of animals by sex in each 5mm length interval. The number of samples measured in each year is used to weight the likelihood. However, since thousands of crab are measured each year, the sample size was set at 200.

$$Length Likelihood = -\sum_{t=1}^{T} \sum_{l=1}^{L} nsamp_t * p_{t,l} \log(\hat{p}_{t,l} + o) - Offset$$

$$Offset = \sum_{t=1}^{T} \sum_{l=1}^{L} nsamp_t * p_{t,l} \log(p_{t,l})$$

Where, T is the number of years, $p_{t,l}$ is the proportion in length bin *l*, an *o* is fixed at 0.001.

An additional length likelihood weight (2) is added to the first year survey length composition fit to facilitate the estimation of the initial abundance parameters. A smoothness constraint is also added to the numbers at length by sex in the first year,

$$\sum_{S=1}^{2} \sum_{l=1}^{L} (first\, differences(N_{1978,s,l}))^2$$

The survey biomass (including biomass in the 2009 and 2010 study areas) assumes a lognormal distribution with the inverse of the standard deviation of the log(biomass) in each year used as a weight,

The survey biomass assumes a lognormal distribution with the inverse of the standard deviation of the log(biomass) in each year used as a weight,

$$\lambda \sum_{t=1}^{ts} \left[\frac{\log(SB_t) - \log(\hat{SB}_t)}{sqrt(2) * s.d.(\log(SB_t))} \right]^2$$

$$s.d.(\log(SB_t)) = sqrt(\log((cv(SB_t))^2 + 1))$$

Recruitment deviations likelihood equation is,

$$\lambda \sum_{s=1}^{2} \sum_{t=1}^{T} \tau_{s,t}^2$$

Smooth constraint on probability of maturing by sex and length

$$\sum_{S=1}^{2} \sum_{l=1}^{L} (\,first\,differences(\,first\,differences(PM_{s,l}))^2$$

Where $PM_{s,l}$ is a vector of parameters that define the probability of molting.

Penalties on Fishing mortalities (Models 4 and 5, 1978 to 1991 only for directed fishery fishing mortality penalties),

Penalty on average F for males (λ = 2 in last phases),

$$\lambda \sum_{t=1}^{T} (F_t - 1.15)^2$$

Fishing mortality deviations for males(λ = 0.1),

$$\lambda \sum_{t=1}^{T} \varepsilon_t^2$$

Female bycatch fishing mortality penalty (λ = 1.0, removed in Model 5).

$$\lambda \sum_{t=1}^{T} (\varepsilon_{female,t})^2$$

Trawl bycatch fishing mortality penalty (λ = 1.0).

$$\lambda \sum_{t=1}^{T} (\varepsilon_{trawl,t})^2$$

Model 5 removes F penalties on female fishing mortality estimates and uses potlifts to estimate fishing mortality for 1978 to 1991,

$$F_j = P_j \frac{\sum_{i=1992}^{\Pr esent} \frac{F_i}{P_i}}{N}$$

Where j is years 1978 to 1991. P is potlifts, N is the number of years from 1992 to present and F is fishing mortality.

Male natural mortality, when estimated in the model uses a penalty which assumes a normal distribution. A 95% CI of +/- 1.7 yrs translates to a 95% CI in M of about +-0.025 using an exponential model, which is a CV= 0.054.

$$0.5(\frac{M-0.23}{0.0125})^2$$

No penalty was used when immature M was estimate.

Likelihood equations were added for the sum of squares fit for the Base model with the new growth data by sex and a linear model by sex, where post-molt CW = a + b Premolt CW.
(λ = 2.0 Base model)

$$\lambda\ 0.5\sum(g_i - \hat{g}_i)^2$$

Where g_i is post-molt size from growth data (Somerton 2013) and $g^{\wedge}_i$ is predicted post-molt size from a linear model with intercept and slope parameters.

There were a total of 309 parameters estimated in the Base model (Table 10) for the 38 years of data (1978-2015). The 94 fishing mortality parameters (one set for the male catch, one set for the female discard catch, and one set for the trawl fishery bycatch) estimated in the model were constrained so that the estimated catch fit the observed catch closely. There were 38 recruitment parameters estimated in the model, one for the mean recruitment, 37 for each year from 1979 to 2014 (male and female recruitment were fixed to be equal). There were 8 fishery selectivity parameters that did not change over time. Survey selectivity was estimated for three different periods resulting in 9 parameters for males and 9 parameters for females. There were 6 survey selectivity parameters estimated for the study area for BSFRF female logistic availability curves for 2009 and 2010. 22 parameters for each year (2009 and 2010) for male crab were estimated for the smooth availability curve for the BSFRF net. Two parameters for natural mortality and 8 growth parameters were also estimated in the Base model.

Molting probabilities for mature males and females were fixed at 0, i.e., growth ceases at maturity which is consistent with the terminal molt paradigm (Rugolo et al. 2005 and Tamone et al. 2005). Molting probabilities were fixed at 1.0 for immature females and males. The intercept and slope of the linear growth function of postmolt relative to premolt size were estimated in the model (3 parameters, Table 10). A gamma distribution was used in the growth transition matrix with the beta parameters fixed at 0.75 for male and females.

The model separates crabs into mature, immature, new shell and old shell, and male and female for the population dynamics. The model estimate of survey mature biomass is fit to the observed survey mature biomass time series by sex. The model fits the size frequencies of the survey by immature and mature separately for each sex. The probability of immature crab maturing was estimated in the model using 22 parameters for each sex with a second difference smooth constraint (44 total parameters). The model fits the size frequencies for the pot fishery catch by new and old shell and by sex.

Crabs 25 mm CW (carapace width) and larger were included in the model, divided into 22 size bins of 5 mm each, from 25-29 mm to a plus group at 130-135mm. In this report the term size as well as length will be considered synonymous with CW. Recruits were distributed in the first few size bins using a two parameter gamma distribution with the alpha parameter of the distribution fixed at 11.5 and the beta parameter fixed at 4.0. Seventy parameters were estimated for the initial population size composition of new and old shell males and females in 1978. No spawner-recruit relationship was used in the population dynamics part of the model. Recruitments for each year were estimated in the model to fit the data.

The NMFS trawl survey occurs in summer each year, generally in June-July. In the model, the time of the survey is considered to be the start of the year (July), rather than January. The modern directed snow crab pot fishery has occurred generally in the winter months (January to February) over a short period of time. In contrast, in the early years the fishery occurred over a longer time period. The mean time of the fishery was estimated from the weighted distribution of catch by day for each year. The fishing mortality was applied all at once at the mean time for that year. Natural mortality is applied to the population from the time the survey occurs until the fishery occurs, then catch is removed. After the fishery occurs, growth and recruitment take place (in spring), with the remainder of the natural mortality through the end of the year as defined above.

Discard mortality

Discard mortality was 30% for all model scenarios as recommended by the CPT and the SSC in 2013 (See Appendix A). The fishery for snow crabs occurs in winter when low temperatures and wind may result in freezing of crabs on deck before they are returned to the sea. Short term mortality may occur due to exposure, which has been demonstrated in laboratory experiments by Zhou and Kruse (1998) and Shirley (1998), where 100% mortality occurred under temperature and wind conditions that may occur in the fishery. Even if damage did not result in short term mortality, immature crabs that are discarded may experience mortality during molting some time later in their life.

Model Scenarios

The base model in the current assessment fits a two part linear function with a smooth transition recommended in the 2014 CIE review (Cadigan 2014). Six model scenarios are presented in this assessment following recommendations by the CPT May 2015. Model 0 is the September 2014 model with the standard deviation parameter of the growth function fixed at a small value (0.5). Models 1 changes the parameterization of the survey logistic curves from estimating a size at 95% selected to an offset from the size at 50% parameter. Also, the survey q for the first time period and the survey availability for the industry survey in 2010 was changed to a probit scale to allow estimation of a variance when q is estimated at 1.0. Model 2 is Model 1 with the constraint on the probability of maturing removed, the weight on the smoothness constraint on the female probability of maturing increased and the weight on the fit to the trawl discard catch increased by 4 times. Model 3 the fixed size at 50% selected for female discard length data was changed from 4.2 to 4.4 (log scale) to better fit the length data. Model 3 also has increased weight on the likelihood for the fit to the growth data from 2.0 to 3.0. Model 4 removes the penalty on the directed fishing mortality estimates (male crab) from 1992 to present. Model 5 removes the penalty on female fishing mortality estimates from 1992 to present, potlift data are used to estimate pre-1992 fishing mortality for female discard.

Model 5 was selected as the base model as it removes all fishing mortality penalties from 1992 to present which have been shown to result in bias.

The CPT and SSC in 2010 and 2011 recommended the use of the BSFRF 2009 and 2010 survey data as an additional survey in the assessment model to inform estimates of survey selectivity.

The current models estimate natural mortality for immature crab (male and female as 1 parameter), mature male crab and growth parameters for male and female crab. Survey selectivities for the BSFRF and NMFS data in the study area are also estimated separately for males and females.

Following the recommendation of the CPT and SSC in 2011, abundance estimates by length as well as survey biomass for the study area for the BSFRF tows and the NMFS tows were included in the September 2011, 2012 stock assessment models and the current assessment as an additional survey. Likelihood equations were added to the model for fits to the length frequency by sex for the BSFRF tows in the study area and the NMFS tows in the study area. A likelihood equation was also added for fit to the mature biomass by sex in the study area for the BSFRF tows and NMFS tows separately.

The formulation used in this assessment (and since the September 2011) was recommended by the February 2011 Crab Modeling Workshop,

$$\tilde{C}_l^s = N_l \, Q_{BSFRF}^s A_l S_l Q_{NMFS}^n$$

$\tilde{C}_l^s =$ numbers by length for NMFS in study area

A_l = a smooth function of availability in the study area for the BSFRF net

S_l = 2 parameter logistic function for the entire Bering Sea for the NMFS net

Q_{BSFRF}^s = Q for study area (s) for the BSFRF net

Q_{NMFS}^n = Q for the entire Bering Sea NMFS net

N_l = population abundance by length

All Bering Sea male survey selectivity was estimated as a 3 parameter logistic function,

$$\text{Selectivity}_l = \frac{Q}{1 + e^{\left\{\frac{-\ln(19)(l - l_{50\%})}{(l_{95\%} - l_{50\%})}\right\}}}$$

The BSFRF availability was estimated as a smooth function (22 parameters, 1 parameter for each length bin(22),

$$A_l = \exp(p_l); \qquad p_l \leq 0.$$

A second difference constraint was added to the likelihood with a weight of 5.0,

$$5.0 \sum_{l=1}^{L} (\mathit{first\,differences}(\mathit{first\,differences}(p_l)))^2 \quad .$$

The maximum survey selectivity (Q) estimated for the entire Bering Sea area in Somerton et al. 2013 was estimated at 0.76 at 140 mm. The maximum size bin in the model is 130-135, which for the Somerton curve has a maximum selectivity of 0.75.

Projection Model Structure

The projection model was used to estimate the OFL, ABC and future biomass values. Variability in recruitment, as well as implementation error, was simulated with temporal autocorrelation. Recruitment was generated from a Beverton-Holt stock-recruitment model,

$$R_t = \frac{0.8\,h\,R_0\,B_t}{0.2\;spr_{F=0}\;R_0(1-h) + (h-0.2)B_t}\; e^{\varepsilon_t - \sigma_R^2/2}$$

$spr_{F=0}$ mature male biomass per recruit fishing at F=0. $B_0 = spr_{F=0}\ R_0$,
B_t mature male biomass at time t,
h steepness of the stock-recruitment curve defined as the fraction of R_0 at 20% of B_0,
R_0 recruitment when fishing at F=0,
σ_R^2 variance for recruitment deviations, estimated at 0.74 from the assessment model.

The temporal autocorrelation error (ε_t) was estimated as,

$$\varepsilon_t = \rho_R \varepsilon_{t-1} + \sqrt{1+\rho_R^2}\ \ \eta_t \qquad where\ \eta_t \sim N(0;\sigma_R^2) \tag{2}$$

ρ_R temporal autocorrelation coefficient for recruitment, set at 0.6.

Recruitment variability and autocorrelation were estimated using recruitment estimates from the stock assessment model. Steepness (h) and R_0 were estimated by setting B_{MSY} and Fmsy equal to $B_{35\%}$ and $F_{35\%}$ using a Beverton and Holt spawner recruit curve.

Implementation error was modeled as a lognormal autocorrelated error on the mature male biomass used to determine the fishing mortality rate in the harvest control rule,

$$B_t^{'} = B_t\ e^{\phi_t - \sigma_I^2/2}\ ;\ \ \phi_t = \rho_I \phi_{t-1} + \sqrt{1+\rho_I^2}\ \ \varphi_t \qquad where\ \varphi_t \sim N(0;\sigma_I^2)$$

$B_t^{'}$ mature male biomass in year t with implementation error input to the harvest control rule,
B_t mature male biomass in year t,
ρ_I temporal autocorrelation for implementation error, set at 0.6 (estimated from the recruitment time series),
σ_I standard deviation of φ which determines the magnitude of the implementation error.

Implementation error was set at a fixed value (e.g., 0.2) plus the s.d. on log scale from the assessment model for mature male biomass. Implementation error in mature male biomass resulted in fishing mortality values applied to the population that were either higher or lower than the values without implementation error. The autocorrelation was assumed to be the same value as that estimated for recruitment. Implementation autocorrelation was used to more closely approximate the process of estimating a biomass time series from within a stock assessment model. The variability in biomass of the simulated population resulted from the variability in recruitment and variability in full selection F arising from implementation error on biomass. The population dynamics equations were identical to those presented for the assessment model in the model structure section of this assessment.

RESULTS

The model estimated total mature biomass increased from about 377,100 t in 1978 to the peak biomass of 1,019,600 t in 1990 for the Base model (Table 6). Table 6a contains model predicted survey biomass and numbers. Model estimated total mature biomass declined after 1996 to about 345,100 t in 2003. Total mature biomass increased from 441,500 t in 2014 to 476,100 t in 2015 (Table 6 and Figure 4). The model results are informed by the population dynamics structure, including natural mortality, the growth and selectivity parameters and the fishery catches. The low observed survey abundance in the mid-1980's were followed by an abrupt increase in the survey abundance of crab in 1987, which followed through the population and resulted in the highest catches recorded in the early 1990's.

Average model estimated discard catch mortality for 1978/79 to 2014/15 was about 9.1% of the retained catch (with 30% mortality applied). The average observed discards from 1992 to 2014 was 8.4% of the retained catch (30% mortality applied) (Tables 1 and 2, and Figure 58). Estimates of observed discard mortality ranged from 2.5% of the retained catch to 19.2% of the retained catch (30% discard mortality). The percent observed discard has increased to 13% in 2013/14 and 11% in 2014/15 possibly due to recruitment.

Parameter estimates are listed in Table 10. The model fit to the total directed male catch, groundfish bycatch, male discard catch and female discard catch are shown in Figures 58, 59, 60, and 61 respectively.

Mature male and female biomass show similar trends (Table 3 and Table 6, Figures 62 and 64). Model estimates of mature male biomass declined from 238,600 t in 2009 to 156,900 t in 2013 then increased to 189, 000 t in 2014 and 209,900 t in 2015. Observed survey mature male biomass increased from 96,100 t in 2013 to 156,900 t in 2014, then declined to 79,000 t in 2015. Mature female biomass observed from the survey increased from 195,100 t in 2013 to 212,500 t in 2014, then declined to 128,100 t in 2015. Model estimates of mature female biomass have an increasing trend from 193,900 t in 2009 to 252,500 t in 2014 and 266,300 t in 2015. Comparisons between models for mature male and female biomass as shown in Figures 63 and 65. Mature male biomass estimates in 2015 declined moving from Model 0 (Model 1 same biomass) to Model 3, Model 2, Model 4 to Model 5. Mature female biomass estimates in 2015 declined moving from Model 0 (Model 1 same biomass) to Model 4, Model 3, Model 5 and Model 2.

Growth for male crab was estimated very similar between models, except the change point between line segments was at a larger size for model 4 (about 33 mm) than the other models (Figure 54e). Somerton et al. (2011) estimated the transition size at 36.1mm.
Growth for female crab varied more by model than for male crab. The change point between line segments was estimated at a smaller size for models 1 and 2 than the other models (Figure 54d). Models 0 and 1 estimated lower growth than others models. Models 3, 4 and 5 growth was very similar.

Fishery selectivities and retention curves were estimated using ascending logistic curves (Figures 56 and 66). Selectivities for trawl bycatch were estimated as ascending logistic curves (Figure 67). Plots of model fits to the survey size frequency data are presented in Figures 68 and 70 by sex for shell conditions combined with residual plots in Figures 69 and 71. A summary of the fit across all years for male and female length frequency data indicates a very good fit overall (Figure 72). The model is not fit to crab by shell condition due to the inaccuracy of shell condition as a measure of shell age. Tagging results presented earlier indicate that the number of animals that are more than one year from molting may be underestimated by using shell condition as a proxy for shell age. However, an accurate measure of shell age is needed to improve the estimation of the composition of the catch that is extracted from the stock.

Differences between the observed and predicted survey length frequencies could be a result of spatial differences in growth due to temperature, or size at maturity. These would need to be investigated using a spatial model. Changing growth or maturity over time simply to fit the length frequency data was not recommended by the 2008 CIE reviewers. There also could be changes in survey catchability by area or between years that could contribute to any lack of fit to the observed survey length frequency data.

The September 2014 assessment survey Q for the 1989 to present period was estimated at 0.61 for male crab (Turnock and Rugolo 2014). The Base model estimate for survey Q was 0.65. The maximum survey selectivity estimated using the 2009 study area by Somerton (2010) was 0.76 at 140 mm for male crab (Figure 90). The survey selectivity curves estimated for the base model are shown in Figure 57. Immature M was estimated at 0.39 (2014 assessment 0.37) and mature male M 0.27 (2014 assessment 0.27). Mature female M was fixed at 0.23.

The estimated number of males > 101mm generally follows the observed survey abundance estimates (Figure 73). Observed survey Males >101mm increased from 73.6 million in 2013 to 138.5 million in 2014 then declined to 57.2 million in 2015 (Table 3). Model estimates of large males show an increasing trend from 92.9 million in 2013 to 134.3 million in 2014 and 160.2 million in 2015.

Several periods of above average recruitment were estimated by the model in 1979-1981, 1983, 1987-1988, 1999, 2005 and 2010 (fertilization year, Figure 74). Recruits are 25mm to about 40 mm and may be about 4 years from hatching, 5 years from fertilization (Figure 75, although age is approximated). Lower than average recruitments were estimated from 1989 to 1998 and 2000 to 2004 and 2006 to 2009. The 2004 to 2006 years are estimated to be close to average recruitment and have resulted in an increase in biomass in recent years. The model estimates a large recruitment in 2010 (fertilization year) due to the higher abundance of small crab in the 2015 survey length data. Recruitment through the male stock can be seen in the abundance by length (Figure 8a).

The size at 50% selected for the pot fishery for total catch (retained plus discarded) was 105.9 mm for males (shell condition combined, Figure 56). The size at 50% selected for the retained catch was about 106 mm. The fishery generally targets and retains new shell animals > 101mm with clean hard shells and all legs intact. The fits to the fishery size frequencies are in Figures 76 through 81. Fits to the trawl fishery bycatch size frequency data are in Figures 82 through 84.

Fishing mortality rates ranged from 0.18 to 3.3 (Figure 85 and Table 6). Fishing mortality rates ranged from 0.9 to 3.9, for the 1986/87 to 1998/99 fishery seasons. For the period after the snow crab stock was declared overfished until rebuilt (1999/2000 to 2010/11), full selection fishing mortality ranged from 0.27 to 0.71. Fishing mortality rate increased from 1.07 in 2012/13 then decreased to 0.94 in 2013/14 then to 0.78 in 2014/15. Fishing mortality rates are higher in the base model than the September 2014 assessment due to the removable of F penalties and other changes to the model resulting in a higher survey Q and lower estimated model biomass (Figure 107). Estimates of male discard in the directed fishery were very similar for all models (Figure 108).

Base Model estimates of mature male biomass at mating decreased from 179,600 t in 2009/10 to 108,300 t in 2013/14 then increased to 129,300 t in 2014/15 (84% of $B_{35\%}$ (146,357 t), Table 6 and Figure 88). Mature male biomass at mating followed the same trends for Models 0 through 5, except in the last few years where biomass in 2015 decreased from Model 0 and Model 1 the same, Models 2 and 3 lower, then Model 4 and , Model 5 the lowest. 2015/16 MMB fishing at FOFL for Model 0 and Model 1 were projected to be 93% of $B_{35\%}$, while models 2 through 5 were projected to be about 84% to 86% of $B_{35\%}$ (Table 14). MMB at mating model estimates were lower for the 2014 assessment and for Model 5 in this assessment than for 2012 and 2013 assessments (Figure 103). This declining pattern is due to the influence on recent recruitment of the increased discard relative to retained crab in the directed fishery in 2013/14 and 2014/15 (2014 assessment and Model 5) as well as the removal of fishing mortality penalties in Model 5 in this assessment.

Recruitment estimates in recent years were higher for Models 0 and 1and lower for models 2 through 5 (Figure 104). All models estimate a much higher recruitment in 2010 (fertilization year).

Likelihood values for all 6 model scenarios are shown in Table 13. Total likelihood values are not comparable between scenarios due to different numbers of parameters, weights on likelihood components (growth and fishing mortality penalties, maturity likelihood) and differences in model structure.

The estimated growth by sex for the base model are shown in Figures 54b and 54c. Comparisons for estimated growth between models are shown in Figures 54d and 54e. The estimated growth transition matrix for males and females are shown in Figures 105 and 106.

Survey selectivity curves estimated for the Base model are shown in Figures 90 to 97. Base Model fits to the length frequency in the 2009 and 2010 study areas are shown in Figure 98. Base Model fits to the mature biomass in the 2009 and 2010 study areas are shown in Figures 99 and 100.

The history of fishing mortality and MMB at mating with the $F_{35\%}$ control rule for the Base model estimates the 2014/15 F to be below the overfishing level and MMB at mating at 84% of $B_{35\%}$ (Figure 101).

Models 4 and 5 have F penalties removed from 1992 to present and show slightly lower $B_{35\%}$ and higher $F_{35\%}$ than models with F penalties (Models 0, 1,2 and 3, Table 14).

The ending biomass estimates from the model are sensitive to the higher levels of discard relative to the retained catch in the 2014/15 fishery (Figures 109 and 110). Model 5 results were compared with various amounts of 2015 data: 1) all 2015 data (Model 5 run), 2) average discard in 2015 at the historical average relative to retained (lowered from 3,510 t to 2,300 t – all other 2015 data included, 3) average discard in 2015 at the historical average relative to retained (lowered from 3,510 t to 2,300 t) – no other 2015 data included, 4) observed discard catch in 2015, no other 2015 data, 5) observed discard and survey biomass 2015, no length data. The run with average discard in 2015 and no other data included results in higher recruitment estimates (Figure 111) and higher ending biomass levels and results in a larger overestimate of 2015 survey biomass than other runs (Figures 109 and 110). The addition of the observed discard catch in 2015 and no other 2015 data has a large effect on lowering ending biomass. Adding the 2015 survey biomass data lowers ending biomass a similar amount. The addition of the survey length data has little effect on ending biomass estimates, however, results in a very large estimate of recruitment in the last year of the model (Figure 111). The addition of the fishery length data has little effect after the survey length data are added (run not included). When all 2015 data are in the model and lower 2015 discard catch is used ending biomass is higher than for Model 5, however, not as high as when other 2015 data are removed.

Harvest Strategy and Projected Catch

Rebuilding Harvest Strategy

A rebuilding harvest strategy was developed and adopted in December 2000 in Amendment 14 and first applied in the 2000/01 fishing season (NPFMC 2000). Harvest strategy simulations are reported by Zheng et al. (2002) based on a model with structure and parameter values different than the model presented here. The harvest strategy by Zheng et al. (2002) was developed for use with survey biomass estimates. Prior to the passage of Amendment 24, B_{MSY} was defined as the average total mature survey biomass for 1983 to 1997. MSST was defined as ½ B_{MSY}. The harvest strategy consists of a threshold for opening the fishery (104,508 t (230.4 million lbs) of total mature biomass (TMB), 0.25* B_{MSY}), a minimum GHL of 6,804 t (15 million lbs) for opening the fishery, and rules for computing the GHL. This strategy without the minimum constraint is currently used by ADFG for setting the TAC.

This exploitation rate is based on total survey mature biomass (TMB) which decreases below maximum E when TMB < average 1983-97 TMB calculated from the survey.

$$E=\begin{cases} Bycatch\ only, Directed\ E=0, & if\ \dfrac{TMB}{averageTMB}<0.25 \\ \dfrac{0.225*\left[\dfrac{TMB}{averageTMB}-\alpha\right]}{(1-\alpha)} & if\ 0.25<\dfrac{TMB}{averageTMB}<1 \\ 0.225 & if\ \ TMB\ \geq\ averageTMB \end{cases} \qquad (13)$$

Where, α = -0.35 and averageTMB = 418,030 t (921.6 million lbs).

The maximum target for the retained catch is determined by using E as a multiplier on survey mature male biomass (MMB),

Retained Catch = E * MMB.

There is a 58% maximum harvest rate on exploited legal male abundance. Exploited legal male abundance is defined as the estimated abundance of all new shell males >=102 mm CW plus a percentage of the estimated abundance of old shell males >= 102 mm CW. The percentage to be used is determined using fishery selectivities for old shell males.

Overfishing Control Rule

Amendment 24 to the FMP introduced revised the definitions for overfishing. The information provided in this assessment is sufficient to estimate overfishing based on Tier 3b. The overfishing control rule for tier 3b is based on spawning biomass per recruit reference points (NPFMC 2007) (Figure 101).

$$F = \begin{cases} Bycatch\ only,\ Directed\ F = 0, & if\ \frac{B_t}{B_{REF}} \le \beta \\ \frac{F_{REF}\left[\frac{B_t}{B_{REF}} - \alpha\right]}{(1-\alpha)} & if\ \beta < \frac{B_t}{B_{REF}} < 1 \\ F_{REF} & if\ B_t \ge B_{REF} \end{cases} \quad (12)$$

B_t mature male biomass at time of mating in year t,

B_{REF} mature male biomass at time of mating resulting from fishing at F_{REF},

F_{REF} F_{MSY} or the fishing mortality that reduces mature male biomass at the time of mating-per-recruit to x% of its unfished level,

α fraction of B_{REF} where the harvest control rule intersects the x-axis if extended below β,

β fraction of B_{REF} below which directed fishing mortality is 0.

$B_{35\%}$ was estimated using average recruitment from1978/79 to 2014/15 and mature male biomass per recruit fishing at $F_{35\%}$.

The natural log of recruits/MMB at mating (5 yr lag for recruitment) indicates productivity of the Bering sea snow crab stock is currently not different from earlier levels (Figure 102).

Biomass and catch projections based on $F_{REF} = F_{35\%}$ and $B_{REF} = B_{35\%}$ were used to estimate the catch OFL and the ABC (Tables 9a and 9b). The OFL was estimated as the median of the distribution of OFLs from the stochastic projection model described earlier. The OFL for the Base model in 2015/16 was estimated at 61,500 t total catch (52,100 t retained catch). The previous year's OFL (2014/15) was 69,000 t of total catch. The average catch from 1978/79 to 1998/99 was 70,348 t, and was 19,975 t during the rebuilding period 1999/2000 to 2010/11.

The ABC was estimated at 61,200 t based on a probability of overfishing of 49% from the projection model with a cv= 0.10 on 2014/15 biomass estimated from the Hessian matrix by the ADMB software and the median of the projected distribution of catch fishing at $F_{35\%}$ as the estimate of OFL (Table 9a and Table 14). The SSC in 2014 recommended an ACL of 90% of the OFL for the 2014/15 fishing season. 90% of the 2015/16 Base Model OFL is 55,400 t of total catch (47,300 t of retained catch).

$F_{35\%}$ in the September 2014 assessment was estimated at 1.40 and $B_{35\%}$ at 142,909 t. $F_{35\%}$ for the Base model was 1.53 and $B_{35\%}$ 146,357 t. The MMB at mating projected for 2014/15 when fishing at the $F_{35\%}$ control rule (OFL) was 96.3% of $B_{35\%}$ from the base model in the September 2014 assessment. The MMB at mating projected for 2015/16 with the base model when fishing at the $F_{35\%}$ control rule (OFL) was 84.4% of $B_{35\%}$. Reference points for scenarios and key parameters for the 6 scenarios are shown in Table 14.

The total catch, including all bycatch of both sexes, using the control rule is estimated by the following equation,

$$catch = \sum_{s} \sum_{l} (1 - e^{-(F*Sel_{s,l} + F_{trawl}*Sel_{Trawl,l})}) w_{s,l} N_{s,l} \, e^{-M_s*.62}$$

Where $N_{S,l}$ is the current year numbers at length(l) and sex at the time of the survey estimated from the population dynamics model, M_s is natural mortality by sex, 0.625 is the time elapsed (in years) from when the survey occurs to the fishery, F is the value estimated from the harvest control rule using the current year mature male biomass projected forward to the time of mating time (Feb. 15), and $w_{s,l}$ is weight at length by sex. $Sel_{s,l}$ are the fishery selectivities by length and sex for the total catch (retained plus discard) estimated from the population dynamics model (Figure 56).

Projections were run for the Base model fishing at the $F_{35\%}$ control rule and fishing at a catch of 90% of the OFL (the SSC recommended ACL method in 2011/12 to 2014/15). Steepness of the Beverton and Holt spawner recruit curve used in projections was estimated at 0.75 and R_0 at 1.79 billion crab, by equating $F_{35\%}$ with Fmsy and $B_{35\%}$ with B_{MSY}.

Projections using the Base model estimate MMB at mating to increase over the next 5 years from 84.4% of $B_{35\%}$ in 2015/16 to 165.5% in 2020/21 fishing at the OFL (Tables 9a and 9b). Fishing at 90% of the OFL also results in increasing MMB over the next several years from about 87.1% of $B_{35\%}$ in 2015/16 to 179.7% of $B_{35\%}$ in 2020/21.

Conservation concerns

- Estimation of natural mortality in the model at values higher than estimates based on current knowledge of snow crab age could be risk prone. Aging methods need to be developed to improve estimation of natural mortality.
- Exploitation rates in the southern portion of the range of snow crab may have been higher than target rates, possibly contributing to the shift in distribution to less productive waters in the north.

Data Gaps and Research Needs

Research is needed to improve our knowledge of snow crab life history and population dynamics to reduce uncertainty in the estimation of current stock size, stock status and optimum harvest rates.

Tagging programs need to be initiated to estimate longevity and migrations. Studies and analyses are needed to estimate natural mortality.

A method of verifying shell age is needed for all crab species. A study was conducted using lipofuscin to age crabs, however verification of the method is needed. Radiometric aging of shells of mature crabs is costly and time consuming. Aging methods will provide information to assess the accuracy of assumed ages from assigned shell conditions (i.e. new, old, very old, etc), which have not been verified, except with the 21 radiometric ages reported here from Orensanz (unpub data).

Techniques for determining which males are effective at mating and how many females they can successfully mate with in a mating season are needed to estimate population dynamics and optimum harvest rates. At the present time it is assumed that when males reach morphometric maturity they stop growing and they are effective at mating. Field studies are needed to determine how morphometric maturity corresponds to male effectiveness in mating. In addition the uncertainty associated with the determination of morphometric maturity (the measurement of chelae height and the discriminate analysis to separate crabs into mature and immature) needs to be analyzed and incorporated into the determination of the maturity by length for male snow crab.

Female opilio in waters less than 1.5 ^{o} C and colder have been determined to be biennial spawners in the Bering Sea. Future recruitment may be affected by the fraction of biennial spawning females in the population as well as the estimated fecundity of females, which may depend on water temperature.

A female reproductive index needs to be developed that incorporates males, mating ratios, fecundity, sperm reserves, biennial spawning and spatial aspects.

Analysis needs to be conducted to determine a method of accounting for the spatial distribution of the catch and abundance in computing quotas.

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Table 1. Catch (1,000 t) for the snow crab pot fishery and groundfish trawl bycatch. Retained catch for 1973 to 1981 contain Japanese directed fishing. Observed discarded catch is the total estimate of discards before applying mortality. Discards from 1992 to 2011/12 were estimated from observer data. Total catch discard mortality applied.

Year fishery occurred	Retained catch (1000 t)	Observed Discard male catch (no mort. applied) (1000 t)	Observed Retained + discard male catch(no mort. Applied) (1000 t)	Year of trawl bycatch	Observed trawl bycatch(no mort. Applied) (1000 t)	Total catch (1000 t) 0.3 mort.applied directed fishery 0.8 mort. Applied GF	GHL(1980-2007) or TAC (2008 to present)(retained catch only) (1000 t)	OFL (2008/9 first year of total catch OFL) (1000 t)
1973/74	3.04			1973	13.63			
1974/75	2.28			1974	18.87			
1975/76	3.74			1975	7.3			
1976/77	4.56			1976	3.16			
1977/78	7.39			1977	2.14			
1978/79	23.72			1978	2.46			
1979/80	34.04			1979	1.98			
1980/81	30.37			1980	1.44		17.9-41.3	
1981/82	13.32			1981	0.6		7.3-10.0	
1982/83	11.85			1982	0.24		7.17	
1983/84	12.17			1983	0.31		22.23	
1984/85	29.95			1984	0.33		44.46	
1985/86	44.46			1985	0.29		25.86	
1986/87	46.24			1986	1.23		25.59	
1987/88	61.41			1987	0		50.23	
1988/89	67.81			1988	0.44		59.89	
1989/90	73.42			1989	0.51		63.43	
1990/91	149.11			1990	0.39		142.92	
1991/92	143.06	43.65	186.71	1991	1.95	157.7	151.09	
1992/93	104.71	56.65	161.37	1992	1.84	123.2	94.01	
1993/94	67.96	17.66	85.62	1993	1.81	74.7	48	
1994/95	34.14	13.36	47.5	1994	3.55	41.0	25.27	
1995/96	29.82	19.1	48.92	1995	1.35	36.6	23	
1996/97	54.24	24.68	78.92	1996	0.93	62.4	53.09	
1997/98	110.41	19.05	129.46	1997	1.5	117.3	102.5	
1998/99	88.02	15.5	103.52	1998	1.02	93.5	84.48	
1999/00	15.2	1.72	16.92	1999	0.61	16.2	12.93	
2000/01	11.46	2.06	13.52	2000	0.53	12.5	12.39	
2001/02	14.85	6.27	21.12	2001	0.39	17.0	13.97	
2002/03	12.84	4.51	17.35	2002	0.23	14.4	11.62	
2003/04	10.86	1.9	12.77	2003	0.76	12.0	9.44	
2004/05	11.29	1.69	12.98	2004	0.96	12.6	9.48	
2005/06	16.78	4.52	21.3	2005	0.37	18.4	16.74	
2006/07	16.5	5.9	22.39	2006	0.84	18.9	16.42	
2007/08	28.6	8.42	37.02	2007	0.44	31.5	28.58	
2008/09	26.56	6.86	33.42	2008	0.3	28.9	26.59	35.07
2009/10	21.82	4.09	25.91	2009/10	0.66	23.6	21.8	33.1
2010/11	24.67	2.05	26.72	2010/11	0.18	25.4	24.62	44.4
2011/12	40.3	5.63	45.93	2011/12	0.17	41.99	40.3	73.5
2012/13	30.06	7.74	37.80	2012/13	0.22	32.38	30.06	67.8
2013/14	24.48	10.88	35.36	2013/14	0.12	27.74	24.48	78.1
2014/15	30.82	11.71	42.53	2014/15	0.20	34.33	30.82	

Table 2. Base model estimates of catch (1,000 t) for Bering Sea snow crab. Model estimates of pot fishery discards include 30% mortality and groundfish discard 80% mortality.

Year	Model estimate of male retained (1000 t)	Model estimate of male discard(30% mort) (1000 t)	Model estimate Discard female catch (1000 t)	Model estimate groundfish bycatch(0.8 mort., 1000 t)	Model estimate total directed male catch (1000 t)	Model estimate total catch (1000 t)
1978/79	23.8	1.6	0	3.9	25.4	29.3
1979/80	34.1	1.8	0	3.1	35.9	39
1980/81	30.5	4.7	0	2.3	35.2	37.5
1981/82	13.4	5.7	0.1	0.9	19.1	20.1
1982/83	11.9	2.2	0	0.4	14.1	14.5
1983/84	12.2	0.8	0	0.5	13.1	13.6
1984/85	30	1.4	0	0.5	31.4	32
1985/86	44.5	2	0	0.4	46.5	47
1986/87	46.3	2.7	0.1	1.9	49	51
1987/88	61.5	7.2	0.1	0	68.7	68.8
1988/89	67.9	10.7	0.1	0.7	78.6	79.4
1989/90	73.6	10.4	0.1	0.8	84	84.9
1990/91	149.4	19	0.2	0.6	168.4	169.2
1991/92	143.3	22.2	0.2	1.9	165.5	167.6
1992/93	105	16.8	0.2	1.8	121.8	123.8
1993/94	67.9	6	0.1	1.8	73.9	75.8
1994/95	34.2	4	0.1	3.6	38.2	41.9
1995/96	29.9	5.9	0	1.3	35.8	37.1
1996/97	54.6	6.1	0.1	0.9	60.7	61.8
1997/98	114.4	6.9	0	1.5	121.4	122.9
1998/99	88.3	4.8	0	1	93.1	94.1
1999/00	15.1	0.8	0	0.6	15.9	16.5
2000/01	11.5	0.6	0	0.5	12.1	12.7
2001/02	15	1.1	0	0.4	16.1	16.5
2002/03	12.9	1.2	0	0.2	14.1	14.3
2003/04	10.9	0.7	0	0.8	11.6	12.3
2004/05	11.3	0.5	0	1	11.8	12.8
2005/06	16.9	0.9	0	0.4	17.8	18.2
2006/07	16.6	1.4	0	0.8	18	18.8
2007/08	28.6	2.7	0	0.4	31.4	31.8
2008/09	26.6	1.9	0	0.3	28.5	28.8
2009/10	21.8	1	0	0.6	22.9	23.5
2010/11	24.6	1	0	0.2	25.6	25.8
2011/12	40.4	1.7	0.3	0.2	42.1	42.5
2012/13	30.1	2.5	0	0.2	32.6	32.9
2013/14	24.7	3.0	0.1	0	27.7	27.8
2014/15	31.0	2.8	0.3	0	33.9	34.2

Table 3. Observed survey female, male and total spawning biomass(1000t) and numbers of males > 101mm (millions of crab).

Year	Observed survey female mature biomass	CV female mature biomass	Observed survey male mature biomass	CV male mature biomass	Observed survey total mature biomass	Observed number of males > 101mm (millions)
1978/79	153.0	0.2	193.1	0.12	346.2	163.4
1979/80	323.7	0.2	240.3	0.12	564.1	169.1
1980/81	364.9	0.2	193.8	0.12	558.7	133.9
1981/82	195.9	0.2	107.7	0.12	303.6	40.7
1982/83	213.3	0.2	173.1	0.12	386.4	60.9
1983/84	125.4	0.2	146.0	0.12	271.5	65.2
1984/85	70.4	0.4	161.2	0.24	231.5	139.9
1985/86	12.5	0.4	69.6	0.24	82.1	71.5
1986/87	47.7	0.4	87.3	0.24	135.1	77.1
1987/88	294.7	0.2	192.1	0.12	486.8	130.5
1988/89	276.9	0.125	251.6	0.12	528.5	170.2
1989/90	427.3	0.32	299.1	0.095	726.4	162.4
1990/91	312.1	0.185	442.4	0.105	754.5	389.6
1991/92	379.2	0.19	430.5	0.145	809.6	418.8
1992/93	242.4	0.2	238.5	0.12	480.9	232.5
1993/94	237.3	0.2	178.3	0.12	415.6	124.4
1994/95	216.8	0.16	163.6	0.15	380.4	71.2
1995/96	257.0	0.115	209.5	0.105	466.5	63.0
1996/97	161.7	0.145	281.7	0.09	443.4	154.8
1997/98	157.5	0.195	319.9	0.09	477.4	280.2
1998/99	124.3	0.255	201.1	0.12	325.4	208.4
1999/00	51.4	0.195	89.5	0.10	140.9	82.1
2000/01	152.4	0.435	88.9	0.14	241.3	65.7
2001/02	131.4	0.28	129.2	0.185	260.6	67.6
2002/03	50.5	0.295	90.2	0.195	140.8	63.1
2003/04	74.2	0.285	73.0	0.20	147.3	52.3
2004/05	84.5	0.28	75.8	0.16	160.3	56.0
2005/06	158.2	0.17	119.5	0.16	277.7	61.5
2006/07	109.6	0.17	134.5	0.18	244.2	118.7
2007/08	121.4	0.26	147.3	0.15	268.7	124.1
2008/09	86.4	0.22	121.6	0.10	208.0	97.7
2009/10	103.8	0.22	141.3	0.12	245.0	125.9
2010/11	145.1	0.156	157.3	0.142	302.4	137.6
2011/12	280.0	0.178	167.4	0.120	447.4	150.7
2012/13	220.6	0.198	120.8	0.143	341.4	87.0
2013/14	195.1	0.185	96.1	0.125	291.2	73.6
2014/15	212.5	0.207	156.9	0.192	369.4	138.5
2015/16	128.1	0.179	79.0	0.229	207.1	57.2

Table 4. Abundance estimates of females and males by size groups for the BSFRF net in the 2009 and 2010 study areas, the NMFS net in the study area, and the NMFS survey of the entire Bering Sea. Mature abundance uses the maturity curve.

		Females			Males	
	>25mm	>50mm	mature	>25mm	Mature	>100
2009 BSFRF Study	585.3	113.6	129.4	422.9	200.9	66.9
2009 NMFS Study	150.2	121.5	120.5	119.2	76.9	36.7
2009 NMFS Bering Sea	1773.5	828.7	1,143.9	1,225.0	463.8	147.2
2010 BSFRF Study	6372.1	2328.9	3459.4	3344.8	877.7	186.9
2010 NMFS Study	2509.2	919.0	1102.6	1318.9	402.8	68.8

Table 5. Observed and Predicted male and female mature biomass for the 2009 and 2010 study areas.

Mature Biomass (1000 t) 2009 and 2010 Study areas.

	BSFRF		NMFS	
	Female	Male	Female	Male
2009 Observed	12.2	68.4	11.9	32.3
2009 Predicted	18.3	57.6	10.2	37.7
2010 Observed	279.0	193.3	91.5	77.7
2010 Predicted	214.9	167.4	118.6	108.7

Table 6. Base model estimates of population biomass (1000t), population numbers, male, female and total mature biomass(1000t) and number of males greater than 101 mm in millions. Recruits enter the population at the beginning of the survey year after molting occurs. * Numbers by length estimated in the first year, so recruitment estimates start in second year.

Year	Biomass (1000t 25mm+)	numbers (million crabs 25mm+)	Female mature biomass(1000t)	Male mature biomass(1 000t)	Total mature biomass (1000t)	Number of males >101mm (millions)	Recruit- ment (millions, 25 mm to 50 mm)	Male mature biomas s at mating time(Fe b of survey year+1) (1000t)	Full selec tion fishin g morta lity	Exp.rat e of total male catch on mature male biomas s
1978/79	589.8	11470.3	192.0	185.1	377.1	130.8	1591.1	132.3	0.50	0.16
1979/80	661.6	11227.8	256.4	168.8	425.1	111.4	1399.3	105.4	0.89	0.25
1980/81	731.7	10788.9	375.4	125.2	500.6	56.0	1058.9	71.6	3.08	0.33
1981/82	754.3	9953.2	388.9	113.1	502.0	25.4	365.7	81.0	2.66	0.20
1982/83	754.9	8033.7	369.1	157.7	526.8	71.6	1396.7	121.9	0.53	0.11
1983/84	779.5	8792.9	325.4	237.5	562.9	184.5	2177.2	188.7	0.18	0.07
1984/85	834.9	10821.7	310.5	281.1	591.6	250.2	2650.0	207.5	0.34	0.13
1985/86	912.9	13100.6	338.3	275.6	614.0	244.0	5210.6	188.1	0.55	0.20
1986/87	1121.1	19784.3	390.4	249.3	639.7	191.0	1041.7	162.8	0.80	0.23
1987/88	1233.2	16042.6	520.9	252.8	773.7	157.3	4908.1	152.2	1.70	0.32
1988/89	1430.4	21402.1	538.4	289.3	827.8	163.1	222.3	177.7	1.91	0.32
1989/90	1463.5	15668.6	609.5	356.9	966.3	215.4	636.0	230.0	1.35	0.28
1990/91	1402.2	12728.3	574.8	444.7	1019.6	321.8	564.9	229.6	2.41	0.45
1991/92	1180.9	10403.6	491.0	407.0	898.1	273.7	6196.8	200.9	3.26	0.48
1992/93	1199.5	19957.6	418.9	335.7	754.5	212.7	2120.7	180.0	2.73	0.43
1993/94	1234.2	18236.7	536.1	289.6	825.7	180.4	907.6	175.5	1.60	0.30
1994/95	1234.4	14911.5	595.4	251.6	847.0	105.1	275.9	175.4	1.22	0.18
1995/96	1196.9	11521.6	549.9	282.0	831.9	109.9	129.3	208.4	0.95	0.15
1996/97	1121.4	8877.6	465.5	389.5	855.0	263.8	176.5	276.2	0.68	0.18
1997/98	970.3	7036.4	380.5	458.4	838.9	401.5	805.1	273.0	1.02	0.31
1998/99	749.2	6836.4	310.6	349.8	660.4	288.6	1067.2	205.5	1.11	0.31
1999/00	604.3	7147.5	275.0	228.1	503.1	155.4	308.5	177.0	0.27	0.08
2000/01	546.5	5889.1	265.4	185.2	450.6	119.5	295.7	144.4	0.27	0.08
2001/02	495.9	4993.4	239.9	157.8	397.7	92.7	627.7	117.7	0.48	0.12
2002/03	463.7	4999.8	207.3	148.0	355.3	88.8	1372.7	112.0	0.44	0.11
2003/04	480.7	6447.3	189.9	155.2	345.1	113.0	2155.2	119.9	0.27	0.09
2004/05	557.6	8972.3	204.6	156.8	361.4	123.8	770.9	120.5	0.25	0.09
2005/06	605.7	7937.4	253.7	151.8	405.5	109.6	972.6	111.0	0.45	0.14
2006/07	640.5	7704.3	264.3	158.3	422.5	101.0	155.7	116.7	0.50	0.13

Table 6 Cont. Base model estimates of population biomass (1000t), population numbers, male, female and total mature biomass(1000t) and number of males greater than 101 mm in millions. Recruits enter the population at the beginning of the survey year after molting occurs. * Numbers by length estimated in the first year, so recruitment estimates start in second year.

Year	Biomass (1000t 25mm+)	numbers (million crabs 25mm+)	Female mature biomass(1000t)	Male mature biomass (1000t)	Total mature biomass (1000t)	Number of males >101mm (millions)	Recruit-ment (millions, 25 mm to 50 mm)	Male mature biomass at mating time(Feb of survey year+1) (1000t)	Full selection fishing mortality	Exp.rate of total male catch on mature male biomass
2007/08	633.6	5926.5	257.8	191.0	448.8	132.3	265.1	133.1	0.71	0.19
2008/09	588.0	4916.2	227.6	224.6	452.3	181.2	1179.9	163.6	0.44	0.15
2009/10	564.1	6027.7	193.9	238.6	432.5	212.7	1679.4	179.6	0.29	0.11
2010/11	581.9	7741.3	195.5	223.8	419.4	204.8	1031.0	164.5	0.34	0.14
2011/12	595.8	7603.1	227.7	195.1	422.8	168.4	960.2	123.9	0.78	0.25
2012/13	593.2	7383.3	243.1	155.5	398.6	101.8	1302.0	100.6	1.07	0.25
2013/14	622.8	7947.4	243.9	156.9	400.8	92.9	1355.6	108.3	0.94	0.21
2014/15	668.5	8445.4	252.5	189.0	441.5	134.3	5660.2	129.3	0.78	0.21
2015/16	896.7	17401.7	266.3	209.9	476.1	160.2	NA	NA	NA	NA

Table 6a. Base model predicted survey values for female, male and total mature biomass and numbers of males > 101mm (millions of crab).

	Predicted Female Survey Mature Biomass:	Predicted Male survey mature Biomass:	Predicted total survey mature Biomass:	model Predicted survey males>101 (millions)
1978	143.7	184.7	328.4	130.8
1979	184.5	167.8	352.3	111.4
1980	276.0	123.4	399.4	56.0
1981	288.4	110.9	399.3	25.4
1982	164.6	108.6	273.2	52.2
1983	145.6	167.0	312.6	134.4
1984	138.7	198.9	337.6	182.2
1985	150.9	194.3	345.3	177.7
1986	174.3	173.9	348.2	139.1
1987	232.0	173.7	405.7	114.6
1988	242.0	198.6	440.5	118.8
1989	336.3	230.5	566.8	141.1
1990	317.5	288.1	605.6	210.8
1991	271.3	263.9	535.1	179.2
1992	231.4	217.6	449.0	139.3
1993	295.7	186.9	482.6	118.2
1994	328.8	161.6	490.4	68.8
1995	303.7	181.7	485.4	72.0
1996	257.2	252.6	509.8	172.8
1997	210.2	298.2	508.4	263.0
1998	171.6	227.5	399.1	189.0
1999	151.9	148.0	299.9	101.8
2000	146.5	120.0	266.5	78.2
2001	132.5	102.1	234.6	60.7
2002	114.5	95.9	210.4	58.2
2003	104.9	100.7	205.6	74.0
2004	112.9	101.7	214.6	81.1
2005	140.0	98.1	238.1	71.8
2006	145.9	102.3	248.2	66.1
2007	142.4	123.7	266.1	86.6
2008	125.8	145.9	271.6	118.7
2009	107.1	155.2	262.4	139.3
2010	108.0	145.6	253.5	134.1
2011	125.7	126.6	252.3	110.3
2012	134.3	100.5	234.8	66.7
2013	134.7	101.5	236.1	60.9
2014	139.4	122.4	261.8	88.0
2015	147.0	136.0	283.0	105.0

Table 7. Radiometric ages for male crabs for shell conditions 1 through 5. Data from Orensanz (unpub).

				Radiometric age	
Shell Condition	description	sample size	Mean	minimum	maximum
1	soft	6	0.15	0.05	0.25
2	new	6	0.69	0.33	1.07
3	old	3	1.02	0.92	1.1
4	very old	3	5.31	4.43	6.6
5	very very old	3	4.59	2.7	6.85

Table 8. Natural mortality estimates for Hoenig (1983), the 5% rule and the 1% rule, given the oldest observed age.

	Natural Mortality		
oldest observed age	Hoenig (1983) empirical	5% rule	1% Rule
10	0.42	0.3	0.46
15	0.28	0.2	0.30
17	0.25	0.18	0.27
20	0.21	0.15	0.23

Tables 9a-b. Projections using a multiplier on the $F_{35\%}$ control rule for 2015/16 to 2025/26 fishery seasons. Median total catch (ABC_{tot} 1000 t), median retained catch (C_{dir} 1000 t), Percent mature male biomass at time of mating relative to B35. Values in parentheses are 90% CI. F is full selection fishing mortality. Base model $B_{35\%}$ = 146,357 t. $F_{35\%}$ = 1.53.

a) 100%OFL Base Model, 100% $F_{35\%}$ $B_{35\%}$ = 146,357 t $F_{35\%}$=1.53

Year	**ABC_{tot} (1000t)**	**C_{dir} (1000t)**	**Percent MMB/ $B_{35\%}$**	**Full Selection Fishing Mortality**
2015/16	61.5(48.7,80.5)	52.1(41.5,67.7)	83.8(74.9,95.5)	1.26
2016/17	54.6(34.4,77)	43(28,58)	87.4(74.2,102.6)	1.27
2017/18	61.5(40.4,78.9)	44.4(31.5,56.3)	103.5(87.2,123.7)	1.47
2018/19	79.2(57.1,102.2)	57.1(43.2,71.4)	130.8(109.3,162.2)	1.49
2019/20	122.3(95,167)	98.2(78.1,126.7)	159.1(124.3,218.1)	1.47
2020/21	142.6(106.3,224.4)	120.6(92.6,182)	165.5(115.4,267.6)	1.48
2021/22	114.9(61.4,249.7)	95.3(50.6,203.8)	146.9(92.2,283.6)	1.48
2022/23	91.5(33.3,229.4)	73.9(26.2,185.2)	133.3(77.8,282.1)	1.43
2023/24	79.6(25.6,221.4)	62.3(19.1,179.4)	123.6(69.9,294.8)	1.43
2024/25	73.4(21.7,212.7)	56.1(16.7,176.9)	120.5(67.4,286.7)	1.39
2025/26	75.9(21.2,216.9)	57.4(15.8,176.6)	120.3(64,293.9)	1.26

b) 90% Catch at FOFL Base Model, $B_{35\%}$ = 146,357 t. $F_{35\%}$ = 1.53.

Year	**ABC_{tot} (1000t)**	**C_{dir} (1000t)**	**Percent MMB/ $B_{35\%}$**	**Full Selection Fishing Mortality**
2015/16	55.4(43.7,73)	47.3(37.5,61.9)	87.1(77.7,99.5)	1.09
2016/17	51.5(32,71.2)	41.4(26.5,55.3)	91.6(77.8,107.6)	1.1
2017/18	56.9(37.8,72.7)	42.7(30,53.7)	108.3(91.5,129.2)	1.23
2018/19	72.1(53.1,94.1)	53.7(41,67.6)	137.5(114.9,169.2)	1.23
2019/20	112(85.8,152.9)	91.5(72.1,119.7)	169.6(133.3,230.3)	1.21
2020/21	133.4(100.1,205.9)	114.5(88.2,171.7)	179.7(126.3,284.9)	1.22
2021/22	110.3(62.9,234.7)	93.5(53.3,193.9)	160.7(99.8,306.8)	1.23
2022/23	89(34.5,216.2)	74.3(28,182.9)	145.2(82.6,307.6)	1.2
2023/24	77.6(25.7,206.9)	62.5(20.2,174.6)	134(74.4,318.2)	1.2
2024/25	70.1(21.5,205.2)	55.6(16.7,175.5)	129(71.7,312.1)	1.17
2025/26	73.1(20.9,206.3)	56.8(15.8,170.2)	129.6(68,321.5)	1.18

Table 10. Base Model Parameters values for the base model, excluding recruitments, probability of maturing and fishing mortality parameters.

Parameter	Value	S.D. for estimated parameters	Estimated(Y/N)	Bounded (bounds)
Natural Mortality immature females and males	0.39	0.02	Y	0.05,0.46
Natural Mortality mature females	0.23		N	
Natural Mortality mature males	0.27	0.01	Y	0.05,0.46
Female intercept (a1) growth	-3.37	0.91	Y	0,10
Male intercept(a1) growth	-16.02	2.28	Y	
Female slope(b1) growth	1.46	0.03	Y	1,1.3
Male slope (b1) growth	1.96	0.09	Y	
Male slope (b2) growth	1.16	0.01	Y	
Female slope(b2) growth	1.09	0.03	Y	
male delta	27.33	0.35	Y	
female delta	33.54	0.81	Y	
female and male s (scale parameter smooth)	0.50		N	
Alpha for gamma distribution of recruits	11.50		N	
Beta for gamma distribution of recruits	4.00		N	
Beta for gamma distribution female growth	0.75		N	
Beta for gamma distribution male growth	0.75		N	
Fishery selectivity total males slope	0.19	0.01	Y	0.1,0.5
Fishery selectivity total males length at 50%	105.84	0.14	Y	55,148
Fishery selectivity retention curve males slope	0.41	0.02	Y	0.05,0.5
Fishery selectivity retention curve males length at 50%	95.71	0.18	Y	85,120
Fishery discard selectivity female slope	0.25	0.01	Y	0.1,0.7
Fishery discard selectivity female length at 50%	81.50		N	
Trawl Fishery selectivity slope	0.09	0.00	Y	0.01,.3
Trawl Fishery selectivity length at 50%	107.19	2.69	Y	30,120
Survey Q 1978-1981 male	1.0(6.1 probit)	120.24	Y	-5.0,6.0
Survey 1978-1981 length at 95% of Q male	59.34	2.88	Y	30,150
Survey 1978-1981 length at 50% of Q male	42.03	1.35	Y	0,150
Survey Q 1978-1981 Female	0.85	0.04	Y	0.04,2.0
Survey 1978-1981 length at 95% of Q female	59.34		Set equal to Male	
Survey 1978-1981 length at 50% of Q female	42.03		Set equal to Male	
Survey Q 1982-1988 male	0.73	0.06	Y	0.2,1.0
Survey 1982-1988 length at 95% of Q male	74.87	4.51	Y	50,160
Survey 1982-1988 length at 50% of Q male	45.69	2.34	Y	0,80
Survey Q 1982-1988 female	0.62	0.03	Y	0.04,2.0
Survey 1982-1988 length at 95% of Q female	74.87		Set equal to Male	50,160
Survey 1982-1988 length at 50% of Q female	45.69		Set equal to Male	0,80

Table 10 cont. Base Model Parameters values for the base model, excluding recruitments, probability of maturing and fishing mortality parameters.

Parameter	Value	S.D. for estimated parameters	Estimated(Y/N)	Bounded (bounds)
Survey Q 1989-present male	0.65	0.04	Y	0.2,1.0
Survey 1989-present, length at 95% of Q male	58.99	2.57	Y	40,200
Survey 1989-present length at 50% of Q male	38.85	1.15	Y	20,90
Female Survey Q 1989-present	0.56	0.02	Y	0.04,2.0
Female Survey 1989-present, length at 95% of Q	46.04	1.26	Y	40,150
Female Survey 1989-present length at 50% of Q	34.36	0.60	Y	0,90
Male BSFRF 2009 Study area Q (availability)	0.39	0.10	Y	0.1,1.0
Female BSFRF 2009 Study area Q (availability)	0.33	0.06	Y	0.01,1.0
Female BSFRF 2009 Study area length at 95% of Q	57.94	2.15	Y	50,120
Female BSFRF 2009 Study are length at 50% of Q	50.87	1.25	Y	-50.0,60.0
male BSFRF 2010 Study area Q (availability)	1.0(6.3 probit)	118.00	Y	-5.0,6.0
Female BSFRF 2010 Study area Q (availability)	1.10	0.13	Y	0.5,2.0
Female BSFRF 2010 Study area length at 95% of Q	25		N	
Female BSFRF 2010 Study are length at 50% of Q	25		N	

Table 11. Weighting factors for likelihood equations.

Likelihood component	Weighting factor	Equivalent CV, SD or sample size
Retained catch	10	SD=0.22
Retained catch length comp	1	Sample size 200
Total catch	10	SD=0.22
Total catch length comp	1	Sample size 200
Female pot catch	10	SD=0.22
Female pot fishery length comp	0.2	Sample size 200
Trawl catch	10	SD=0.22
Trawl catch length comp	0.25	Sample size 200
Survey biomass	survey cv by year	See cv table
Survey length comp	1	Sample size 200
Recruitment deviations	1	CV=0.7
Second difference maturity probability male, female	2,10	
Growth	3.0	
Fishing mortality deviations males 1978-1991	5.0	CV=0.2
Initial length comp smoothness	1	SD=0.7
Trawl catch fishing mortality deviations	0.01	

Table 12. Base Model estimated recruitments (male) and mature male biomass at mating with standard deviations. Recruits enter the population at the beginning of the survey year.

Survey year	Recruit (male,millions)	S.D.	MMB at mating (1000 tons)	S.D.
1978/79			132.34	10.53
1979/80	1,591.10	365.29	105.42	7.04
1980/81	1,399.30	332.17	71.59	5.28
1981/82	1,058.90	272.56	80.98	5.71
1982/83	365.67	160.63	121.89	9.36
1983/84	1,396.70	266.26	188.66	14.21
1984/85	2,177.20	380.64	207.52	16.29
1985/86	2,650.00	452.83	188.05	15.52
1986/87	5,210.60	651.37	162.79	13.34
1987/88	1,041.70	357.57	152.19	11.67
1988/89	4,908.00	508.50	177.65	12.49
1989/90	222.33	94.15	229.98	14.25
1990/91	635.99	109.54	229.60	13.82
1991/92	564.89	137.13	200.88	12.41
1992/93	6,196.80	627.03	179.97	11.50
1993/94	2,120.70	380.23	175.55	11.27
1994/95	907.60	158.72	175.43	12.01
1995/96	275.86	86.06	208.41	14.66
1996/97	129.34	46.66	276.16	18.22
1997/98	176.48	62.65	272.97	18.53
1998/99	805.13	146.07	205.54	16.04
1999/00	1,067.20	180.14	176.96	13.39
2000/01	308.52	88.88	144.38	11.16
2001/02	295.70	85.73	117.73	9.78
2002/03	627.70	131.02	112.00	9.28
2003/04	1,372.70	229.16	119.89	9.23
2004/05	2,155.20	293.34	120.50	8.86
2005/06	770.90	189.12	111.05	8.44
2006/07	972.59	162.74	116.69	8.85
2007/08	155.71	56.51	133.05	10.26
2008/09	265.06	63.93	163.58	11.66
2009/10	1,179.90	150.30	179.57	11.24
2010/11	1,679.40	258.61	164.47	9.50
2011/12	1,031.00	238.57	123.87	8.14
2012/13	960.16	229.36	100.59	8.19
2013/14	1,302.00	274.47	108.28	10.14
2014/15	1,355.60	346.01	129.29	13.88
2015/16	5,660.20	1,167.80		

Table 13. Likelihood values for base model and 5 model scenarios.

Likelihood Component	Model 0	Model 1	Model 2	Model 3	Model 4	Model 5 (Base Model)
Recruitment	35.66	35.47	34.38	34.6	36.91	36.25
Initial numbers old shell males small length bins	2.21	2.22	2.19	2.19	2.33	2.33
ret fishery length	352.94	353.40	347.94	350.71	339.03	339.29
total fish length	787.15	787.37	781.83	783.45	779.05	778.23
female fish length	228.95	229.14	244.93	215.3	215.94	216.20
survey length	3845.13	3841.43	3873.05	3885.34	3882.91	3883.35
trawl length	274.61	275.01	278.54	279.53	274.21	275.33
2009 BSFRF length	-83.22	-83.03	-83.37	-82.88	-83.15	-83.37
2009 NMFS study area length	-71.02	-70.89	-71.57	-72	-71.68	-71.75
M prior	9.62	9.51	9.53	9.11	8.72	8.99
maturity smooth	57.29	57.59	34.17	15.4	15.07	15.15
growth males	35.56	35.68	37.53	43.7	42.81	45.88
growth females	47.04	47.29	34.56	37.87	37.79	37.77
2009 BSFRF biomass	0.14	0.15	0.18	0.17	0.21	0.22
2009 NMFS study area biomass	0.06	0.06	0.08	0.09	0.13	0.13
retained catch	2.36	2.38	2.13	2.2	2.68	2.52
discard catch	115.58	116.88	103.56	107.59	121.11	112.64
trawl catch	9.30	9.32	17.05	16.60	5.67	6.18
female discard catch	23.68	23.66	4.91	5.19	5.06	0.25
survey biomass	192.78	192.76	192.08	191.97	184.52	184.17
F penalty	84.37	84.53	86.46	86.33	40.67	30.49
2010 BSFRF Biomass	1.50	1.47	1.86	1.77	2.12	2.20
2010 NMFS Biomass	1.01	1.03	1.41	1.31	1.72	1.76
initial numbers fit	508.09	508.61	507.85	509	508.12	507.64
2010 BSFRF length	-58.25	-59.41	-59.32	-58.49	-58.02	-58.16
2010 NMFS length	-67.07	-67.68	-67.65	-66.69	-66.25	-66.05
male survey selectivity smooth constraint	3.74	3.72	3.92	3.96	3.78	3.80
init nos smooth constraint	39.81	39.3103	40.41	40.92	40.62	40.80
Total	6379.01	6376.97	6358.64	6344.24	6272.04	6252.20

Table 13. Differences in Likelihood values for 5 model scenarios relative to model 0 (negative values are better fits than Model 0).

Likelihood Component	Model 0	Model 1	Model 2	Model 3	Model 4	Model 5 (Base Model)
Recruitment	0.00	-0.19	-1.28	-1.06	1.24	0.58
Initial numbers old shell males small length bins	0.00	0.01	-0.03	-0.02	0.11	0.11
ret fishery length	0.00	0.46	-4.99	-2.23	-13.91	-13.65
total fish length	0.00	0.22	-5.32	-3.70	-8.10	-8.92
female fish length	0.00	0.19	15.98	-13.65	-13.02	-12.75
survey length	0.00	-3.70	27.92	40.21	37.78	38.22
trawl length	0.00	0.40	3.93	4.92	-0.40	0.72
2009 BSFRF length	0.00	0.19	-0.15	0.34	0.06	-0.16
2009 NMFS study area length	0.00	0.13	-0.55	-0.98	-0.66	-0.73
M prior	0.00	-0.11	-0.08	-0.51	-0.90	-0.62
maturity smooth	0.00	0.30	-23.12	-41.89	-42.23	-42.15
growth males	0.00	0.12	1.97	8.14	7.26	10.33
growth females	0.00	0.25	-12.48	-9.17	-9.25	-9.28
2009 BSFRF biomass	0.00	0.00	0.04	0.03	0.07	0.07
2009 NMFS study area biomass	0.00	0.00	0.03	0.03	0.07	0.08
retained catch	0.00	0.02	-0.23	-0.16	0.32	0.17
discard catch	0.00	1.30	-12.02	-7.99	5.53	-2.94
trawl catch	0.00	0.02	7.75	7.30	-3.63	-3.11
female discard catch	0.00	-0.01	-6.63	-7.08	-18.01	-17.49
survey biomass	0.00	-0.02	-0.71	-0.81	-8.27	-8.61
F penalty	0.00	0.16	2.09	1.96	-43.70	-53.88
2010 BSFRF Biomass	0.00	-0.03	0.36	0.27	0.62	0.70
2010 NMFS Biomass	0.00	0.02	0.40	0.30	0.70	0.74
initial numbers fit	0.00	0.51	-0.24	0.91	0.03	-0.46
2010 BSFRF length	0.00	-1.16	-1.06	-0.24	0.23	0.09
2010 NMFS length	0.00	-0.61	-0.58	0.38	0.82	1.02
male survey selectivity smooth constraint	0.00	-0.02	0.18	0.22	0.04	0.05
init nos smooth constraint	0.00	-0.50	0.60	1.11	0.82	0.99
Total	0.00	-2.04	-20.37	-34.77	-106.97	-126.81
No. Parameters	323	323	323	323	323	309

Table 14. Reference values for 6 model scenarios.

Model	0	1	2	3	4	5
$B_{35\%}$	157.8	157.8	149.5	150.8	147.4	146.4
$F_{35\%}$	1.42	1.42	1.22	1.21	1.51	1.53
OFL 2014/15	83.1	82.5	60.9	61.5	63.2	61.5
ABC(p*=.49) 2014/15	82.7	82.1	60.9	61.2	62.9	61.2
ABC(90%OFL) 2014/15	74.8	74.3	54.8	55.4	56.9	55.4
Percent MMB/ $B_{35\%}$ 2015/16 fishing at OFL	93.3	93.3	84.9	85.1	85.5	84.4
MMB 2014/15	168.0	167.4	136.5	137.4	132.4	129.3
Survey Q 1989-present	0.58	0.58	0.62	0.61	0.65	0.65
M mature males	0.27	0.27	0.27	0.27	0.27	0.27

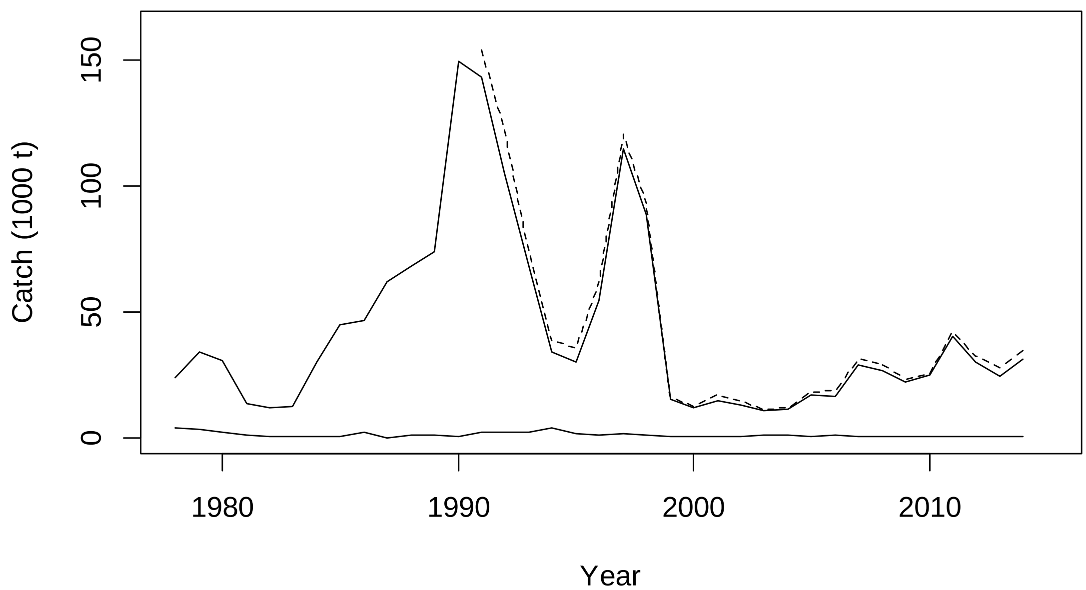

Figure 1. Catch (1000 t) from the directed snow crab pot fishery and groundfish trawl bycatch. Total catch (dashed line) is retained catch(solid line) plus discarded catch after 30% discard mortality was applied. Trawl bycatch (lower solid line) is male and female bycatch from groundfish trawl fisheries with 80% mortality applied.

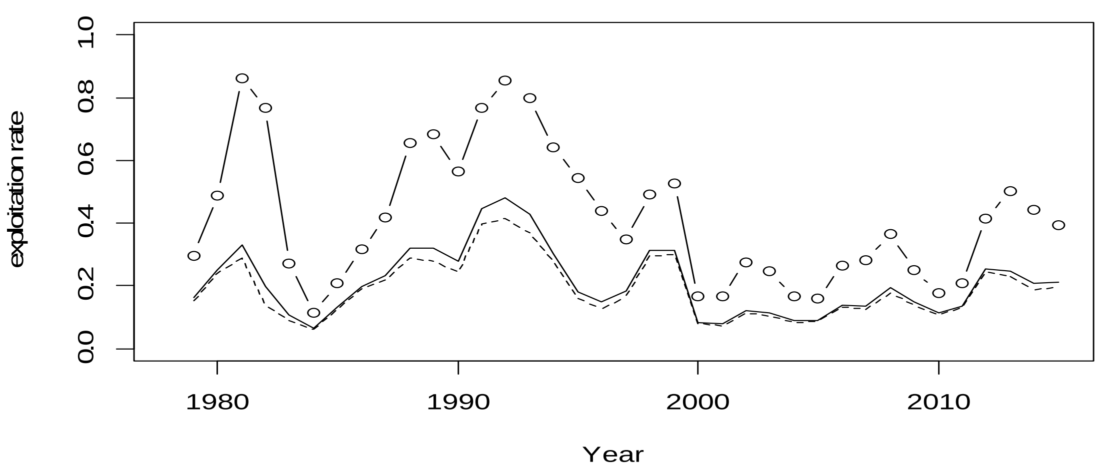

Figure 2. Base Model. Exploitation fraction estimated as the catch biomass (total or retained) divided by the mature male biomass from the model at the time of the fishery (solid line is total and dotted line is retained). The exploitation rate for total catch divided by the male biomass greater than 101 mm is the solid line with dots. Year is the year of the fishery.

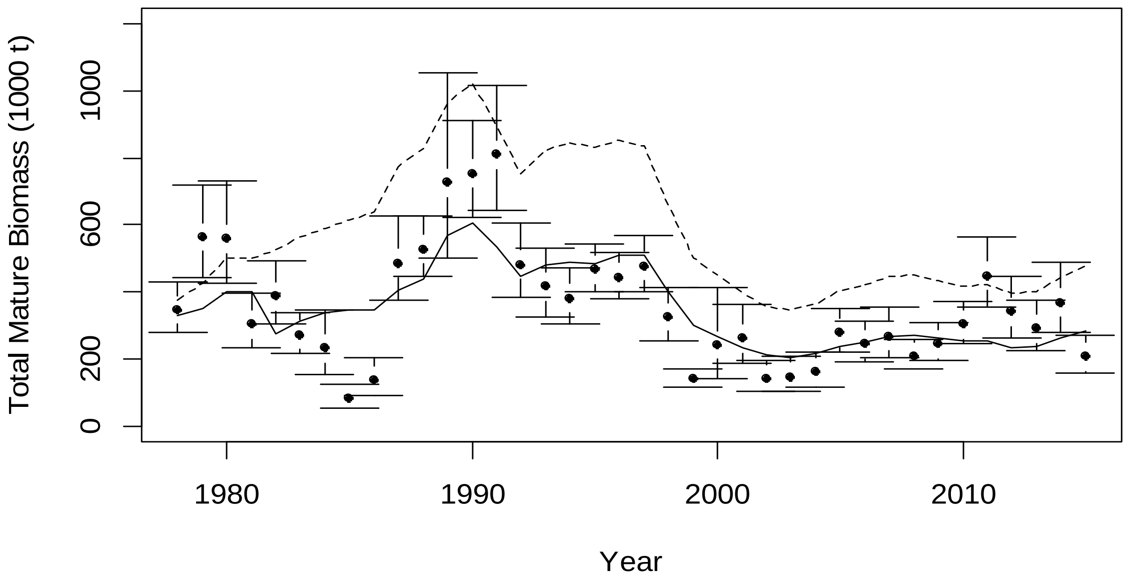

Figure 3. Population total mature biomass (millions of pounds, solid line), model estimate of survey mature biomass (dotted line) and observed survey mature biomass with approximate lognormal 95% confidence intervals.

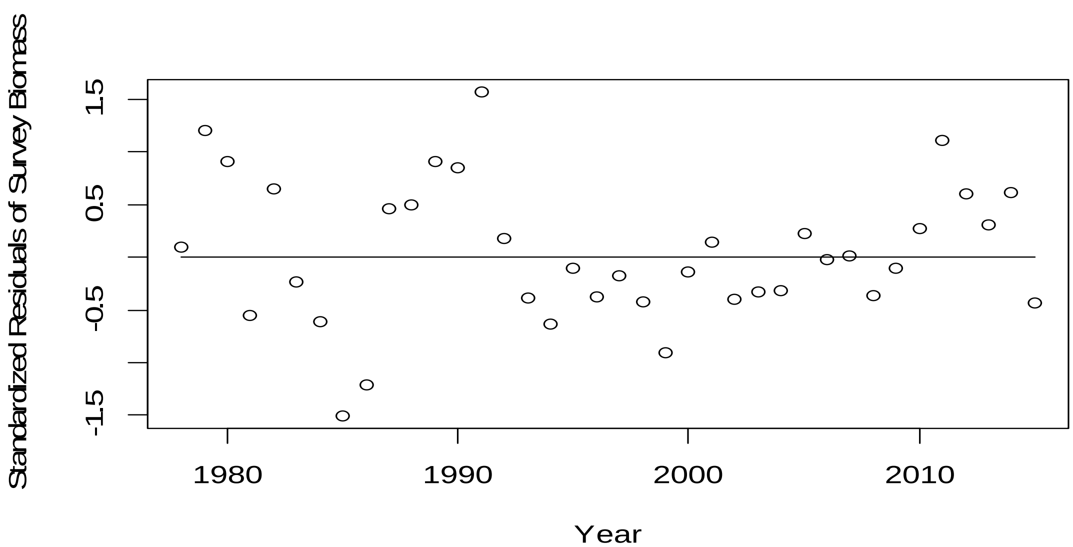

Figure 4. Standardized residuals for model fit to total mature biomass from Figure 3.

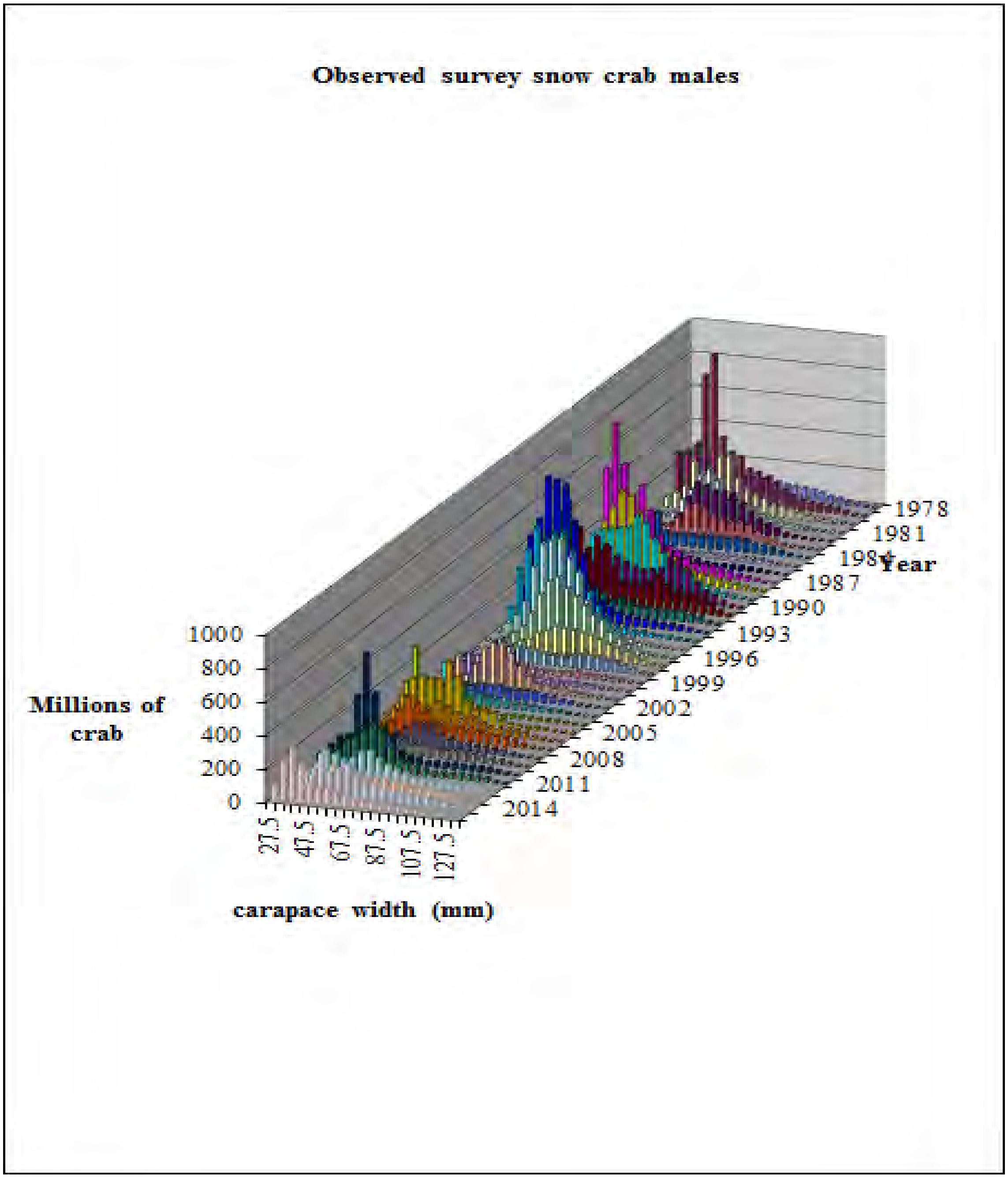

Figure 5. Observed survey numbers (millions of crab) by carapace width and year for male snow crab.

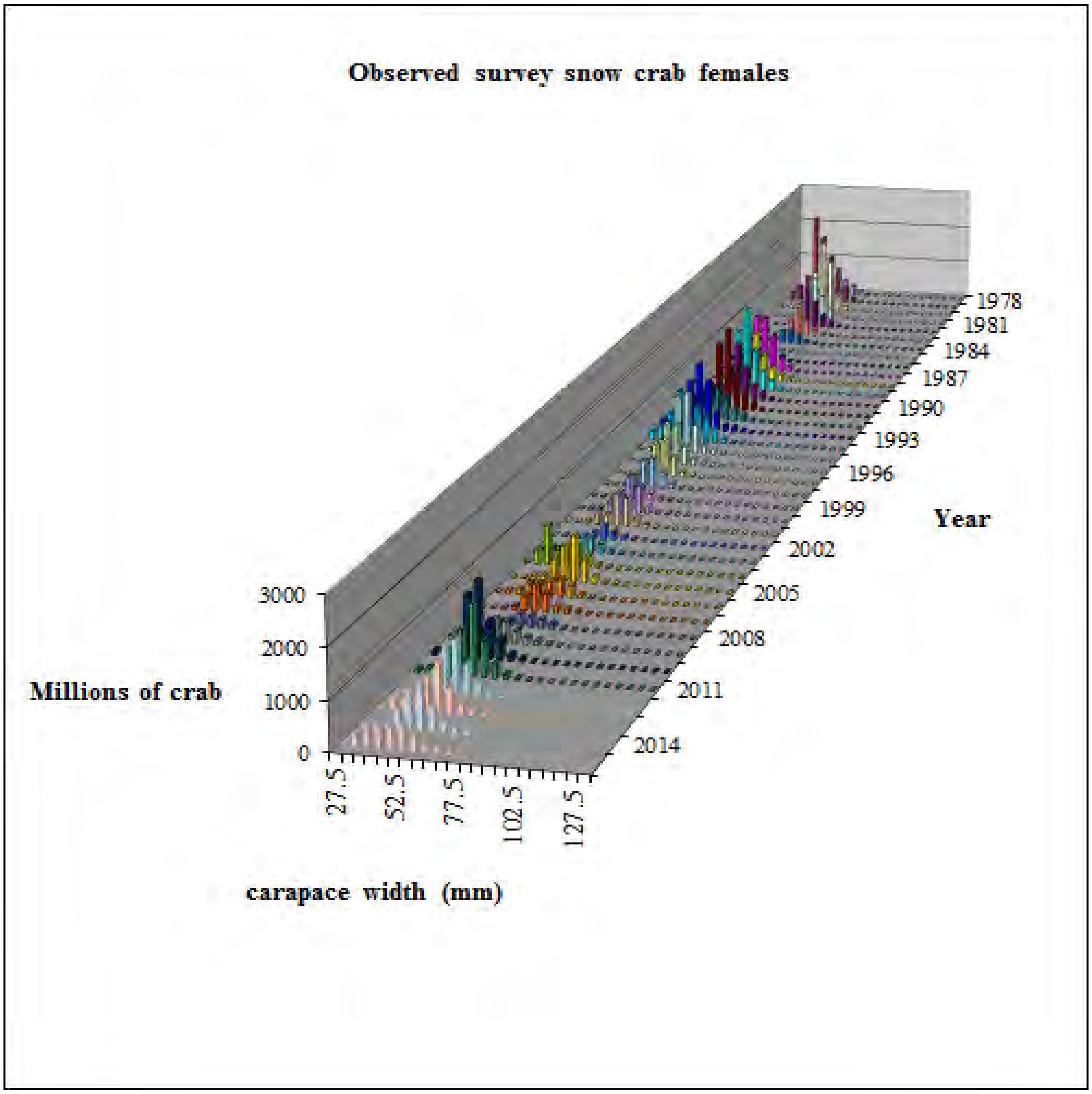

Figure 6. Observed survey numbers (millions of crab) by carapace width and year for female snow crab.

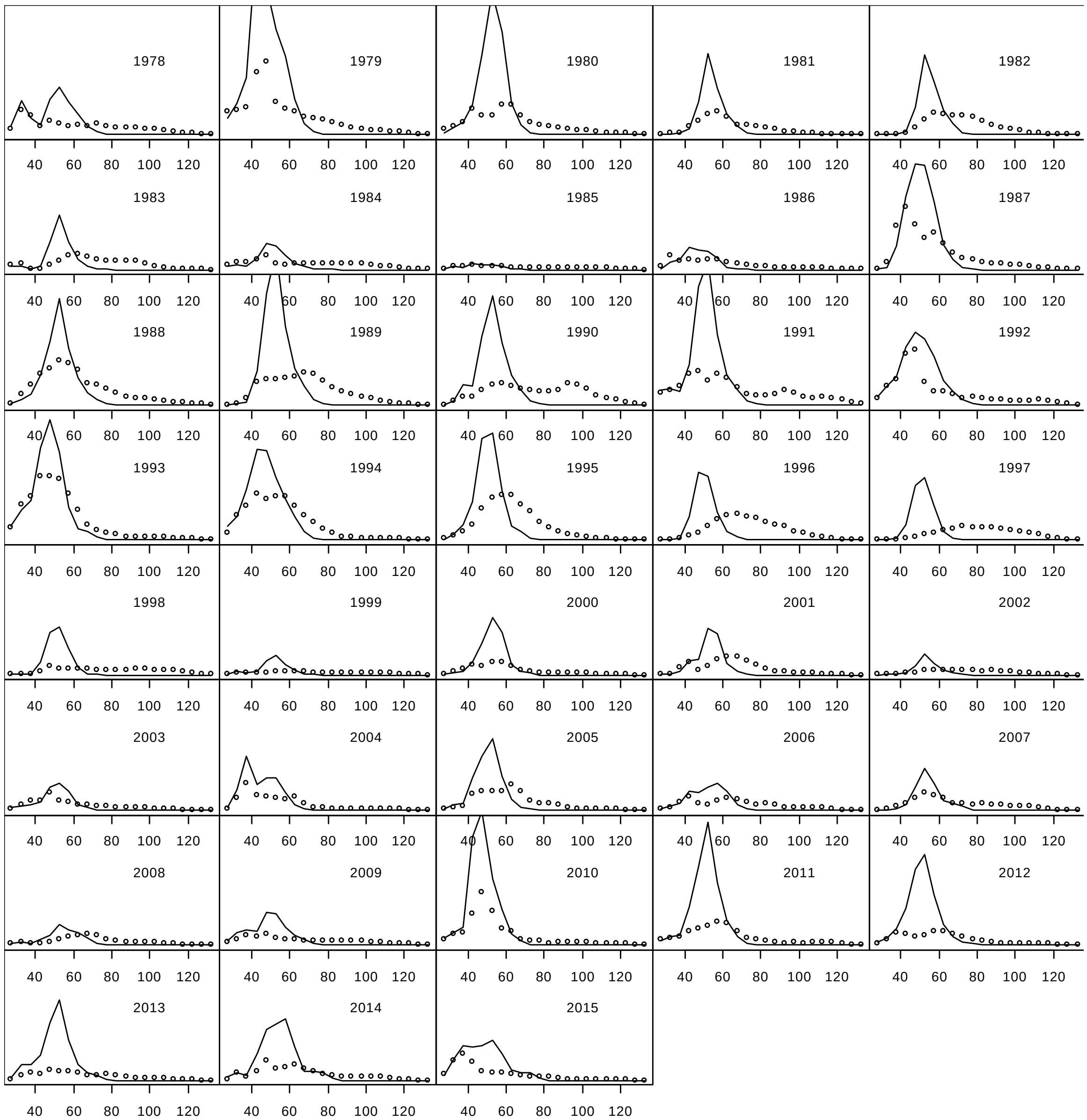

Figure 7. Observed survey numbers 1978 to 2015 by length, males circles, females solid line.

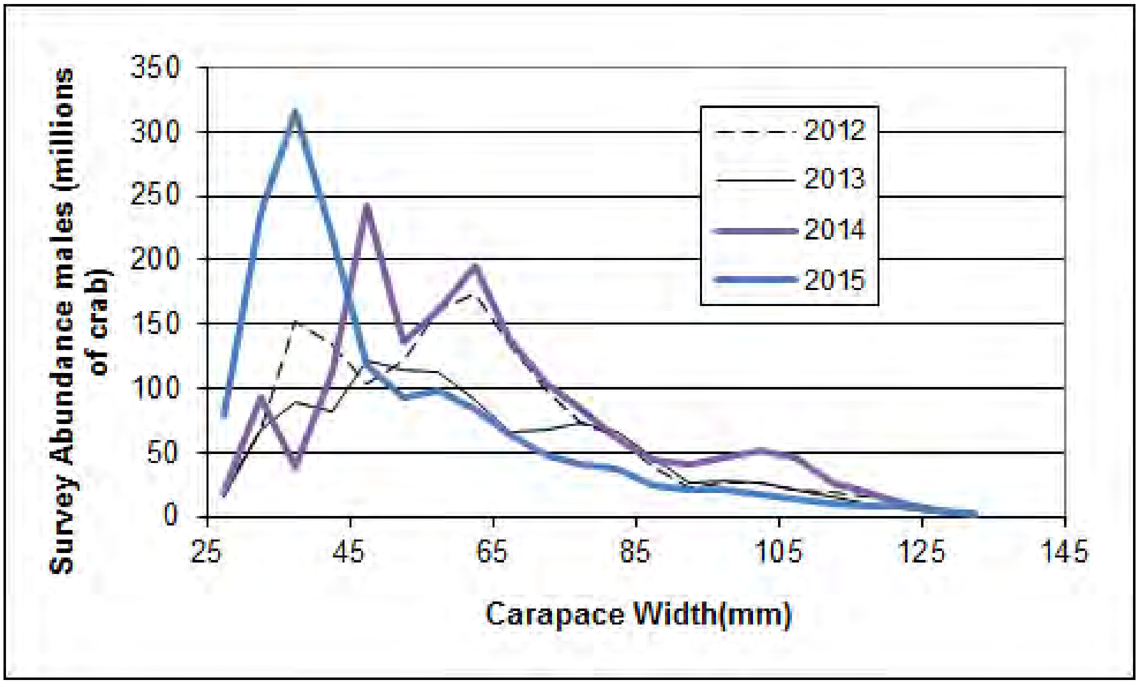

Figure 8. Survey male abundance by length for 2012 to 2015.

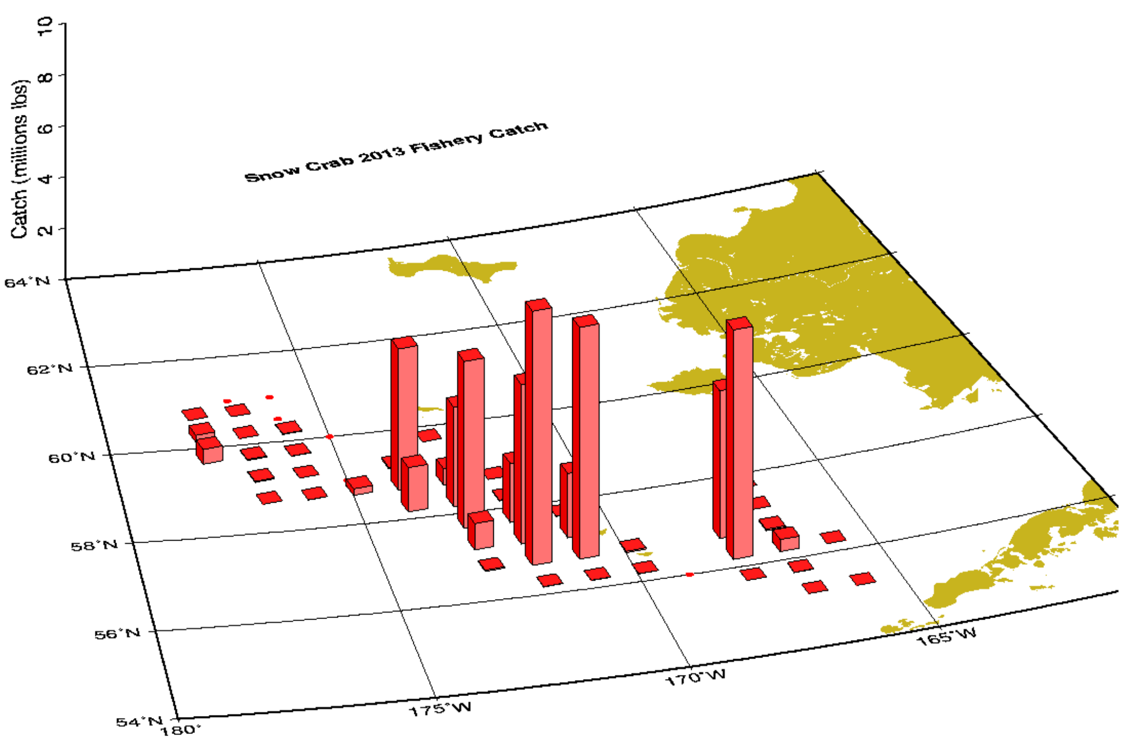

Figure 9. 2012/13 snow crab pot fishery retained catch(million lbs) by statistical area. Statistical areas are 1 degree longitude by 0.5 degree latitude.

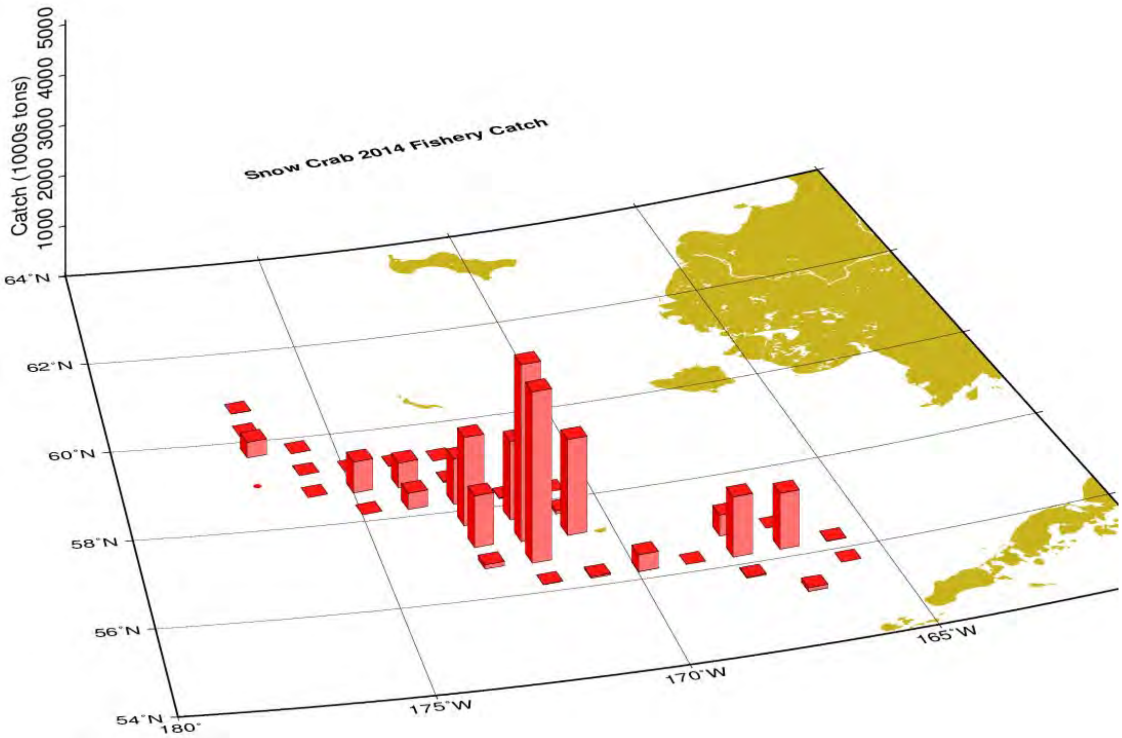

Figure 10. 2013/14 snow crab pot fishery retained catch (1000s tons) by statistical area. Statistical areas are 1 degree longitude by 0.5 degree latitude.

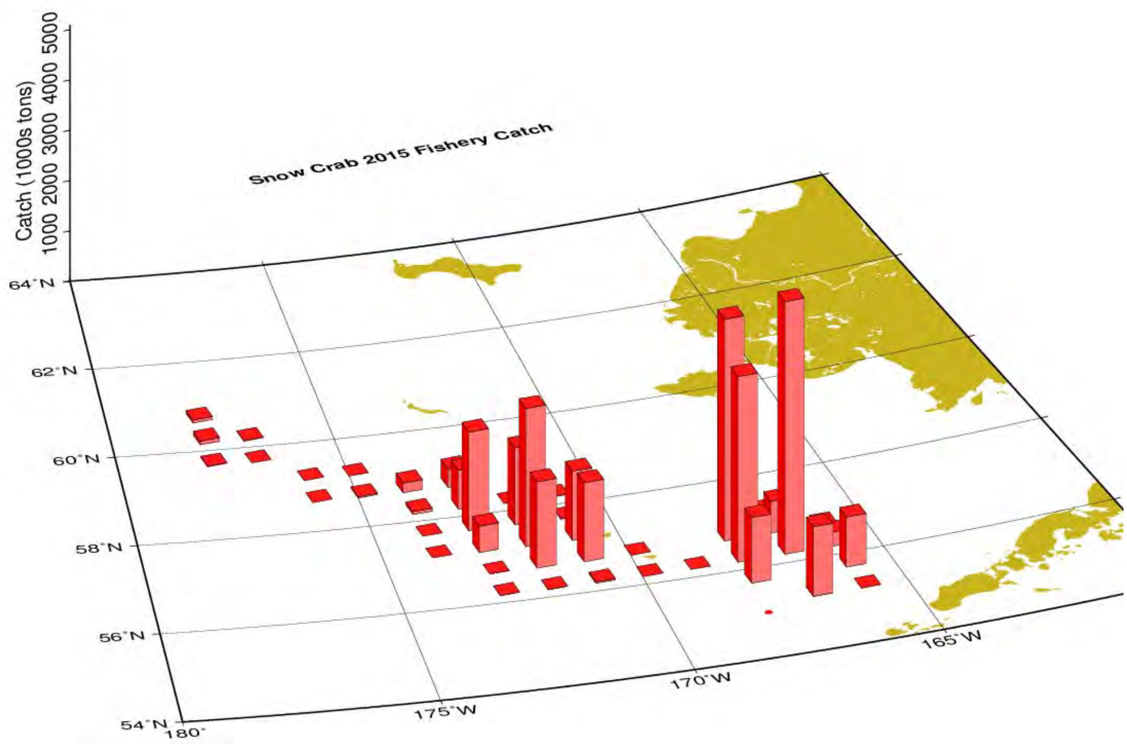

Figure 11. 2014/15 snow crab pot fishery retained catch(1000s tons) by statistical area. Statistical areas are 1 degree longitude by 0.5 degree latitude.

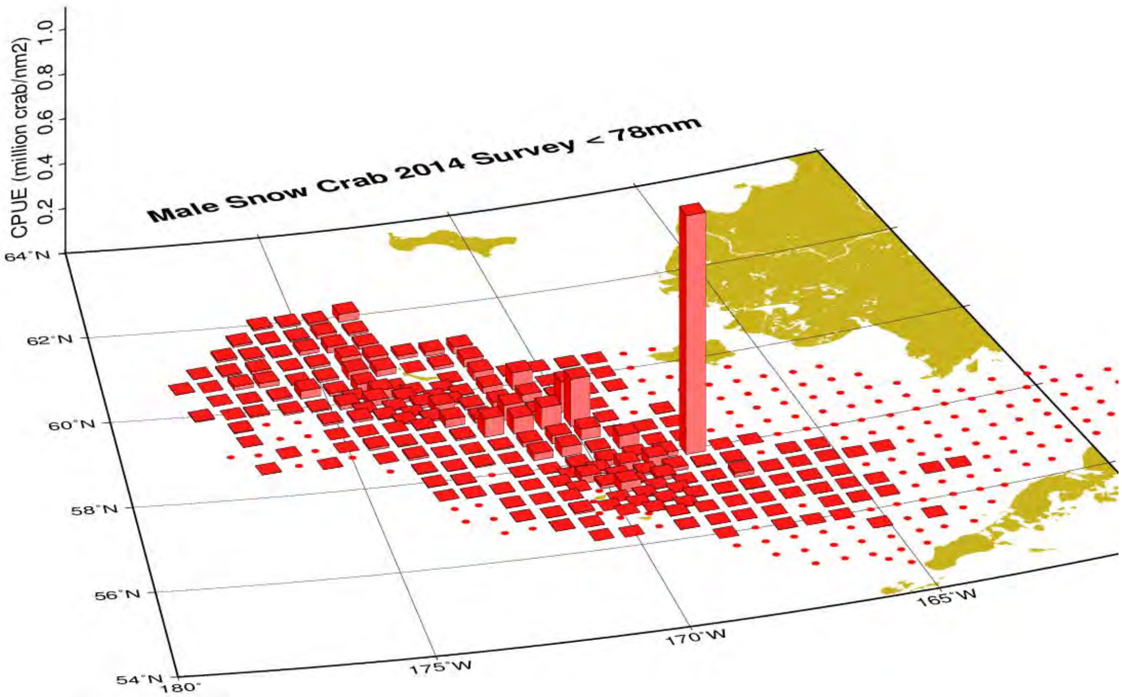

Figure 12. 2014 Survey CPUE (million crab per nm2) of males < 78mm by tow. Filled circles are tows with 0 cpue.

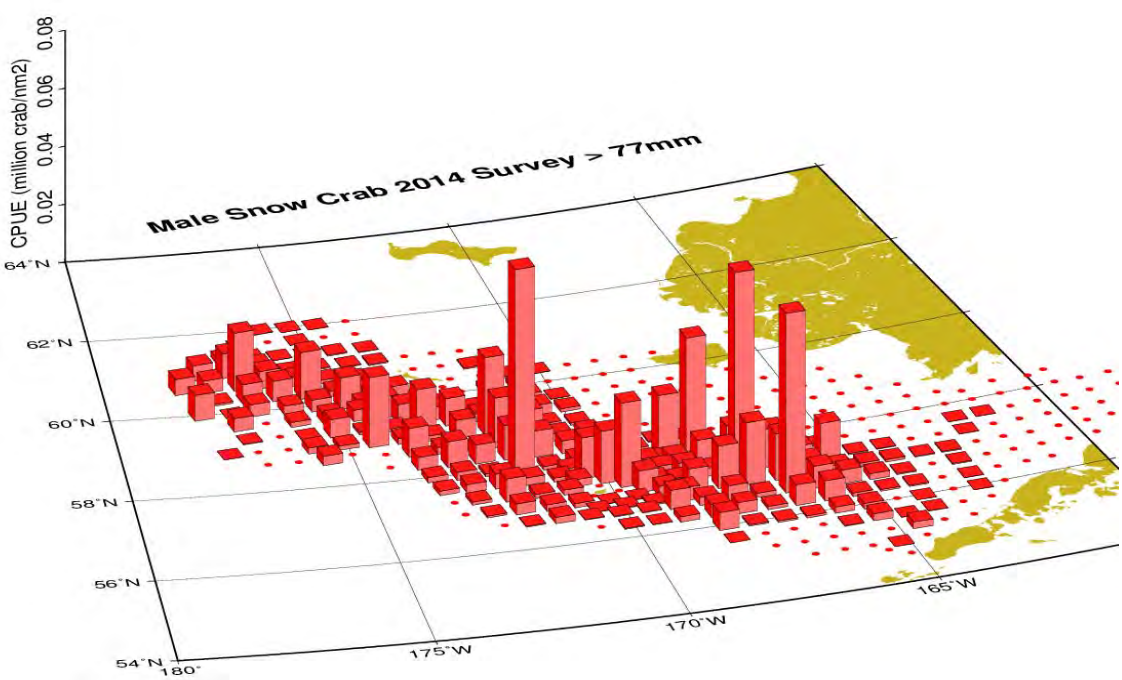

Figure 13. 2014 Survey CPUE (million crab per nm2) of males > 77mm by tow. Filled circles are tows with 0 cpue.

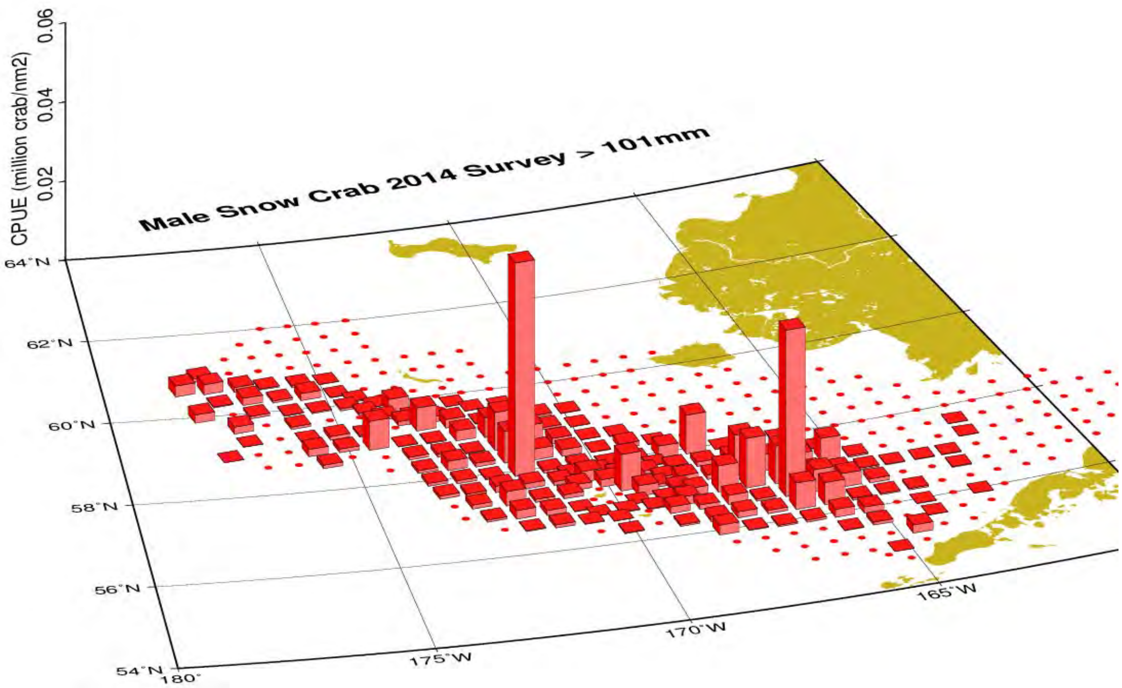

Figure 14. 2014 Survey CPUE (million crab per nm2) of males > 101mm by tow. Filled circles are tows with 0 cpue.

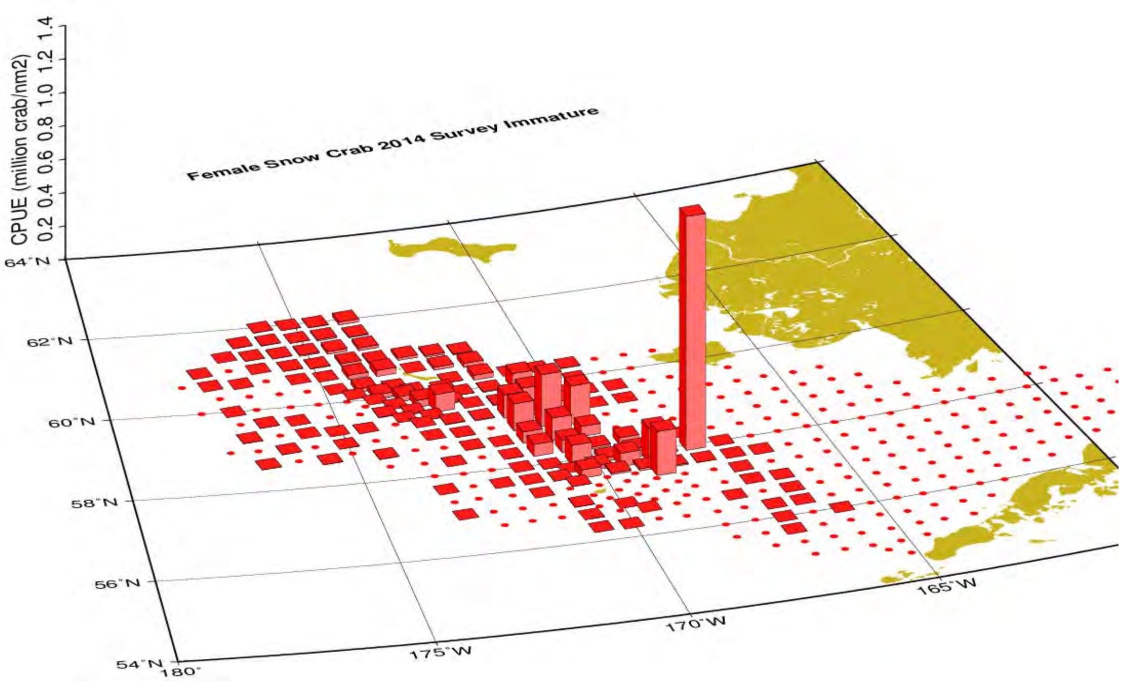

Figure 15. 2014 Survey CPUE (million crab per nm2) of immature females by tow. Filled circles are tows with 0 cpue.

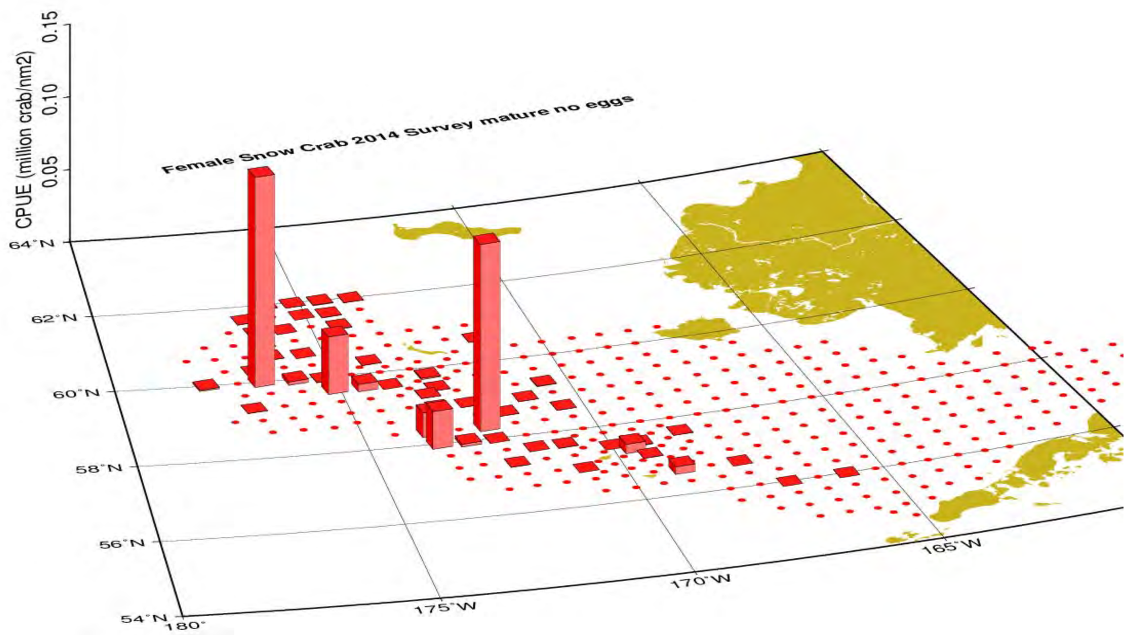

Figure 16. 2014 Survey CPUE (million crab per nm2) of mature females with no eggs by tow. Filled circles are tows with 0 cpue.

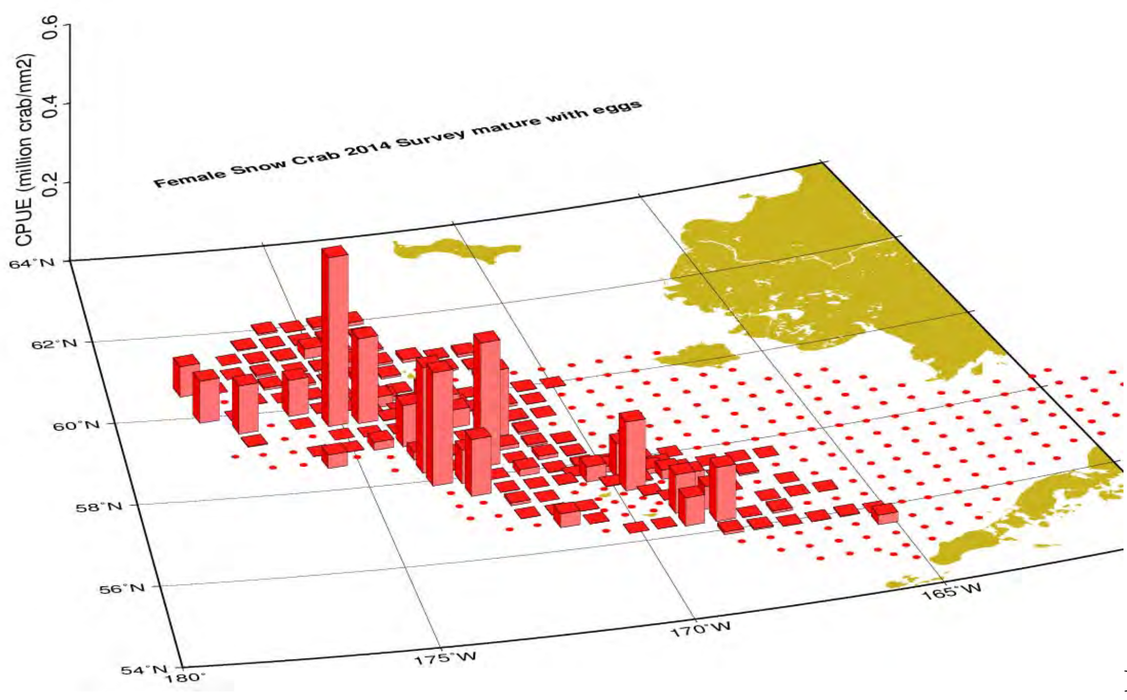

Figure 17. 2014 Survey CPUE (million crab per nm2) of mature females with eggs (all clutch sizes) by tow. Filled circles are tows with 0 cpue.

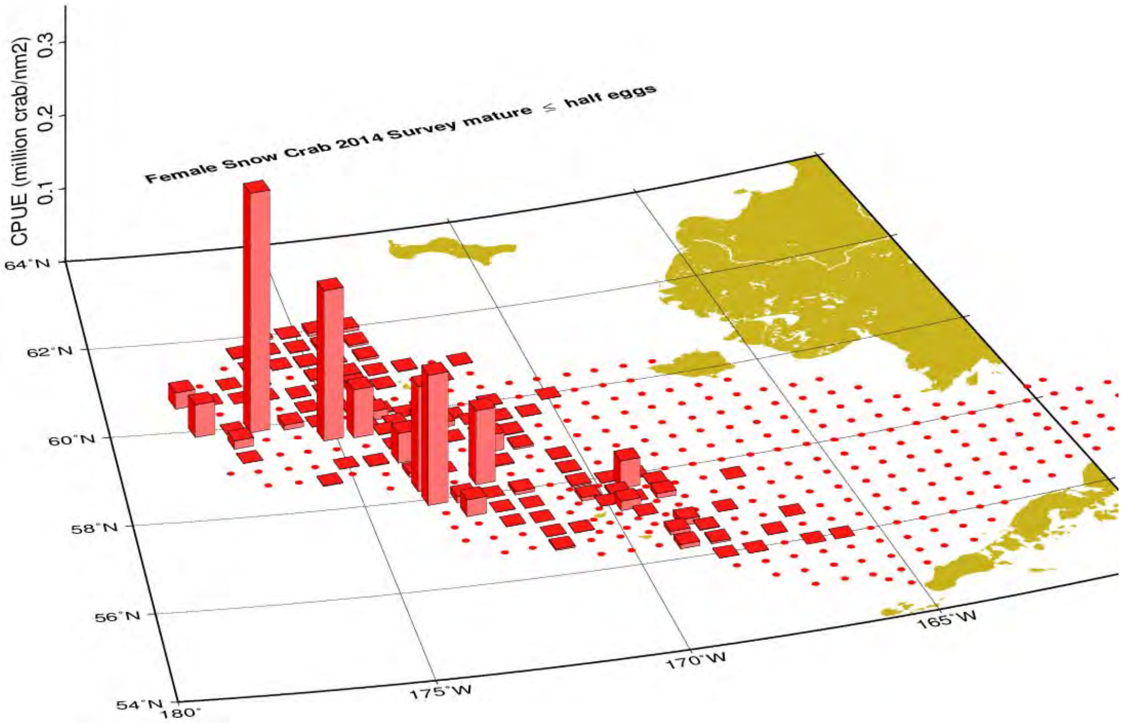

Figure 18. 2014 Survey CPUE (million crab per nm2) of mature females with <= half clutch of eggs by tow. Filled circles are tows with 0 cpue.

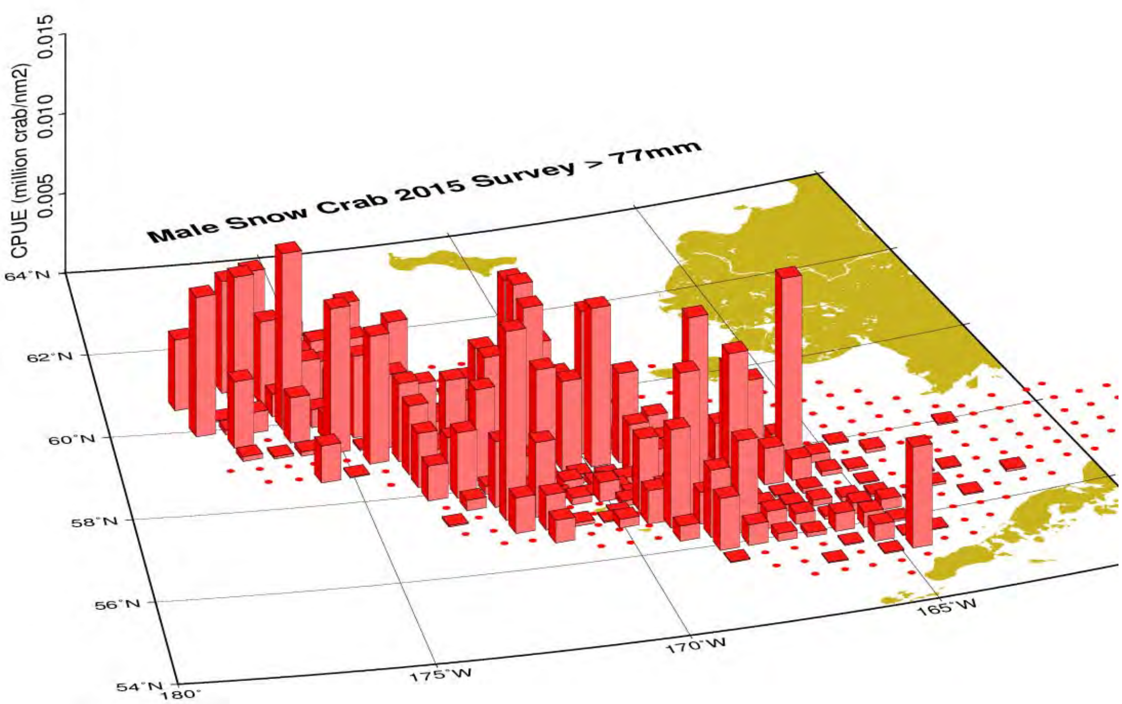

Figure 19. 2015 Survey CPUE (million crab per nm2) of males > 77mm by tow. Filled circles are tows with 0 cpue.

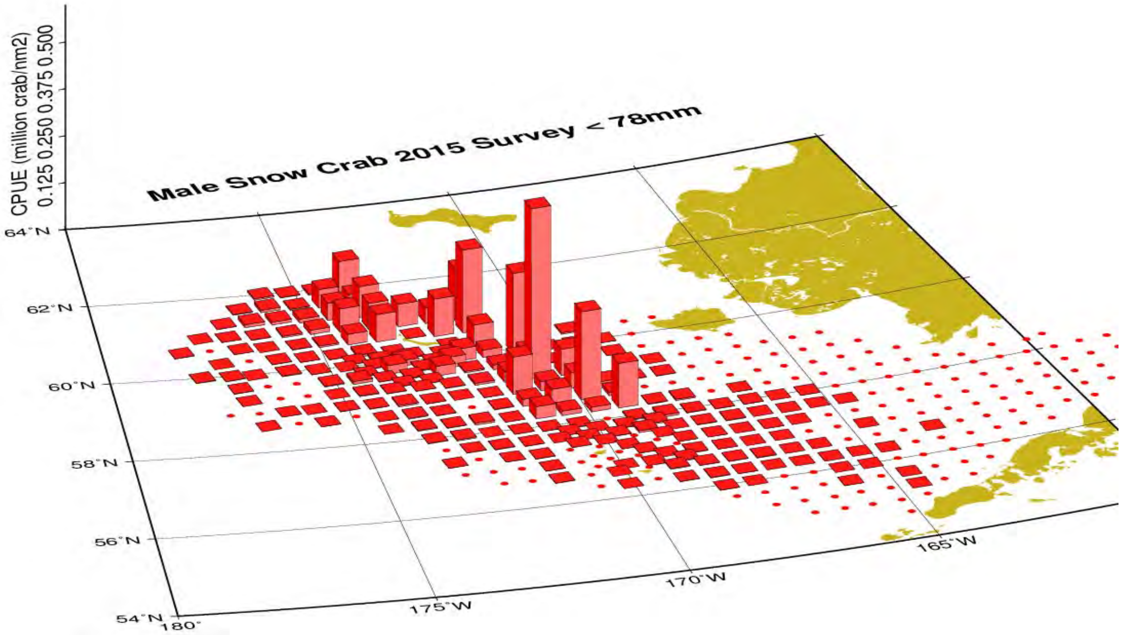

Figure 20. 2015 Survey CPUE (million crab per nm2) of males < 78mm by tow. Filled circles are tows with 0 cpue.

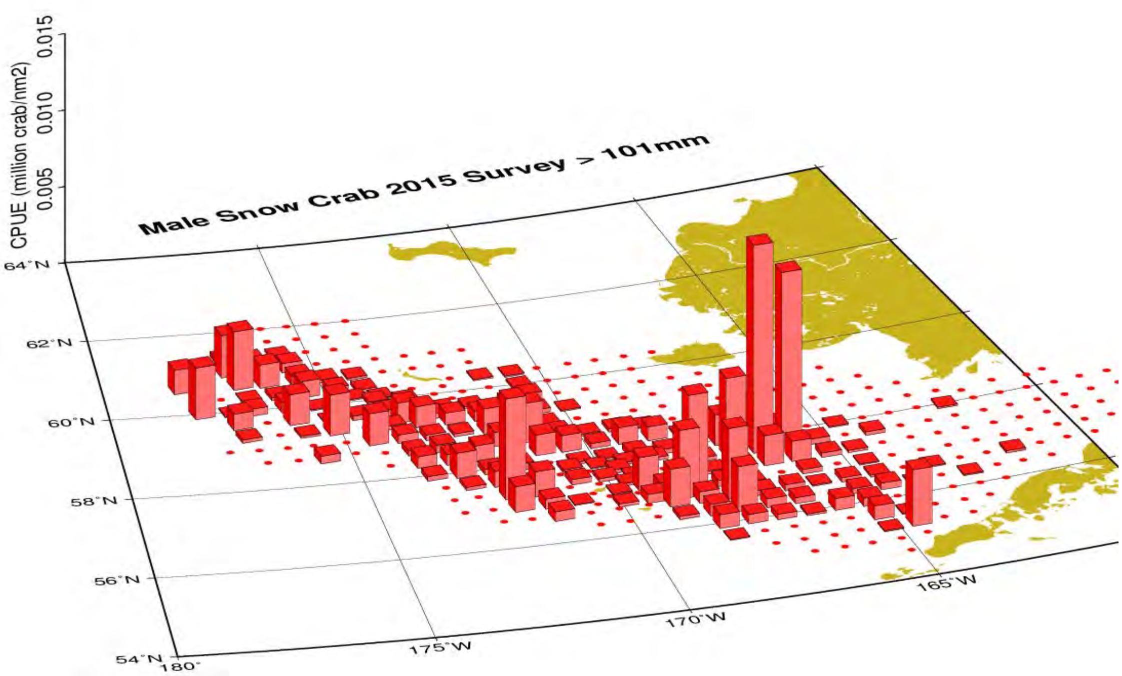

Figure 21. 2015 Survey CPUE (million crab per nm2) of males > 101mm by tow. Filled circles are tows with 0 cpue.

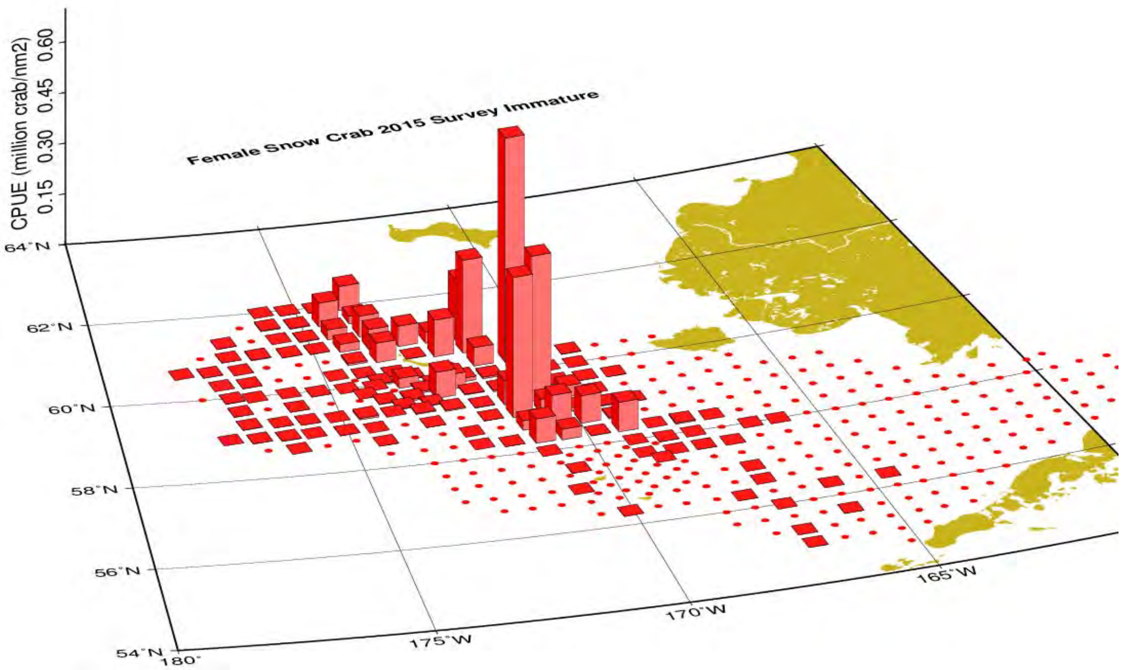

Figure 22. 2015 Survey CPUE (million crab per nm2) of immature females by tow. Filled circles are tows with 0 cpue.

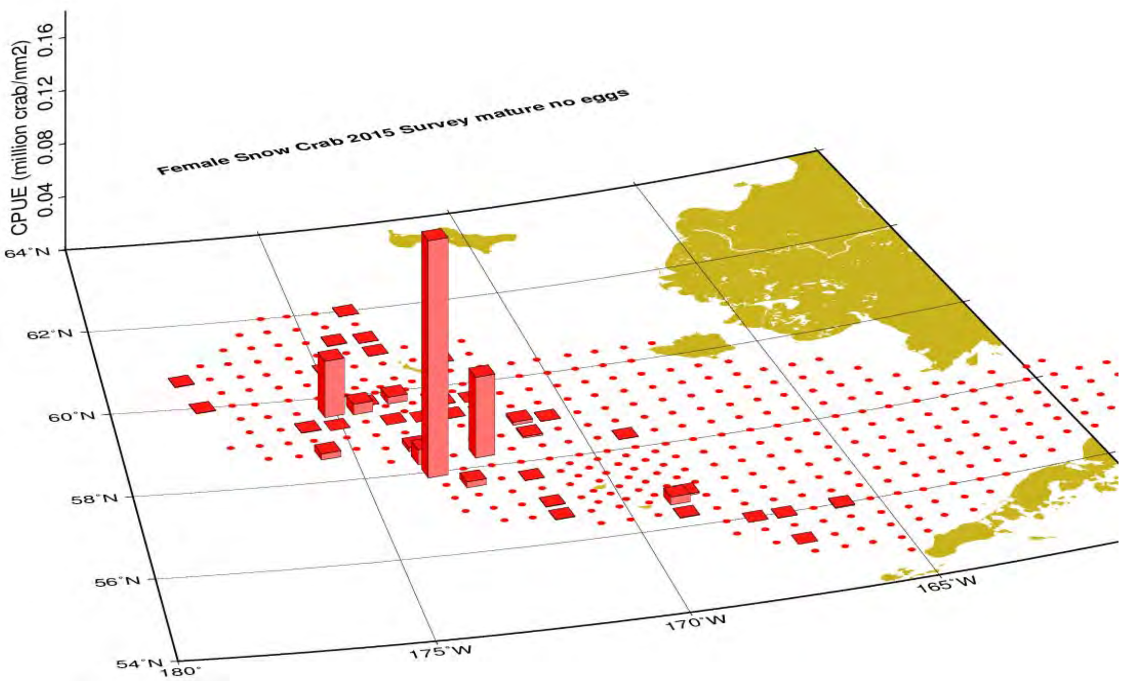

Figure 23. 2015 Survey CPUE (million crab per nm2) of mature females with no eggs by tow. Filled circles are tows with 0 cpue.

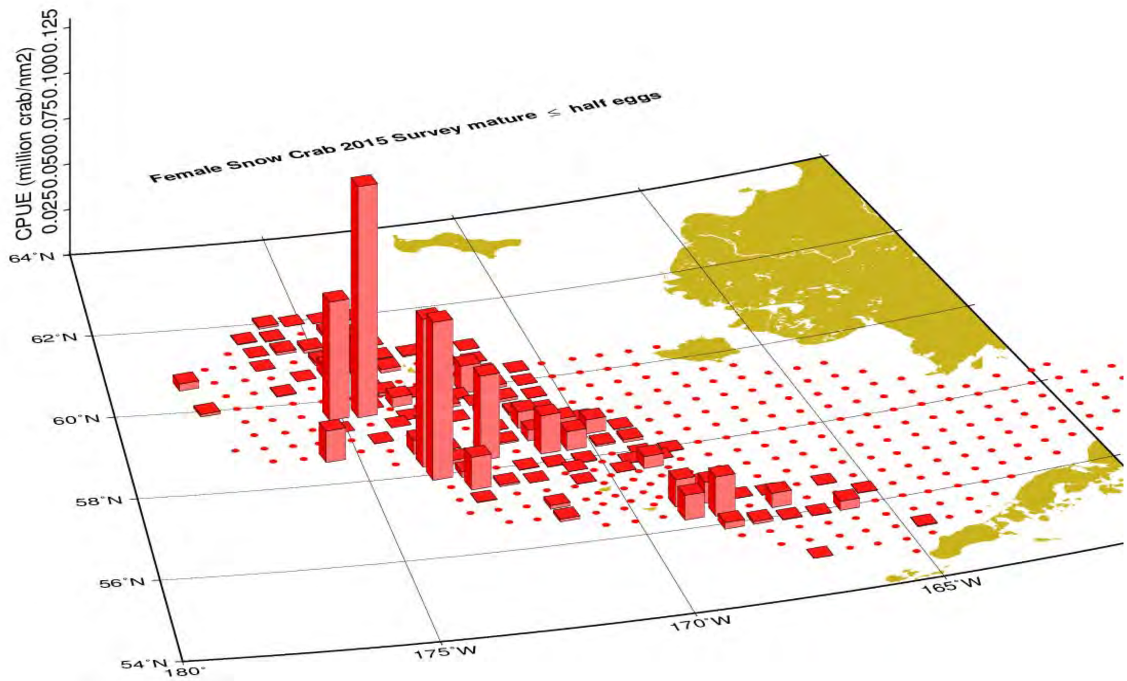

Figure 24. 2015 Survey CPUE (million crab per nm2) of mature females with <= half clutch of eggs by tow. Filled circles are tows with 0 cpue.

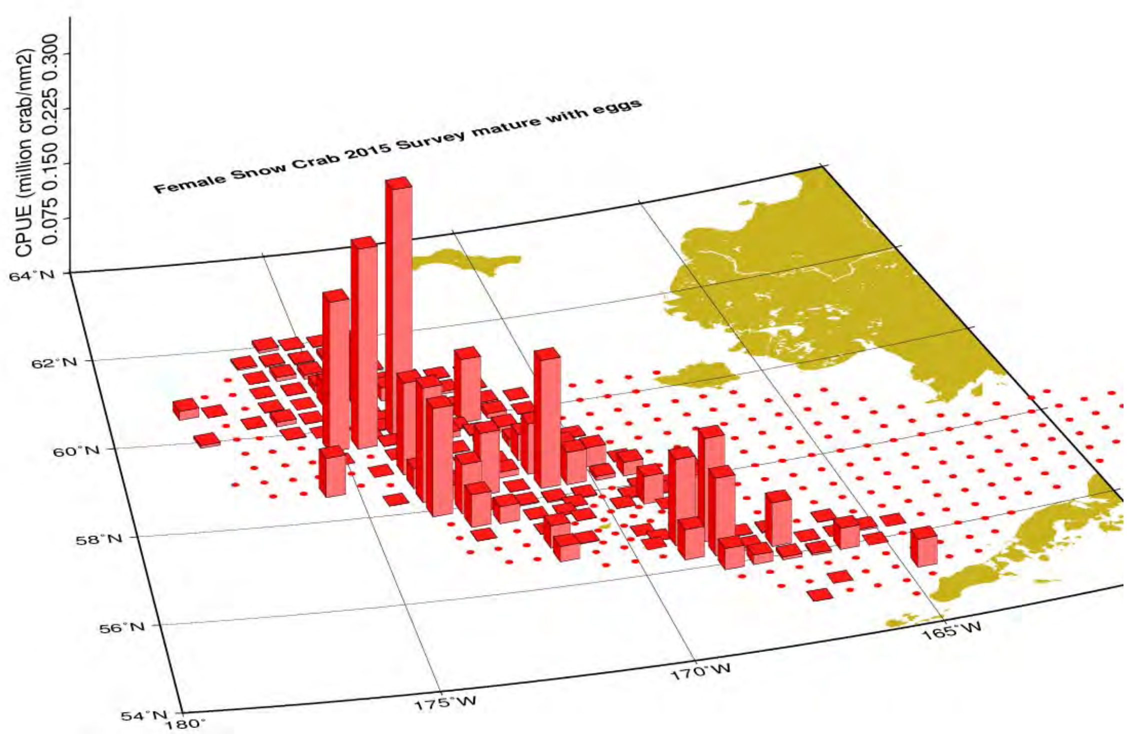

Figure 25. 2015 Survey CPUE (million crab per nm2) of mature females with eggs by tow. Filled circles are tows with 0 cpue.

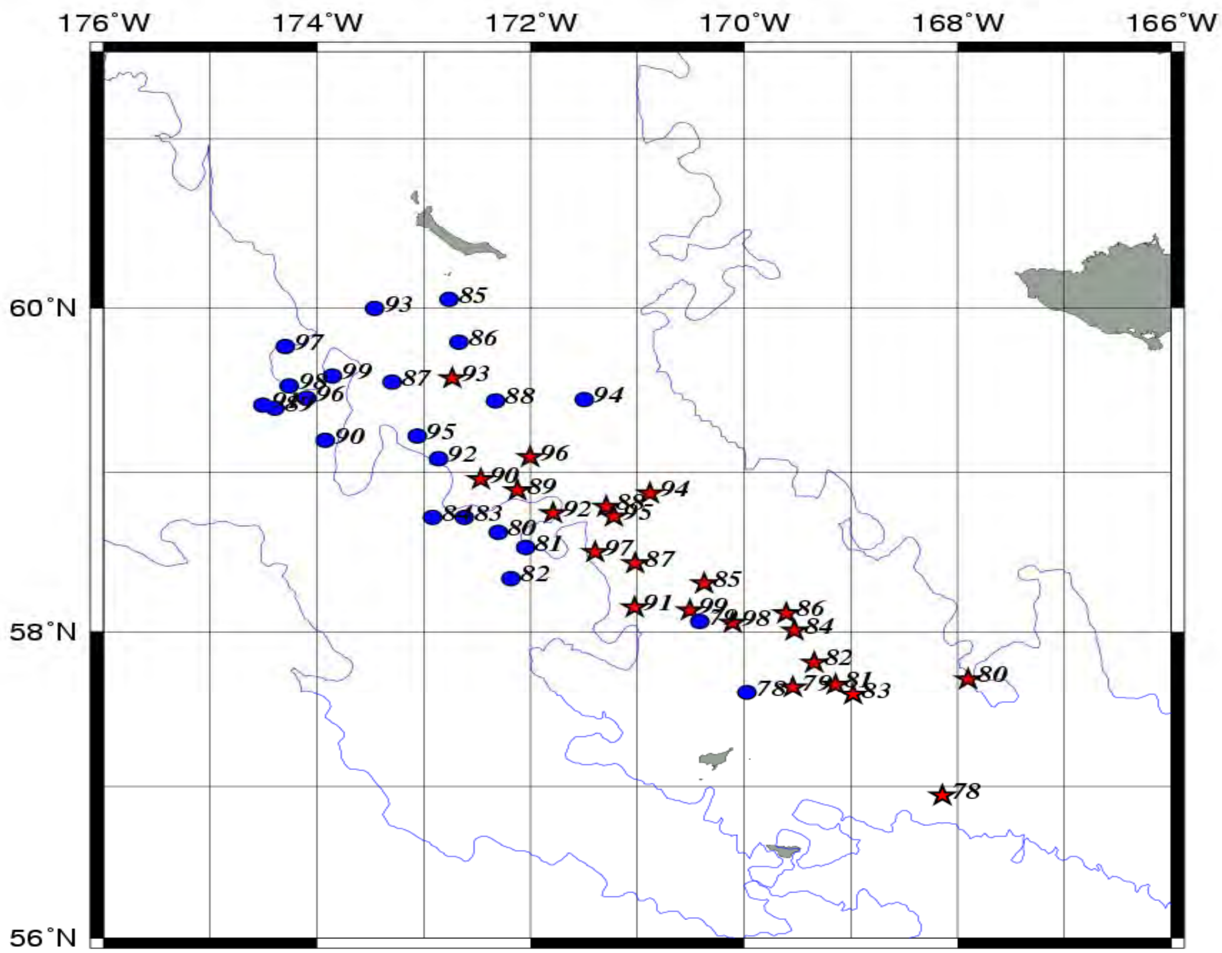

Figure 26. Centroids of abundance of mature female snow crabs (shell condition 2+) in blue circles and mature males (shell condition 3+) in red stars (Ernst, et al. 2005).

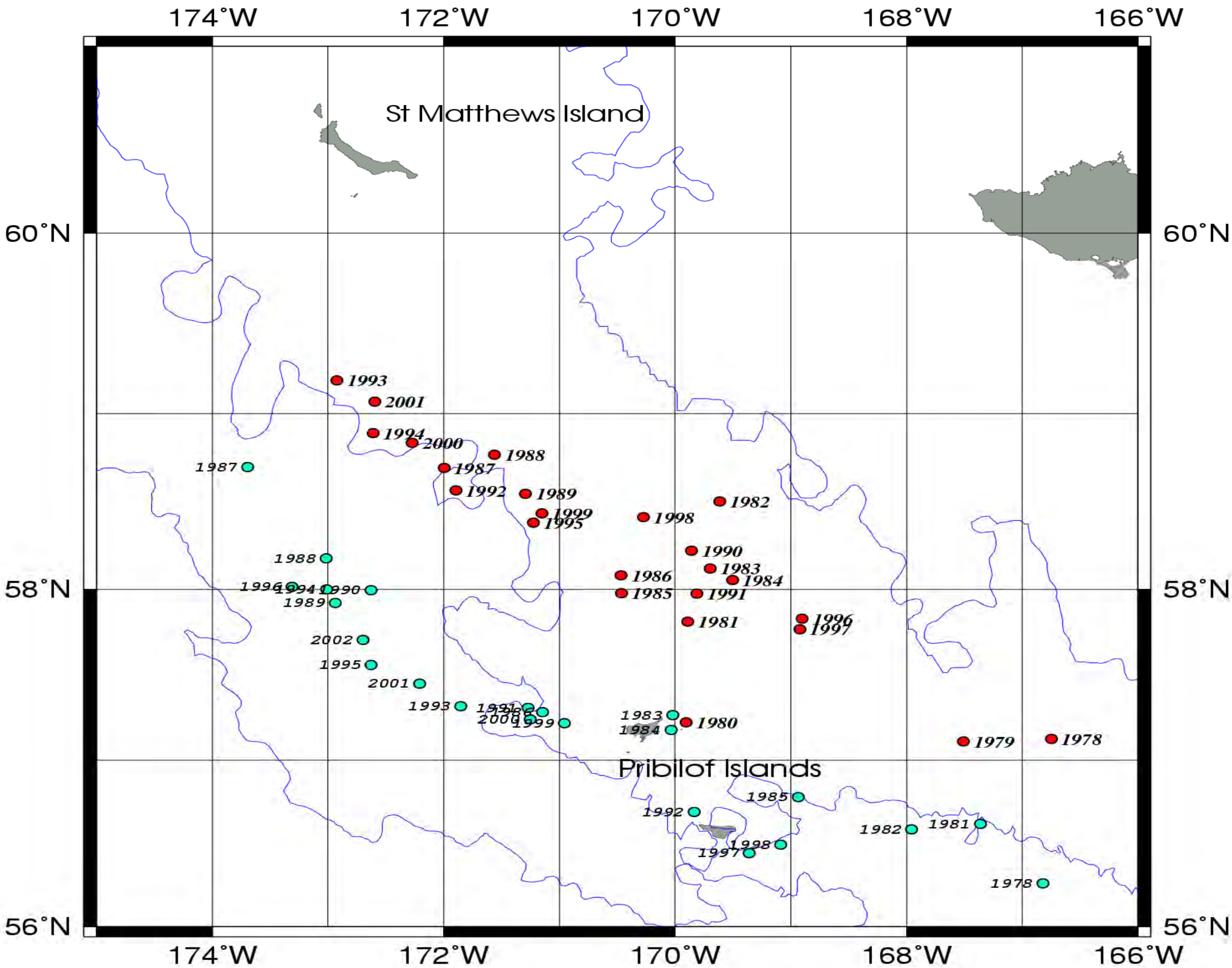

Figure 27. Centroids abundance (numbers) of snow crab males > 101 mm from the summer NMFS trawl survey (red) and from the winter fishery (blue-green) (Ernst, et al. 2005).

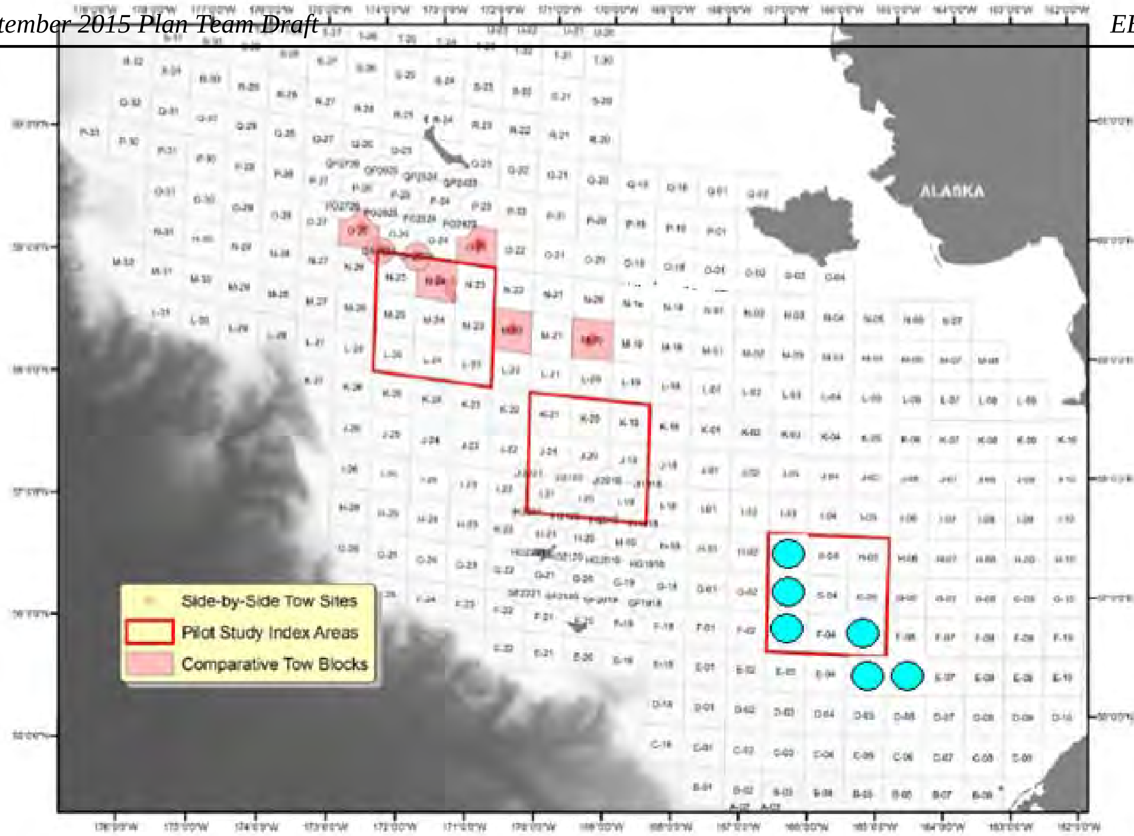

Figure 28. Location of the side-by-side trawling areas (shown with pink shading) and the 3 BSFRF survey areas encompassing the 27 NMFS survey blocks (shown with a red line). Location of the 1998 auxiliary bag experiment sampling areas are the blue circles.

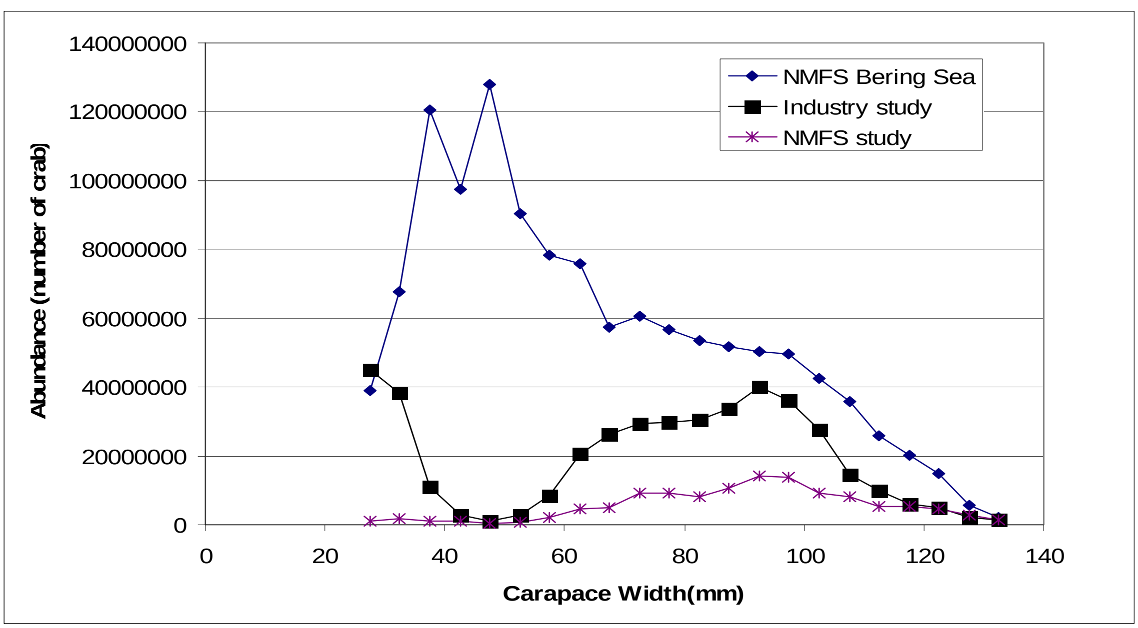

Figure 29. Abundance estimates of male snow crab by 5 mm carapace width(>=25mm) for the NMFS survey of the entire Bering Sea survey area (NMFS Bering Sea), the BSFRF net in the study area (108 tows) and the NMFS survey in the 2009 study area.

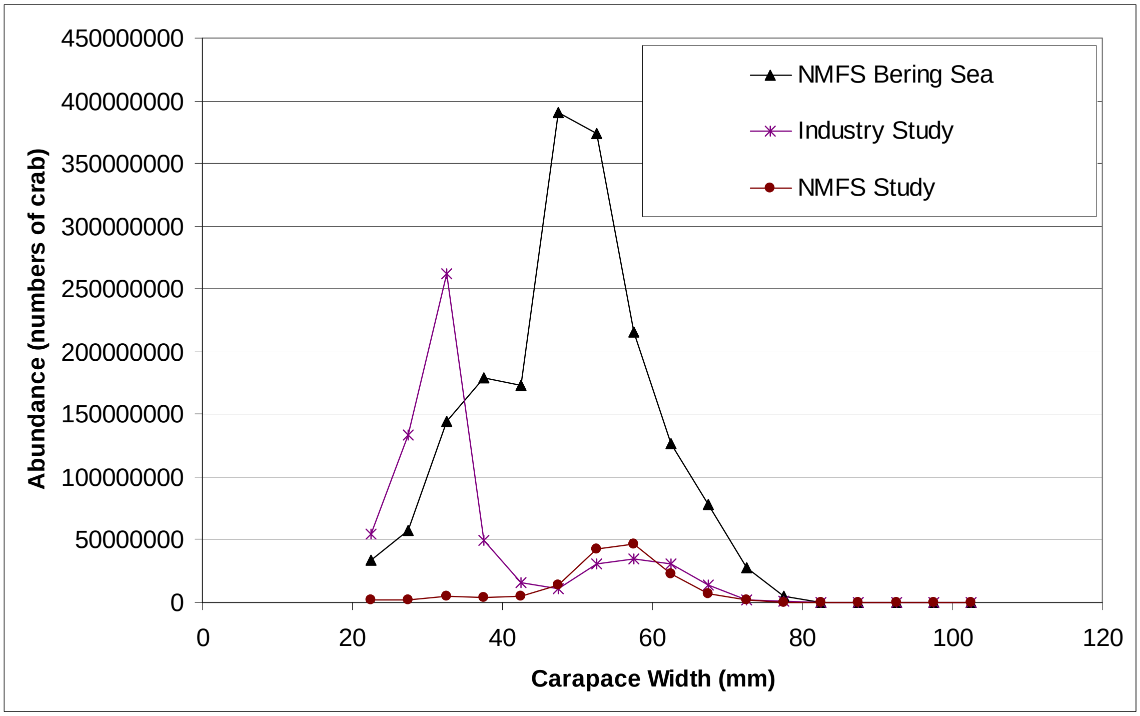

Figure 30. Abundance estimates of female snow crab by 5 mm carapace width for the NMFS survey of the entire Bering Sea survey area (NMFS Bering Sea), the BSFRF net in the study area (108 tows) and the NMFS survey in the 2009 study area.

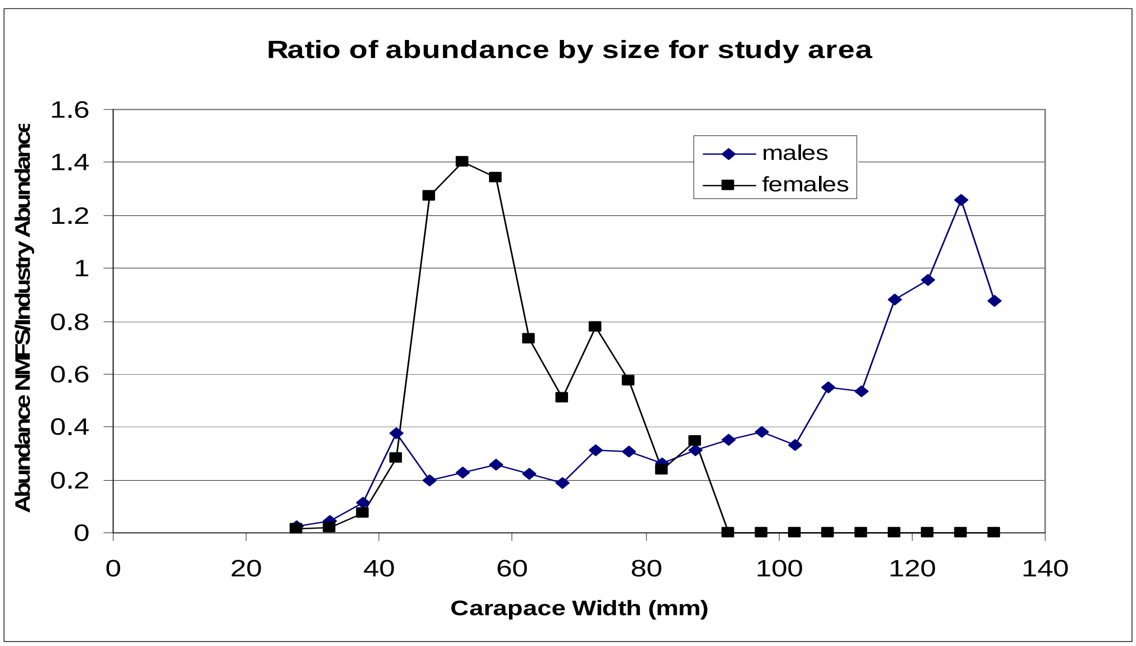

Figure 31. Ratio of abundance in the 2009 study area from the NMFS net to the BSFRF net for male and female crab.

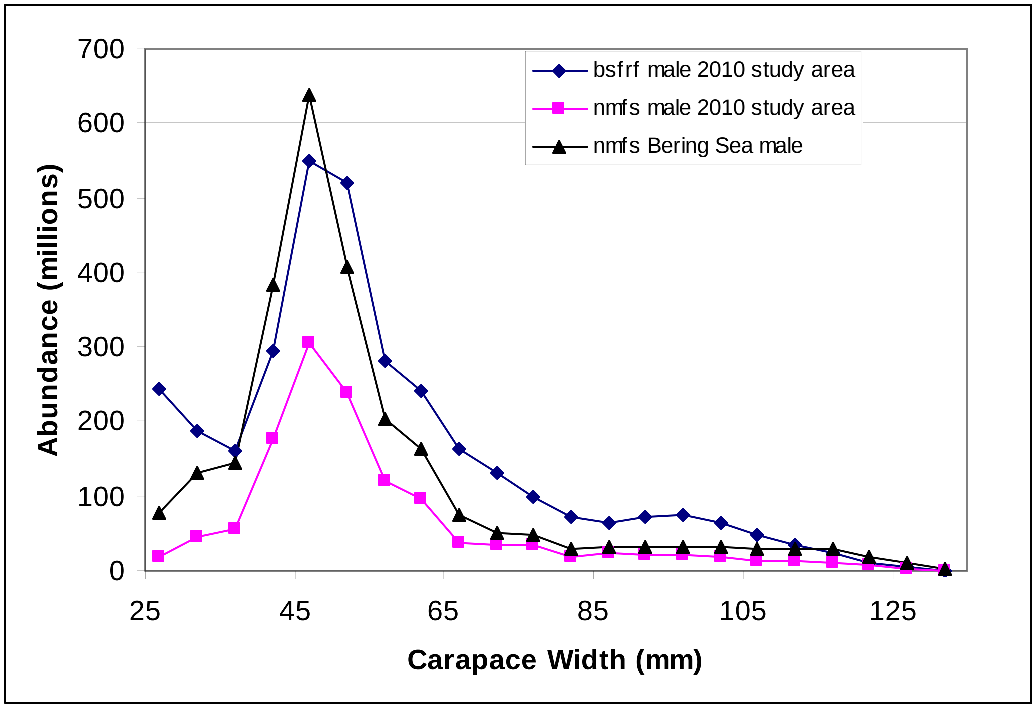

Figure 32. 2010 study area Male abundance.

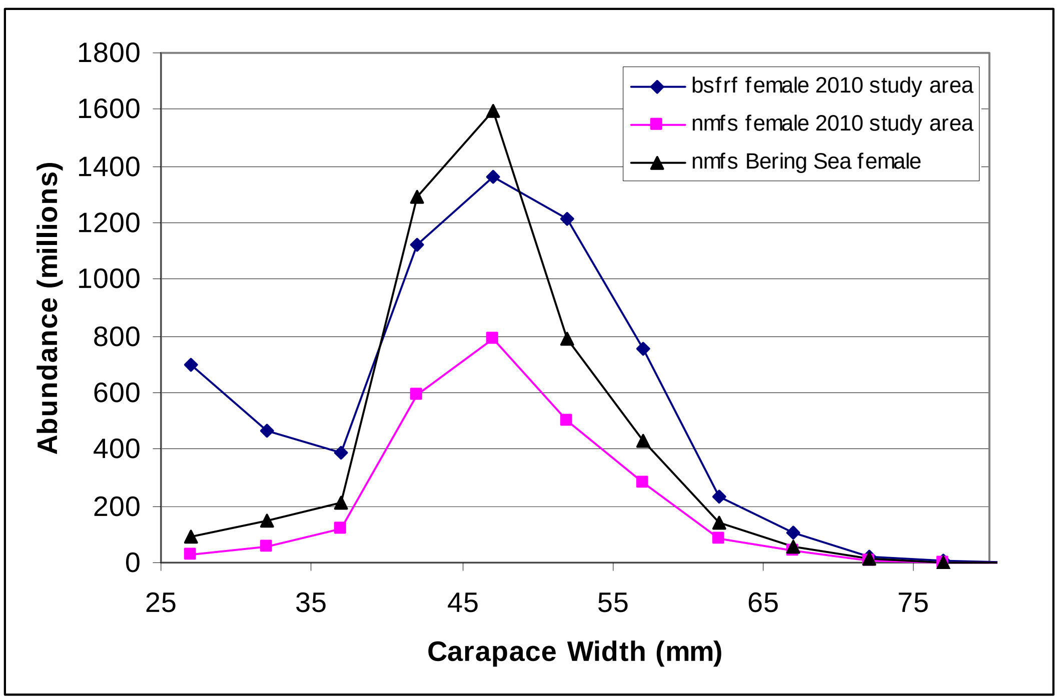

Figure 33. 2010 study area Female abundance.

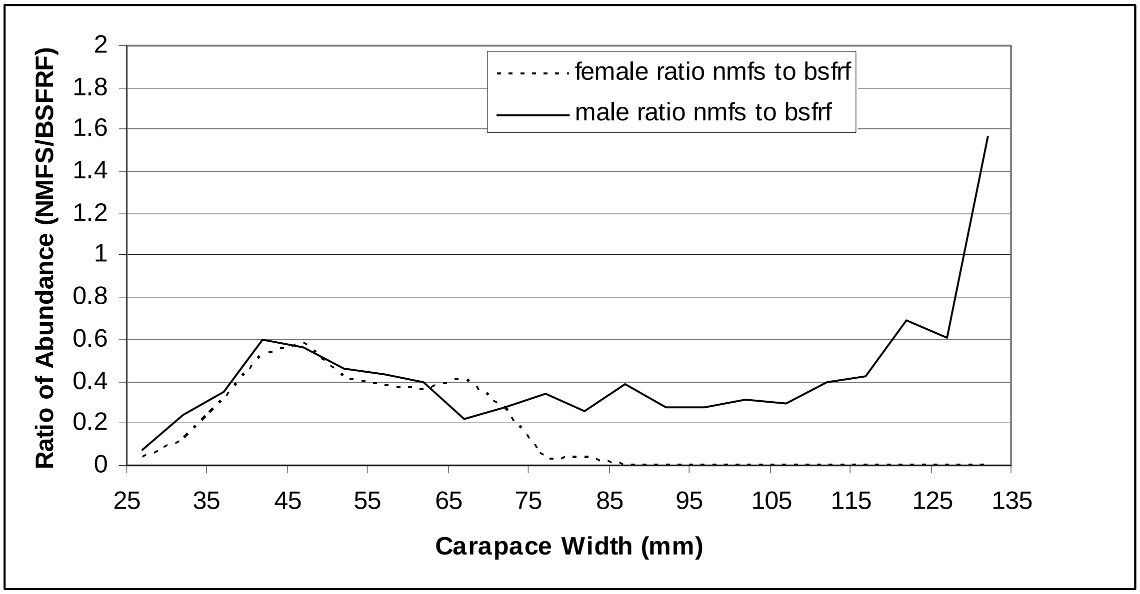

Figure 34. 2010 study area ratio of abundance

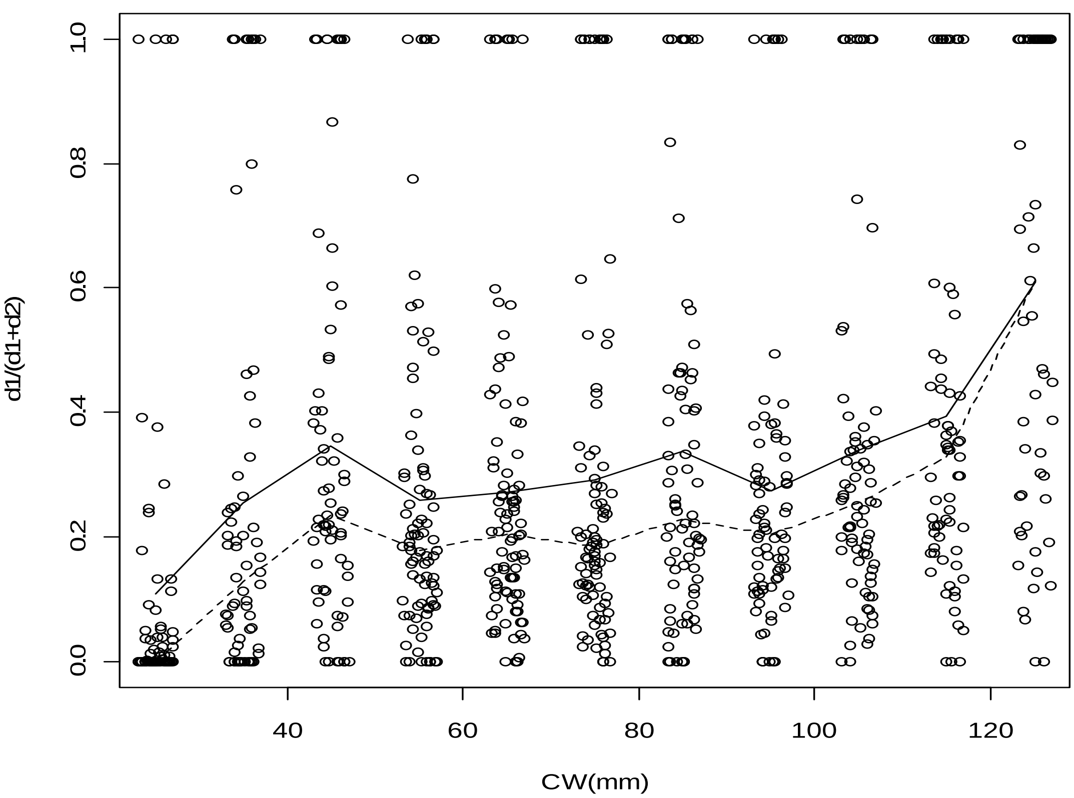

Figure 35. Male crab. Density (catch/nm2) of NMFS tow (d1) divided by sum of density (d2 is density of BSFRF tow). Solid line is unweighted mean, dotted line median of each length bin. A value of 0.5 is equal density (d1=d2). Length values are jittered to show multiple 1.0 and 0.0 data.

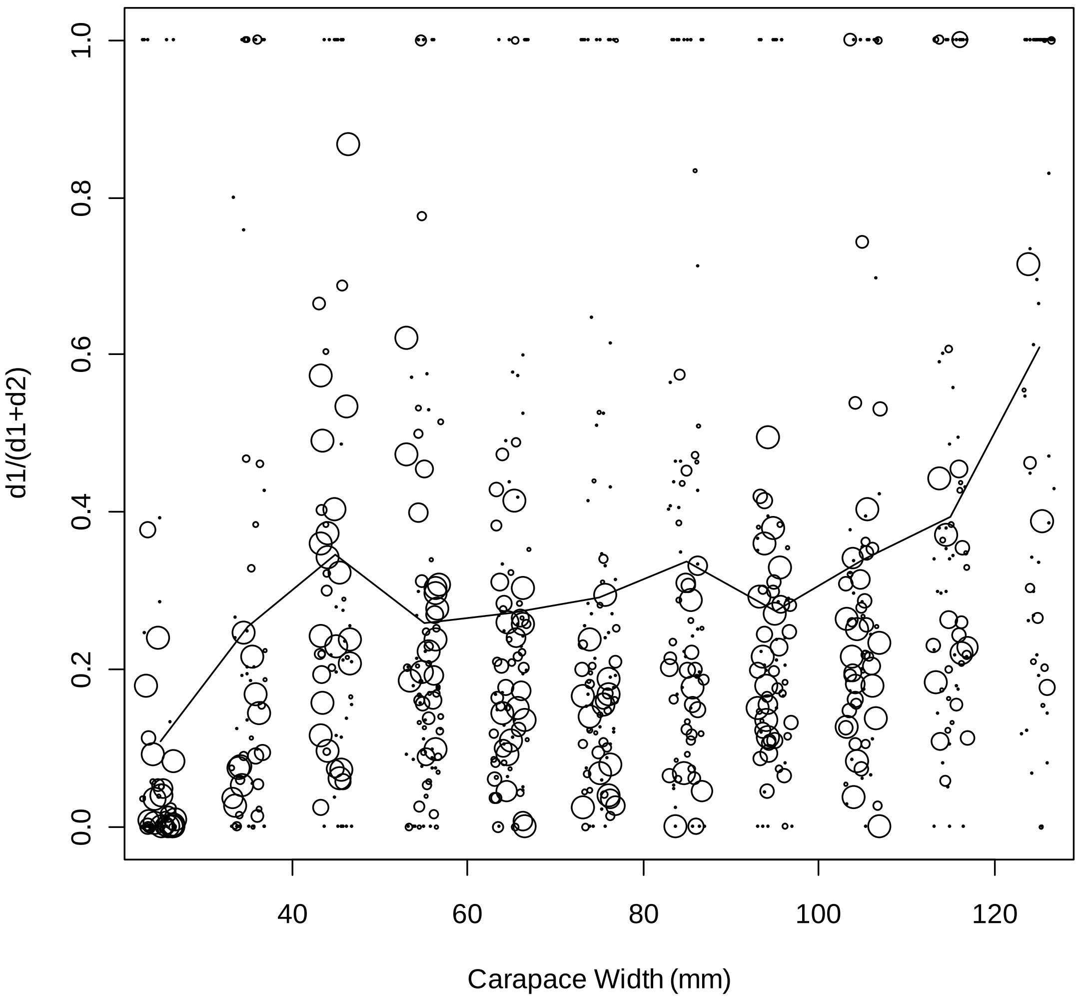

Figure 36. Density of NMFS tow (d1) divided by the sum of the density of the NMFS tow (d1) and the Industry tow (d2). The radius of the circle at each point is proportional to the sum of the catch in numbers where the Industry numbers are adjusted by the ratio of the NMFS area swept to the Industry area swept. The line is the unweighted mean values of d1/(d1+d2) in each size bin.

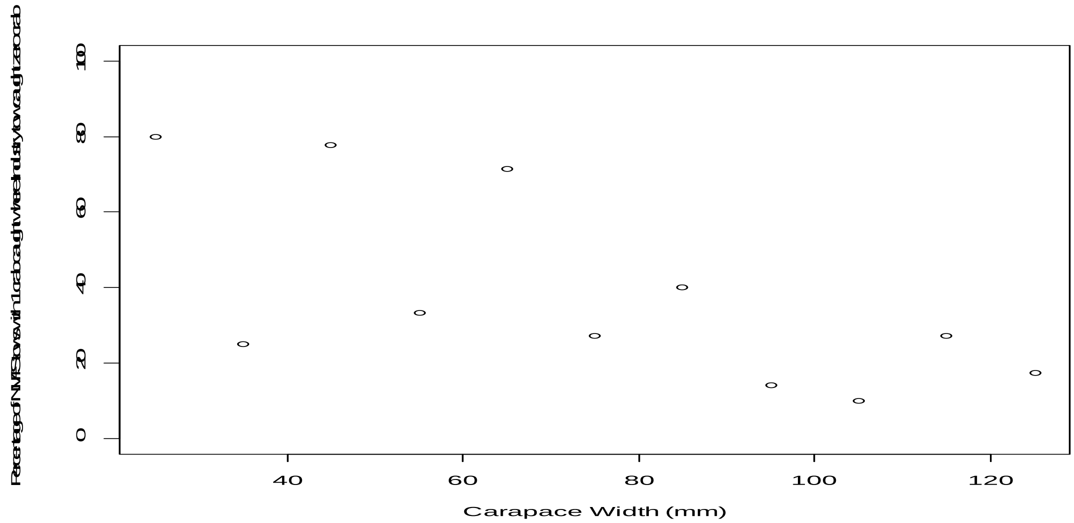

Figure 37. Percentage of paired tows where BSFRF caught no crab and NMFS caught only 1 crab.

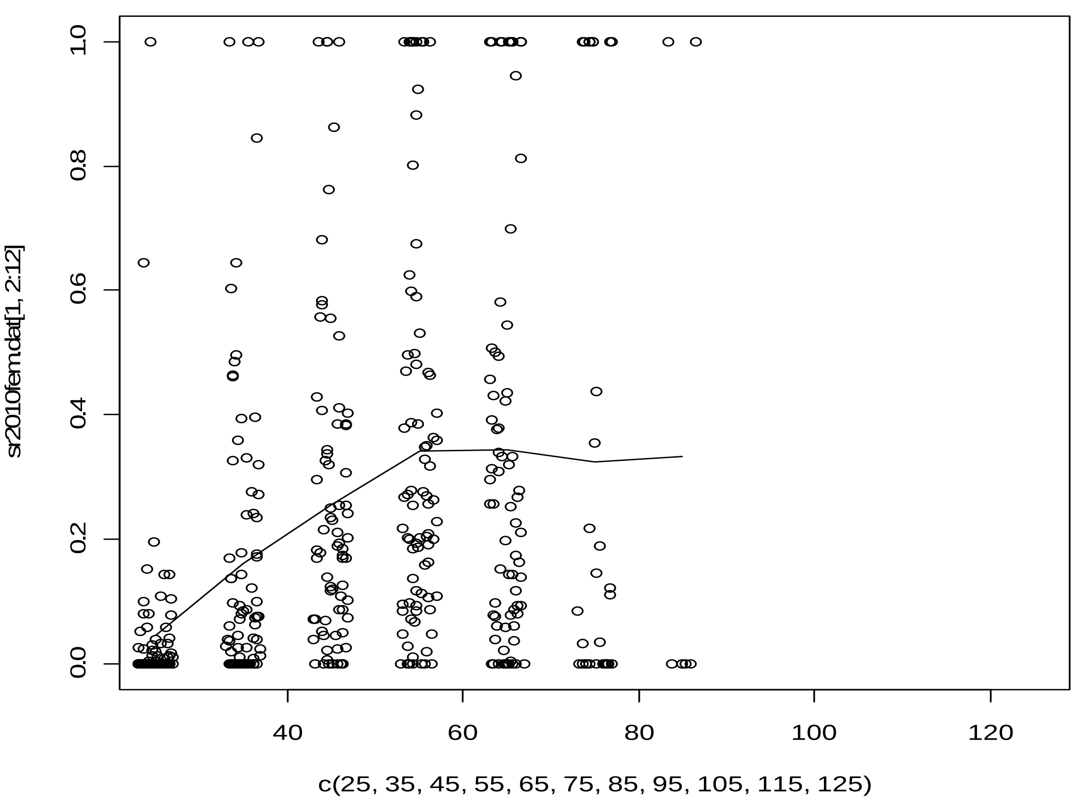

Figure 38. Female d1/(d1+d2) with mean. Density (catch/nm2) of NMFS tow (d1) divided by sum of density (d2 is density of BSFRF tow). Solid line is mean, dotted line median of each length bin. A value of 0.5 is equal density (d1=d2). Length values are jittered to show multiple 1.0 and 0.0 data.

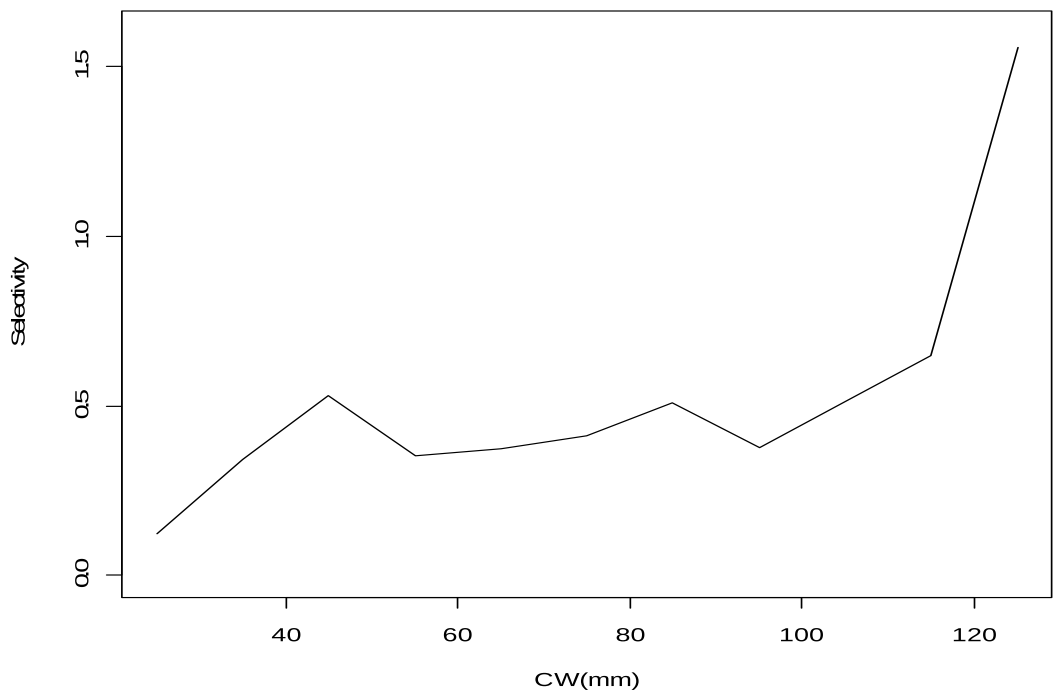

Figure 39. Mean from Figure 9 translated to selectivity (selectivity = p/(1-p), where p= d1/(d1+d2)).

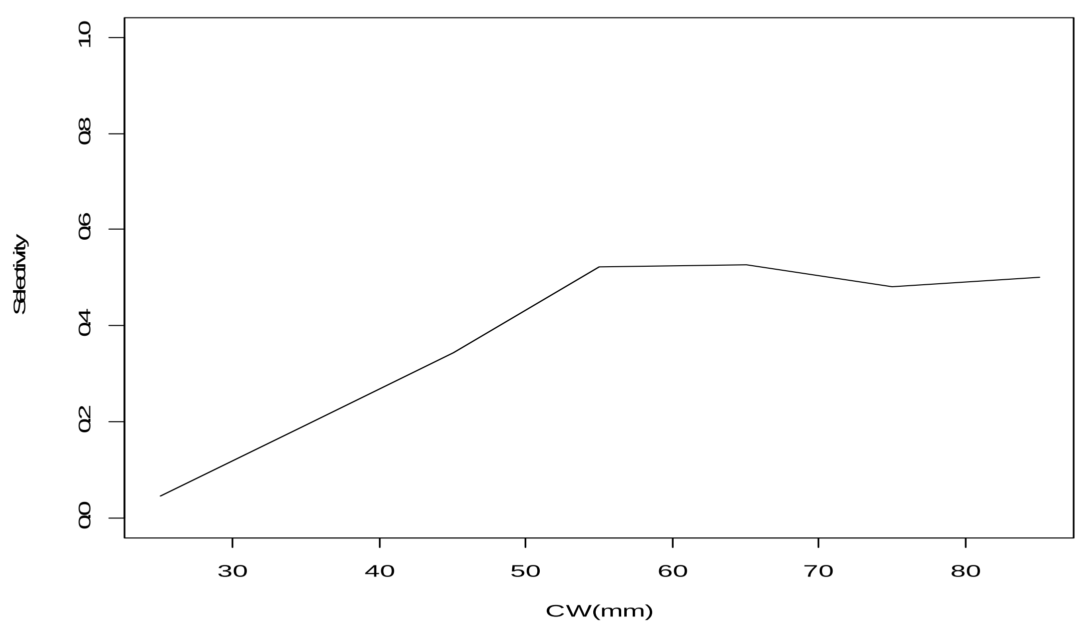

Figure 40. Mean from Figure 38, female crab translated to selectivity (selectivity = p/(1-p), where p= d1/(d1+d2))

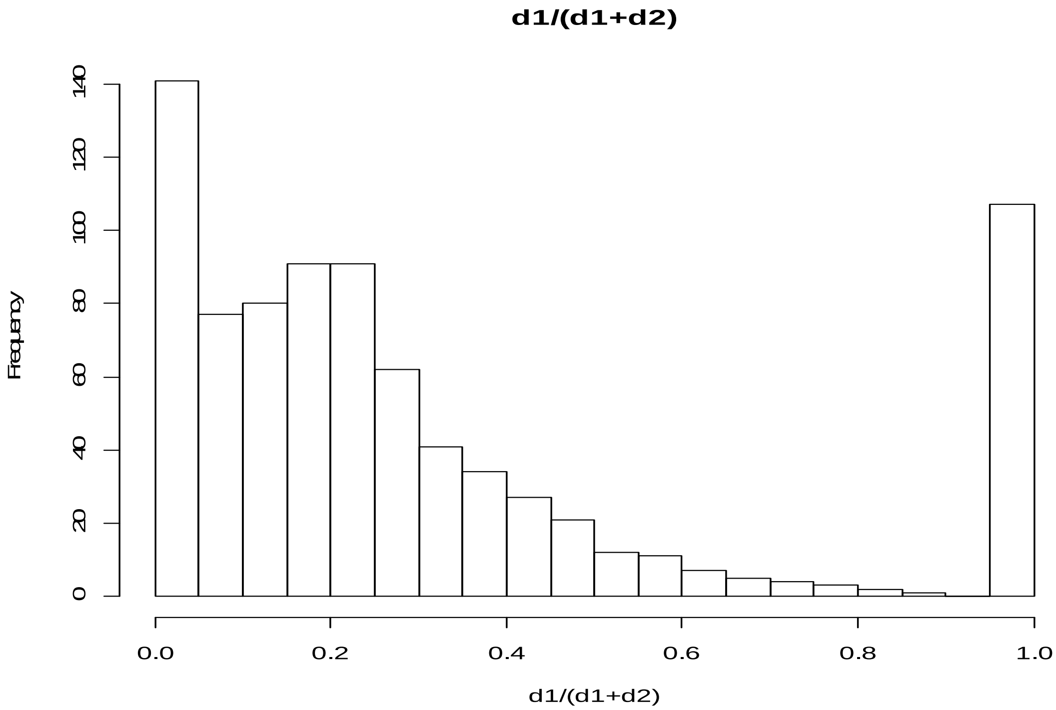

Figure 41. Histogram of d1/(d1+d2) over all sizes and tows. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

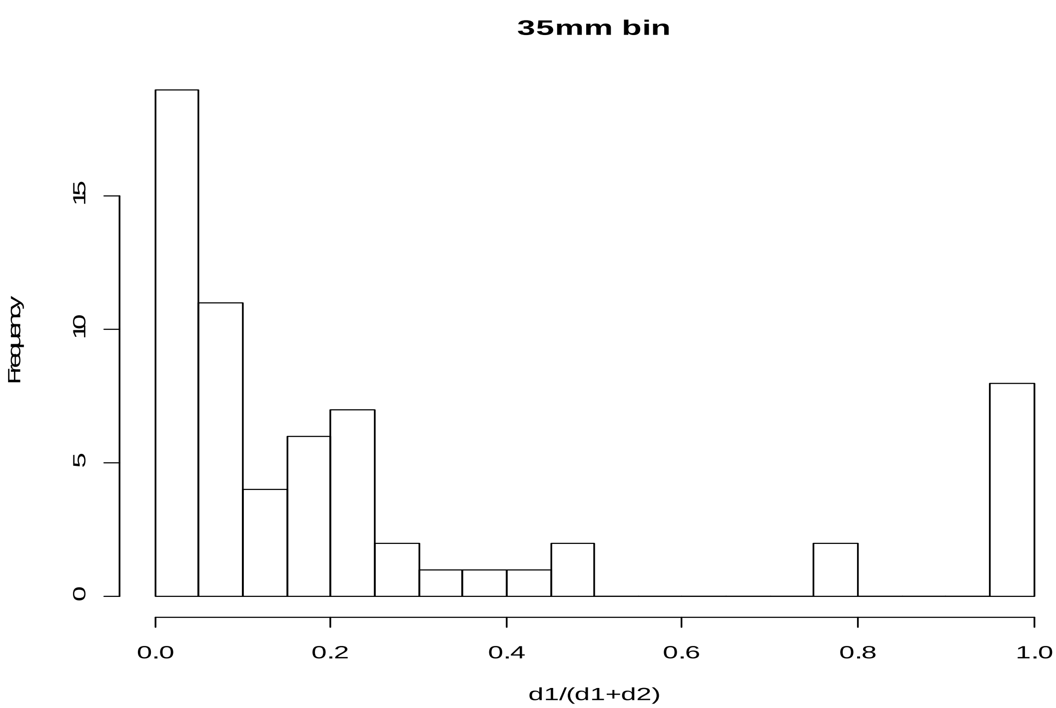

Figure 42. Histogram of d1/(d1+d2) for the 30 to 40 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

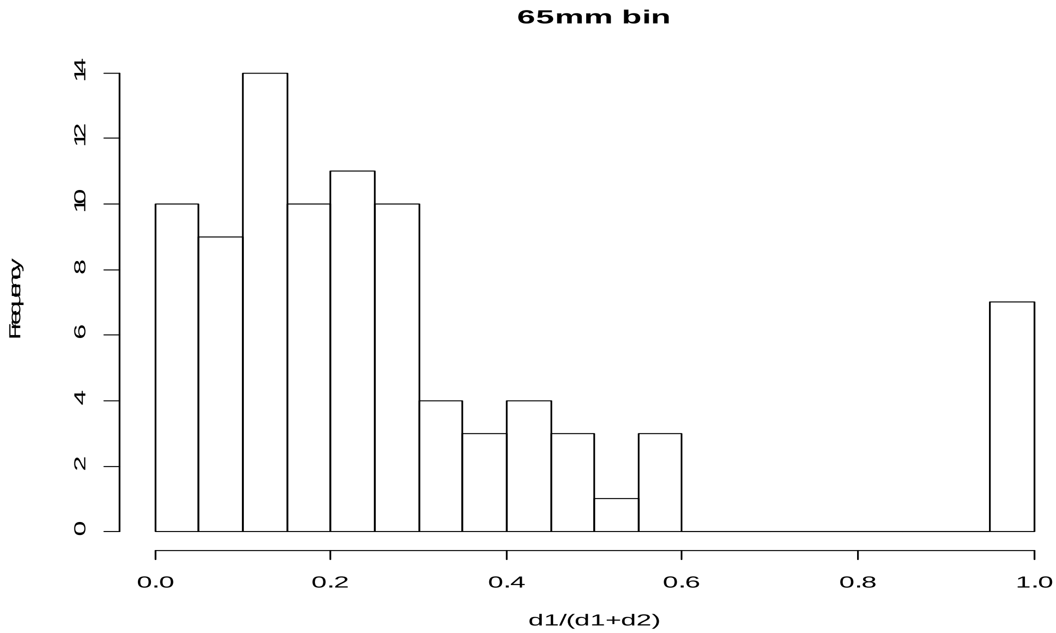

Figure 43. Histogram of d1/(d1+d2) for the 60 to 70 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

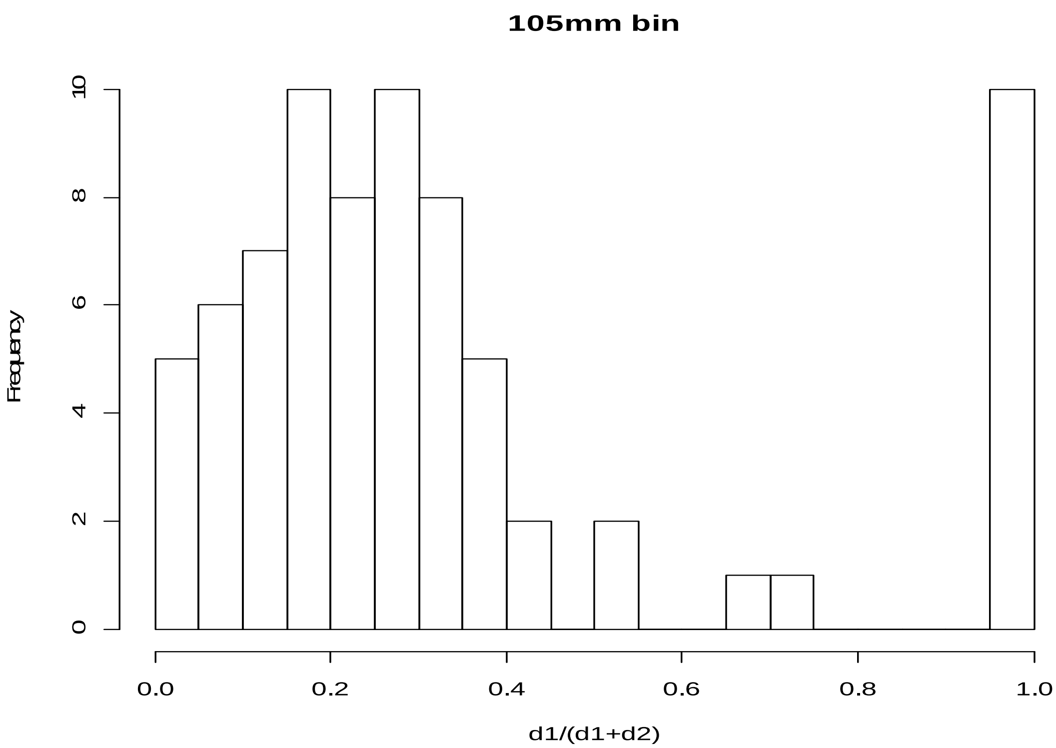

Figure 44. Histogram of d1/(d1+d2) for the 100 to 110 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

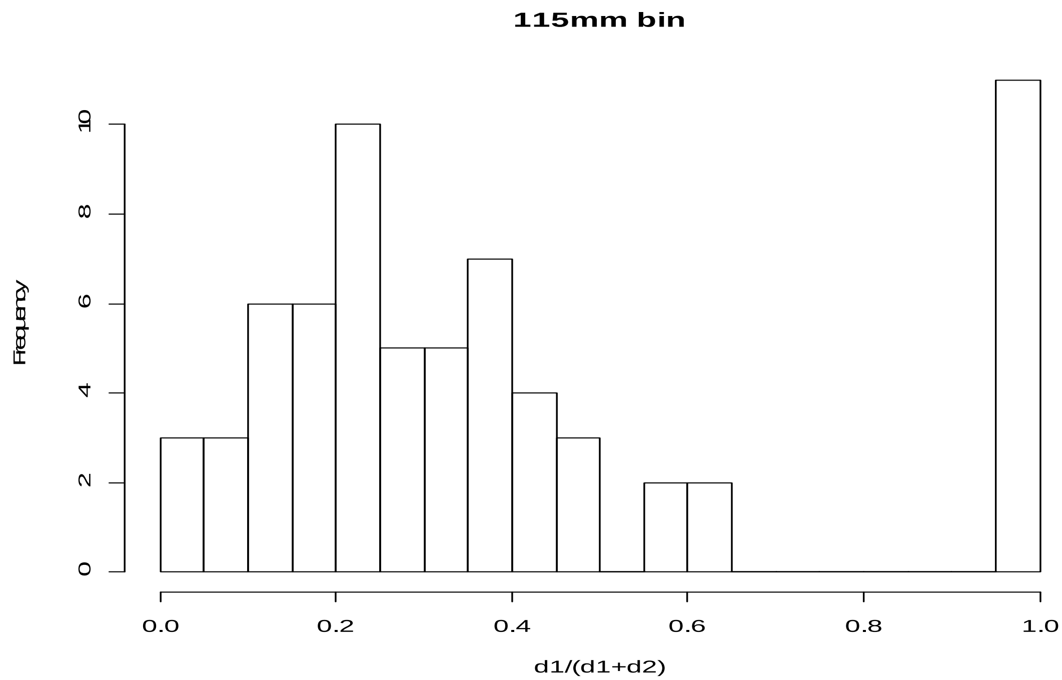

Figure 45. Histogram of d1/(d1+d2) for the 100 to 120 mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

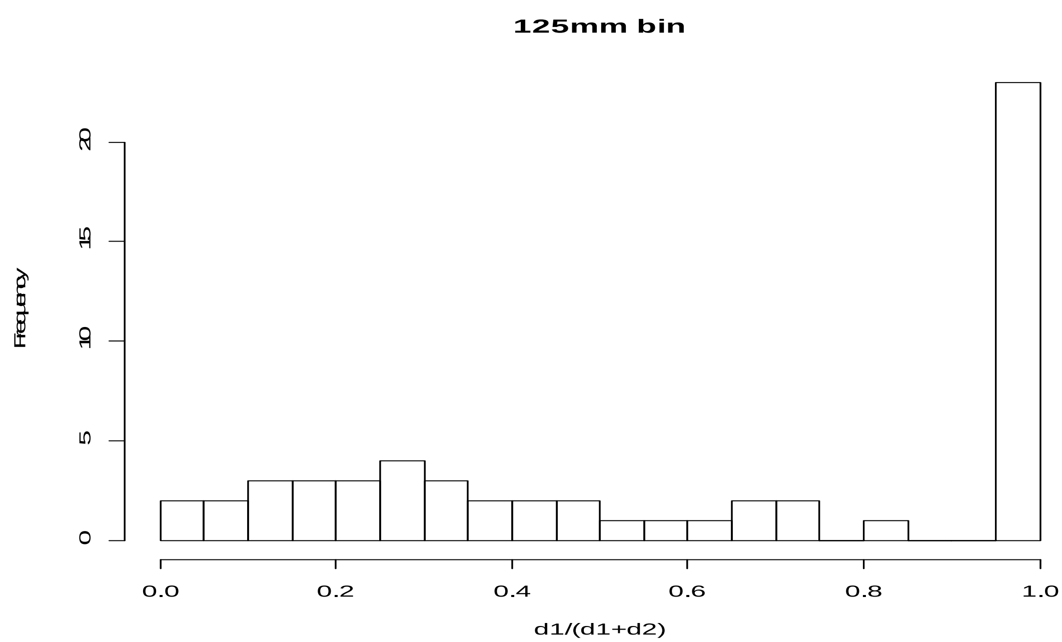

Figure 46. Histogram of d1/(d1+d2) for the 120+mm size bin. A value of 1.0 is a positive catch in the NMFS tow and a zero catch in the BSFRF tow. A value of 0.0 is a 0 catch in the NMFS tow and a positive catch in the BSRFR tow.

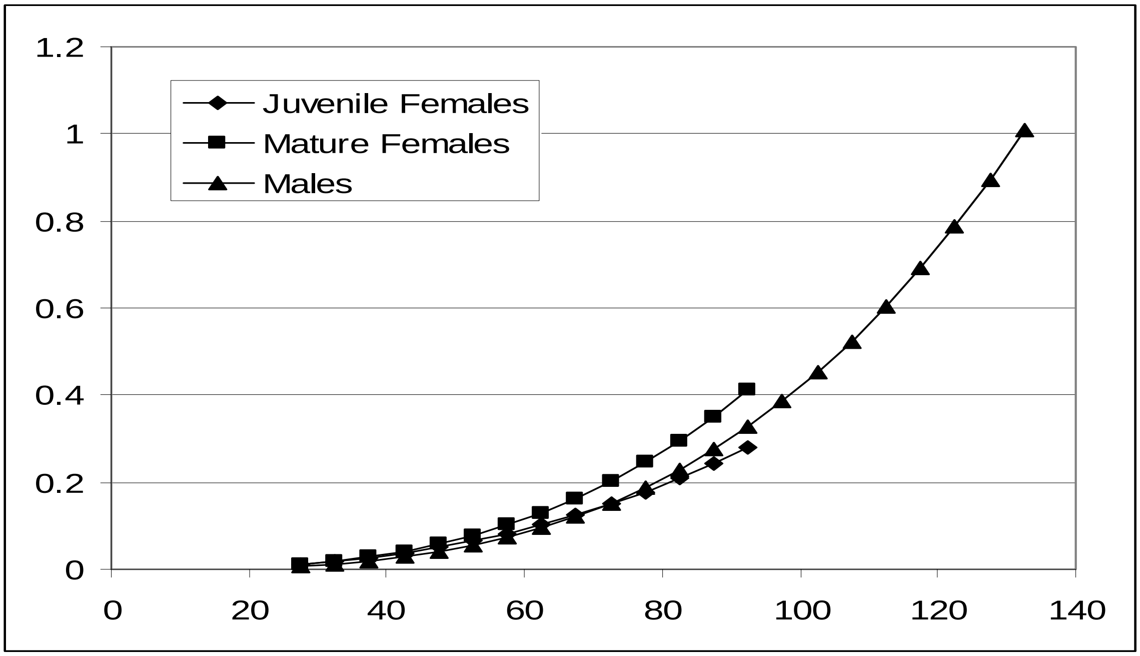

Figure 47. Weight (kg) – size (mm) relationship for male, juvenile female and mature female snow crab.

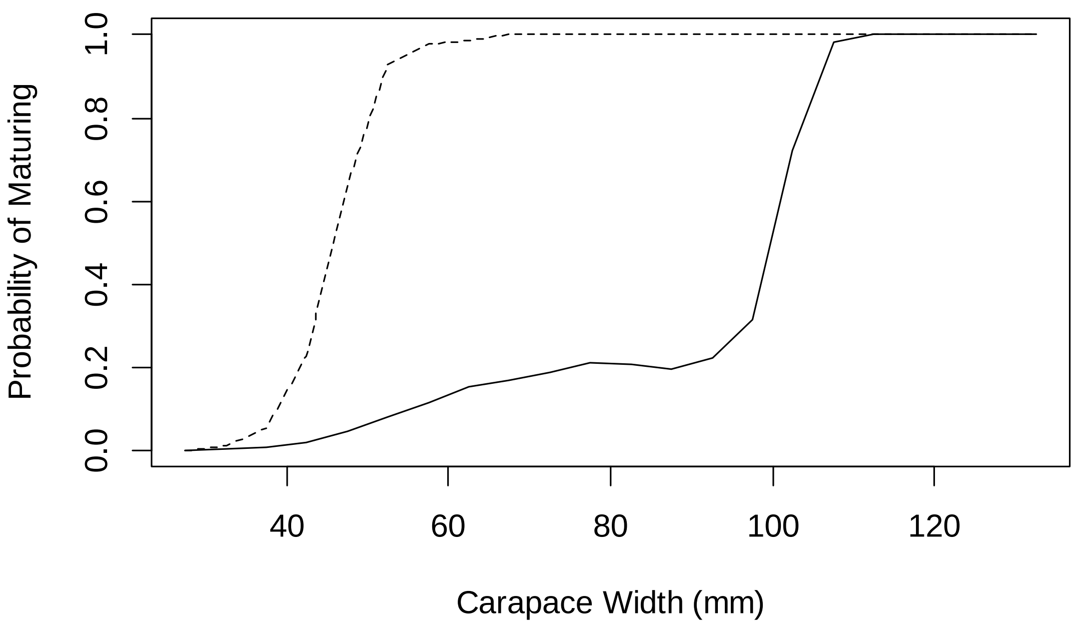

Figure 48. Probability of maturing by size estimated in the model for male(solid line) and female (dashed line) snow crab (not the average fraction mature).

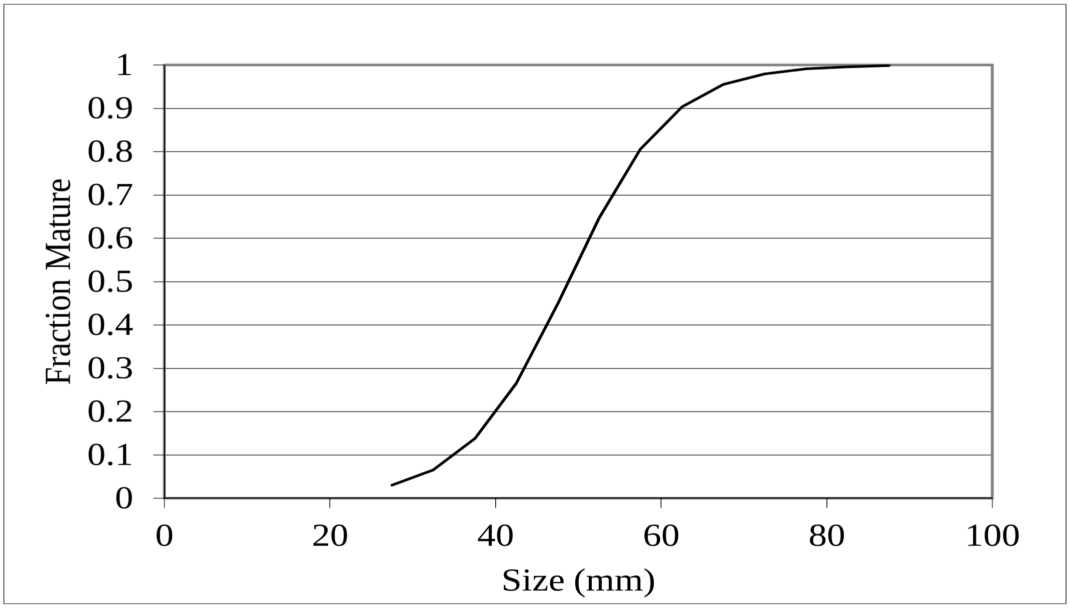

Figure 48b. Logistic fit to fraction mature for female snow crab (not used in model).

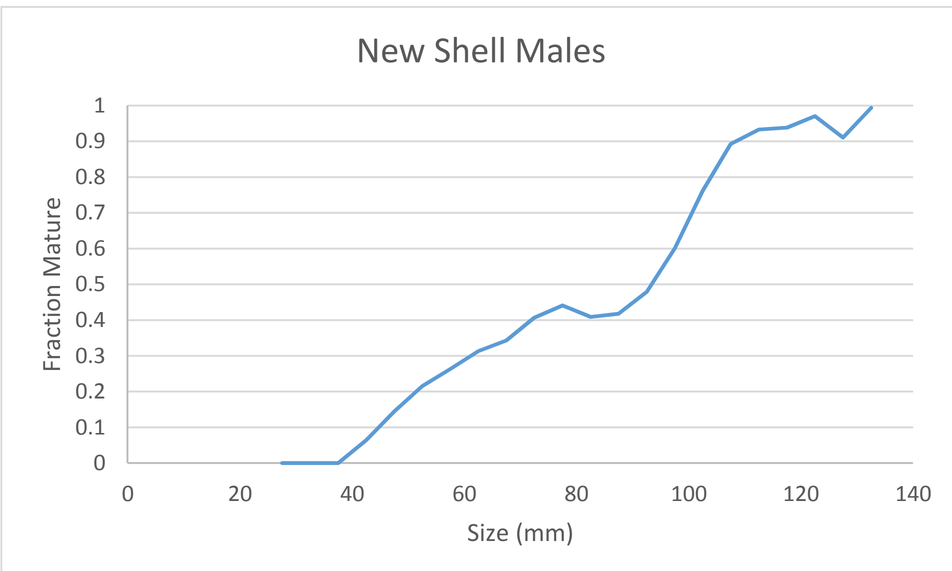

Figure 48c. Average fraction mature for new shell males from chela height data 1989-2007.

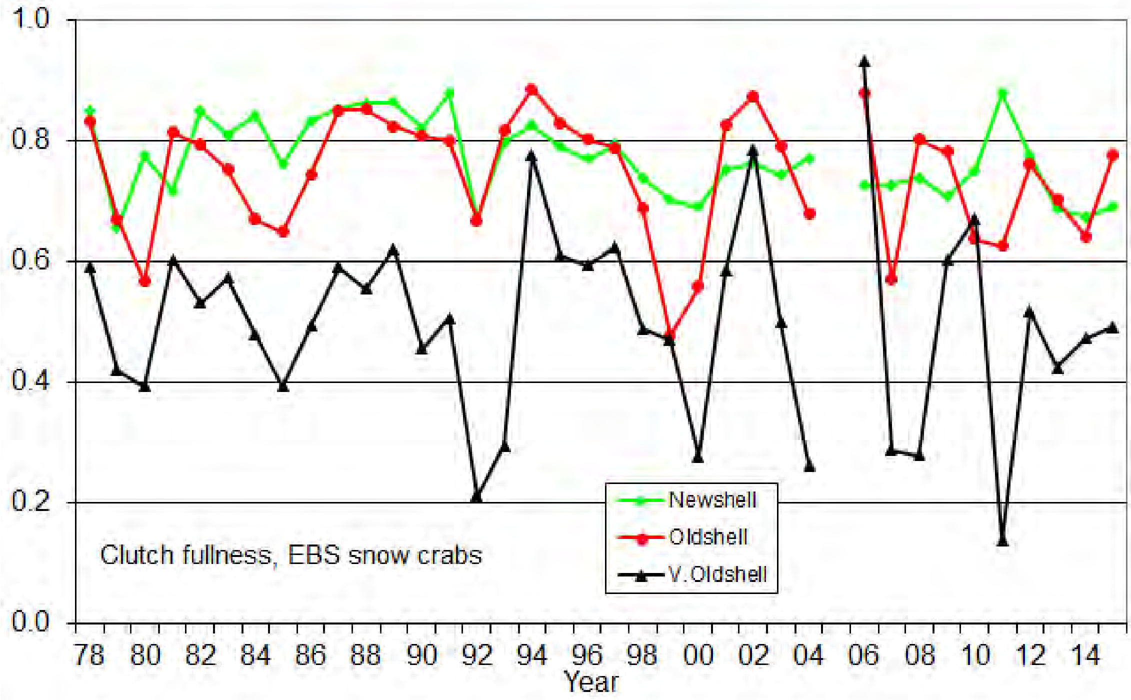

Figure 49. Clutch fullness for Bering Sea snow crab survey data by shell condition for 1978 to 2015.

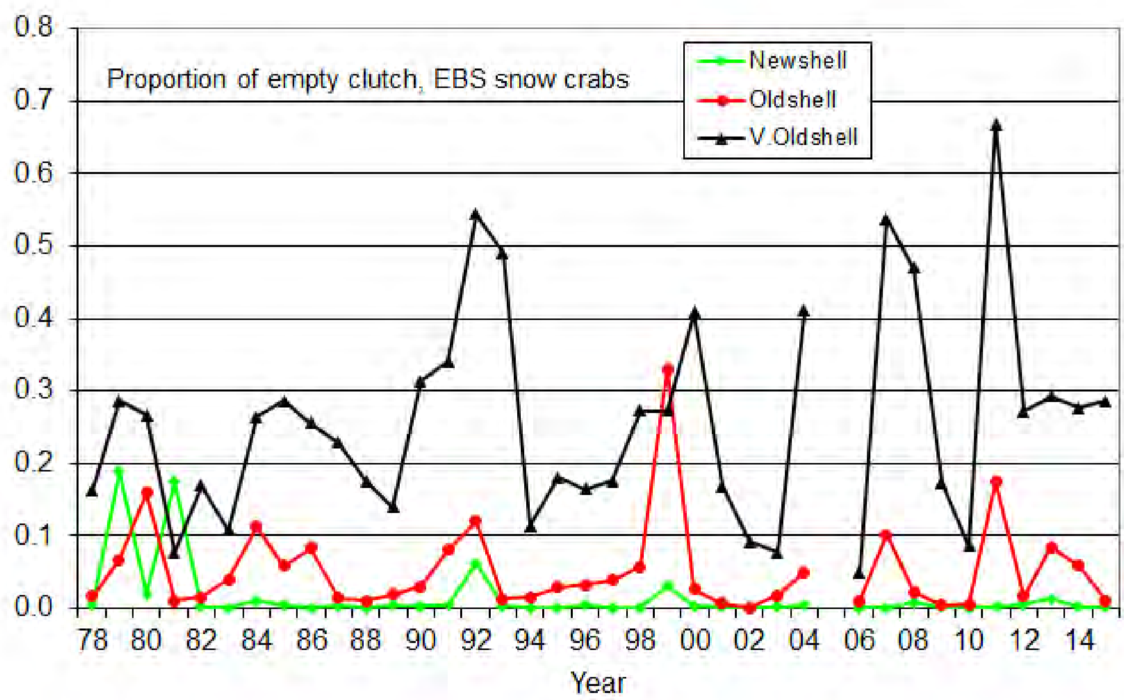

Figure 50. Proportion of barren females by shell condition from survey data 1978 to 2015.

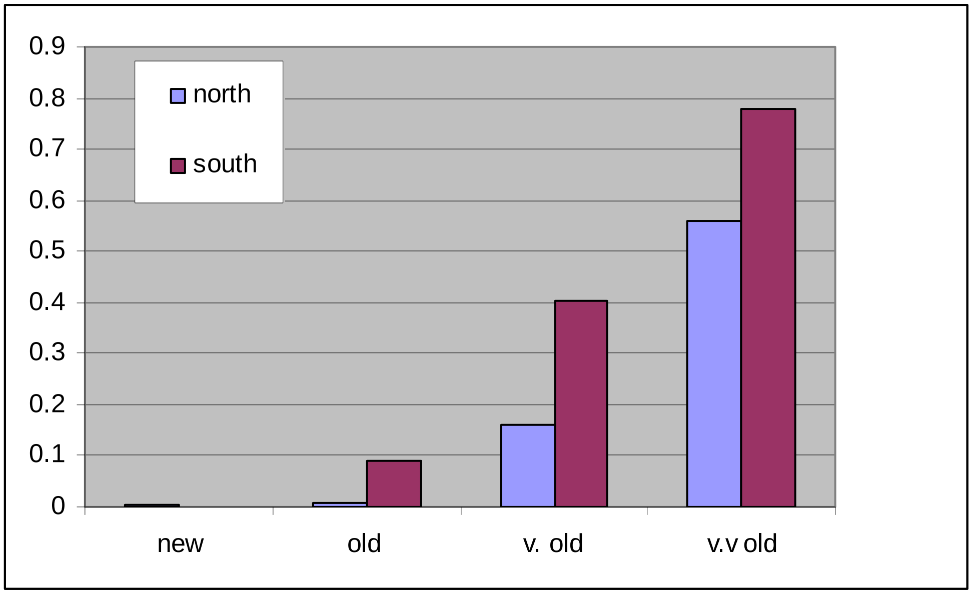

Figure 51. Fraction of barren females in the 2004 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N.

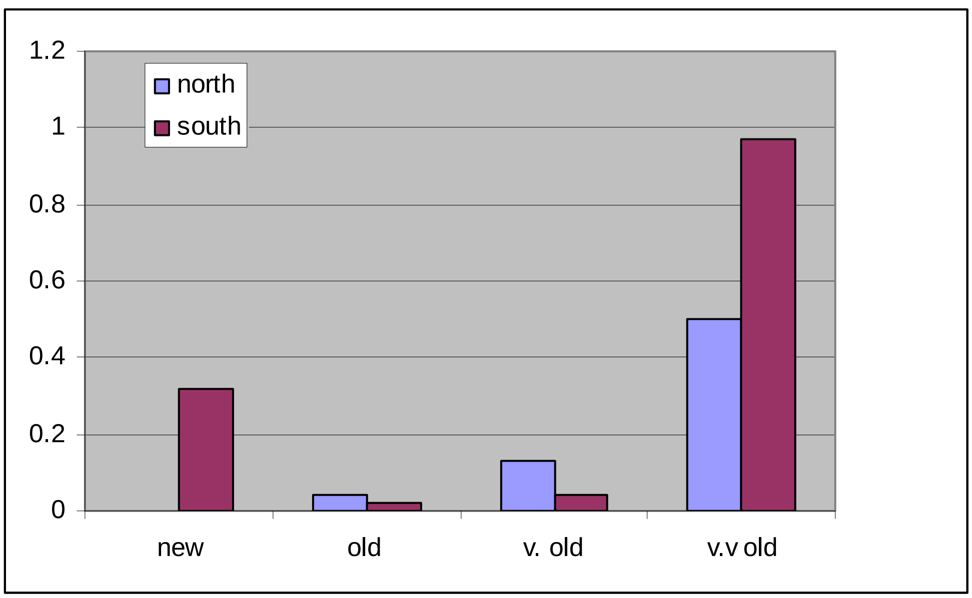

Figure 52. Fraction of barren females in the 2003 survey by shell condition and area north of 58.5 deg N and south of 58.5 deg N. The number of new shell mature females south of 58.5 deg N was very small in 2003.

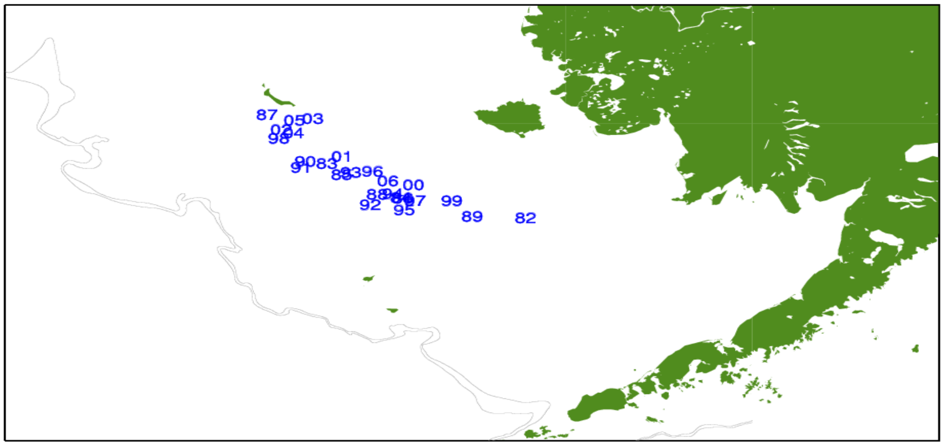

Figure 53. Centroids of cold pool (<2.0 deg C) from 1982 to 2006. Centroids are average latitude and longitude.

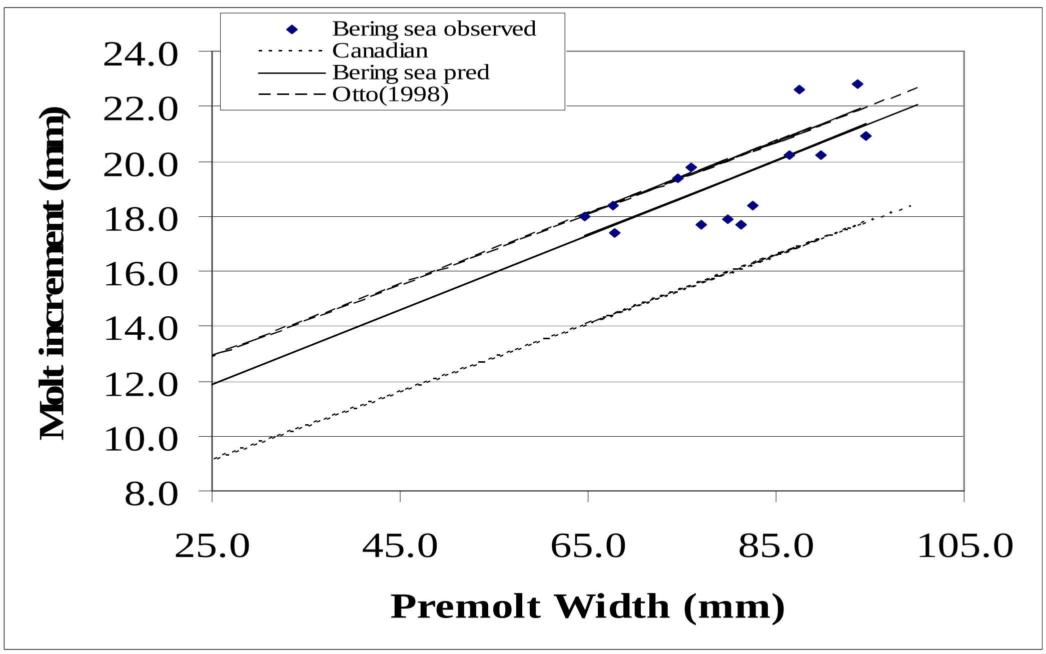

Figure 54. Growth increment as a function of premolt size for male snow crab. Points labeled Bering Sea observed are observed growth increments from Rugolo (unpub data). The line labeled Bering Sea pred is the predicted line from the Bering Sea observed growth, which was used as a prior for the growth parameters estimated in Scenarios 3 and 4. The line labeled Canadian is estimated from Atlantic snow crab (Sainte-Marie data). The line labeled Otto(1998) was estimated from tagging data from Atlantic snow crab less than 67 mm, from a different area from Sainte-Marie data.

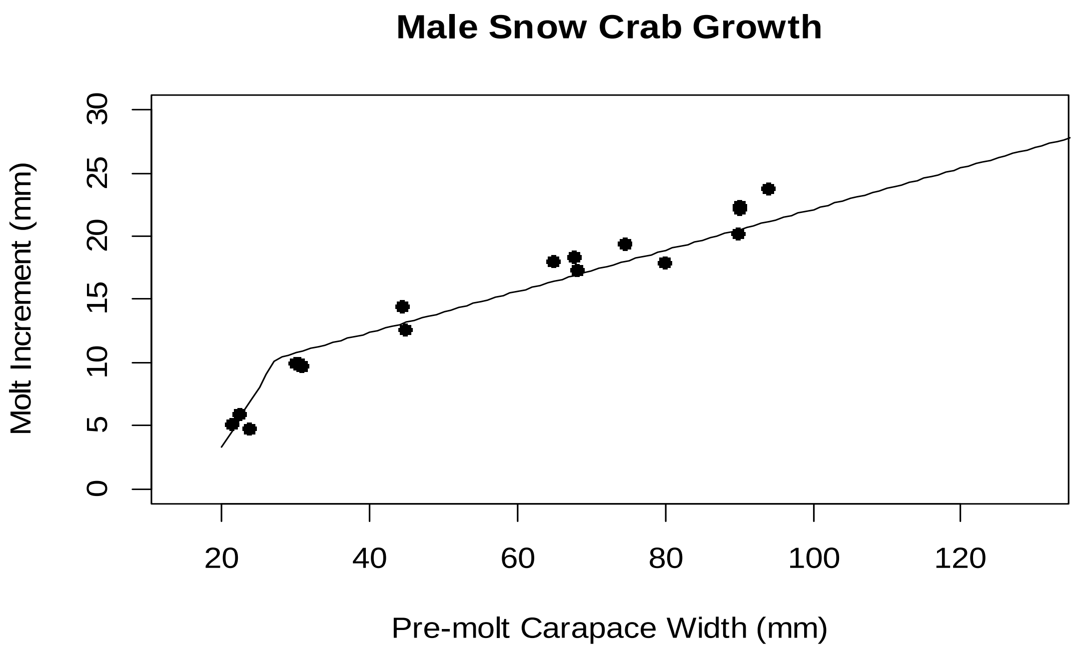

Figure 54b. Male growth data from 2011 growth study and model fit for the Base model (Model 5).

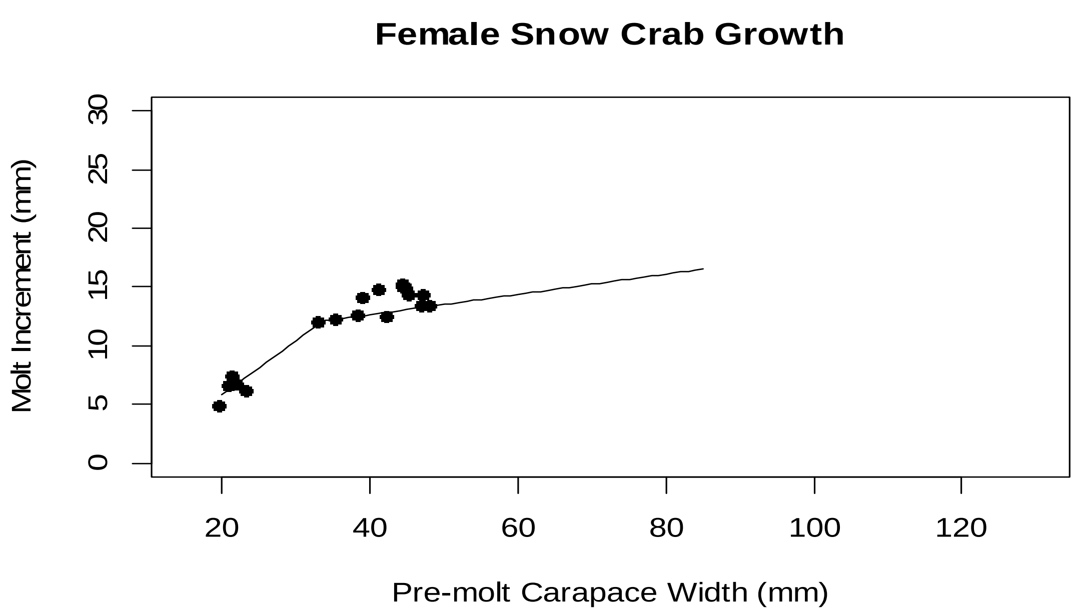

Figure 54c. Female growth data from 2011 growth study and model fit for the Base model (Model 5).

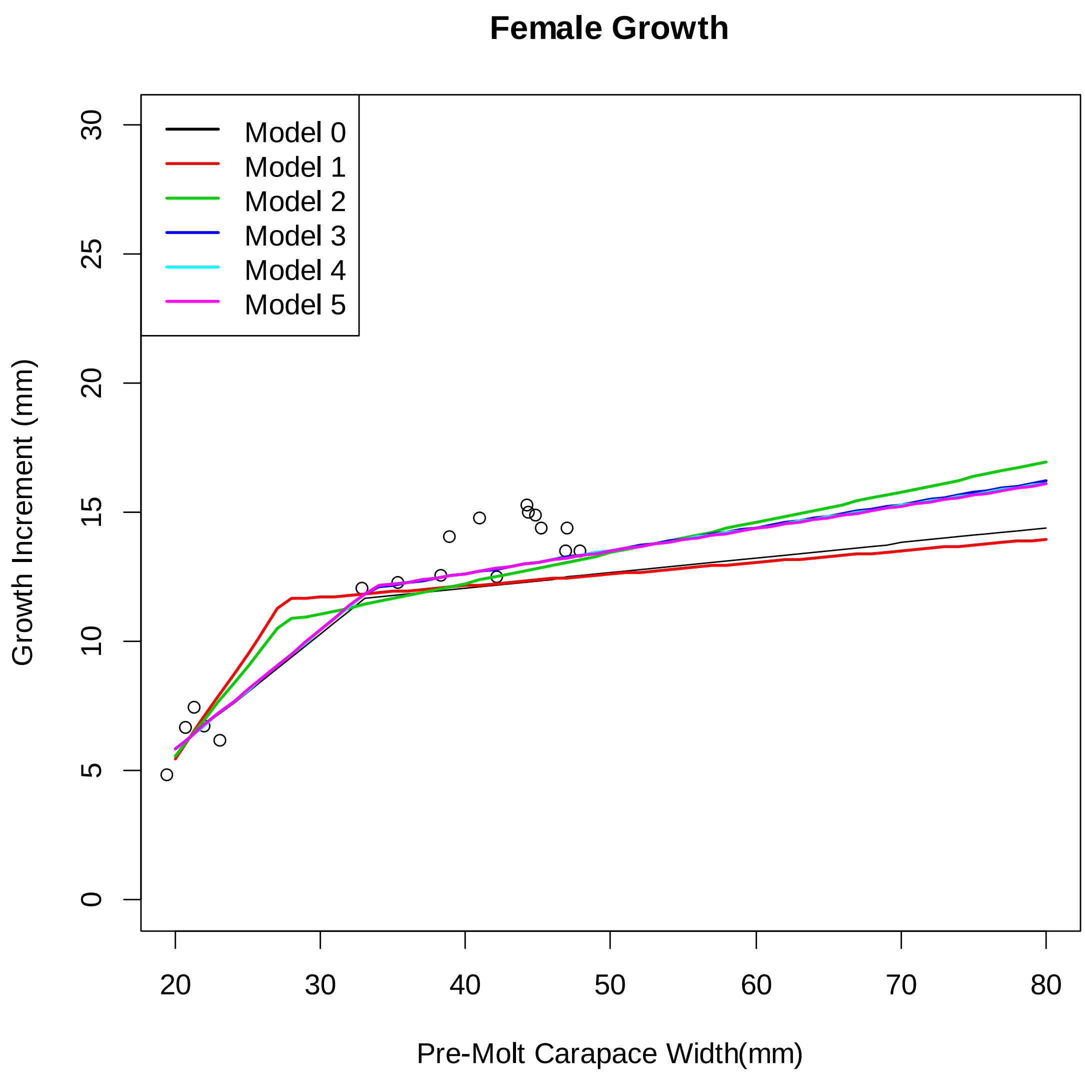

Figure 54d. Estimated female growth for Models 0 through 5. Model 3 and 5 transition between line segments is at a larger size (34mm) than Models 0, 1, 2 and 4 (about 28mm).

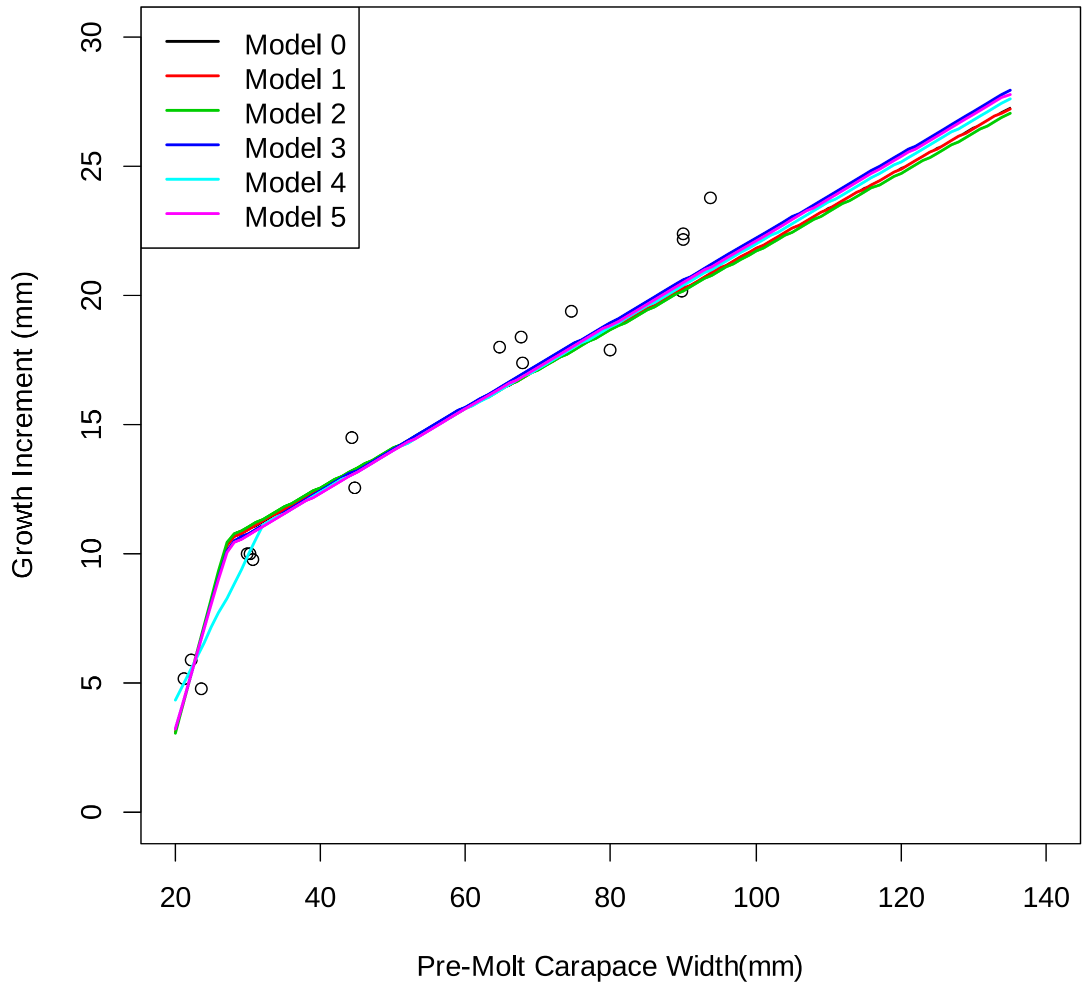

Figure 54e. Estimated male growth for models 0 through 5. Model 4 has a transition at a higher size (about 33 mm) than other models.

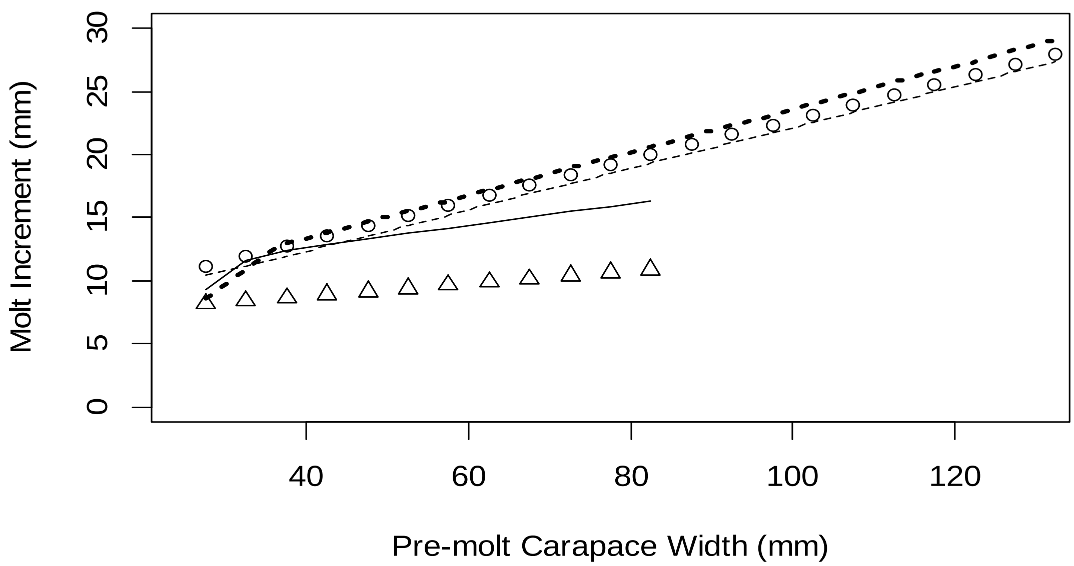

Figure 55. Growth(mm) for male(dotted line) and female snow crab (solid line) estimated from the base model. The priors for the growth curve used in models before September 2013 are circles (males) and triangle (females). Heavy dotted line is the growth curve estimated by Somerton for males and females from the 2011 growth study (Somerton 2012).

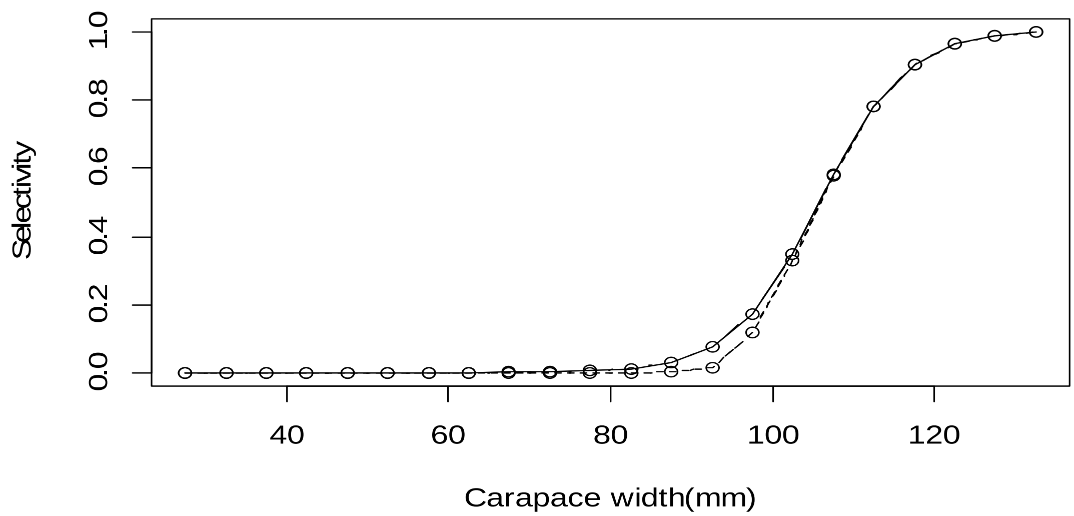

Figure 56. Base Model. Selectivity curve for total catch (discard plus retained, solid line) and retained catch (dotted line) for combined shell condition male snow crab.

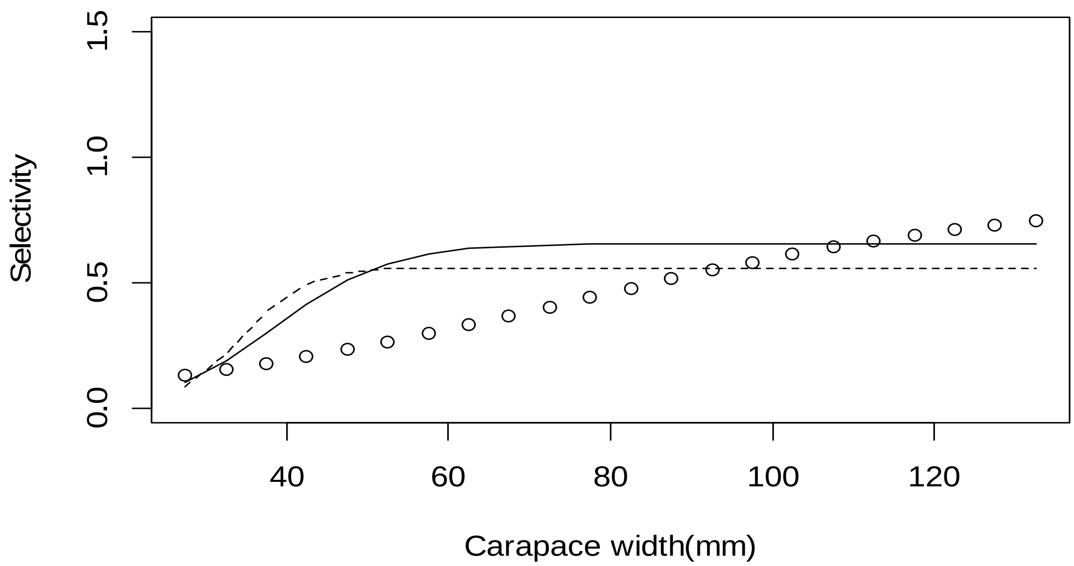

Figure 57. Base Model. Survey selectivity curves for female (dotted lines) and male snow crab (solid lines) estimated by the model for 1989 to present. Survey selectivities estimated by Somerton from 2009 study area data (2010) are the circles.

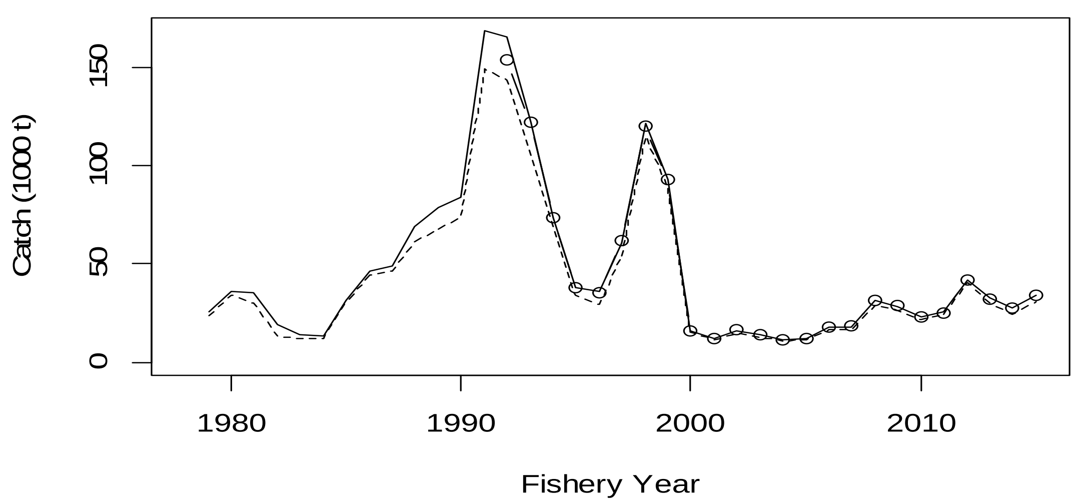

Figure 58. Base Model. Estimated total catch(discard + retained) (solid line), observed total catch (solid line with circles) (assuming 30% mortality of discarded crab) and observed retained catch (dotted line)

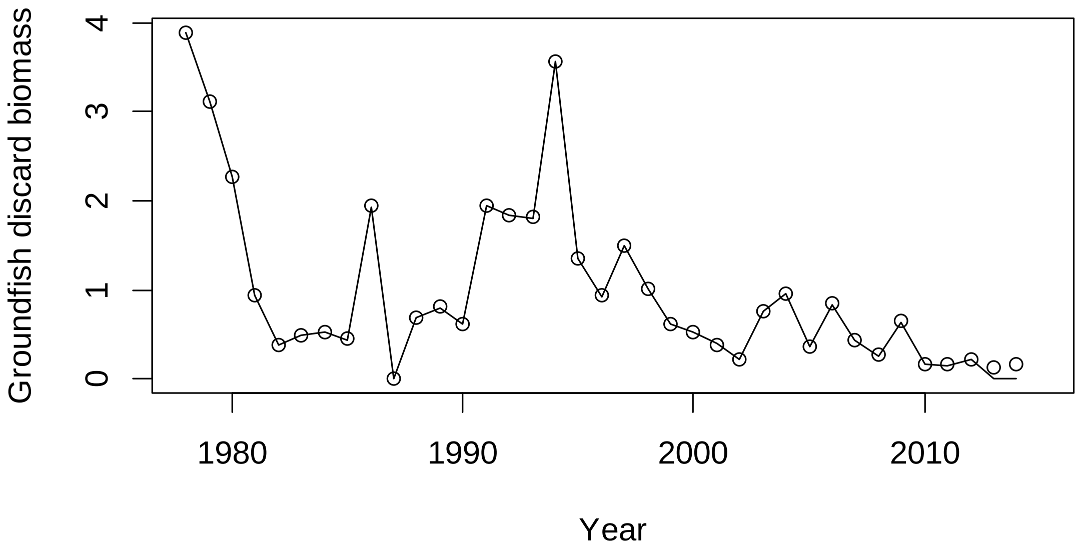

Figure 59. Base Model. Model fit to groundfish bycatch. Circles are observed catch, line is model estimate.

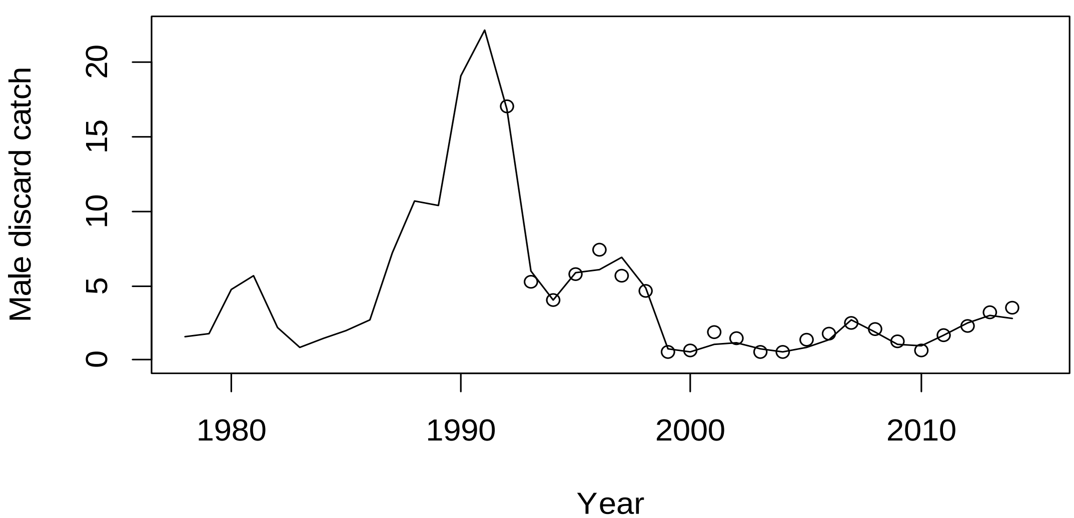

Figure 60. Base Model. Model fit to male directed discard catch for 1992/93 to present and model estimated male discard catch from 1978 to 1991.

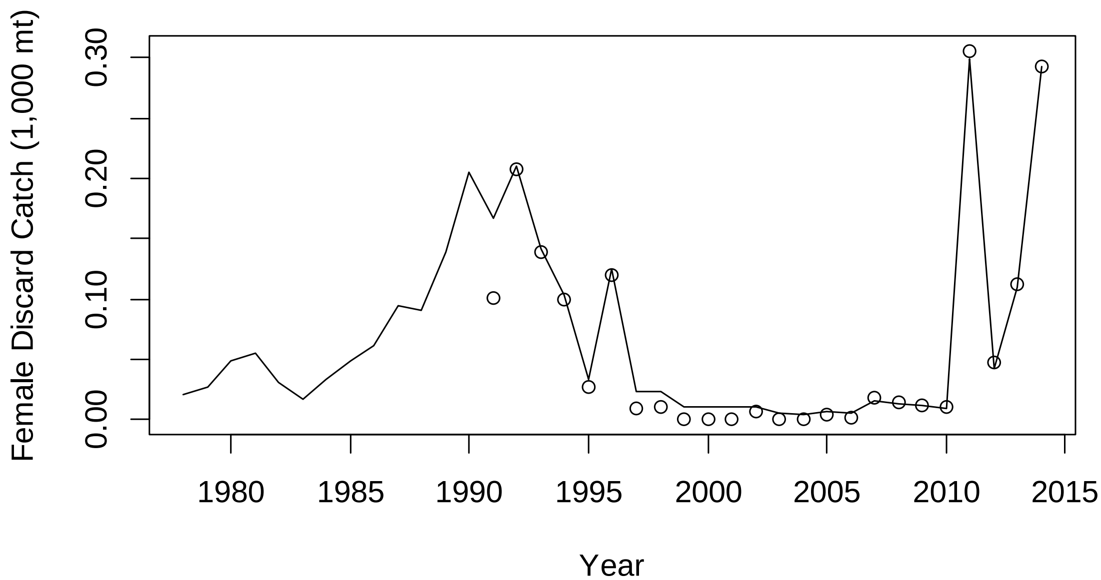

Figure 61. Base Model. Model fit to female discard bycatch in the directed fishery from 1992/93 to present and model estimates of discard from 1978 to 1991.

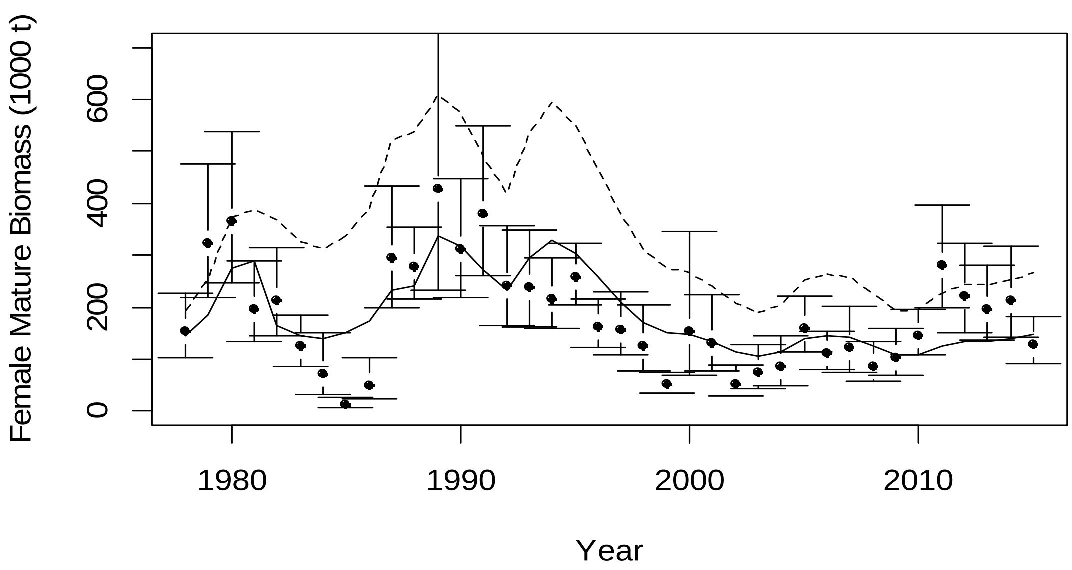

Figure 62. Base Model. Population female mature biomass (1000 t, dotted line), model estimate of survey female mature biomass (solid line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

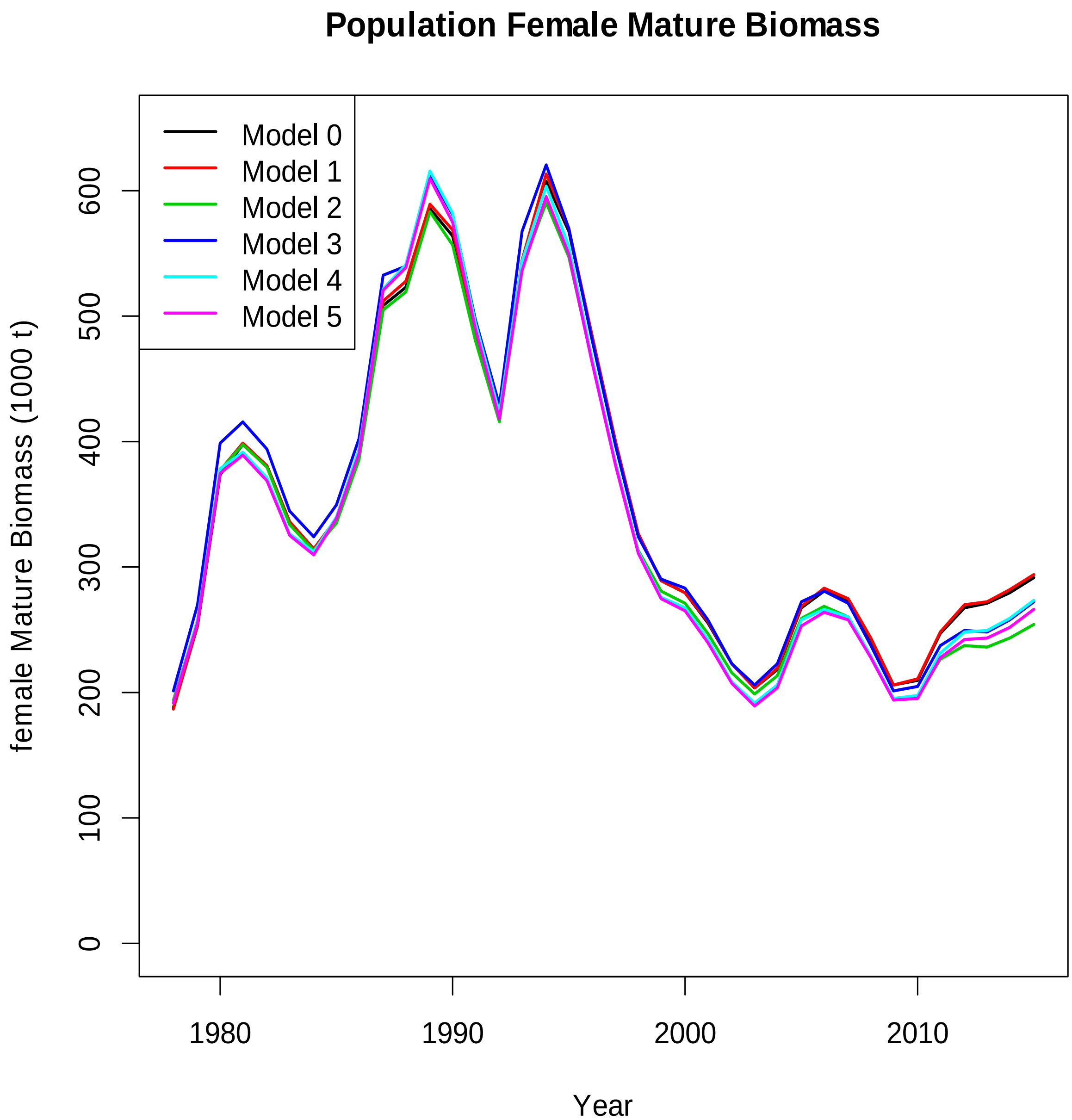

Figure 63. Population female mature biomass Models 0 through 5. Mature female biomass estimates in 2015 declined moving from Model 0 to Model 4, Model 3, Model 5, Model 2 to Model 1.

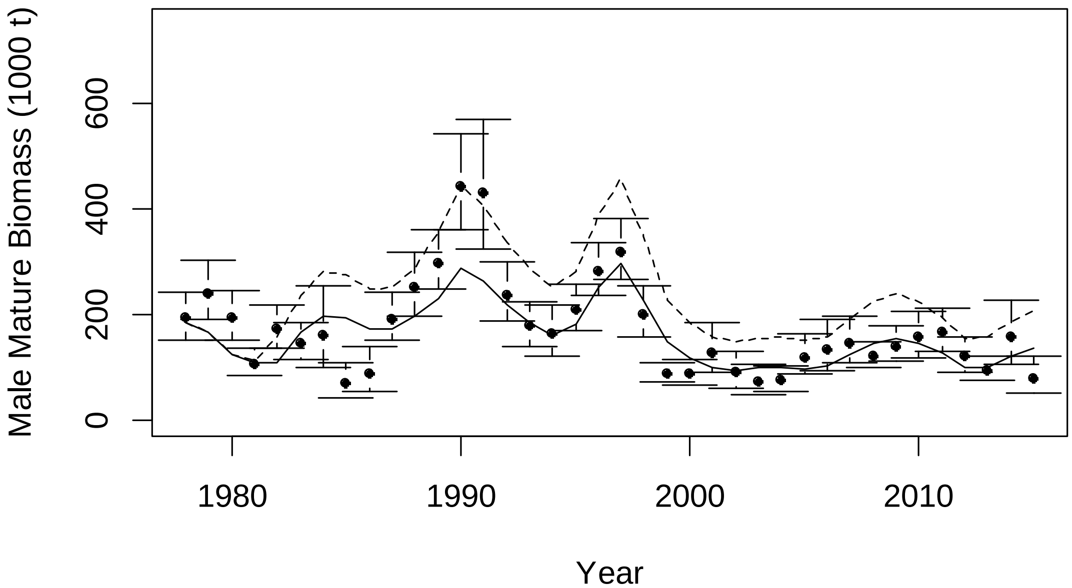

Figure 64. Base Model. Population male mature biomass (1000 t, dotted line), model estimate of survey male mature biomass (solid line) and observed survey male mature biomass with approximate lognormal 95% confidence intervals.

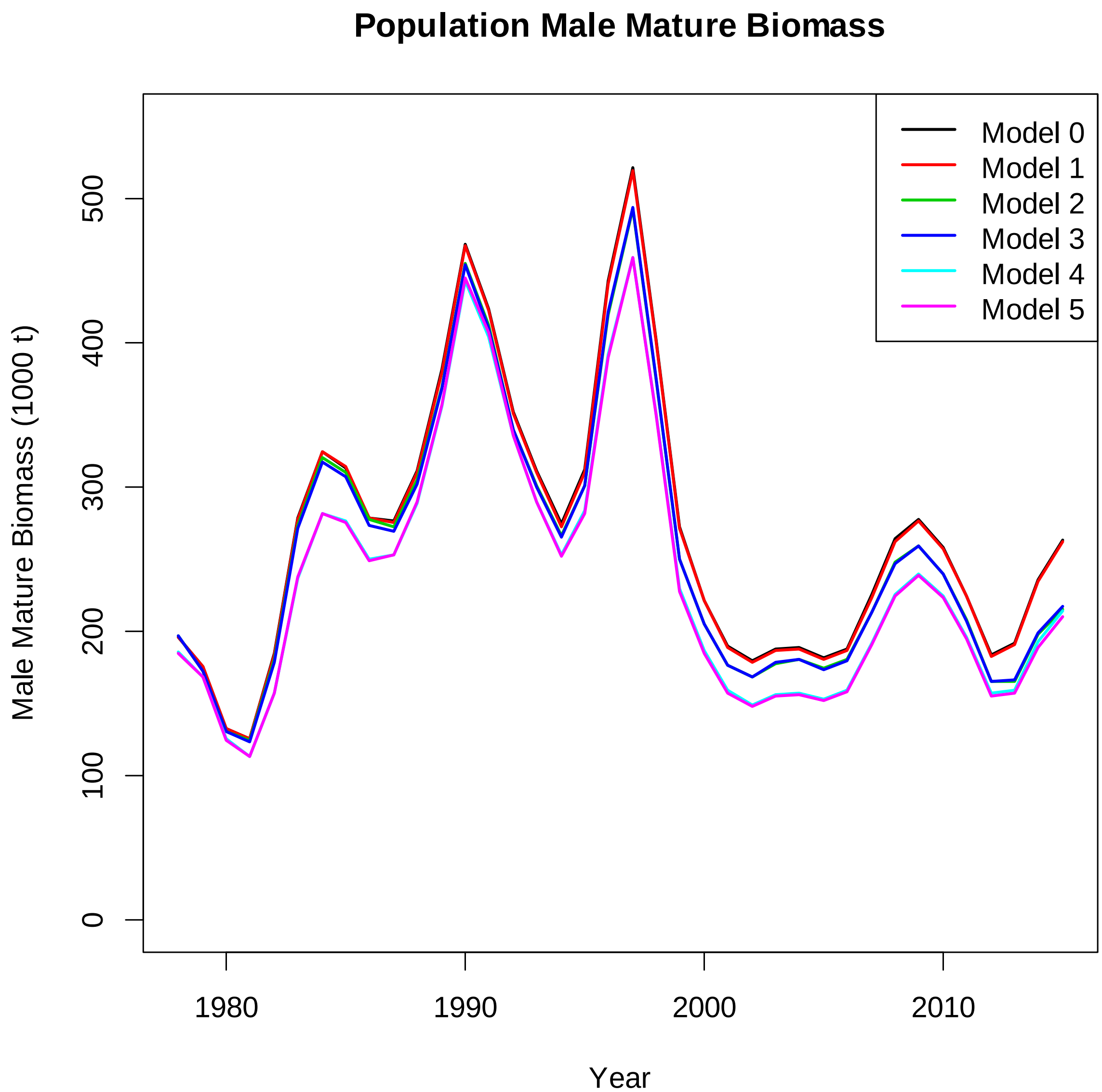

Figure 65. Population male mature biomass for Models 0 through 5. Mature male biomass estimates in 2015 declined moving from Model 0 to Model 1, Model 3, Model 2, Model 4 to Model 5.

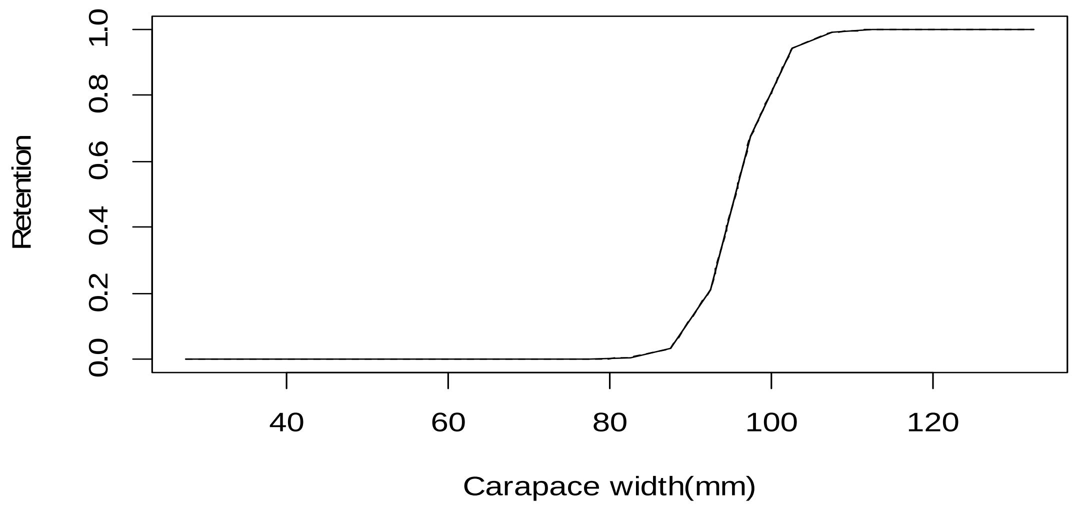

Figure 66. Base Model. Model estimated fraction of the total catch that is retained by size for male snow crab combined shell condition.

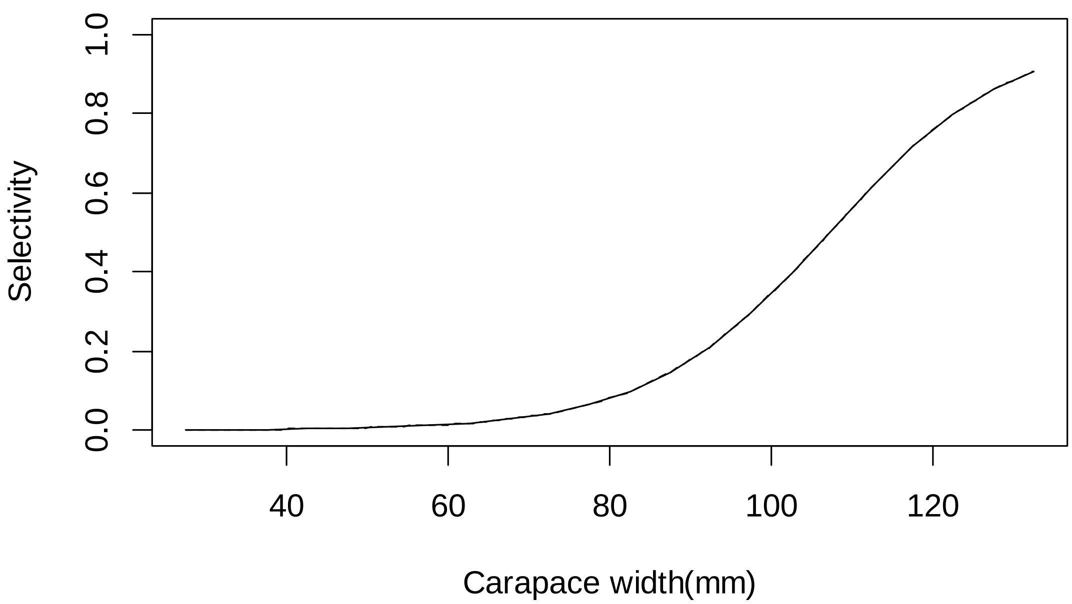

Figure 67. Base Model. Selectivity curve estimated by the model for bycatch in the groundfish trawl fishery for females and males.

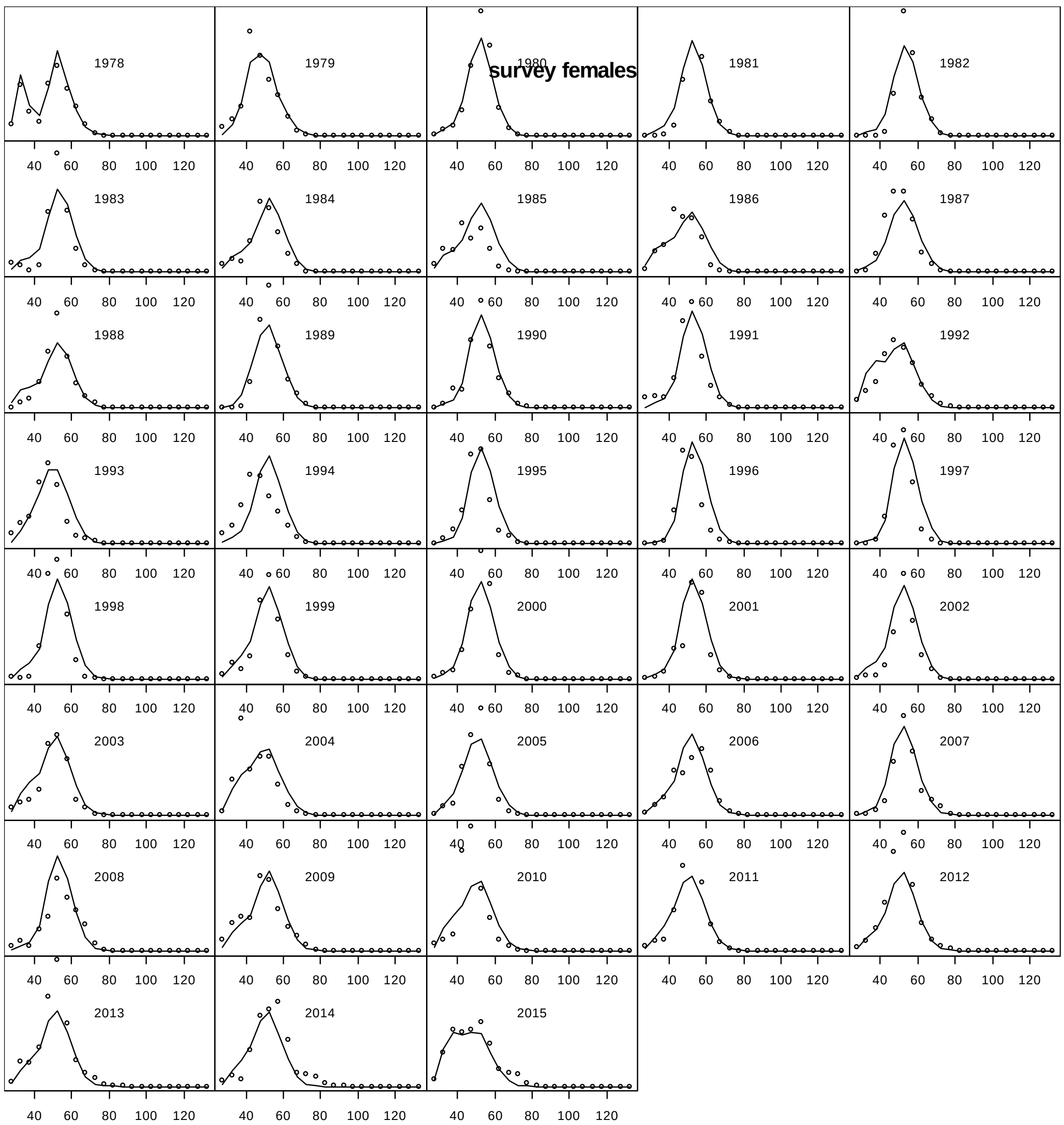

Figure 68. Base Model. Model fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

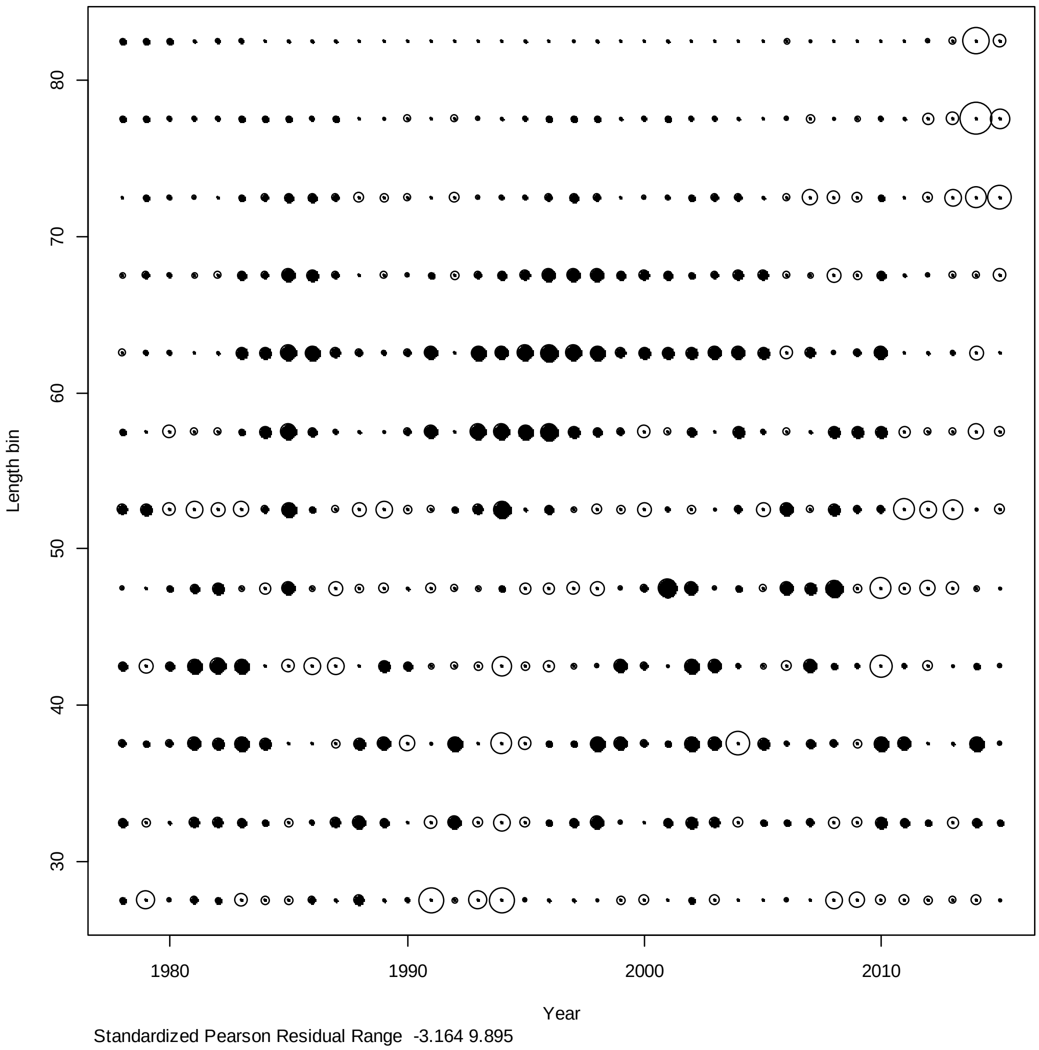

Figure 69. Base Model. Residuals of fit to survey female size frequency. Filled circles are negative residuals.

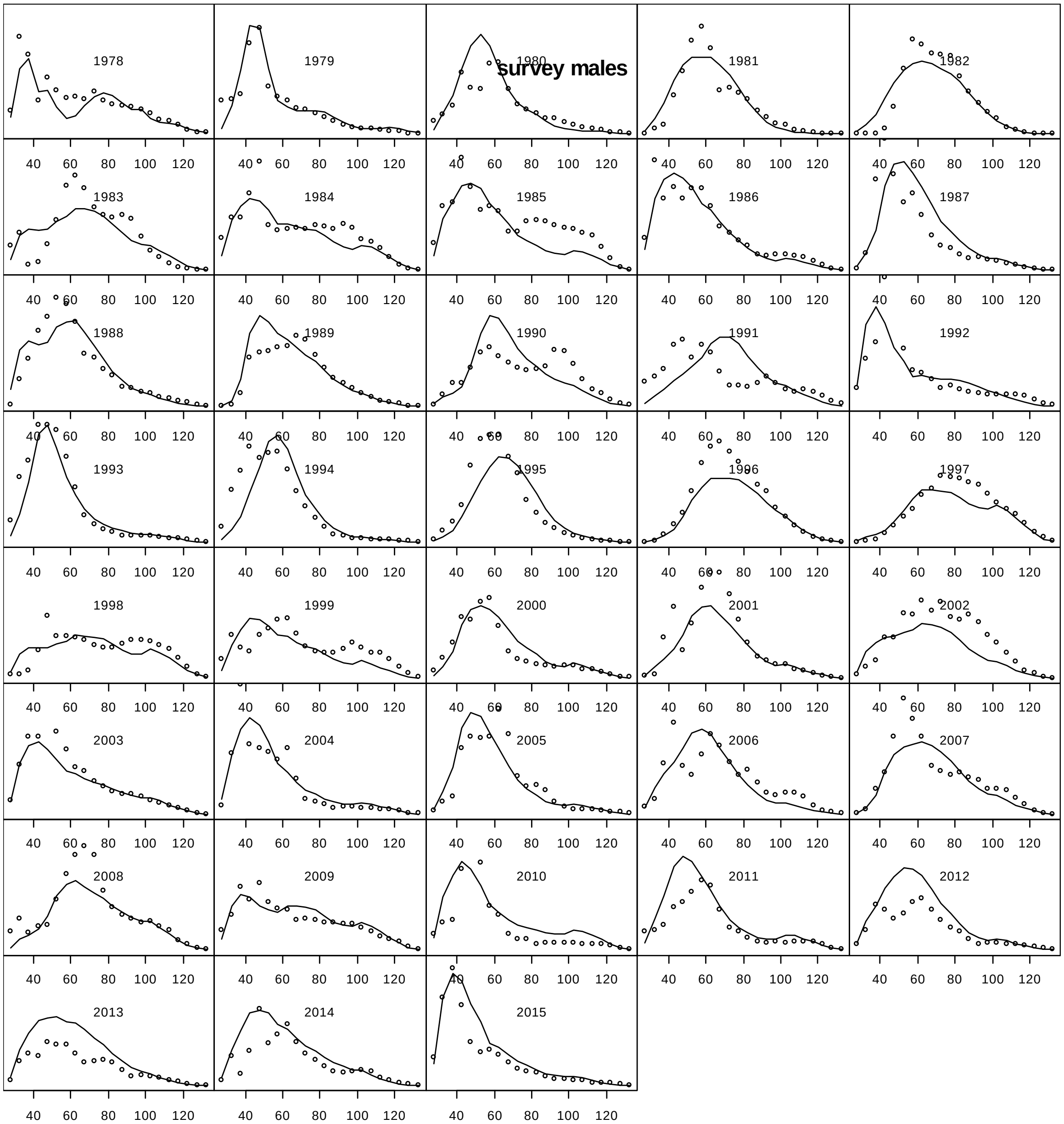

Figure 70. Base Model. Model fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

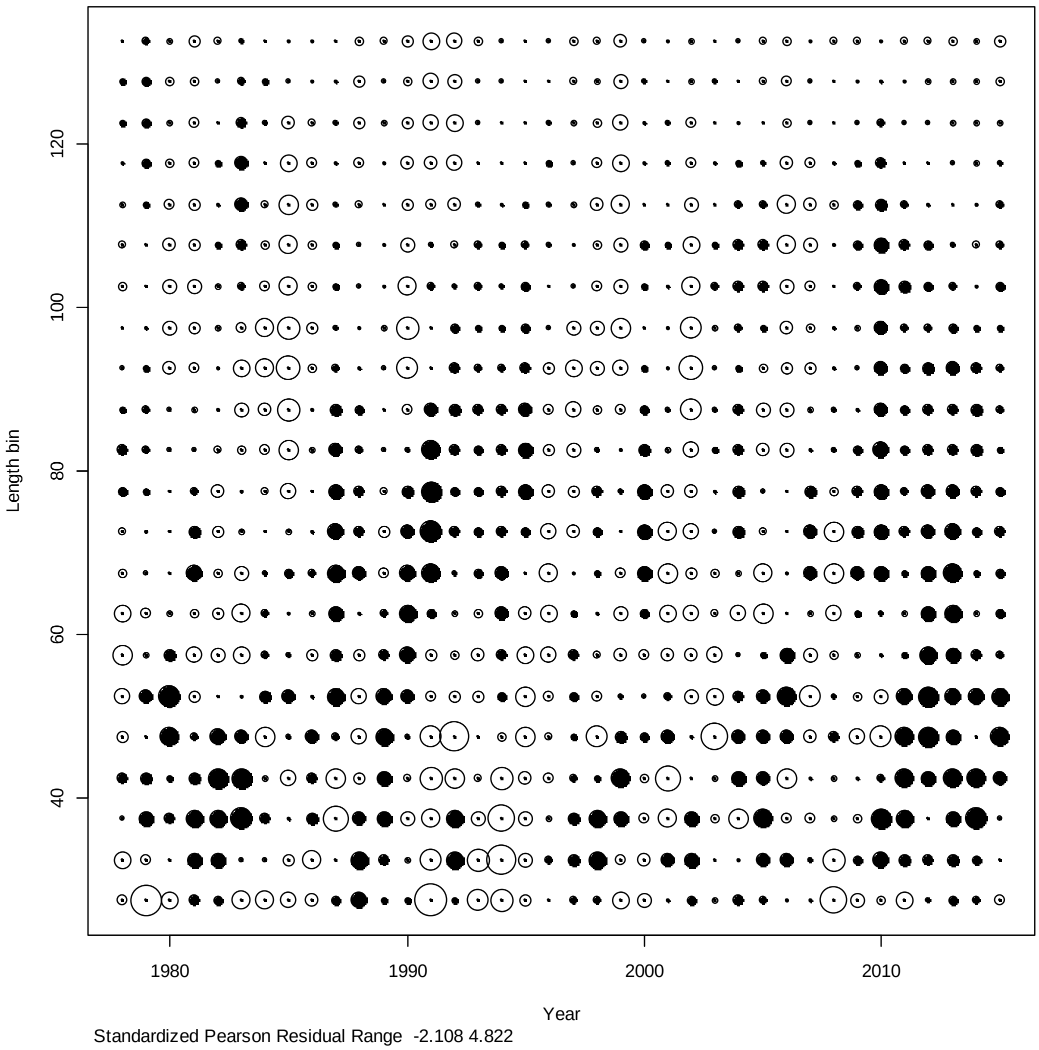

Figure 71. Base Model. Residuals for fit to survey male size frequency. Filled circles are negative residuals (predicted higher than observed).

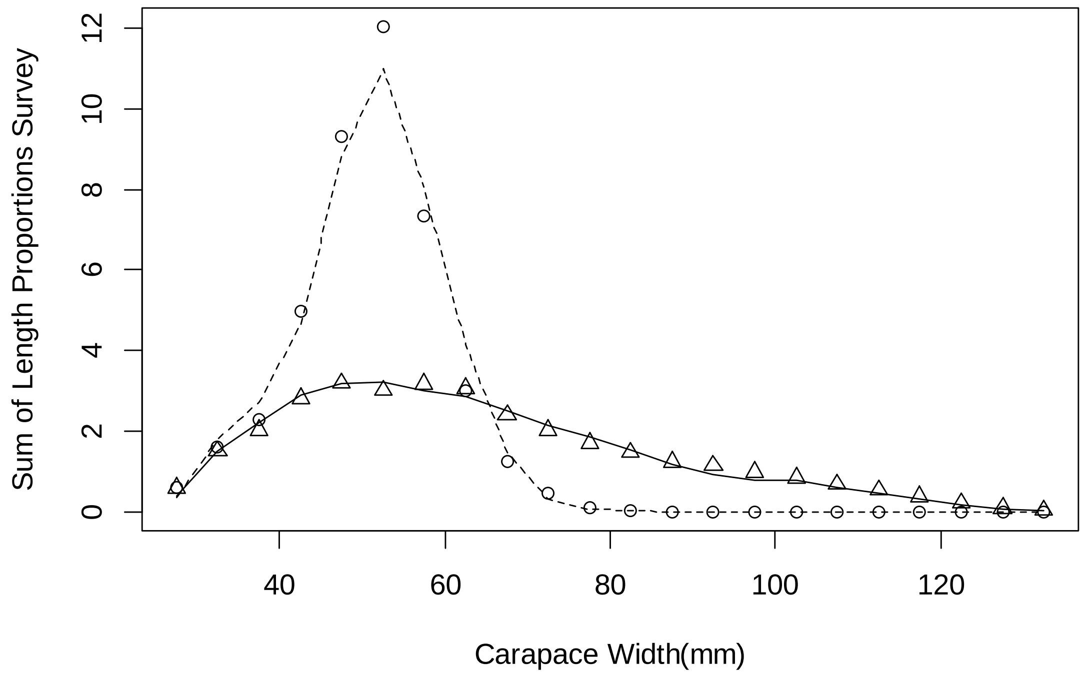

Figure 72. Base Model. Summary over years of fit to survey length frequency data by sex. Dotted line is fit for females, circles are observed. Solid line is fit for males, triangles are observed.

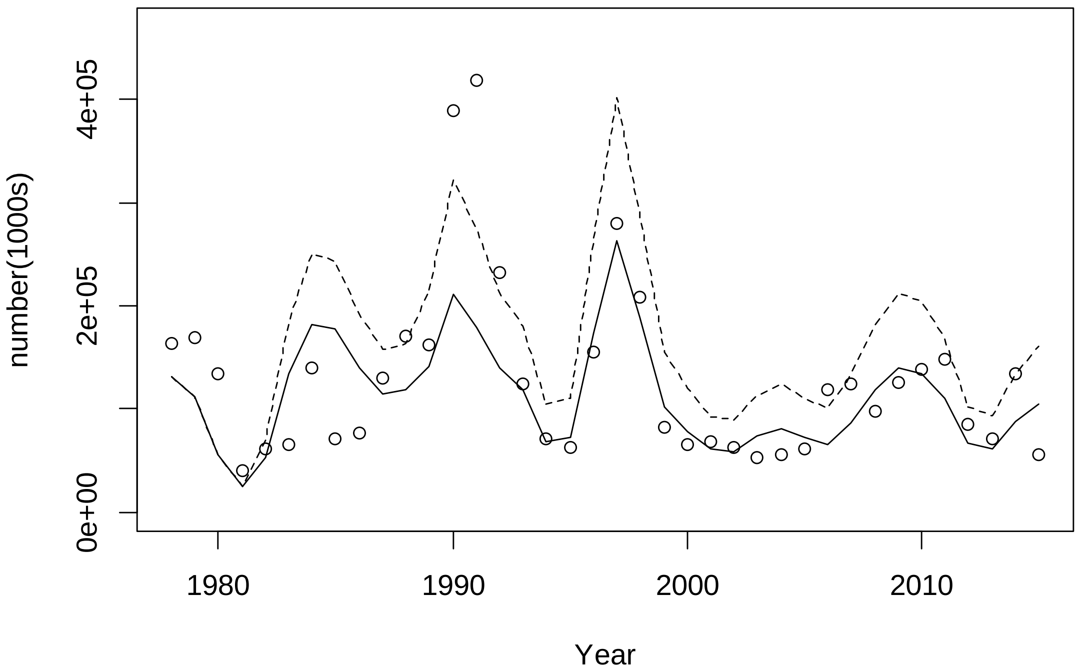

Figure 73. Base Model. Observed survey numbers of males >101mm (circles), model estimates of the population number of males >101mm(solid line) and model estimates of survey numbers of males >101 mm (dotted line).

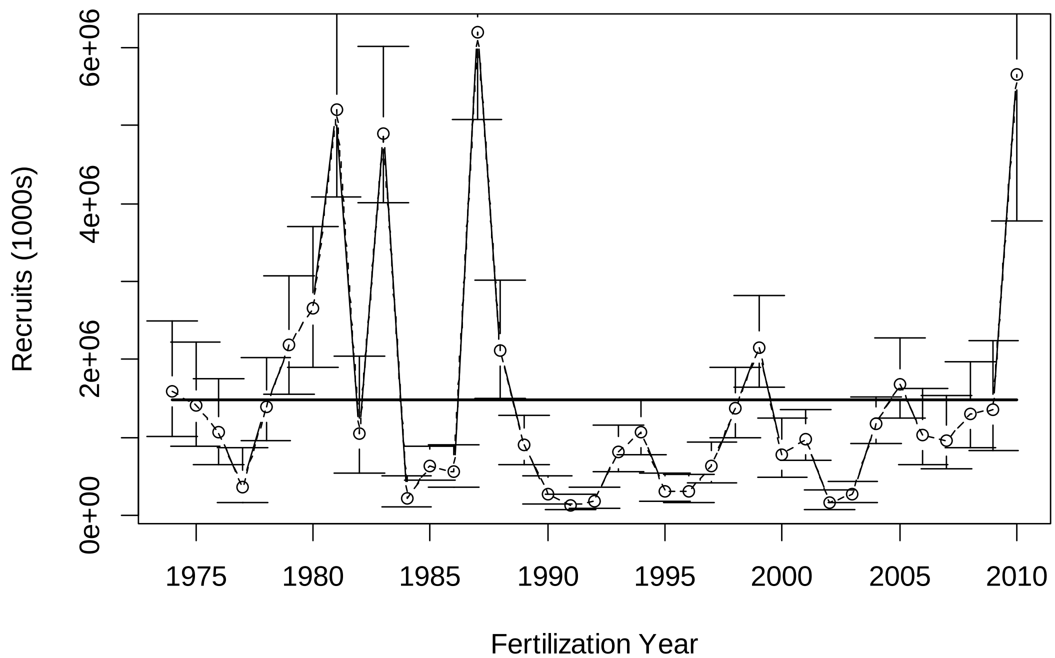

Figure 74. Base Model. Recruitment to the model for crab 25 mm to 50 mm. Total recruitment is 2 times recruitment in the plot. Male and female recruitment fixed to be equal. Solid horizontal line is average recruitment. Error bars are 95% C.I.

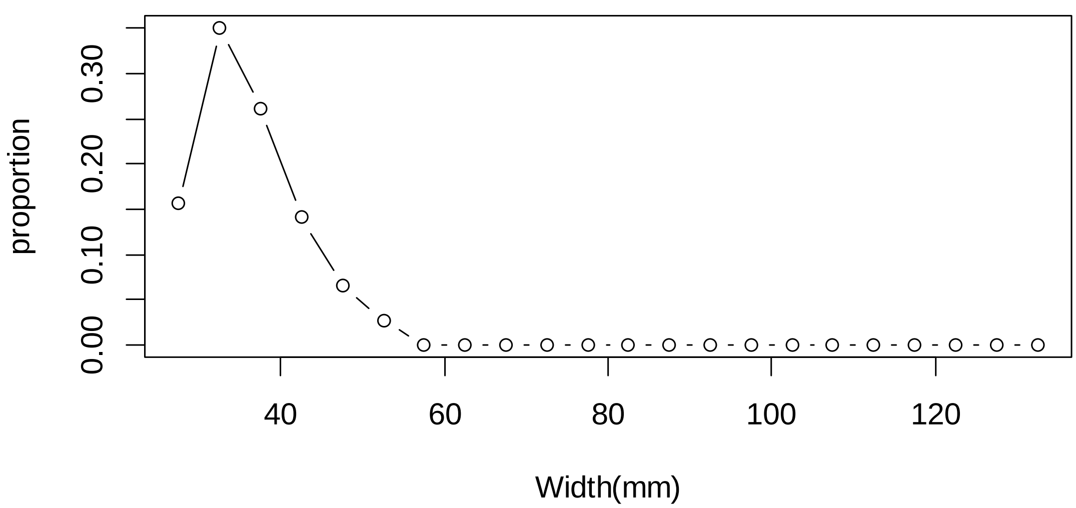

Figure 75. Base Model. Distribution of recruits to length bins estimated by the model.

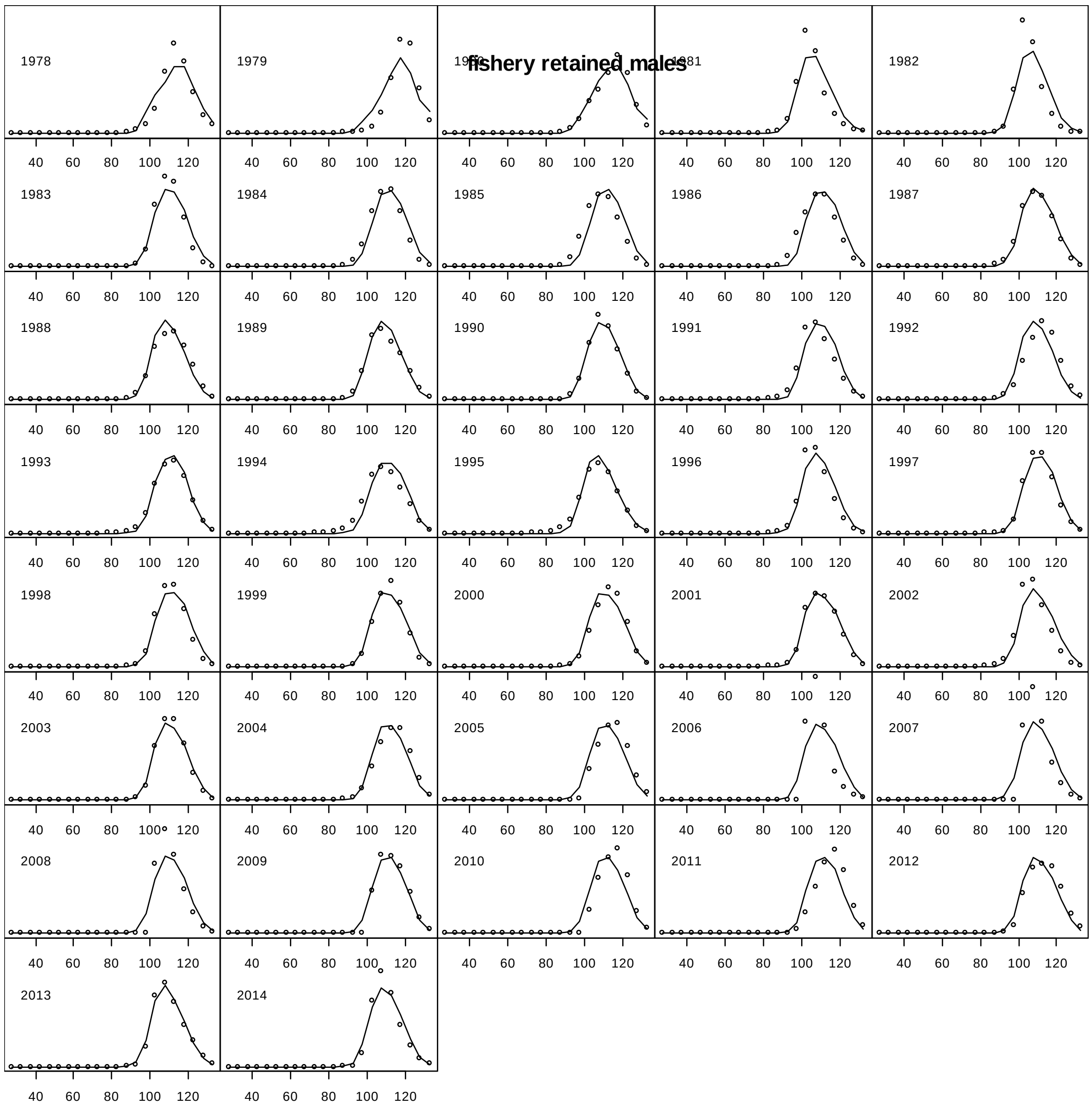

Figure 76. Base Model. Model fit to the retained male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

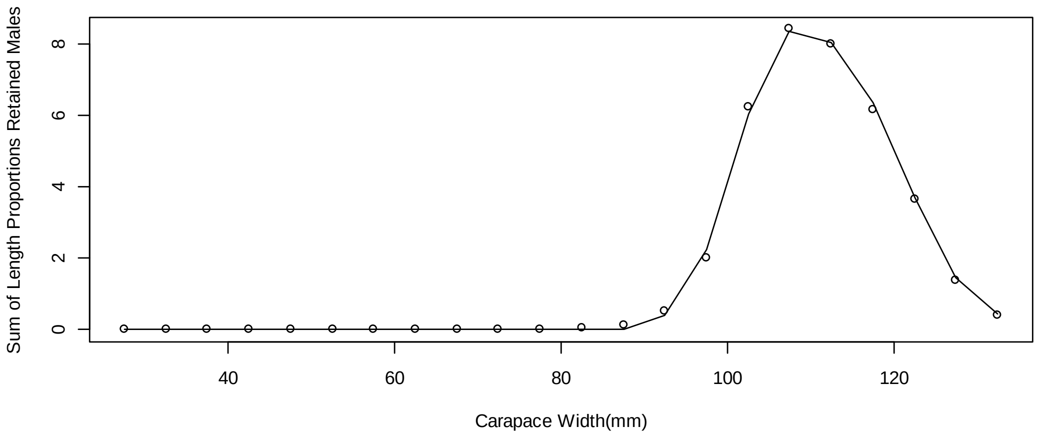

Figure 77. Base Model. Summary fit to retained male length.

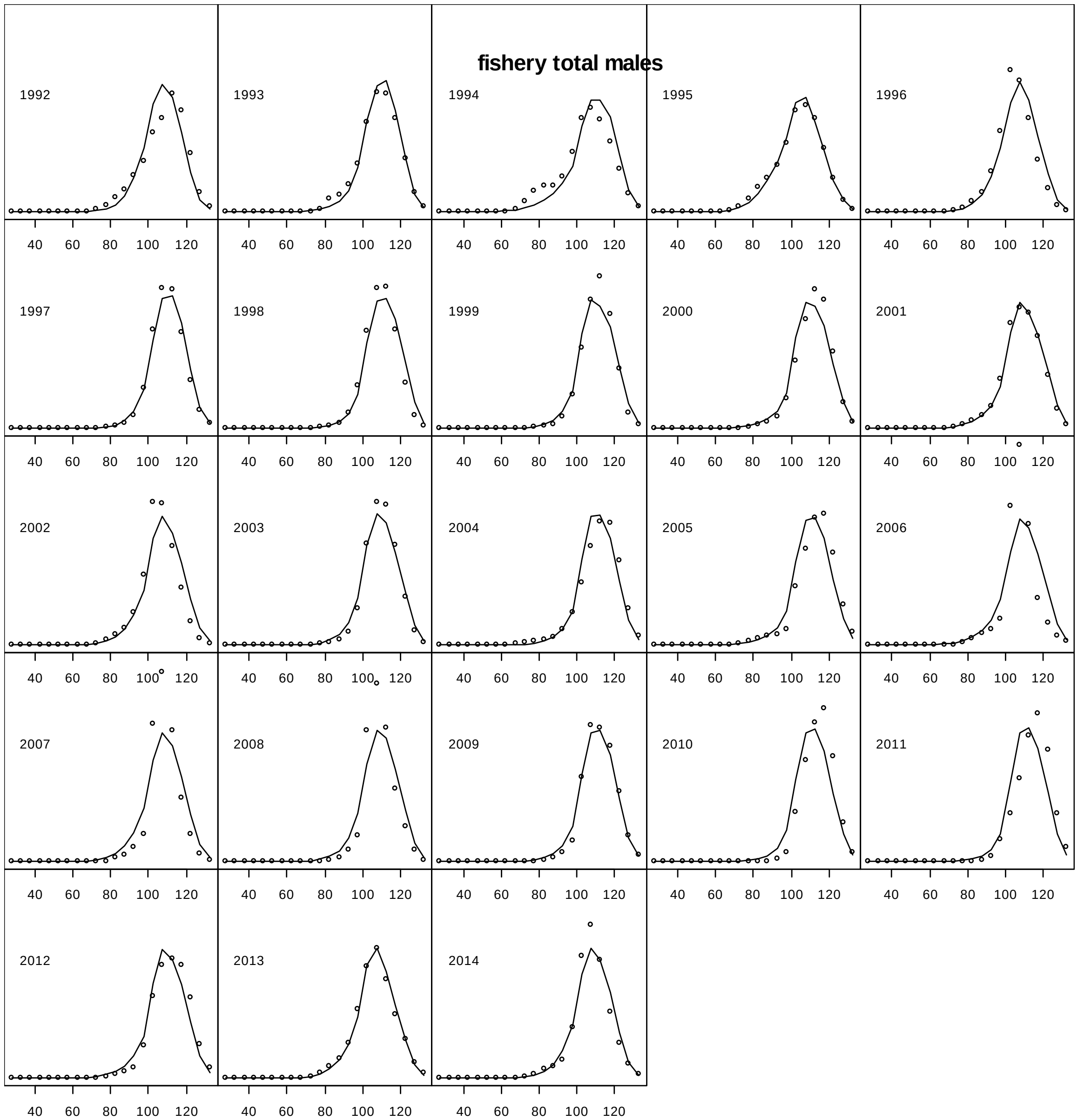

Figure 78. Base Model. Model fit to the total (discard plus retained) male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

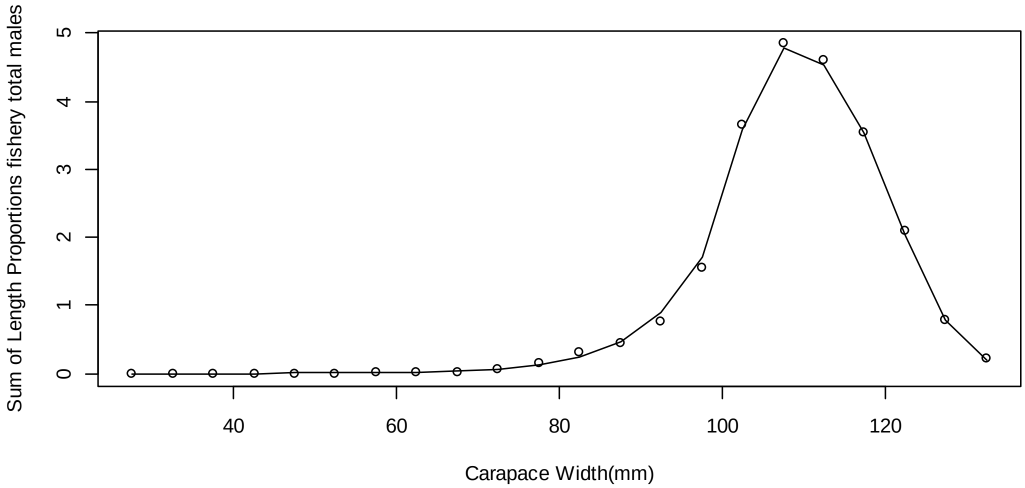

Figure 79. Base Model. Summary fit to total length frequency male catch.

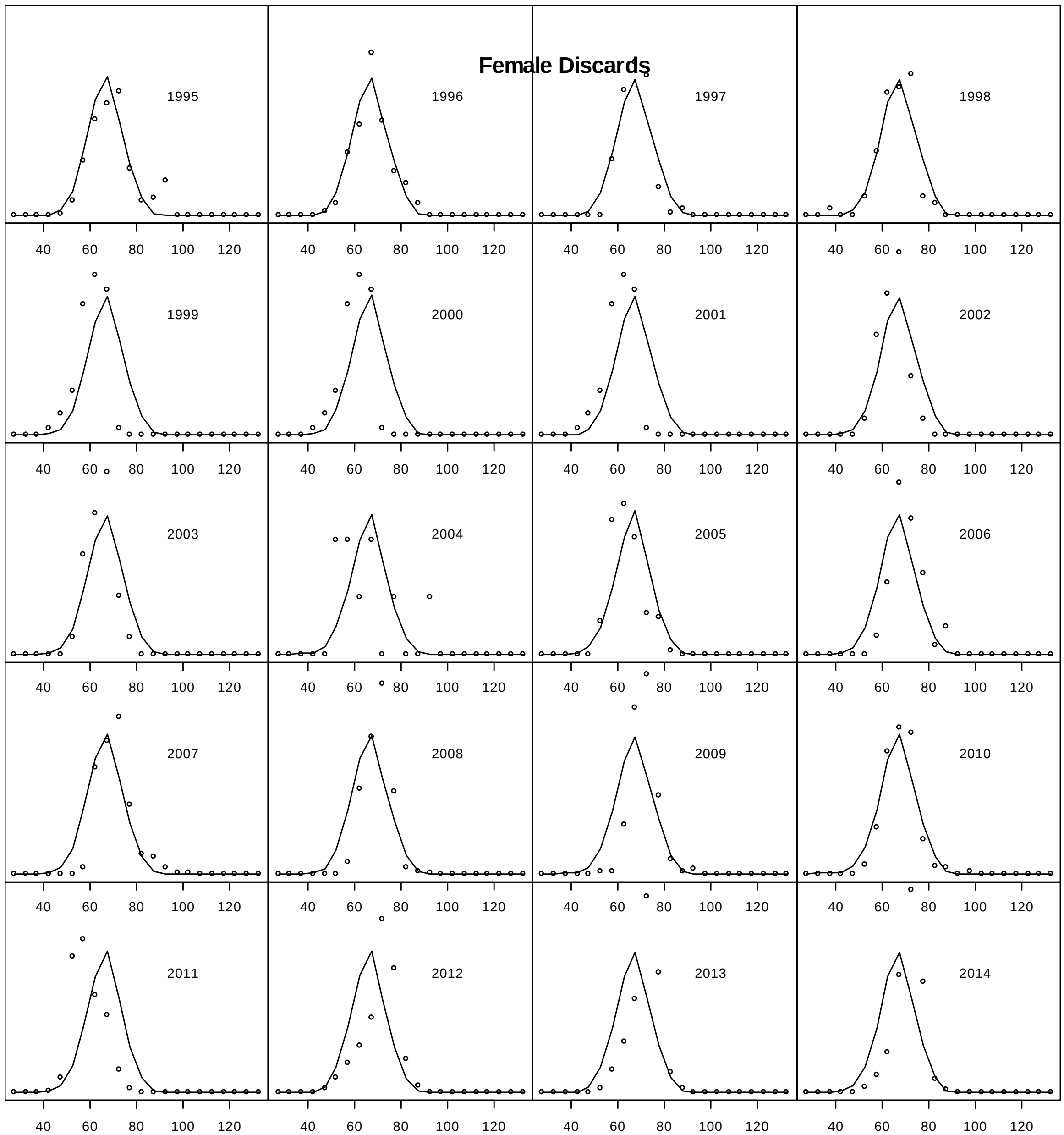

Figure 80. Base Model. Model fit to the discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

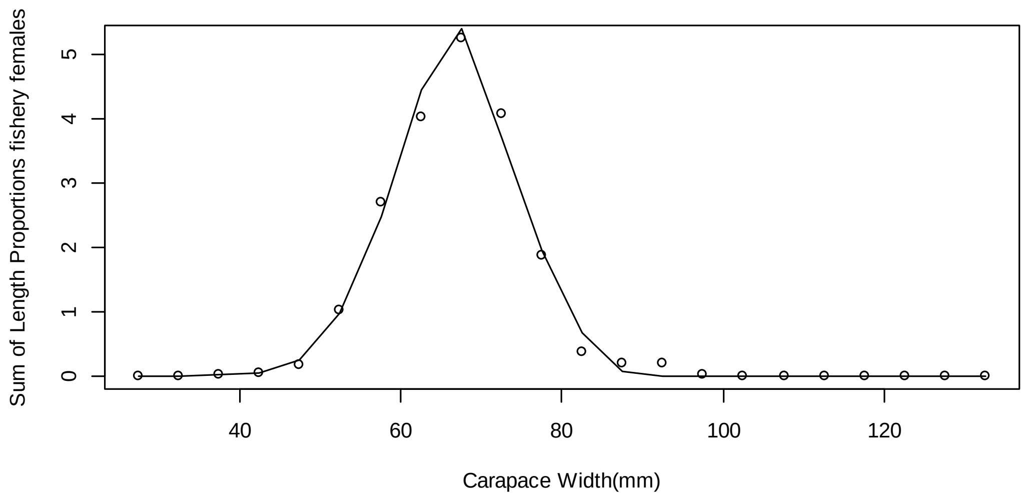

Figure 81. Base Model. Summary fit to directed fishery female discards.

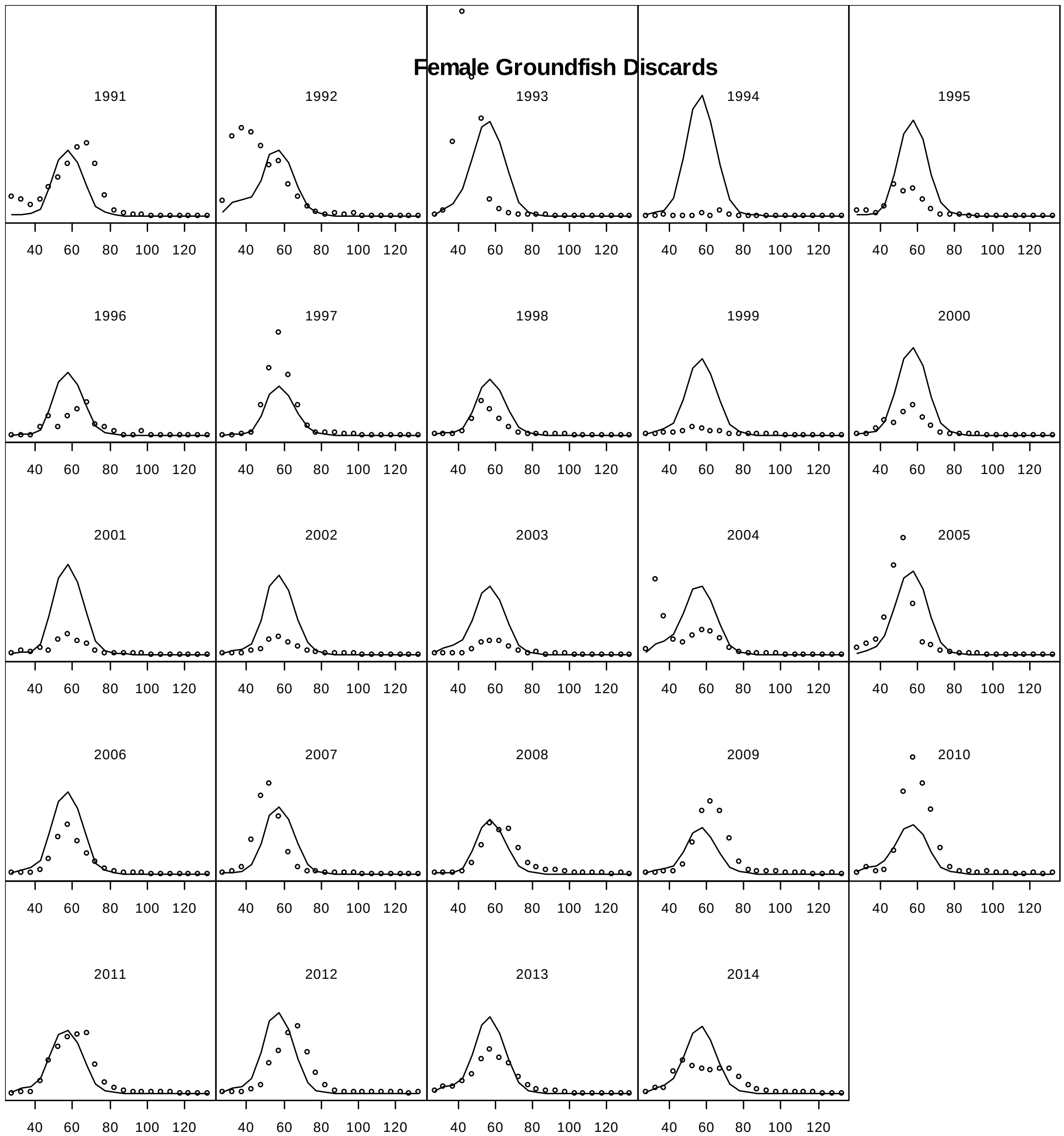

Figure 82. Base Model. Model fit to the groundfish trawl discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

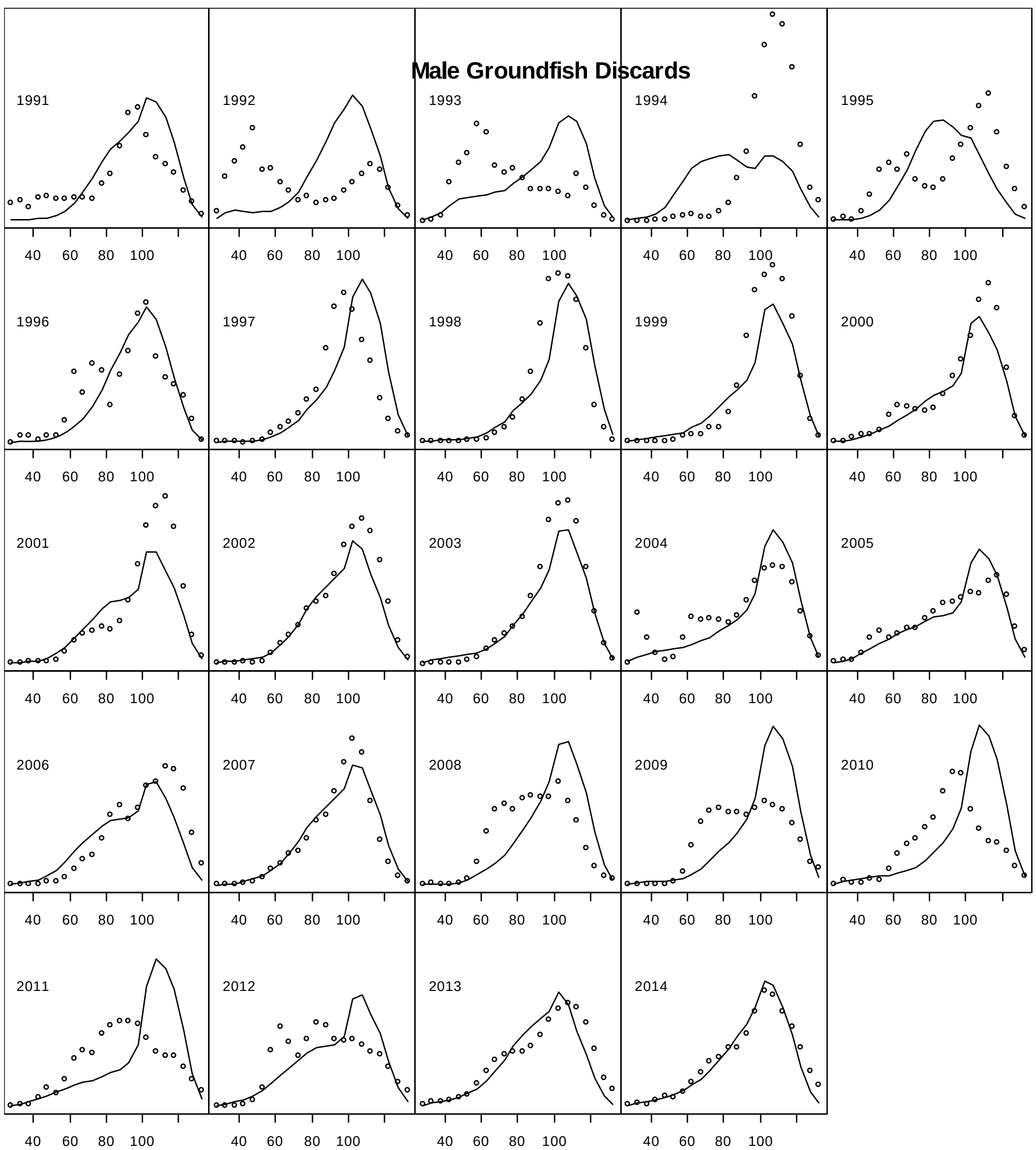

Figure 83. Base Model. Model fit to the groundfish trawl discard male size frequency data. Solid line is the model fit. Circles are observed data.

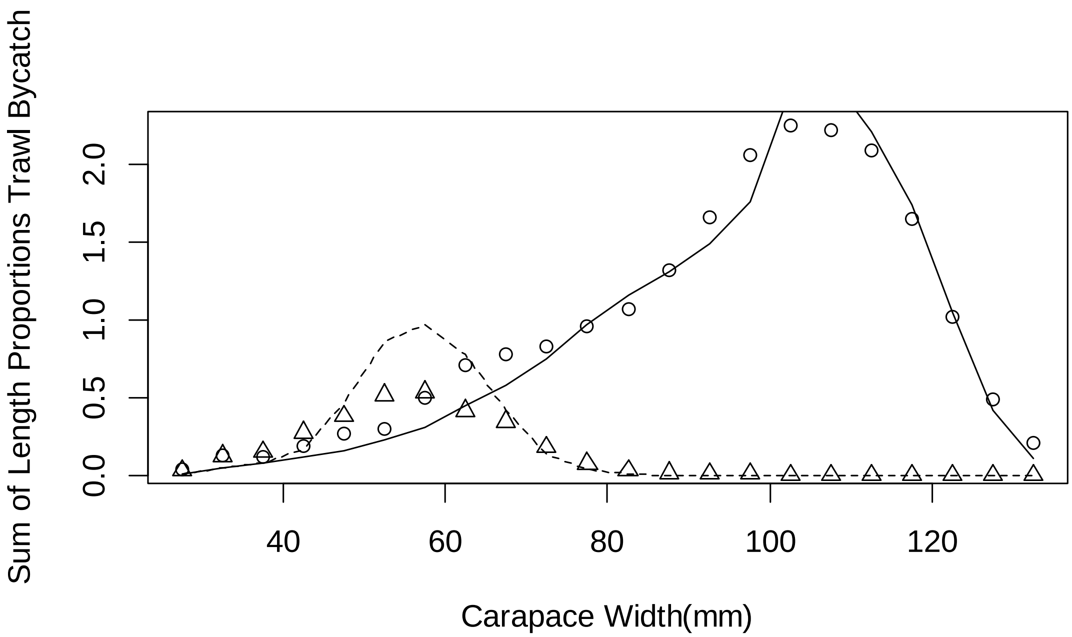

Figure 84. Base Model. Summary fit to groundfish length frequency.

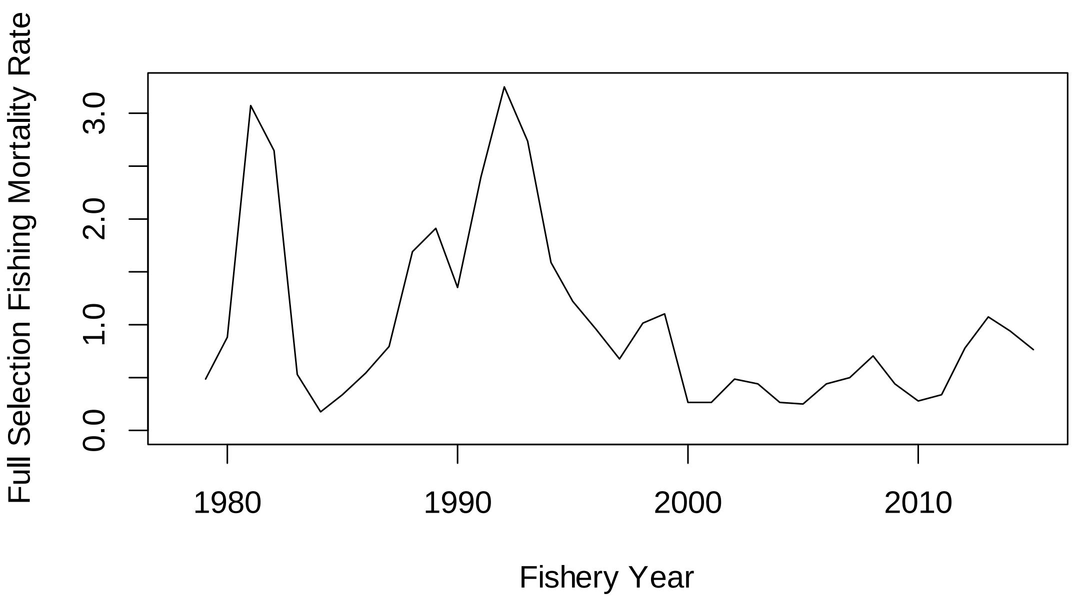

Figure 85. Base Model. Full selection fishing mortality estimated in the model from 1978/79 to present.

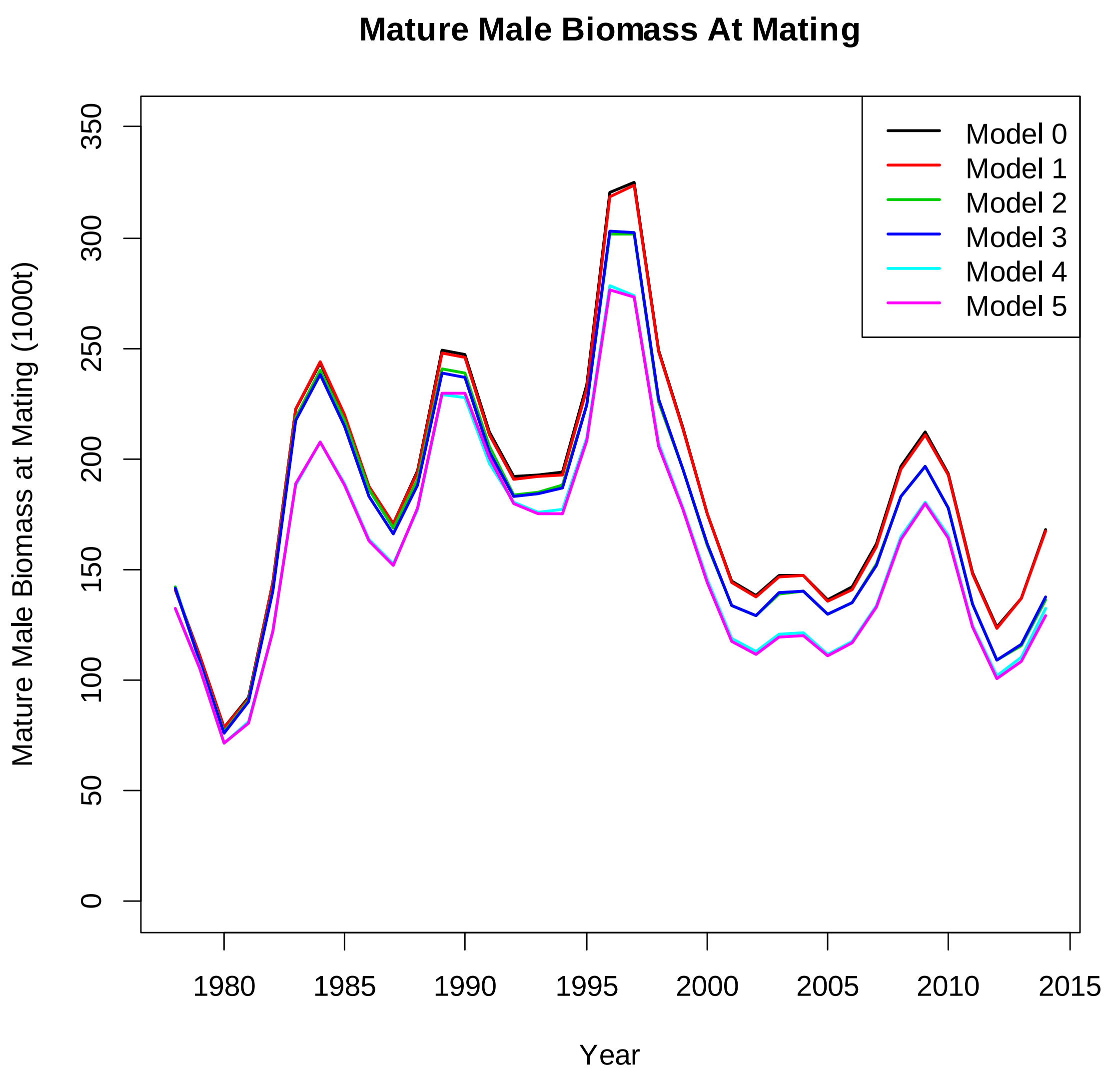

Figure 86. Mature male biomass at mating for Models 0 through 5.

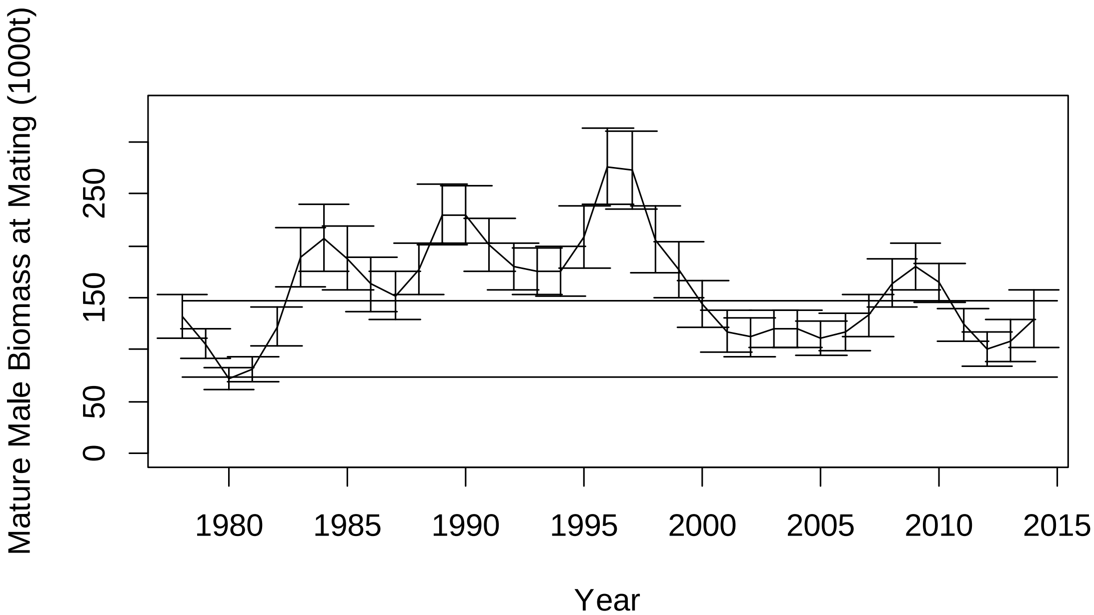

Figure 88. Base Model. Mature Male Biomass at mating with 95% confidence intervals. Top horizontal line is $B_{35\%}$, lower line is ½ $B_{35\%}$.

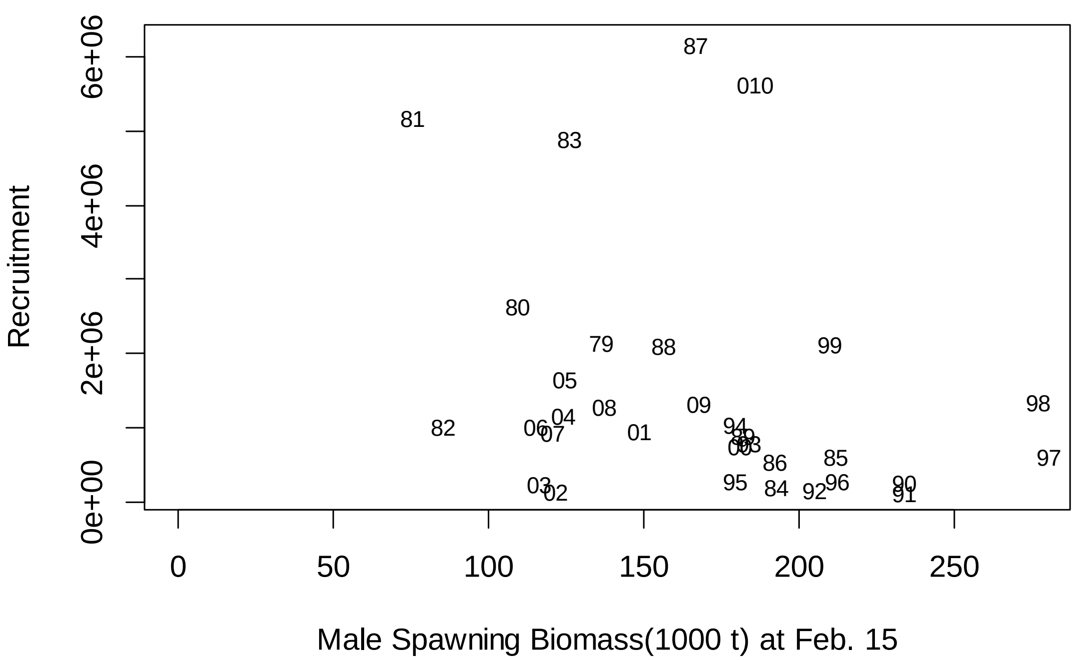

Figure 89. Base Model. Spawner recruit estimates using male mature biomass at time of mating (1000t). Numbers are fertilization year assuming a lag of 5 years. Recruitment is half total recruits in thousands of crab.

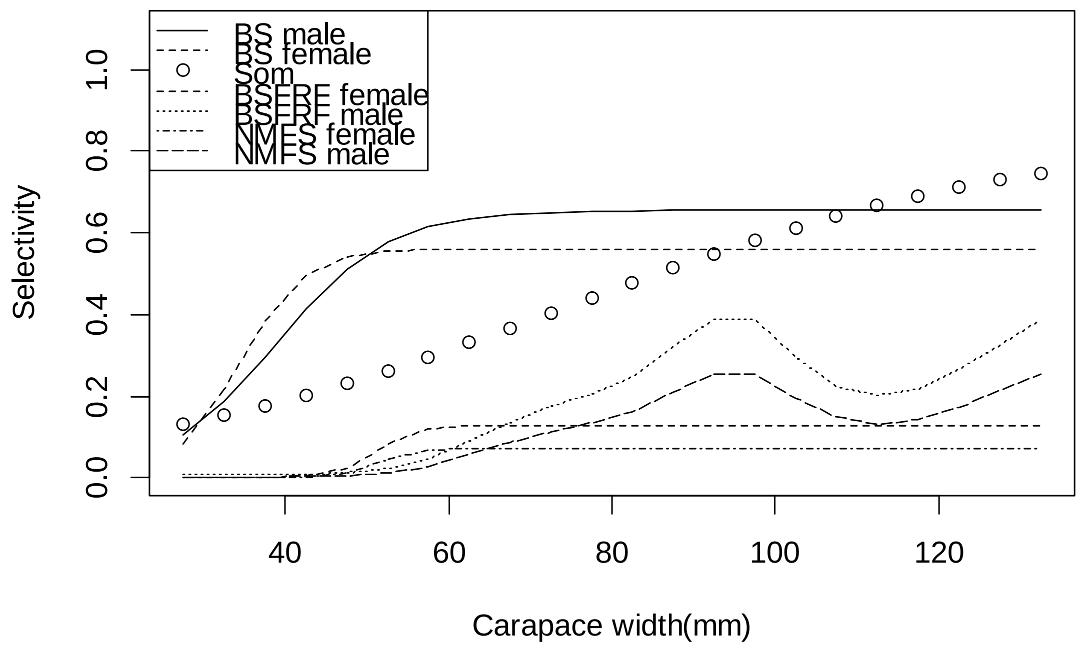

Figure 90. Base Model. Survey selectivity curves entire Bering Sea survey for female (upper dashed line) and male snow crab (solid lines) estimated by the model for 1989 to present. Survey selectivities estimated by Somerton(2010) from 2009 study area data are the circles. Lower lines are survey selectivities in the study area for BSFRF male and female crab and NMFS male and female crab.

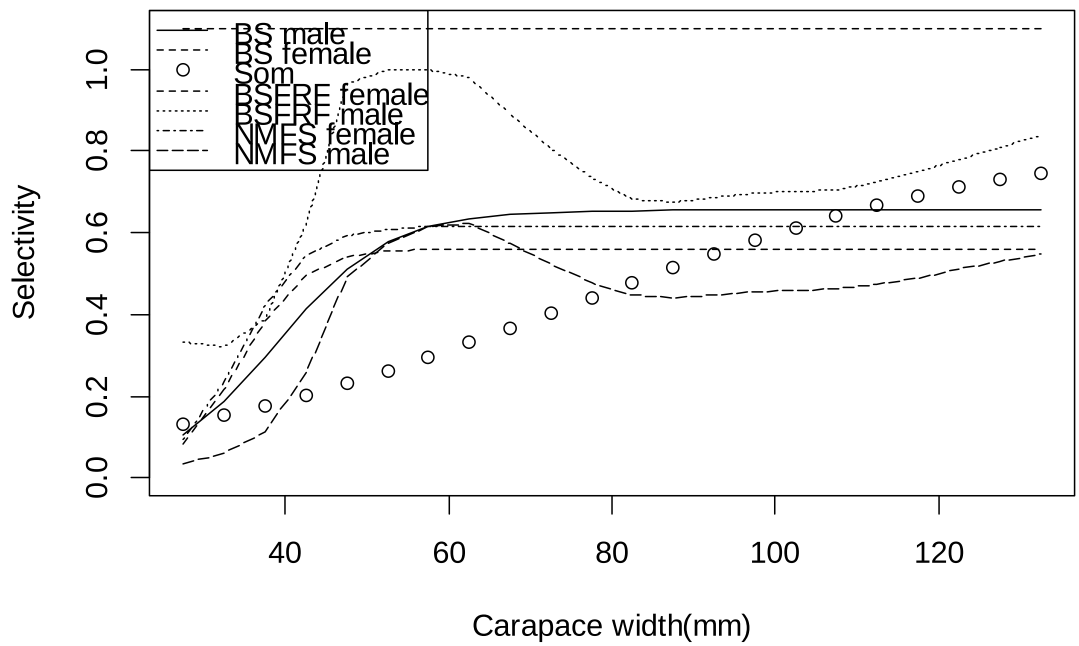

Figure 91. Base Model. 2010 study area survey availability curve (BSFRF) and selectivity curves (NMFS). BSFRF female is 1.0 all sizes (need to extend y axis). BS are survey selectivity curves for the entire Bering Sea. Som is the selectivity curve estimated by Somerton from the 2009 study area data.

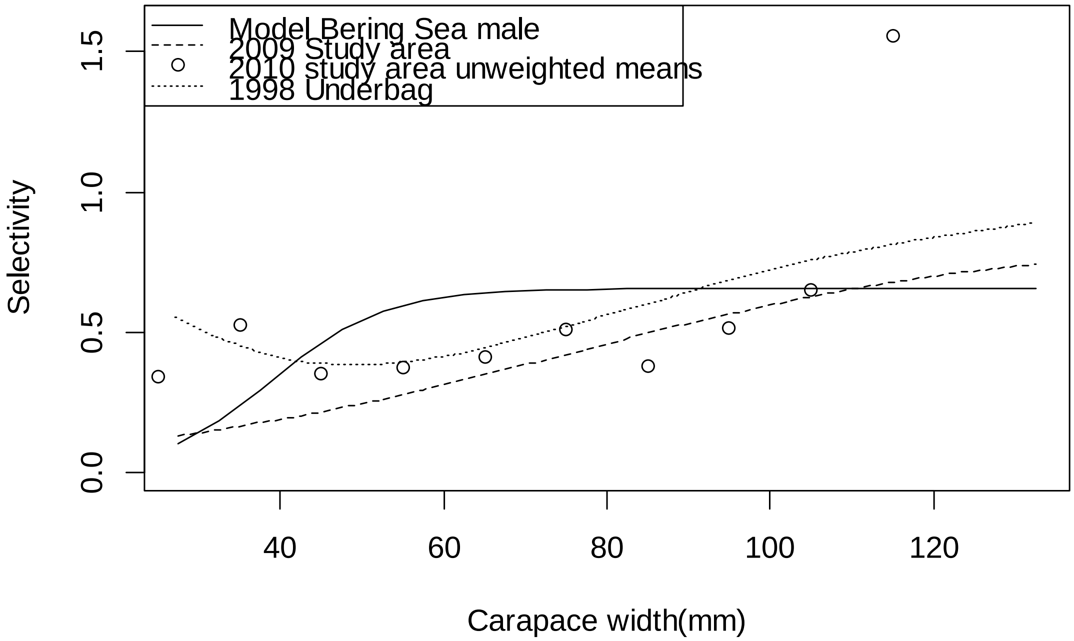

Figure 92. Base Model. Survey selectivity for male crab 1989- present (Model Bering Sea male), with selectivity curves estimated outside the model. 2009 study area is the curve estimated by Somerton from the 2009 study area data.

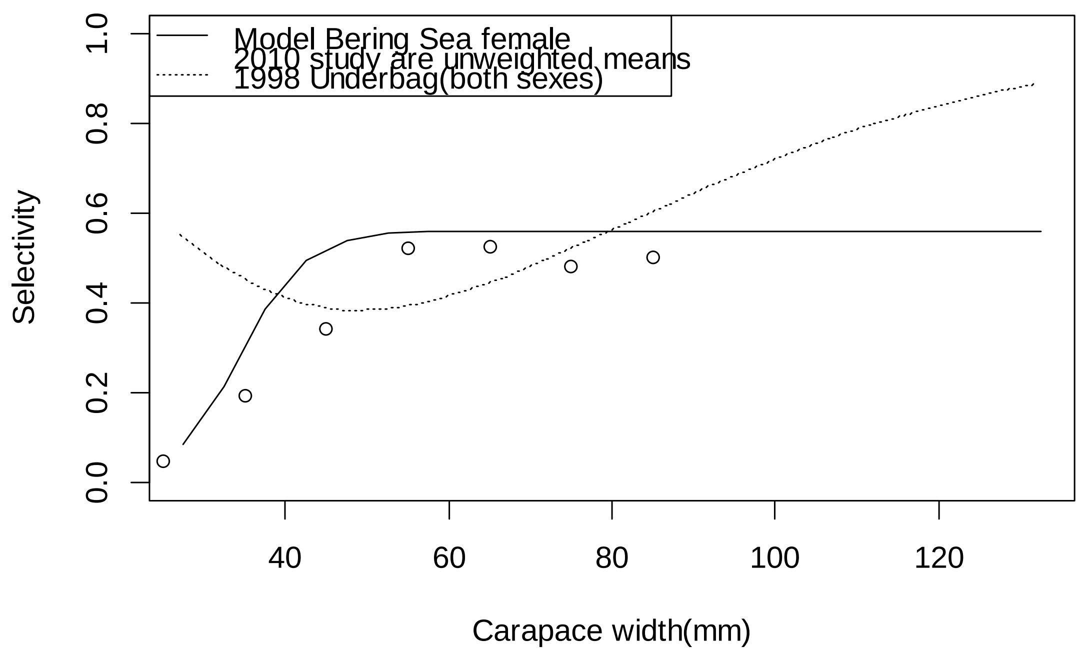

Figure 93. Base Model. Survey selectivity for female crab 1989- present (Model Bering Sea female).

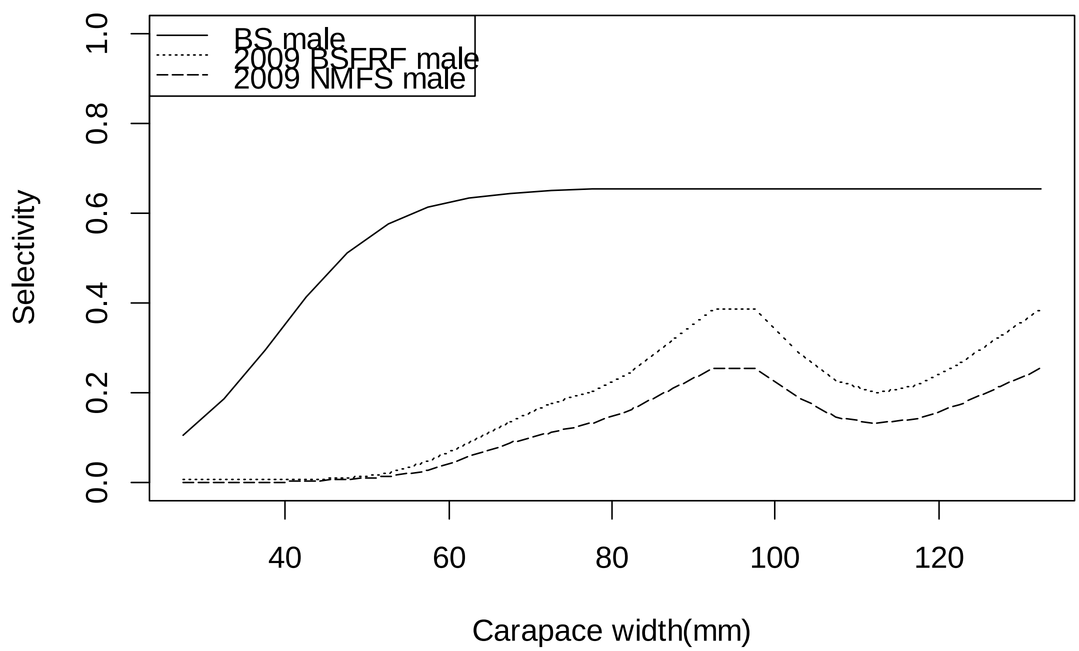

Figure 94. Base Model. Survey selectivity curves for male crab in the entire Bering sea 1989-present (BS male), 2009 study area BSFRF male and 2009 study area NMFS male.

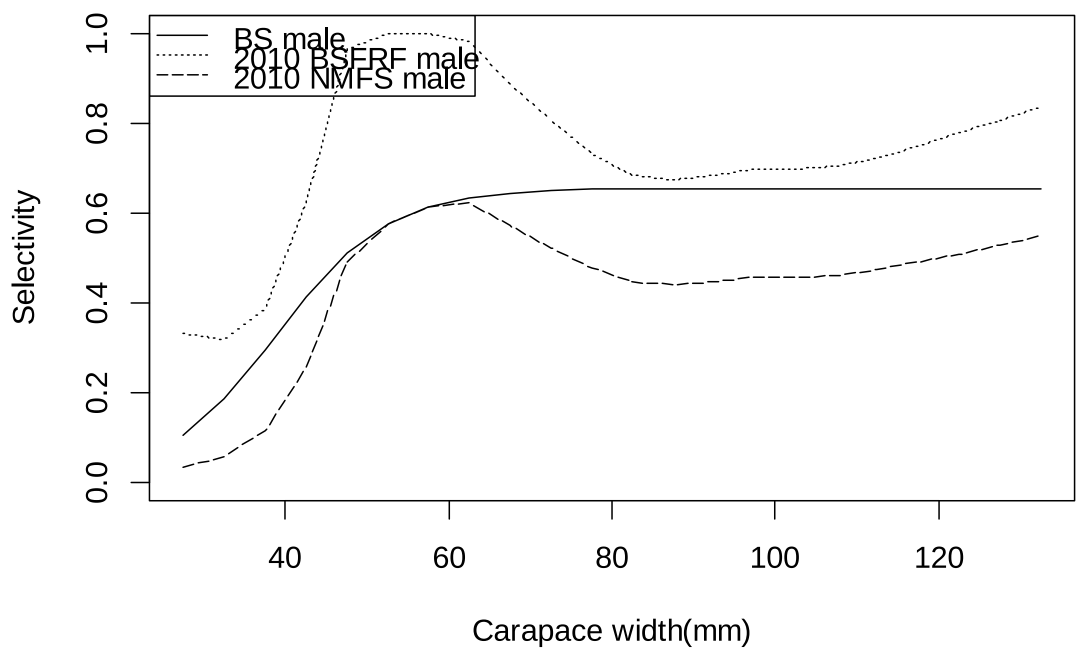

Figure 95. Base Model. Survey selectivity curves for male crab in the entire Bering sea 1989-present (BS male), 2010 study area BSFRF male and 2010 study area NMFS male.

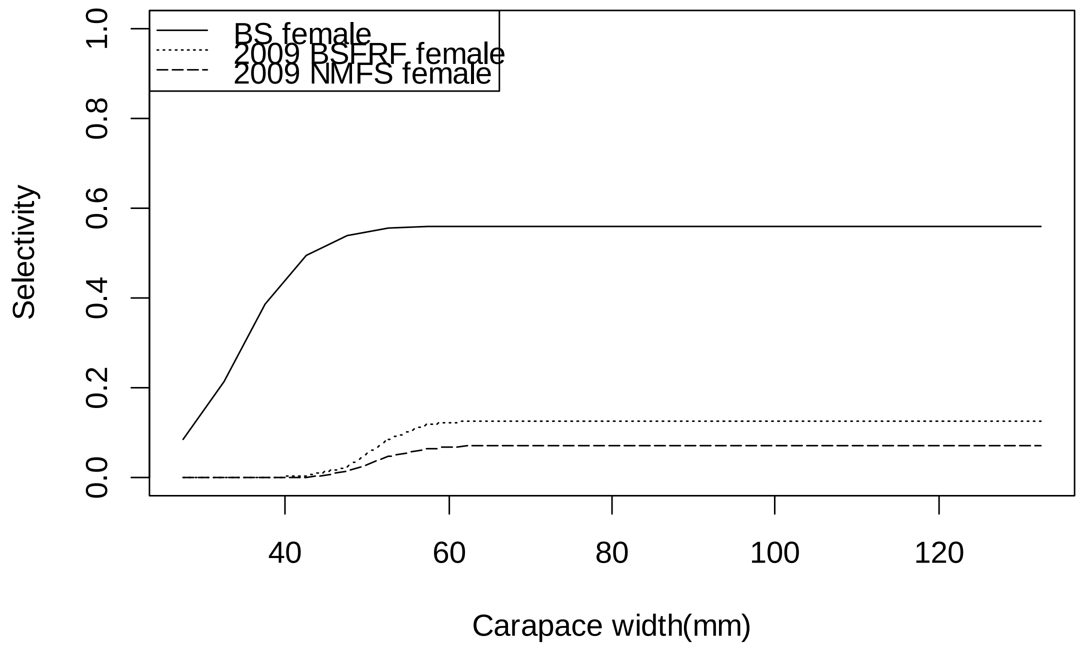

Figure 96. Base Model. Survey selectivity curves for female crab in the entire Bering sea 1989-present (BS female), 2009 study area BSFRF female and 2009 study area NMFS female.

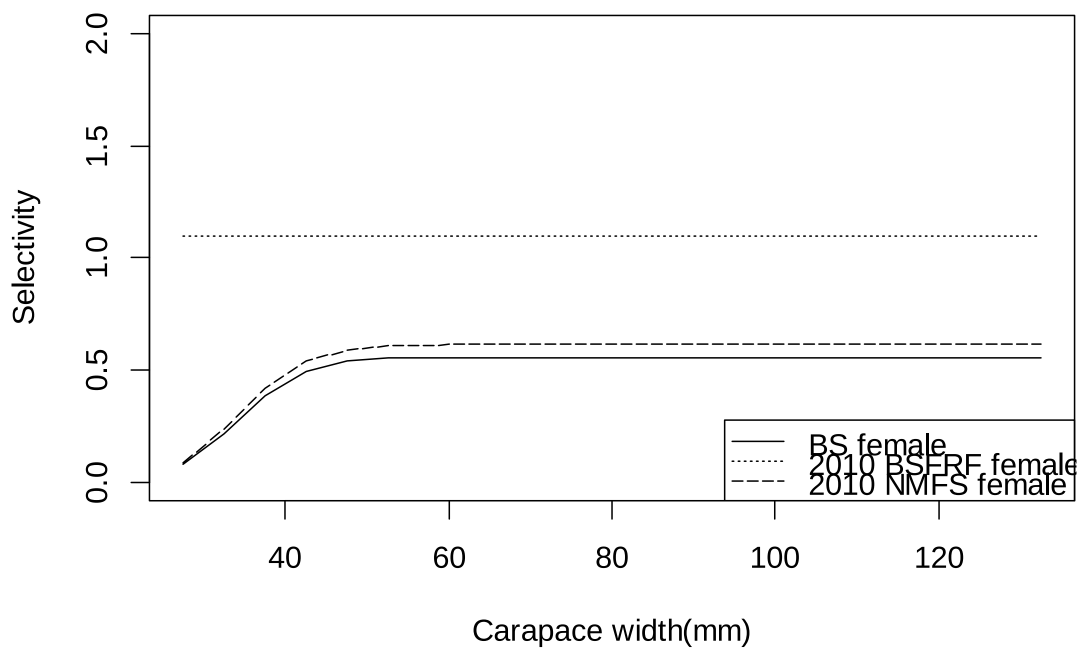

Figure 97. Base Model. Survey selectivity curves for female crab in the entire Bering sea 1989-present (BS female), 2010 study area BSFRF female and 2010 study area NMFS female.

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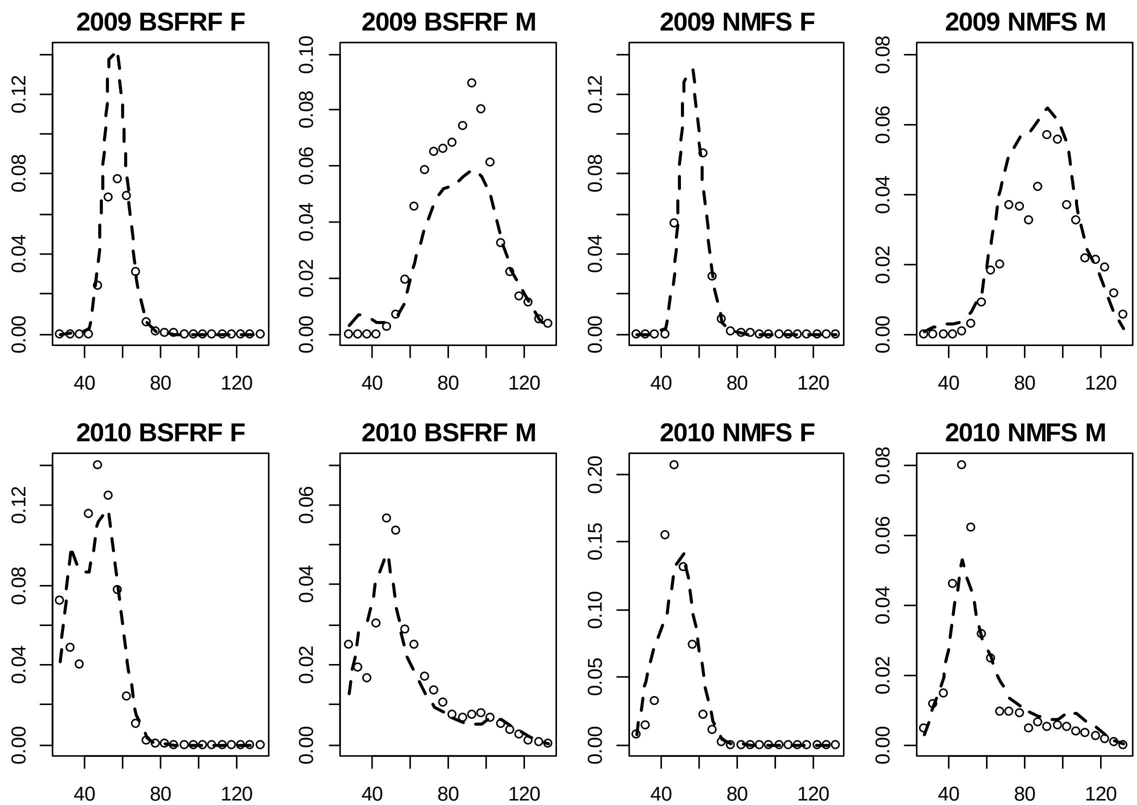

Figure 98. Base Model. Model fit to length frequency for BSFRF and NMFS females and males in the study area.

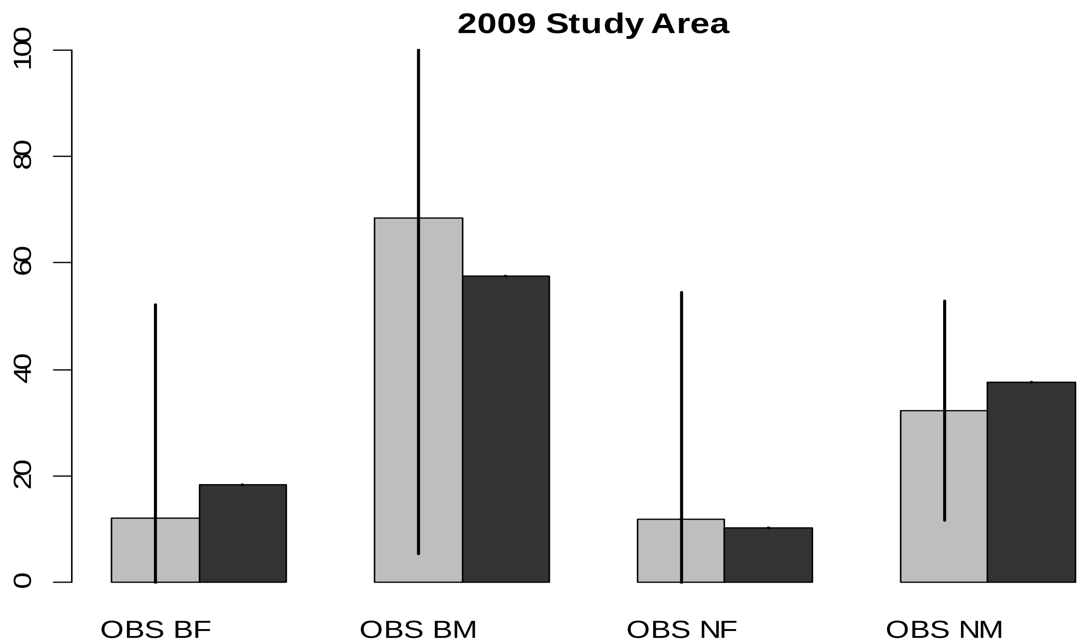

Figure 99. Base Model. Fits to 2009 study area mature biomass by sex for BSFRF and NMFS data.

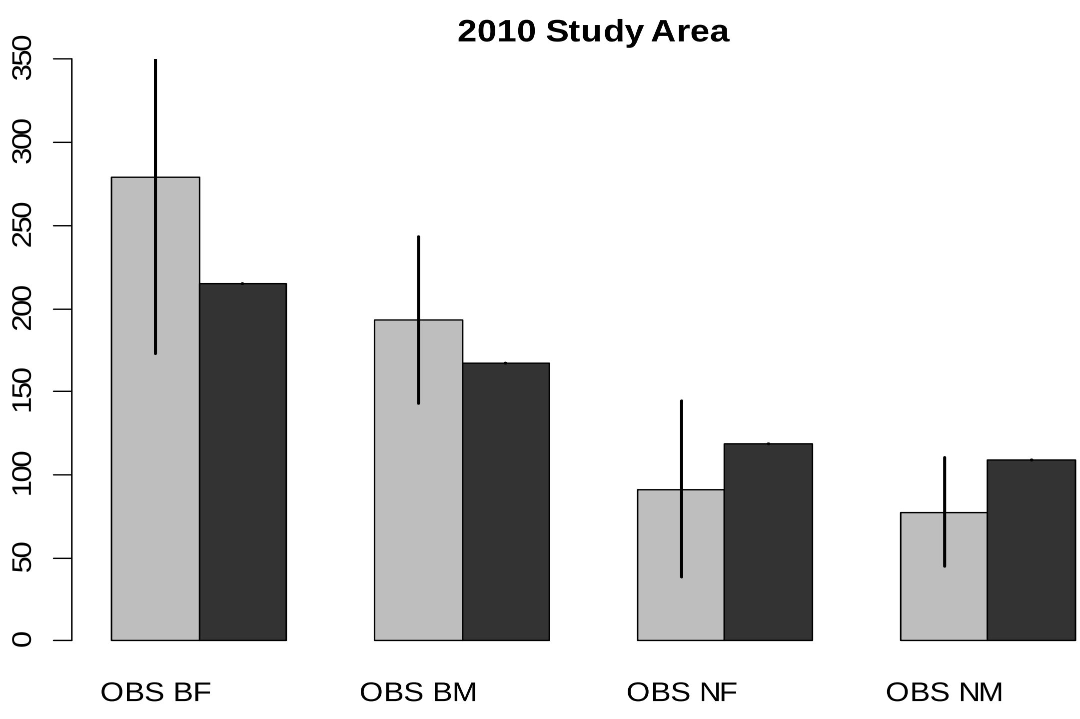

Figure 100. Base Model. Fits to 2010 study area mature biomass by sex for BSFRF and NMFS data.

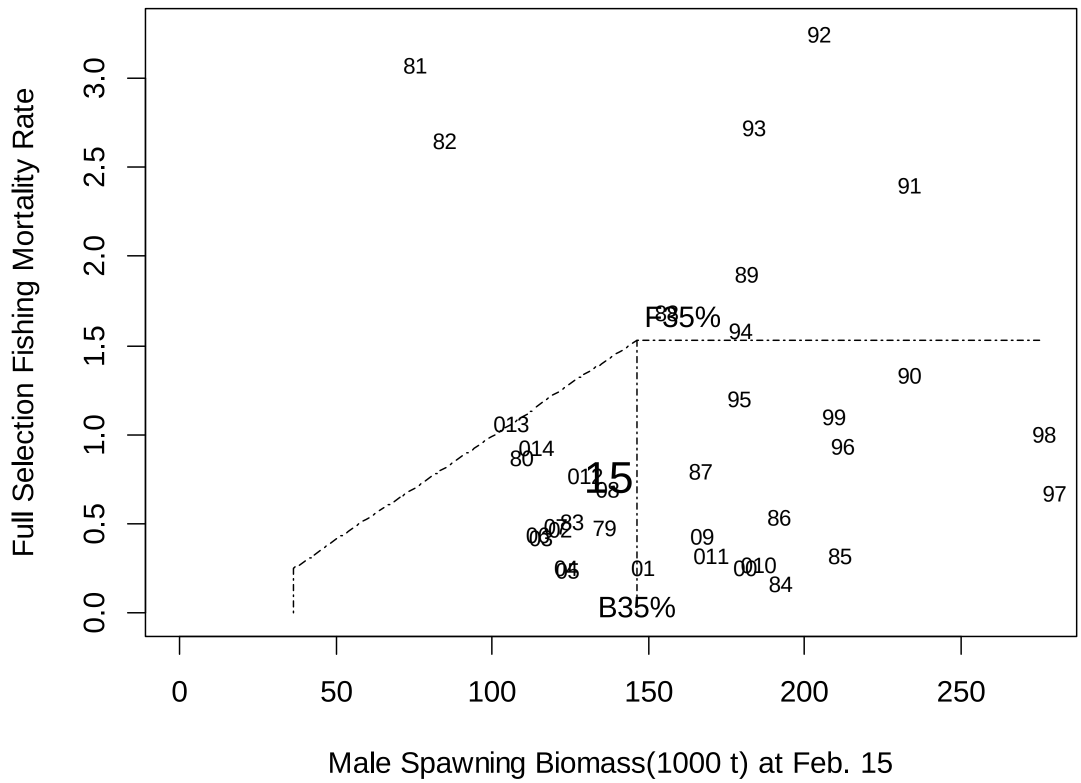

Figure 101. Base Model. Fishing mortality estimated from fishing years 1979 to 20013/14 (labeled 14 in the plot). The OFL control rule ($F_{35\%}$) is shown for comparison. The vertical line is $B_{35\%}$, estimated from the product of spawning biomass per recruit fishing at $F_{35\%}$ and mean recruitment from the stock assessment model.

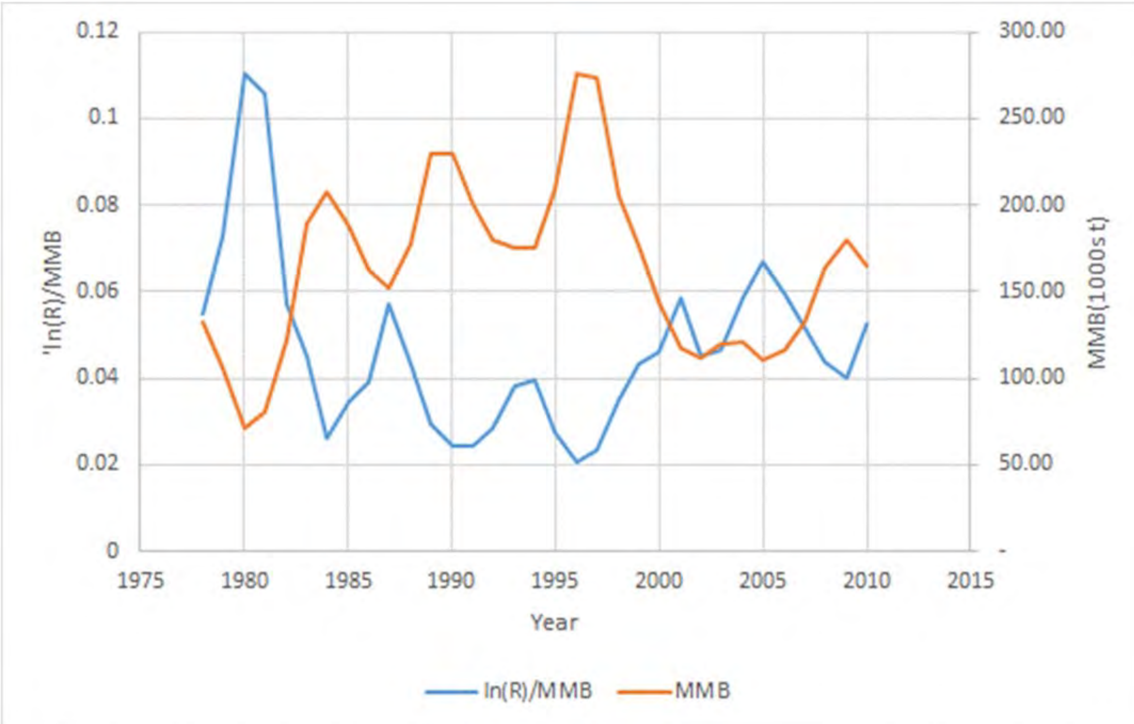

Figure 102. Log of recruits/MMB at mating with a 5 yr lag for recruitment and mature male biomass at mating.

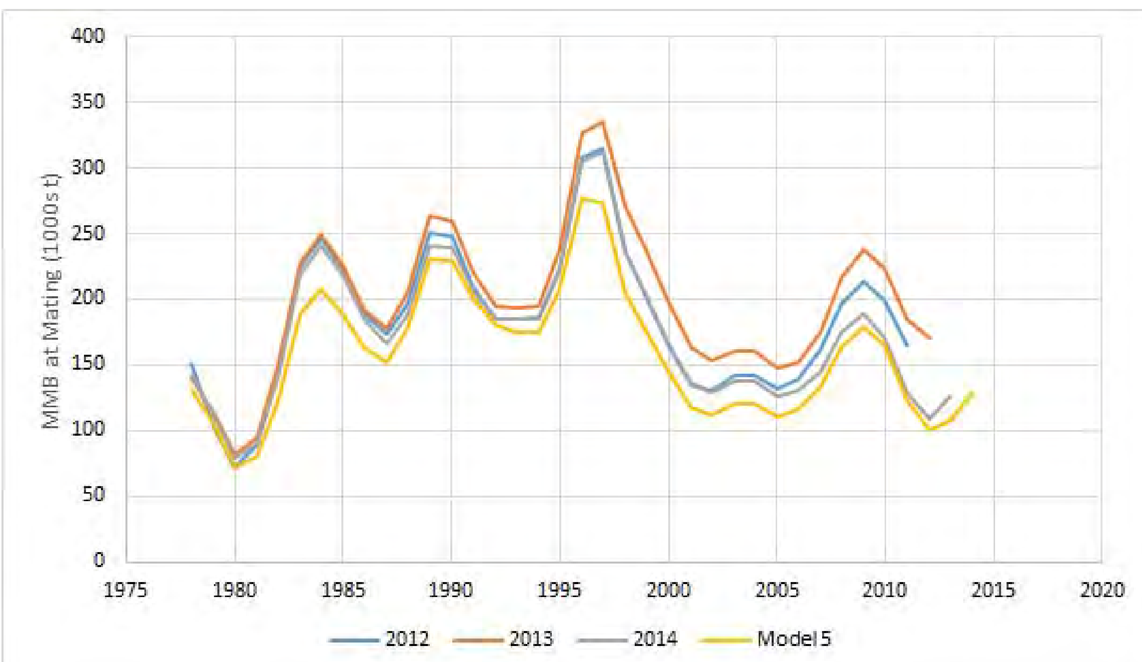

Figure 103. MMB at mating from the 2012, 2013 and 2014 assessments, and the Base model (Model 5).

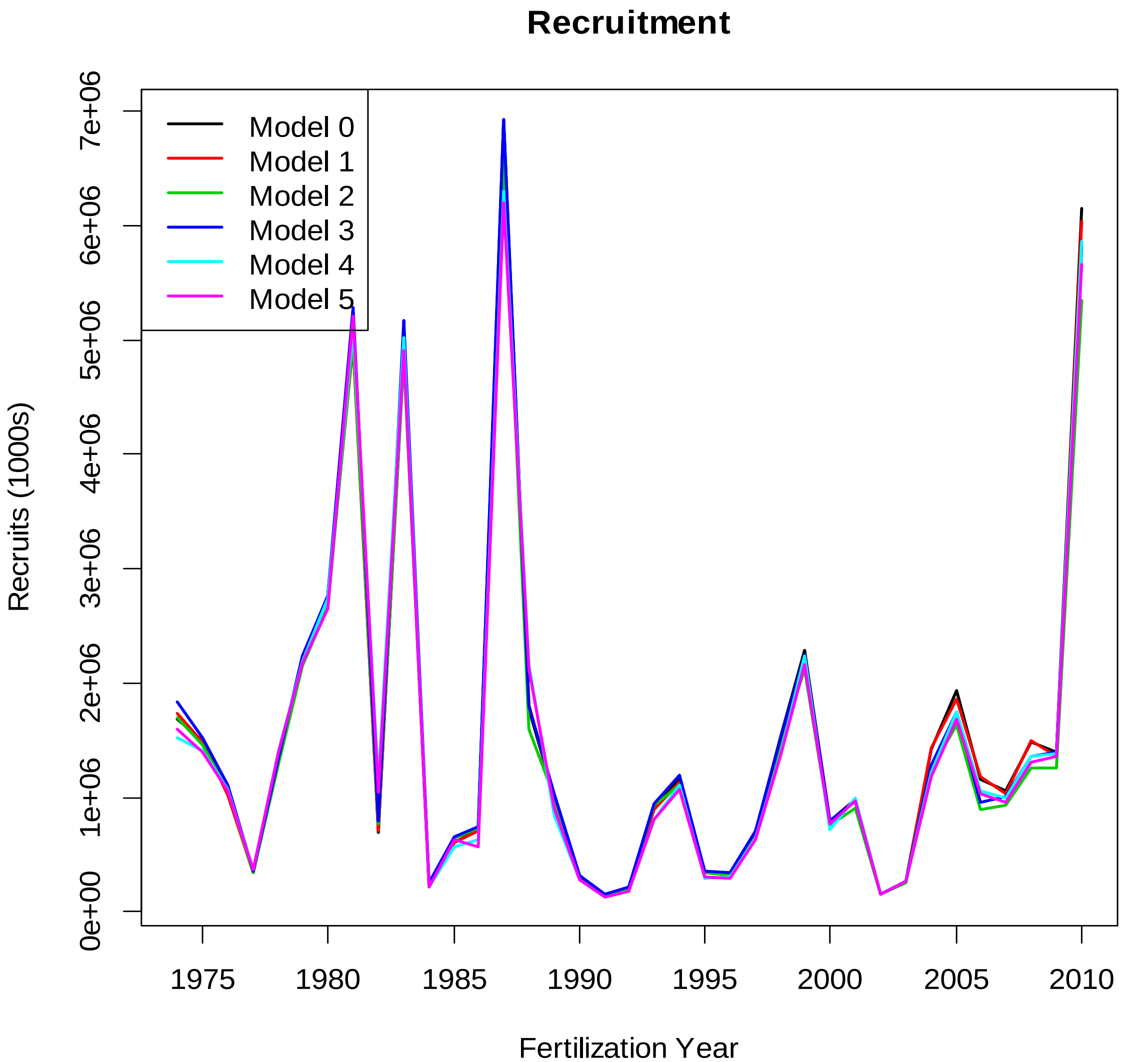

Figure 104. Recruitment estimates from the Models 0, 1, 2, 3, 4 and 5 (Base model).

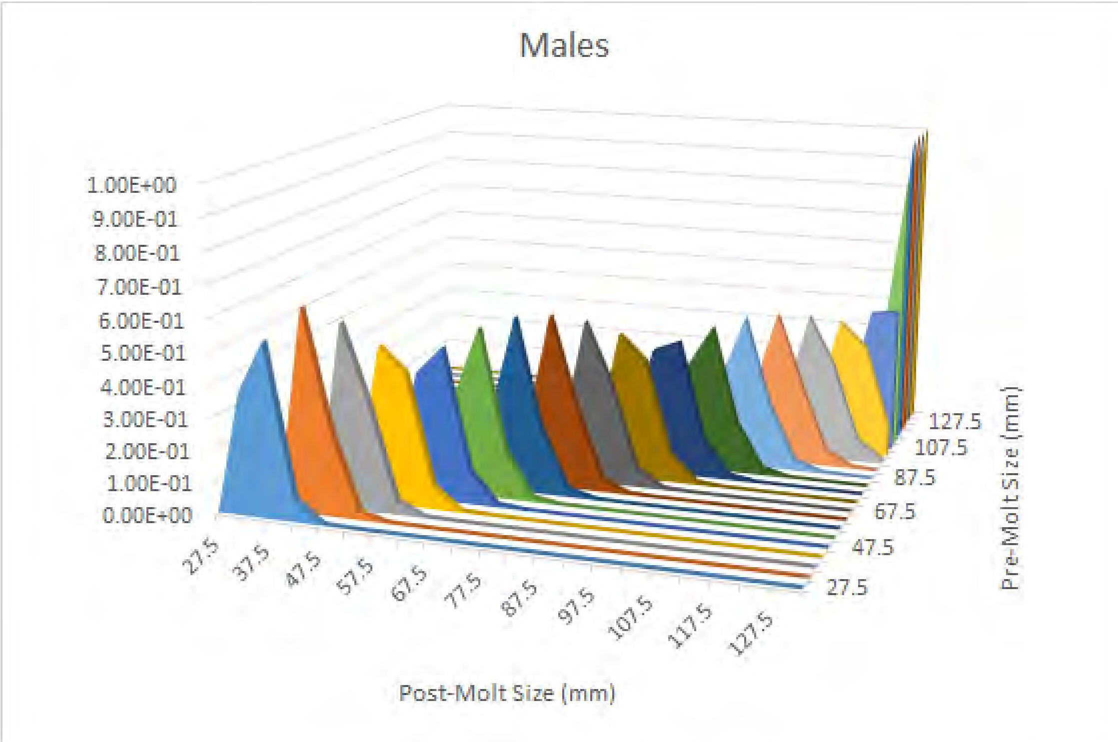

Figure 105. Male growth matrix for the Base model.

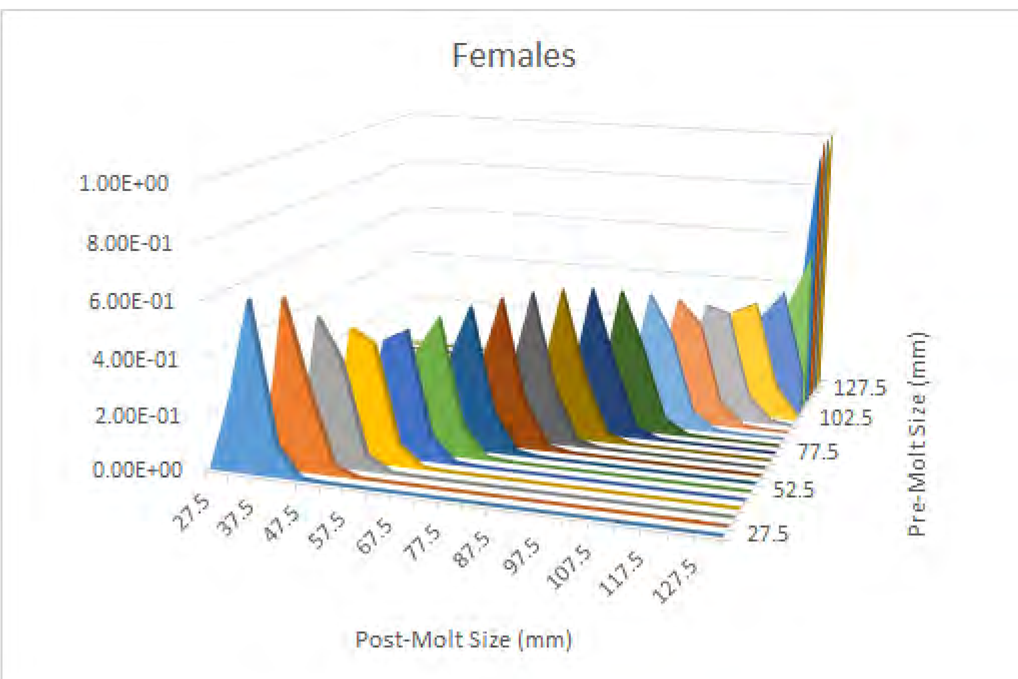

Figure 106. Female growth matrix for the Base model.

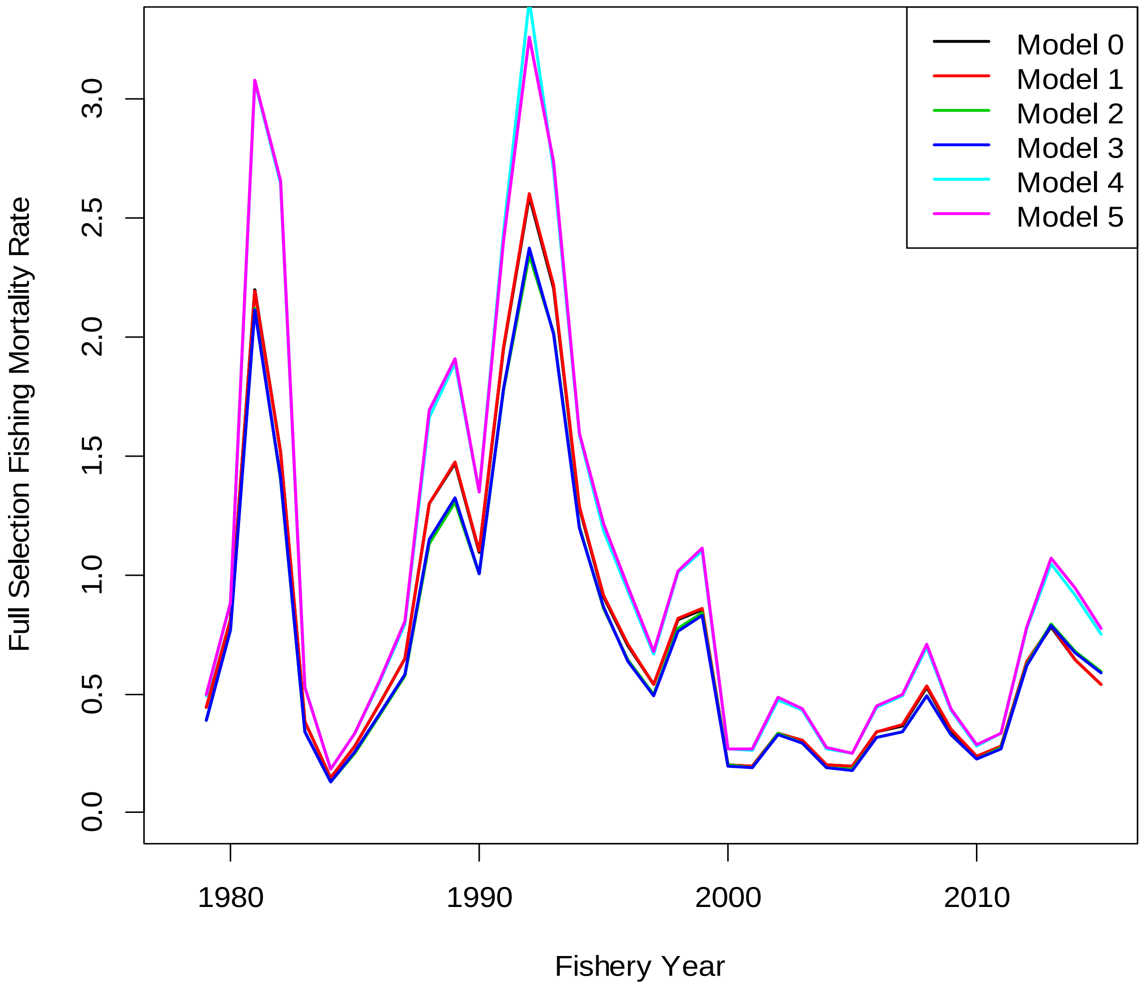

Figure 107. Full selection fishing mortality rate for models 0, 1, 2, 3, 4 and 5 (base model). Model 4 and 5 estimates are very similar.

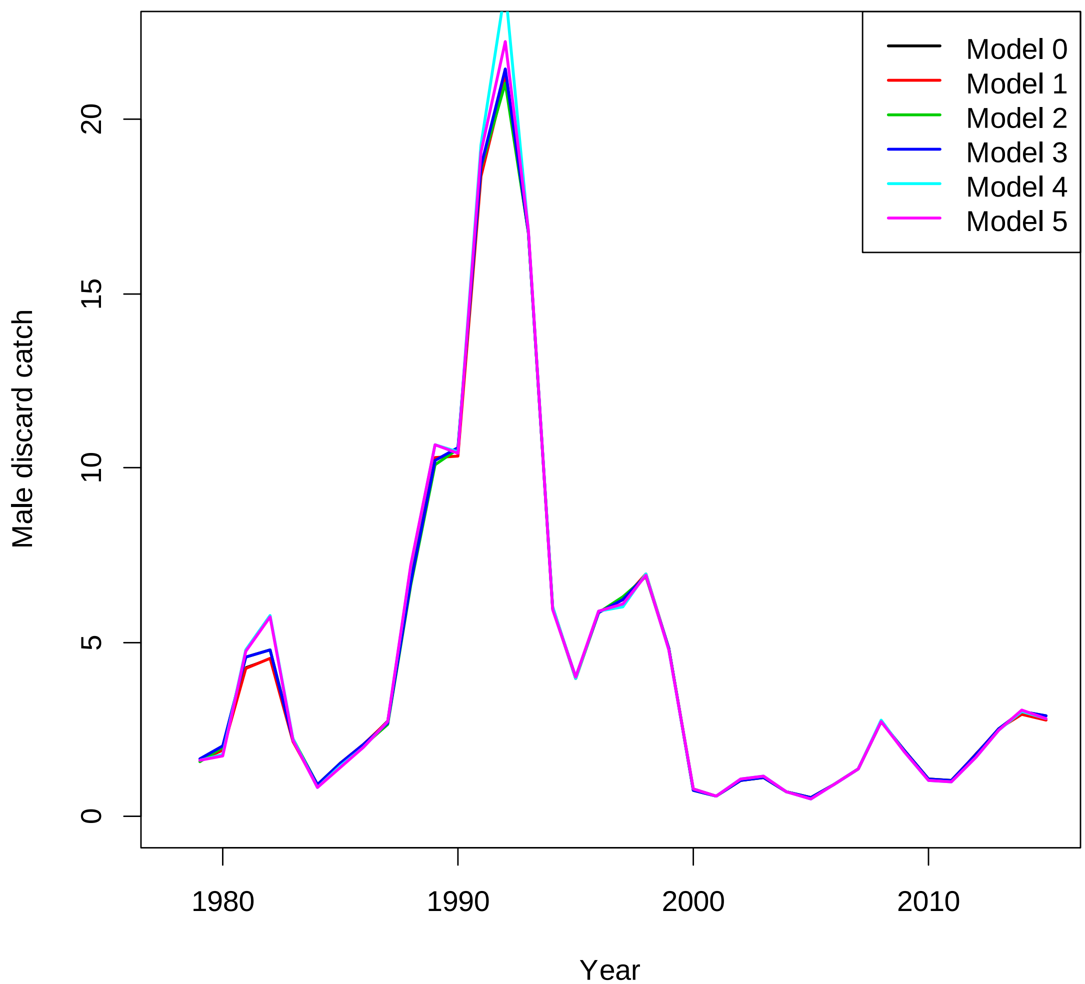

Figure 108. Male discard catch estimates from models 0, 1, 2, 3, 4 and 5 (base model).

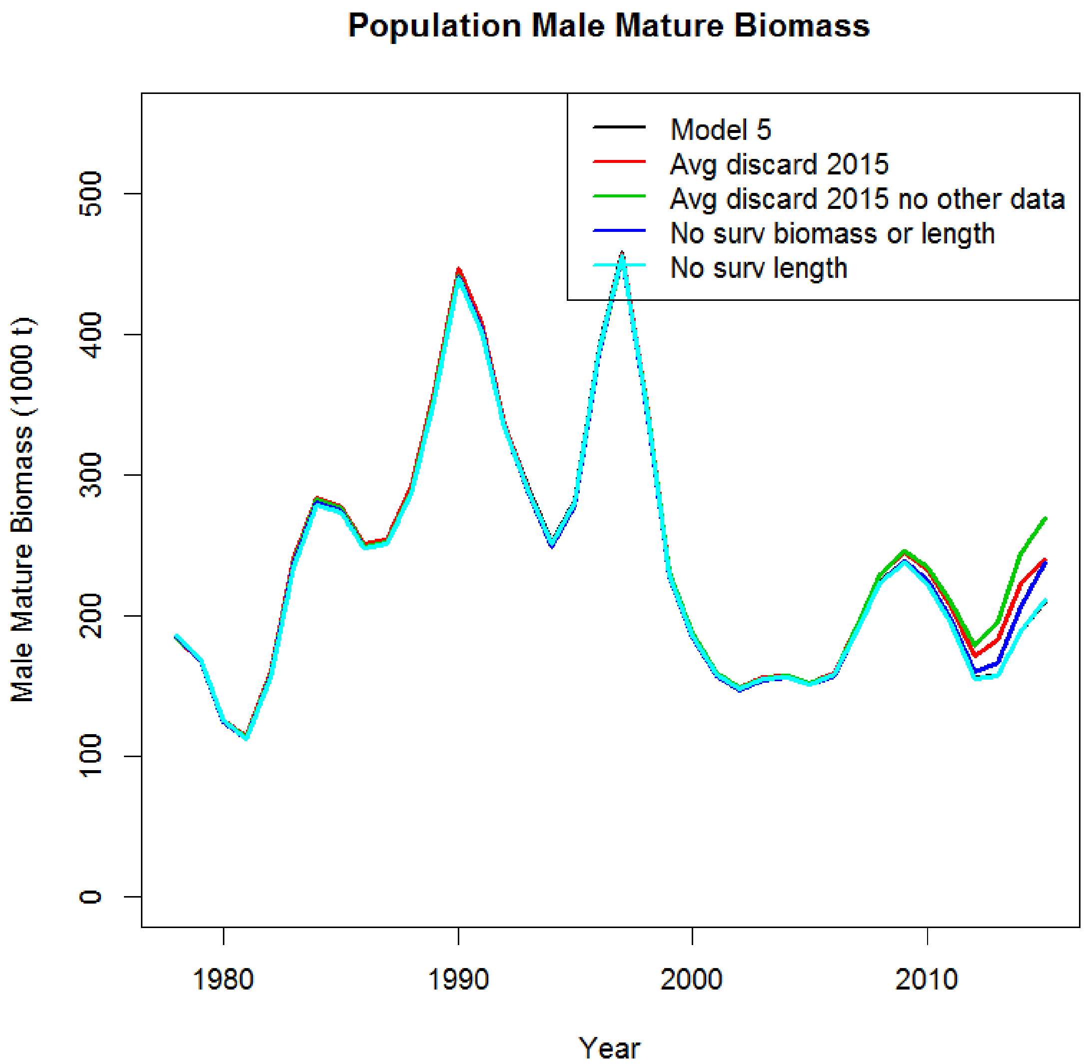

Figure 109. Population mature male biomass estimated from runs with Model 5 with 1) all data (Model 5), 2) Avg discard 2015 - All 2015 data except average discard in 2015 at the historical average relative to retained, 3) Avg discard 2015 no other dta - average discard in 2015 at the historical average relative to retained – no other 2015 data 4) No surv biomass or length - Observed discard catch in 2015, no other 2015 data, and 5) No surv length - observed discard and survey biomass 2015 – no length data.

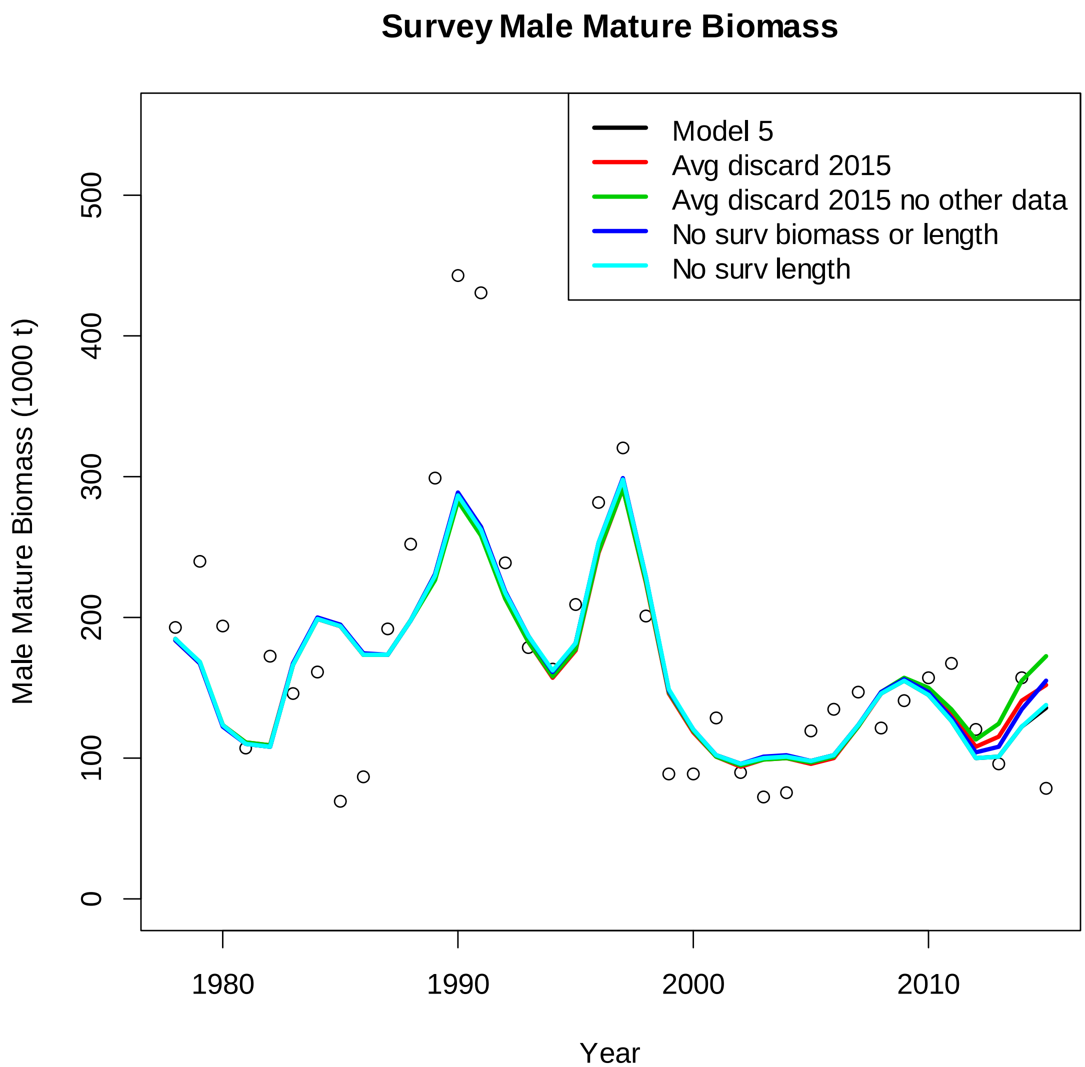

Figure 110. Predicted survey mature male biomass estimated from runs with Model 5 with 1) all data (Model 5), 2) Avg discard 2015 - All 2015 data except average discard in 2015 at the historical average relative to retained, 3) Avg discard 2015 no other dta - average discard in 2015 at the historical average relative to retained – no other 2015 data 4) No surv biomass or length - Observed discard catch in 2015, no other 2015 data, and 5) No surv length - observed discard and survey biomass 2015 – no length data.

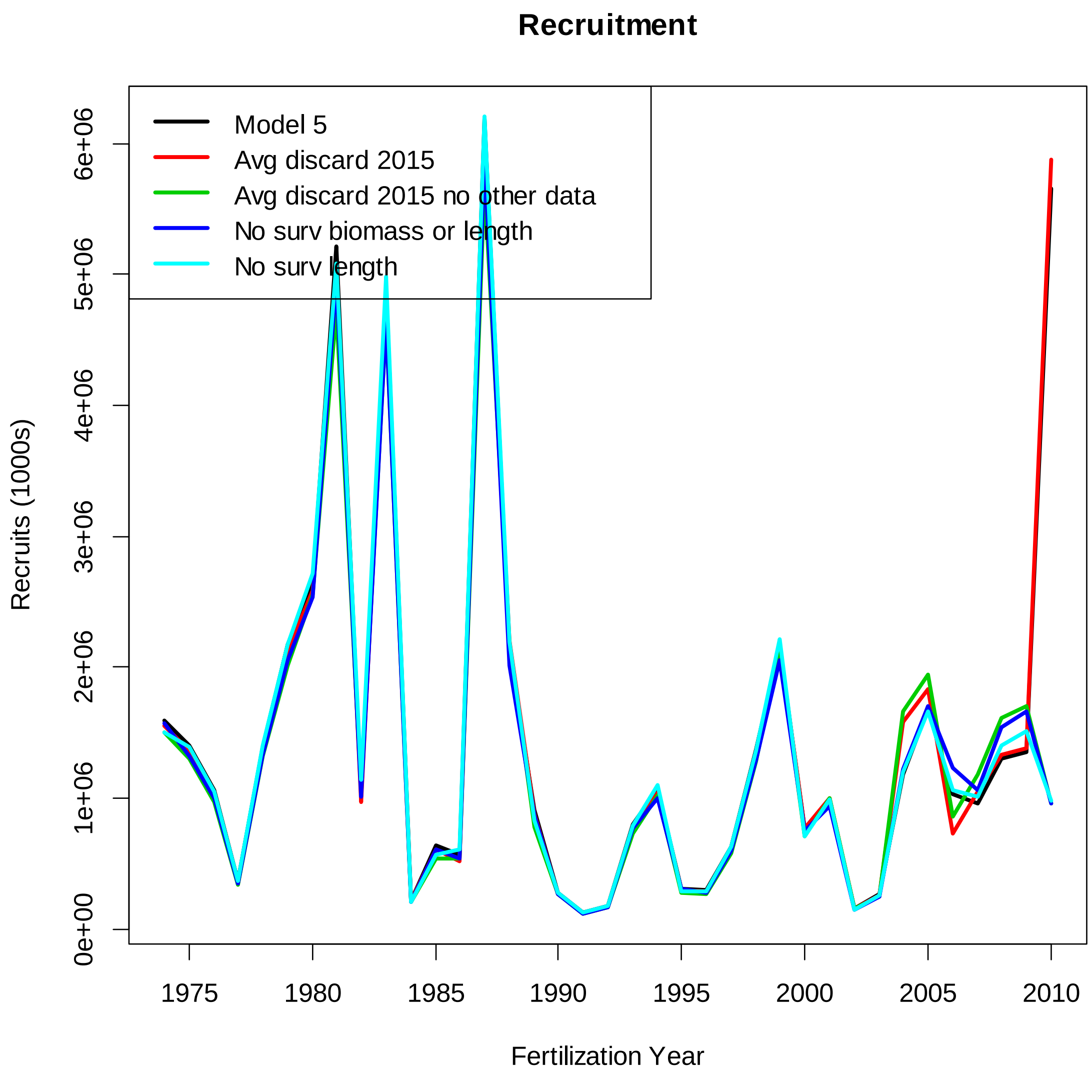

Figure 111. Recruitment estimated from runs with with Model 5 with 1) all data (Model 5), 2) Avg discard 2015 - All 2015 data except average discard in 2015 at the historical average relative to retained, 3) Avg discard 2015 no other dta - average discard in 2015 at the historical average relative to retained – no other 2015 data 4) No surv biomass or length - Observed discard catch in 2015, no other 2015 data, and 5) No surv length - observed discard and survey biomass 2015 – no length data.

Appendix A

Minutes of Crab Plan Team May 2013 on Handling Mortality

Dan Urban (AFSC – Kodiak) provided a presentation on application of the "reflex action mortality predictor" (RAMP) method to estimating handling mortality of discarded crab in the commercial BSAI crab fisheries.

Urban reviewed information on the short and long term handling mortality of discarded crab relevant to crab stock assessment and development of fishery management measures, with an emphasis on EBS snow crab. Estimates of bycatch biomass during the fishery are multiplied by the handling mortality rate and that product is added to the retained catch biomass to estimate total fishery mortality. Hence, assumptions about handling mortality will affect the time series of estimates of total fishery mortality used in stock assessment models, the determination of annual OFLs, and annual total-catch accounting.

In the EBS snow crab fishery, the discarded catch of snow crab is about 1/3 of the catch of retained crab; the discarded snow crab are mainly males smaller than the size preferred by processors (4 inches carapace width). The EBS snow crab assessment model has been using 0.5 as the handling mortality rate for snow crab discarded during the directed fishery. Urban noted that there is high uncertainty on this value; consensus of the CPT discussion during the presentation was that, rather than being directly estimated from data, the 0.5 value was largely based on balancing the concerns that handling mortality could be close to 100% versus an assumption closer to 0% based on an inferred low retained-crab deadloss rate

(~2%).

Urban reviewed the sources of short term handling mortality for discards during crab fisheries, which include trauma at dumping and sorting of the catch, on-deck anoxia, and temperature stress on deck.

Temperature stress and freezing is a particular concern for the winter snow crab fishery, which is often conducted during sub-freezing temperatures that are known from laboratory studies to induce mortality in snow crab (e.g., Shirley and Warrenchuck) and to freeze eyestalks (ongoing project). On-deck sorting and discarding may induce short-term mortality, long-term mortality, and long-term reductions in reproductive potential. Short-term mortality can be directly studied and estimated; estimation of longterm effects is more difficult. Long-term effects could include: increased risk to predation, decreased ability to feed or mate, and increased mortality during molting. Laboratory studies have confirmed that increased mortality of molting Tanner crab after exposure to sub-freezing temperatures and freezing of eye stalks could be reasonably assumed to have long-term effects on survival and reproduction.

The RAMP approach provides a means to estimate short-term (< 2 weeks) mortality due to discarding by scoring a suite of reflex responses of crab captured during fisheries prior to their being discarded.

Previous studies by Allan Stoner allow short-term mortality rates to be predicted from the RAMP reflex response scores. With RAMP scores recorded from uninjured snow crab caught on 22 vessels during

2009/10 season, the predicted handling mortality of discards varied from 1.4% to 32% among vessels; overall RAMP-predicted mortality of discards using the data from all vessels was 5.9%. Additional studies on commercial fishing vessels were conducted on one vessel during the 2010/11 snow crab season and on four vessels during the 2011/12 season. The RAMP-predicted handling mortality from the 2010/11

study was 4.6% and from the 2011/12 study was 4.5%.

The predicted handling mortality was negatively correlated with back-deck temperature on the vessel during the time that RAMP-scoring occurred, such that temperature can be used to predict handling mortality; e.g., predicted mortality was approximately 35% at -14° C and <10% at temperatures ≥ -6° C.

Directly obtaining back-deck temperatures on all vessels throughout the season is not feasible. Urban therefore used the temperatures recorded at the St. Paul airport as a proxy for on-deck temperatures to extend the results to all vessels fishing. Most of the temperatures recorded at the St. Paul airport during the 2009/10 season were at levels associated with low RAMP-predicted mortality. Urban estimated the average per-season handling mortality rate during the 1990/91–2010/11 seasons to be 4%, with the highest estimate for any single season to be 8% (during the early 1990s) using the historical St. Paul airport temperatures to estimate the freezing-related handling mortality. Urban provided ADF&G's estimates of injury rates of snow crab captured during the fishery. Those estimates of injury rates (from data collected by observers during the 1997/98 and 1998/99 seasons) are approximately 10% (it should be noted that data on injury rates observed during the 2009/10–2011/12 seasons in conjunction with the

RAMP study were lower). Urban suggested that the injury rates could be used to predict short-term mortality due to factors other than temperature.

Urban acknowledged that a determination of the true handling mortality rate is difficult, particularly when considering the long-term mortality. Nonetheless, he felt that evidence from the RAMP studies and the observed injury rates suggest that the 0.5 currently assumed for handling mortality in the snow crab assessment and for determining the OFL is too high. Urban proposed three options for handling mortality rates for use in the snow crab assessment: status quo (handling mortality rate = 0.5, a conservative approach); a constant in the range of 0.15–0.20 (based on adding the highest or average estimate of

RAMP-predicted mortality and the highest observed injury rate); or using the historic St. Paul airport temperatures and applying the temperature-mortality relationship to obtain an annual handling mortality rate.

Urban concluded his presentation with a summary of the attempts to develop a RAMP-based method to estimate handling mortality for red and golden king crab. Those attempts were not successful and suggested that the RAMP approach may have no useful application to king crab. Red king crab mortality showed no relationship with reflex-response scores, whereas experimenters had a difficult time inducing the golden king crab subjects to die. Urban noted that one observation from this study was that golden king crab appear to be more hardy than red king crab. As an example, clipping the leg of a golden king crab caused only 3% mortality; significant mortality (80%) required complete severing of the leg.

The CPT discussed how to apply the findings presented for use in the snow crab stock assessment. The

CPT was reminded that estimates used in the stock assessment should be unbiased and that conservation concerns due to uncertainty should enter in the consideration of the ABC. Much of the initial CPT discussion focused on the uncertainty related to long-term handling mortality and on the effects due to discarding itself (as opposed to the injuries suffered when brought on deck). The CPT felt that the weight of evidence is that 0.5 is too high, but struggled with reconciling the results presented by Urban with the uncertainty associated with other, long-term effects to survival, growth, and reproduction (e.g., predation, displacement, affects to hormone regulation, additional stresses during molting, etc). Some voiced concerns that, given those uncertainties, the CPT may be placing more weight on the results of recent studies than is warranted. With regard to some of the concerns, it was noted that most of the discards are males > 3 inches carapace width, which Urban noted may have low risk of predation relative to smaller crab. In addition, although the long-term effects will be much higher for crab that will molt, data collected on chela heights of males captured during the fishery suggest that most of the discarded males have already completed their terminal molt.

Discussion provided four options to consider for a total handling mortality rate for snow crab:

1. 0.2, derived by summing the highest estimate due to freezing (0.08) with the highest estimate of injury rates (0.12); i.e., one of the options that Urban presented
2. 0.25, derived as a balance between the extremes of 0.0 and 0.5; the argument for this was that it was consistent with the approach to obtain the currently-used 0.5, which was derived as a balance between the two extremes of 0.0 and 1.0
3. 0.3, derived by taking the “base” of 20% handling mortality that is applied to king crab stocks and adding the highest estimate of freezing-related handling mortality (0.08) and rounding up to the nearest 0.1.
4. 0.3, derived by summing the highest estimate due to freezing (0.08) with the highest estimate of injury rates (0.12) to capture the short-term mortality and multiplying that sum by 1.5 to provide an estimate that includes long-term mortality. Since there is no information on long-term mortality, the CPT agreed that the best first-order estimate of the long-term mortality is 50% of the short-term mortality.

The consensus of the CPT was that the best current estimate of handling mortality of snow crab was 0.3, based on the argument of the last bullet (above). The CPT requested that the next snow crab assessment use 0.3 as handling mortality for all pot fisheries (crab and fish) in the base run and 0.5 as an alternative scenario (there was some discussion as to whether 0.3 or 0.5 should be the base, but if 0.3 is chosen it should be the base run so that the new handling mortality is included in the remaining alternative runs).

The 0.5 run should be included so that the effects on OFL, stock status, etc., can be evaluated.

The CPT recommended that the 0.3 handling mortality not be applied to Tanner crab, neither as bycatch in the snow crab fishery or in the directed Tanner crab fishery; i.e., the recommended handling mortality for Tanner crab remains at 0.5 until sufficient data suggests otherwise. Stoner's work suggests that Tanner crab may suffer higher handling mortality than snow crab, but no data were presented at this meeting for

Tanner crab similar to what were presented for snow crab. The CPT recommended that a sensitivity analysis on handling mortality be done in the Tanner crab assessment to provide impetus for research on

Tanner handling mortality during the snow crab fishery because Tanner bycatch mortality during snow crab fishery has a large effect on the Tanner crab stock assessment, OFL setting, and available TAC.

Discussion turned to the results that Urban presented on king crabs, for which the RAMP approach appears to be not useful. Currently, the Bristol Bay red king crab and the golden king crab assessments assume that handling mortality is 0.2. Although on-deck injury rates for king crab during the red and golden king crab fisheries have been estimated using data collected by ADF&G during the late 1990s, no new data was presented on king crab handling mortality at the meeting. The CPT discussed the apparently greater "hardiness" of golden king crab relative to red king crab and some members of the public suggested that this observation could justify reducing the handling mortality used for golden king crab to less than 0.2. The CPT was unable to recommend a change to the golden king crab handling mortality on the basis of what was presented during the meeting and recommended that it stay at the status quo 0.2 until some data providing estimates of the handling mortality rate are presented. It was noted that both the golden king crab stocks (Aleutian Islands and Pribilof Islands) are currently managed as Tier 5 stocks, for which the assumed handling mortality rates have no impact on the retained-catch portion of the OFL or of the ABC; handling mortality would become an important consideration if the golden king crab stocks become managed under Tier 4.

The CPT emphasizes that handling mortality remains a priority research objective for king crab species and Tanner crab.

BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN FALL 2015

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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 2014/15 was about 10 million lbs (4,500 t) less than it was in 2009/10. The magnitude of bycatch from groundfish trawl fisheries has been stable and small relative to stock abundance during the last 10 years.
3. Stock biomass: Estimated mature biomass increased dramatically in the mid 1970s and decreased precipitously in the early 1980s. Estimated mature crab abundance had increased during 1985-2009 with mature females being about 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 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 1984-2015, only in 1984, 1986, 1995, 1999, 2002 and 2005 were estimated recruitments above the historical average for 1976-2015. Estimated recruitment was extremely low during the last 9 years.
5. Management performance:

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	13.77[A]	30.88[A]	3.55	3.61	4.09	8.80	7.92
2012/13	13.19[B]	29.05[B]	3.56	3.62	3.90	7.96	7.17
2013/14	12.85[C]	27.12[C]	3.90	3.99	4.56	7.07	6.36
2014/15	13.03[D]	27.25[D]	4.49	4.54	5.44	6.82	6.14
2015/16		24.69[D]				6.73	6.06

The stock was above MSST in 2014/15 and is hence not overfished. Overfishing did not occur.

Status and catch specifications (million lbs):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	30.4[A]	68.1[A]	7.83	7.95	9.01	19.39	17.46
2012/13	29.1[B]	64.0[B]	7.85	7.98	8.59	17.55	15.80
2013/14	28.3[C]	59.9[C]	8.60	8.80	10.05	15.58	14.02
2014/15	28.7[D]	60.1[D]	9.99	10.01	11.99	15.04	13.53
2015/16		54.4[D]				14.84	13.36

Notes:
A – Calculated from the assessment reviewed by the Crab Plan Team in September 2012
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2013
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2014
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2015

6. Basis for the OFL: All table values are in 1000 t (Scenario 1):

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2011/12	3a	27.3	29.8	1.09	0.32	1984-2011	0.18
2012/13	3b	27.5	26.3	0.96	0.31	1984-2012	0.18
2013/14	3b	26.4	25.0	0.95	0.27	1984-2013	0.18
2014/15	3b	25.7	24.7	0.96	0.28	1984-2014	0.18
2015/16	3b	26.1	24.7	0.95	0.27	1984-2015	0.18

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
2011/12	3a	60.1	65.6	1.09	0.32	1984-2011	0.18
2012/13	3b	60.7	58.0	0.96	0.31	1984-2012	0.18
2013/14	3b	58.2	55.0	0.95	0.27	1984-2013	0.18
2014/15	3b	56.7	54.4	0.96	0.28	1984-2014	0.18
2015/16	3b	57.5	54.4	0.95	0.27	1984-2015	0.18

A. Summary of Major Changes

1. Change to management of the fishery: None.

2. Changes to the input data:

a. The new time series of NMFS trawl survey area-swept estimates provided by NMFS in 2015 with new 2015 trawl survey data were used.

b. Catch and biomass data were updated to present.

c. Bottom temperature data collected during the NMFS summer trawl surveys were used to estimate trawl survey catchability.

3. Changes to the assessment methodology:

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

Scenario 1: Scenario 1 is renamed from scenario 4nb in the SAFE report in September 2014 for simplicity with the new time series of the NMFS trawl survey data.

Scenario 1a: Scenario 1a is the same as scenario 1 except using the bottom temperature data to estimate annual trawl survey catchability with the “data method” described in Schirippa et al. (2009).

Scenario 1b: Scenario 1b is the same as scenario 1 except using the bottom temperature data to estimate annual trawl survey catchability with the “model method” based on Wilderbuer et al. (2013).

4. Changes to assessment results:

The population biomass estimates in 2015 are slightly lower than those in 2014. Among the three scenarios, model estimated relative survey biomasses are very similar between scenarios 1 and 1b and fluctuate a lot more for scenario 1a, primarily due to a much better fit of total survey biomass. The absolute population biomass estimates are slightly higher for scenario 1a than for scenarios 1 and 1b due to a slightly lower estimate of trawl survey catchability for scenario 1a.

B. Responses to SSC and CPT Comments

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

None.

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

Response to CPT Comments (from September 2014)

"The CPT recommended that the assessment authors consider the affects of the final size bin used in the retained size composition data on model fitting (including the effects of the assumption of fixed sample size in the final bin) and consider the possibility of subdividing the final size bin into more than one bin."

This question comes from the difficulty of GMACS to fit the length composition data. The primary reason for the difficult fit is due to problems of estimating the growth transition matrix and survey selectivities. However, the final plus-length group does have impacts on the results. It is a trade-off between the numbers of empty length groups and relatively low impacts of large plus groups. We may consider examining this in the future.

Response to CPT Comments (from May 2015)

"1) Use new survey data for all runs."

Done.

"2). Do runs with stepwise changes from scenario 1 to 2, with one change for each scenario."

Due to lack of female juvenile growth data, we will not include scenario 2 in this report. Scenario 2 will be evaluated in future.

"3). Run a scenario with a temperature relationship to survey q. Use a method that allows variability in the index such as the "data method" described in Schirippa et al (2009)."

Scenario 1a is the "data method" to estimate annual trawl survey catchabilities with bottom temperature data. As a comparison, scenario 1b is the "model method" to estimate annual survey catchabilities based on Wilderbuer et al. (2013).

"4. Use egg code data in the survey to separate immature and mature females and input as data to the model as an alternative for tracking changes in maturity over time. Fit immature and mature females separately in the model."

Will follow this recommendation in future when working with scenario 2.

"*5). Label x axis on length composition plots with actual length in millimeters."*

Done.

Response to SSC Comments specific to this assessment (from October 2014)

"The SSC recommends that if Model 4n7 is brought forward in 2015 as an alternative model, that reference points for Model 4n7 be recalculated with the higher M = 0.27 estimated for 2006 – 2010. The SSC looks forward to the additional work planned by the author: implementing a random walk for natural mortality, investigation of recruitment dynamics, and investigation of survey weighting."

A scenario with random walk is not added in this report. We feel that the random walk approach may be used to examine the temporal trend of natural mortality, but the estimated natural mortality value may not be suitable for reference point estimates due to the mean recruitment estimated under different natural mortality.

In May 2015, we investigated a model scenario on examining female maturity as suggested by the SSC in 2013. This model scenario will be further developed in the future once juvenile red king crab female growth data are available.

We appreciate SSC suggestions on spatial statistical analysis similar to that conducted by Kotwicki and Lauth (2012) and incorporating bottom temperature as a covariate on survey Q using the method in Wilderbuer et al. (2013). We will consider conducting spatial statistical analysis in the future.

In this report, we examine annual trawl survey Q values with temperature data with two methods (scenarios 1a and 1b). Scenario 1b uses the method in Wilderbuer et al. (2013) to estimate survey Q.

Response to SSC Comments specific to this assessment (from June 2015):

No comments.

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 and eastern Bering Sea.

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

A new time series of NMFS trawl survey results was provided by NMFS in 2015. We compared the old and new time series of the NMFS trawl survey results in May 2015. The trawl survey data were updated to include the survey data in 2015.

Catch and biomass data were updated to present.

Mean annual bottom temperature data collected during the NMFS summer trawl surveys within the area of >54.75°N and <58.75°N, >-166°W and <-158°W were used to estimate trawl survey catchability. Bristol Bay red king crab primarily occur in this area.

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 2014. Bycatch data are available starting from 1990 and were obtained from the ADF&G observer database and reports (Gaeuman 2013). Sample sizes for catch by length and shell condition are summarized in Table 2. Relatively large samples were taken from the retained catch each year. Sample sizes for trawl bycatch were the annual sums of length frequency samples in the National Marine Fisheries Service (NMFS) database.

(i). Catch Biomass

Retained catch and estimated bycatch biomasses are summarized in Table 1 and illustrated in Figure 2. Retained catch and estimated bycatch from the directed fishery include the general, open-access fishery (prior to rationalization), or the individual fishery quota (IFQ) fishery (after rationalization), as well as the Community Development Quota (CDQ) fishery and the ADF&G cost-recovery harvest. Starting in 1973, the fishery generally occurred during the late summer and fall. Before 1973, a small portion of retained catch in some years was caught from April to June. Because most crab bycatch from the groundfish trawl fisheries occurred during the spring, the years in Table 1 are one year less than those from the NMFS trawl bycatch database to approximate the annual bycatch for reporting years defined as June 1 to May 31; e.g., year 2002 in Table 1 for trawl bycatch corresponds to what is reported for year 2003 in the NMFS database. Catch biomass is shown in Figure 2. 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 3). 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 3). 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 $\approx$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 1975-2015 were provided by NMFS.

Abundance estimates by sex, carapace length, and shell condition were derived from survey data using an area-swept approach (Figures 4 and 5). 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 in 2015 discards all "hot spot" tows. We used the new area-swept estimates provided by NMFS in 2015.

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

4. Bering Sea Fisheries Research Foundation Survey Data

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

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 2015.

2. Model Description

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

a-f. See appendix A.

g. Critical assumptions of the model:

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

ii. Survey and fisheries selectivities are a function of length and were constant over shell condition. Selectivities are also a function of sex except for trawl bycatch selectivities, which are the same for both sexes. Two different survey selectivities were estimated: (1) 1975-1981 and (2) 1982-2015, 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 with scenarios 1, 1a, and 1b, growth-per-molt increments as a function of length were estimated for three periods (1975-1982, 1983-1993, and 1994-2015) based on sizes at maturity. Once mature, female red king crab grow with a much smaller growth increment per molt.

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

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

vi. The prior of survey catchability (*Q*) was estimated to be 0.896, based on a trawl experiment by Weinberg et al. (2004) with a standard deviation of 0.025. *Q* is assumed to be constant over time and is estimated in the model for scenario 1. Annual *Q* values for scenarios 1a and 1b are estimated with bottom temperature data.

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:

Several scenarios were compared for this report:

Scenario 1 (renamed from previous scenario 4nb): base scenario. Scenario 1 includes:

(1) Basic *M* = 0.18, with an additional mortality level during 1980-1984 for males and two additional mortality levels (one for 1980-1984 and the other for 1976-1979 and 1985-1993) for females. For scenario 2, the additional mortality level for 1976-1979 and 1985-1993 is 0 based on the model estimate, and thus is fixed to 0.

(2) Including BSFRF survey data in 2007 and 2008.

(3) Survey catchability is estimated in the model and is assumed to be constant over time.

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

(5) Estimating effective sample size from observed sample sizes. Effective sample sizes are estimated as min(0.5*observed-size, N) for trawl surveys and min(0.1* observed-size, N) for catch and bycatch, where N is the maximum sample size (200 for trawl surveys, 100 for males from the pot fishery and 50 for females from pot fishery and both males and females from the trawl fisheries. 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:

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

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

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

(7) Estimating initial year length compositions.

Scenario 1a: Scenario 1a differs with scenario 1 by using the bottom temperature data to estimate annual trawl survey catchability with the "data method" described in Schirippa et al. (2009):

$T_t = \beta\, \varepsilon_t$,
where β is a parameter, $\varepsilon_t \sim$ N(0, σ_ε^2), the process error deviation for year t and T_t is the estimated bottom temperature deviation for year t. Annual survey Q_t are
$Q_t = Q \exp(\varepsilon_t)$,
where Q is a parameter. The negative log likelihood value is
$L = \sum [\ln(\sigma_T^2\ \beta^2)^{0.5} + (T_t^{obs} - T_t)^2 / (2\,\sigma_T^2\ \beta^2)]$,
where T_t^{obs} is the observed bottom temperature deviation for year t, and σ_T is the assumed standard deviation value of the residual error for the bottom temperatures. σ_T is assumed to be 0.3 for a reasonable trade-off between the over-fitting and under-fitting of the trawl survey biomass.

Scenario 1b: Scenario 1b differs with scenario 1 by using the bottom temperature data to estimate annual trawl survey catchability with the "model method" based on Wilderbuer et al. (2013):

$Q_t = Q \exp(b * T_t^{obs})$, where Q and b are parameters and T_t^{obs} is the observed temperature deviation in year t.

Only the full results for scenarios 1 and 1a are presented in this report, since the results of scenarios 1 and 1b are about the same. Each figure or table is indicated with a scenario.

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.

4. Results

a. Effective sample sizes and weighting factors.

i. The effective sample sizes are:

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

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

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

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

b. Tables of estimates.

i. Parameter estimates for scenarios 1 and 1a are summarized in Tables 4 and 5.

ii. Abundance and biomass time series are provided in Table 6 for scenarios 1 and 1a.

iii. Recruitment time series for scenarios 1 and 1a are provided in Table 6.

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

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

c. Graphs of estimates.

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

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

   For scenarios 1 and 1a, estimated molting probabilities during 1975-2015 (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 between scenarios 1 and 1b and fluctuate a lot more for scenario 1a, primarily due to a much better fit of total survey biomass. The absolute population biomass estimates are slightly higher for scenario 1a than for scenarios 1 and 1b due to a slightly lower estimate of trawl survey catchability for scenario 1a.

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

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

iii. Estimated recruitment time series are plotted in Figure 12 for scenarios 1 and 1a.

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

The average of estimated male recruits from 1984 to 2015 (Figure 12) and mature male biomass per recruit were used to estimate $B_{35\%}$. Alternative periods of 1976-present and 1976-1983 were compared in our report. The full fishing mortalities for the directed pot fishery at the time of fishing were plotted against mature male biomass on Feb. 15 (Figure 13). Estimated fishing mortalities in most years before the current harvest strategy was adopted in 1996 were above $F_{35\%}$ (Figure 13). Under the current harvest strategy, estimated fishing mortalities were at or above the $F_{35\%}$ limits in 1998, 2005, 2007-2009 for both scenarios 1 and 1a but below the $F_{35\%}$ limits in the other post-1995 years. The estimated higher survey catchabilities with scenarios 1 and 1b result in relatively higher fishing mortalities than those with scenario 1a.

For scenario 1, estimated full pot fishing mortalities ranged from 0.00 to 1.52 during 1975-2014, with estimated values over 0.40 during 1975-1981, 1986-1987 and 2008 (Table 5, Figure 13). For scenario 1a, estimated full pot fishing mortalities ranged from 0.00 to 1.46 during 1975-2014, with estimated values over 0.40 during 1975-1981, 1986 and 2008 (Figure 13). Estimated fishing mortalities for pot female bycatch and trawl bycatch were generally less than 0.06.

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

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

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

d. Graphic evaluation of the fit to the data.

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

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

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

The model (scenarios 1 and 1a) fit the fishery biomass data well and the survey biomass reasonably well, especially for scenario 1a (Figures 10 and 16). Because the model estimates annual fishing mortality for directed pot male catch, undirected pot male bycatch, pot female bycatch, and trawl bycatch, the deviations of observed and predicted (estimated) fishery biomass are mainly due to size composition differences.

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

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

Standardized residuals of total survey biomass and proportions of length are plotted to examine their patterns. Residuals were calculated as observed minus predicted and standardized by the estimated standard deviation. Standardized residuals of total survey biomass did not show any consistent patterns (Figure 17). Standardized residuals of proportions of survey males appear to be random over length and year (Figure 25). There is an interesting pattern for residuals of proportions of survey females. Residuals were generally negative for large-sized mature females during 1975-1987 for scenarios 1 and 1a (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.

iv. Temperature deviations and use of temperature data to estimate annual trawl survey catchability (Q_t) are summarized in Figure 27. The choice of σ_T = 0.3 for temperature measurement errors and process errors is supported by the relationship between total negative log likelihood, negative log trawl survey biomass likelihood and assumed σ_T values (Figure 27a). σ_T =0.3 is a good trade-off between the over-fitting and under-fitting. Furthermore, the estimated mature biomass is not sensitive to the σ_T values (Figure 27a).

    As expected, annual estimated Q_t values are much more variable for scenario 1a than for scenario 1b (Figure 27b). In fact, very little change of estimated Q_t values occurs over time for scenario 1b. The standardized residuals of temperatures look reasonable (Figure 27c). The correlation between estimated Q_t values and temperatures depends on the σ_T values. Generally, high temperature values increase the estimated survey Q_t values (Figure 27c).

e. Retrospective and historic analyses.

Two kinds of retrospective analyses were conducted for this report: (1) the 2015 model (scenarios 1 and 1a) hindcast results and (2) historical results. The 2015 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 2015 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 2015 model includes sequentially excluding one-year of data. The models with scenarios 1 and 1a performed reasonably well during 2008-2014 with a lower terminal year estimates in 2012 and 2013 and higher estimates during 2008-2010 (Figure 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 2015 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 2015 model results (retrospective analysis) performed reasonably well. No great overestimates or underestimates occurred as was observed in assessments for Pacific halibut (*Hippoglossus stenolepis*) (Parma 1993) and some eastern Bering Sea groundfish stocks (Zheng and Kruse 2002; Ianelli et al. 2003). Since the most recent model was not used to set TAC or overfishing limits until 2009, historical implications for management from the stock assessment errors cannot be evaluated at the current time. However, management implications of the ADF&G stock assessment model were evaluated by Zheng and Kruse (2002).

f. Uncertainty and sensitivity analyses

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

ii. Probabilities for trawl survey catchability *Q* are illustrated in Figure 30 for scenarios 1 and 1a using the mcmc approach; estimated *Q*s are generally less than 1.0. Probabilities for mature male biomass and OFL in 2014 are illustrated in Figure 31 for scenarios 1 and 1a using the mcmc appproach. The confidence intervals are quite narrow.

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

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

g. Comparison of alternative model scenarios

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

In this report (September 2015), three scenarios are compared. Model estimated relative survey biomasses are very similar between scenarios 1 and 1b and fluctuate a lot more for scenario 1a, primarily due to much better fit of total survey biomass. The absolute population biomass estimates are slightly higher for scenario 1a than for scenarios 1 and 1b due to a slightly lower estimate of trawl survey catchability for scenario 1a. Overall, the results for all three scenarios are similar.

F. Calculation of the OFL and ABC

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

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

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

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

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

Where

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

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

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

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

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

Because trawl bycatch fishing mortality was not related to pot fishing mortality, average trawl bycatch fishing mortality during 2005 to 2014 was used for the per recruit analysis as well as for projections in the next section. Pot female bycatch fishing mortality was set equal to pot male fishing mortality times 0.02, an intermediate level during 1990-2014. 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 2012-2014 were used to represent current trends for per recruit analysis and projections. Average molting probabilities during 2005-2014 were used for per recruit analysis and projections.

Average recruitments during three periods were used to estimate $B_{35\%}$: 1976-1983, 1976-2015, and 1984-2015 (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 1984-2015 as the baseline.

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

The estimated probability distribution of MMB in 2015 is illustrated in Figure 30. Based the SSC suggestion in 2011, ABC = 0.9*OFL is used to estimate ABC.

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

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	13.77[A]	30.88[A]	3.55	3.61	4.09	8.80	7.92
2012/13	13.19[B]	29.05[B]	3.56	3.62	3.90	7.96	7.17
2013/14	12.85[C]	27.12[C]	3.90	3.99	4.56	7.07	6.36
2014/15	13.03[D]	27.25[D]	4.49	4.54	5.44	6.82	6.14
2015/16		24.69[D]				6.73	6.06

The stock was above MSST in 2014/15 and is hence not overfished. Overfishing did not occur.

Status and catch specifications (million lbs):

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2011/12	30.4[A]	68.1[A]	7.83	7.95	9.01	19.39	17.46
2012/13	29.1[B]	64.0[B]	7.85	7.98	8.59	17.55	15.80
2013/14	28.3[C]	59.9[C]	8.60	8.80	10.05	15.58	14.02
2014/15	28.7[D]	60.1[D]	9.99	10.01	11.99	15.04	13.53
2015/16		54.4[D]				14.84	13.36

Notes:

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2012
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2013
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2014
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2015

4. Based on the $B_{35\%}$ estimated from the average male recruitment during 1984-2015, the biological reference points and OFL were estimated as follows:

	Scenario 1		Scenario 1a		Scenario 1b	
	1,000t	Mill. lbs	1,000t	Mill. lbs	1,000t	Mill. lbs
$B_{35\%}$	26.064	57.462	26.467	58.350	26.075	57.486
$F_{35\%}$	0.29		0.29		0.29	
MMB_{2015}	24.691	54.433	25.019	55.156	24.778	54.626
OFL_{2015}	6.732	14.841	6.824	15.044	6.783	14.954
ABC_{2015}	6.059	13.357	6.141	13.539	6.105	13.459

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

G. Rebuilding Analyses

NA.

H. Data Gaps and Research Priorities

1. The following data gaps exist for this stock:
   a. Information about changes in natural mortality in the early 1980s;
   b. Un-observed trawl bycatch in the early 1980s;
   c. Natural mortality;
   d. Crab availability to the trawl surveys;

e. Juvenile crab abundance;

f. Female growth per molt as a function of size and maturity;

g. Changes in male molting probability over time.

2. Research priorities:

a. Estimating natural mortality;

b. Estimating crab availability to the trawl surveys;

c. Surveying juvenile crab abundance in nearshore;

d. Studying environmental factors that affect the survival rates from larvae to recruitment.

I. Projections and Future Outlook

1. Projections

Future population projections primarily depend on future recruitment, but crab recruitment is difficult to predict. Therefore, annual recruitment for the projections was a random selection from estimated recruitments during 1984-2015. Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2015. The 2015 abundance was randomly selected from the estimated normal distribution of the assessment model output for each replicate. Three scenarios of fishing mortality for the directed pot fishery were used in the projections:

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

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

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

Each scenario was replicated 1,000 times and projections made over 10 years beginning in 2015 (Table 7).

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

2. Near Future Outlook

The near future outlook for the Bristol Bay RKC stock is a declining trend. The three recent above-average year classes (hatching years 1990, 1994, and 1997) had entered the legal population by 2006 (Figure 34). Most individuals from the 1997 year class will continue to gain weight to offset loss of the legal biomass to fishing and natural mortalities. The above-average year class (hatching year 2000) with lengths centered around 87.5 mm CL for both males and females in 2006 and with lengths centered around 112.5-117.5 mm CL for males and around 107.5 mm CL for females in 2008 has largely entered the mature male population in 2009 and the legal population by 2014

(Figure 34). No strong cohorts have been observed in the survey data after this cohort through 2010 (Figure 34). There was a huge tow of juvenile crab of size 45-55 mm in 2011, but these juveniles were not observed during 2012-2015 surveys. This singe tow is unlikely to be an indicator for a strong cohort. The high survey abundance of large males and mature females in 2014 cannot be explained by the survey data during the previous years and were not followed with the 2015 survey results (Figure 34). Due to lack of recruitment, mature and legal crab should continue to decline next year. Current crab abundance is still low relative to the late 1970s, and without favorable environmental conditions, recovery to the high levels of the late 1970s is unlikely.

J. Acknowledgements

We thank the Crab Plan Team and Joel Webb for reviewing the earlier draft of this manuscript.

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

Year	Retained Catch				Pot Bycatch		Trawl Bycatch	Tanner Fishery Bycatch	Total Catch
	U.S.	Cost-Recovery	Foreign	Total	Males	Females			
1953	1331.3		4705.6	6036.9					6036.9
1954	1149.9		3720.4	4870.2					4870.2
1955	1029.2		3712.7	4741.9					4741.9
1956	973.4		3572.9	4546.4					4546.4
1957	339.7		3718.1	4057.8					4057.8
1958	3.2		3541.6	3544.8					3544.8
1959	0.0		6062.3	6062.3					6062.3
1960	272.2		12200.7	12472.9					12472.9
1961	193.7		20226.6	20420.3					20420.3
1962	30.8		24618.7	24649.6					24649.6
1963	296.2		24930.8	25227.0					25227.0
1964	373.3		26385.5	26758.8					26758.8
1965	648.2		18730.6	19378.8					19378.8
1966	452.2		19212.4	19664.6					19664.6
1967	1407.0		15257.0	16664.1					16664.1
1968	3939.9		12459.7	16399.6					16399.6
1969	4718.7		6524.0	11242.7					11242.7
1970	3882.3		5889.4	9771.7					9771.7
1971	5872.2		2782.3	8654.5					8654.5
1972	9863.4		2141.0	12004.3					12004.3
1973	12207.8		103.4	12311.2					12311.2
1974	19171.7		215.9	19387.6					19387.6
1975	23281.2		0	23281.2					23281.2
1976	28993.6		0	28993.6			682.8		29676.4
1977	31736.9		0	31736.9			1249.9		32986.8
1978	39743.0		0	39743.0			1320.6		41063.6
1979	48910.0		0	48910.0			1331.9		50241.9
1980	58943.6		0	58943.6			1036.5		59980.1
1981	15236.8		0	15236.8			219.4		15456.2
1982	1361.3		0	1361.3			574.9		1936.2
1983	0.0		0	0.0			420.4		420.4
1984	1897.1		0	1897.1			1094.0		2991.1
1985	1893.8		0	1893.8			390.1		2283.8
1986	5168.2		0	5168.2			200.6		5368.8
1987	5574.2		0	5574.2			186.4		5760.7
1988	3351.1		0	3351.1			597.8		3948.9
1989	4656.0		0	4656.0			174.1		4830.1
1990	9236.2	36.6	0	9272.8	526.9	651.5	247.6		10698.7
1991	7791.8	93.4	0	7885.1	407.8	75.0	316.0	1401.8	10085.7
1992	3648.2	33.6	0	3681.8	552.0	418.5	335.4	244.4	5232.2
1993	6635.4	24.1	0	6659.6	763.2	637.1	426.6	54.6	8541.0
1994	0.0	42.3	0	42.3	3.8	1.9	88.9	10.8	147.8
1995	0.0	36.4	0	36.4	3.3	1.6	194.2	0.0	235.5
1996	3812.7	49.0	0	3861.7	164.6	1.0	106.5	0.0	4133.9
1997	3971.9	70.2	0	4042.1	244.7	19.6	73.4	0.0	4379.8
1998	6693.8	85.4	0	6779.2	959.7	864.9	159.8	0.0	8763.7
1999	5293.5	84.3	0	5377.9	314.2	8.8	201.6	0.0	5902.4
2000	3698.8	39.1	0	3737.9	360.8	40.5	100.4	0.0	4239.5
2001	3811.5	54.6	0	3866.2	417.9	173.5	164.6	0.0	4622.1
2002	4340.9	43.6	0	4384.5	442.7	7.3	155.1	0.0	4989.6

2003	7120.0	15.3	0	7135.3	918.9	430.4	172.3	0.0	8656.9
2004	6915.2	91.4	0	7006.7	345.5	187.0	119.6	0.0	7658.8
2005	8305.0	94.7	0	8399.7	1359.5	498.3	155.2	0.0	10412.8
2006	7005.3	137.9	0	7143.2	563.8	37.0	116.7	3.8	7864.4
2007	9237.9	66.1	0	9303.9	1001.3	186.1	138.5	1.8	10631.6
2008	9216.1	0.0	0	9216.1	1165.5	148.4	159.5	4.0	10693.5
2009	7226.9	45.5	0	7272.5	888.1	85.2	103.7	1.6	8351.2
2010	6728.5	33.0	0	6761.5	797.5	122.6	85.3	0.0	7767.0
2011	3553.3	53.8	0	3607.1	395.0	24.0	68.8	0.0	4094.9
2012	3560.6	61.1	0	3621.7	205.2	12.3	61.2	0.0	3900.5
2013	3901.1	89.9	0	3991.0	310.6	99.8	136.2	28.5	4566.0
2014	4530.0	8.6	0	4538.6	584.7	86.2	186.1	42.0	5437.6

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

Year	Trawl Survey		Retained Catch	Pot Bycatch		Trawl Bycatch		Tanner Fishery Bycatch	
	Males	Females		Males	Females	Males	Females	Males	Females
1968	3,684	2,165	18,044						
1969	6,144	4,992	22,812						
1970	1,546	1,216	3,394						
1971			10,340						
1972	1,106	767	15,046						
1973	1,783	1,888	11,848						
1974	2,505	1,800	27,067						
1975	2,943	2,139	29,570						
1976	4,724	2,956	26,450			2,327	676		
1977	3,636	4,178	32,596			14,014	689		
1978	4,132	3,948	27,529			8,983	1,456		
1979	5,807	4,663	27,900			7,228	2,821		
1980	2,412	1,387	34,747			47,463	39,689		
1981	3,478	4,097	18,029			42,172	49,634		
1982	2,063	2,051	11,466			84,240	47,229		
1983	1,524	944	0			204,464	104,910		
1984	2,679	1,942	4,404			357,981	147,134		
1985	792	415	4,582			169,767	30,693		
1986	1,962	367	5,773			1,199	284		
1987	1,168	1,018	4,230			723	927		
1988	1,834	546	9,833			437	275		
1989	1,257	550	32,858			3,147	194		
1990	858	603	7,218	873	699	761	1,570		
1991	1,378	491	36,820	1,801	375	208	396	885	2,198
1992	513	360	23,552	3,248	2,389	214	107	280	685
1993	1,009	534	32,777	5,803	5,942			232	265
1994	443	266	0	0	0	330	247		
1995	2,154	1,718	0	0	0	103	35		
1996	835	816	8,896	230	11	1,025	968		
1997	1,282	707	15,747	4,102	906	1,202	483		
1998	1,097	1,150	16,131	11,079	9,130	1,627	915		
1999	764	540	17,666	1,048	36	2,154	858		
2000	731	1,225	14,091	8,970	1,486	994	671		
2001	611	743	12,854	9,102	4,567	4,393	2,521		
2002	1,032	896	15,932	9,943	302	3,372	1,464		
2003	1,669	1,311	16,212	17,998	10,327	1,568	1,057		
2004	2,871	1,599	20,038	8,258	4,112	1,689	1,506		
2005	1,283	1,682	21,938	55,019	26,775	1,815	1,872		
2006	1,171	2,672	18,027	32,252	3,980	1,481	1,983		
2007	1,219	2,499	22,387	59,769	12,661	1,011	1,097		
2008	1,221	3,352	14,567	49,315	8,488	1,867	1,039		
2009	830	1,857	16,708	52,359	6,041	1,482	870		
2010	705	1,633	20,137	36,654	6,868	734	846		
2011	525	994	10,706	20,629	1,920	600	1,069		
2012	580	707	8,956	7,206	561	1,577	1,752		
2013	633	560	10,197	13,828	6,048	4,681	4,198	218	596
2014	1,106	1,255	9,618	13,040	1,950	1958	2580	256	381
2015	600	677							

Table 3. Annual retained catch (millions of crab) and catch per unit effort of the Bristol Bay red king crab fishery.

Year	Japanese Tanglenet		Russian Tanglenet		U.S. Pot/Trawl		Standardized Crab/tan
	Catch	Crab/tan	Catch	Crab/tan	Catch	Crab/Potlift	
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	

Table 4. Summary of statistics for the model (Scenarios 1 and 1a).

Parameter counts	**Scenario 1**	**Scenario 1a**
Fixed growth parameters	9	9
Fixed recruitment parameters	2	2
Fixed length-weight relationship parameters	6	6
Fixed mortality parameters	4	4
Fixed survey catchability parameter	1	1
Fixed high grading parameters	10	10
Total number of fixed parameters	32	32
Free survey catchability parameter	1	1
Free growth parameters	6	6
Initial abundance (1975)	1	1
Recruitment-distribution parameters	2	2
Mean recruitment parameters	1	1
Male recruitment deviations	40	40
Female recruitment deviations	40	40
Natural and fishing mortality parameters	4	4
Pot male fishing mortality deviations	42	42
Bycatch mortality from the Tanner crab fishery	10	10
Pot female bycatch fishing mortality deviations	27	27
Trawl bycatch fishing mortality deviations	41	41
Initial (1975) length compositions	35	35
Free selectivity parameters	22	22
Temperature deviation	0	42
Total number of free parameters	272	314
Total number of fixed and free parameters	304	346
Negative log likelihood components (see table 4)		
Length compositions---retained catch		
Length compositions---pot male discard		
Length compositions---pot female discard		
Length compositions---survey		
Length compositions---trawl discard		
Length compositions---Tanner crab discards		
Pot discard male biomass		
Retained catch biomass		
Pot discard female biomass		
Trawl discard		
Survey biomass		
Recruitment variation		
Others		
Total		

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

	Scenario					
Negative log likelihood	1	1a	1b	1 – 1a	1 - 1b	1a – 1b
R-variation	80.61	78.40	80.09	2.21	0.52	-1.69
Length-like-retained	-979.49	-979.04	-979.53	-0.45	0.04	0.49
Length-like-discmale	-998.27	-999.01	-998.23	0.74	-0.04	-0.78
Length-like-discfemale	-2334.30	-2336.26	-2333.88	1.96	-0.42	-2.38
Length-like-survey	-46200.10	-46198.50	-46200.40	-1.60	0.30	1.90
Length-like-disctrawl	-2027.93	-2027.24	-2027.70	-0.69	-0.23	0.46
Length-like-discTanner	-398.41	-397.76	-398.49	-0.65	0.08	0.74
Length-like-bsfrfsurvey	-237.78	-237.57	-237.86	-0.21	0.08	0.29
Catchbio_retained	47.31	47.22	47.44	0.10	-0.13	-0.23
Catchbio_discmale	219.50	219.35	219.57	0.15	-0.06	-0.22
Catchbio-discfemale	0.13	0.10	0.12	0.03	0.00	-0.02
Catchbio-disctrawl	0.90	0.90	0.90	0.00	0.00	0.00
Catchbio-discTanner	0.13	0.12	0.13	0.01	-0.01	-0.02
Biomass-trawl survey	95.08	27.81	94.44	67.27	0.64	-66.64
Biomass-bsfrfsurvey	-4.95	-5.40	-4.96	0.45	0.01	-0.44
Q-trawl survey	0.64	0.22	0.64	0.43	0.01	-0.42
Temperature deviation		24.70				
Others	20.82	20.86	20.70	-0.04	0.12	0.16
Total	-52716.10	-52761.10	-52717.00	45.00	0.90	-44.10
Free parameters	272	314	273	-42	-1	41

Table 5(1). Summary of model parameter estimates (scenario 1) for Bristol Bay red king crab. Estimated values and standard deviations. All values are on a log scale. Male recruit is exp(mean+males), and female recruit is exp(mean+males+females).

Year	Recruits				F for Directed Pot Fishery				F for Trawl	
	Females	SD	Males	SD	Males	SD	Females	SD	Estimate	SD
Mean	15.913	0.026	15.913	0.026	-2.011	0.043	0.011	0.001	-5.300	0.062
Limits↑	13,18		13,18		-4.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-15,2.43		-6.0,3.5		-10,10	
1975					1.118	0.099				
1976	0.157	0.246	0.734	0.142	1.126	0.071			0.175	0.107
1977	0.557	0.158	0.648	0.104	1.127	0.061			0.702	0.105
1978	0.486	0.134	0.865	0.085	1.339	0.056			0.698	0.104
1979	0.751	0.102	1.140	0.077	1.613	0.052			0.735	0.104
1980	0.278	0.115	1.333	0.077	2.413	0.049			0.777	0.105
1981	0.150	0.146	0.515	0.105	2.425	0.007			0.342	0.104
1982	-0.001	0.051	2.155	0.050	0.563	0.047			2.056	0.106
1983	-0.033	0.071	1.430	0.051	-	0.725			1.935	0.105
1984	0.431	0.060	1.394	0.053	0.938	0.057			2.900	0.103
1985	0.161	0.182	-0.663	0.123	1.032	0.064			1.840	0.105
1986	0.518	0.059	0.667	0.048	1.549	0.063			0.769	0.104
1987	-0.062	0.136	-0.215	0.075	1.154	0.059			0.453	0.104
1988	0.274	0.169	-0.906	0.108	0.211	0.051			1.429	0.102
1989	0.150	0.146	-0.750	0.089	0.315	0.047			0.025	0.102
1990	-0.081	0.068	0.382	0.046	0.919	0.044	2.046	0.101	0.318	0.102
1991	-0.130	0.096	-0.082	0.056	0.892	0.045	-0.097	0.101	0.652	0.103
1992	-0.355	0.346	-1.831	0.173	0.372	0.047	2.209	0.101	0.824	0.103
1993	-0.307	0.100	-0.306	0.056	1.015	0.049	2.115	0.102	1.081	0.103
1994	-0.078	0.376	-2.191	0.201	-4.126	0.048	1.482	0.129	-0.388	0.104
1995	-0.022	0.039	1.253	0.036	-4.457	0.045	1.594	0.133	0.249	0.103
1996	-0.637	0.234	-0.585	0.115	0.092	0.043	-3.674	0.150	-0.454	0.103
1997	-0.755	0.361	-1.447	0.171	0.202	0.043	-0.970	0.102	-0.836	0.103
1998	-0.319	0.122	-0.186	0.069	0.893	0.044	2.135	0.100	-0.112	0.102
1999	0.044	0.060	0.643	0.044	0.448	0.043	-2.003	0.105	0.107	0.102
2000	-0.114	0.143	-0.322	0.082	0.081	0.042	-0.233	0.100	-0.645	0.102
2001	0.718	0.182	-0.974	0.142	0.105	0.042	1.145	0.099	-0.194	0.102
2002	0.185	0.055	1.078	0.041	0.210	0.042	-2.184	0.106	-0.288	0.101
2003	0.077	0.229	-0.700	0.149	0.736	0.042	1.190	0.100	-0.223	0.101
2004	-0.184	0.150	0.061	0.083	0.599	0.042	0.417	0.099	-0.568	0.102
2005	0.317	0.061	0.978	0.047	1.022	0.043	0.950	0.100	-0.336	0.101
2006	-0.692	0.161	0.354	0.067	0.743	0.043	-1.492	0.101	-0.621	0.102
2007	-0.308	0.154	-0.199	0.085	1.073	0.044	-0.250	0.100	-0.501	0.102
2008	0.083	0.160	-0.673	0.105	1.169	0.047	-0.555	0.100	-0.364	0.102
2009	0.225	0.143	-0.678	0.100	0.879	0.049	-0.784	0.101	-0.804	0.104
2010	-0.074	0.103	-0.065	0.066	0.745	0.052	-0.250	0.101	-1.026	0.105
2011	-0.012	0.107	-0.091	0.071	0.075	0.053	-1.184	0.103	-1.226	0.106
2012	-0.253	0.147	-0.346	0.084	-0.025	0.056	-1.726	0.105	-1.348	0.107
2013	-0.758	0.192	-0.458	0.089	0.157	0.059	0.221	0.103	-0.539	0.107
2014	-0.204	0.376	-1.943	0.217	0.400	0.065	-0.100	0.104	-0.201	0.108
2015	-0.181	0.151	-0.015	0.104						

Table 5(1) (continued). Summary of model parameter estimates for Bristol Bay red king crab (scenario 1). Estimated values and standard deviations. 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	0.464	0.016	0.184, 1.0	68	1.159	0.103	-5, 5
Mf80-84	0.813	0.021	0.276, 1.5	73	1.178	0.090	-5, 5
Mf76-79,85-93	0.086	0.006	0.0, 0.108	78	0.512	0.108	-5, 5
log_betal, females	0.220	0.055	-0.67, 1.32	83	0.586	0.090	-5, 5
log_betal, males	0.646	0.082	-0.67, 1.32	88	0.396	0.089	-5, 5
log_betar, females	-0.620	0.062	-1.14, 0.5	93	0.205	0.094	-5, 5
log_betar, males	-0.620	0.050	-1.14, 0.5	98	0.211	0.093	-5, 5
Bsfrf_CV	0.069	0.071	0.00, 0.40	103	-0.001	0.105	-5, 5
moltp_slope, 75-78	0.132	0.021	0.01, 0.207	108	0.076	0.104	-5, 5
moltp_slope, 79-14	0.104	0.004	0.01, 0.207	113	0.207	0.101	-5, 5
log_moltp_L50, 75-78	4.968	0.013	4.47, 5.62	118	0.008	0.119	-5, 5
log_moltp_L50, 79-14	4.947	0.004	4.47, 5.62	123	0.051	0.124	-5, 5
log_N75	20.010	0.034	15.0, 21.0	128	-0.030	0.139	-5, 5
log_avg_L50_ret	4.920	0.002	4.78, 5.05	133	-0.041	0.148	-5, 5
ret_fish_slope	0.536	0.032	0.05, 0.70	138	-0.140	0.138	-5, 5
pot disc.males, φ	-0.345	0.015	-0.40, 0.00	143	-0.251	0.142	-5, 5
pot disc.males, κ	0.004	0.000	0.0, 0.005	148	-0.436	0.153	-5, 5
pot disc.males, γ	-0.016	0.001	-0.025, 0.0	153	-0.775	0.188	-5, 5
pot disc.fema., slope	0.454	0.216	0.05, 0.69	158	-1.304	0.260	-5, 5
log_pot disc.fema., L50	4.391	0.012	4.24, 4.61	163	-1.318	0.273	-5, 5
trawl disc slope	0.063	0.003	0.01, 0.20	68	1.614	0.105	-5, 5
log_trawl disc L50	4.939	0.028	4.40, 5.20	73	1.525	0.102	-5, 5
log_srv_L50, m, bsfrf	4.394	0.045	3.59, 5.49	78	1.498	0.094	-5, 5
srv_slope, f, bsfrf	0.012	0.005	0.01, 0.435	83	1.337	0.093	-5, 5
log_srv_L50, f, bsfrf	5.331	0.510	4.09, 5.54	88	1.291	0.086	-5, 5
log_srv_L50, m, 75-81	4.350	0.010	4.09, 5.54	93	0.830	0.102	-5, 5
srv_slope, f, 75-81	0.068	0.004	0.01, 0.33	98	0.453	0.124	-5, 5
log_srv_L50, f, 75-81	4.491	0.018	4.09, 4.70	103	0.156	0.148	-5, 5
log_srv_L50, m, 82-14	4.485	0.009	4.09, 5.10	108	0.007	0.152	-5, 5
srv_slope, f, 82-14	0.061	0.002	0.01, 0.30	113	-0.249	0.179	-5, 5
log_srv_L50, f, 82-14	4.513	0.011	4.09, 4.90	118	-0.825	0.278	-5, 5
TC_slope, females	0.365	0.135	0.02, 0.40	123	-0.942	0.318	-5, 5
log_TC_L50, females	4.535	0.015	4.24, 4.90	128	-1.218	0.411	-5, 5
TC_slope, males	0.231	0.093	0.05, 0.90	133	-2.139	0.899	-5, 5
log_TC_L50, males	4.585	0.022	4.25, 5.14	138	-2.150	0.990	-5, 5
Q	0.924	0.021	0.6, 1.2	143	NA	NA	
log_TC_F, males, 91	-4.177	0.087	-10.0, 1.00				
log_TC_F, males, 92	-6.146	0.088	-10.0, 1.00				
log_TC_F, males, 93	-6.877	0.091	-10.0, 1.00				
log_TC_F, males, 13	-8.245	0.099	-10.0, 1.00				
log_TC_F, males, 14	-7.390	0.098	-10.0, 1.00				
log_TC_F, females, 91	-2.920	0.086	-10.0, 1.00				
log_TC_F, females, 92	-4.569	0.086	-10.0, 1.00				
log_TC_F, females, 93	-6.457	0.087	-10.0, 1.00				
log_TC_F, females, 13	-7.680	0.085	-10.0, 1.00				
log_TC_F, females, 14	-7.529	0.085	-10.0, 1.00				

Table 5(1a). Summary of model parameter estimates (scenario 1a) for Bristol Bay red king crab. Estimated values and standard deviations (SD). All values are on a log scale. Male recruit is exp(mean+males), and female recruit is exp(mean+males+females).

	Recruits				F for Directed Pot Fishery				F for Trawl	
Year	Females	SD	Males	SD	Males	SD	Females	SD	Estimate	SD
Mean	15.916	0.027	15.916	0.027	-2.047	0.036	0.012	0.001	-5.342	0.061
Limits↑	13,18		13,18		-4.0,0.0		.001,0.1		-8.5,-1.0	
Limits↓	-15,15		-15,15		-15,2.43		-6.0,3.5		-10,10	
1975					1.184	0.102				
1976	0.083	0.244	0.721	0.136	1.177	0.072			0.226	0.108
1977	0.523	0.158	0.594	0.104	1.168	0.060			0.750	0.106
1978	0.461	0.134	0.801	0.087	1.373	0.054			0.745	0.105
1979	0.728	0.102	1.068	0.079	1.647	0.048			0.785	0.105
1980	0.249	0.115	1.254	0.079	2.425	0.014			0.827	0.105
1981	0.131	0.146	0.444	0.106	2.425	0.006			0.384	0.104
1982	0.010	0.051	2.115	0.051	0.571	0.047			2.081	0.106
1983	-0.025	0.071	1.417	0.052	-10.026	0.595			1.945	0.105
1984	0.445	0.060	1.398	0.055	0.923	0.057			2.892	0.104
1985	0.165	0.182	-0.628	0.123	1.000	0.065			1.819	0.105
1986	0.527	0.059	0.697	0.050	1.518	0.063			0.751	0.105
1987	-0.055	0.136	-0.182	0.076	1.124	0.059			0.433	0.104
1988	0.280	0.168	-0.873	0.109	0.188	0.050			1.409	0.103
1989	0.158	0.145	-0.720	0.090	0.296	0.047			0.008	0.103
1990	-0.074	0.068	0.416	0.048	0.893	0.043	2.038	0.101	0.302	0.103
1991	-0.125	0.096	-0.045	0.058	0.855	0.046	-0.094	0.101	0.629	0.104
1992	-0.344	0.348	-1.810	0.175	0.330	0.047	2.214	0.101	0.792	0.104
1993	-0.299	0.100	-0.277	0.058	0.965	0.049	2.126	0.101	1.046	0.103
1994	-0.077	0.378	-2.162	0.202	-4.174	0.049	1.492	0.129	-0.429	0.105
1995	-0.018	0.040	1.280	0.038	-4.490	0.045	1.592	0.133	0.219	0.103
1996	-0.645	0.238	-0.575	0.116	0.065	0.042	-3.677	0.150	-0.477	0.103
1997	-0.748	0.362	-1.431	0.172	0.174	0.042	-0.968	0.102	-0.858	0.103
1998	-0.314	0.123	-0.173	0.069	0.863	0.043	2.143	0.100	-0.133	0.102
1999	0.055	0.061	0.654	0.044	0.422	0.042	-2.000	0.105	0.087	0.102
2000	-0.109	0.144	-0.312	0.083	0.062	0.041	-0.234	0.100	-0.660	0.102
2001	0.723	0.183	-0.966	0.142	0.090	0.040	1.143	0.099	-0.205	0.102
2002	0.191	0.056	1.086	0.042	0.198	0.040	-2.186	0.106	-0.296	0.101
2003	0.072	0.229	-0.682	0.148	0.728	0.039	1.186	0.100	-0.227	0.101
2004	-0.182	0.150	0.069	0.083	0.592	0.040	0.420	0.099	-0.571	0.102
2005	0.318	0.062	0.992	0.047	1.013	0.041	0.950	0.100	-0.337	0.101
2006	-0.691	0.161	0.361	0.068	0.738	0.041	-1.494	0.101	-0.621	0.102
2007	-0.296	0.155	-0.200	0.087	1.069	0.042	-0.250	0.100	-0.498	0.102
2008	0.098	0.161	-0.680	0.107	1.161	0.046	-0.550	0.100	-0.361	0.103
2009	0.234	0.144	-0.684	0.102	0.873	0.050	-0.781	0.101	-0.801	0.104
2010	-0.067	0.103	-0.068	0.069	0.744	0.054	-0.250	0.101	-1.019	0.106
2011	-0.004	0.107	-0.098	0.074	0.079	0.057	-1.188	0.103	-1.217	0.107
2012	-0.251	0.148	-0.353	0.086	-0.016	0.059	-1.733	0.105	-1.336	0.109
2013	-0.753	0.192	-0.468	0.092	0.169	0.064	0.212	0.103	-0.524	0.109
2014	-0.199	0.376	-1.954	0.218	0.415	0.071	-0.110	0.105	-0.184	0.110
2015	-0.174	0.151	-0.027	0.107						

Table 5(1a) (continued). Summary of model parameter estimates for Bristol Bay red king crab (scenario 1a). Estimated values and standard deviations. 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 Comp. 1975			Temperature Deviation		
Parameter	Value	SD	Limits	Length	Value	SD	Year	Value	SD
Mm80-84	0.438	0.017	0.184, 1.00	68	1.154	0.101	1975	-0.186	0.127
Mf80-84	0.792	0.022	0.276, 1.50	73	1.181	0.088	1976	0.008	0.101
Mf76-79,85-93	0.085	0.006	0.0, 0.108	78	0.521	0.107	1977	0.291	0.104
log_betal, females	0.225	0.055	-0.67, 1.32	83	0.601	0.089	1978	0.281	0.100
log_betal, males	0.630	0.082	-0.67, 1.32	88	0.417	0.089	1979	-0.252	0.111
log_betar, females	-0.614	0.062	-1.14, 0.50	93	0.228	0.094	1980	0.047	0.139
log_betar, males	-0.624	0.050	-1.14, 0.50	98	0.236	0.093	1981	0.405	0.124
Bsfrf_CV	0.050	0.062	0.00, 0.40	103	0.025	0.105	1982	0.628	0.152
moltp_slope, 75-79	0.133	0.019	0.01, 0.168	108	0.102	0.103	1983	0.060	0.135
moltp_slope, 80-14	0.102	0.004	0.01, 0.168	113	0.234	0.101	1984	0.452	0.234
log_moltp_L50, 75-79	4.975	0.012	4.47, 5.52	118	0.034	0.119	1985	-0.154	0.108
log_moltp_L50, 80-14	4.942	0.004	4.47, 5.52	123	0.075	0.123	1986	-0.294	0.203
log_N75	19.967	0.035	15.0, 21.00	128	-0.007	0.138	1987	0.199	0.132
log_avg_L50_ret	4.920	0.002	4.78, 5.05	133	-0.020	0.147	1988	-0.099	0.140
ret_fish_slope	0.538	0.032	0.05, 0.70	138	-0.129	0.138	1989	-0.240	0.142
pot disc.males, φ	-0.350	0.015	-0.40, 0.00	143	-0.239	0.142	1990	-0.055	0.146
pot disc.males, κ	0.004	0.000	0.0, 0.005	148	-0.424	0.154	1991	0.142	0.208
pot disc.males, γ	-0.016	0.001	-0.025, 0.0	153	-0.763	0.189	1992	-0.367	0.115
pot disc.fema., slope	0.472	0.209	0.05, 0.69	158	-1.300	0.264	1993	0.029	0.127
log_pot disc.fema., L50	4.390	0.011	4.24, 4.61	163	-1.317	0.277	1994	-0.392	0.115
trawl disc slope	0.063	0.004	0.01, 0.20	68	1.574	0.106	1995	-0.372	0.157
log_trawl disc L50	4.936	0.028	4.40, 5.20	73	1.488	0.103	1996	-0.177	0.129
log_srv_L50, m, bsfrf	4.390	0.045	3.59, 5.49	78	1.464	0.095	1997	0.147	0.155
srv_slope, f, bsfrf	0.012	0.005	0.01, 0.435	83	1.308	0.094	1998	0.260	0.118
log_srv_L50, f, bsfrf	5.319	0.508	4.09, 5.54	88	1.266	0.086	1999	-0.210	0.129
log_srv_L50, m, 75-81	4.346	0.011	4.09, 5.54	93	0.810	0.102	2000	-0.073	0.137
srv_slope, f, 75-81	0.069	0.004	0.01, 0.33	98	0.435	0.126	2001	-0.227	0.120
log_srv_L50, f, 75-81	4.478	0.018	4.09, 4.70	103	0.139	0.149	2002	-0.069	0.127
log_srv_L50, m, 82-14	4.474	0.009	4.09, 5.10	108	-0.004	0.154	2003	0.335	0.163
srv_slope, f, 82-14	0.062	0.002	0.01, 0.30	113	-0.258	0.182	2004	0.344	0.176
log_srv_L50, f, 82-14	4.504	0.012	4.09, 4.90	118	-0.835	0.283	2005	0.241	0.113
TC_slope, females	0.364	0.135	0.02, 0.40	123	-0.950	0.324	2006	0.016	0.111
log_TC_L50, females	4.534	0.015	4.24, 4.90	128	-1.227	0.421	2007	0.013	0.132
TC_slope, males	0.238	0.098	0.05, 0.90	133	-2.158	0.930	2008	0.027	0.139
log_TC_L50, males	4.581	0.021	4.25, 5.14	138	-2.180	1.035	2009	-0.186	0.178
Q	0.912	0.021	0.6, 1.2	143	NA	NA	2010	-0.149	0.139
Beta, temperature	3.115	0.334			Limits	(-5,5)	2011	-0.204	0.134
log_TC_F, males, 91	-4.253	0.087	-10.0, 1.00				2012	-0.364	0.144
log_TC_F, males, 92	-6.222	0.088	-10.0, 1.00				2013	-0.265	0.149
log_TC_F, males, 93	-6.960	0.090	-10.0, 1.00				2014	0.407	0.126
log_TC_F, males, 13	-8.267	0.102	-10.0, 1.00				2015	0.004	0.135
log_TC_F, males, 14	-7.409	0.103	-10.0, 1.00						
log_TC_F, females, 91	-2.976	0.086	-10.0, 1.00						
log_TC_F, females, 92	-4.625	0.086	-10.0, 1.00						
log_TC_F, females, 93	-6.515	0.088	-10.0, 1.00						
log_TC_F, females, 13	-7.698	0.087	-10.0, 1.00						
log_TC_F, females, 14	-7.545	0.087	-10.0, 1.00						

Table 6(1). Annual abundance estimates (millions of crab), mature male biomass (MMB, 1000 t), and total survey biomass (1000 t) for red king crab in Bristol Bay estimated by length-based analysis (scenario 1) from 1975-2015. Mature male biomass for year *t* is on Feb. 15 of year *t*+1. Size measurements are mm carapace length.

Year (t)	Males				Females	Total Recruits	Trawl Survey Biomass	
	Mature (>119 mm)	Legal (>134 mm)	MMB (>119 mm)	SD MMB	Mature (>89 mm)		Model Est. (>64 mm)	Area-Swept
1975	56.544	29.673	83.547	5.406	75.729		247.095	202.731
1976	61.901	35.966	92.900	4.584	114.592	36.805	283.885	331.868
1977	63.401	38.539	95.840	3.842	143.620	42.747	294.188	375.661
1978	69.567	39.527	98.692	3.186	137.306	50.808	286.326	349.545
1979	65.614	41.036	84.270	2.677	119.716	79.437	264.621	167.627
1980	47.110	33.884	25.260	1.023	109.495	71.679	229.457	249.322
1981	14.771	8.599	8.632	0.485	50.436	29.466	94.758	132.669
1982	7.541	3.226	8.428	0.440	23.387	140.497	53.145	143.740
1983	6.735	3.137	8.810	0.420	14.746	66.968	45.803	49.320
1984	6.364	3.132	6.683	0.393	15.005	83.319	45.765	155.311
1985	7.747	2.596	10.990	0.585	13.772	9.131	37.790	34.535
1986	12.695	5.000	16.291	0.890	20.294	42.510	50.347	48.158
1987	16.172	7.219	23.021	1.086	24.063	12.748	57.376	70.263
1988	16.958	9.650	29.036	1.189	28.945	7.621	61.640	55.372
1989	18.397	11.484	32.738	1.247	26.581	8.320	64.853	55.941
1990	18.578	12.497	30.622	1.272	22.848	22.938	64.938	60.321
1991	15.147	11.242	25.642	1.251	20.769	14.102	59.235	85.055
1992	12.033	9.092	23.437	1.198	20.474	2.221	53.258	37.687
1993	12.598	8.244	20.866	1.172	18.297	10.416	51.387	53.703
1994	12.415	7.627	26.346	1.199	15.104	1.753	45.657	32.335
1995	12.831	9.437	29.032	1.165	14.647	56.436	51.986	38.396
1996	12.794	10.023	26.898	1.106	19.854	6.935	59.340	44.649
1997	12.007	9.042	24.935	1.055	28.763	2.818	63.795	85.277
1998	16.330	8.723	27.240	1.143	26.882	11.684	67.090	85.176
1999	17.979	10.345	31.814	1.255	23.504	31.692	66.745	65.604
2000	15.984	11.749	31.595	1.241	25.774	11.168	68.720	68.342
2001	14.871	11.213	30.284	1.189	29.796	9.377	71.145	53.188
2002	16.450	10.671	31.996	1.181	29.457	52.744	75.427	69.786
2003	17.106	11.432	30.504	1.164	34.791	8.414	80.008	116.794
2004	15.211	10.815	28.211	1.118	42.019	15.858	81.627	131.910
2005	17.453	10.204	28.279	1.138	40.259	51.420	86.391	107.341
2006	17.620	10.680	30.051	1.195	43.965	17.406	89.175	95.676
2007	16.962	11.166	27.100	1.218	50.850	11.589	93.930	104.841
2008	18.413	10.298	27.958	1.361	47.706	8.672	93.514	114.430
2009	19.423	10.970	31.366	1.570	43.245	9.313	90.277	91.673
2010	18.309	12.053	31.296	1.696	39.509	14.725	86.919	81.642
2011	15.696	11.583	31.198	1.732	37.101	14.782	82.479	67.053
2012	14.194	11.034	29.788	1.721	36.059	10.239	80.813	61.248
2013	13.832	10.226	28.453	1.744	34.694	7.565	78.898	62.410
2014	13.935	9.753	27.254	1.815	31.776	2.120	75.332	114.103
2015	13.417	9.425	24.691	1.502	27.947	14.718	70.766	64.240

Table 6(1a). Annual abundance estimates (million crab), mature male biomass (MMB, 1000 t), and total survey biomass (1000t) for red king crab in Bristol Bay estimated by length-based analysis (scenario 1a) from 1975-2015. Mature male biomass for year *t* is on Feb. 15, year *t*+1. Size measurements are mm carapace length.

Year (t)	Males				Females	Total Recruits	Total Survey Biomass	
	Mature (>119 mm)	Legal (>134mm)	MMB (>119 mm)	SD MMB	Mature (>89 mm)		Model Est. (>64 mm)	Area-Swept (>64 mm)
1975	55.546	28.972	81.338	5.079	72.112		198.950	202.731
1976	60.860	35.415	91.029	4.326	108.445	35.040	276.719	331.868
1977	62.265	38.024	94.246	3.648	135.225	39.760	379.414	375.661
1978	68.099	38.998	96.975	3.058	129.049	47.051	364.798	349.545
1979	63.964	40.418	82.400	2.586	112.356	73.009	197.014	167.627
1980	45.585	33.186	25.183	1.007	102.471	65.319	228.809	249.322
1981	14.506	8.505	8.816	0.448	47.985	27.245	136.577	132.669
1982	7.553	3.265	8.652	0.415	22.598	136.133	97.839	143.740
1983	6.845	3.205	9.140	0.417	14.569	66.588	48.812	49.320
1984	6.558	3.245	7.096	0.413	15.222	84.631	73.699	155.311
1985	8.132	2.745	11.674	0.620	14.346	9.503	33.950	34.535
1986	13.310	5.248	17.379	0.942	21.179	44.185	39.207	48.158
1987	16.999	7.607	24.538	1.167	25.160	13.256	73.233	70.263
1988	17.867	10.178	30.812	1.290	30.279	7.928	58.403	55.372
1989	19.360	12.096	34.695	1.362	27.843	8.638	53.267	55.941
1990	19.556	13.167	32.699	1.394	23.967	23.889	64.179	60.321
1991	16.070	11.937	27.726	1.371	21.837	14.698	71.705	85.055
1992	12.893	9.781	25.449	1.311	21.562	2.285	38.988	37.687
1993	13.463	8.899	22.860	1.279	19.294	10.786	55.930	53.703
1994	13.296	8.266	28.401	1.302	15.957	1.811	32.753	32.335
1995	13.663	10.079	31.021	1.259	15.441	58.224	37.761	38.396
1996	13.562	10.643	28.762	1.190	20.791	7.008	52.112	44.649
1997	12.715	9.624	26.674	1.128	29.923	2.879	77.269	85.277
1998	17.131	9.265	29.057	1.210	27.924	11.890	90.702	85.176
1999	18.820	10.901	33.705	1.315	24.417	32.320	56.295	65.604
2000	16.760	12.323	33.391	1.291	26.689	11.347	66.283	68.342
2001	15.568	11.776	31.938	1.230	30.754	9.512	58.628	53.188
2002	17.102	11.189	33.545	1.215	30.352	53.508	72.584	69.786
2003	17.711	11.895	31.923	1.192	35.725	8.572	114.945	116.794
2004	15.750	11.232	29.492	1.142	43.016	16.046	118.108	131.910
2005	17.975	10.586	29.487	1.166	41.181	52.282	112.519	107.341
2006	18.126	11.029	31.206	1.230	44.920	17.584	92.682	95.676
2007	17.451	11.498	28.203	1.261	51.864	11.666	97.171	104.841
2008	18.935	10.631	29.099	1.432	48.632	8.704	97.976	114.430
2009	19.963	11.310	32.533	1.681	44.062	9.336	76.337	91.673
2010	18.812	12.393	32.401	1.842	40.226	14.765	76.156	81.642
2011	16.132	11.914	32.177	1.902	37.730	14.781	68.254	67.053
2012	14.554	11.334	30.622	1.910	36.613	10.200	56.890	61.248
2013	14.123	10.480	29.144	1.955	35.168	7.526	61.142	62.410
2014	14.160	9.950	27.803	2.053	32.167	2.106	114.123	114.103
2015	13.587	9.566	25.019	1.712	28.270	14.635	71.416	64.240

Table 7(1). Comparison of projected mature male biomass (1000 t) on Feb. 15, retained catch (1000 t), their 95% limits, and mean fishing mortality with no directed fishery, $F_{40\%}$, and $F_{35\%}$ harvest strategy with $F_{35\%}$ constraint during 2015-2024. Parameter estimates with scenario 1 are used for the projection.

			No Directed Fishery			
Year	MMB	95% LCI	95% UCI	Catch	95% LCI	95% UCI
2015	30.724	27.489	33.779	0.000	0.000	0.000
2016	33.018	29.541	36.301	0.000	0.000	0.000
2017	33.484	29.957	36.813	0.000	0.000	0.000
2018	34.705	31.111	38.305	0.000	0.000	0.000
2019	38.166	32.836	48.627	0.000	0.000	0.000
2020	42.649	33.256	61.471	0.000	0.000	0.000
2021	47.243	32.996	73.521	0.000	0.000	0.000
2022	51.505	33.146	83.714	0.000	0.000	0.000
2023	55.307	33.345	89.071	0.000	0.000	0.000
2024	58.542	34.355	93.149	0.000	0.000	0.000
			$F_{40\%}$			
2015	25.529	23.229	27.896	5.172	4.241	5.857
2016	23.707	21.842	25.554	4.531	3.783	5.333
2017	21.351	19.838	22.808	3.768	3.209	4.342
2018	20.602	19.202	22.039	3.298	2.850	3.776
2019	22.186	18.845	30.387	3.397	2.745	4.437
2020	24.524	17.955	39.313	3.825	2.518	5.972
2021	26.621	17.322	46.211	4.383	2.297	7.665
2022	28.171	17.079	49.689	4.874	2.206	8.999
2023	29.235	16.998	50.926	5.233	2.154	9.776
2024	29.866	17.177	50.513	5.469	2.210	10.025
			$F_{35\%}$			
2015	24.725	22.587	26.828	5.972	4.880	6.920
2016	22.554	20.869	24.159	4.936	4.159	5.731
2017	20.083	18.738	21.340	3.987	3.426	4.542
2018	19.315	18.059	20.639	3.442	2.999	3.902
2019	20.835	17.680	28.639	3.575	2.856	4.912
2020	23.009	16.765	36.907	4.088	2.611	6.659
2021	24.861	16.188	43.158	4.725	2.375	8.538
2022	26.148	16.010	45.651	5.247	2.279	9.998
2023	26.972	15.912	46.628	5.606	2.237	10.574
2024	27.409	16.092	45.946	5.820	2.294	10.781

Table 7(1a). 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 2015-2024. Parameter estimates with scenario 1a are used for the projection.

Year	MMB	95% LCI	95% UCI	Catch	95% LCI	95% UCI
No Directed Fishery						
2015	31.144	27.449	34.633	0.000	0.000	0.000
2016	33.310	29.358	37.042	0.000	0.000	0.000
2017	33.667	29.673	37.440	0.000	0.000	0.000
2018	34.795	30.738	38.880	0.000	0.000	0.000
2019	38.225	32.479	48.850	0.000	0.000	0.000
2020	42.739	33.120	61.812	0.000	0.000	0.000
2021	47.386	32.948	73.669	0.000	0.000	0.000
2022	51.708	33.164	83.504	0.000	0.000	0.000
2023	55.573	33.515	89.813	0.000	0.000	0.000
2024	58.866	34.452	93.604	0.000	0.000	0.000
$F_{40\%}$						
2015	25.878	23.247	28.584	5.240	4.182	6.018
2016	23.925	21.798	26.025	4.545	3.701	5.455
2017	21.490	19.768	23.142	3.752	3.125	4.399
2018	20.688	19.130	22.288	3.268	2.767	3.802
2019	22.270	18.829	30.468	3.365	2.684	4.436
2020	24.653	18.017	39.290	3.798	2.468	5.956
2021	26.799	17.474	46.388	4.367	2.254	7.654
2022	28.391	17.146	50.203	4.868	2.188	9.060
2023	29.489	17.147	51.148	5.237	2.140	9.789
2024	30.140	17.353	50.856	5.481	2.220	9.962
$F_{35\%}$						
2015	25.060	22.611	27.486	6.053	4.814	7.111
2016	22.759	20.837	24.598	4.950	4.073	5.860
2017	20.214	18.682	21.646	3.969	3.339	4.597
2018	19.395	17.990	20.815	3.410	2.915	3.925
2019	20.917	17.639	28.652	3.541	2.799	4.926
2020	23.138	16.825	36.821	4.059	2.569	6.628
2021	25.038	16.335	43.423	4.707	2.348	8.488
2022	26.366	16.083	45.953	5.240	2.260	9.965
2023	27.220	16.051	46.908	5.609	2.223	10.631
2024	27.676	16.302	46.266	5.832	2.293	10.830

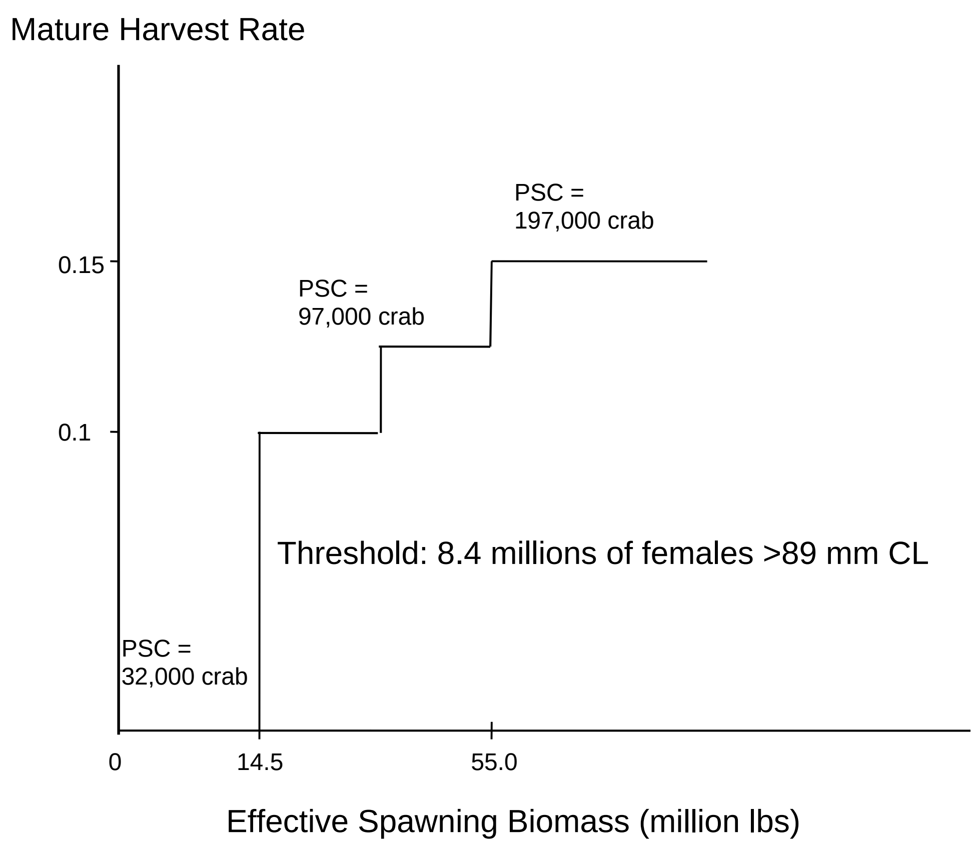

Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crab) of Bristol Bay red king crab in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates of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

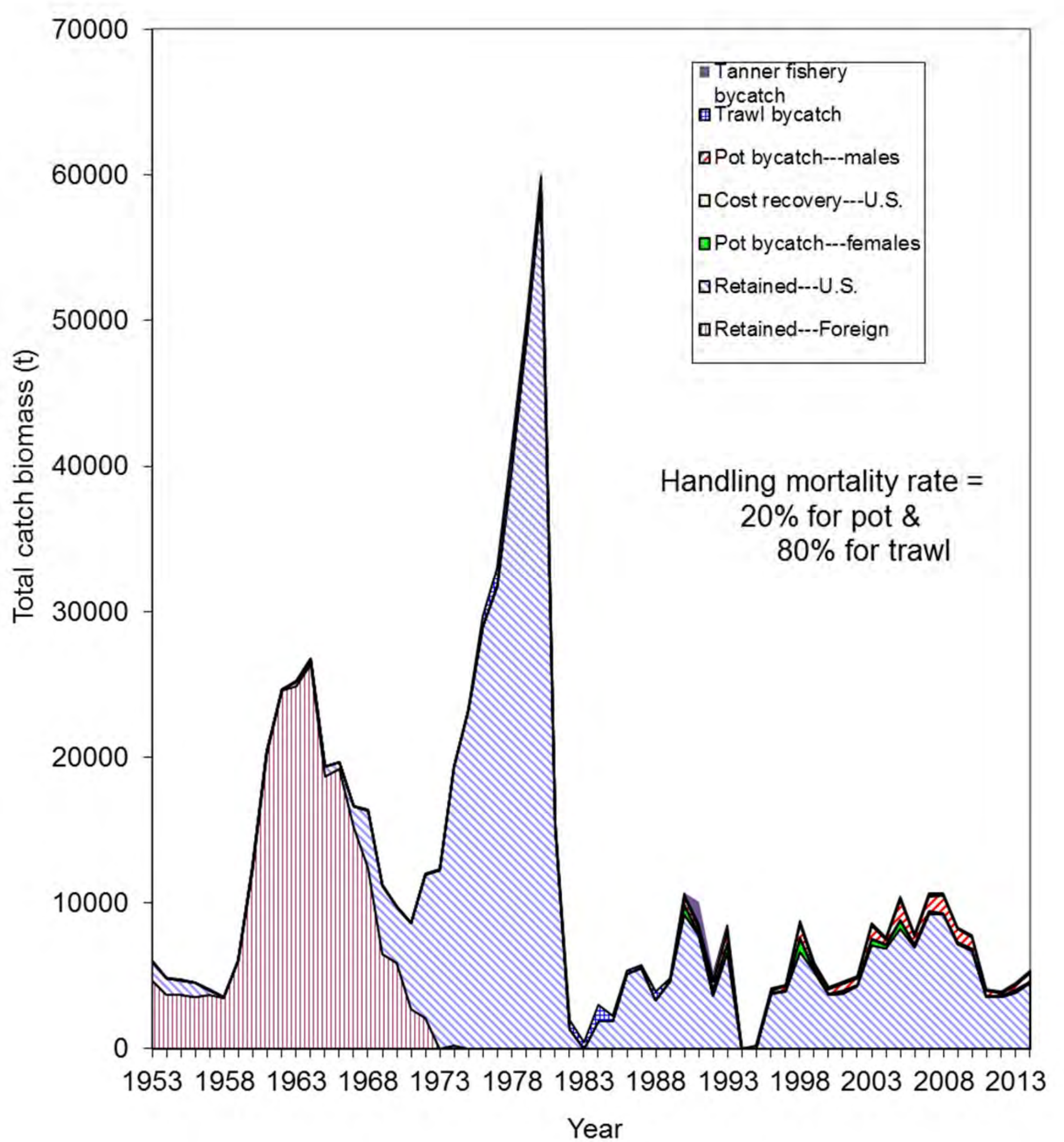

Figure 2. Retained catch biomass and bycatch mortality biomass (t) for Bristol Bay red king crab from 1953 to 2014. Handling mortality rates were assumed to be 0.2 for the directed pot fishery 0.25 for the Tanner crab fishery and 0.8 for the trawl fisheries.

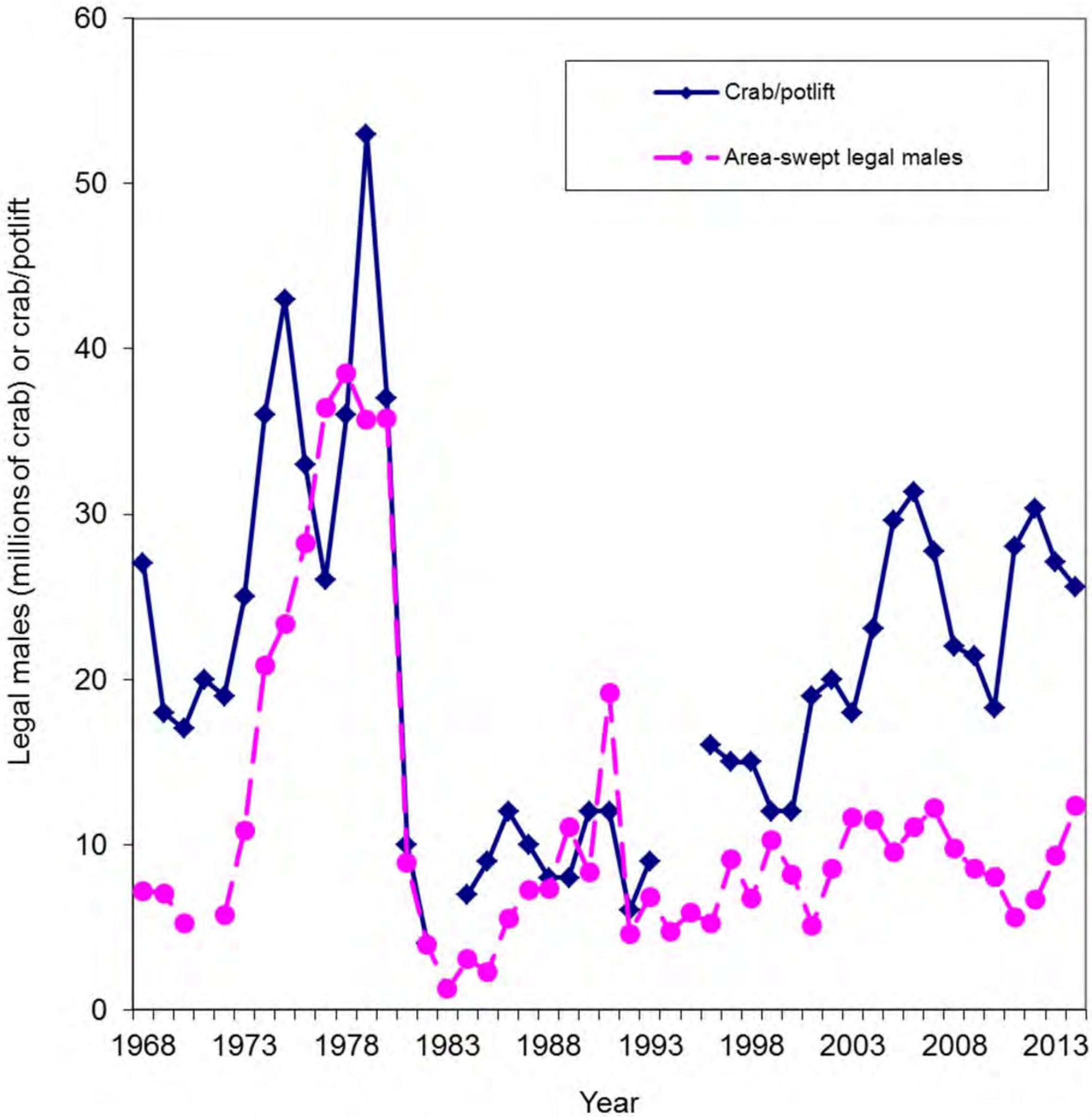

Figure 3. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2014.

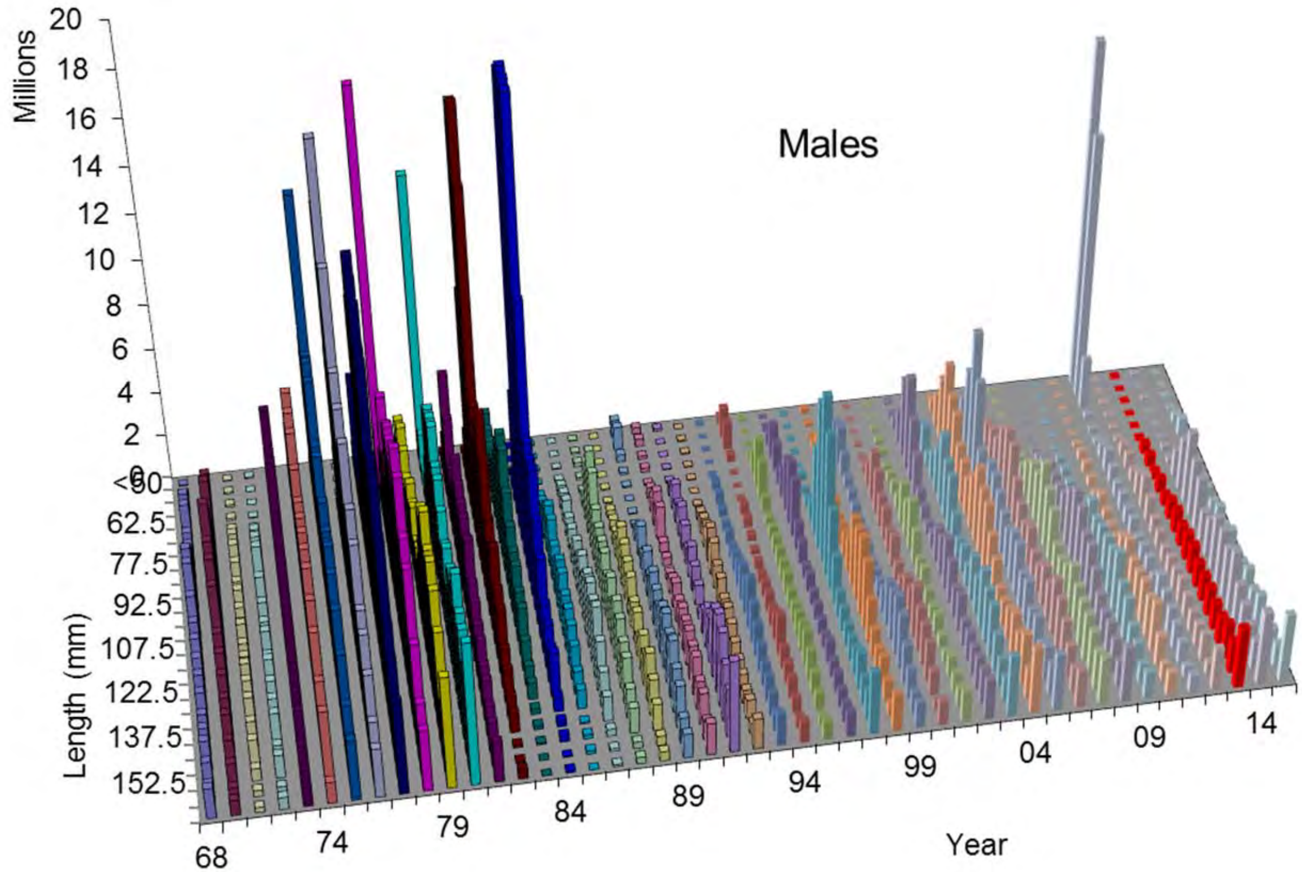

Figure 4. Survey abundances by 5-mm carapace length bin for male Bristol Bay red king crab from 1968 to 2015.

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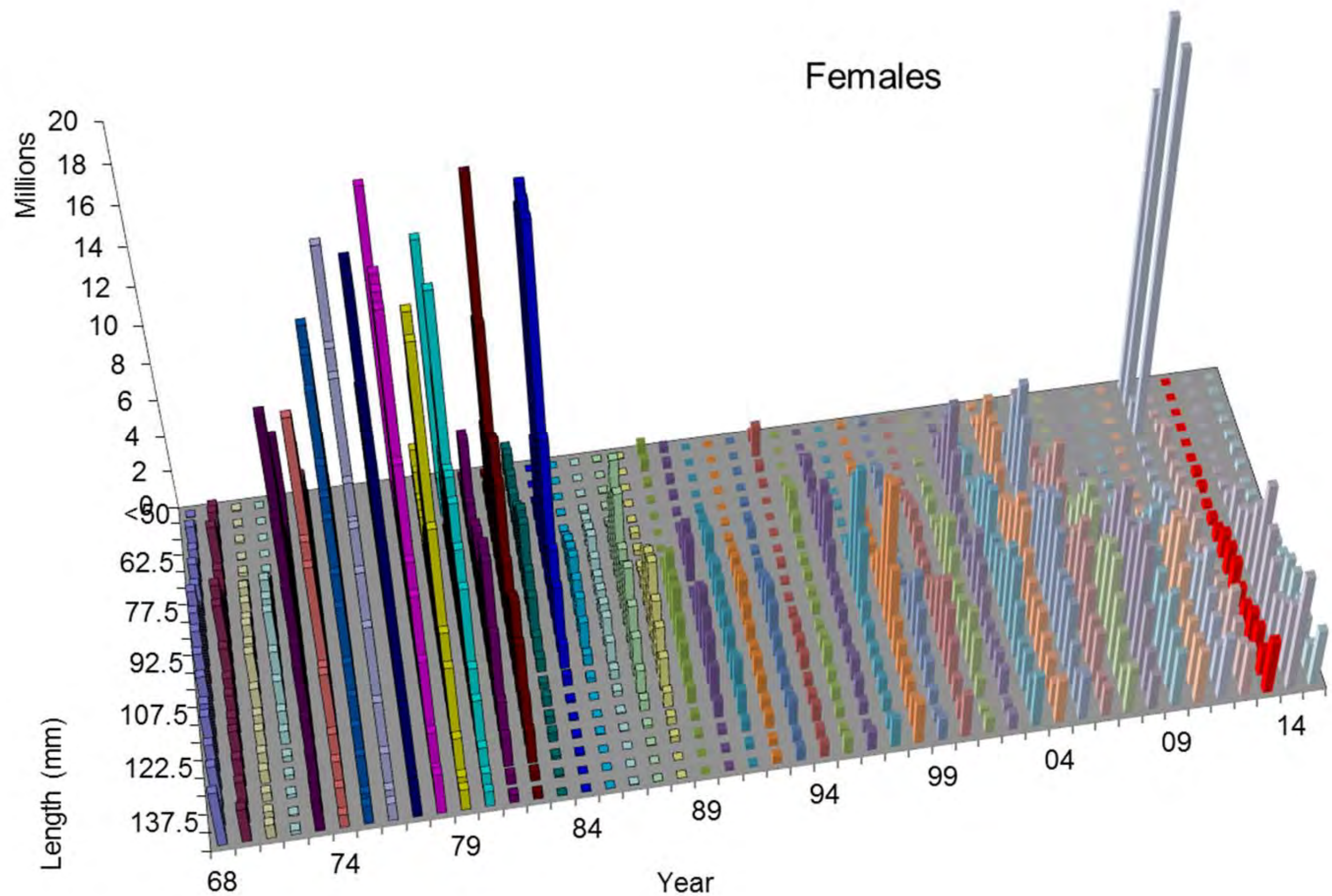
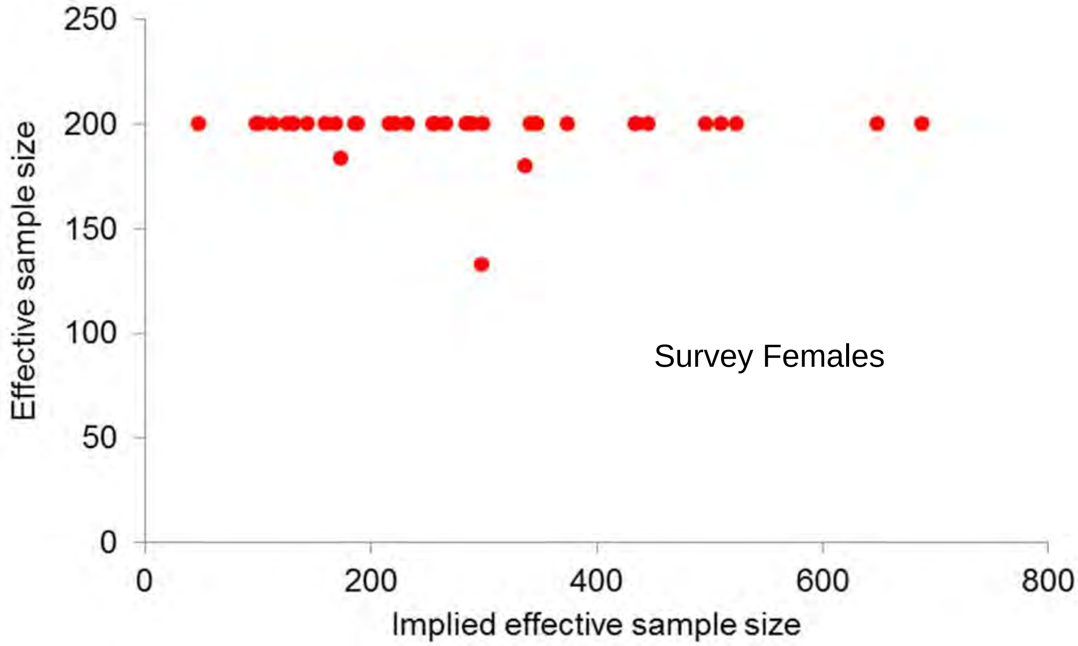


Figure 5. Survey abundances by 5 mm carapace length bin for female Bristol Bay red king crab from 1968 to 2015.



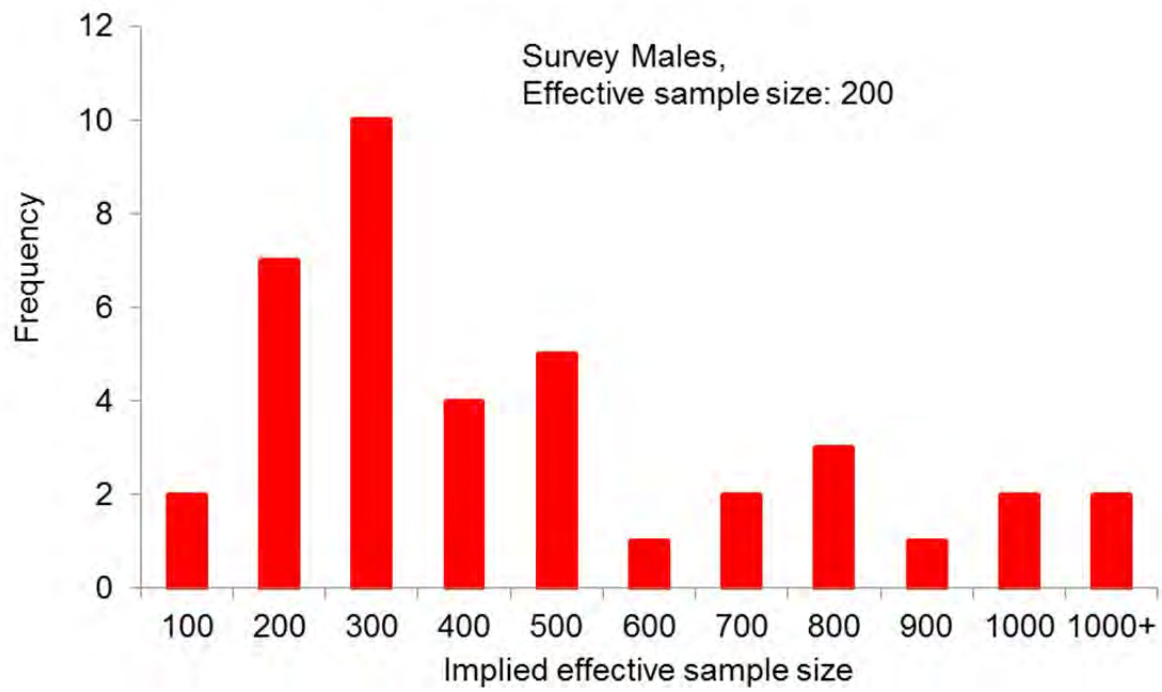


Figure 6. Relationship between implied effective sample sizes (section 3(a)(5)(i)) and effective sample sizes (see effective sample sizes for scenario 1) for length/sex composition data with scenario 1: trawl survey data.

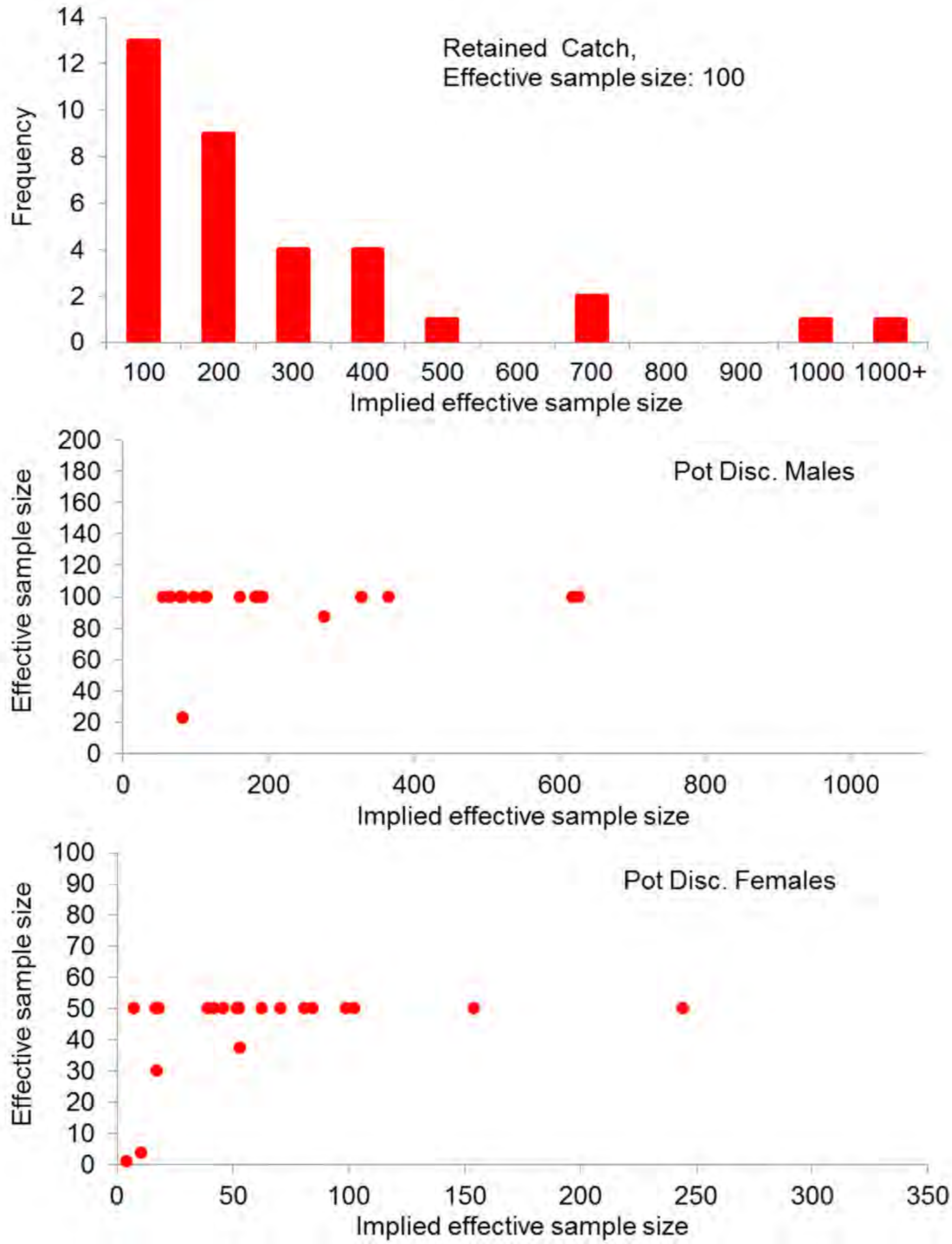


Figure 7. Relationship between implied effective sample sizes (section 3(a)(5)(i)) and effective sample sizes (see effective sample sizes for scenario 1) for length/sex composition data with scenario 1: directed pot fishery data.

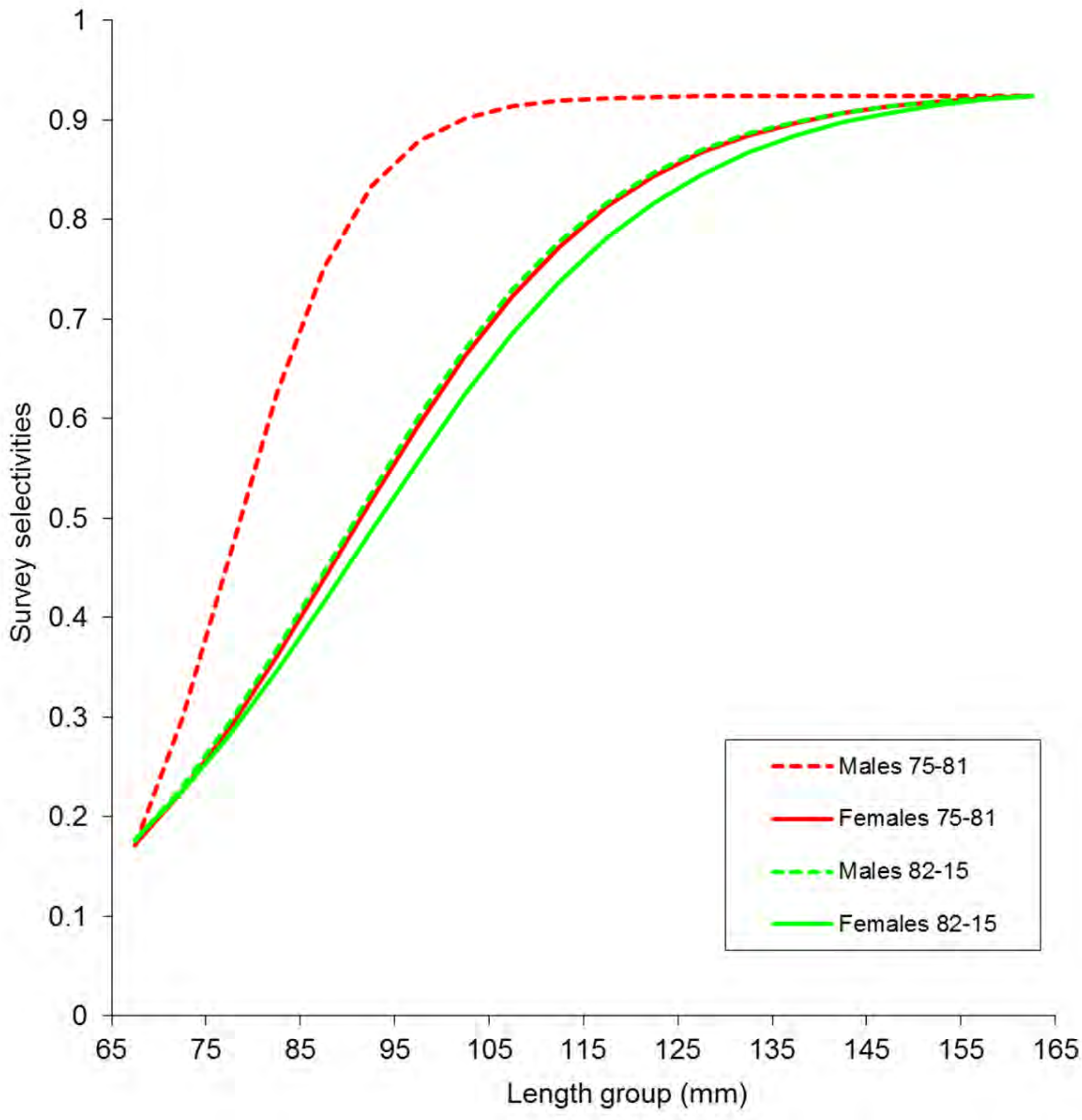


Figure 8a(1). Estimated trawl survey selectivities/catchability under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

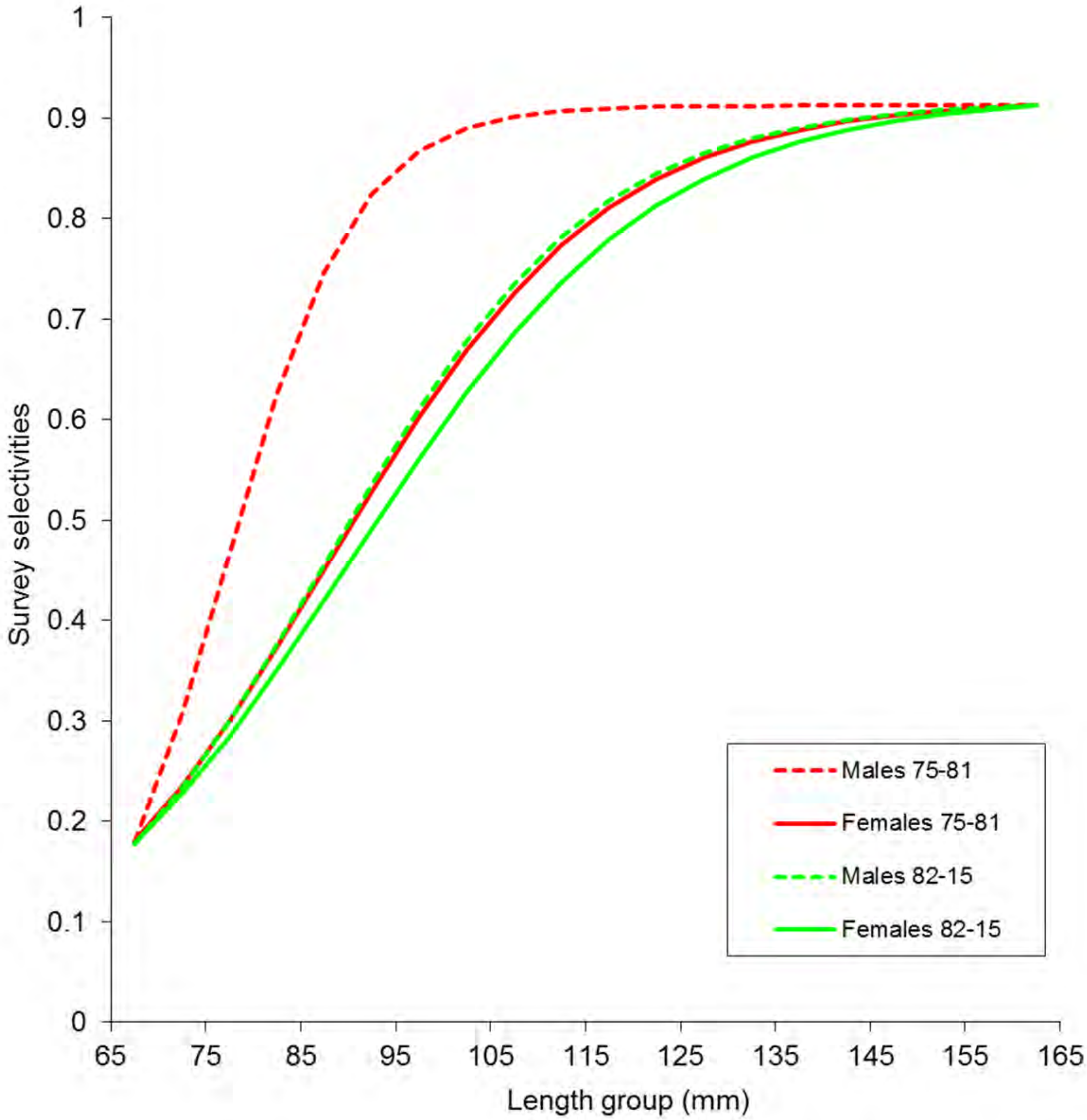
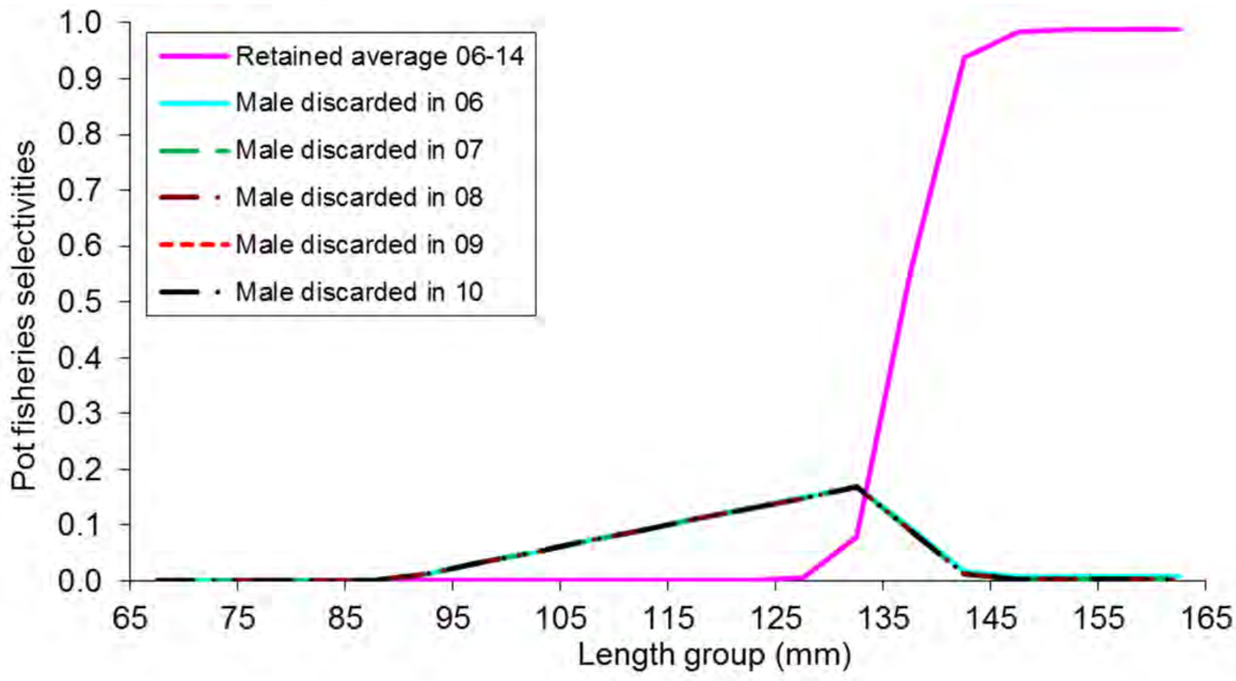


Figure 8a(1a). Estimated trawl survey selectivities/catchability under scenario 1a. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.



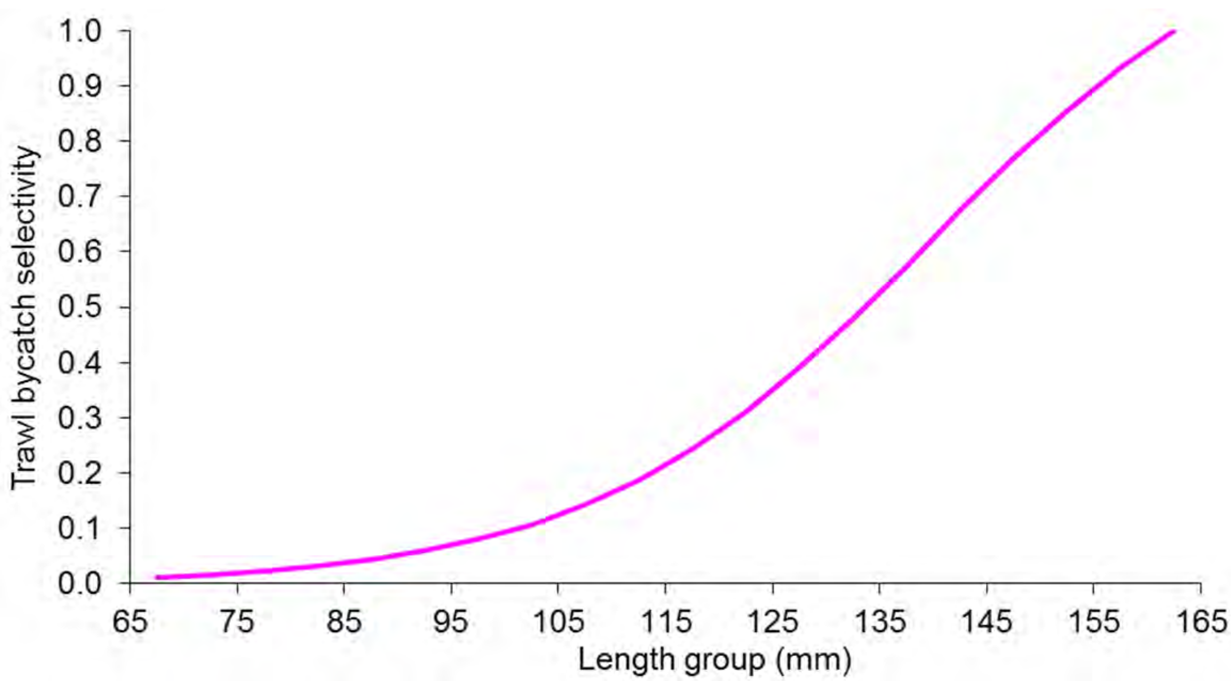


Figure 8b. Estimated pot fishery selectivities and groundfish trawl bycatch selectivities under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

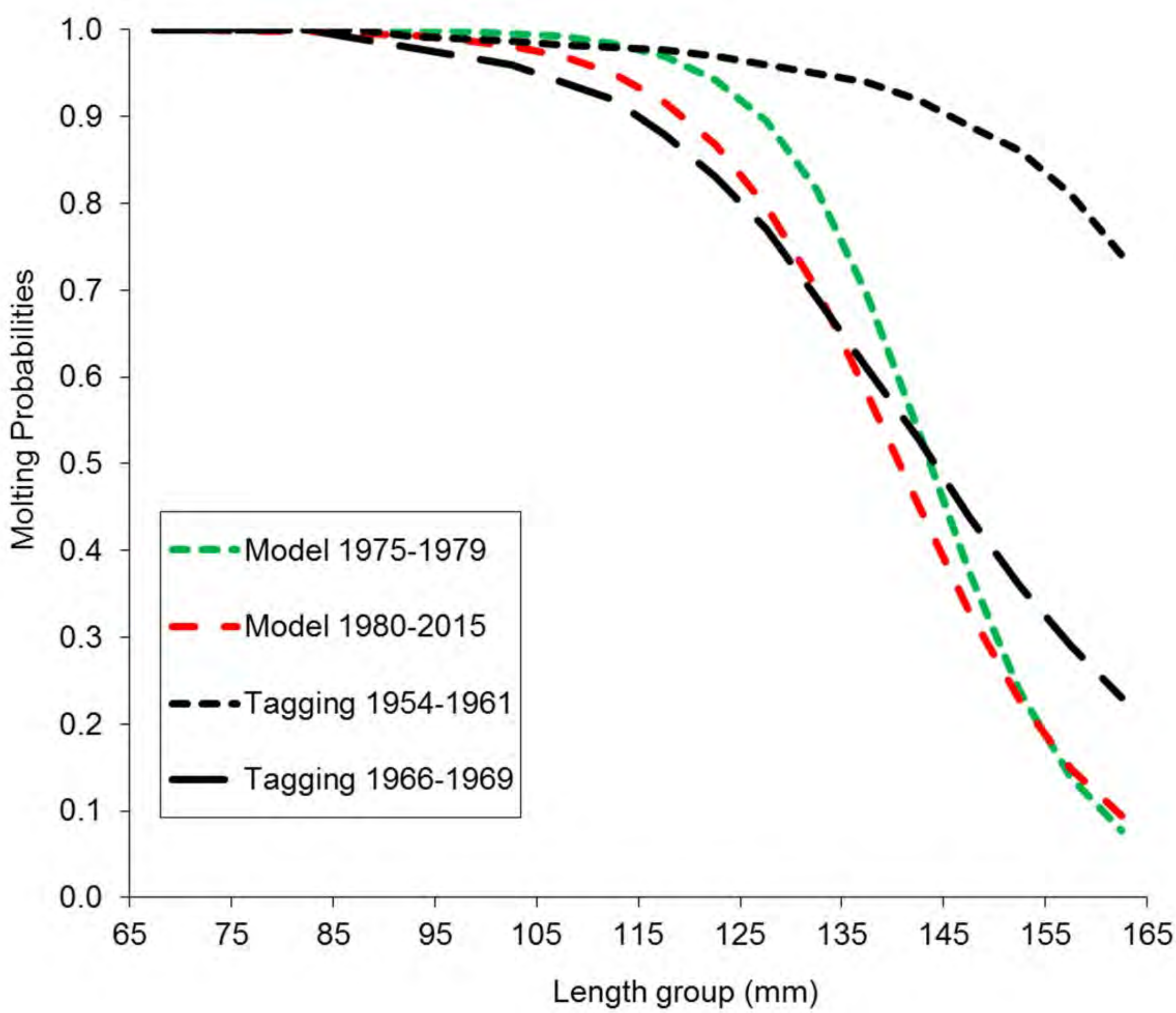


Figure 9(1). Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-2015 were estimated with a length-based model with a pot handling mortality rate of 0.2 under scenario 1.

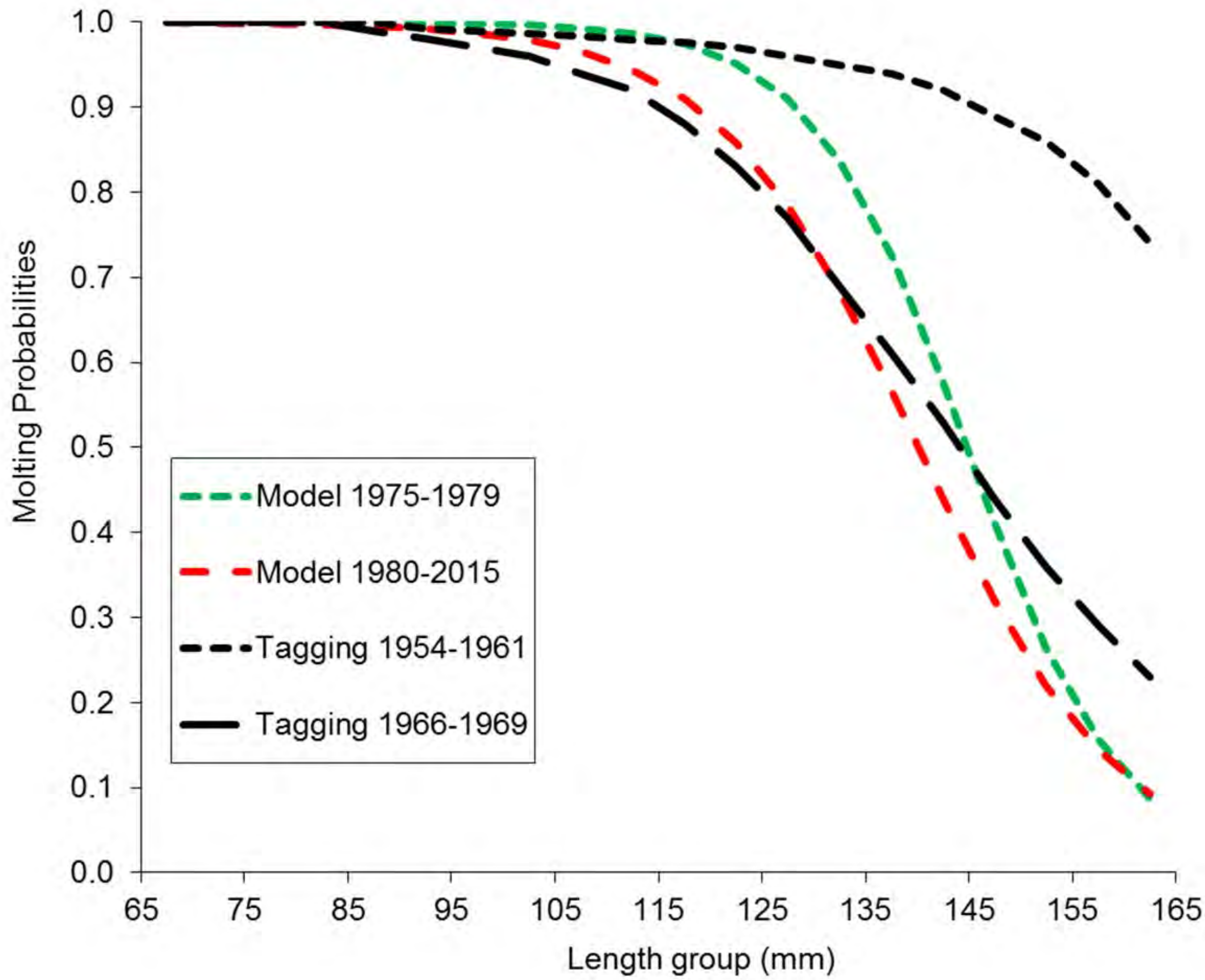


Figure 9(1a). Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-2015 were estimated with a length-based model with pot handling mortality rate of 0.2 under scenario 1a.

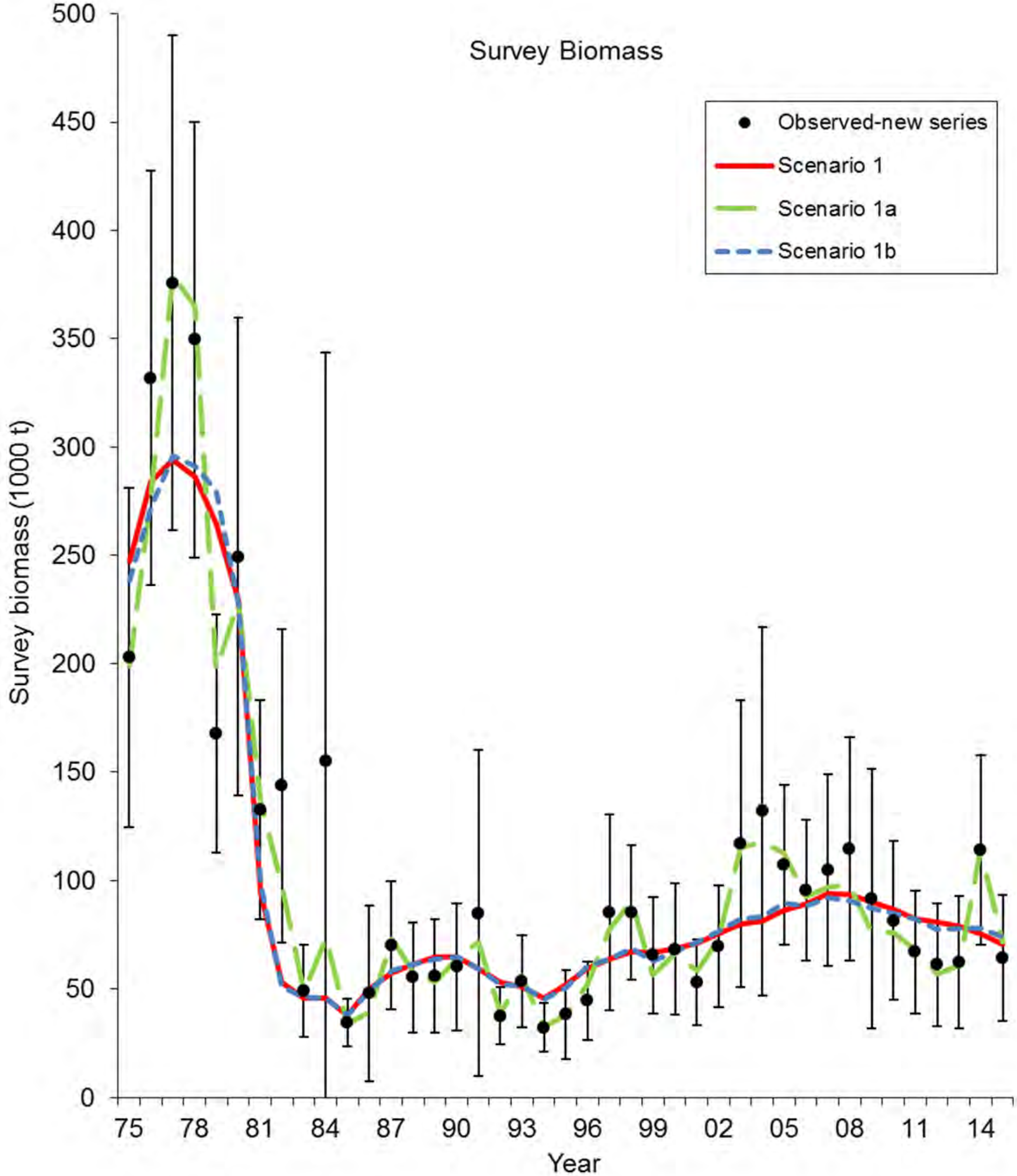


Figure 10a(1, 1a & 1b). Comparisons of area-swept estimates of total survey biomass and model prediction for model estimates in 2015 under scenarios 1, 1a and 1b. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively. The error bars are plus and minus 2 standard deviations.

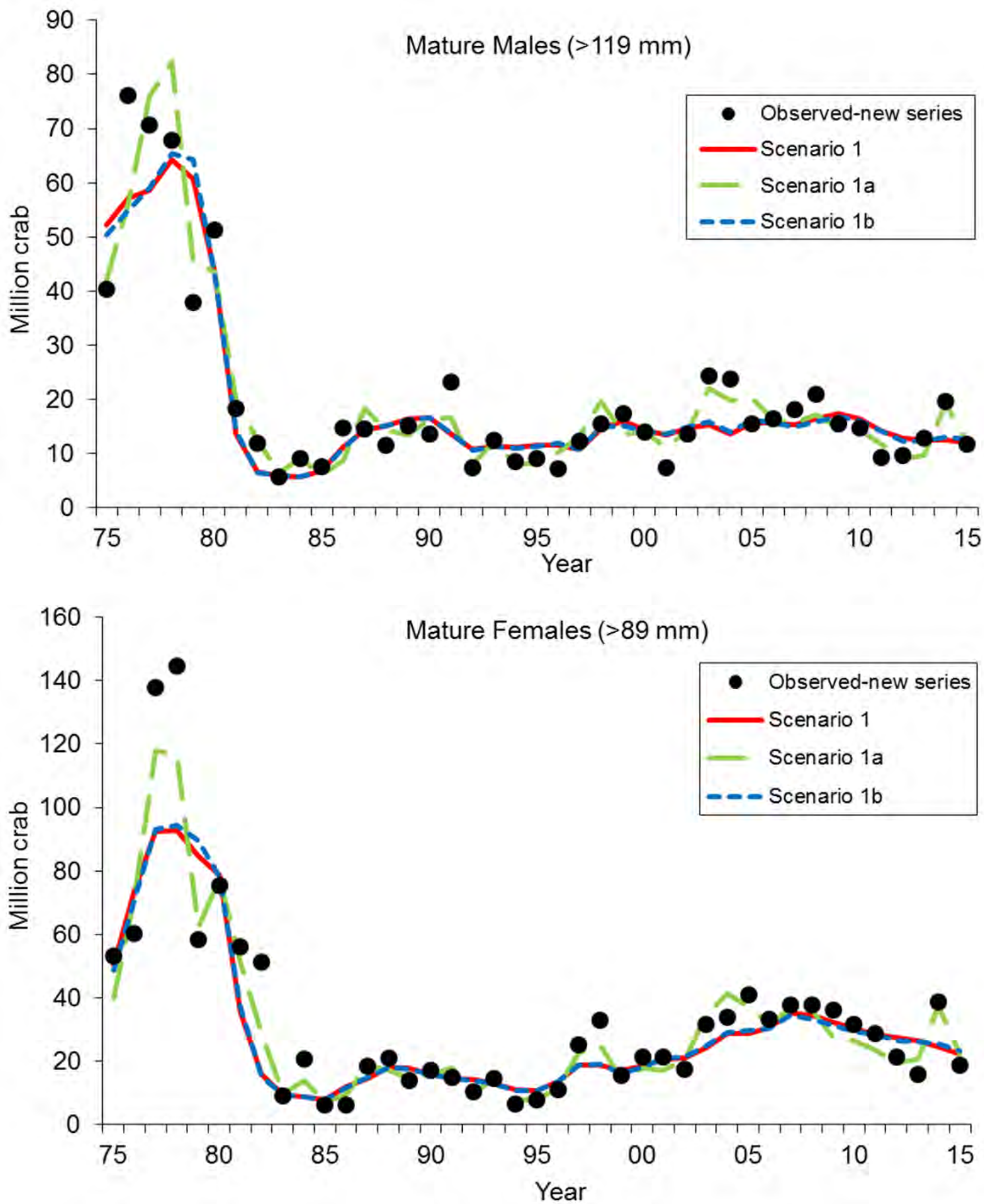


Figure 10b(1, 1a & 1b). Comparisons of area-swept estimates of male (>119 mm) and female (>89 mm) abundance and model prediction for model estimates in 2014 under scenarios 1, 1a and 1b. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

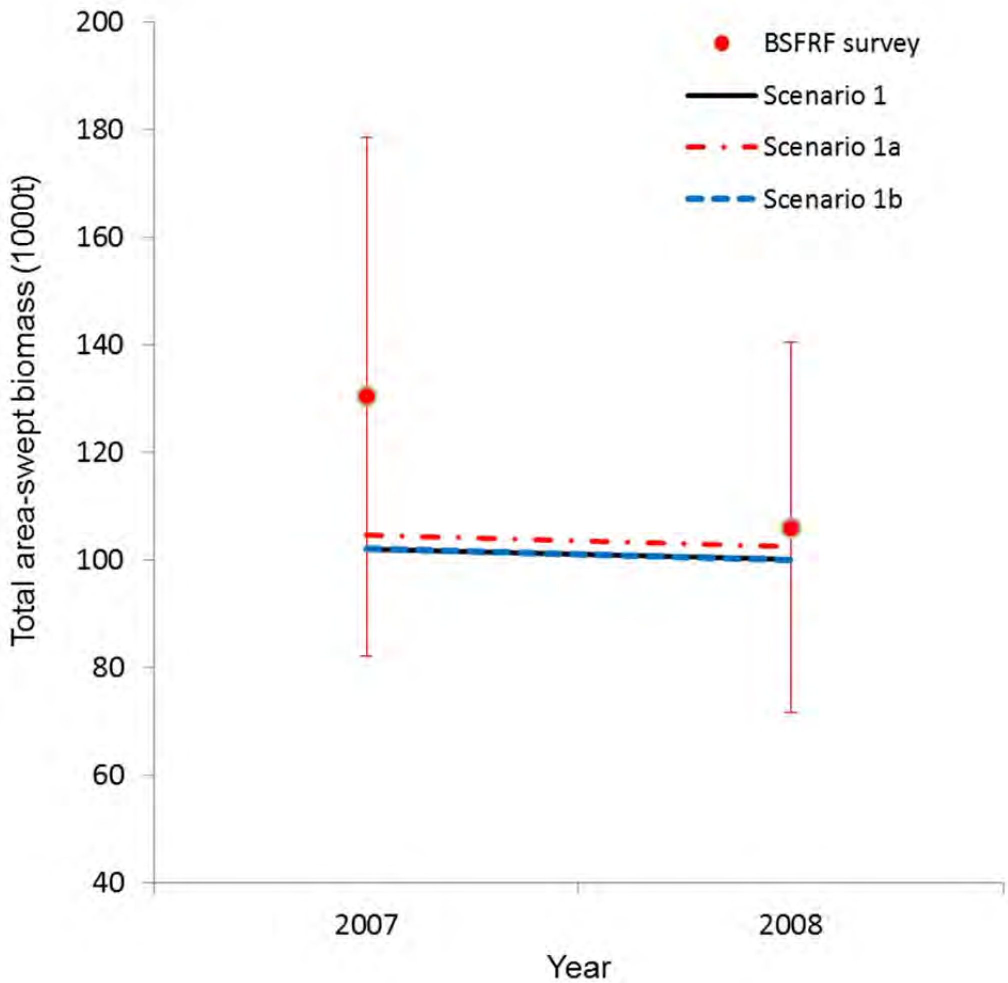


Figure 10c. Comparisons of total survey biomass estimates by the BSFRF survey and the model for model estimates in 2015 (scenarios 1, 1a & 1b). The error bars are plus and minus 2 standard deviations of scenario 1.

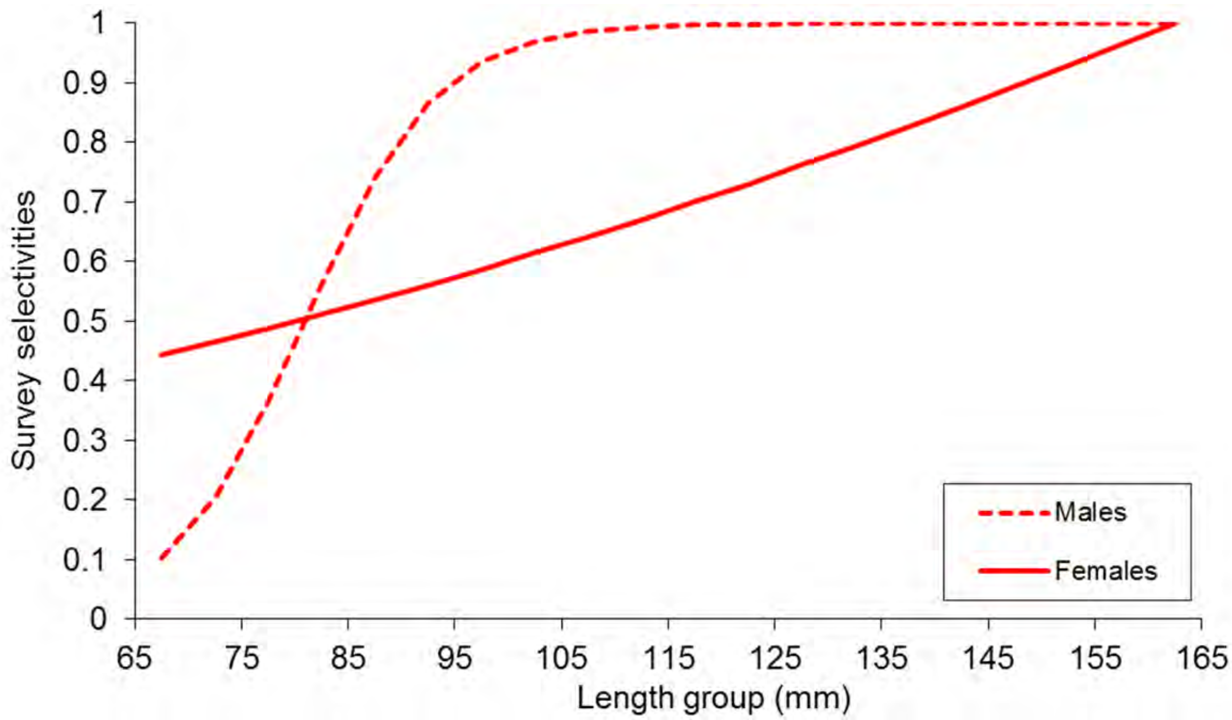


Figure 10d(1). Estimated BSFRF survey selectivities with scenario 1. The catchability is assumed to be 1.0.

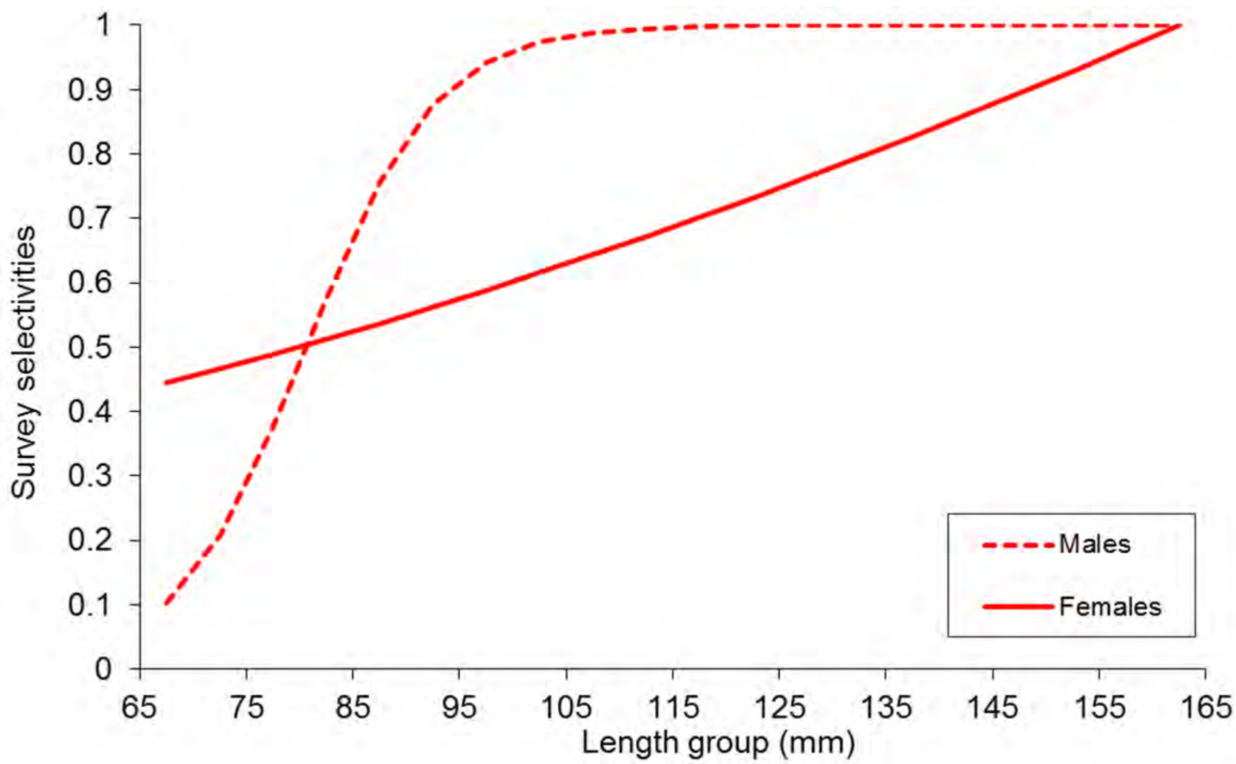
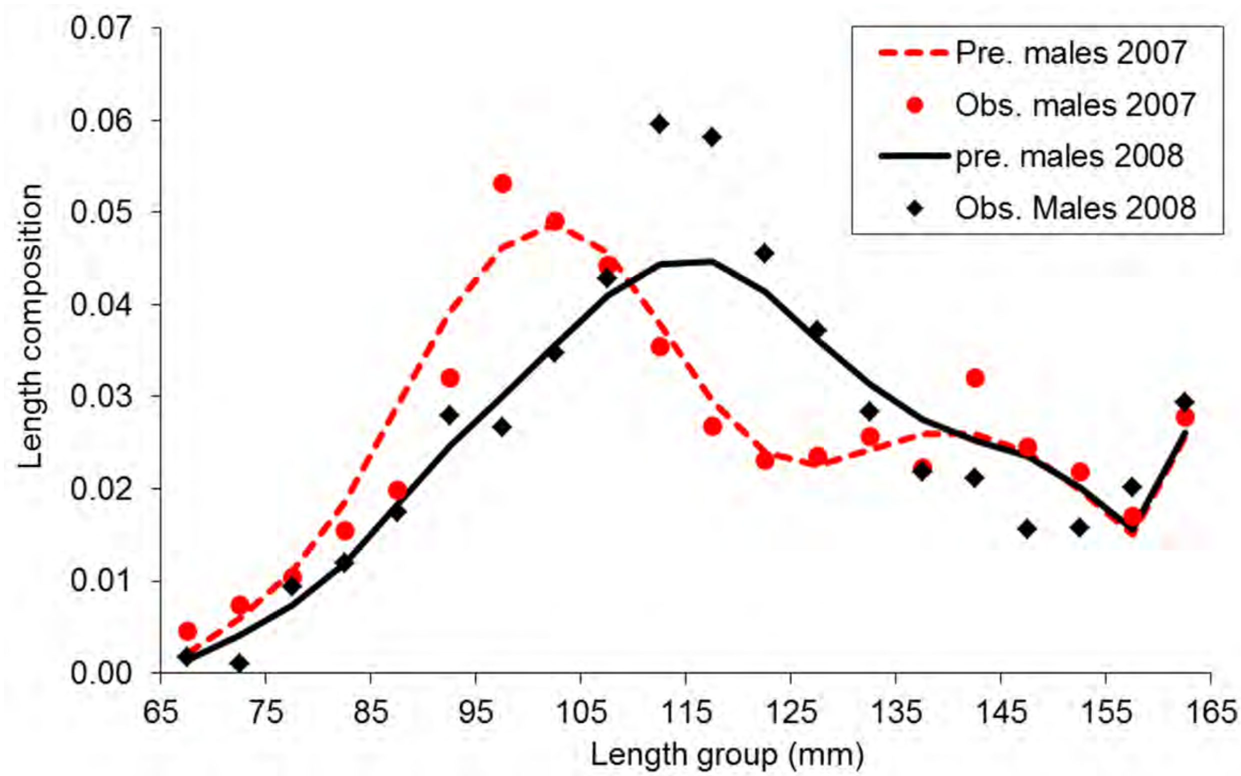


Figure 10d(1a). Estimated BSFRF survey selectivities with scenario 1a. The catchability is assumed to be 1.0.



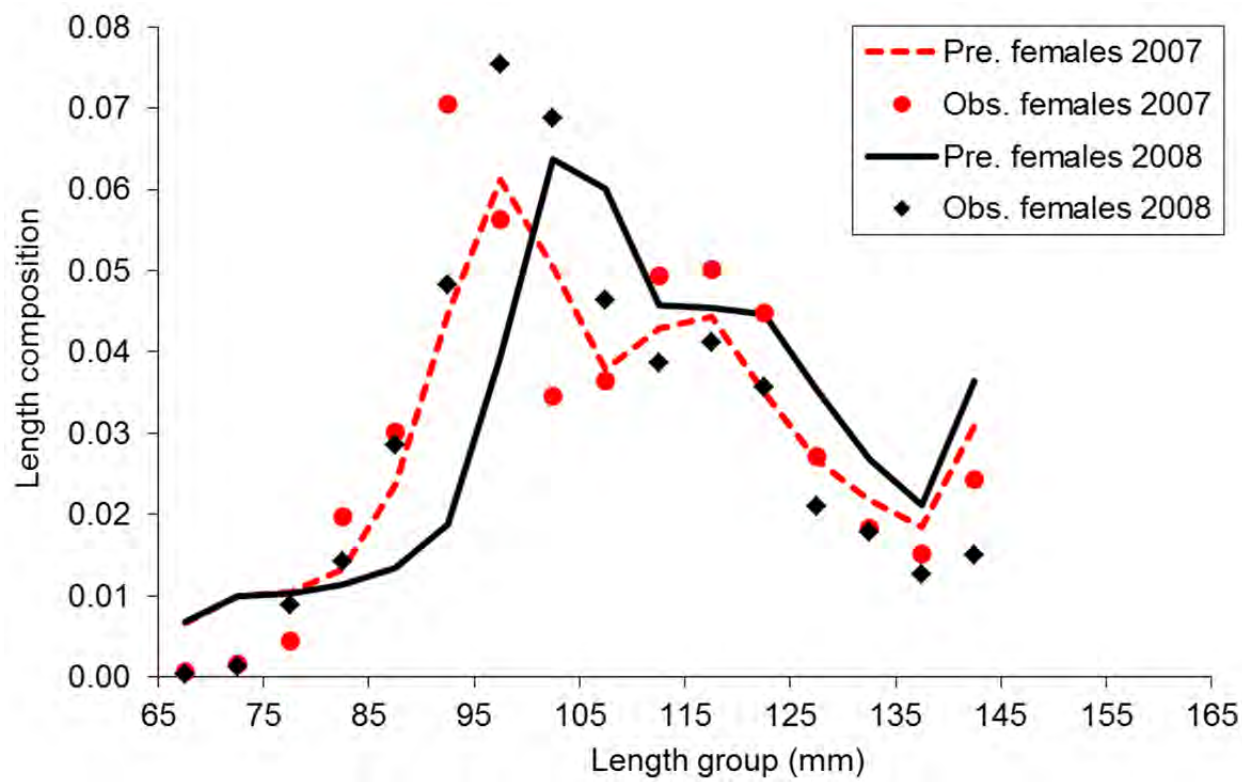


Figure 10e(1). Comparisons of length compositions by the BSFRF survey and the model estimates in 2007 and 2008 with scenario 1.

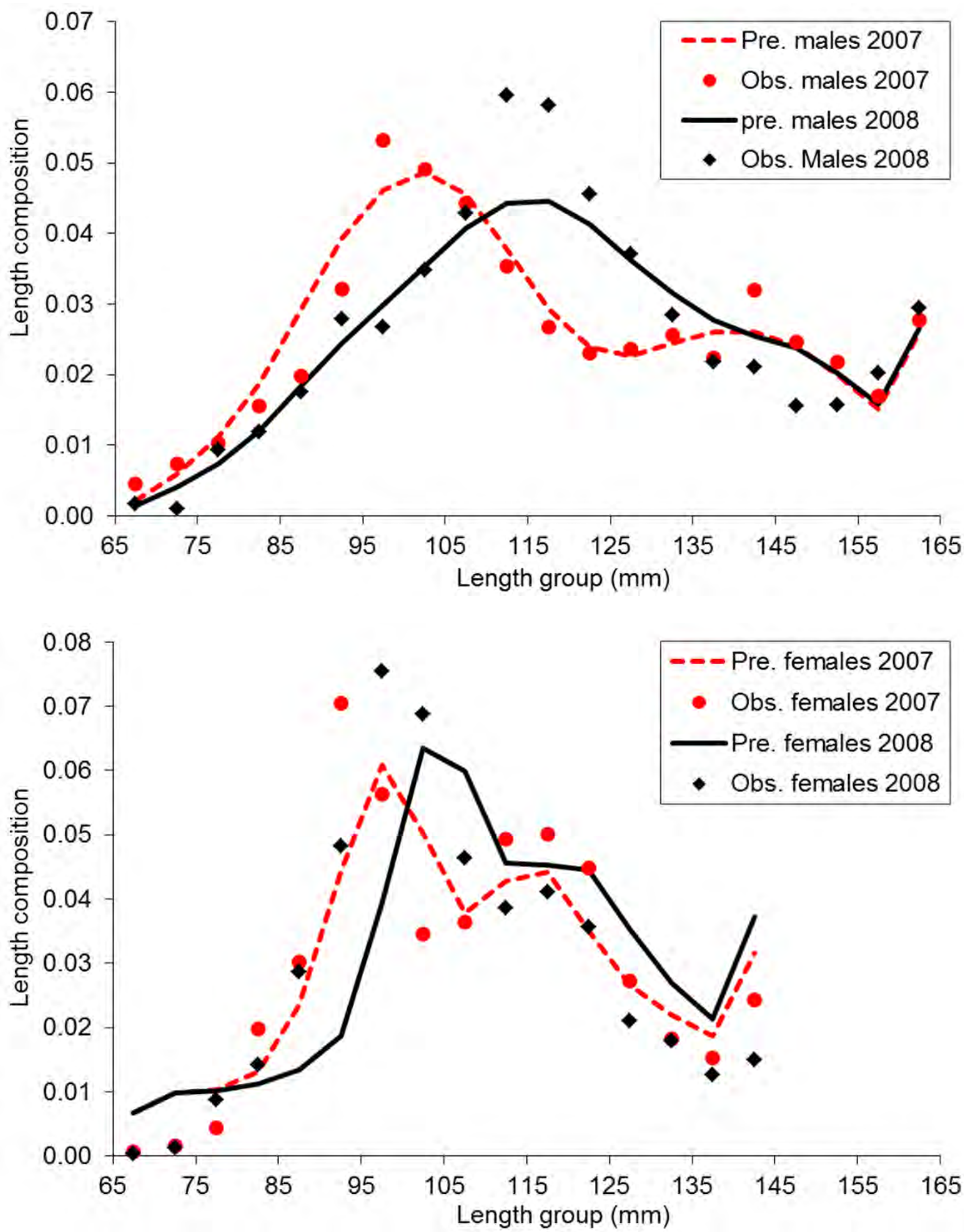


Figure 10e(1a). Comparisons of length compositions by the BSFRF survey and the model estimates in 2007 and 2008 with scenario 1a.

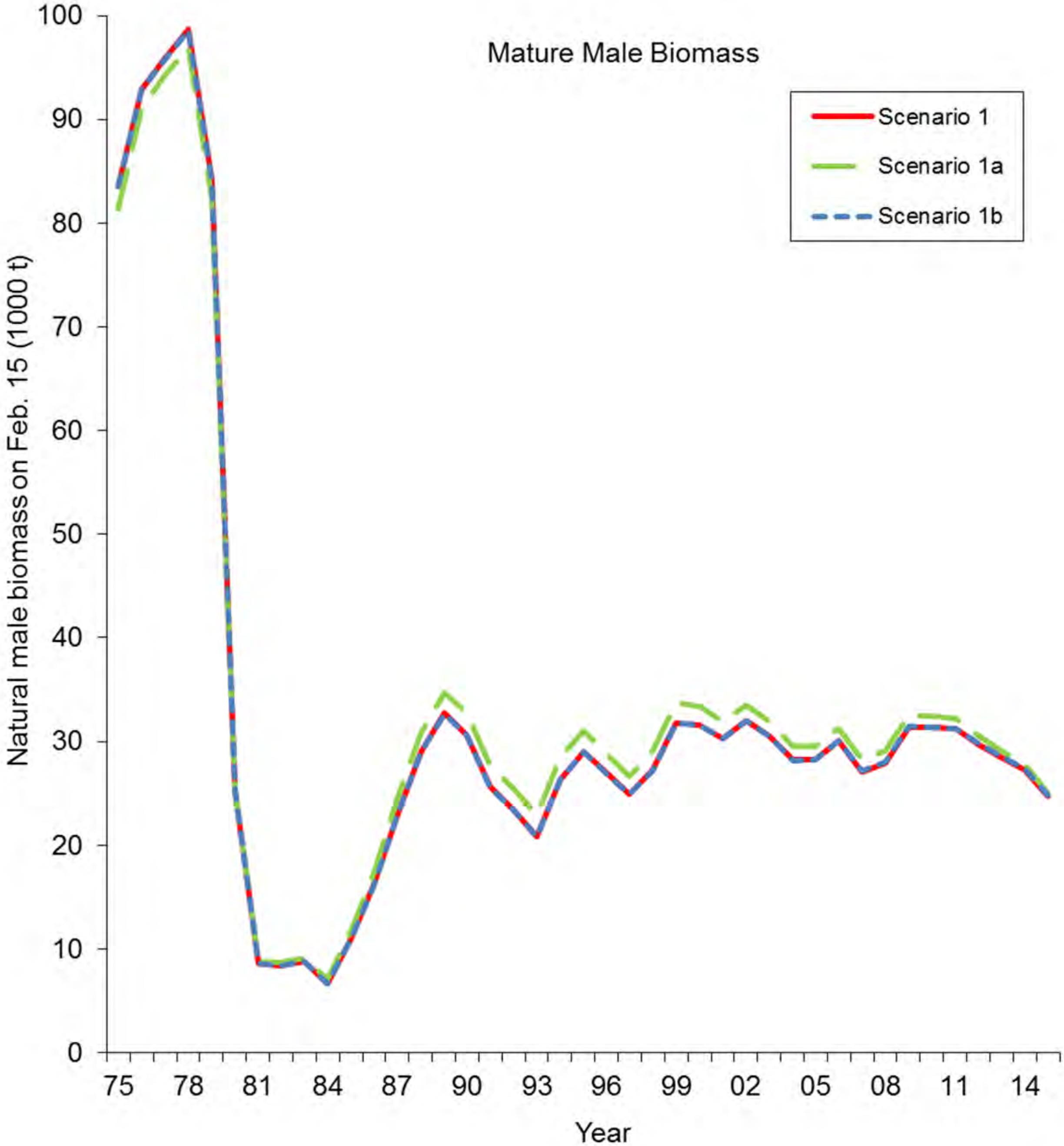


Figure 11. Estimated absolute mature male biomasses during 1975-2015 for scenarios 1, 1a and 1b.

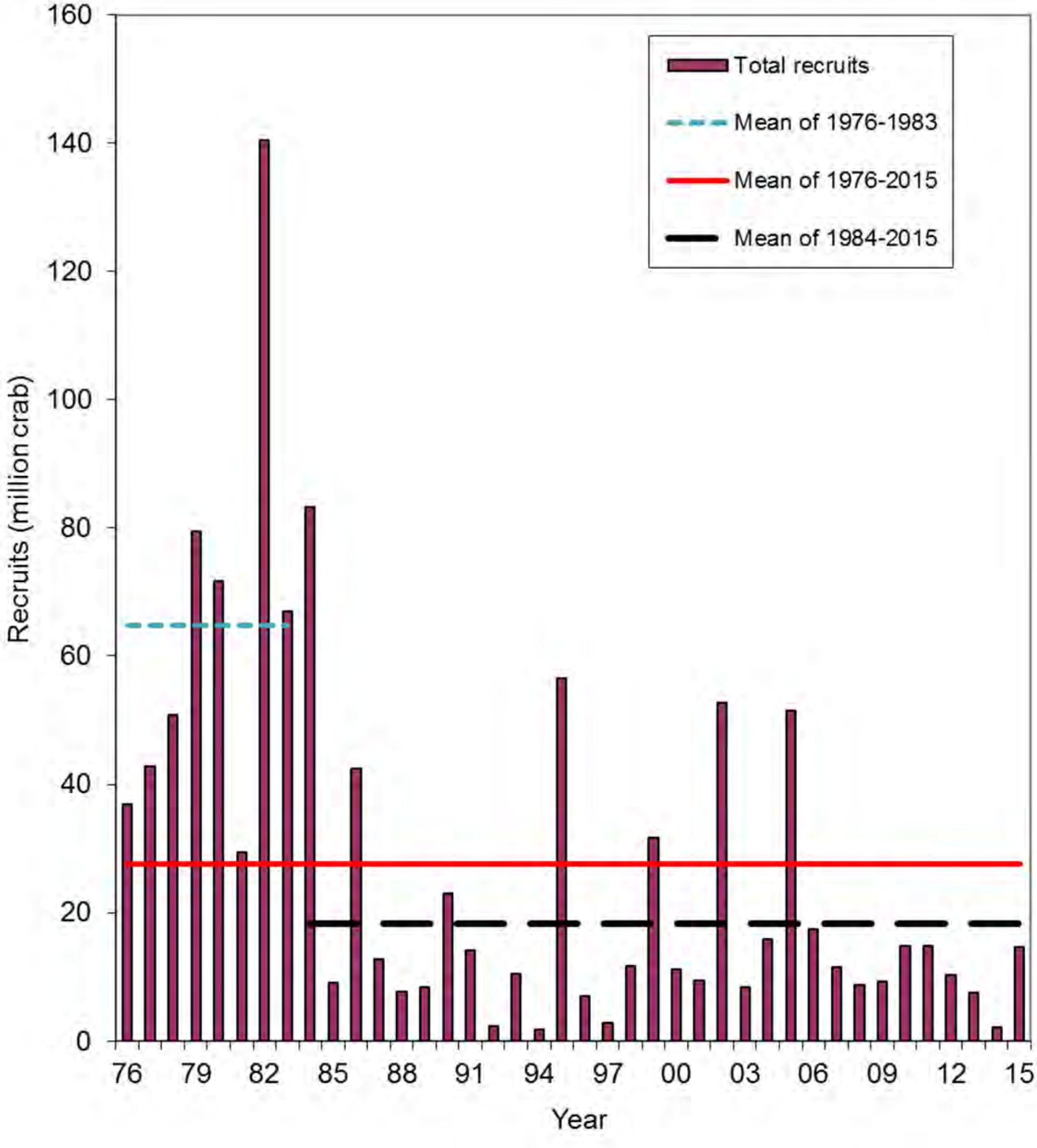


Figure 12(1). Estimated recruitment time series during 1976-2015 with scenario 1. Mean male recruits during 1984-2015 was used to estimate $B_{35\%}$.

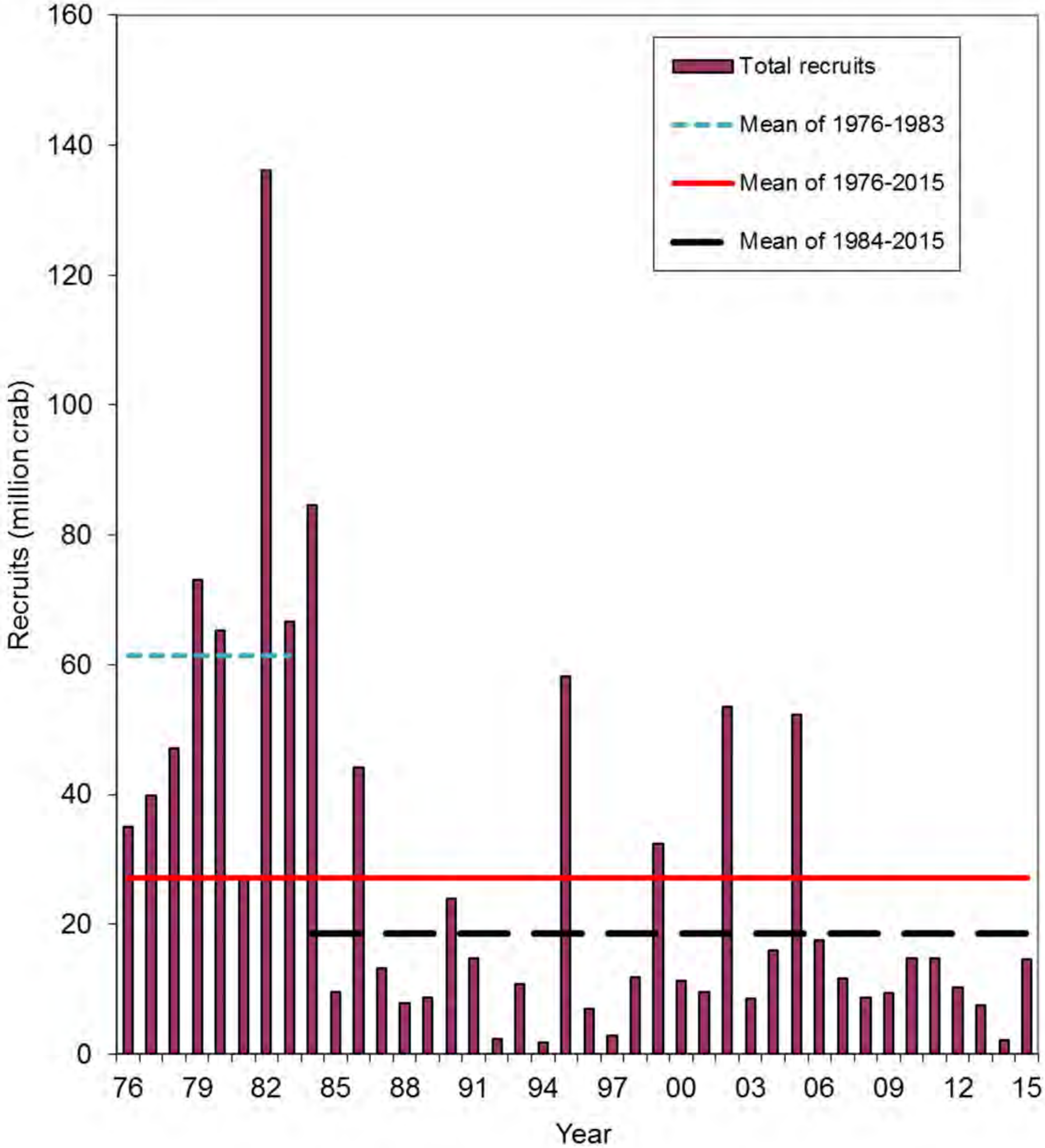


Figure 12(1a). Estimated recruitment time series during 1976-2015 with scenario 1a. Mean male recruits during 1984-2015 was used to estimate $B_{35\%}$.

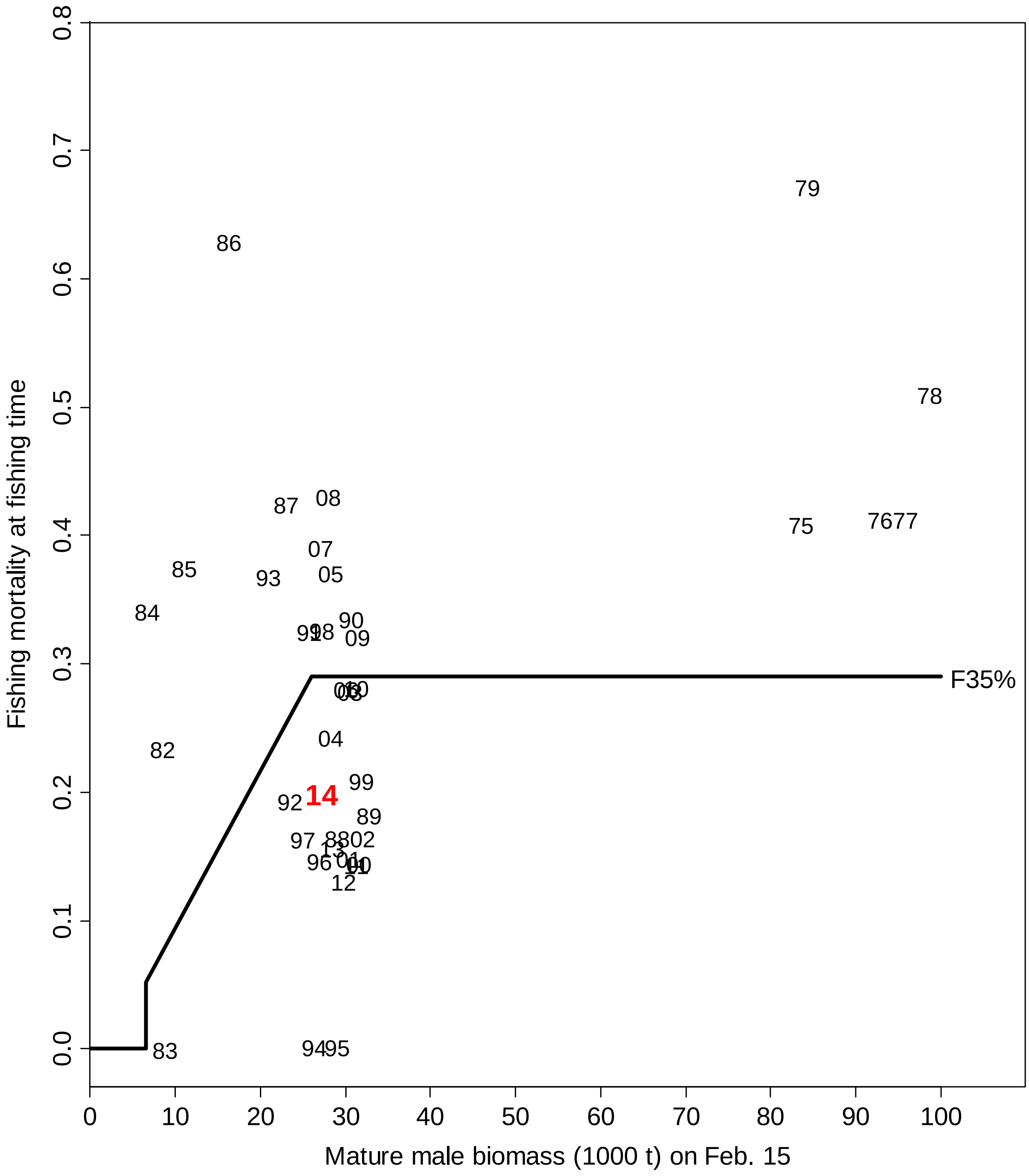


Figure 13(1). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2014 under scenario 1. Average of recruitment from 1984 to 2015 was used to estimate B_{MSY}. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

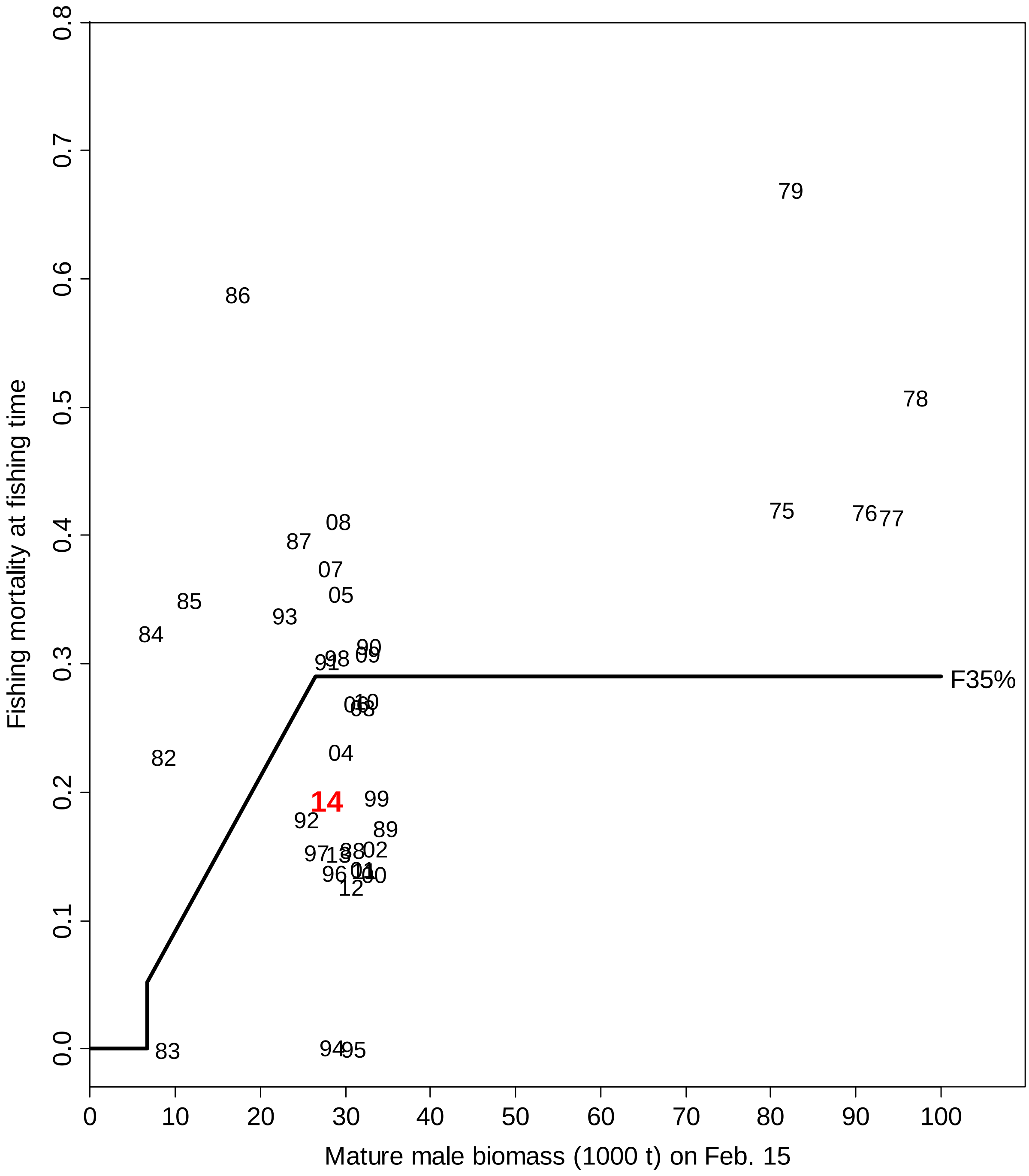


Figure 13(1a). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2014 under scenario 1a. Average of recruitment from 1984 to 2015 was used to estimate B_{MSY}. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

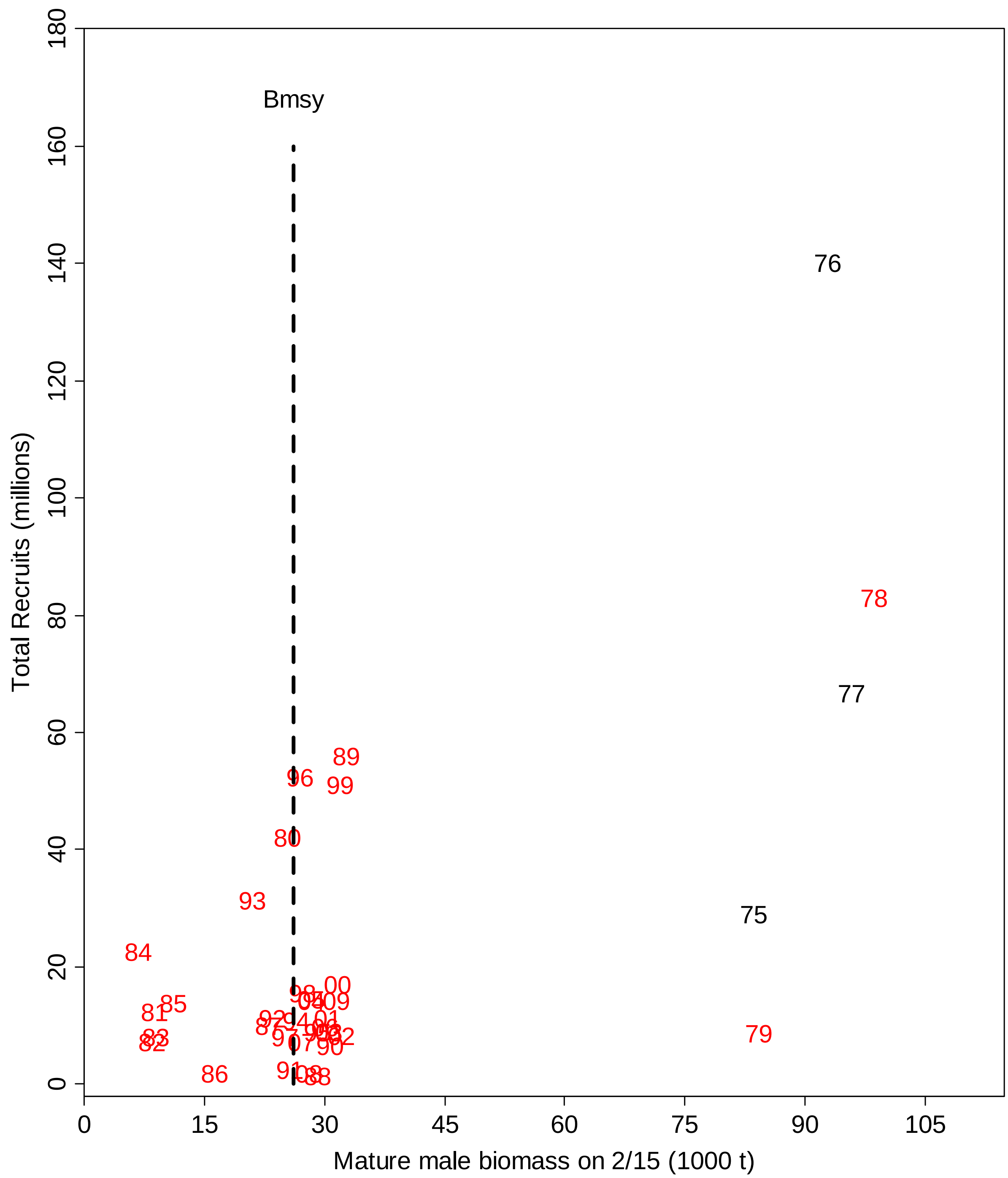


Figure 14a. Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6-year time lag) for Bristol Bay red king crab with pot handling mortality rate of 0.2 under scenario 1. Numerical labels are years of mating, and the vertical dotted line is the estimated $B_{35\%}$ based on the mean recruitment level during 1984 to 2015.

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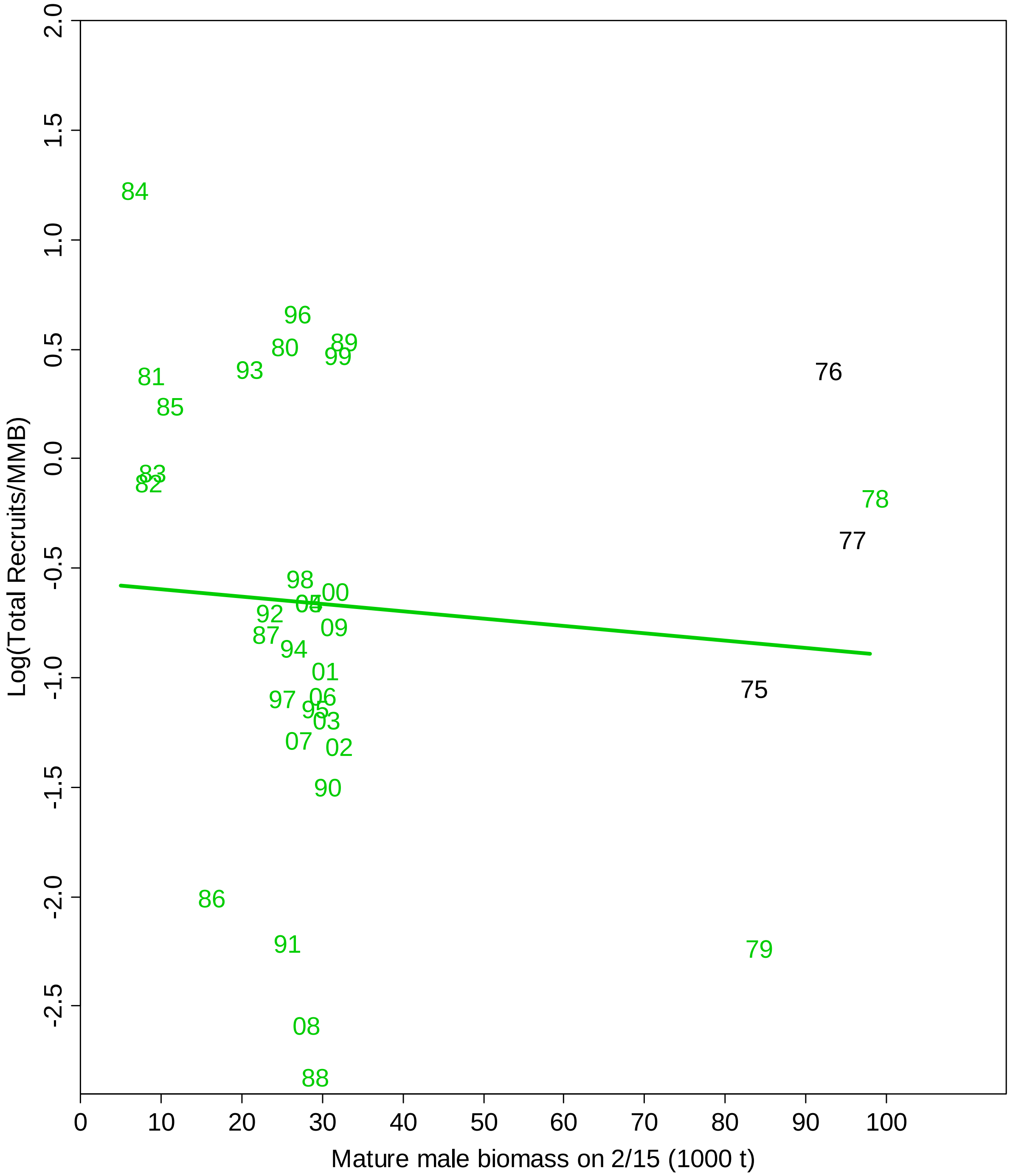

Figure 14b. Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate of 0.2 under scenario 1. Numerical labels are years of mating, and the line is the regression line for data of 1978-2009.

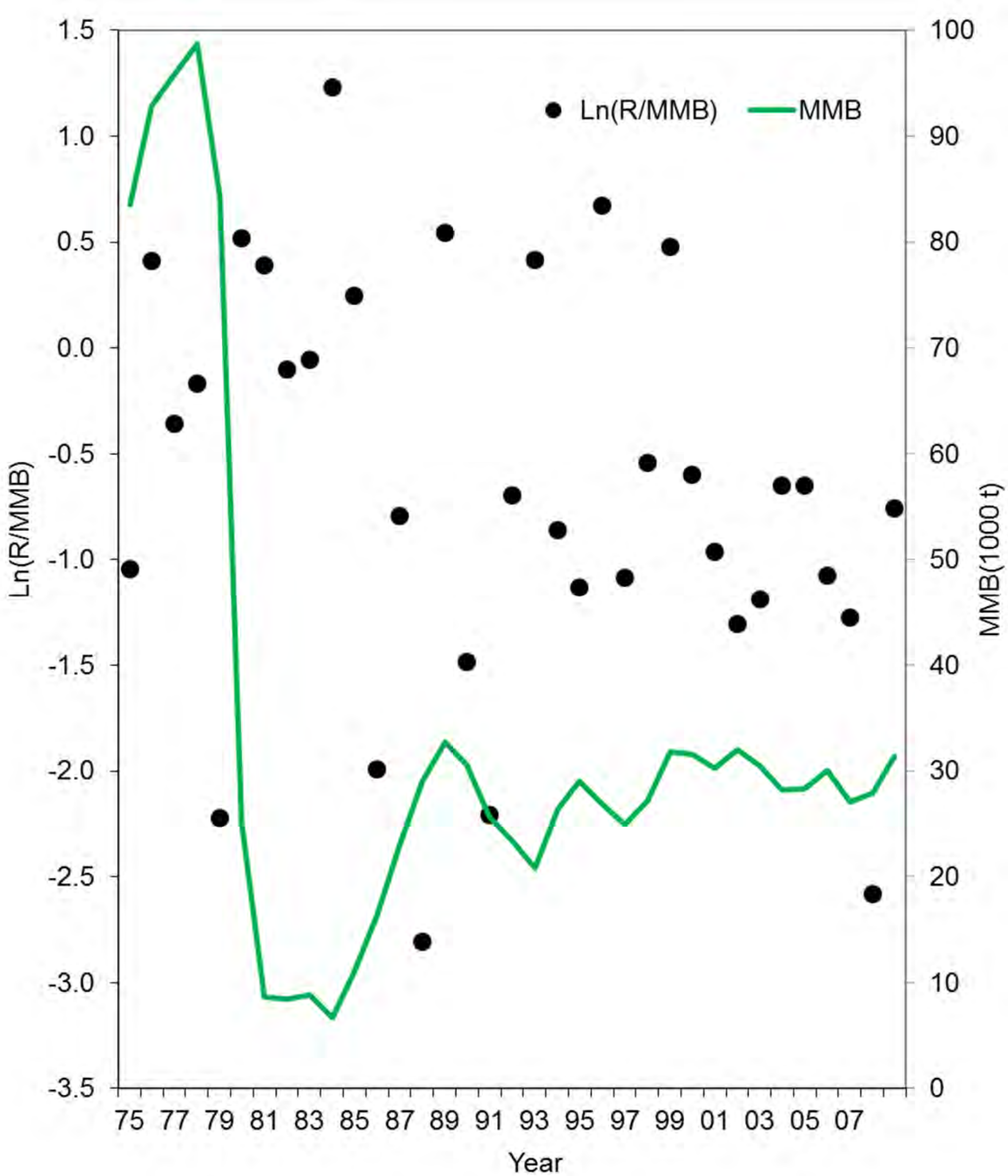

Figure 14c. Time series of log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate of 0.2 under scenario 1.

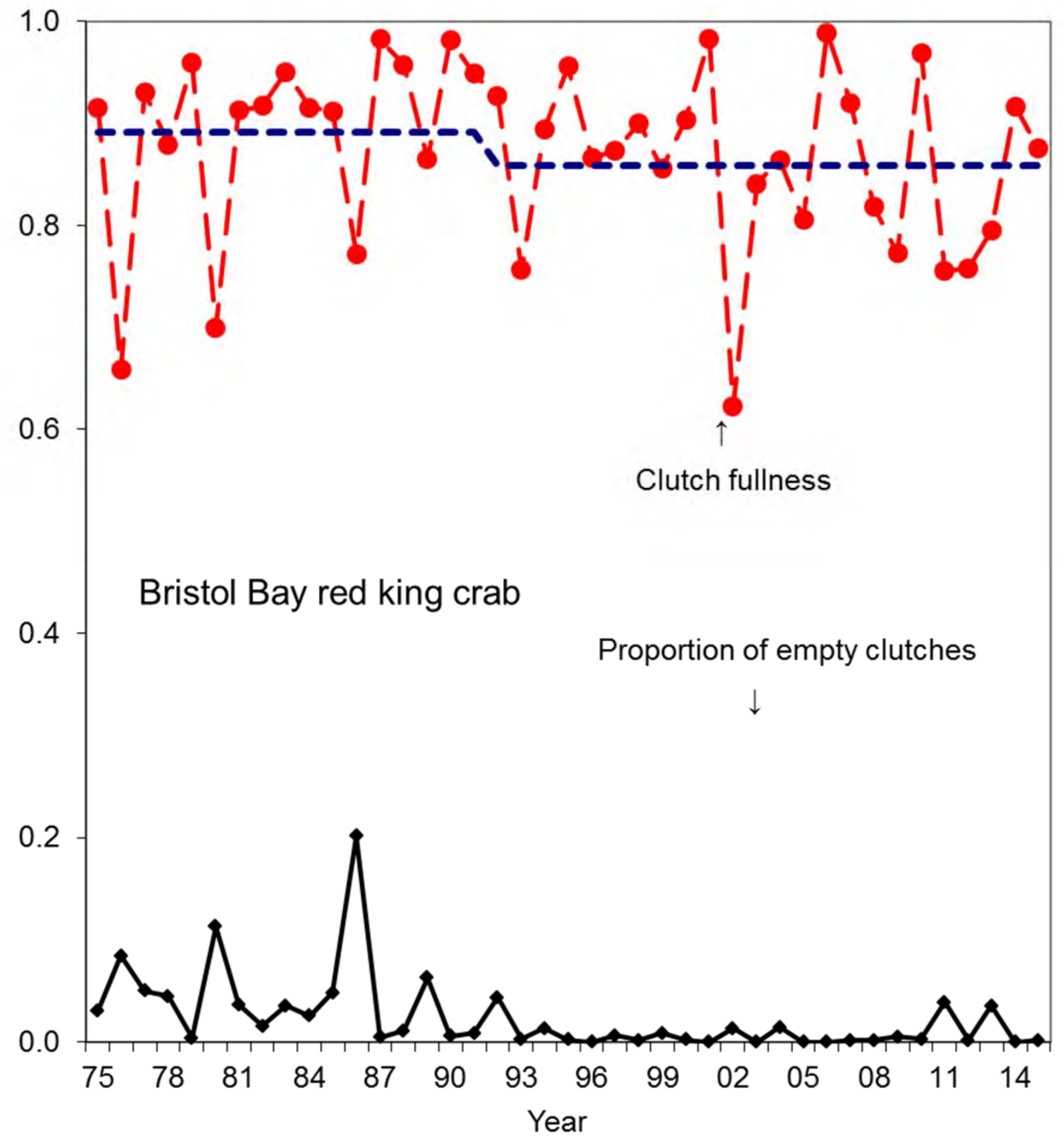

Figure 15. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crab >89 mm CL from 1975 to 2015 from survey data. Oldshell females were excluded.

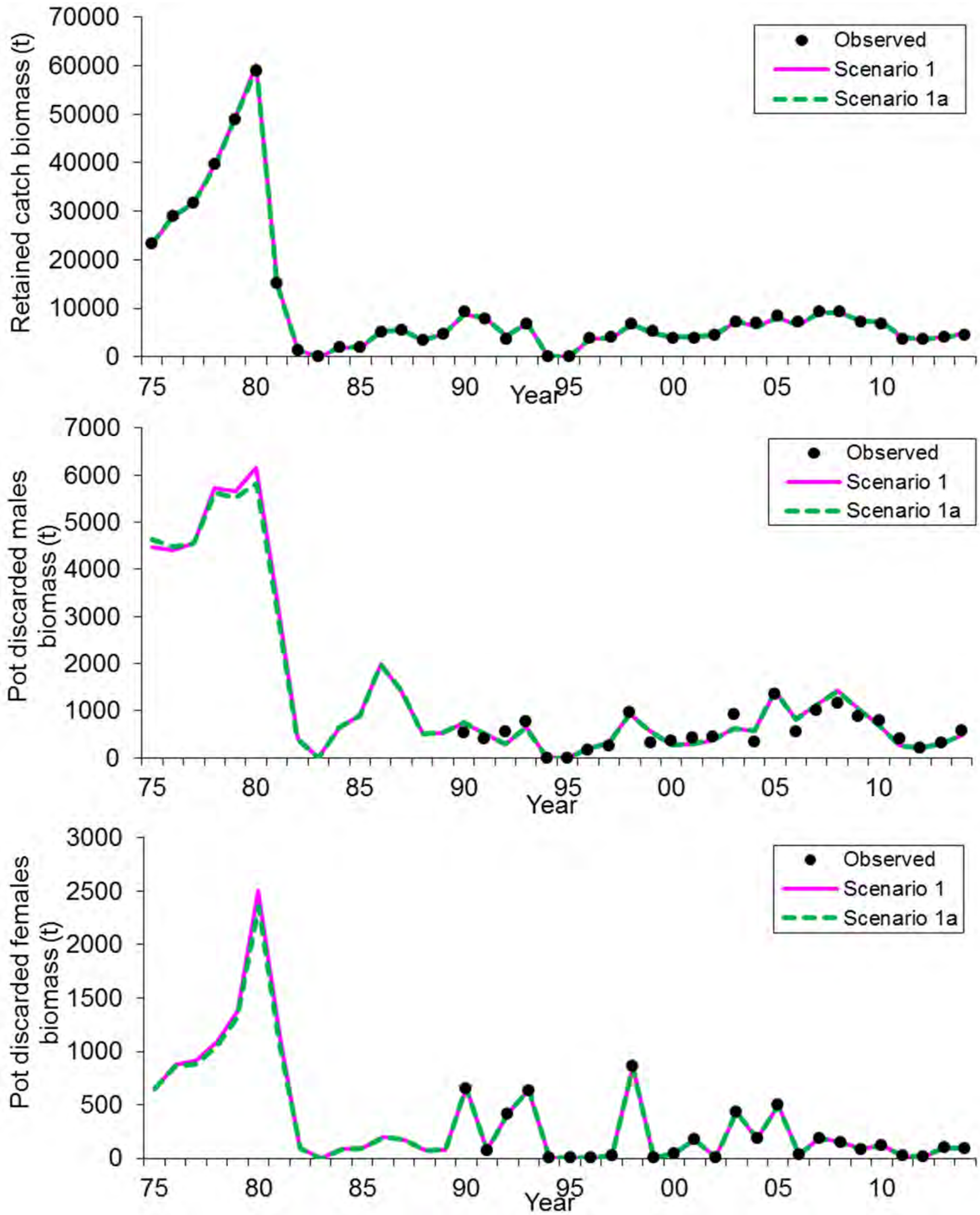

Figure 16a. Observed and predicted catch mortality biomass under scenarios 1 and 1a. Mortality biomass is equal to caught biomass times a handling mortality rate. Pot handling mortality rate is 0.2.

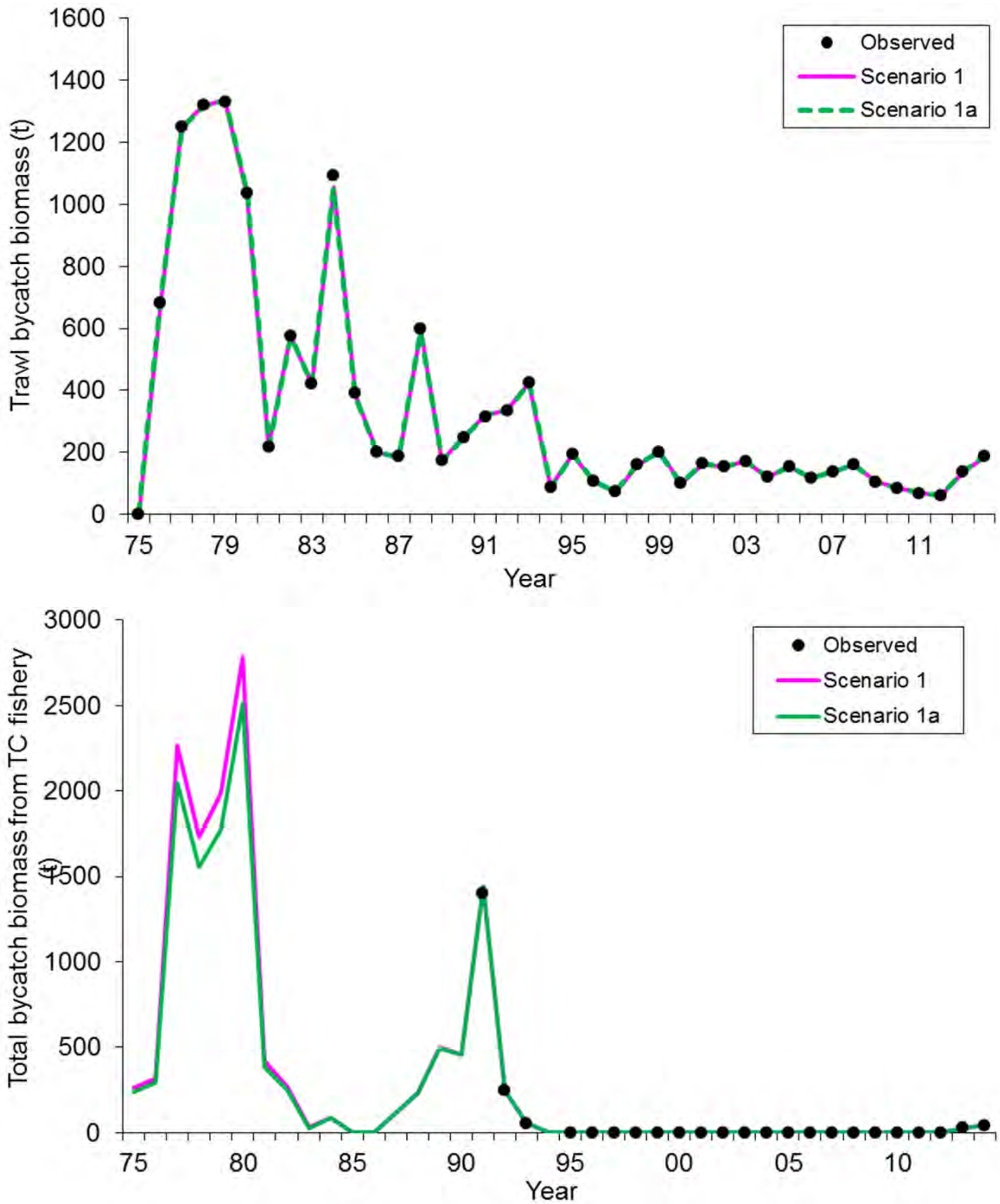

Figure 16b. Observed and predicted bycatch mortality biomass from trawl fisheries and the Tanner crab fishery under scenarios 1 and 1a. Mortality biomass is equal to caught biomass times a handling mortality rate. Trawl handling mortality rate is 0.8, and Tanner crab pot handling mortality is 0.25. Trawl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

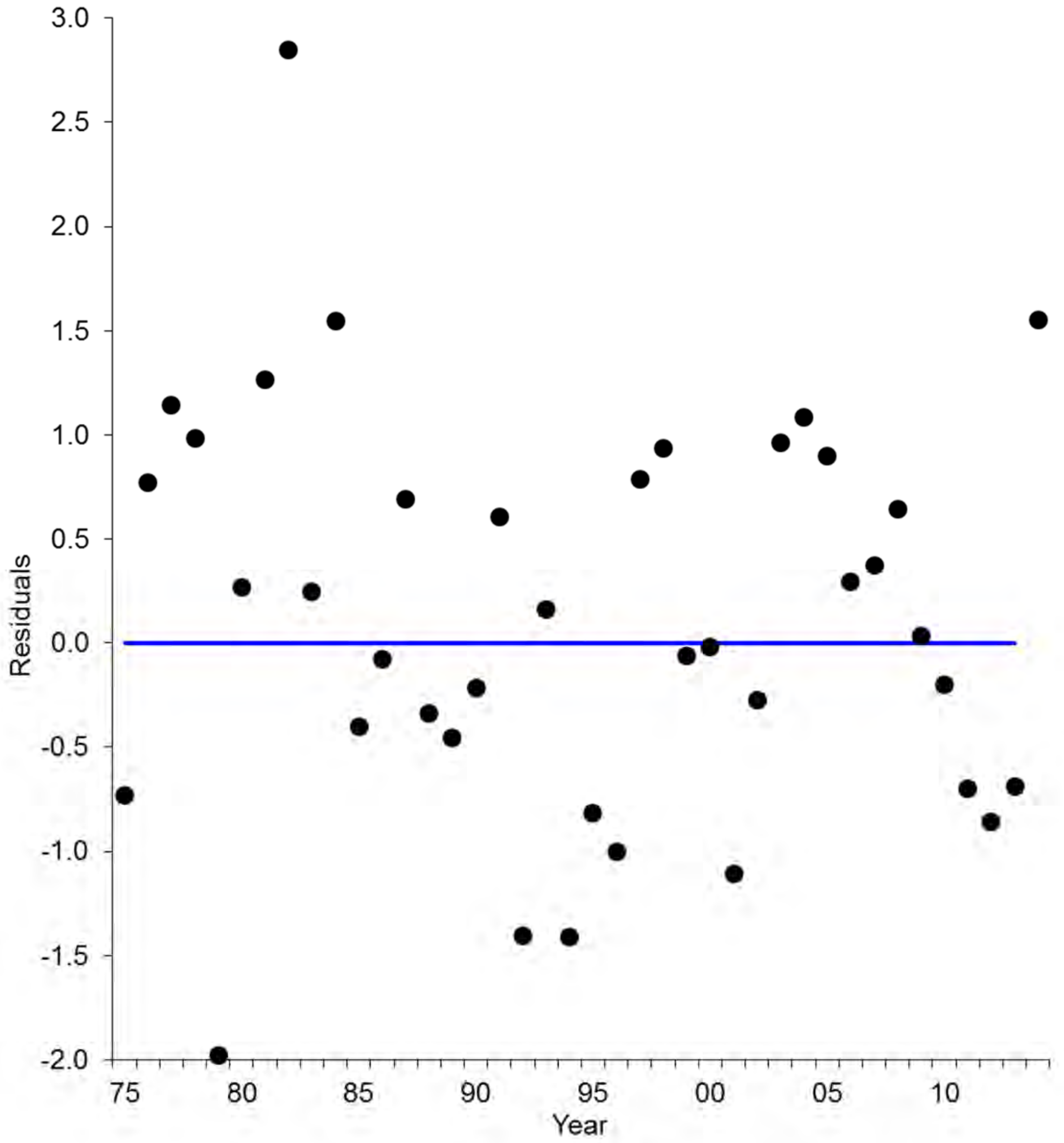

Figure 17(1). Standardized residuals of total survey biomass under scenario 1. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

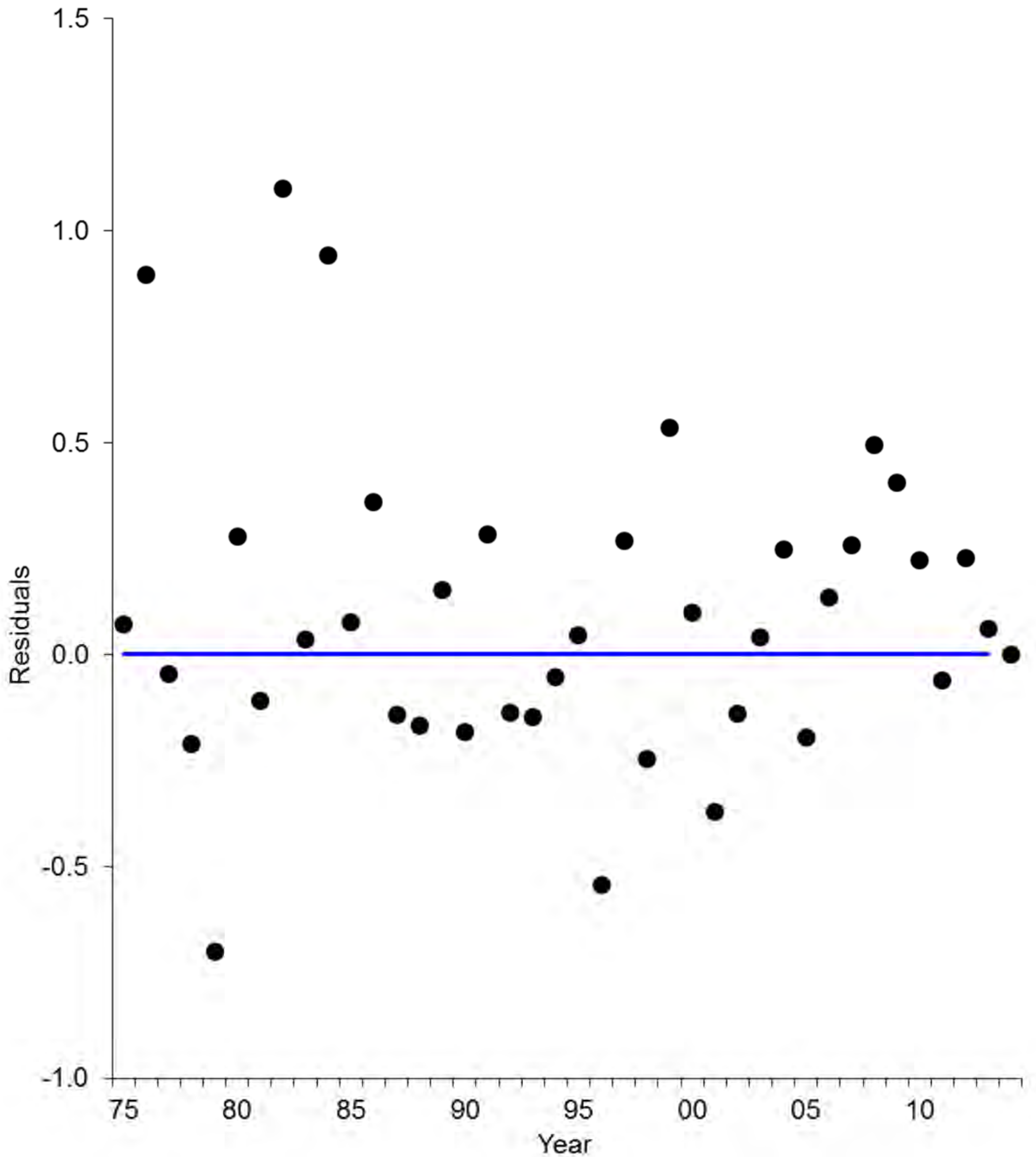

Figure 17(1a). Standardized residuals of total survey biomass under scenario 1a. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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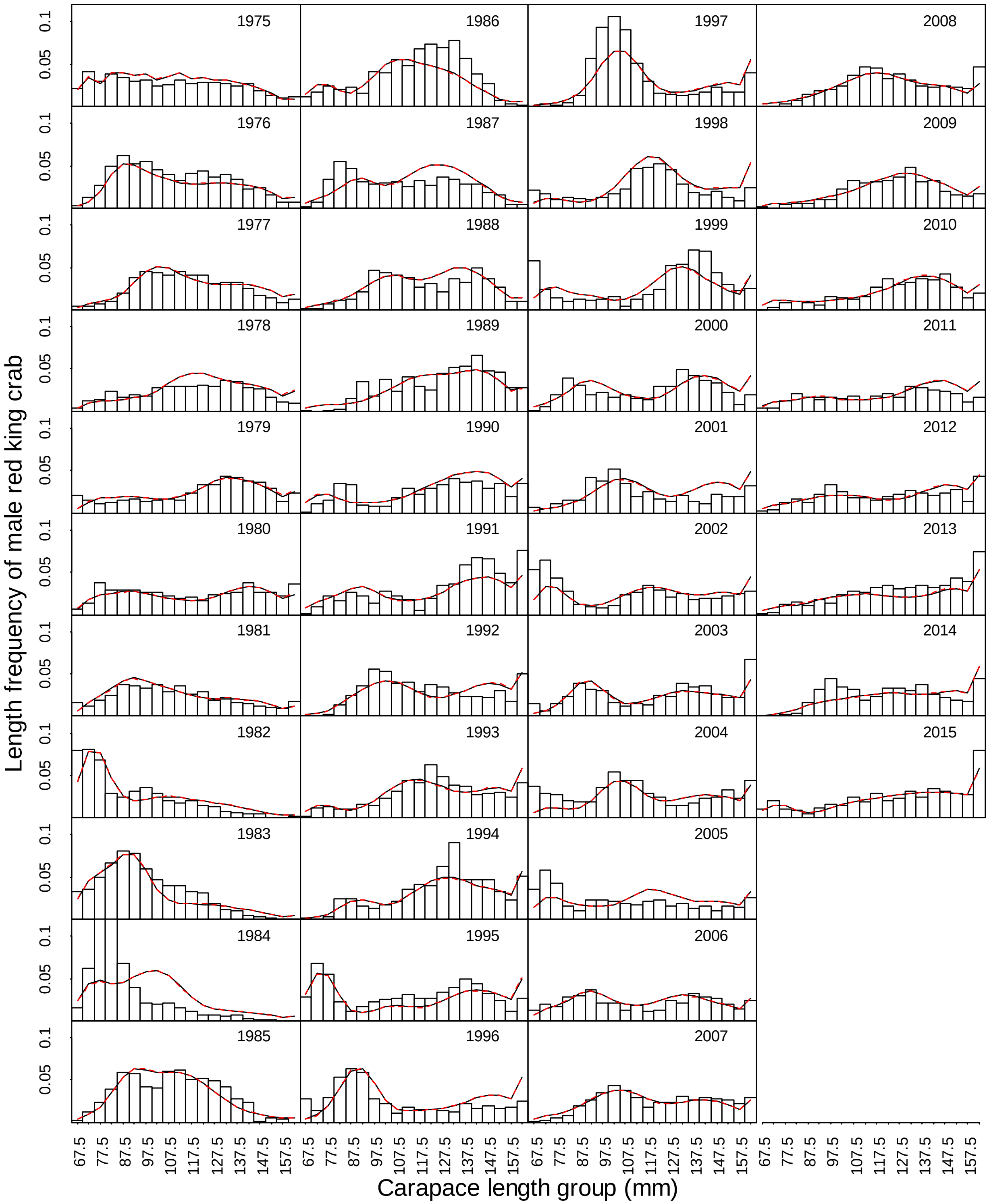

Figure 18(1 & 1a). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay male red king crab by year under scenarios 1(solid black) and 1a(dashed red). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8.

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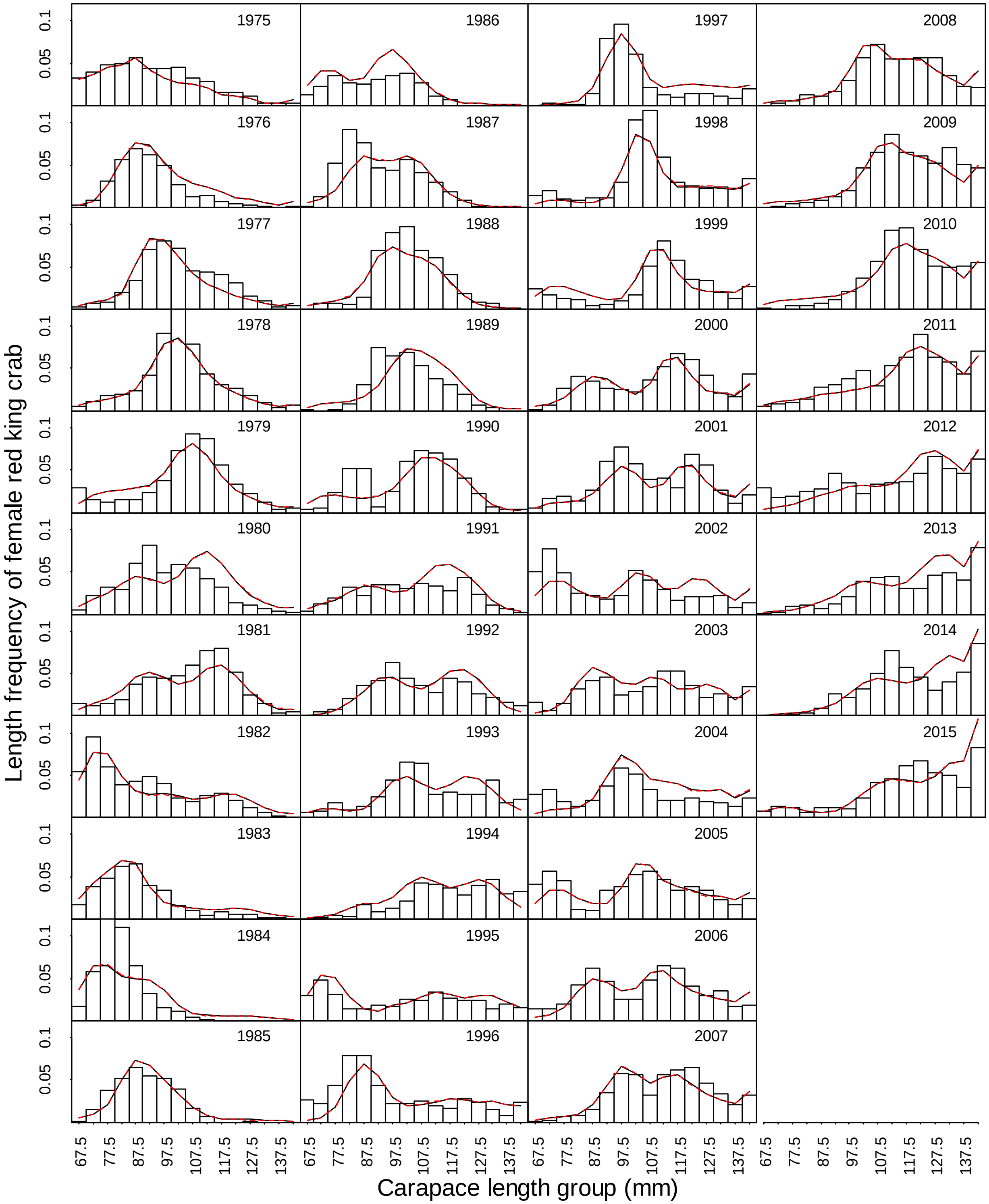

Figure 19(1 & 1a). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crab by year under scenarios 1(solid black) and 1a(dashed red). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

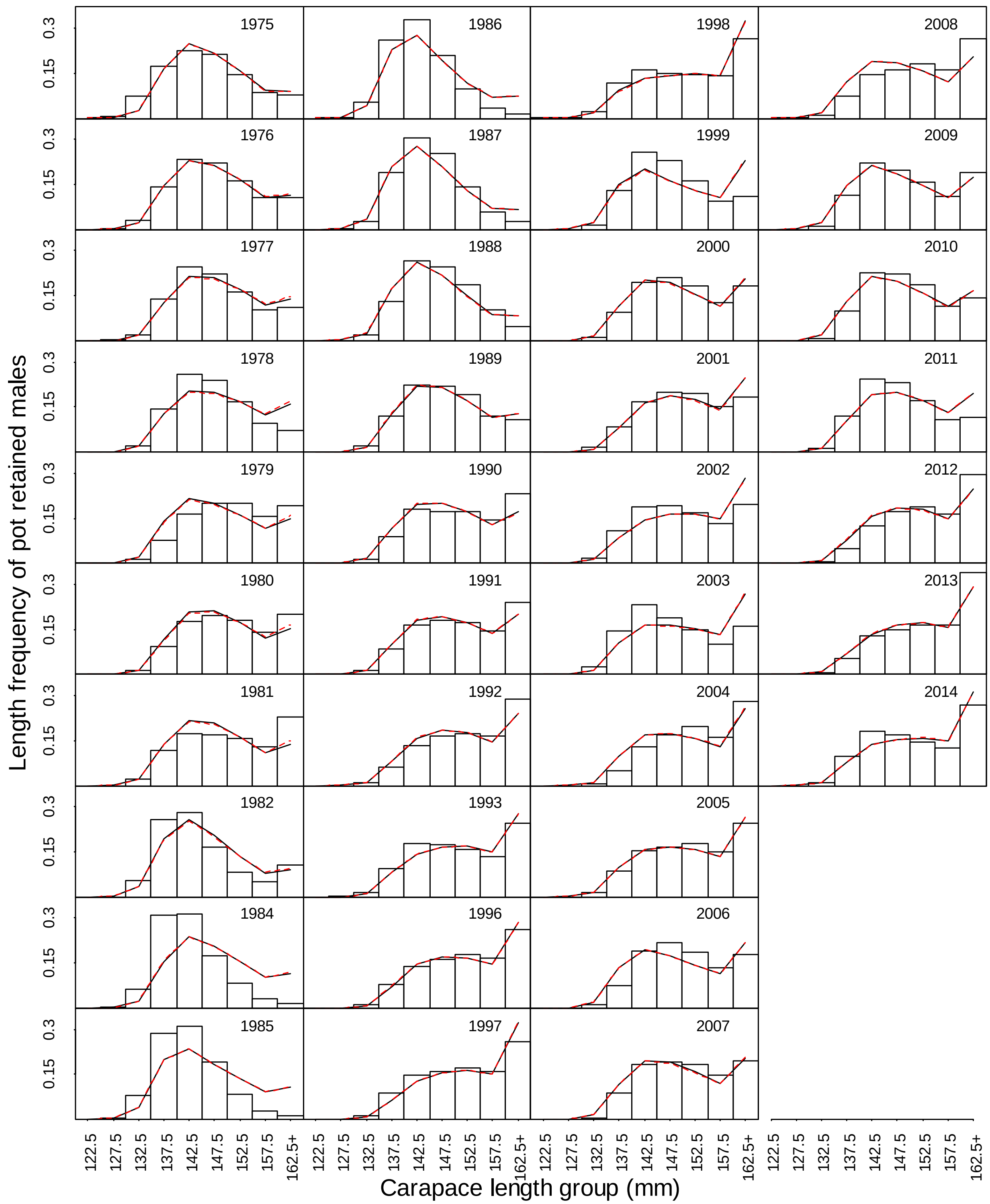

Figure 20(1 & 1a). Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under scenarios 1 (solid black) and 1a(dashed red). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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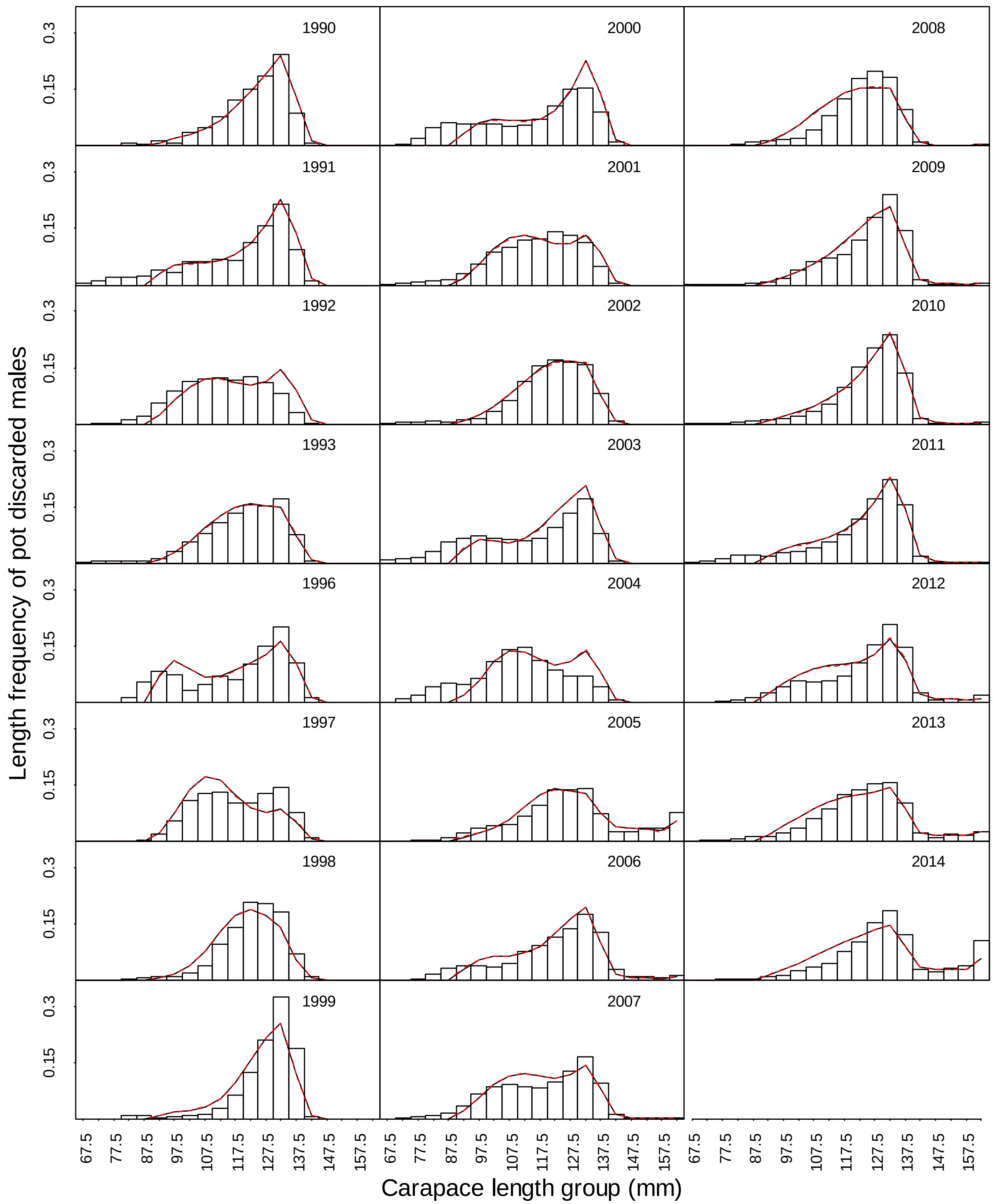

Figure 21(1 & 1a). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under scenarios 1 (solid black) and 1a (dashed red). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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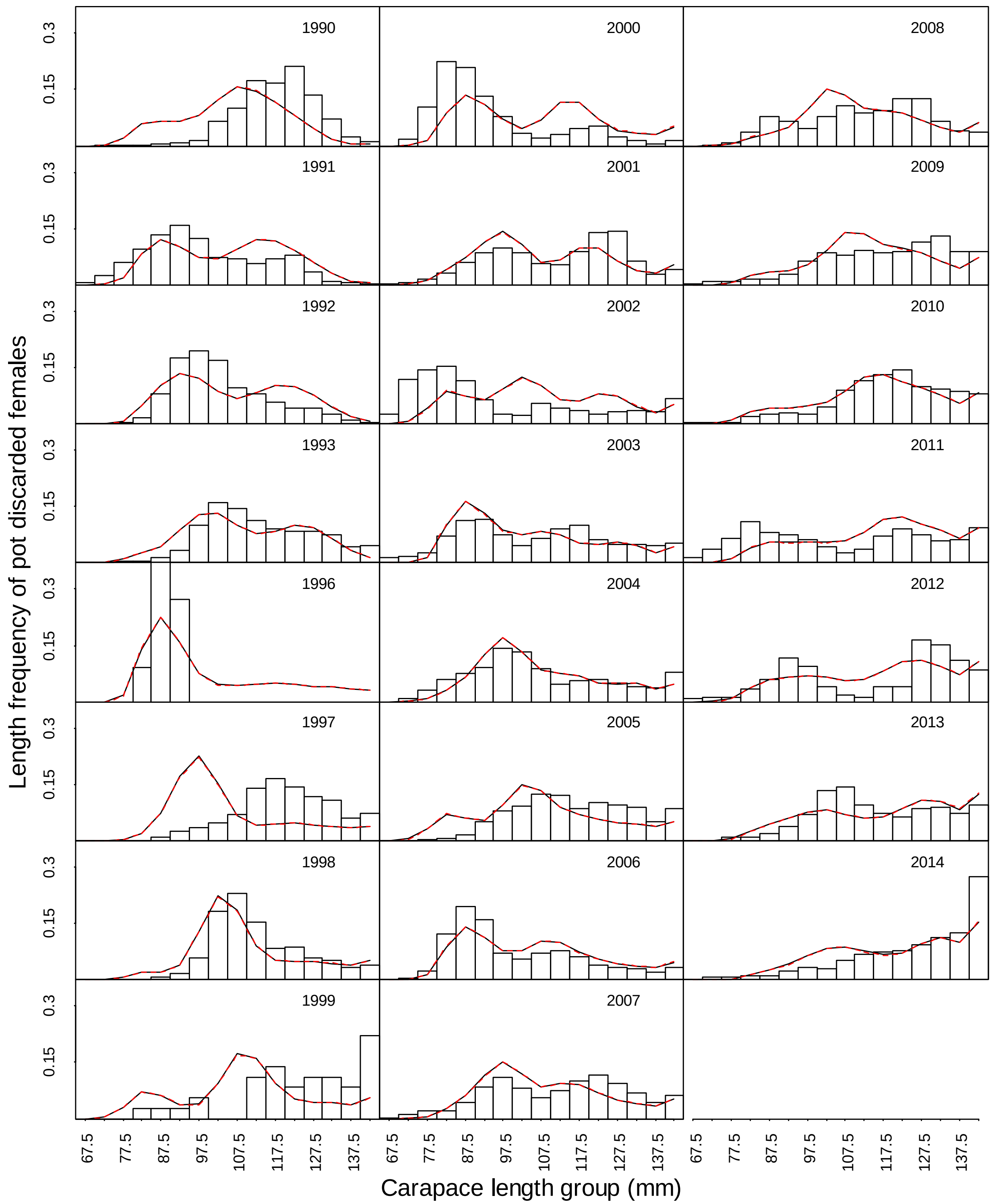

Figure 22(1 & 1a). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the directed pot fishery under scenarios 1 (solid black) and 1a (dashed red). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

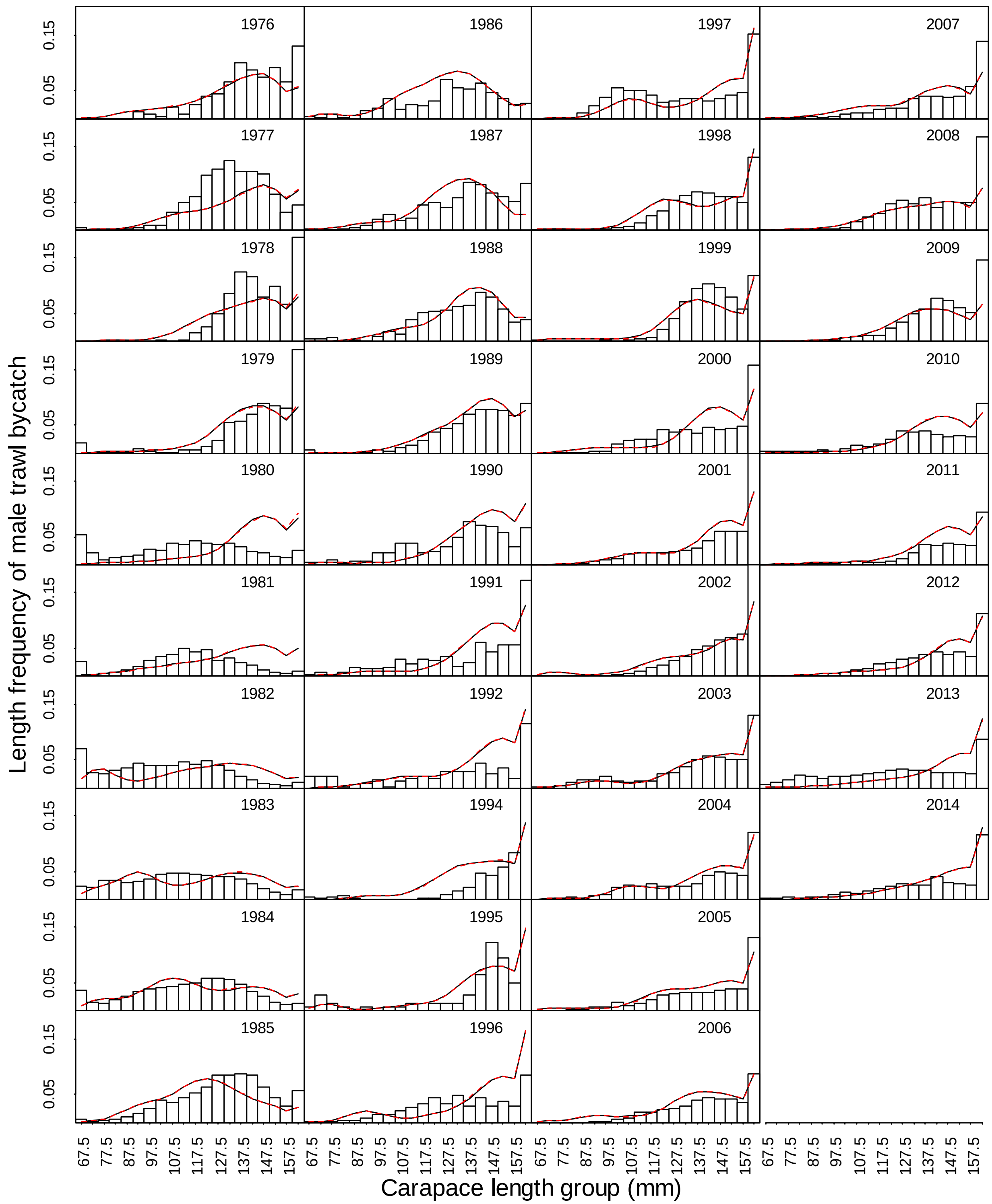

Figure 23(1 & 1a). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish trawl fisheries under scenarios 1 (solid black) and 1a (dashed red). Pot handling mortality rate is 0.2, and trawl bycatch mortality rate is 0.8.

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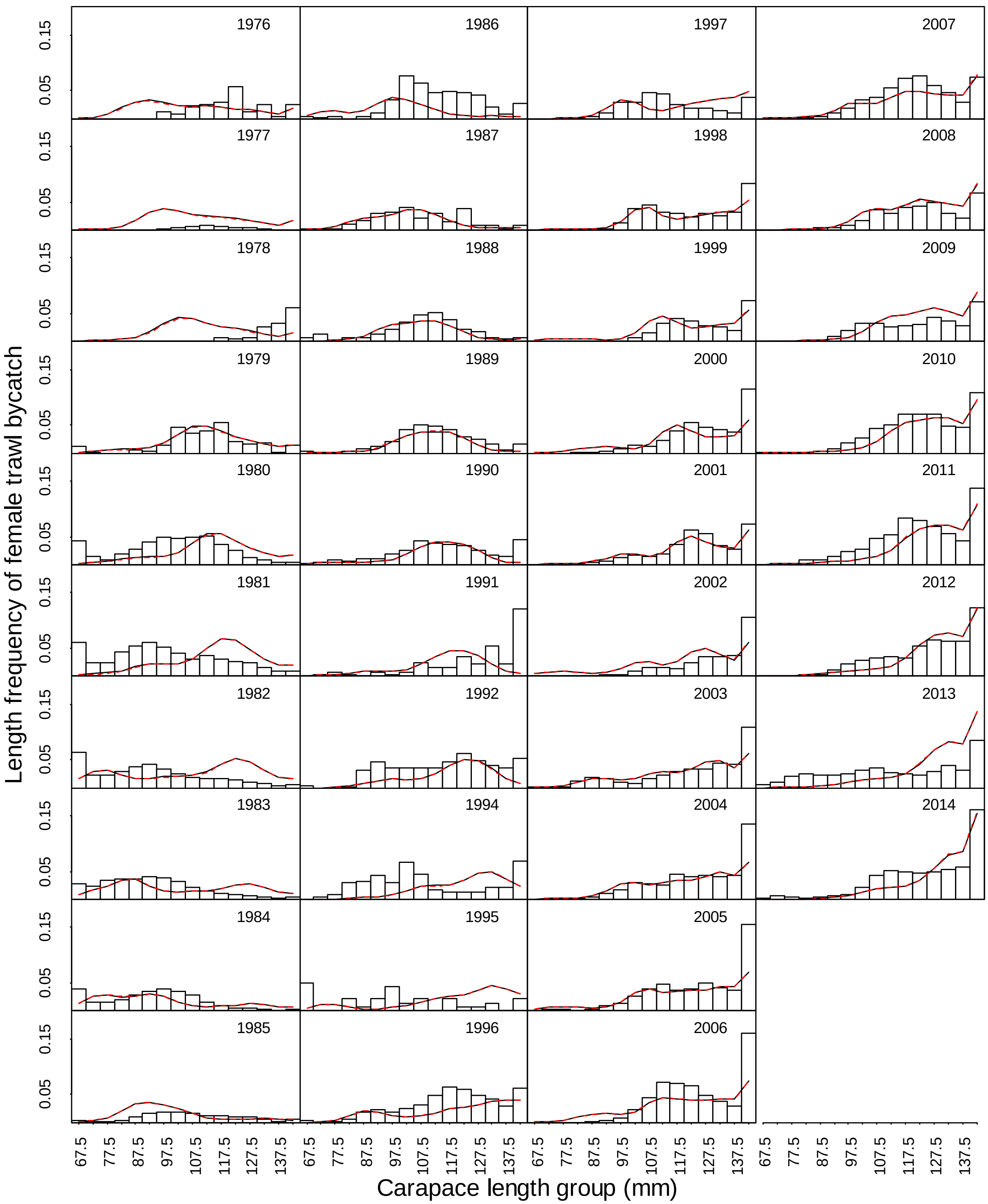

Figure 24(1 & 1a). Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish trawl fisheries under scenarios 1 (solid black) and 1a (dashed red). Pot handling mortality rate is 0.2, and trawl bycatch mortality rate is 0.8.

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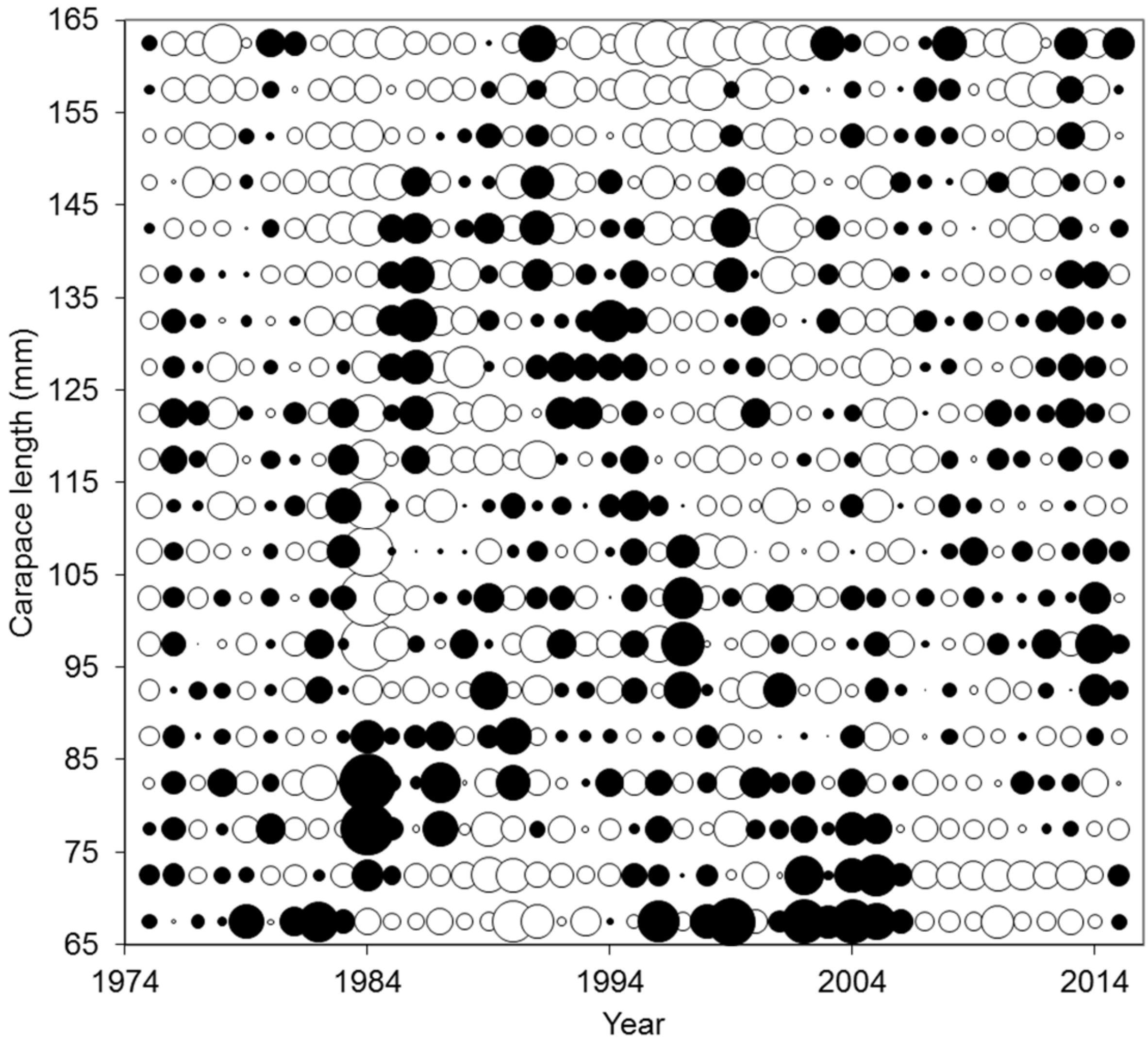

Figure 25(1). Standardized residuals of proportions of survey male red king crab under scenario 1. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

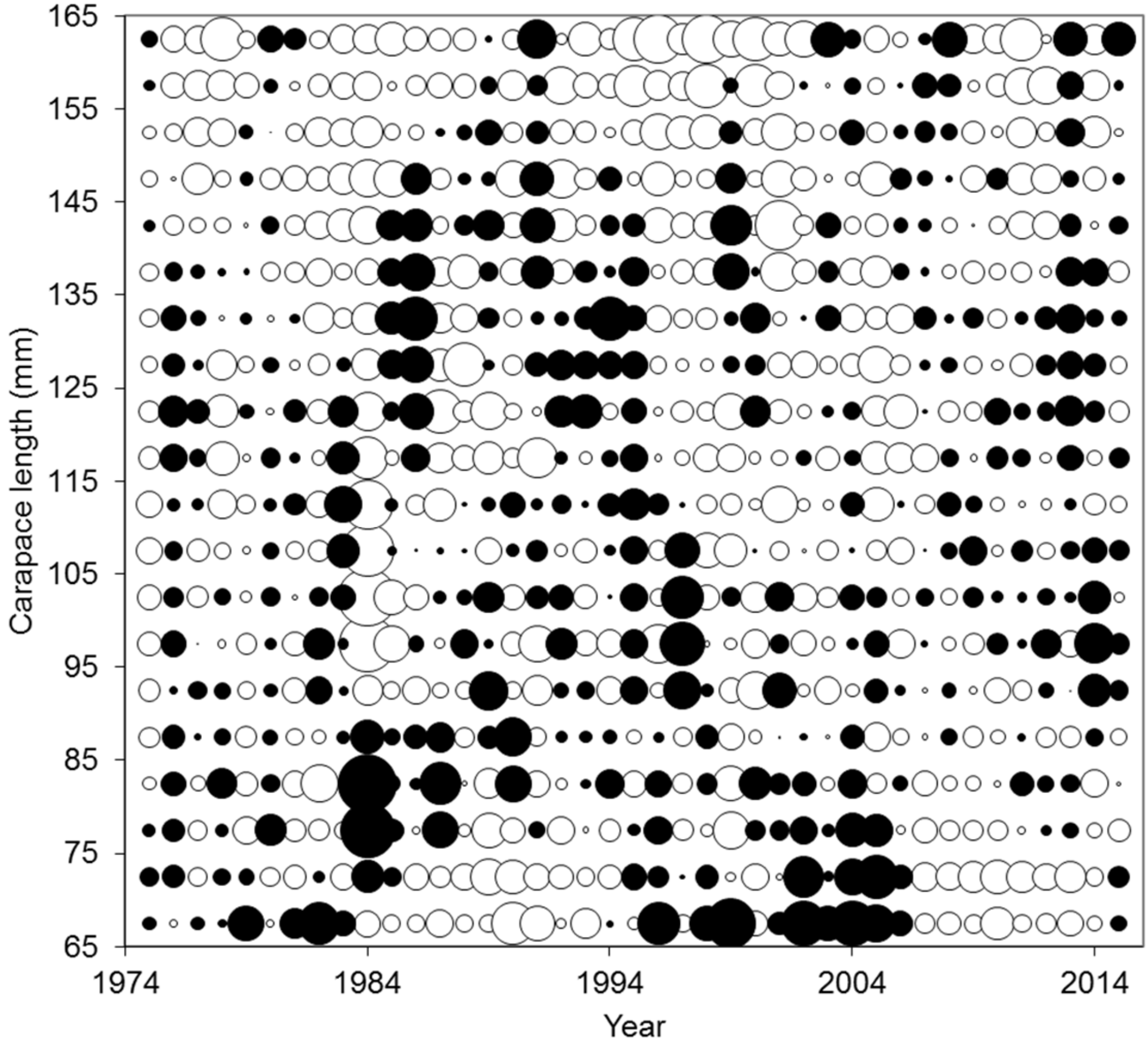

Figure 25(1a). Standardized residuals of proportions of survey male red king crab under scenario 1a. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

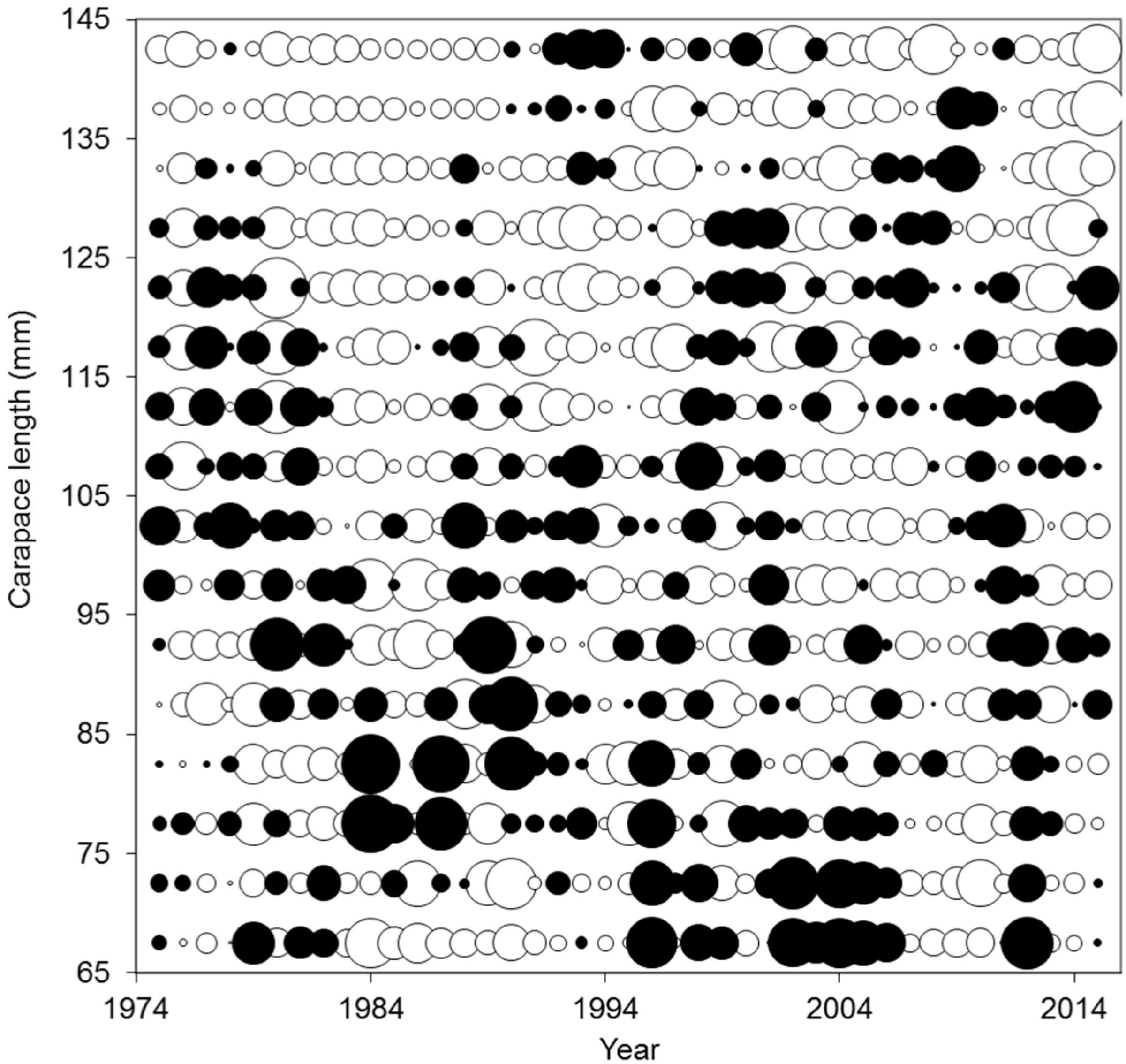

Figure 26(1). Standardized residuals of proportions of survey female red king crab under scenario 1. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

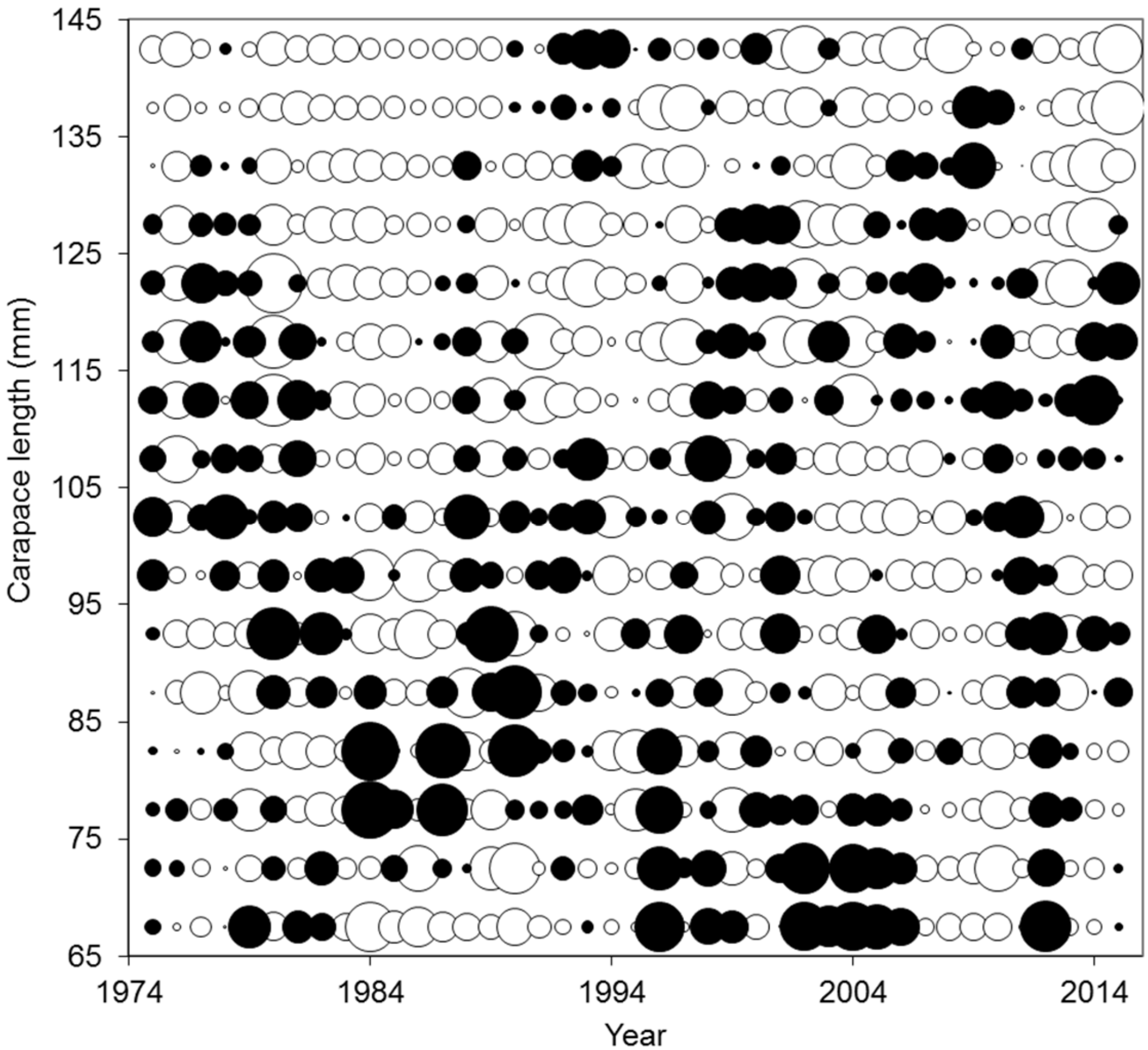

Figure 26(1a). Standardized residuals of proportions of survey female red king crab under scenario 1a. Solid circles are positive residuals, and open circles are negative residuals. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

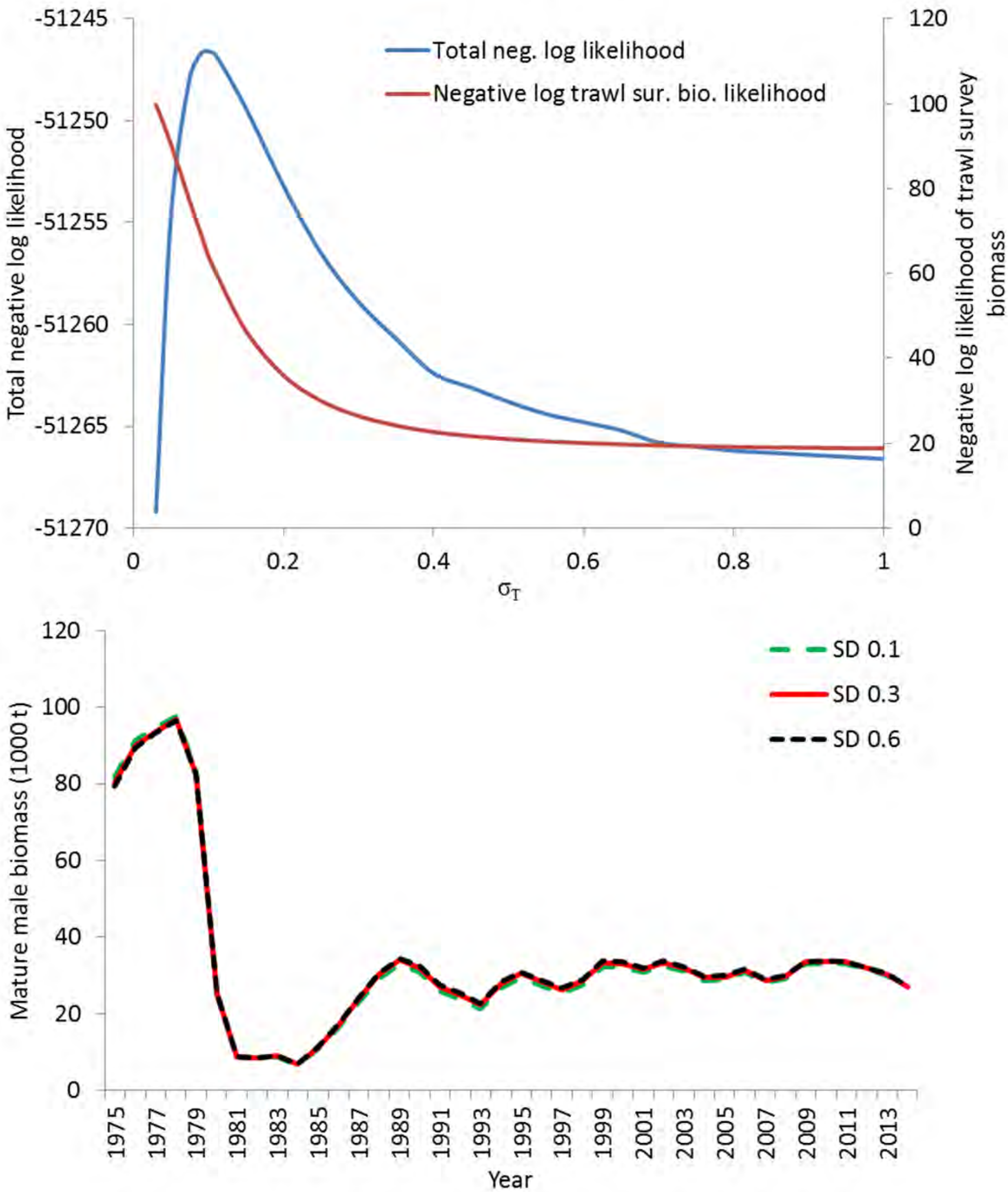

Figure 27a. Relationships among assumed temperature σ_T, total negative log likelihood and negative log trawl survey biomass likelihood (upper panel) and comparison of mature male biomass over time with assumed σ_T of 0.1, 0.3 and 0.6 (lower panel) for scenario 1a, based on data during 1975-2014.

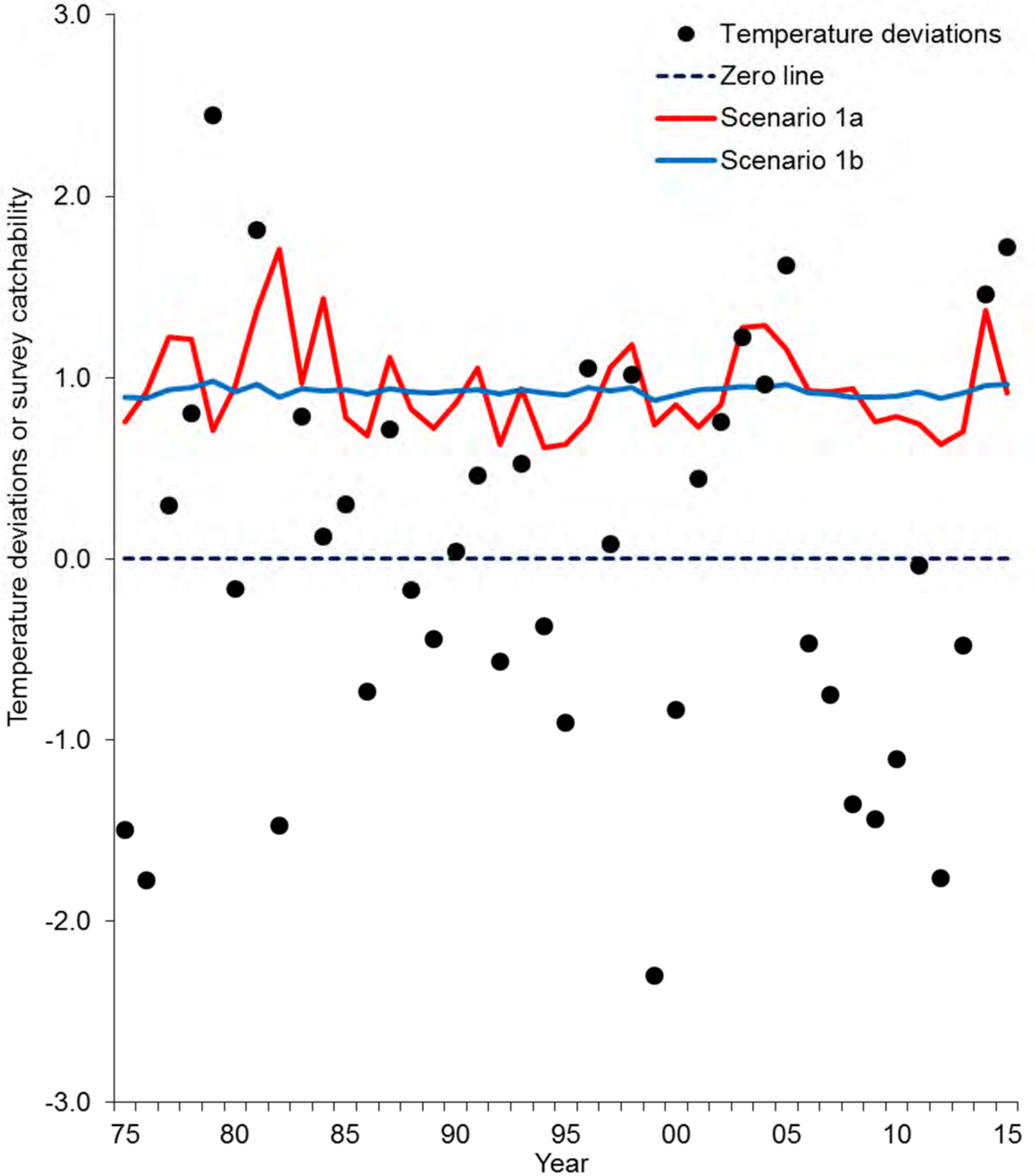

Figure 27b. Annual summer temperature deviations in Bristol Bay and annual estimated trawl survey catchabilities for scenarios 1a and 1b during 1975-2015.

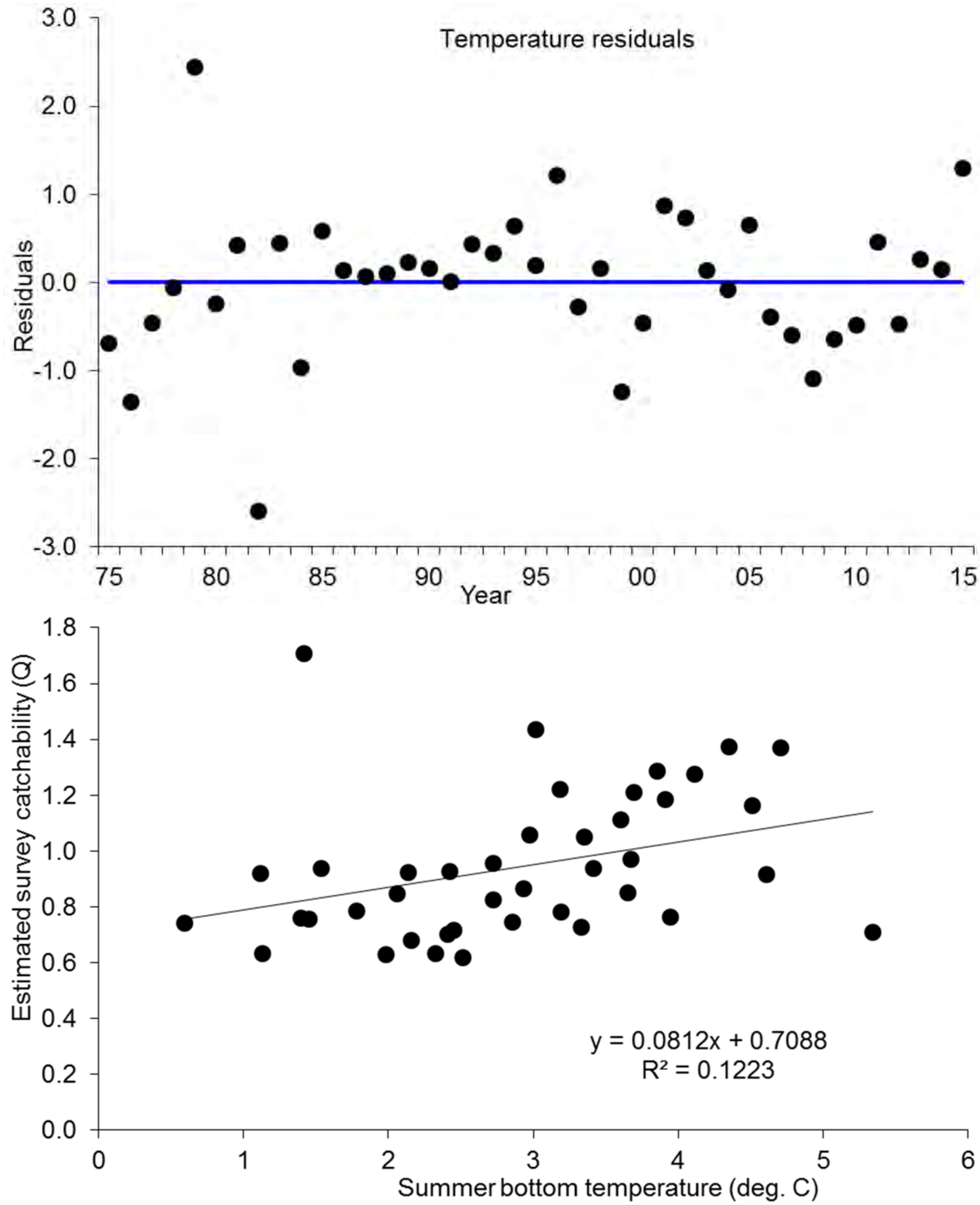

Figure 27c. Standardized temperature residuals during 1975-2015 (upper panel) and the relationship between annual estimated trawl survey catchabilities and summer bottom temperatures (lower panel) with an assumed σ_T of 0.3 for scenario 1a.

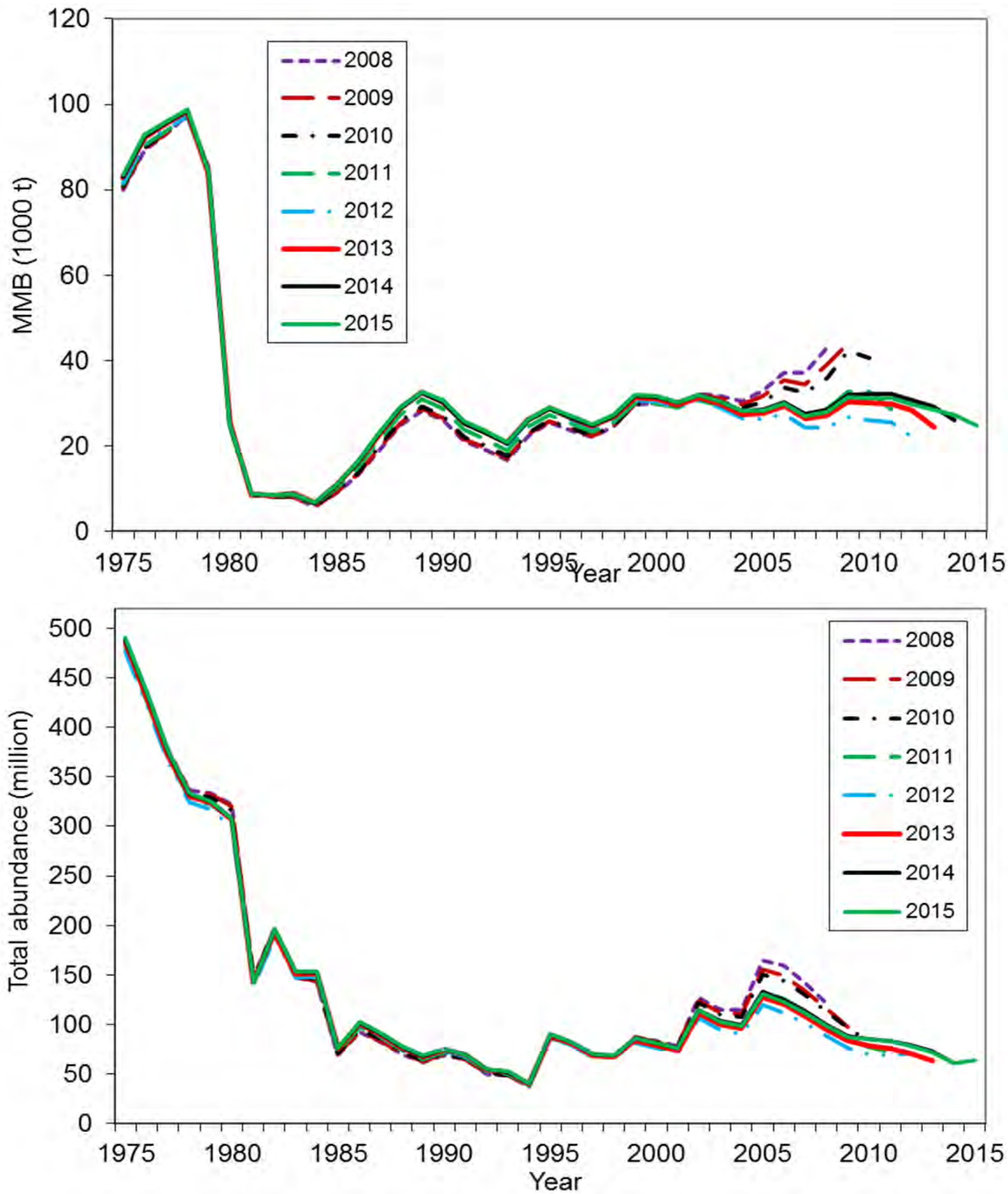

Figure 28a(1). Comparison of hindcast estimates of mature male biomass on Feb. 15 (top) and total abundance (bottom) of Bristol Bay red king crab from 1975 to 2015 made with terminal years 2008-2015 with scenario 1. These are results of the 2015 model. Legend shows the terminal year. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

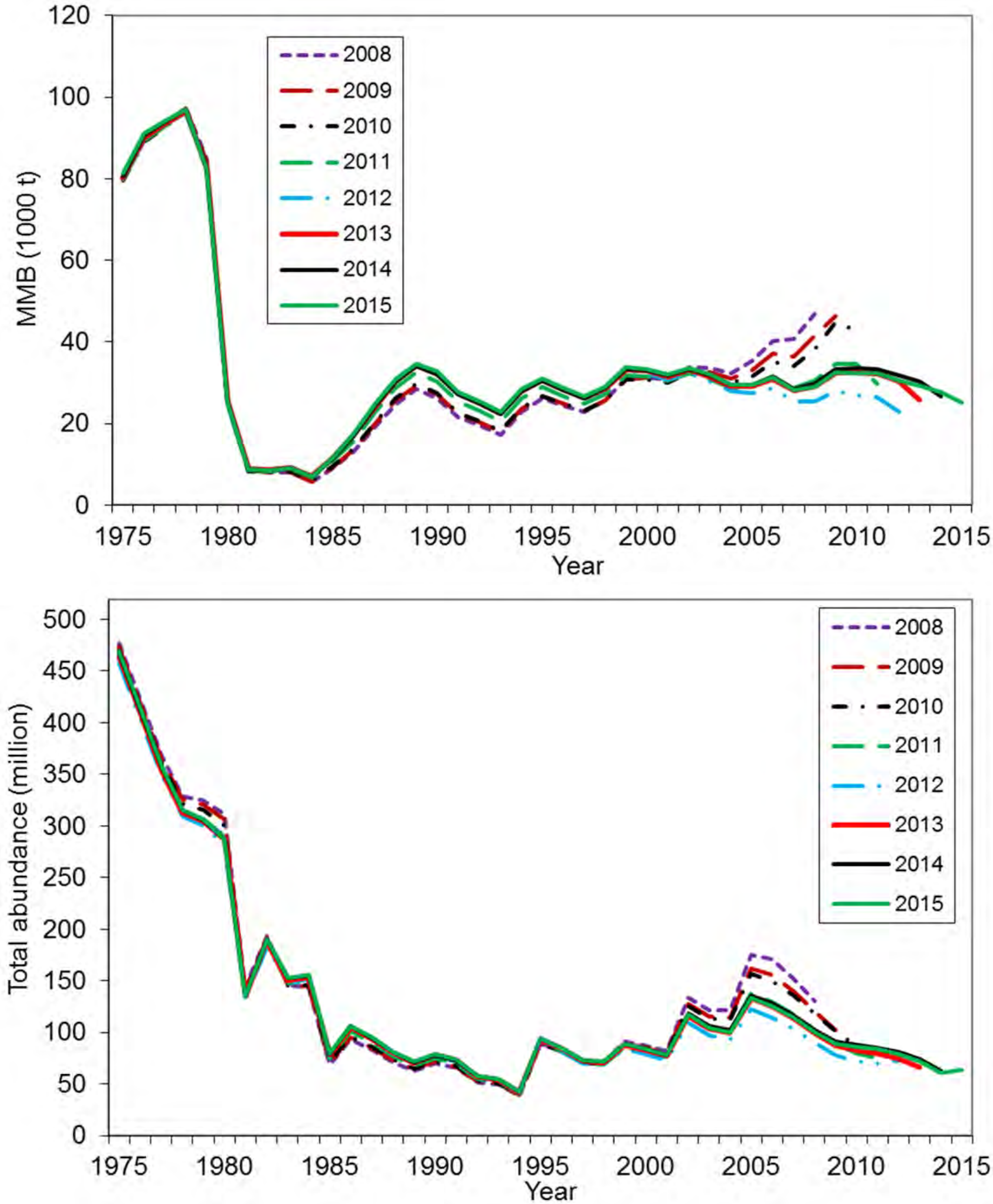

Figure 28a(1a). Comparison of hindcast estimates of mature male biomass on Feb. 15 (top) and total abundance (bottom) of Bristol Bay red king crab from 1975 to 2015 made with terminal years 2008-2015 with scenario 1a. These are results of the 2015 model. Legend shows the terminal year. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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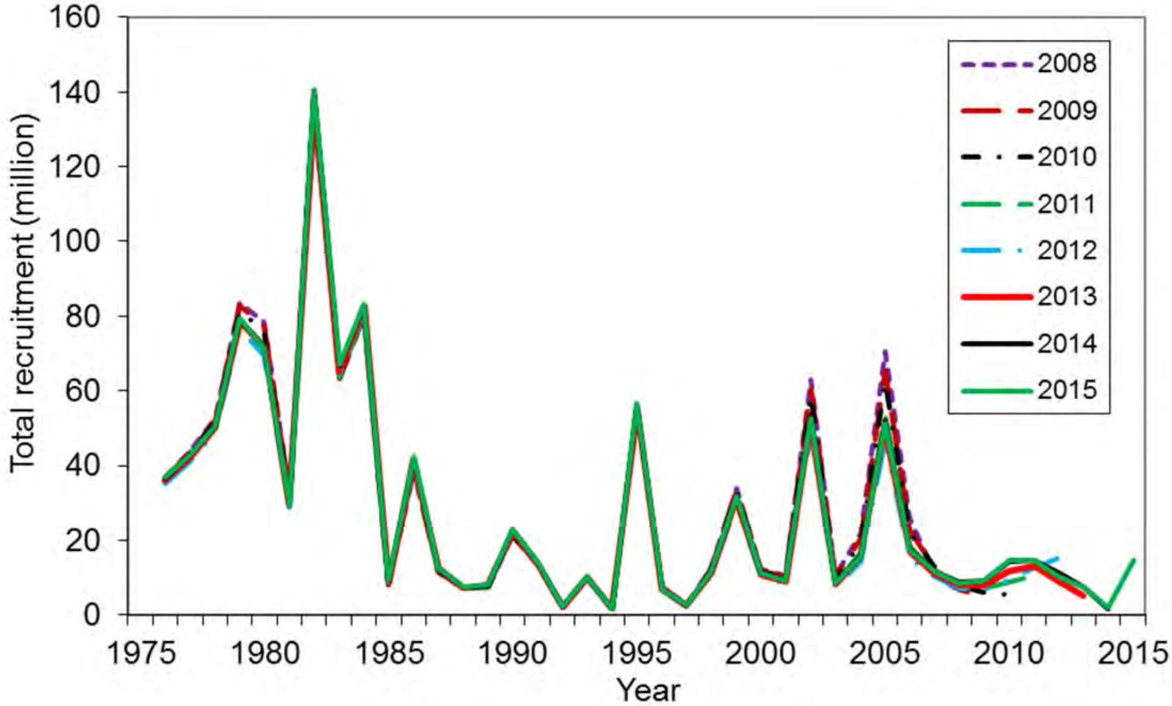

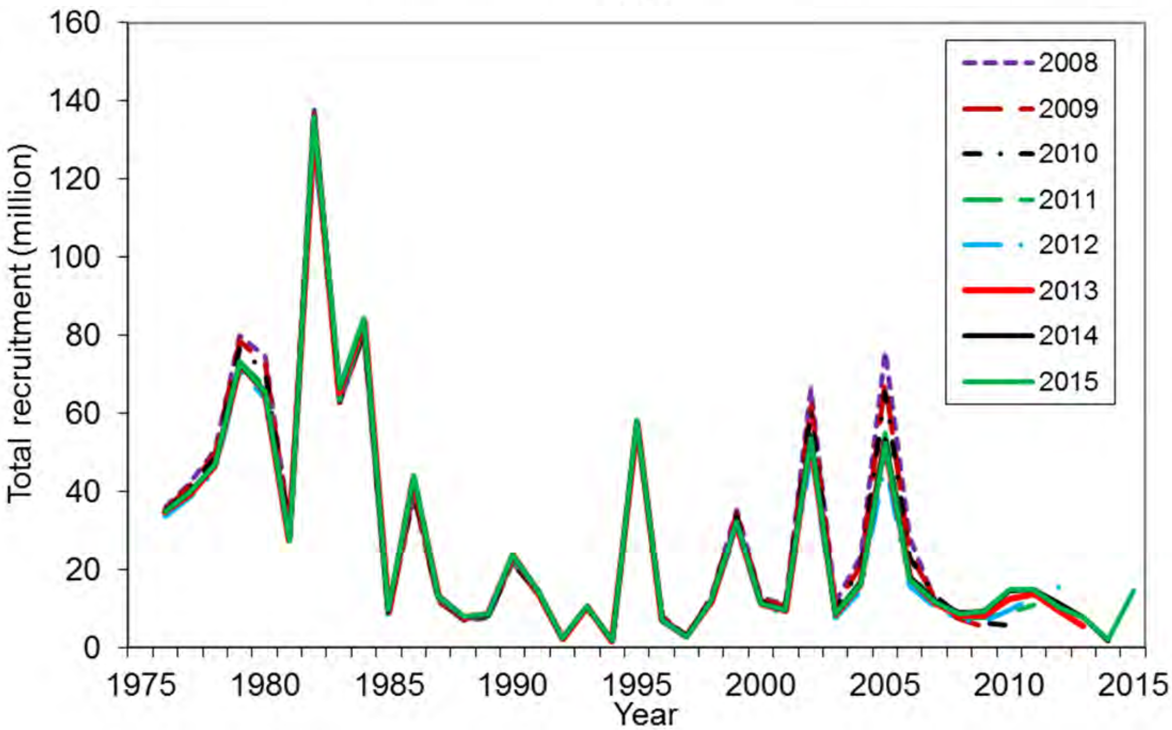

Figure 28b(1 & 1a). Comparison of hindcast estimates of total recruitment for scenario 1 (upper panel) and scenario 1a (lower panel) of Bristol Bay red king crab from 1976 to 2015 made with terminal years 2008-2015. These are results of the 2015 model. Legend shows the terminal year. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

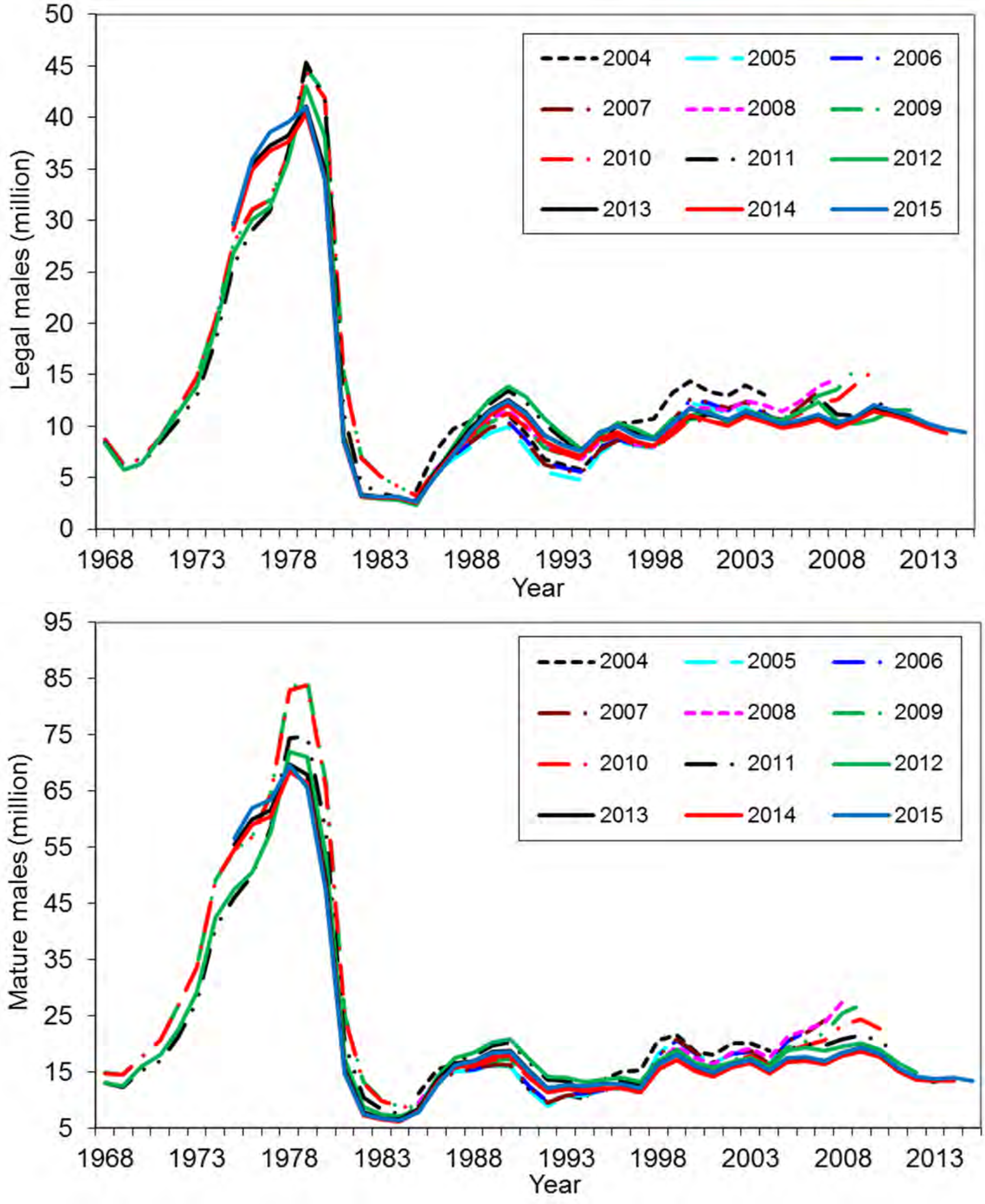

Figure 29. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1968 to 2015 made with terminal years 2004-2015 with the base scenarios. Scenario 1 is used for 2014 and 2015. These are results of historical assessments. Legend shows the year in which the assessment was conducted. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

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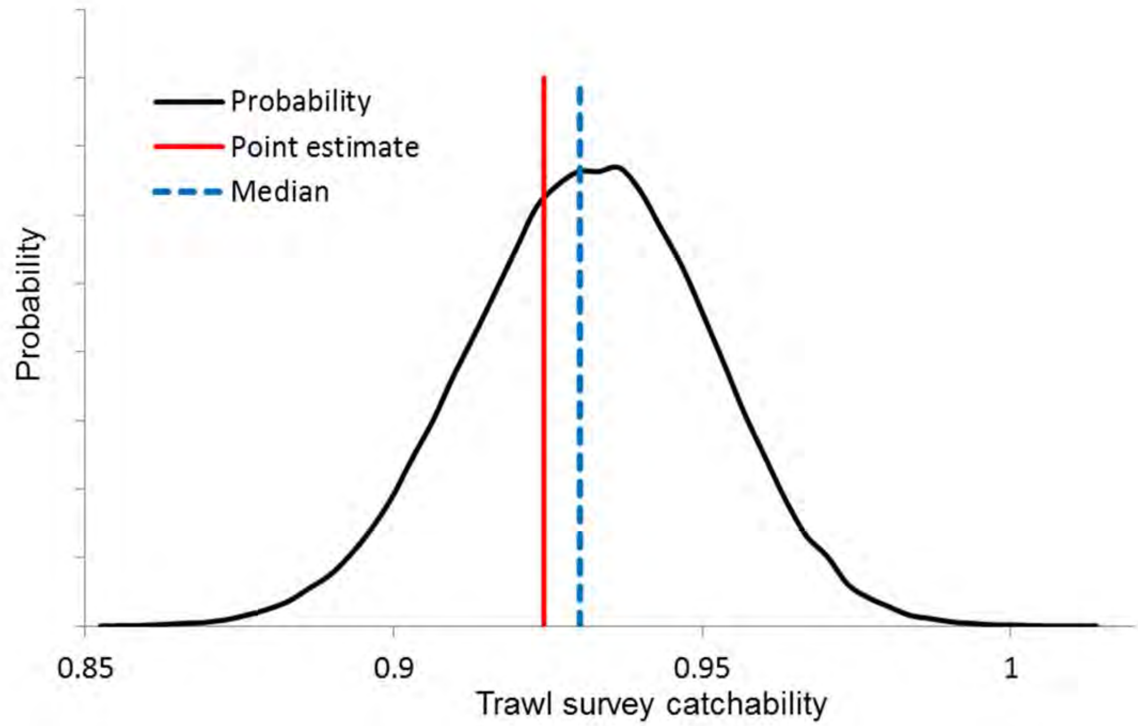


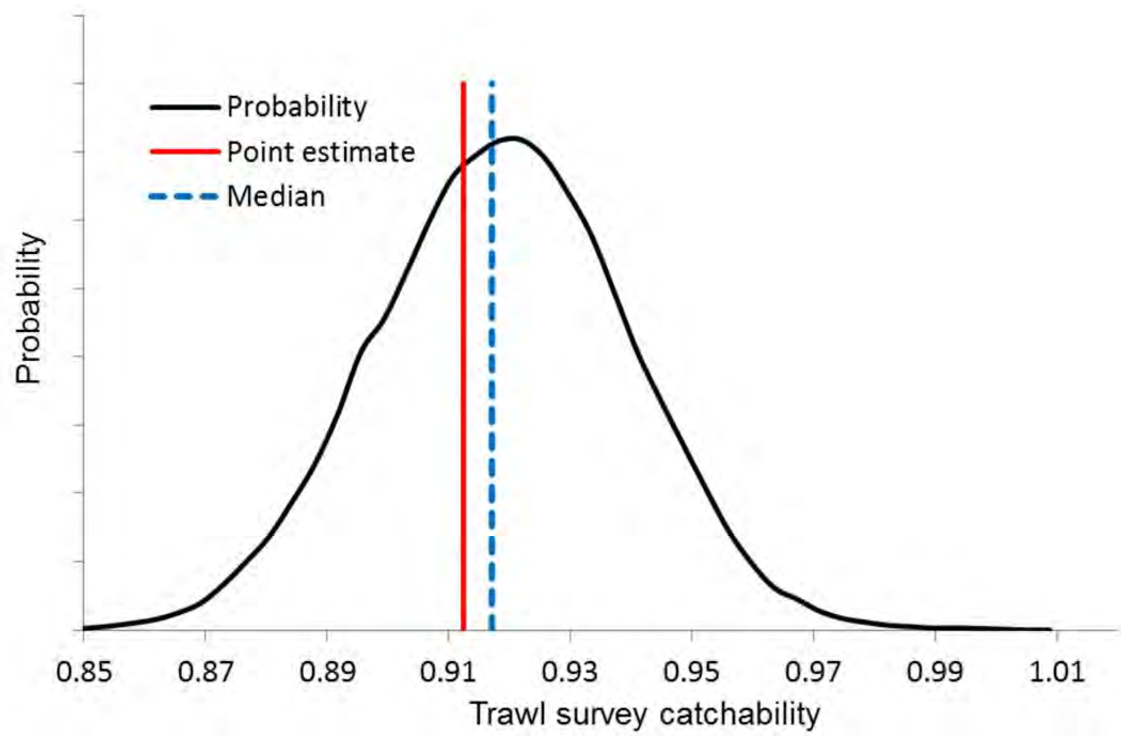


Figure 30(1&1a). Probability distributions of estimated trawl survey catchability (*Q*) under scenarios 1 (upper panel) and 1a (lower panel) with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

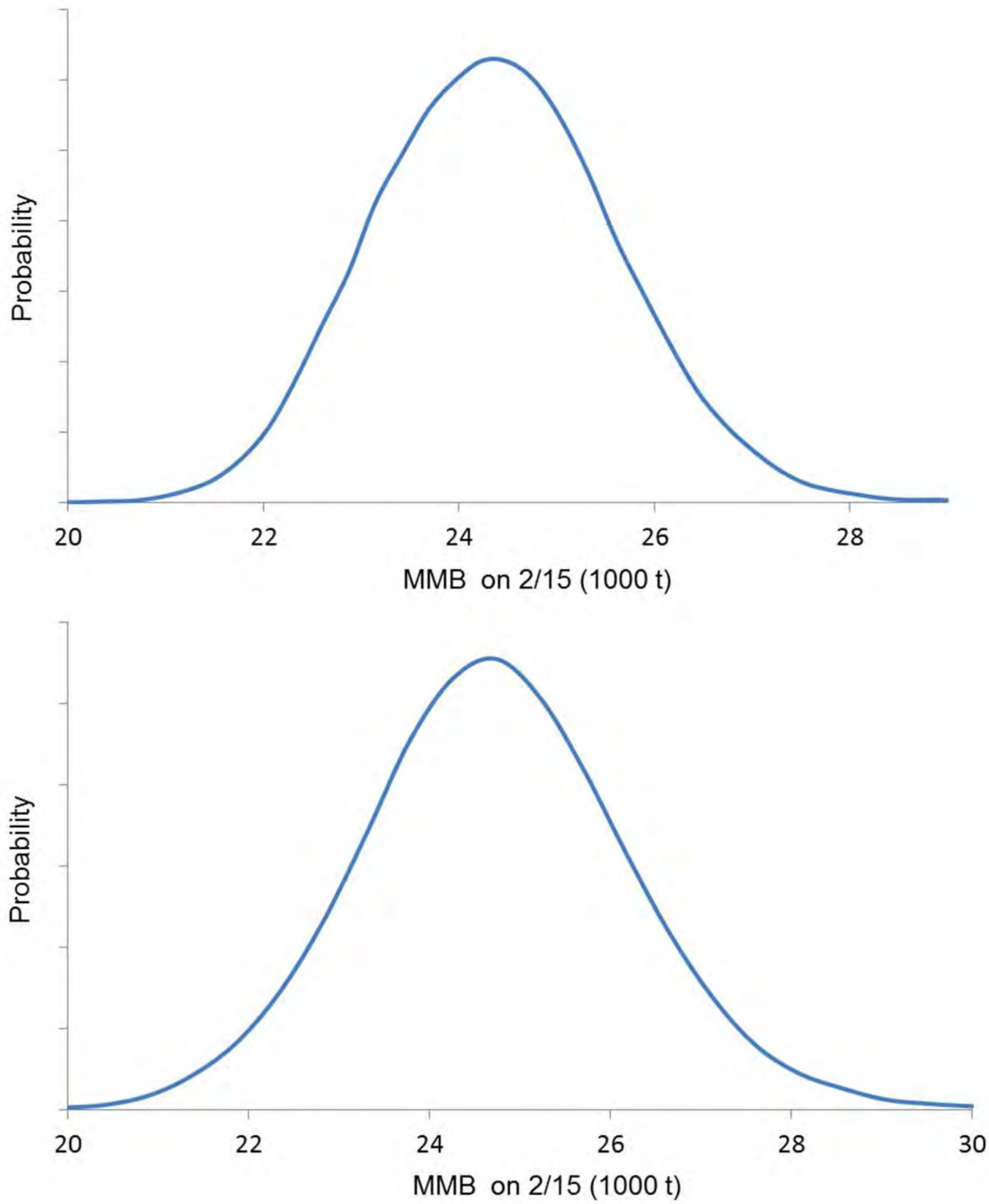


Figure 31a(1&1a). Probability distributions of estimated mature male biomass on Feb. 15, 2015 with $F_{35\%}$ under scenarios 1 (upper panel) and 1a (lower panel) with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

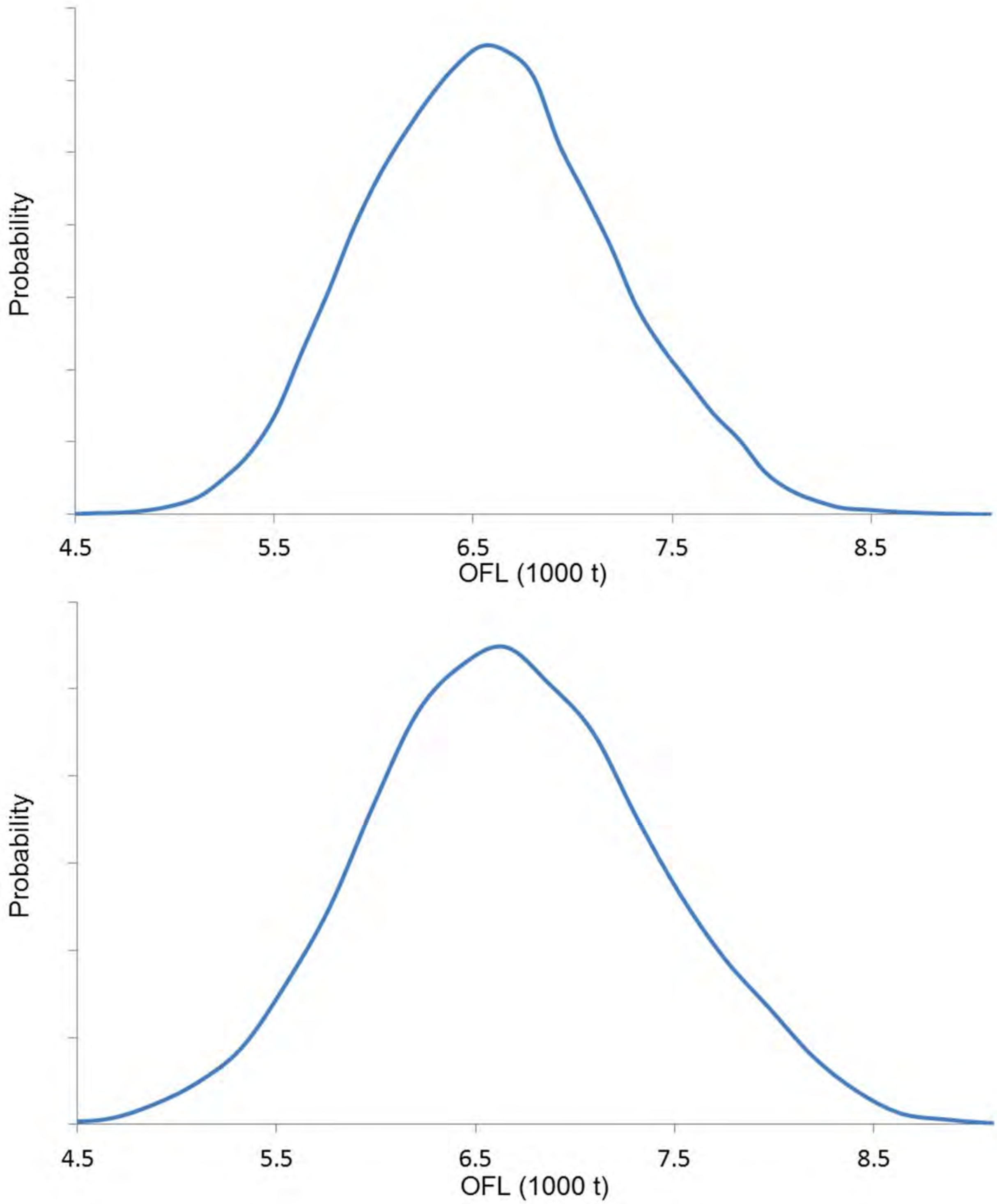


Figure 31b(1&1a). Probability distributions of the 2015 estimated OFL with scenarios 1 (upper panel) and 1a (lower panel) with the mcmc approach. Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively.

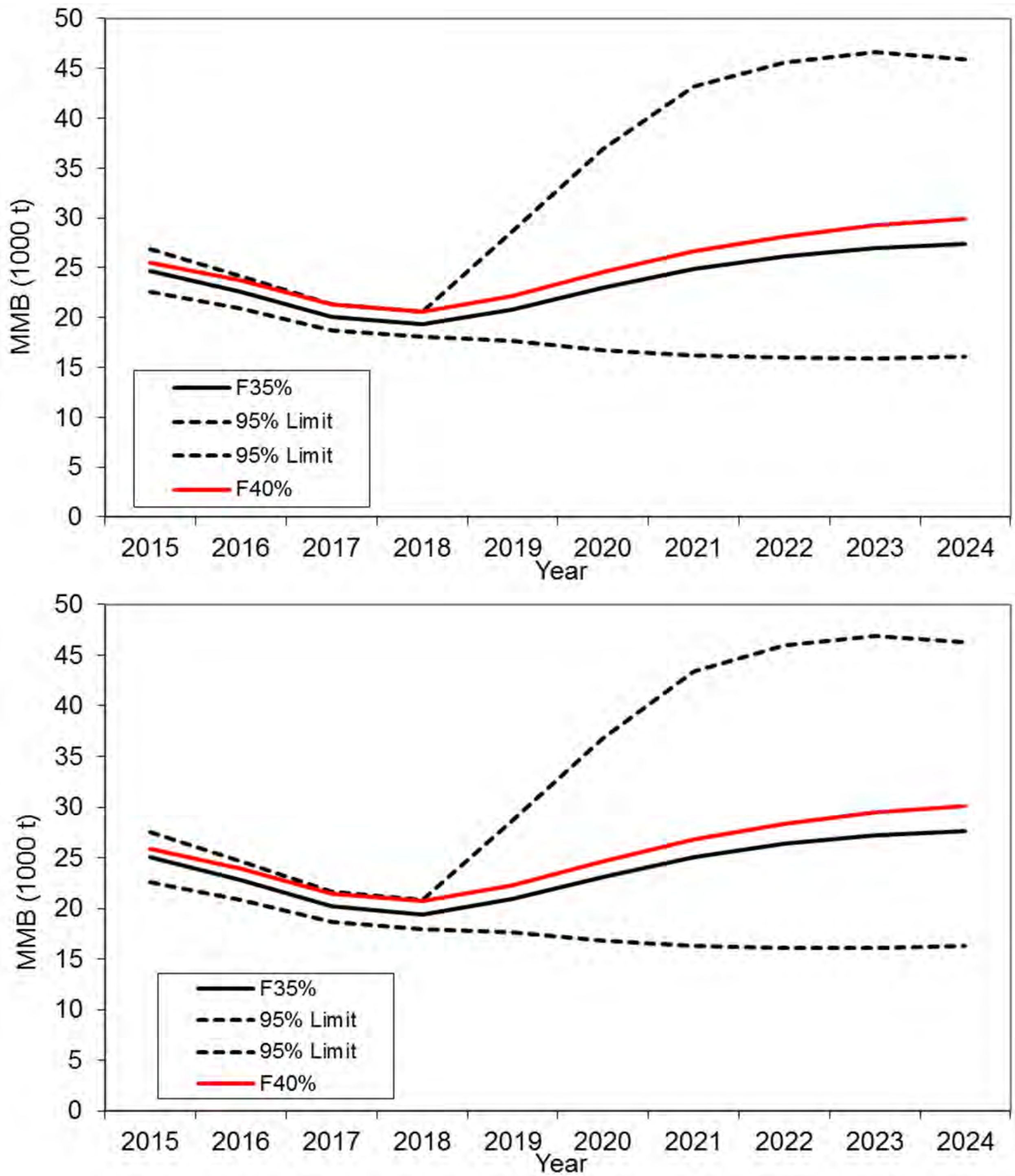


Figure 32(1&1a). Projected mature male biomass on Feb. 15 with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2015-2024. Input parameter estimates are based on scenarios 1 (upper panel) and 1a (lower panel). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence limits are for the $F_{35\%}$ harvest strategy.

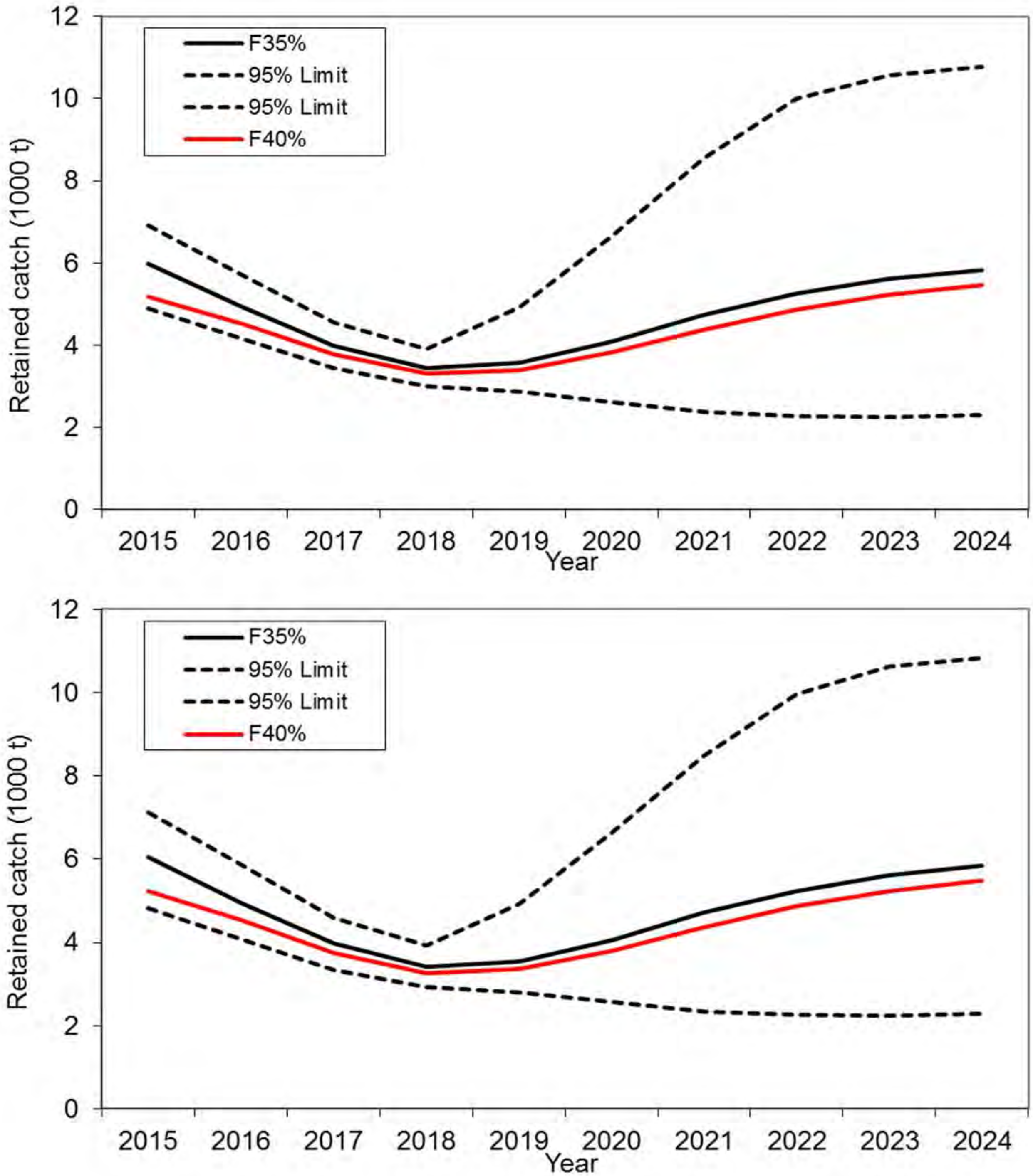


Figure 33(1&1a). Projected retained catch biomass with $F_{40\%}$ and $F_{35\%}$ harvest strategy during 2015-2124. Input parameter estimates are based on scenarios 1 (upper panel) and 1a (lower panel). Pot and trawl handling mortality rates were assumed to be 0.2 and 0.8, respectively, and the confidence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

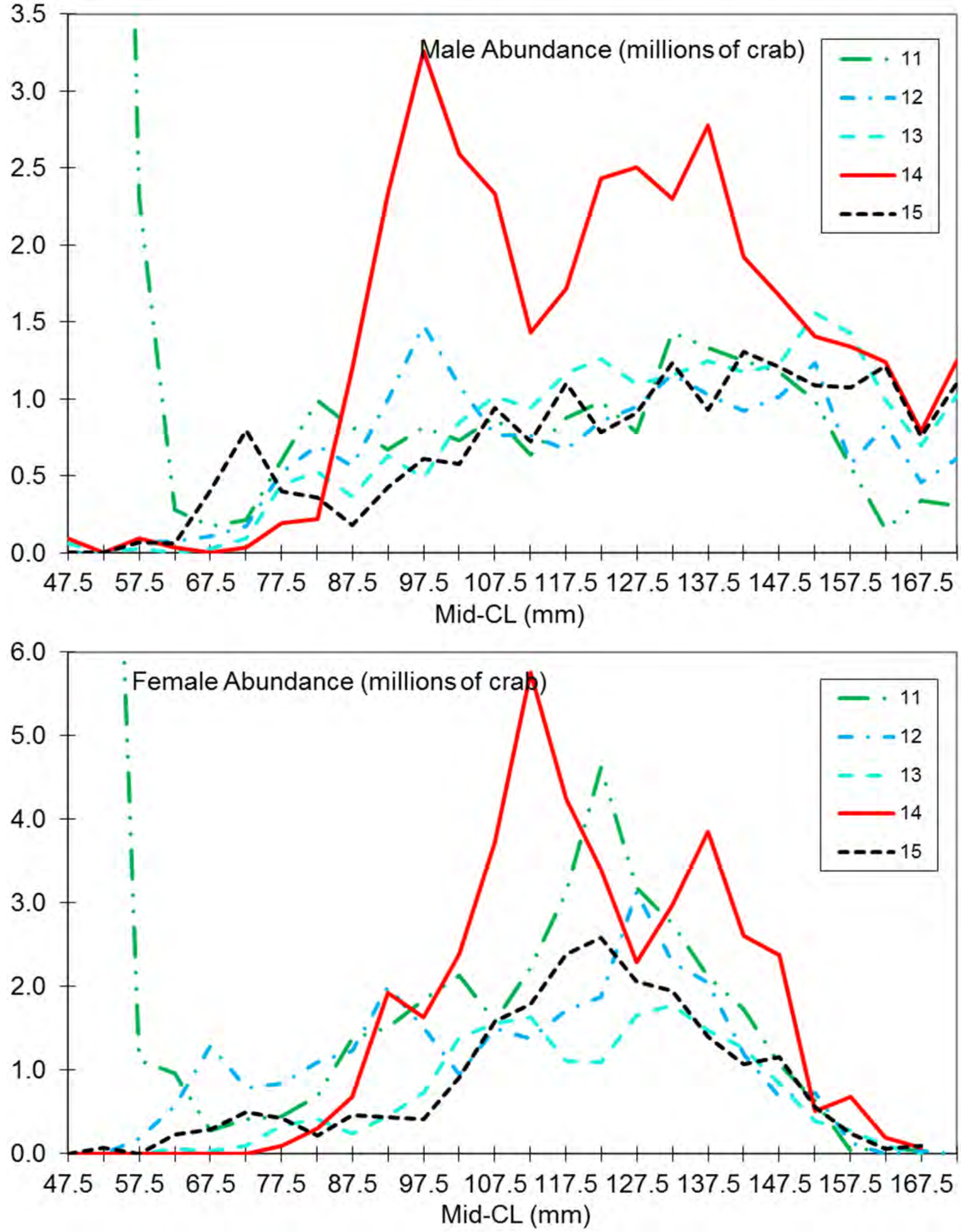


Figure 34. Length frequency distributions of male (top panel) and female (bottom panel) red king crab in Bristol Bay from NMFS trawl surveys during 2011-2015. For purposes of these graphs, abundance estimates are based on area-swept methods.

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:

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

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

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

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

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

where L_l is the mid-point of length-class *l*, ΔL the width of each size-class (5 mm carapace length), a_t^s, b_t^s the parameters of the length–growth increment relationship for sex *s* and year *t*, and β^s the parameter determining the variance of the growth increment. Growth is time-invariant for males, and specified for three time-blocks for females (1968-82; 1983-93; 1994-2014) based on changes to the size at maturity for females. The probability of moulting as a function of length for males is given by an inverse logistic function, i.e.:

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

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

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

The above population models are for scenarios 1, 1a and 1b. For scenario 2, immature and mature females are modeled separately. Defining N^i as immature females and N^m as mature females, the female abundances by carapace length and mature status for scenario 2 are:

$$N_{l,t+1}^i = \sum_{l'=1}^{l} \{P_{l',l,t}^i (N_{l',t}^i e^{-M_t^{fem}} - D_{l',t}^i e^{(y_t-1)M_t^{fem}} - T_{l',t}^i\, e^{(j_t-1)M_t^{fem}})(1-o_{l',t})\} + R_{t+1}^{fem} U_l^{fem}$$

$$\begin{aligned} N_{l,t+1}^m &= \sum_{l'=1}^{l} [P_{l',l,t}^m (N_{l',t}^m e^{-M_t^{fem}} - D_{l',t}^m e^{(y_t-1)M_t^{fem}} - T_{l',t}^m\, e^{(j_t-1)M_t^{fem}})] \\ &+ \sum_{l'=1}^{l} [P_{l',l,t}^i (N_{l',t}^i e^{-M_t^{fem}} - D_{l',t}^i e^{(y_t-1)M_t^{fem}} - T_{l',t}^i\, e^{(j_t-1)M_t^{fem}}) o_{l',t}] \end{aligned} \tag{A4}$$

where superscripts *i* stands for immature females, *m* for mature females and *fem* for females, and $o_{l,t}$ is the mature probability in length-class *l* in year *t*. Equations A1-A3 apply to scenario 2 except for the growth increments for mature females. Although the linear relationship is used for mature female growth increments, due to lack of data, the linear equation is used to estimate growth increments starting at 90 mm CL and estimated growth increments per molt for mature females <90 mm CL are assumed as the same as that of 90 mm CL.

Mature probability, $o_{l,t}$, is a logistic function of length with two parameters like equation A3. A random walk approach is used to model the annual changes of sizes at the 50% maturity for females ($L_{50,t}$) for scenario 2:

$$L_{50,t+1} = L_{50,t}\, e^{\delta_t} \tag{A5}$$

where δ_t are independent, normally distributed random variables with a mean of zero. This allows us to model the changes in maturity probability over time under a constraint condition.

ii. Catches and Fisheries Selectivities

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

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

$$G_{l,t}^{s} = (N_{l,t}^{s} + O_{l,t}^{s})e^{-y_t M_t^s}(1-e^{-F_{l,t}^{s}}) \tag{A6}$$

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

$$F_{l,t}^{s} = \begin{cases} S_l^{\text{dir,land}} F_t^{\text{dir}} + (S_l^{\text{dir,disc,mal}} + h_t \phi S_{l,t}^{\text{dir,land}}) F_t^{\text{disc,mal}} + S_l^{\text{trawl}} F_t^{\text{trawl}} & \text{if } s = \text{mal} \\ S_l^{\text{dir,disc,fem}} F_t^{\text{disc,fem}} + S_l^{\text{trawl}} F_t^{\text{trawl}} & \text{if } s = \text{fem} \end{cases} \tag{A7}$$

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

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

$$\begin{aligned} C_{l,t}^{\text{mal}} &= (N_{l,t}^{\text{mal}} + O_{l,t}^{\text{mal}})e^{-y_t M_t^{\text{mal}}}(1-e^{-S_l^{\text{dir,land}} F_t^{\text{dir}}}) \\ D_{l,t}^{\text{mal}} &= G_{l,t}^{\text{mal}} - C_{l,t}^{\text{mal}} \end{aligned} \tag{A8}$$

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

$$T_{l,t}^{s} = (N_{l,t}^{s} + O_{l,t}^{s}) e^{-j_t M_t^s} e^{-F_{l,t}^{s}} (1 - e^{-\tilde{F}_{l,t}^{s}}) \tag{A9}$$

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

$$\tilde{F}_{l,t}^{s} = S_l^{\text{Tanner},s} F_t^{\text{Tanner},s} \tag{A10}$$

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

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

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

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

$$\begin{aligned} T_{l,t}^{i} &= N_{l,t}^{i} e^{-j_t M_t^{fem}} e^{-F_{l,t}^{fem}} (1 - e^{-\tilde{F}_{l,t}^{fem}}) \\ T_{l,t}^{m} &= N_{l,t}^{m} e^{-j_t M_t^{fem}} e^{-F_{l,t}^{fem}} (1 - e^{-\tilde{F}_{l,t}^{fem}}) \end{aligned} \tag{A12}$$

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

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

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

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

$$\begin{aligned} s_l &= \varphi + \kappa \iota, \quad if\ \iota < 135 \text{mm CL}, \\ s_l &= s_{l-1} + 5\gamma, \quad if\ \iota > 134 \text{mm CL} \end{aligned} \tag{A14}$$

where φ, κ, γ are parameters.

iii. Trawl Survey Selectivities/Catchability

Trawl survey selectivities/catchability are estimated as

$$S^s_{l,t} = \frac{Q}{1 + e^{-\beta^s_t \ (t - L^s_{50,t})}} \tag{A15}$$

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

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

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

c. Likelihood Components

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

$$Rf = \prod_{l=1}^{L}\prod_{t=1}^{T}\prod_{s=1}^{2}\prod_{sh=1}^{2} \frac{\left\{\exp\left[-\frac{(p_{l,t,s,sh} - \hat{p}_{l,t,s,sh})^2}{2\sigma^2}\right] + 0.01\right\}}{\sqrt{2\pi\sigma^2}} \tag{A16}$$

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

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:

$$\begin{aligned}
&Length\ compositions: \quad -\sum \ln(Rf_i) \\
&Biomasses\ other\ than\ survey: \quad \lambda_j \sum \left[\ln(C_t / \hat{C}_t)^2\right] \\
&NMFS\ survey\ biomass: \quad \sum \left[\ln(B_t / \hat{B}_t)^2 / (2\ln(CV_t^2 + 1))\right] \\
&BSFRF\ mature\ males: \quad \sum [\ln(\ln(CV_t^2 + 1))^{0.5} + \ln(B_t / \hat{B}_t)^2 / (2\ln(CV_t^2 + 1))] \\
&R\ variation: \quad \lambda_R \sum [\ln(R_t / \overline{R})^2] \\
&R\ sex\ ratio: \quad \lambda_s [\ln(\overline{R}_M / \overline{R}_F)^2] \\
&Trawl\ bycatch\ fishing\ mortalities: \lambda_t [\ln(F_{t,t} / \overline{F}_t)^2] \qquad \text{(A17)} \\
&Pot\ female\ bycatch\ fishing\ mortalities: \lambda_p [\ln(F_{t,f} / \overline{F}_f)^2] \\
&Trawl\ survey\ catchability: (Q - \hat{Q})^2 / (2\sigma^2) \\
&Scenario 2, each\ of\ six\ growth\ increment\ parameters: (a - \hat{a})^2 / (2\sigma^2) \\
&Scenario 2, penalty\ for\ random\ walk\ at\ size\ of\ 50\%\ maturity: \lambda_m \delta^2
\end{aligned}$$

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, 0.1 for trawl bycatch fishing mortality, and 200 for female maturity (scenario 2). These λ_j values represent prior assumptions about the accuracy of the observed catch biomass data and about the variances of these random variables.

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, and 0.1605 in 2014, based on the proportions of discarded legal males to total caught legal males. Handling mortality rates were set to 0.2 for the directed pot fishery, 0.25 for the Tanner crab fishery, and 0.8 for the trawl fisheries.

(1). Natural Mortality

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

(2). Length-weight Relationship

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

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

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

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

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

(3). Growth Increment per Molt

A variety of data are available to estimate male mean growth increment per molt for Bristol Bay RKC. Tagging studies were conducted during the 1950s, 1960s and 1990s, and mean growth increment per molt data from these tagging studies in the 1950s and 1960s were analyzed by Weber and Miyahara (1962) and Balsiger (1974). Modal analyses were conducted for the data during 1957-1961 and the 1990s (Weber 1967; Loher et al. 2001). Mean growth increment per molt may be a function of body size and shell condition and vary over time (Balsiger 1974; McCaughran and Powell 1977); however, for simplicity, mean growth increment per molt was assumed to be only a function of body size in the models. Tagging data were used to estimate mean growth increment per molt as a function of pre-molt length for males (Figure A2). The results from modal analyses of 1957-1961 and the 1990s were used to estimate mean growth increment per molt for immature females during 1975-1993 and 1994-2015, respectively, and the data presented in Gray (1963) were used to estimate those for mature females for scenarios 1, 1a and 1b (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 1994-2015, 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).

For females with scenario 2, some new immature female growth data from Kodiak red king crab are used to estimate initial parameter values of immature female growth increments per molt function (Figure A2(2)). Initial parameter values for three growth increments-per-molt functions are estimated using the growth increments per molt data: immature females, mature females, and males. Parameters for growth increments per molt are estimated inside the model with these initial estimates as a prior.

(4). Sizes at Maturity for Females

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

(5). Sizes at Maturity for Males

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

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

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

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

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

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

Overall, the likely causes for the sharp decline in the early 1980s are combinations of the above factors, such as pot fisheries on legal males, bycatch, and predation on females and juvenile and sublegal males, senescence for older crab, and disease for all crab. In our model, we estimated one mortality parameter for males and another for females during 1980-1984. We also estimated a mortality parameter for females during 1976-1979 and 1985-1993. These three mortality parameters are additional to the basic natural mortality of 0.18, 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 2015), 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 are estimated for the survey data from the Bering Fisheries Research Foundation. Annual fishing mortalities were also estimated for the directed pot fishery for males (1975-2014), pot-discarded females from the directed fishery (1990-2014), pot-discarded males and females from the eastern Bering Sea Tanner crab fishery (1991-93, 2013-14), and groundfish trawl discarded males and females (1976-2014). 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 number of males in the 1st seven length classes (65- 99 mm CL) and new number of females in the 1st five length classes (65-89 mm CL).

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

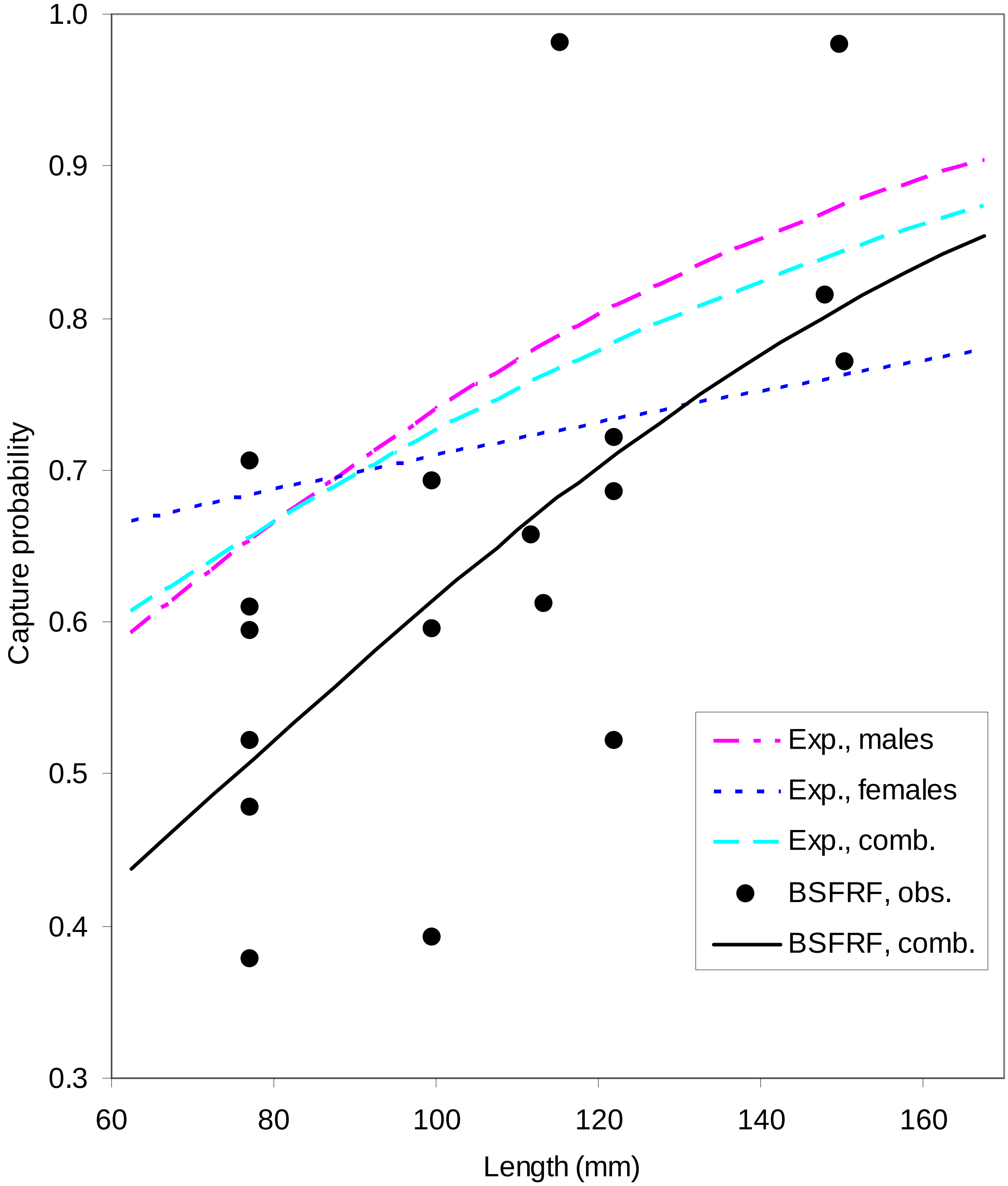
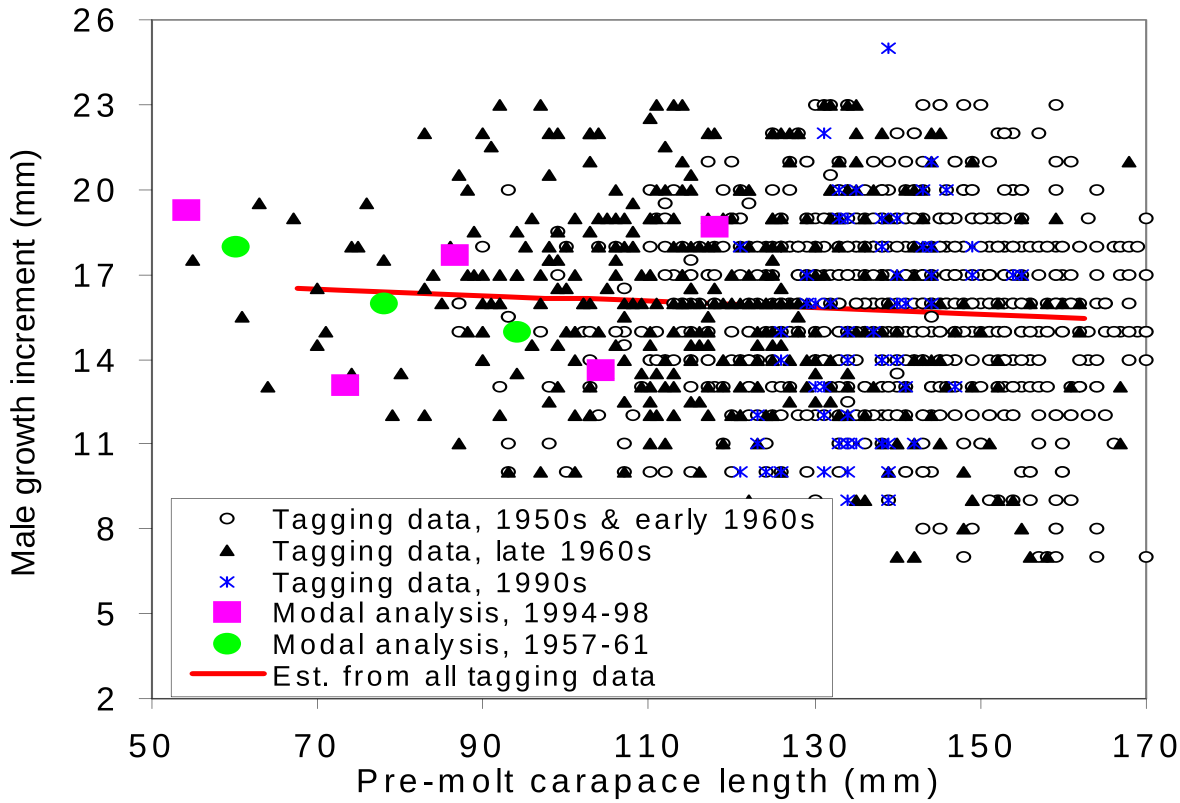


Figure A1. Estimated capture probabilities for NMFS Bristol Bay red king crab trawl surveys by Weinberg et al. (2004) and the Bering Sea Fisheries Research Foundation surveys.



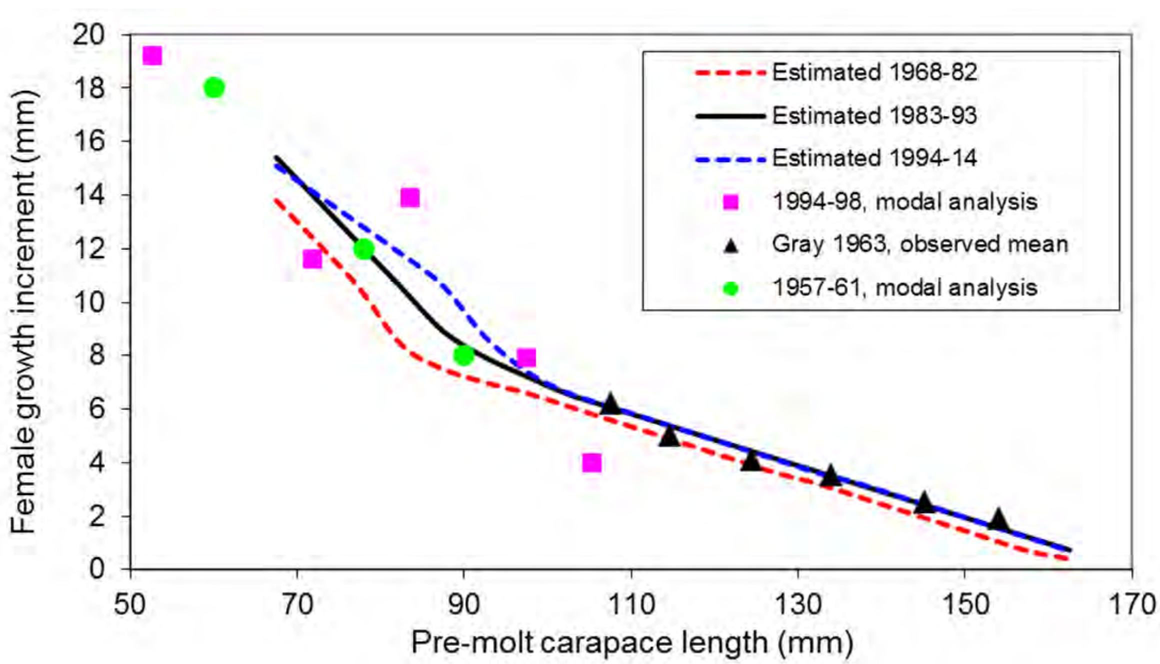


Figure A2. Mean growth increments per molt for Bristol Bay red king crab. Note: "tagging"---based on tagging data; "mode"---based on modal analysis. The female growth increments per molt are for scenarios 1, 1a and 1b.

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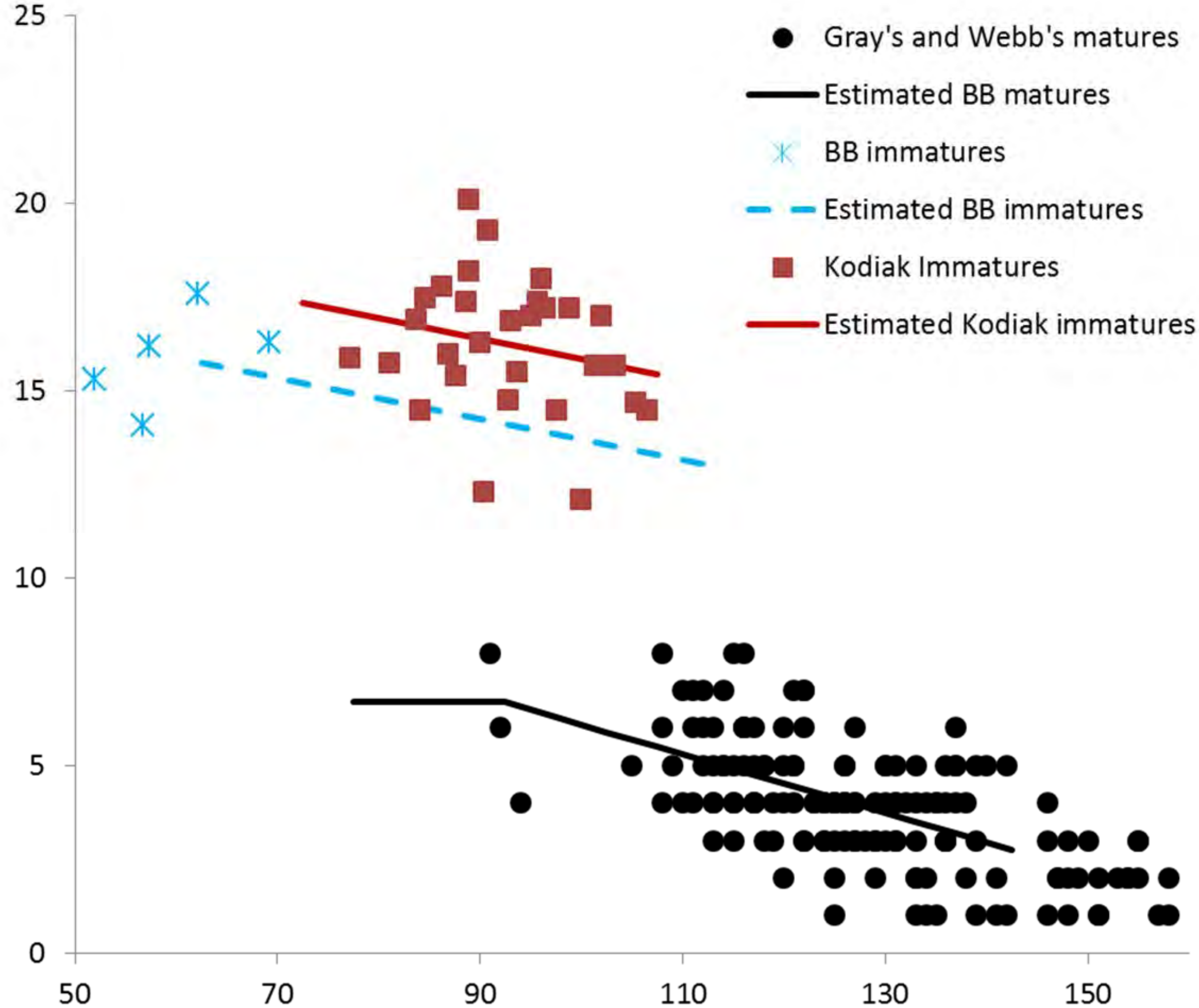

Figure A2(2). Mean growth increments per molt for female Bristol Bay red king crab for scenario 2. The slope parameter of the Bristol Bay immature female function is assumed to be the same as that of Kodiak red king crab; Estimated growth increments per molt for mature females <90 mm CL are assumed as the same as that of 90 mm CL.

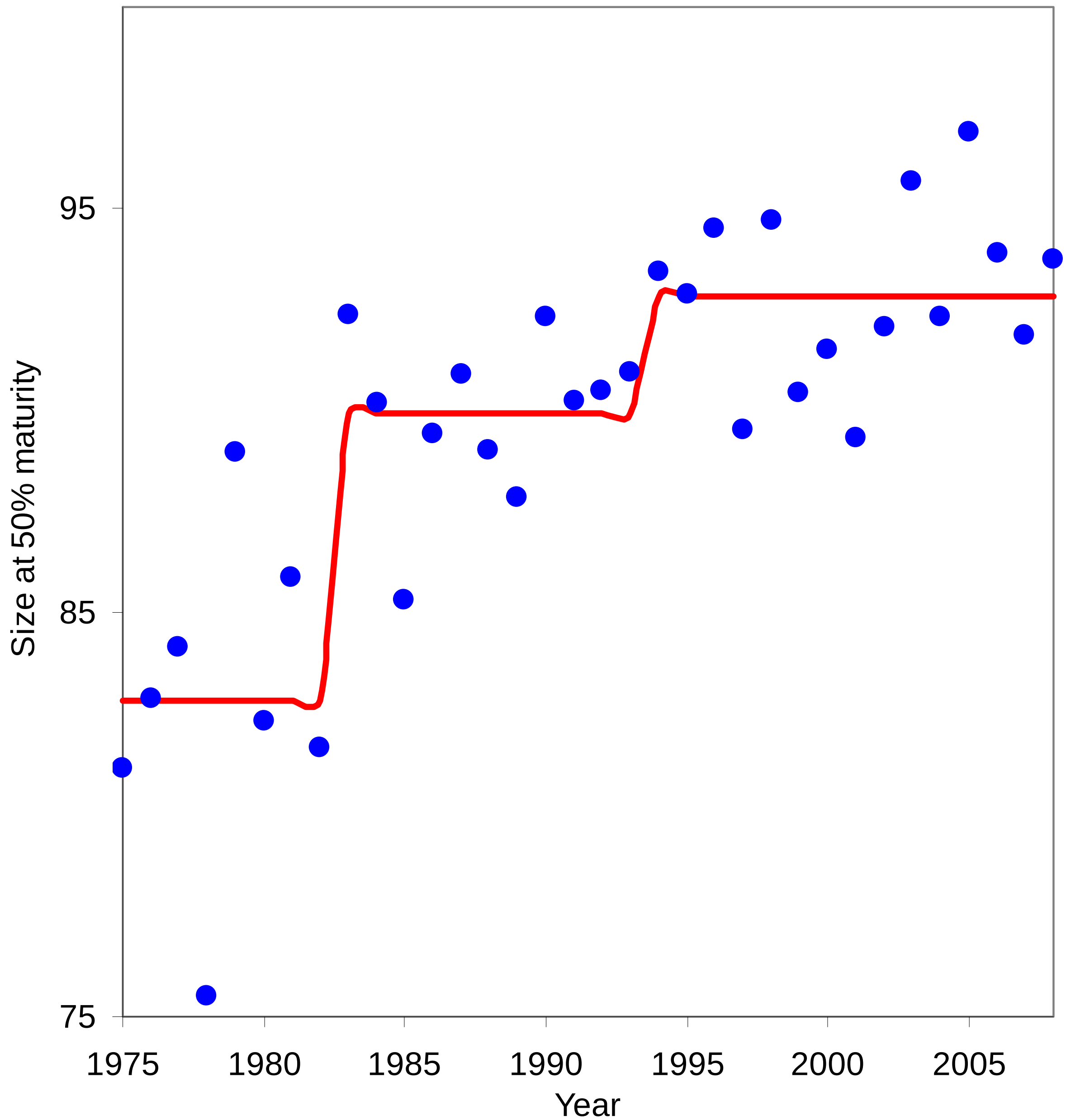

Figure A3. Estimated sizes at 50% maturity for Bristol Bay female red king crab from 1975 to 2008. Averages for three periods (1975-82, 1983-93, and 1994-08) are plotted with a line.

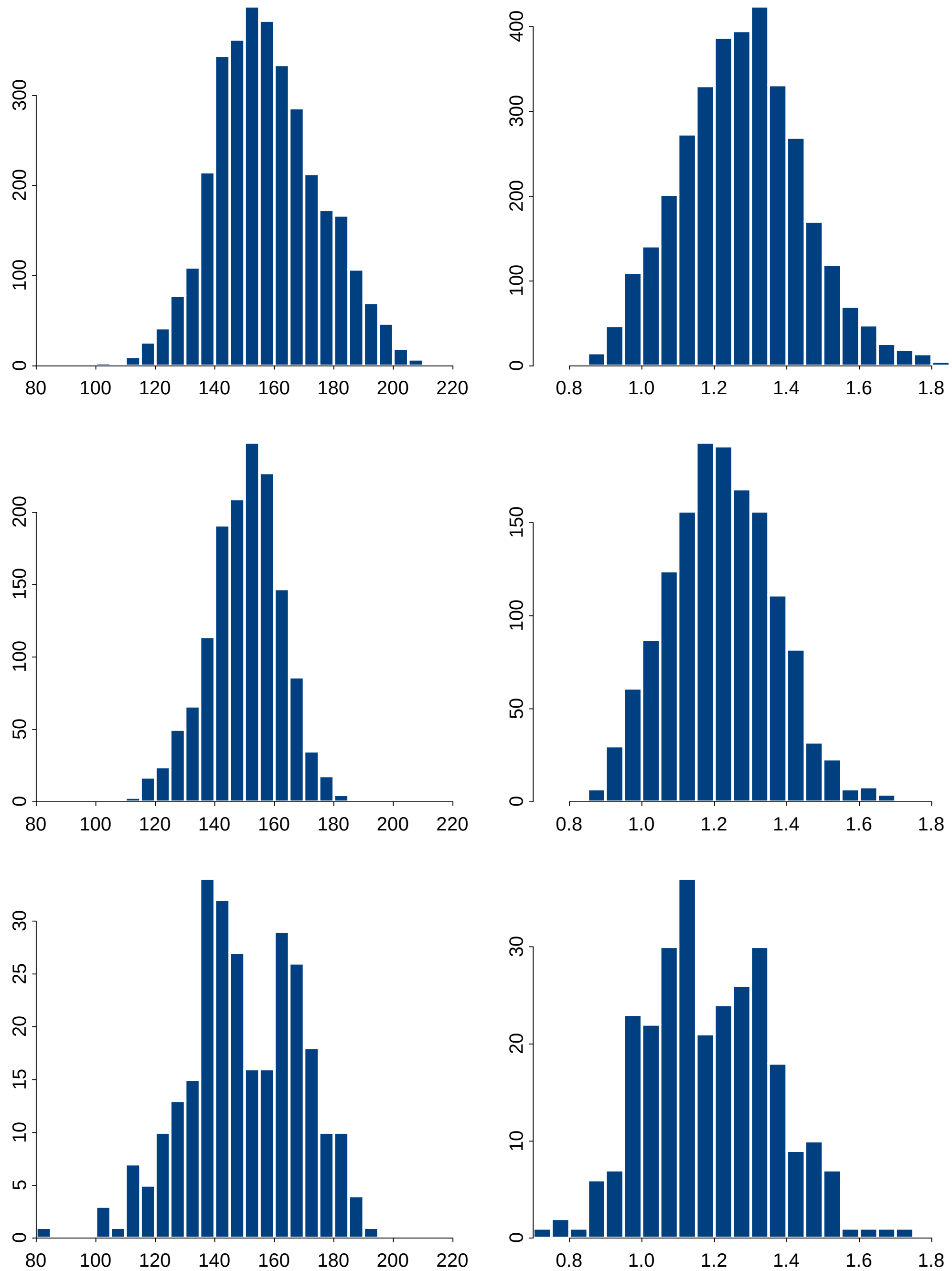

Figure A4. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages ≤13 months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak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

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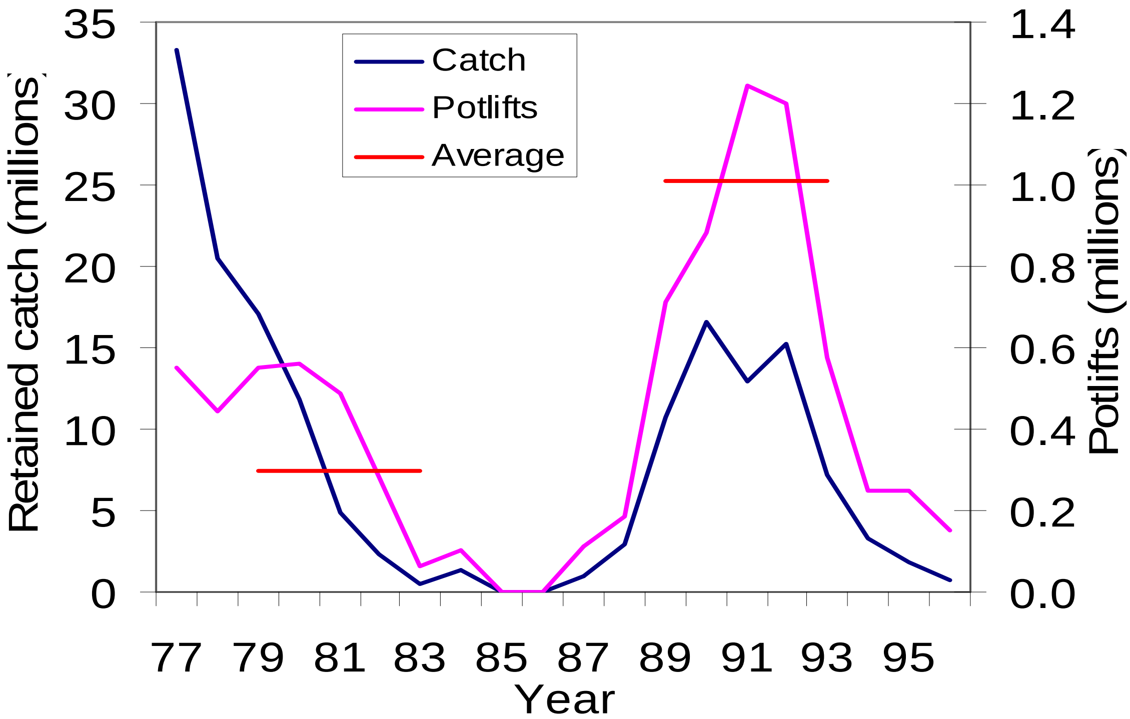


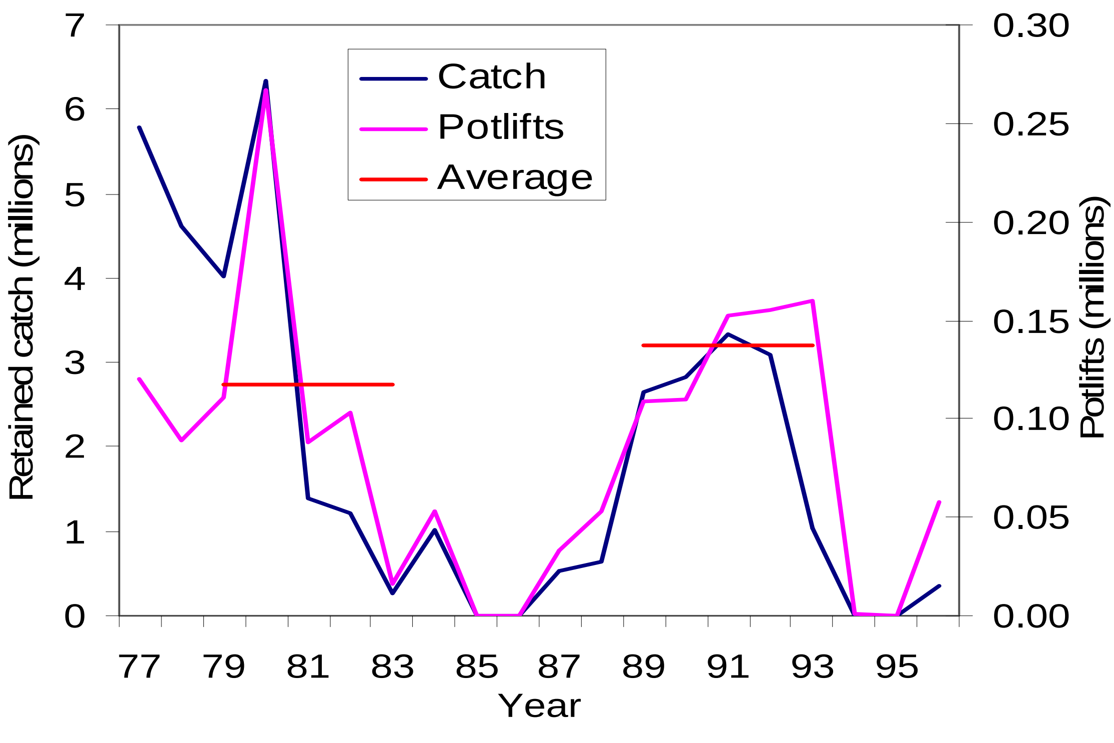
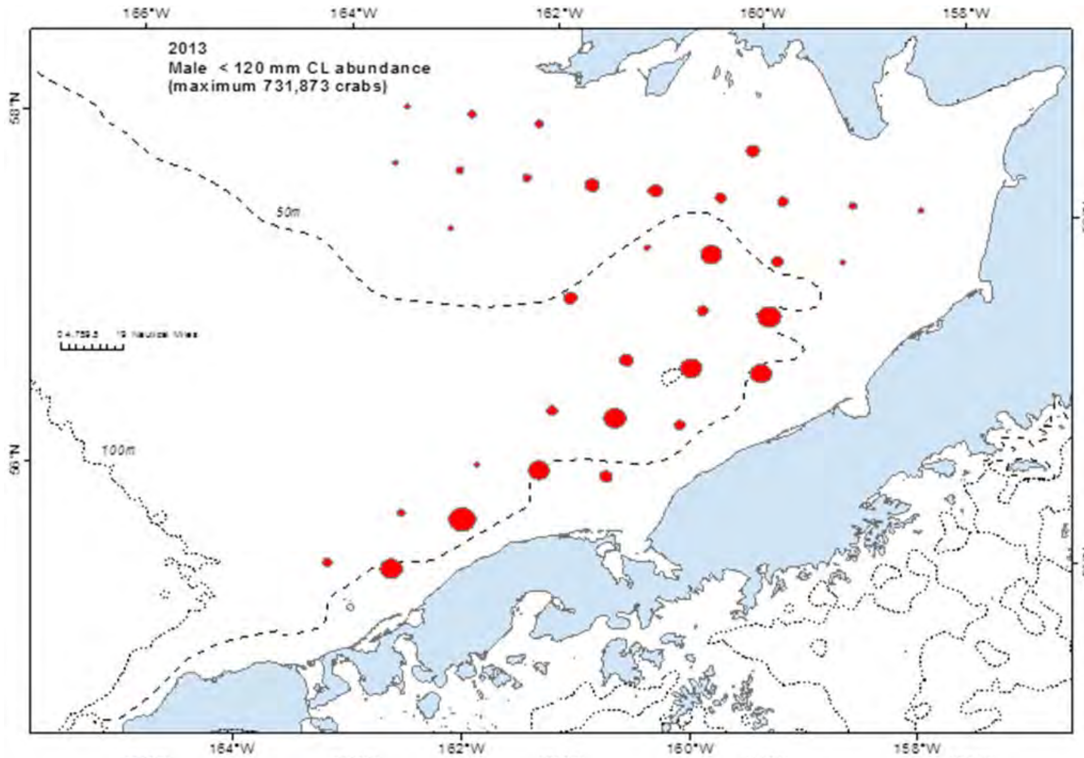
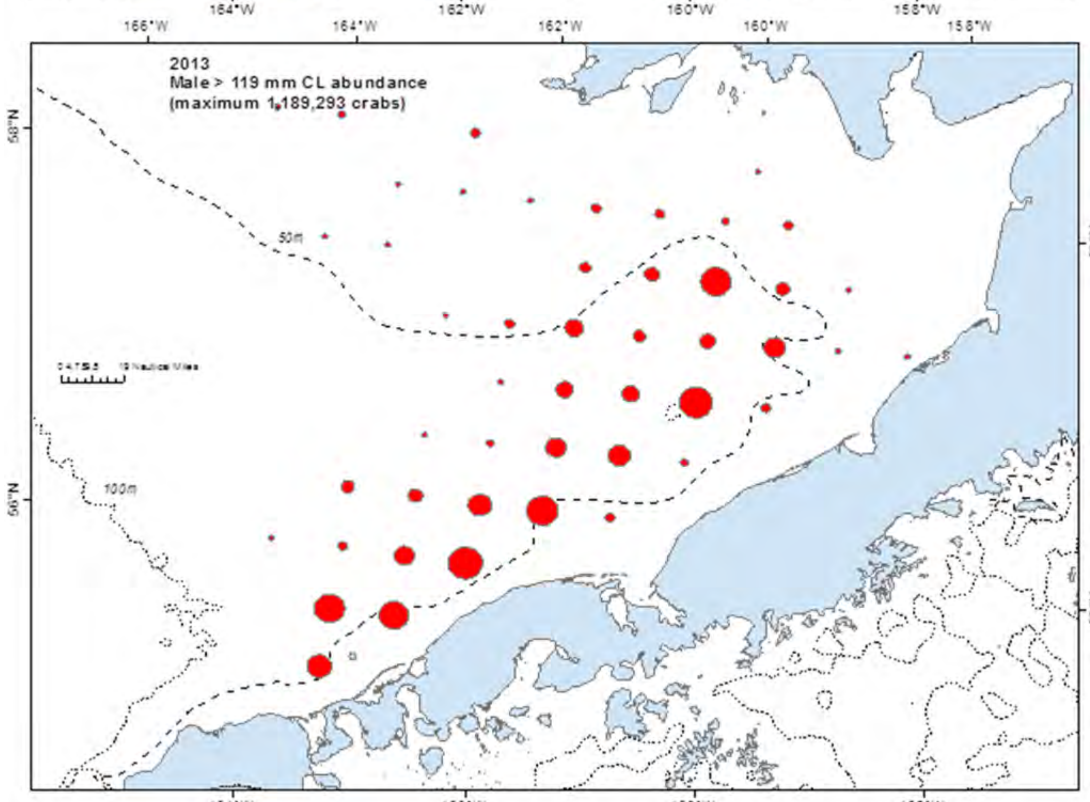


Figure A5. Retained catch and potlifts for total eastern Bering Sea Tanner crab fishery (upper plot) and the Tanner crab fishery east of 163^{o} W (bottom).

Appendix B. Spatial distributions of mature and juvenile male and female red king crab in Bristol Bay from 2013-2014 summer standard trawl surveys.





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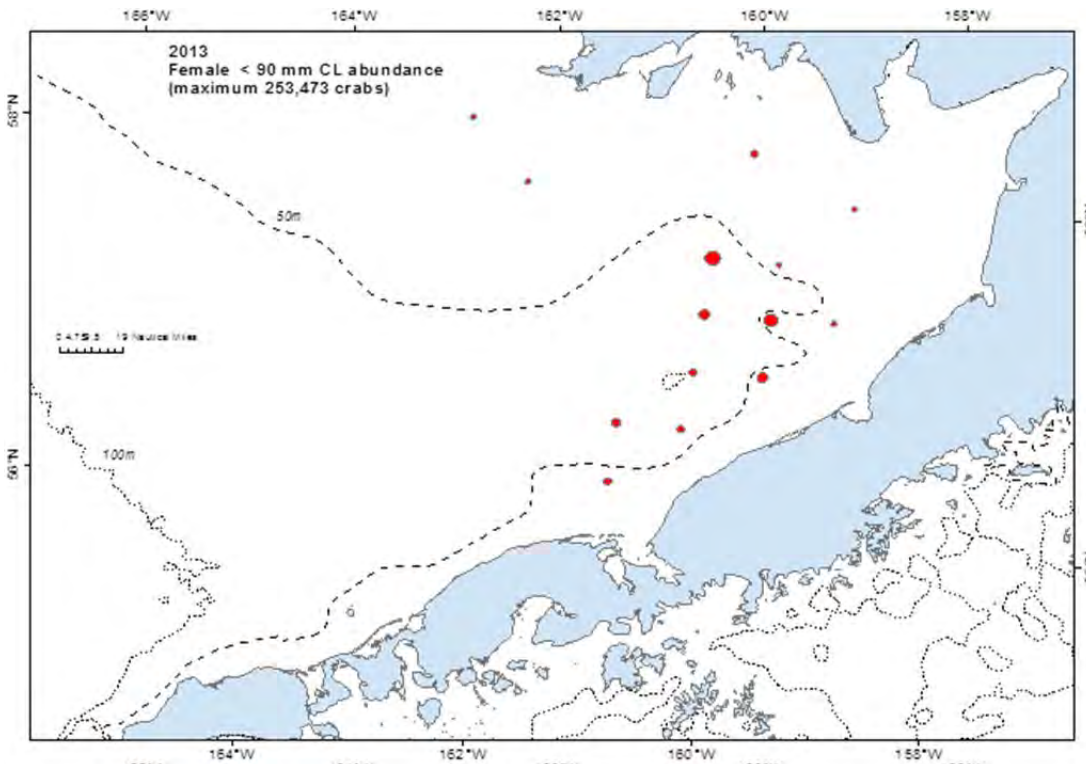
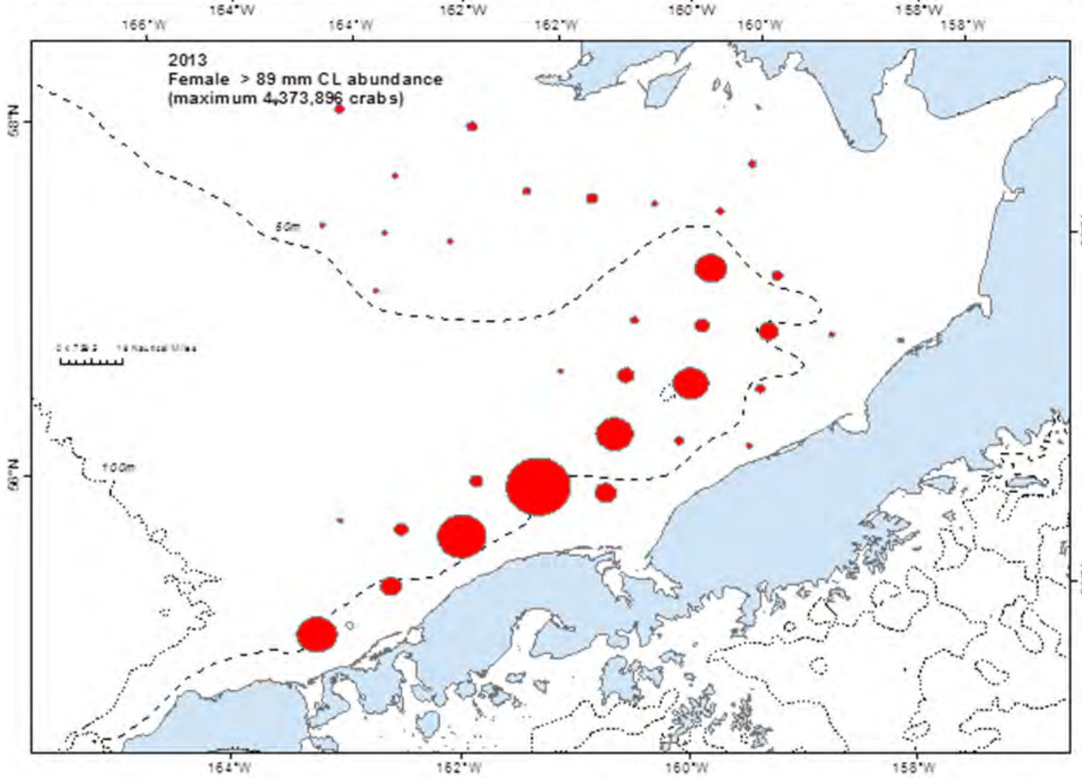
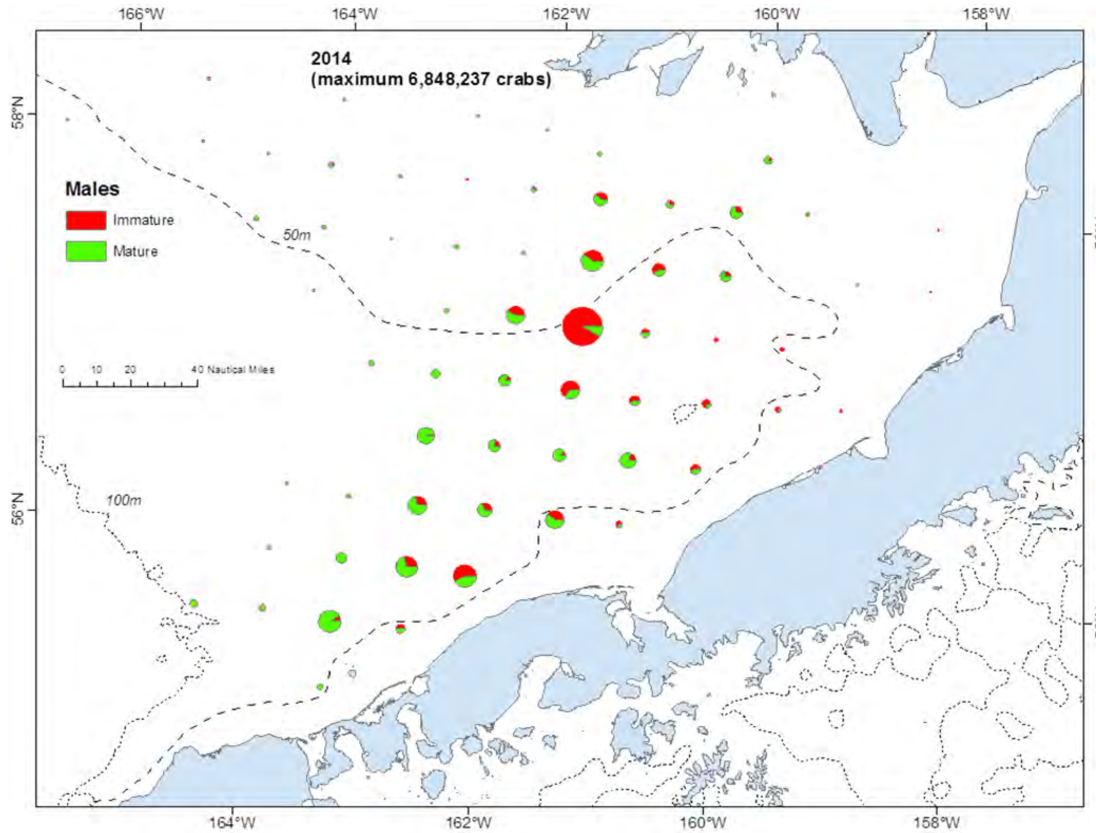
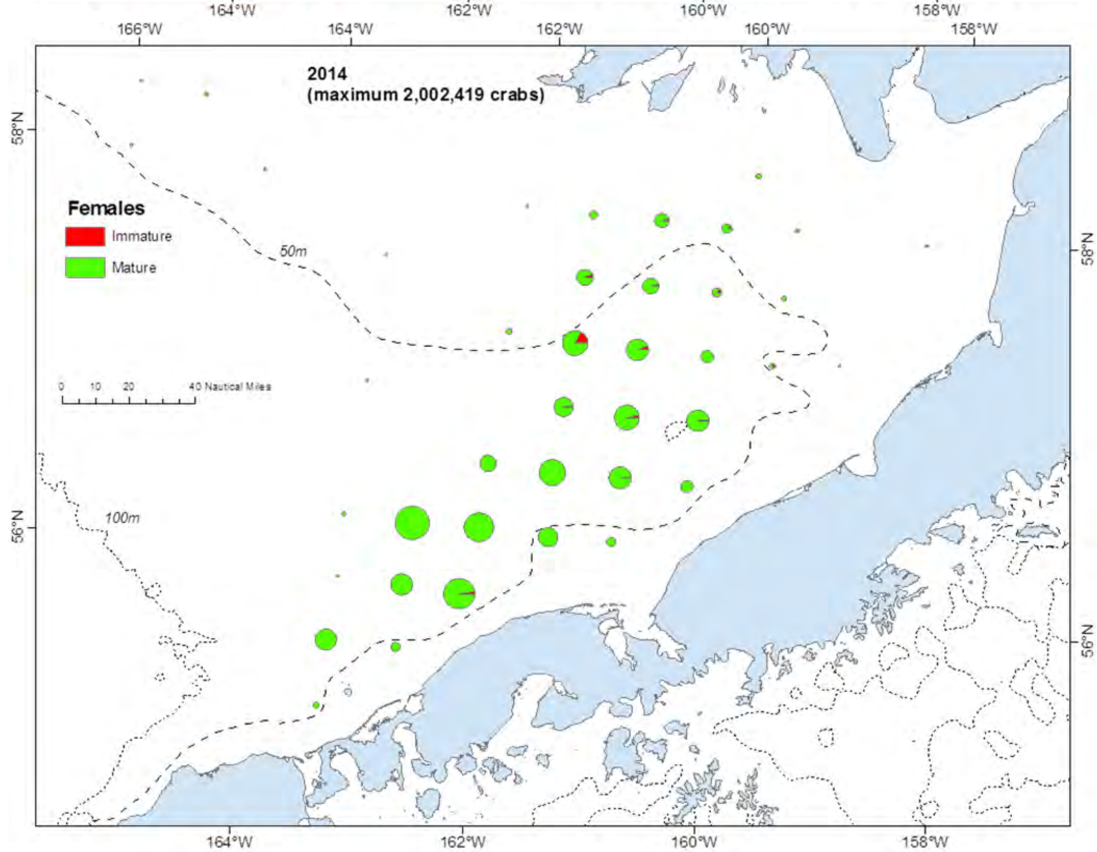

2013
Female < 90 mm CL abundance
(maximum 253,473 crabs)
50m
100m


2013
Female > 89 mm CL abundance
(maximum 4,373,896 crabs)
50m
100m

113


166°W
164°W
162°W
160°W
158°W
2014
(maximum 6,848,237 crabs)
58°N
Males
Immature
Mature
50m
0 10 20 40 Nautical Miles
100m
56°N
164°W
162°W
160°W
158°W


166°W
164°W
162°W
160°W
158°W
2014
(maximum 2,002,419 crabs)
58°N
Females
Immature
Mature
50m
0 10 20 40 Nautical Miles
100m
56°N
164°W
162°W
160°W
158°W

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2015 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

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Alaska Fisheries Science Center
20 September 2015

Executive Summary

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

2. Catches: trends and current levels.
Legal-sized male Tanner crab are caught and retained in the directed (male-only) Tanner crab fishery in the EBS. The directed fishery was opened in 2013/14 for the first time since 2009/10 because the stock was not overfished in 2012/13 (Stockhausen et al., 2013) and stock metrics met the State of Alaska (SOA) criteria for opening the fishery in 2013/14. TAC was set at 1,645,000 lbs (746.2 t) for the area west of 166° W and at 1,463,000 lbs (663.6 t) for the area east of 166° W in the SOA's Eastern Subdistrict of the Bering Sea District Tanner crab Registration Area J. The fisheries opened on October 15 and closed on March 31. On closing, 79.6% (593.6 t) of the TAC was taken in the western area while 98.6% (654.3 t) was taken in the eastern area. Prior to the closures, the retained catch averaged 770 t per year between 2005/06-2009/10.

Following the last year's assessment (Stockhausen, 2014), TAC was set at 6,625,000 lbs (2,328.7 t) for the area west of 166° W and at 8,480,000 lbs (3,829.3 t) for the area east of 166° W. On closing, 77.5% (2,328.7 t) of the TAC was taken in the western area while 99.6% (3,829.3 t) were taken in the eastern area.

Non-retained females and sub-legal males are caught in the directed fishery as bycatch and discarded. Total bycatch (not discounted for assumed handling mortality) in the directed fishery was 2,553 t. Tanner crab are also caught as bycatch in the snow crab and Bristol Bay red king crab fisheries, in the groundfish fisheries and, to a minor extent, in the scallop fishery. Over the last five years, the snow crab fishery has been the major source of Tanner crab bycatch among these fisheries, averaging 1,197 t for the 5-year period 2010/11-2014/15. Bycatch in the snow crab fishery in 2014/15 was 5,433 t. The groundfish fisheries have been the next major source of Tanner crab bycatch over the same five year time period, averaging 272 t. Bycatch in the groundfish fisheries in 2014/15 was 423 t. The Bristol Bay red king crab fishery has typically been the smallest source of Tanner crab bycatch among these fisheries, averaging 51 t over the 5-year time period, although 297 t caught and discarded in 2014/15.

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

3. Stock biomass: trends and current levels relative to virgin or historic levels
For EBS Tanner crab, spawning stock biomass is expressed as mature male biomass (MMB) at the time of mating (mid February). From the author's preferred model (Model A), estimated MMB for 2014/15

was 71.6 thousand t (Table 19, Fig. 60). This was larger than that for 2013/14 (60.6 thousand t). The 2014 model estimate for 2013/14 MMB was 72.7 thousand t. MMB had undergone a slight downward trend since its most recent peak in 2008/09, but 2014/15 represents a return to values slightly higher than that peak. It remains above the very low levels seen in the mid-1990s to early 2000s (1990 to 2005 average: 29.3 thousand t). However, it is considerably below model-estimated historic levels in the early 1970s when MMB peaked at 328.2 thousand t (1972/73).

4. Recruitment: trends and current levels relative to virgin or historic levels.
From the author's preferred model (Model A, Dataset D), the estimated total recruitment in 2015/16 (number of crab entering the population on July 1) is 80.71 million crab (Table 18, Fig. 62. Recruitment is estimated to have declined from a peak last year of 124.0 million.

5. Management performance

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

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2011/12	25.13	129.17 A	0.00	0.00	2.73	6.06	5.47
2012/13	36.97	130.84 A	0.00	0.00	1.57	41.93	18.01
2013/14	37.43	160.28 A	3.11	2.78	6.14	55.89	39.29
2014/15	29.53 C	157.78 A	15.10	13.58	20.19	69.40	55.51
2015/16		116.39 B				61.14 C	48.92 C

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

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2011/12	11.40	58.59 A	0.00	0.00	1.24	2.75	2.48
2012/13	16.77	59.35 A	0.00	0.00	0.71	19.02	8.17
2013/14	16.98	72.70 A	1.41	1.26	2.78	25.35	17.82
2014/15	13.40 C	71.57 A	6.85	6.16	9.16	31.48	25.18
2015/16		52.80 B				27.73 C	22.19 C

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

6. Basis for the OFL

Basis for the OFL (thousands t).

Year	Tier^{A}	B_{MSY}^{A}	Current MMB^{A}	B/B_{MSY} (MMB)^{A}	F_{OFL}^{A}	Years to define B_{MSY}^{A}	Natural Mortality^{A,B}
2012/13	3a	33.45	58.59	1.75	0.61 yr^{-1}	1982-2012	0.23 yr^{-1}
2013/14	3a	33.54	59.35	1.77	0.73 yr^{-1}	1982-2013	0.23 yr^{-1}
2014/15	3a	29.82	63.80	2.14	0.61 yr^{-1}	1982-2014	0.23 yr^{-1}
2015/16	3a	26.79	52.80	1.97	0.64 yr^{-1}	1982-2015	0.23 yr^{-1}

A—Calculated from the assessment reviewed by the Crab Plan Team in 20XX of 20XX/YY or based on the author's preferred model for 2015/16.
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 2015/16, is estimated at 52.80 thousand t. B_{MSY} for this stock is calculated to be 26.79 thousand t, so MSST is 13.40 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 32.1% for pot gear and 0.8 for trawl gear) in 2014/15 was 9.16 thousand t, which was less than the OFL for 2014/15 (25.18 thousand t); consequently **overfishing did not occur**. The OFL for 2015/16 based on the author's preferred model (Model A) is 27.73 thousand t. The ABC_{max} for 2015/16, based on the p^* ABC, is 27.70 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 22.19 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. Consequently no rebuilding analyses were conducted.

A. Summary of Major Changes

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

In the September 2013 assessment (Stockhausen et al., 2013), the Tanner crab stock was again found to be not overfished. For the 2013/14 fishing season, the SOA opened the fisheries for Tanner crab and set Total Allowable Catch limits in the two areas in which Tanner crab is commercially fished in the eastern Bering Sea (east and west of 166° W in the Eastern Subdistrict of the Bering Sea District Tanner crab Registration Area J, Fig. 1). TAC was set at 1,645,000 lbs (746.2 t) for the area west of 166° W and at 1,463,000 lbs (663.6 t) for the area east of 166° W. The fisheries opened on October 15 and closed on March 31. On closing, 79.6% (593.6 t) of the TAC was taken in the western area while 98.6% (654.3 t) was taken in the eastern area. Prior to the closures, the retained catch averaged 770 t per year between 2005/06-2009/10.

Following the last year's assessment (Stockhausen, 2014), TAC was set at 6,625,000 lbs (2,328.7 t) for the area west of 166° W and at 8,480,000 lbs (3,829.3 t) for the area east of 166° W. On closing, 77.5% (2,328.7 t) of the TAC was taken in the western area while 99.6% (3,829.3 t) were taken in the eastern area.

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

2. Changes to the input data

During the two past years, and involving considerable effort, the set of stations and hauls constituting the "standard" dataset for calculating crab-related trends in abundance, biomass and size compositions from the annual NMFS EBS bottom trawl survey was redefined for each crab stock to improve sampling design and consistency across the 40-plus year dataset (Daly et al., in prep.). The "old" dataset included stations with multiple hauls associated with special projects and "re-tows", as well as somewhat inconsistent strata definitions across the time series. The new dataset consists of a single haul per station and strata definitions that are temporally consistent. In conjunction with this effort, the weight-at-size regressions used to convert crab abundance to biomass were also revised (Daly et al., in prep.).

New survey size compositions have been calculated from the 1975-2015 annual survey results and incorporated into this assessment. In addition, the weight-at-size regressions used in past assessments have been updated to reflect the standardized trawl survey regressions. For comparison purposes, survey time series based on the "old" survey dataset have been updated with the results of the 2015 bottom trawl survey, and model results showing a progression from the old time series to the new time series have been compared.

Much of the crab fishery data from 1990-2013/14 was re-calculated last year (Stockhausen, 2014) by D. Pengilly and H. Fitch (ADF&G), including: 1) retained size frequencies; 2) effort (number of potlifts); and 3) bycatch numbers, biomass and size frequencies from fish ticket and dockside and at-sea observer sampling. These data were not re-calculated this year, except to update the 2013/14 data. Estimates of total retained biomass and abundance, as well as retained size frequencies by shell condition, in the 2014/15 directed fishery were provided by Mr. Pengilly based on fish ticket data and dockside observer sampling. Mr. Pengilly also provided estimates of Tanner crab bycatch (sex-specific numbers, biomass and size compositions) in the 2014/15 directed Tanner crab, snow crab, and Bristol Bay red king crab fisheries.

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

Much of the data concerning Tanner crab bycatch in the groundfish fisheries (biomass, size compositions) was recalculated last year and incorporated into the 2014 assessment (Stockhausen, 2014). This year, these data were updated for 2013/14 and newly-extracted for 2014/15 from the groundfish observer and AKFIN databases.

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

Updated data sources.

Data source	Data types	Time frame	Notes	Agency
NMFS EBS Bottom Trawl Survey	abundance, biomass, size compositions	2015	new	NMFS
NMFS EBS Bottom Trawl Survey	abundance, biomass, size compositions	1975-2015	new standardization	NMFS
Directed fishery	retained catch (numbers, biomass)	2013/14, 2014/15	updated, new	ADFG
	retained catch size compositions	2013/14, 2014/15	updated, new	ADFG
	effort	2013/14, 2014/15	updated, new	ADFG
	total catch, discards (biomass)	2013/14, 2014/15	updated, new	ADFG
	total catch, discards size compositions	2013/14, 2014/15	updated, new	ADFG
Snow Crab Fishery	effort	2013/14, 2014/15	updated, new	ADFG
	total catch, discards (biomass)	2013/14, 2014/15	updated, new	ADFG
	size compositions	2013/14, 2014/15	updated, new	ADFG
Bristol Bay Red King Crab Fishery	effort	2013/14, 2014/15	updated, new	ADFG
	total catch, discards (biomass)	2013/14, 2014/15	updated, new	ADFG
	size compositions	2013/14, 2014/15	updated, new	ADFG
Groundfish Fisheries	total catch, discards (biomass)	2013/14, 2014/15	updated, new	NMFS
	size compositions	2013/14, 2014/15	updated, new	NMFS

3. Changes to the assessment methodology.

The computer code for a new assessment model has substantially been completed but was not used for this assessment. It will be reviewed by the CPT in May, 2016. The current assessment remains essentially unchanged from last year (see Stockhausen, 2014, Appendix 3 for a detailed description of the current model). Options to use an alternative fishing mortality model (Gmacs), to impose a lognormal error structure when fitting to fishery catch data, and to require logistic selectivity curves to reach 1 in the largest model size bin were implemented in the current assessment code and tested. However, the author's preferred model for status determination and OFL setting is the same as the model adopted last year by the CPT (Model Alt4b).

4. Changes to the assessment results

Results from the author's preferred model this year (Model A, Dataset D) are reasonably similar to those from the previous assessment, considering the large number of changes in the (primarily survey-related) data. Average recruitment (1982-present) was estimated at 187.90 million in last year's models, whereas it was estimated at 179.37 million in the author's preferred model this year. F_{MSY} was estimated at 0.61 yr^{-1} last year and 0.64 yr^{-1} this year. B_{MSY} was estimated at 29.82 thousand t last year and 26.79 thousand t this year.

B. Responses to SSC and CPT Comments

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

June 2015 SSC Meeting
Comment: "The SSC would like to reiterate a request to stock assessment author's for consistency in units used in the assessment. The SSC appreciates the author's inclusion of standard and metric units in the text but requests consistency in which units are used (e.g., lbs., thousands of lbs., …). The SSC also requests consistency in the units chosen for tables and figures, requests that units cited in the table match the values in the tables, and suggests authors refer to the terms of reference for chapters."
Response: Data sources vary widely as to units used, as do figures for which historical comparisons with previous assessments may be of interest. It would be convenient to standardize completely to metric units, but this is not necessarily responsive to public accessibility. When units vary, it is generally because one choice affords a reasonable scale and another does not (, e.g. 1 kg vs 0.001 t). However, the author has made an effort to accommodate this request in most instances, although some inconsistencies probably still exist.

May 2015 Crab Plan Team Meeting
No general comments.

January 2015 Crab Modeling Workshop
Comment: The team requested author's use the new NMFS EBS bottom trawl survey dataset in future assessments, but provide comparison runs with the old survey dataset for comparison.
Response: This has been addressed in this assessment.

October 2014 SSC Meeting
No general comments.

September 2014 Crab Plan Team Meeting
No general comments.

June 2014 SSC Meeting
No general comments.

January 2014 Crab Modeling Workshop
Comment: The CPT requested "all assessment authors should provide model scenarios which mimic the September 2013 assessments by replacing the bycatch data in the crab fisheries with updated data from Bill Gaeuman using the 'simple averaging' method and by replacing the NMFS survey data with recalculated series based on updated methodologies so the CPT can evaluate the implications of these changes to the data."
Response: This was addressed for the crab bycatch data provided by W. Gaeuman at the May, 2014 CPT Meeting (see http://www.npfmc.org/wp-content/PDFdocuments/membership/PlanTeam/Crab/CrabSafe14/tanner_rev.docx). The revised NMFS time series data (abundance, biomass and size frequencies) is incorporated into this assessment.

Comment: "The CPT recommends that assessment authors investigate the effects of the new [NMFS trawl survey] time series on size frequencies."
Response: Results (e.g., abundance and biomass estimates, size frequencies) for the revised NMFS trawl survey data have been incorporated into this assessment and compared with results using the old survey data.

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 2015 SSC Meeting

No specific comments.

May 2015 CPT Meeting

Comment: "The CPT agrees that the September 2015 assessment should use the updated retained size frequencies and be based on an assessment that ignores the survey data from 1974."
Response: This has been done.

Comment: "The assessment author should report results in September 2015 using the new and original trawl survey data to allow the impact of updating these data to be quantified."
Response: This has been done.

Comment: "Future exploration…should consider the impact of handling mortality on the estimate of natural mortality and how the model behaves if Q for the most recent years is assumed known rather than being estimated."
Response: Model runs have been completed to address this issue, but time was not sufficient to complete the analysis.

Comment: "The CPT would like to see the results of analyses based on this (new) model at its September 2015 meeting".
Response: The new model is currently undergoing testing. Time constraints precluded presenting interim results at this point to the CPT. These will be presented at the Modeling Workshop (if there is one), or at the May 2016 CPT meeting.

Comment: "The CPT reiterates its suggestions from the September 2014 meeting, in particular that the sensitivity of the results to the prior on Q should be explored."
Response: Model runs have been completed to address this issue, but there was not sufficient time to complete the analysis.

Comment: The CPT recommends that model results for the four model configurations be provided to the September 2015 meeting: 1) the 2014 model with 2015 data added (Model 1), 2) Model 1, with revised trawl survey time series (Model 2), 3) Model 2, with survey selectivity constrained to 1 for at least one size class (Model 3), and 4) Model 3, with a lognormal likelihood for the fishery catch data.
Response: Results from these configurations are provided in the assessment.

Comment: "The CPT recommends that the change (in minimum preferred size in the area east of 166^{o}W for TAC setting) be addressed for OFL calculation by setting the retention curves for the areas east and west of 166oW with the approach currently used to compute selectivity for the area west of 166^{o}W."
Response: This has been addressed in the assessment.

October 2014 SSC Meeting

Comment: "The SSC encourages authors to explore alternative models such as time-varying growth to help address retrospective bias and patterns in other residuals."
Response: This can be addressed in the future with the new model code (currently being tested), but not with the current model.

Comment: "The SSC also encourages authors to explore model alternatives without time-varying selectivity for the groundfish fishery."
Response: This can be addressed in the future with the new model code (currently being tested), but not with the current model.

Comment: "The SSC also encourages…use of MSE to explore the effect of alternative harvest rates on stock status and yield under various sources of uncertainty."
Response: A good suggestion but a major undertaking. This represents an opportunity for a PhD student or post-doctoral researcher.

Comment: "The SSC encourages efforts to obtain better and more representative growth data."
Response: Growth increment data on ~60 individuals was collected in the EBS this spring by NMFS and ADF&G researchers. The author looks forward to incorporating the results of this study into the assessment context.

September 2014 CPT Meeting
Comment: "Explain/justify the three periods used for groundfish bycatch."
Response: The 1973-1987 time period represents the time of foreign and joint-venture fishing, the 1988-1996 represents the beginning of the domestic-only groundfish fisheries, and the start of the 1997-present time period (1997-2003/4) is when the directed Tanner crab fishery was closed. It seems reasonable to assume that changes in fleet composition associated with the transition to a domestic-only fleet would involve changes to selectivity. It also seems reasonable to assume that closure of the Tanner crab fishery and concern over prohibited species catches (i.e., crab) would alter fishing behavior, thus affecting selectivity. These periods are hard-wired in the current code and cannot be changed without a lot of difficulty. However, it will be possible to investigate this issue more fully when the new model code completes testing.

Comment: "Examine of clarify why the different H scenarios do not result in greater differences in total mortality for the directed fishery."
Response: This issue was addressed at the May 2015 CPT meeting.

Comment: "Examine issues related to misfits of the size composition residuals for retained males and total males in the directed fishery. Consider exploring alternative growth components, specification of sample sizes, or a combination of fishing selectivity and handling mortality is causing mis-fits."
Response: Not yet addressed.

June 2014 SSC Meeting
Comment: "Examine retrospective patterns of models being brought forward."
Response: I tried to address this issue for this assessment. Unfortunately, the current model code is not set up to make retrospective model runs in a time-effective manner. This is addressed in the new model code currently being tested.

May 2014 Crab Plan Team Meeting
Comment: "Compare actual discarded catch with model-estimated discarded catch (separately for directed fishery bycatch, snow crab bycatch, red king crab bycatch, and groundfish bycatch)."
Response: Plots and tables making these comparisons are provided in the assessment.

3. Older comments that were addressed this year or remain to be addressed:
Comment: "The SSC recommends conducting a management strategy evaluation (MSE) to determining [sic] the long-term consequences of alternative harvest rates on stock status and yield under various sources of uncertainty."
Response: It will not be feasible to address this request at least until the new model code is completed.

Comment: "The SSC continues to encourage alternative model specifications to address these patterns" [i.e., retrospective patterns in model-estimated biomass], which "inclusion of a time-varying growth function may address…"
Response: The option for time-varying growth (constant over blocks of time) has been implemented in the new model code that is currently under testing.

Comment: "The SSC…encourages a thorough review and re-compilation of all data sources."
Response: The review has been initiated and is ongoing. W. Gaeuman (ADFG) has re-extracted size composition data from the ADFG crab fisheries databases for (dockside) retained catch in the directed Tanner crab fishery and total and discarded catch in the directed, snow crab, and BBRKC fisheries. I have re-extracted size frequencies for Tanner bycatch in the groundfish fisheries from the NMFS groundfish observer database which I have adjusted to the crab fishery year (July 1-June 30) from the groundfish fishery year (Jan. 1-Dec.31). Effort in the directed Tanner crab, snow crab and BBRKC fisheries has been painstakingly re-evaluated by D. Pengilly (ADFG), resulting in substantially revised estimates for effort in the Tanner crab fishery primarily during the early 1990s. R. Foy (NMFS) is also revising data from the NMFS trawl survey; changes, however, will not be reviewed until the 2015 Crab Modeling Workshop.

Comment: "The CPT recommended that a sensitivity analysis on handling mortality be done in the Tanner crab assessment…"
Response: A sensitivity analysis addressing this issue was presented to the CPT at its May 2015 meeting.

Comment: "Collection of growth data specific to the Tanner crab stock in the EBS should be given a high research priority."
Response: Individuals were collected by NMFS, ADF&G, and BSFRF in May 2015 to address this issue. The author looks forward to incorporating the results of this study into the assessment..

Comment: "Evaluate the feasibility of estimating F_{MSY} (and B_{MSY}) for the stock using the estimates of recruitment and MMB during the post-1982 period, and compare to the $F_{35\%}$ MSY proxy."
Response: Not yet addressed.

Comment: "If time permits, apply the groundfish plan team's stock structure template to Tanner crab to synthesize the available information on stock structure."
Response: Not yet addressed.

Comment: The CPT "recommends that crab authors apply the [groundfish stock structure template] criteria for considering spatial issues in stocks."
Response: Not yet addressed.

Comment: The CPT "recommends that all assessment authors document assumptions and simulate data under those assumptions to test the ability of the model to estimate key parameters in an unbiased manner."
Response: Not yet addressed. Simulation testing will be possible with the new model now being tested (an R package has been developed already to facilitate this using independent code).

Comment: The CPT encourages authors to "…develop approaches for accounting for this source of process error" (i.e., fitting to length-composition data accounts for sampling error but not within-year variability in selectivity).
Response: The size at 50% selected is allowed to vary annually (1992+) for males in the directed fishery, but the size at 50% retained is not. Given the recent change in minimum preferred size used to calculate TAC in the area east of 166°W, it may be a good idea to allow this to vary annually, as well. Allowing annually-varying selectivity in the discard fisheries may be problematic in terms estimability. However, these sorts of issues can be addressed with the new code currently undergoing testing.

Comment: "Plot the input effective sample sizes for the compositional data versus the effective sample sizes inferred by the fit of the model…"
Response: Not yet addressed.

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

Comment: "Consider treating all of the F-deviations (except for which catch is known to be zero) as parameters, and include the fishing mortality-effort relationship as a prior—this will allow the uncertainty associated with this relationship to be reflected in the measures of uncertainty."
Response: Not yet addressed.

Comment: "Consider fitting to total biomass (by sex?) and to the compositional data rather than to mature biomass (include the fit to mature biomass by sex as a diagnostic)."
Response: Not yet addressed.

Comment: "Do not fit to male compositional data by maturity state for the years for which chela height-maturity relationships are not available."
Response: Not yet addressed.

Comment: "There is still a residual pattern in the fit to the size-composition data for the survey. This could be due to time-varying growth, which should be examined as an alternative model."
Response: Not yet addressed. Time-varying growth (using time blocks) is an option in the new model code now being tested.

Comment: "A major concern for the CPT was the inability of the model to match the magnitude of discards in the EBS snow crab and Bristol Bay red king crab fisheries…The CPT requested the analysts conduct further analyses in which mimicking the observer data was given higher weight."
Response: The model appears to fit male discard mortality in the snow crab fishery fairly well. Discard mortality for females in the snow crab fishery and both sexes in the BBRKC fishery are very small. I tried using a lognormal error structure this year to fit these data, but results were not satisfactory with the cv's that were assumed. This is an area for continued development.

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 sub-legal sized males (≤138 mm CW) and ovigerous and immature females of all sizes are distributed broadly from southern Bristol Bay northwest to St. Matthew Island (Rugolo and Turnock, 2011a). The southern range of the cold water congener the snow crab, *C. opilio*, in the EBS is near the Pribilof Islands (Turnock and Rugolo, 2011). The distributions of snow and Tanner crab overlap on the shelf from approximately 56° to 60°N, and in this area, the two species hybridize (Karinen and Hoopes 1971).

3. Evidence of stock structure

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

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

4. Life history characteristics

a. Molting and Shell Condition

Tanner crabs, like all crustaceans, normally exhibit a hard exoskeleton of chitin and calcium carbonate. This hard exoskeleton requires individuals to grow through a process referred to as molting, in which the individual sheds its current hard shell, revealing a new, larger exoskeleton that is initially soft but which rapidly hardens over several days. Newly-molted crab in this "soft shell" phase can be vulnerable to predators because they are generally torpid and have few defenses if discovered. Subsequent to hardening, an individual's shell provides a settlement substrate for a variety of epifaunal "fouling" organisms such as barnacles and bryozoans. The degree of hard-shell fouling was once thought to correspond closely to post-molt age and led to a classification of Tanner crab by shell condition (SC) in survey and fishery data similar to that described in the following table (NMFS/AFSC/RACE, unpublished):

Shell Condition Class	Description
0	pre-molt and molting crab
1	carapace soft and pliable
2	carapace firm to hard, clean
3	carapace hard; topside usually yellowish brown; thoracic sternum and underside of legs yellow with numerous scratches; pterygostomial and bronchial spines worn and polished; dactyli on meri and metabranchial region rounded; epifauna (barnacles and leech cases) usually present but not always.
4	carapace hard, topside yellowish-brown to dark brown; thoracic sternum and undersides of legs data yellow with many scratches and dark stains; pterygostomial and branchial spines rounded with tips sometimes worn off; dactyli very worn, sometimes flattened on tips; spines on meri and metabranchial region worn smooth, sometimes completely gone; epifauna most always present (large barnacles and bryozoans).
5	conditions described in Shell Condition 4 above much advanced; large epifauna almost completely covers crab; carapace is worn through in metabranchial regions, pterygostomial branchial spines, or on meri; dactyli flattened, sometimes worn through, mouth parts and eyes sometimes nearly immobilized by barnacles.

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

b. Growth

Growth in immature Tanner crab larger than 25 mm CW proceeds by a series of annual molts, up to a final (terminal) molt to maturity (Tamone et al., 2007). Growth relationships specific to Tanner crab in the EBS are unknown, although data was collected this May on individual molt increments. Rugolo and Turnock (2012a) derived the growth relationships for male and female Tanner crab used 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, pers. comm.; Donaldson et al. 1981). The relationship between pre-molt and post-molt size for males and females was modeled as two parameter exponential functions of the general form $y = ax^b$, where y is post-molt size (CW) and x is pre-molt size. The resulting parameters are:

sex	parameter	
	a	b
male	1.55	0.949
female	1.76	0.913

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

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

c. Weight at Size

Previously, trawl survey biomass calculations were made for surveys conducted before 2010 and for those conducted after 2009 using different weight-at-size parameter values in power-law models of the form $w = a \cdot z^b$ (Daly et al., 2014; table below). Rugolo and Turnock (2012a) derived a separate set of weight-at-size parameters for male, immature female, and mature female Tanner crab in the EBS based on special collections of size and weight data during the summer bottom trawl surveys in 2006, 2007 and 2009. Power-law models of the form $w = a \cdot z^b$, where w is weight in kg and z is size in mm CW, were fit to the survey data. These relationships were used in the 2012, 2013 and 2014 assessments to convert individual size to biomass in the assessment model in a consistent fashion across all years. The various parameter values are presented in the following table:

		Category					
		assessment model (2012-2014)		trawl survey (pre-2010)		trawl survey (2010-present)	
sex	maturity	a	b	a	b	a	b
males	all	0.00016	3.136	0.00019	3.09894	0.00027	3.022134
females	all	--	--	0.00182	2.70462	--	--
	immature	0.00064	2.794	--	--	0.000562	2.816928
	mature	0.00034	2.956	--	--	0.000441	2.898686

The relationships used for the 2012-2014 assessments and the post-2009 surveys differ slightly at the largest crab sizes, but both give substantially larger weights-at-size than the pre-2010 relationships (Table 1, Fig. 2). This year, in conjunction with the NMFS trawl survey standardization, the pre-2010 weight-at-size regressions were dropped and the post-2009 weight-at-size relationships were adopted as standard and are used for the entire survey time series (Daly et al., in prep.). To be consistent with the survey data, I propose to adopt the now-standard survey parameters for use in this and subsequent assessments. Model runs using both the Rugolo and Turnock (2012a) parameters and the new standard survey parameters are compared below.

d. Maturity and Reproduction

It is now generally accepted that both Tanner crab males (Tamone et al. 2007) and females (Donaldson and Adams 1989) undergo a terminal molt to maturity, as in most majid crabs. Females usually undergo their terminal molt from their last juvenile, or pubescent, instar while being grasped by a male (Donaldson and Adams 1989). Subsequent mating takes place annually in a hard shell state (Hilsinger 1976) and after extruding the female's clutch of eggs. While mating involving old-shell adult females has been documented (Donaldson and Hicks 1977), fertile egg clutches can be produced in the absence of males by using sperm stored in the spermathacae (Adams and Paul 1983, Paul and Paul 1992). Two or more consecutive egg fertilization events can follow a single copulation using stored sperm to self-fertilize the new clutch (Paul 1982, Adams and Paul 1983), although egg viability decreases with time and age of the stored sperm (Paul 1984).

Maturity in males can be classified either physiologically or morphometrically. Physiological maturity refers to the presence or absence of spermataphores in the gonads whereas morphometric maturity refers to the presence or absence of a large claw (Brown and Powell 1972). During the molt to morphometric maturity, there is a disproportionate increase in the size of the chelae in relation to the carapace (Somerton 1981a). While many earlier studies on Tanner crabs assumed that morphometrically mature male crabs continued to molt and grow, there is now substantial evidence supporting a terminal molt for males (Otto 1998, Tamone et al. 2007). A consequence of the terminal molt in male Tanner crab is that a substantial portion of the population may never achieve legal size (NPFMC 2007).

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

e. Fecundity

A variety of factors affect female fecundity, including somatic size, maturity status (primiparous vs. multiparous), age post terminal molt, and egg loss (NMFS 2004). Of these factors, somatic size is the most important, with estimates of 89 to 424 thousand eggs for females 75 to 124 mm CW, respectively (Haynes et al. 1976). Maturity status is another important factor affecting fecundity, with primiparous females being only ~70% as fecund as equal size multiparous females (Somerton and Meyers 1983). The number of years post maturity molt, and whether or not, a female has had to use stored sperm from that first mating can also affect egg counts (Paul 1984, Paul and Paul 1992). Additionally, older senescent females often carry small clutches or no eggs (i.e., are barren) suggesting that female crab reproductive output is a concave function of age (NMFS 2004).

f. Size at Maturity

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

g. Mortality

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

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

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

The Bering Sea District of Tanner crab Registration Area J (Fig. 1) includes all waters of the Bering Sea north of Cape Sarichef at 54° 36'N and east of the U.S.-Russia Maritime Boundary Line of 1991. This district is divided into the Eastern and Western Subdistricts at 173°W. The Eastern Subdistrict is further divided at the Norton Sound Section north of the latitude of Cape Romanzof and east of 168°W and the General Section to the south and west of the Norton Sound Section (Bowers et al. 2008). In this report, I use the terms "east region" and "west region" as shorthand to refer to the regions demarcated by 166°W.

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

In previous assessments, the term "legal males" was used to refer to male crab ≥ 138 mm CW (not including the lateral spines), although this was not strictly correct as it referred to the industry's "preferred" crab size in the east region, as well as to the minimum size in the east used in the SOA's harvest strategy for TAC setting. Because the previous fishery season was conducted under the 2011 harvest strategy (and minimum preferred sizes), I continue to use the term "legal males" to refer to crab ≥ 138 mm CW in this assessment.

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 2; Fig.s 3 and 4). Foreign fishing for Tanner crab ended in 1980.

The domestic Tanner crab pot fishery developed rapidly in the mid-1970s (Tables 2 and 3; Fig.s 3 and 4). Domestic US landings were first reported for Tanner crab in 1968 at 0.46 thousand t taken incidentally to the EBS red king crab fishery (Table 2). Tanner crab was targeted thereafter by the domestic fleet and landings rose sharply in the early 1970s, reaching a high of 30.21 thousand t in 1977/78 (Tables 2 and 3; Fig. 3). 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 2 and 3). For the 2010/11-2012/13 seasons, the State of Alaska closed directed commercial fishing for Tanner crab due to estimated female stock metrics being below thresholds adopted in the state harvest strategy. However, these thresholds were met in fall 2013 and the directed fishery was opened in 2013/14. TAC was set at 1,645,000 lbs (746.2 t) for the area west of 166^{o} W and at 1,463,000 lbs (663.6 t) for the area east of 166^{o} 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% (593.6 t) of the TAC had been taken in the western area while 98.6% (654.3 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. Following the last year's assessment (Stockhausen, 2014), TAC was set at 6,625,000 lbs (2,328.7 t) for the area west of 166^{o} W and at 8,480,000 lbs (3,829.3 t) for the area east of 166^{o} W. On closing, 77.5% (2,328.7 t) of the TAC was taken in the western area while 99.6% (3,829.3 t) were taken in the eastern area.

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 4, Fig. 5). 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. 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

During the two past years, and involving considerable effort, the set of stations and hauls constituting the "standard" dataset for calculating crab-related trends in abundance, biomass and size compositions from the annual NMFS EBS bottom trawl survey was redefined for each crab stock to improve sampling design and consistency across the 40-plus year dataset (Daly et al., in prep.). The "old" dataset included stations with multiple hauls associated with special projects and "re-tows", as well as somewhat inconsistent strata definitions across the time series. The new dataset consists of a single haul per station and strata definitions are temporally consistent. In conjunction with this effort, the size-weight regressions used to convert crab abundance to biomass were also revised (Table 1, Fig. 1).

Two sets of size compositions were employed in this assessment. The first dataset consisted of the "old" survey size compositions used in the 2014 assessment, which were updated with size compositions from the 2015 bottom trawl survey. The second dataset consisted of survey size compositions from 1975 to 2015 based on the "new" standardized survey dataset.

Much of the crab fishery data from 1990-2013/14 was re-calculated last year (Stockhausen, 2014) by D. Pengilly and H. Fitch (ADF&G), including: 1) retained size frequencies; 2) effort (number of potlifts); and 3) bycatch numbers, biomass and size frequencies from fish ticket and dockside and at-sea observer sampling. These data were not re-calculated this year, except to update the 2013/14 data. Estimates of total retained biomass and abundance, as well as retained size frequencies by shell condition, in the 2014/15 directed fishery were provided by Mr. Pengilly based on fish ticket data and dockside observer sampling. Mr. Pengilly also provided estimates of Tanner crab bycatch (sex-specific numbers, biomass and size compositions) in the 2014/15 directed Tanner crab, snow crab, and Bristol Bay red king crab fisheries.

Much of the data concerning Tanner crab bycatch in the groundfish fisheries (biomass, size compositions) was recalculated last year (to standardize to the crab fishery year, rather than the groundfish fishery year, and to utilize new estimates by ADF&G statistical areas) and incorporated into the 2014 assessment (Stockhausen, 2014). This year, these data were updated for 2013/14 and newly-extracted for 2014/15 from the groundfish observer and AKFIN databases.

Updated data sources.

Data source	Data types	Time frame	Notes	Agency
NMFS EBS Bottom Trawl Survey	abundance, biomass, size compositions	2015	new	NMFS
NMFS EBS Bottom Trawl Survey	abundance, biomass, size compositions	1975-2015	new standardization	NMFS
Directed fishery	retained catch (numbers, biomass)	2013/14, 2014/15	updated, new	ADFG
	retained catch size compositions	2013/14, 2014/15	updated, new	ADFG
	effort	2013/14, 2014/15	updated, new	ADFG
	total catch, discards (biomass)	2013/14, 2014/15	updated, new	ADFG
	total catch, discards size compositions	2013/14, 2014/15	updated, new	ADFG
Snow Crab Fishery	effort	2013/14, 2014/15	updated, new	ADFG
	total catch, discards (biomass)	2013/14, 2014/15	updated, new	ADFG
	size compositions	2013/14, 2014/15	updated, new	ADFG
Bristol Bay Red King Crab Fishery	effort	2013/14, 2014/15	updated, new	ADFG
	total catch, discards (biomass)	2013/14, 2014/15	updated, new	ADFG
	size compositions	2013/14, 2014/15	updated, new	ADFG
Groundfish Fisheries	total catch, discards (biomass)	2013/14, 2014/15	updated, new	NMFS
	size compositions	2013/14, 2014/15	updated, new	NMFS

2. Data presented as time series

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

a. Total catch

Retained catch (1000's t) in the directed fisheries for Tanner crab conducted by the foreign fisheries (Japan and Russia) and the domestic fleet, starting in 1965/66, is presented in Table 2 (and Fig.s 3 and 4) by fishery year. More detailed information on retained catch in the directed domestic pot fishery is provided in Table 3, which lists total annual catches in numbers of crab and biomass (in lbs), as well as the SOA's Guideline Harvest Level (GHL) or Total Allowable Catch (TAC) , number of vessels participating in the directed fishery, and the fishery season. Information from the Community Development Quota (CDQ) is included in the totals starting in 2005/06.

b. Information on bycatch and discards

Annual bycatch and discards (1000's t) of Tanner crab by sex are provided in Table 4 (and Fig.s 5 and 6) from crab observer sampling, starting in 1992/93 for the directed Tanner crab fishery, the snow crab fishery, and the BBRKC fishery. Annual discards for the groundfish fisheries are also provided starting in 1973/74, but sex is undifferentiated.

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

Retained (male) catch at size in the directed Tanner crab fishery from landings data is presented in Fig. 7 by fishery region for the most recent fishery periods from 2006/07-2014/15. Size compositions of total catch (retained + discards) from at-sea crab fishery observer sampling in the directed fishery are presented by shell condition and fishery region in Fig. 8 for male crab and in Fig. 9 for female crab. Size compositions for Tanner crab bycatch in the snow crab fishery from at-sea crab fishery observer sampling are presented by shell condition in Fig. 10 for males and in Fig. 11 for females. Fig.s 12 and 13 present similar information for the BBRKC fishery. Fig.s 14 and 15 present relative catch size composition information from groundfish observer sampling in the groundfish fisheries for undifferentiated males and females, respectively, from 1973/74 to the present. Raw sample sizes (number of individuals measured) for the various fisheries are presented in Tables 5-9.

d. Survey biomass estimates

Survey biomass estimates are not direct inputs to the stock assessment model. Instead, survey size compositions and sex-specific weight-at-size regressions from Rugolo and Turnock (2012a) are used to calculate the corresponding sex-specific mature survey biomass on an annual basis. This approach has been used since the 2012 assessment (Rugolo and Turnock, 2012a). These biomass estimates, while similar in scale, do not correspond exactly to corresponding time series published in recent survey technical memoranda for several reasons. First, the minimum size of crab included in the assessment model is 25 mm CW, while the “tech memo” time series include all crab. Second, the assessment model applies a single sex- and maturity state-specific weight-at-size regression to the entire size composition time series when calculating survey biomass components, whereas, prior to the survey standardization this year, the tech memos applied different regressions to pre-2010 and post-2009 survey data. Third, maturity state for females in the assessment has been based on morphological characters observed during the survey (clutch size), while prior to 2015 a size cut-point was used to classify females as mature or immature in the tech memos. Fourth, maturity state for males in the assessment has been based on a maturity ogive developed by Rugolo and Turnock (2010), while another size cut-point was used to classify male maturity for the tech memos.

Comparisons among survey biomass time series derived from the three “flavors” of the NMFS trawl survey considered in this assessment are shown in Fig. 16. The three flavors are: 1) Dataset A: size compositions from the “old” survey dataset, with the Rugolo and Turnock (2012a) weight-at-size regressions; 2) Dataset C: size compositions from the “new” survey dataset, with the Rugolo and Turnock (2012a) weight-at-size regressions; and 3) Dataset D: Dataset C but using the “new” standardized weight-at-size regressions. The largest differences, as judged by differences in survey biomass estimates, occur early in the time series (i.e., before 1985). The change in weight-at-size regressions (from Dataset C to D) has very little impact on the time series.

Estimates for mature male biomass, mature female biomass, and total biomass in the survey based on the size compositions from the new standardized survey dataset (stations/hauls and weight-at-size regressions) used in the assessment model increased from 2013 to 2014 by 21% for mature biomass, decreased 17% for mature females, and increased by 13% for all crab (> 25 mm CW) but decreased from 2014 to 2015 by 24% in all three categories (Fig. 17).

e. Survey catch-at-length

Plots of survey size compositions, expanded to total abundance, are presented for male and female crab in Fig.s 18 and 19, respectively, by shell condition and fishery region. Sample sizes for these size compositions are presented in Table 11.

f. Other time series data.
Spatial patterns of abundance in the 2012-2015 NMFS bottom trawl surveys are plotted in Fig.s 20-24 for immature males, mature males, "preferred" males, immature females, and mature females, respectively. A table of annual effort (number of potlifts) is provided for the snow crab and BBRKC fisheries (Table 12).

3. Data which may be aggregated over time:

a. Growth-per-molt
Sex-specific growth curves derived by Rugolo and Turnock (2010) are presented in Fig. 25. These curves provide the basis for priors on sex-specific growth estimated within the assessment model.

b. Weight-at size
Weight-at-size relationships used in the assessment model for males, immature females, and mature females are presented in Table 1 and depicted in Fig.2.

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

4. Information on any data sources that were available, but were excluded from the assessment.
The 1974 NMFS trawl survey was dropped entirely from the new standardized survey dataset due to inconsistencies in spatial coverage with the standardized dataset.

E. Analytic Approach

1. History of modeling approaches for this stock
Prior to the 2012 stock assessment, Tanner crab was managed as a Tier-4 stock using a survey-based assessment approach (Rugolo and Turnock 2011b). The Tier 3 Tanner Crab Stock Assessment Model (TCSAM) was developed by Rugolo and Turnock and presented for review in February 2011 to the Crab Modeling Workshop (Martel and Stram 2011), to the SSC in March 2011, to the CPT in May 2011, and to the CPT and SSC in September 2011. The model was revised after May 2011 and the report to the CPT in September 2011 (Rugolo and Turnock 2011a) described the developments in the model per recommendations of the CPT, SSC and Crab Modeling Workshop through September 2011. In January 2012, the TCSAM was reviewed at a second Crab Modeling Workshop. Model revisions were made during the Workshop based on consensus recommendations. The model resulting from the Workshop was presented to the SSC in January 2012. Recommendations from the January 2012 Workshop and the SSC, as well as Rugolo's and Turnock's research plans, guided changes to the model. A model incorporating all revisions recommended by the CPT, the SSC and both Crab Modeling Workshops was presented to the SSC in March 2012.

In May 2012 and June 2012, respectively, the TCSAM was presented to the CPT and SSC to determine its suitability for stock assessment and the rebuilding analysis (Rugolo and Turnock 2012b). The CPT agreed that the model could be accepted for management of the stock in the 2011/12 cycle, and that the stock should be promoted to Tier-3 status. The CPT also agreed that the TCSAM could be used as the basis for rebuilding analyses to underlie a rebuilding plan developed in 2012. In June 2012, the SSC reviewed the model and accepted the recommendations of the CPT. The Council subsequently approved the SSC recommendations in June 2012. For 2011/12, the Tanner crab was assessed as a Tier-3 stock and the model was used for the first time to estimate status determination criteria and overfishing levels.

In December 2012, a new analyst (Stockhausen) was assigned as principal author for the Tanner crab assessment. Modifications have been made to the TCSAM computer code to improve code readability, computational speed, model output, and user friendliness without altering its underlying dynamics and overall framework. A detailed description of the 2013 model (TCSAM2013) is presented in Appendix 3 of the 2014 SAFE chapter (Stockhausen, 2014). Following the 2014 assessment, the model code was put under version control using "git" software and is publicly available for download from the GitHub website[2].

2. Model Description

a. Overall modeling approach

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

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

Model parameters are estimated using a maximum likelihood approach, with Bayesian-like priors on some parameters and penalties for smoothness and regularity on others. Data components entering the likelihood include fits to survey biomass, survey size compositions, retained catch, retained catch size compositions, discard mortality in the bycatch fisheries, and discard size compositions in the bycatch fisheries (Stockhausen, 2014).

b. Changes since the previous assessment.

Although the fishing mortality equations implemented in the current Tanner crab model (TCSAM2013) represent a workable description of the fishing mortality process, the interpretation of the retention function in TCSAM2013 is not a simple reflection of the on-deck sorting process (see Appendix A). The fishing mortality model formulated in Gmacs, on the other hand, allows a simple and intuitive description of the on-deck process of retention and discarding whereas the standard model in TCSAM does not (Appendix A). Last year, an alternative version of the Tanner crab model implementing the Gmacs equations (TCSAM-FRev) was developed by modifying a copy of the TCSAM2013 code in Spring 2014, with results from initial model runs presented to the CPT in May. However, satisfactory runs with this model were not achieved in time for the September CPT meeting due to a presumed bug in the model code. This year, the Gmacs equations have been successfully integrated into the TCSAM2013 model code as an option that can be selected in the model control file. Several alternative models presented here use the Gmacs fishery model option.

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

Two other options that have now been implemented in the model and are incorporated in some of the alternative models used in this assessment are: 1) using lognormal likelihoods, as opposed to normal likelihoods, for fitting bulk fishery catch time series, and 2) forcing logistic selectivity functions to 1 in the largest model size bin.

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

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

3. Model Selection and Evaluation

a. Description of alternative model configurations

Six data configurations were considered in this assessment. These are briefly outlined in the following table:

Dataset Name	Base Dataset	Modifications
base (2014 assesssment)	--	--
2014 Corrected	2014 assessment	corrects 2013/14 retained catch, size frequencies
A	2014 corrected	updates 2013/14 fisheries data, adds 2014/15 data; adds 2015 survey data
B	A	replaces old trawl survey data with new time series
C	B	updates 2009/10-present bycatch size compositions in the groundfish fisheries
D	C	uses the standardized trawl survey LW regressions

The dataset used in the 2014 assessment is the base dataset for this assessment. Dataset D represents the complete 2015 assessment dataset against which all the alternative model configurations have been run. The base assessment model (the 2014 assessment model, also referred to as Model A below) has been run for each incremental change in the data from the base dataset to Dataset D to identify the sources of important data-related (as opposed to model-related) changes to the assessment results.

Soon after the September, 2014 CPT meeting, W. Gaeuman (ADF&G) discovered that the 2013/14 retained size compositions he had provided for the assessment were incorrect. The “2014 corrected” dataset replaces the bogus size compositions with the correct ones (Fig. 27) and corrects an additional problem with the 2013/14 retained catch in which the values for biomass and abundance were switched in the input files to the assessment model (Fig. 28).

Dataset A updates the 2013/14 fisheries data for interim changes since the 2014 assessment and adds abundance, biomass and size composition data from the 2014/15 fishery season for the directed and bycatch crab fisheries, as well as for the groundfish fisheries. Size composition data from the 2015 NMFS EBS bottom trawl survey was also added to the “old” trawl survey dataset. Input sample sizes were also recalculated for all size composition data, based on the approach described in Appendix 5 of the 2014 assessment (Stockhausen, 2014).

Dataset B replaces the “old” trawl dataset (1974-2015) with size compositions from the newly-defined standard trawl survey dataset (1975-2015). Dataset C replaces the relative bycatch size compositions from the 2009/10-2014/15 groundfish fisheries with estimates of total crab bycatch by size based on an algorithm that apportions AKRO estimates of total gear-specific bycatch available from AKFIN to size bins using relative gear-specific size compositions from groundfish observer sampling. Previous estimates of relative bycatch by size were based on the assumption of simple random sampling across all gear types.

Finally, Dataset D replaces the Rugolo and Turnock (2012a) weight-at-size regressions used in model runs with all previous datasets with the newly-defined, standard survey regressions (i.e., the regressions formerly used with the 2010-present surveys) when calculating biomass-related quantities from numbers-at-size.

Ten models (including the model configuration from the 2014 assessment) were evaluated against the five datasets just described and compared with to the 2014 assessment results. The CPT-preferred model configuration from the 2014 assessment, model Alt4b, was used as the base model (also referred to here as Model A) against which to judge the alternative models. In the interest of time, Model A was the only model run using all five datasets; the alternative models were all run using Dataset D (the final dataset). The principal interest in examining model results from the intermediate datasets was to more easily disentangle assessment results due to changes in the data from changes in the model. Running a single model against each dataset should suffice in this regard.

The ten models and the datasets they were run against are summarized in the following table:

Alternative Model	Base Model	ModelConfiguration			Datasets
		Fishing Mortality Model	Fishery Catch Likelihoods	Asymptotic Selectivity Forced?	
A	--	TCSAM2013	normal	no	2014 corrected, A, B, C, D
B	A	TCSAM2013	lognormal	no	D
C	A	Gmacs	normal	no	D
D	C	Gmacs	lognormal	no	D
E	A	TCSAM2013	normal	yes	D
F	B	TCSAM2013	lognormal	yes	D
G	C	Gmacs	normal	yes	D
H	D	Gmacs	lognormal	yes	D

The ten models differ as to whether the TCSAM2013 or Gmacs fishing mortality model was used, whether the fishery catch likelihoods reflected normal or lognormal error distribution assumptions, and whether or not logistic selectivity functions were normalized to 1 in the largest size bin ("Asymptotic Selectivity Forced?"). The nine alternative models were constructed by changing one of the features of a "base model" to obtain the alternative so that incremental effects in model configuration could be examined; the base models are listed in the second column of the table above (Model A does not really have a base model, it is the 2014 assessment model, Alt4b, updated to 2015).

In implementing the lognormal fishery catch likelihoods, it was necessary to specify relative error sizes for each data source. The same set of values were used for all models that included lognormal fishery catch likelihoods, and are documented in the following table:

Fishery	Data Source	Likelihood Component	Assumed CV
Directed fishery	fish tickets	retained catch	5%
	at-sea observers	total catch/discards	20%
snow crab	at-sea observers	total catch/discards	20%
BBRKC	at-sea observers	total catch/discards	20%
groundfish	at-sea observers	total catch/discards	20%

The values chosen were subjective, based on the author's experience with such data. It seems likely the chosen values can be refined in future work.

b. Progression of results from the previous assessment to the preferred base model
Basic results for Model A (the 2014 assessment model) run against the progression of incremental datasets from the 2014 assessment to Dataset D (the final 2015 dataset) are listed in the following table:

Model	Dataset	Description	Converged?	Positive-definite Hessian	Mean Recruitment (millions)		MMB (1000's t)			Objective Function Value
					1982+	2000+	1982+	3-year mean	Final Year	
A (2014)	2014	2014 assessment	Yes	Yes	187.9	186.8	40.5	62.9	72.7	1,701.2
A	2014 Corrected	2014 data with corrected retained catch and size compositions	Yes	Yes	187.1	186.3	39.1	65.1	72.1	1,722.9
A	A	2014 + 2014, 2015 Updates	Yes	Yes	178.6	166.7	40.5	62.2	72.6	1,847.8
A	B	A + Revised Trawl Survey Time Series	Yes	Yes	174.2	160.1	37.3	59.3	70.4	2,053.3
A	C	B + Revised Fishery Data	Yes	Yes	173.5	161.3	36.7	58.8	70.8	2,036.0
A	D	C + standard LW regressions	Yes	Yes	179.4	164.9	36.5	59.6	71.6	2,049.1

For each run, the model converged successfully, the hessian was invertible, and standard deviation estimates based on the "delta method" were obtained for all parameters and other selected quantities (e.g., recruitment time series). Resulting time series for recruitment and MMB-at-mating are listed in Tables 13 and 14 and compared visually in Fig.s 29 and 30. Correcting the 2013/14 retained catch abundance, biomass and size compositions had almost no effect on estimates of recruitment and only small effects on MMB (less than 5% change in mean values). Updating the 2013/14 fishery data for interim changes, adding the 2014/15 fishery data, and adding the 2014/15 trawl survey results to obtain Dataset A led to small declines (5-10%) in estimated mean recruitment and recent MMB. However, it had a substantial negative effect (-35%) on estimated recruitment in 2014/15, although large changes in terminal year estimates of recruitment are not surprising given the uncertainty in these estimates. Replacing the "old" trawl survey time series with the new version to obtain Dataset B had little effect on terminal year estimates of recruitment or MMB, but resulted in declines to estimated mean recruitment and MMB of 5-10% due to changes in estimates earlier in the time series. The incremental changes involved from Dataset A to Dataset D had little impact on estimates of mean recruitment and MMB. The most variability in recent recruitment occurred between 2003/04 and 2012/13, although the temporal patterns are similar. Because different datasets are involved in each of these model runs, it is not appropriate to compare the model results directly using their objective function values as relative measures of model fit.

Parameter estimates and associated uncertainties for each model run are listed in Table 15.

Basic results for the progression of alternative models from A to H are summarized in the following table:

Model	Dataset	Fishing Mortality Model	Fishery Catch Likelihoods	Asymptotic Selectivity Forced?	Converged?	Positive-definite Hessian?	Mean Recruitment (millions)		MMB (1000's t)			Objective Function Value	Delta OFV
							1982+	2000+	1982+	3-year mean	2014/15		
A (2014)	2014	TCSAM2013	normal	No	Yes	Yes	187.9	186.8	40.5	62.9	63.8	--	--
A	D	TCSAM2013	normal	No	Yes	Yes	179.4	164.9	36.5	59.6	71.6	2,049.1	0.0
B	D	TCSAM2013	lognormal	No	Yes	Yes	133.2	110.8	23.1	37.2	42.4	3,761.6	0.0
C	D	Gmacs	normal	No	Yes	Yes	180.9	168.1	36.4	58.2	70.6	2,112.5	63.4
D	D	Gmacs	lognormal	No	Yes	Yes	154.0	135.9	29.2	48.1	56.6	3,912.4	150.7
E	D	TCSAM2013	normal	Yes	No	No	151.0	133.1	28.3	46.7	55.3	2,052.8	3.7
F	D	TCSAM2013	lognormal	Yes	No	No	147.6	126.6	25.6	41.0	47.2	3,768.7	7.0
G	D	Gmacs	normal	Yes	No	No	151.6	133.1	28.4	46.3	55.3	2,116.2	67.1
H	D	Gmacs	lognormal	Yes	No	No	149.9	130.6	27.3	45.3	53.0	3,929.5	167.8

In the above table, "Delta OFV" is the difference between the objective function values for the alternative model and its base comparable model (comparable models are highlighted similarly). Positive values for OFV indicate that the alternative model fits the data more poorly than the base comparable model. For the model configurations considered above, models that don't share the same fishery catch likelihood functions are not comparable. Consequently, Model A was used as the base comparable model for alternative models C, E and G while Model B was used as the base comparable model for models D, F, and H. Overall, Models A and B had the smallest objective functions (fit the data better) compared to the comparable alternative models. In addition, none of the models that forced asymptotic selectivity (E-H) converged successfully. This is probably a result of structural constraints in the model: one possible candidate for a structural constraint is that fully-selected bycatch mortality rates in the groundfish fisheries are not explicitly sex-specific in the model. When asymptotic selectivity is not forced, effective sex-specific rates are possible if one of the associated sex-specific selectivity functions asymptotes at a value less than one. In the models runs where asymptotic selectivity was not forced, Models A-D, the selectivity curve estimated for female bycatch in the groundfish fisheries during the 1977-1996 time period asymptotes to much less than one in all models (Fig. 31).

The remaining models that incorporated lognormal fishery catch likelihoods (B, D) were eliminated as candidates for the preferred model because they tended to substantially mis-fit the discard mortality time series (Fig. 32)—overestimating total male mortality in the directed fishery, underestimating discard mortality in the groundfish fishery, and both under- and over-estimating male discard mortality in the snow crab fishery. The models that incorporated normal fishery catch likelihoods (A, C) fit the observed values quite well. This indicates that perhaps the relative error levels specified for the lognormal likelihoods overestimating the size of these errors, essentially not penalizing Models B and D enough for mis-fitting the fishery bycatch data. Better fitting models may be achieved by exploring alternative values for the specified cv's. As a consequence, however, Models B and D were eliminated from further consideration as preferred model candidates for this assessment, leaving only Models A and C.

Parameter values for Models A and C (as well as B and D) obtained using Dataset D are listed in Table 16.

Results for Models A and C are compared with those from the 2014 assessment for sex-specific mature survey biomass in Table 17 and Fig.s 33 and 34. All three models exhibit similar temporal patterns. Estimates are nearly identical for Models A and C after 1980 for both males and females. Estimates after 2005 are slightly less than those obtained last year.

Results for Models A and C are compared with those from the 2014 assessment for estimated trends in recruitment in Table 18 and Fig. 35. The temporal patterns are similar for all three models. Time series from Models A and C are almost identical after 1975 (when trawl survey data starts to inform the models). Since 2000, Models A and C estimates tend to be slightly lower than those from the 2014 assessment, and are substantially lower for last year (2013/14), although the associated uncertainty for 2013/14 in the assessment model (not shown) is large.

Time series estimates of MMB-at-mating for Models A and C are also almost identical after 1975. The temporal patterns are very similar to those from the 2014 asessment, as well, but Models A and C yield lower estimates of recent (since 2005) MMB-at-mating.

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

All models considered were parameterized in similar fashion, so no simpler or more realistic models were considered.

d. Convergence status and convergence criteria

Convergence in all models was assessed by running each model iteratively from a set of initial parameter configurations. Following an initial run, the final parameter estimates from the run were used as initial parameter estimates in a following run and this sequence was repeated six times. The model with the smallest objective function value was selected as the "converged" model, if it was possible to invert the associated hessian and obtain standard deviation estimates for parameter values. As noted previously, none of the four models (E-H) that forced asymptotic selectivity converged successfully. All other model runs converged, had invertible hessians, and standard deviation estimates based on the "delta method" were obtained for all parameter values.

e. Sample sizes assumed for the compositional data

Sample sizes assumed for compositional data used in Dataset D (the final dataset) are listed in Tables 4-8 for fishery-related size compositions. Sample sizes for all survey size compositions were set to 200, which was also the maximum allowed for the fishery-related sample sizes. Otherwise, input sample sizes were scaled as in the 2014 assessment (see 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. Input sample sizes for all the size compositions that comprise Dataset D are compared in Fig. 37.

f. Parameter sensibility

For Models A-D, evaluated using Dataset D, most model parameter estimates obtained from the alternative models appear to be reasonable, or at least consistent with the 2014 assessment (Table 16). One notable exception is "af1", the ln-scale intercept for the mean female growth increment. This parameter reaches its upper bound (0.7) in every model, including the 2014 assessment. Anothe notable exception is "log_sel50_dev_3" (index 6), the ln-scale deviation from mean size at 50%-selected for males in the directed fishery for 1996, which hit the lower bounds put on the parameter (-0.5) in the 2014 assessment and remains small (-0.43) in Model A (Dataset D). This results in an unreasonably small estimates (~75 mm CW) for size at 50%-selected in 1996 in the directed fishery. The small input sample sizes associated with total catch size frequencies in the directed fishery for 1996 (< 3) seems to be the main factor allowing this parameter to go so small, but it is not clear what conflict in the data is pushing it that way.

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

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

h. Residual analysis

Residuals for the author's preferred model are discussed below under the Results section.

i. Evaluation of the model(s)

As discussed previously, Models E-H were eliminated from further consideration based on their non-convergence. Model B and D were eliminated because they tended to substantially mis-fit the discard mortality time series (Fig. 32)—overestimating total male mortality in the directed fishery, underestimating discard mortality in the groundfish fishery, and both under- and over-estimating male discard mortality in the snow crab fishery.

For the most part, Models A and C gave very similar results for estimated time series. Overall, however, Model A fit the data, with smaller penalties, much better than Model C did, as judged by comparing the total objective functions for the two models (Table 23). Model A had an objective function that was lower than Model C by more than 60 units, indicating a much better fit. Examination of the individual components to the objective function (Table 23, Fig.s 38 and 39) indicates that Model A fit the size compositions for retained males and total male catch in the directed fishery substantially better than Model C, size compositions for mature females in the trawl survey somewhat better (6 units), and biomass for mature males in the survey marginally better (4 units). Comparing Pearson's residuals from the fits to total male catch and retained catch for Models A and C indicate the generally the same patterns, although what appear to be rather small differences can be identified (primarily the patterns for 2005/06-200/10).

Model C, on the other hand, fit the data somewhat better (6-12 units) than Model A for size compositions for bycatch in the groundfish fisheries and for mature males in the survey, as well as for catch biomass of retained males and total males in the directed fishery.

However, given that Model A appears to fit the data substantially better than Model C, while both models give substantially similar results for population trends, I selected Model A as my "preferred" model for the 2015 assessment. This model is essentially identical to the 2014 assessment model selected by the CPT last year.

4. Results (best model(s))

Model A was selected as the author's preferred model for the 2015/16 assessment.

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

Input sample sizes for the various fishery-related size compositions are given in Tables 5-9 and Fig. 37. Input sample sizes for all survey-related size compositions were set to 200. Weighting factors for likelihood components and penalties are listed in Table 23, as are the associated objective function values from the converged model.

b. Tables of estimates:

i. All parameters

Parameter estimates and associated standard errors, based on inversion of the converged model's Hessian, are listed in Table 16 (non-"devs" parameters) and in Table 24 ("devs" parameters).

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

Estimates of mature survey biomass are listed in Table 17 and presented graphically in Fig. 58. Estimates MMB are listed in Table 19 and presented graphically in Fig. 60. Estimates of mature female biomass at the time of mating (MFB) are presented graphically in Fig. 61. Numbers at size for males and females are given by year in 5 mm CW size bins in Tables 21 and 22, respectively.

iii. Recruitment time series

The estimated recruitment time series from the 2014 assessment and Model A are compared in Table 18 and Fig. 62.

iv. Time series of catch divided by biomass.

A comparison of catch divided by biomass (i.e., exploitation rate) from the 2014 assessment and Model A (Dataset D) is presented as a graph in Fig. 42.

c. Graphs of estimates

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

Model-estimated growth curves from last year's model and the author's preferred model (Model A) are compared with empirical curves developed from growth data on Tanner crab in the GOA near Kodiak Island in Fig. 43. The model-estimated female growth is almost identical to that from Kodiak, while the model-estimated male growth curve suggests that molt increments are larger in the EBS than in the GOA. Model-estimated sex-specific probabilities at size of immature crab molting to maturity are compared in Fig. 44. The curve for males suggests an unlikely decline at the largest sizes, but it is not constrained to increase. In addition, size bins for which the curve is 1 (or 0) have corresponding parameter estimates that are on the upper (lower) boundary of the range of allowable values. This does not seem to affect model convergence or its ability to estimate standard deviations, which would ordinarily be a concern under such circumstances.

Estimates of natural mortality by sex and maturity state are shown in Fig. 45. Mortality rates are assumed equal by sex for immature crab, but are allowed to differ by sex for mature crab. Mortality rates for mature crab are estimated by sex across two time periods: 1949-1979+1985-2013 and 1980-1984. The latter period has been identified as a period of high natural mortality in the BBRKC stock (Zheng et al., 2012) and was identified as a separate period for Tanner crab in the 2012 assessment. The following table summarizes the estimated rates by stock component:

Stock component	Normal period		High Mortality	
	2014 assessment	Model A	2014 Assessment	Model A
immature crab	0.24	0.24	0.24	0.24
mature females	0.33	0.35	0.37	0.52
mature males	0.26	0.26	0.66	0.92

While the rates are almost identical in the "normal" period, Model A's estimates for mature males and females are substantially larger than those from the 2014 assessment. Examining the dataset progression results, this jump occurs with the replacement of the old trawl survey dataset with the new one to obtain Dataset B.

Estimated total mortality selectivity curves for males in the directed fishery are very similar between Model A and the 2014 assessment model (Fig. 46). Small (< 5 mm CW) differences in size-at-50% selected occurred for 1994 and 1996. Retained mortality selectivity curves are also similar, although Model A indicates retention at slightly smaller sizes than the 2014 assessment did (Fig. 47). This is due to the difference in the estimated retention functions for the two models after 1990: the curve estimated by Model A indicates a slightly less steep rise in retention probability with size, as compared with the 2014 assessment estimate. The estimated selectivity curves for females in the model are also quite similar (Fig. 49).

Estimated bycatch selectivity curves for males and females are shown in Fig. 50 for the snow crab fishery, in Fig. 51 for the BBRKC fishery, and in Fig. 52 for the groundfish fisheries. Separate curves are estimated for 3 different time periods for each fishery, corresponding to changes in available data and fishery activity. For the snow crab fishery, separate sex-specific curves are estimated for 1989/90-1996/97, 1997/98-2004/05, and 2005/06-present. The time periods are the same for the BBRKC fishery. The directed Tanner crab fishery was closed during 1997/98-2004/05, which may have encouraged changes in how the snow crab and BBRKC fisheries were prosecuted—with associated changes in bycatch selectivity on Tanner crab. For the groundfish fisheries, the three time periods corresponding to the selectivity curves are 1973-1987, 1988-1996, and 1997-present. These correspond to changes in the groundfish fleets and Tanner crab fishery, with the curtailment of foreign and joint-venture fishing by 1988, the expansion of domestic fisheries from 1988 to 1996, and the closure of the tanner crab fishery in 1996/97.

The estimated selectivity curves for the snow crab fishery from Model A are similar to those from the 2014 assessment for both sexes (Fig. 50). The estimated selectivity curves for the BBRKC fishery are also quite similar, except for female bycatch selectivity before 1996, in which case Model A estimated a much smaller size-at-50% selection, compared with the 2014 assessment (Fig. 51). The pre-1996 curve estimated by Model A is, however, similar to that from the 2013 assessment—indicating, to some extent, the sensitivity of these underlying parameter estimates, in general. This may reflect differences in sex/size-specific bycatch fishing mortality in the BBRKC fishery such that the largest females and similarly-sized males are not subject to the same fishing mortality, as is assumed in the model by applying a fully-selected fishing mortality equally to selectivity curves for both sexes. If such were the case, the model might achieve a "better" fit to data by adjusting either the slope or location parameter (size at 50% selected) such that selectivity on females was less than 1 across the range of sizes found in the data. A possible solution to this confounding would be to fix sex-specific sizes for "fully-selected" animals in each fishery within observed size ranges and then estimate female-specific offsets to male "fully-selected" fishing mortality.

A similar phenomenon may be occurring in the groundfish selectivity curves for both Model A and the 2014 assessment model (Fig. 52), but with effects seen on the slope of the curves for females rather on size at 50% selected. For both models, the slopes of the female selectivity curves during 1977-1996 period are such that the curves never reach 1 (fully-selected) within the model's size range (the largest size bin corresponds to 182.5 mm CW). This did not occur in the 2013 Model, but the difference was traced, at least in part, to the extra emphasis placed on fitting female bycatch size compositions as a result of correcting input sample sizes between male and female groundfish bycatch size compositions (the true male sample sizes were always several times larger than the corresponding female ones).

Estimated survey selectivity curves (multiplied by sex-specific survey catchability) for males and females in three time periods (1974-1981, 1982-1987, and 1988-present) are shown in Fig.53, together with the selectivity curves inferred from Somerton's "underbag" experiments (Somerton and Otto, 1999). The curves are quite similar to those obtained in the 2014 assessment, except that the curve for females pre-1982 exhibits a smaller value for female catchability in the survey than was found in the 2014 assessment. This is a result of using the new survey dataset.

iii. Estimated full selection F over time

Estimated time series of fully-selected F on males in the directed fishery and as bycatch in the snow crab, BBRKC and groundfish fisheries are compared in Fig.s 54-57 between Model A and the 2014 assessment. Estimated trends are similar for the models across all four fisheries. In the directed fishery, fully-selected F peaked in 1980 at values larger than 2 in both models, then rapidly declined and was at low levels in the mid-1980s. It peaked again in 1993 and subsequently declined to low levels (when the fishery was open; Fig. 54). Exploitation rates (catch/biomass) in the directed fishery for total catch and large males > 138 mm CW followed similar trends (Fig. 42), with exploitation rates reaching almost 80% on large males in 1981 and 50 % in 1993.

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

Time series of observed biomass of mature crab in the NMFS bottom trawl surveys are compared by sex with model-predicted values for Model A (Dataset D) and the 2014 assessment in Fig. 58. Both the model and the assessment under-predict mature female survey biomass in the early 1980s and again in the early 1990s. They also under-predict mature male survey biomass in the early 1990s as well as in the mid-2000s. The scale of the standardized log-scale residuals (Fig. 59) indicates a mediocre fit, as in the 2014 assessment,between the model and the data (the standard deviation of the residuals is ~2, whereas ~1 would indicate a good fit).

The time series of model-predicted MMB (i.e., mature male biomass at the time of mating) from the 2014 assessment and Model A is compared in Fig. 60, while mature female biomass (MFB) at the time of mating is shown in Fig. 61. For both models, MMB and MFB decline from peaks in the mid-1970s to low levels in the early-1980s. This period is followed by buildups to much lower peaks in 1989, followed by steady declines to minima in 1999. After 1999, both MMB and MFB have been on fairly steady increasing trends.

iv. Estimated fishing mortality versus estimated spawning stock biomass
See Section F (Calculation of the OFL).

v. Fit of a stock-recruitment relationship, if feasible.
Not available.

e. Evaluation of the fit to the data:

i. Graphs of the fits to observed and model-predicted catches
Graphs of model fits to retained catch, total male (retained + discard) mortality, and female discard mortality in the directed fishery are provided in Fig. 63. The fits are quite good for males, but less so for females. Model fits to discard mortality in the snow crab fishery in Fig. 64. As with the directed fishery, fits are better for males and less so for females. Model fits to discard mortality in the BBRKC fishery are shown in Fig. 65. These fits are quite poor for both sexes. Part of the problem is that the effective variance for fishery catch data is 1,000 t, but the observed discard mortalities, particularly for the BBRKC fishery, are much smaller than this level—consequently the model has no "motivation", as it were, to fit them more closely. Model fits to discard mortality in the groundfish fisheries are shown in Fig. 66, and are quite good.

ii. Graphs of model fits to survey numbers
Model predictions for total numbers of large males (≥ 138 mm CW), all females, and all males in the survey are compared with observations from the survey in Fig. 66. The model over-predicts numbers of large crab in recent years, but under-predicts the decline in survey numbers of both males and females in the mid-1980s and anticipates the subsequent increase in survey numbers to 1990. In the more recent past (since 2000), the model tends to underestimate the numbers of both sexes in the survey. These results suggest that growth in the model may be too rapid.

Model predictions for the number of mature males and females in the survey are compared with observed numbers in Fig. 67 for Model A. The fits seem to be better than those in Fig. 66.

iii. Graphs of model fits to catch proportions by length
Model-predicted proportions at size for retained males in the directed Tanner crab fishery are presented in Fig. 68 from the 2014 assessment and Model A. Both models appear to fit the observed proportions quite similarly. The peak in the predicted size compositions tends to be quite sharp in the 2014 assessment, but more rounded in Model A. Model A over-predicts the proportion of retained small crabs in 1996, but the input sample size for this year is very small and thus the mis-fit is not heavily penalized.

Model-predicted patterns from the 2014 assessment and Model A for the proportion caught-at-size in the directed fishery for all males are shown in Fig. 70. General residual patterns again indicate, more strongly than with the retained catch, that the fishery catches a larger proportion of smaller crab than predicted by the model (except in 1996) and catches fewer large crab than predicted by the model. Conceivably, among other potential explanations, this pattern may indicate that an asymptotic selectivity curve is inappropriate for the selection process or that the model overestimates growth into the largest size classes for males. 1996 is the exception to this, and exhibits an extremely poor fit to the data. However, as previously noted, the relative weight (input sample size) put on fitting this weight in the likelihood is quite small. It is notable that the fit to the 1996 size composition for females taken in the directed fishery (Fig. 71) is much better. The general pattern of residuals for females is similar to the general pattern for males. It should be noted, however, that the scale of the residuals for males is larger than that for females.

iv. Graphs of model fits to survey proportions by length

Model fits from the 2014 assessment and Model A (Dataset D) to observed proportions at size in the annual NMFS trawl survey are shown for males in Fig. 72. The similarity in results between the two models is fairly remarkable, and indicates that relative size compositions were not substantially different between the old and new trawl survey datasets. As with the 2014 assessment model, Model A appears to be suitably sensitive to relatively large cohorts recruiting to the model size range (e.g., 1997-2002), but appear to be less able to track strong cohorts through time (the mode in the model proportions at ~100 mm CW in 1982 disappears after two years, but appears to last until at least 1985 in the observed proportions. After 1982, the model tends to under-predict size proportions for males in the 70-120 mm range and over-predict the proportion of large (> 120 mm CW) males after 2000. Model fits to proportions at size in the survey for females are shown in Fig. 73. The model tends to over-predict proportions-at-size in the 65-85 mm CW range. The patterns of residuals for males and females evident in the bubble plots for Model A are almost identical to those obtained from the 2014 assessment.

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

Marginal fits of the Model A-predicted proportion of crab by size in the directed fishery catch show the model slightly over-predicts proportions for retained males at sizes smaller than the peak and under-predicts proportions at sizes larger than the peak (Fig. 74, upper graph). In contrast, the model under-predicts proportions near the peak and somewhat smaller for all males caught (retained and discarded), but over-estimates the proportions for crab larger than the peak (Fig. 74, middle graph). A similar pattern is evident for the model-predicted marginal proportion at size for female bycatch in the directed fishery (Fig. 74, lower graph).

The observed and predicted (Model A) marginal proportions for males taken as bycatch in the snow crab fishery are in good agreement at all sizes, while the model tends to underestimate the proportion of females taken as bycatch near the peak proportions (~80-90 mm CW) and over-estimate the proportions at larger sizes (Fig. 75, upper row).

The opposite pattern is true of the proportion-at-size of females taken as bycatch in the BBRKC fishery, where intermediate-size females are over-represented in the model predictions and under-represented at larger sizes (Fig. 75, middle row). The pattern of model-predicted marginal proportions-at-size for males taken as bycatch in the BBRKC fishery is similar to that found for the snow crab fishery, but shifted to larger sizes by ~20 mm CW. Unfortunately, it presents a poorer fit to the observations, overestimating proportions at larger sizes and underestimating them at smaller sizes, than in the snow crab fishery. The patterns of marginal predicted proportions at size for males and females taken in the groundfish fishery (Fig. 75, bottom row) obtained by Model A are again quite similar to those obtained in the 2014 assessment. Male proportions are over-estimated across the size range while female proportions are under-predicted. Somewhat oddly, the model predicts a plateau at smaller female sizes and suggests a bimodal distribution not seen in the data.

Marginal fits of Model A-predicted proportion-at-sizes in the survey are presented in Fig. 76. The model's marginal survey proportions fit the data quite well, and in quite similar fashion to the 2014 assessment.

Overall, the patterns for all of the marginal distributions are quite similar to those obtained in the 2014 assessment.

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

Not available.

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

Not available.

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

Not available.

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

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

As currently coded, it is not possible to perform retrospective analyses with the TCSAM in the compressed time span allowed for this assessment. This deficiency has been addressed in the new code undergoing testing.

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

Many of the plots contained in this assessment feature comparisons between results from the 2014 assessment model and the author's preferred model for this assessment. Most of them indicate little difference between the two models, particularly for more recent periods (e.g., since 1990).

g. Uncertainty and sensitivity analyses

Not available.

F. Calculation of the OFL and ABC

1. Status determination and OFL calculation

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

The (total catch) OFL for 2014/15 was 31.48 thousand t while the total catch mortality for 2014/15 was 9.16 thousand t, based on applying discard mortality rates of 0.321 for pot fisheries and 0.8 for the groundfish fisheries to the reported catch by fleet for 2014/15 (Tables 1 and 3). Therefore overfishing did not occur.

Amendment 24 to the NPFMC fishery management plan (NPFMC 2007) revised the definitions for overfishing for EBS crab stocks. The information provided in this assessment is sufficient to estimate overfishing limits for Tanner crab under Tier 3. The OFL control rule for Tier 3 is (Fig. 77):

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 MMB at mating in the assessment year) and spawning biomass per recruit (SBPR)-based proxies for F_{MSY} and B_{MSY}. In the above equations, α=0.1 and β=0.25. For Tanner crab, the proxy for F_{MSY} is $F_{35\%}$, the fishing mortality that reduces the SBPR to 35% of its value for an unfished stock. Thus, if $\phi(F)$ is the SBPR at fishing mortality F, then $F_{35\%}$ is the value of fishing mortality that yields $\phi(F) = 0.35 \cdot \phi(0)$. The Tier 3 proxy for B_{MSY} is $B_{35\%}$, the equilibrium biomass achieved when fishing at $F_{35\%}$, where $B_{35\%}$ is simply 35% of the unfished stock biomass. Given an estimate of average recruitment, $\bar{R}$, then $B_{35\%} = 0.35 \cdot \bar{R} \cdot \phi(0)$.

Thus Tier 3 status determination and OFL setting for 2015/16 require estimates of B = $MMB_{2015/16}$ (the projected MMB at mating time for the coming year), $F_{35\%}$, spawning biomass per recruit in an unfished stock ($\phi(0)$), and $\bar{R}$. Current stock status is determined by the ratio $B/B_{35\%}$ for Tier 3 stocks. If the ratio is greater than 1, then the stock falls into Tier 3a and $F_{OFL} = F_{35\%}$. If the ratio is less than one but greater than β, then the stock falls into Tier 3b and F_{OFL} is reduced from $F_{35\%}$ following the descending limb of the control rule (Fig. 73). If the ratio is less than β, then the stock falls into Tier 3c and directed fishing must cease. In addition, if B is less than 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). It would be desirable, if possible, to incorporate this change in harvest strategy in the projections made to determine F_{OFL} and calculate OFL.

In order to incorporate the spatial division of the directed fishery into two management areas into the projection model, previous assessments approached the problem using the following assumptions:

1. The whole-stock total (retained + discard) fishing mortality selectivity function, as estimated by the assessment model (an average over the last 4 years of fishing), applied equally to both areas.
2. The whole-stock retained mortality selectivity function, as estimated in the assessment model (an average over the last 4 years of fishing), applied to the area east of 166°W.
3. The whole-stock retained mortality selectivity function, as estimated in the assessment model, applied to the area west of 166°W, but was shifted 10 mm (two size bins) toward smaller sizes to incorporate the difference in preferred sizes between the two areas.
4. The effective whole stock retained mortality selectivity function was a weighted version of the functions in 2 and 3, with the size-specific weighting equal to the fraction of total survey abundance derived from each area.

This approach, referred to here as the 2014 projection approach, appeared to work satisfactorily. The selectivity functions used in the 2014 approach to calculate the OFL for Model A (Dataset D) are shown in Fig. 78.

Because of the changes noted previously to the preferred minimum size used for TAC setting in the area east of 166°W, two new approaches were considered in this assessment, as well the 2014 approach. The first one ("new (1)") applied the same rationale to step 2 above as was used in step 3 to assign a new retained mortality curve to the eastern area, but used a more flexible calculated version of the retention function that rises to 1 at the new minimum preferred size to left-shift the retained mortality selectivity function estimated in the assessment model. To be consistent, this was also done for the west area (rather than left-shifting by two size bins). For the 2015/16 preferred minimum sizes (which are the same in both areas), this approach assumes the whole stock retained mortality selectivity function for 2015/16 will simply be a left-shifted version of the average over the last four fishing years. However, total (retained + discard) directed fishing mortality selectivity would be the same as average over the last four fishing years. This approach, like the 2014 approach, attempts to capture changes in size-specific retention while size-specific total selectivity remains unchanged. The curves used to calculate OFL for Model A using the new (1) approach are shown in Fig. 79.

The second new approach ("new (2)") assumed that both the total directed fishing mortality selectivity and the retained mortality selectivity would be left-shifted versions of their equivalent assessment model averages. This approach attempts to capture changes in size-specific total selectivity as well as changes in size-specific retention. The curves used to calculate OFL for Model A using the new (2) approach are shown in Fig. 80.

Fully-selected fishing mortality and selectivity curves in the bycatch fisheries were set using the same approach as in previous assessments (Rugolo and Turnock, 2012b; Stockhausen 2014). The curves used for Model A are shown in Fig. 81.

The alternative models presented in the snow crab assessment this year resulted in substantially different snow crab F_{OFL}'s. Because the snow crab F_{OFL} is incorporated into the Tanner crab projection model, I considered two snow crab F_{OFL} scenarios (based on Turnock's preferred and 2014 models) for each of the three approaches outlined above for handling potential changes to the size-specific patterns of retained (and total) fishing mortality in the directed fishery. For Turnock's "preferred" snow crab model, I used his snow crab F_{OFL}=0.89 and recent 5-year average of fully-selected F's (1.54) to scale the recent 5-year average fully-selected Tanner crab discard mortality rate estimated in the assessment model to that used in the projection (0.012). For Turnock's 2014 model, F_{OFL} was 1.01, the 5-year average snow crab F was 1.02, and the fully-selected Tanner crab discard mortality rate used in the projection model was 0.021.

OFL results from the projection model using the snow crab F_{OFL} (0.89 yr^{-1}) from Turnock's preferred model and the 2014 projection approach are presented in Table 27 for illustrative purposes only to show the effects of the progression of datasets from the 2014 assessment to the final 2015 dataset (Dataset D). Correcting the 2013/14 directed fishery data had surprisingly little impact on the OFL and related quantities. The largest changes occurred with the addition of the 2015 data (Dataset A), when estimated average recruitment dropped 5 %, B_{MSY} dropped 7%, and the OFL dropped 10%. Replacing the "old" trawl survey dataset (A) with the "new" dataset (B) led to fairly small (< 5%) changes in these quantities, as did changing to the standardized trawl survey weight-at-size regressions (C->D).

OFL results from the 6 projection model scenarios for the author's preferred model, Model A, using the final 2015 dataset (Dataset D), are compared in Table 28 with results from the 2014 assessment and from running the projection model on results from Model C (for illustrative purposes). The author's preferred approach is highlighted in yellow: use results from Model A (Dataset D) as the preferred model, use the snow crab F_{OFL} from Turnock's preferred model, and use the 2014 projection approach (used in previous assessments). The choice of snow crab F_{OFL} has little impact on the resulting OFL values. Somewhat surprisingly, the 2014 and "new (1)" projection approaches yield identical results. In retrospect, this should have been anticipated because the OFL, as calculated, is a total catch mortality OFL—not a retained catch OFL—and thus depends only on the *total* fishing mortality selectivity in the directed fishery, and not the retained mortality selectivity, as currently formulated in the projection model. As discussed in Appendix B, the OFL is independent of the retained mortality selectivity (as currently formulated in the projection model). A different OFL is obtained if the "new (2)" projection model approach is used, but this scenario assumes an overall relative increase in directed fishing mortality on smaller crab (left-shifted total fishing mortality selectivity)—essentially a change in fishing patterns—while the change in the TAC setting which motivated this new approach is based on a change in retention, not fishing, patterns.

The estimate of B from Model A (Dataset D, preferred snow crab model F_{OFL}, 2014 projection approach), the author's preferred model and OFL calculation, is 52.80 thousand t (Table 28). Male spawning biomass per recruit in an unfished stock was calculated using the TCSAM population dynamics equations (Stockhausen, 2014) with total recruitment set to 1 and fishing mortality from all sources (directed fishery and all bycatch fisheries) set to 0, resulting in $\phi(0)$ = 0.427 kg/recruit. $F_{35\%}$ was calculated for this scenario as 0.64 yr^{-1}, which is somewhat larger than that calculated last year (0.61 yr^{-1}) but smaller than that calculated for 2013 (0.73 yr^{-1}; Stockhausen, 2014).

The determination of B_{MSY}=$B_{35\%}$ for Tanner crab depends on the selection of an appropriate time period over which to calculate average recruitment ($\bar{R}$). After much discussion in 2012 and 2013, the SSC endorsed an averaging period of 1982+. Starting the average recruitment period in 1982 is consistent with a 5-6 year recruitment lag from 1976/77, when a well-known climate regime shift occurred in the EBS (Rodionov and Overland, 2005) that may have affected stock productivity. The value of $\bar{R}$ for this period from the author's preferred model is 179.37 million. The estimates of average recruitment are reasonably similar between the 2014 assessment model and the author's preferred model (Table 27). The value of B_{MSY}=$B_{35\%}$ for $\bar{R}$ is 26.79 thousand t. Thus, the stock is "not overfished" because B/$B_{35\%}$ > 0.5 (i.e., B > MSST).

Once F_{OFL} is determined using the control rule (Fig. 77), 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, 2015 as estimated by the assessment model.

Assessment uncertainty was included in the calculation of OFL using the same approach as that used for the 2014 assessment (Stockhausen, 2014). Basically, initial numbers at size on July 1, 2015 were randomized based on an assumed lognormal assessment error distribution and the cv of estimated MMB for 2014/15 from the assessment model, the control rule was applied to obtain F_{OFL}, and the population projected forward to next year assuming that fishing occurred consistent with F_{OFL}. This was repeated 10,000 times to generate a distribution of total catch OFLs. **The value of OFL for 2014/15 from the author's preferred model (Model A) is 27.73 thousand t** (Table 28, Fig. 78)**.**

Model A is the author's preferred model for calculating the B_{MSY} proxy as $B_{35\%}$, so MSST = 0.5 B_{MSY} = 13.40 thousand t. Because current B = 52.80 thousand t > MSST, **the stock is not overfished**. The population state (directed F vs. MMB) is plotted for each year from 1965-2014 in Fig. 79 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%. For 2014/15, however, the SSC adopted a buffer of 20% on OFL for the Tanner crab stock for calculating ABC. Here, ABCs are provided based on both methods.

ABCs based on the P*=0.49 approach were calculated from quantiles of the associated OFL distributions such that probability that the selected ABC was greater than the true OFL was 0.49. The resulting ABC for each scenario was almost identical to the associated OFL (Table 27). ABCs were also calculated using the SSC's 20% OFL buffer (Table 27).

For the author's preferred model and projection (Model A, Turnock's preferred snow crab model F_{OFL}, 2014 projection approach), the P* ABC_{max} is 27.70 thousand t while the 20% Buffer ABC_{max} is 22.19 thousand t. The author remains concerned that the projection model, based on $F_{35\%}$ as a proxy for F_{MSY}, is overly optimistic regarding the actual productivity of the stock. Fishery-related mortality similar to these ABC levels has occurred only in the latter half of the 1970s and in 1992/93, coincident with collapses in stock biomass to low levels. This suggests that $F_{35\%}$ may not be a realistic proxy for F_{MSY} and/or that MMB may not be a good proxy for reproductive success, as are currently assumed for this stock. Given this uncertainty concerning the stock, **the author recommends using the 20% buffer adopted by the SSC last yearfor this stock to calculate ABC. Consequently, the author's recommended ABC is 22.19 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

Some information on growth-per-molt has finally been collected in the EBS on Tanner crab (molt increments observed on ~60 individuals collected in May, 2015; R. Foy, AFSC, pers. comm.). Data on temperature-dependent effects on molting frequency would be helpful to assess potential impacts of the EBS cold pool on the stock. In addition, it would be extremely worthwhile to develop a "better" index of reproductive potential than MMB and to revisit the issue of MSY proxies for this stock.

The characterization of fisheries in the assessment model needs to be carefully reconsidered. How, and whether or not, the East 166°W and West 166°W directed fisheries should be explicitly represented in the assessment model should be addressed. In addition, how, and whether or not, bycatch in the groundfish fisheries should be split into pot- and trawl-related components should be addressed.

It is clear that a new projection model based on the Gmacs fishing mortality model needs to be developed

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

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

Figure captions

Tables

Table 1. Weight-at-size relationships for Tanner crab used to convert size to weight in the current assessment, NMFS EBS bottom trawl survey time series (post-2009 and pre-2010), and in previous assessments. Weights are in kilograms, size in mm CW.

Size	2015 Assessment/New Survey Time Series			Old Survey Time Series (pre-2010)			2014 Assessment		
	Females		Males	Females		Males	Females		Males
	immature	mature		immature	mature		immature	mature	
27.5	0.006	0.006	0.006	0.014	0.014	0.005	0.006	0.006	0.005
32.5	0.010	0.010	0.010	0.022	0.022	0.009	0.010	0.010	0.009
37.5	0.015	0.016	0.015	0.033	0.033	0.014	0.015	0.015	0.013
42.5	0.021	0.022	0.022	0.046	0.046	0.021	0.022	0.022	0.020
47.5	0.029	0.031	0.031	0.062	0.062	0.030	0.030	0.030	0.029
52.5	0.038	0.042	0.042	0.082	0.082	0.041	0.040	0.041	0.039
57.5	0.050	0.054	0.055	0.105	0.105	0.054	0.051	0.053	0.052
62.5	0.063	0.069	0.071	0.131	0.131	0.070	0.065	0.068	0.068
67.5	0.078	0.087	0.089	0.161	0.161	0.089	0.081	0.086	0.087
72.5	0.096	0.107	0.111	0.196	0.196	0.111	0.099	0.106	0.109
77.5	0.116	0.130	0.136	0.234	0.234	0.136	0.119	0.130	0.134
82.5	0.138	0.156	0.164	0.278	0.278	0.165	0.142	0.156	0.164
87.5	0.163	0.185	0.196	0.325	0.325	0.198	0.167	0.186	0.197
92.5	0.191	0.217	0.233	0.378	0.378	0.235	0.196	0.220	0.235
97.5	0.222	0.253	0.273	0.436	0.436	0.277	0.227	0.257	0.277
102.5	0.256	0.293	0.318	0.499	0.499	0.323	0.261	0.298	0.324
107.5	0.293	0.337	0.367	0.568	0.568	0.375	0.298	0.343	0.377
112.5	0.333	0.384	0.421	0.642	0.642	0.432	0.339	0.393	0.435
117.5	0.377	0.436	0.481	0.722	0.722	0.494	0.383	0.447	0.499
122.5	0.424	0.492	0.546	0.809	0.809	0.562	0.430	0.506	0.569
127.5	0.474	0.553	0.616	0.901	0.901	0.636	0.481	0.570	0.645
132.5	0.529	0.619	0.692	1.000	1.000	0.717	0.536	0.639	0.728
137.5	0.587	0.689	0.774	1.105	1.105	0.804	0.595	0.713	0.818
142.5	0.650	0.764	0.863	1.217	1.217	0.898	0.658	0.792	0.916
147.5	0.716	0.845	0.958	1.336	1.336	0.999	0.724	0.878	1.021
152.5	0.787	0.931	1.060	1.462	1.462	1.108	0.795	0.969	1.134
157.5	0.862	1.023	1.169	1.595	1.595	1.225	0.870	1.066	1.255
162.5	0.942	1.120	1.285	1.736	1.736	1.349	0.950	1.170	1.384
167.5	1.026	1.223	1.409	1.884	1.884	1.482	1.034	1.280	1.523
172.5	1.115	1.332	1.540	2.040	2.040	1.623	1.123	1.396	1.670
177.5	1.208	1.448	1.679	2.204	2.204	1.774	1.217	1.520	1.827
182.5	1.307	1.569	1.827	2.376	2.376	1.933	1.315	1.650	1.994

Table 2. Retained catch (males) in directed Tanner crab fisheries.

Eastern Bering Sea *Chionoecetes bairdi* Retained Catch (1000T)				
Year	US Pot	Japan	Russia	Total
1965/66		1.17	0.75	1.92
1966/67		1.69	0.75	2.44
1967/68		9.75	3.84	13.60
1968/69	0.46	13.59	3.96	18.00
1969/70	0.46	19.95	7.08	27.49
1970/71	0.08	18.93	6.49	25.49
1971/72	0.05	15.90	4.77	20.71
1972/73	0.10	16.80		16.90
1973/74	2.29	10.74		13.03
1974/75	3.30	12.06		15.24
1975/76	10.12	7.54		17.65
1976/77	23.36	6.66		30.02
1977/78	30.21	5.32		35.52
1978/79	19.28	1.81		21.09
1979/80	16.60	2.40		19.01
1980/81	13.47			13.43
1981/82	4.99			4.99
1982/83	2.39			2.39
1983/84	0.55			0.55
1984/85	1.43			1.43
1985/86	0.00			0.00
1986/87	0.00			0.00
1987/88	1.00			1.00
1988/89	3.15			3.18
1989/90	11.11			11.11
1990/91	18.19			18.19
1991/92	14.42			14.42
1992/93	15.92			15.92
1993/94	7.67			7.67
1994/95	3.54			3.54
1995/96	1.92			1.92
1996/97	0.82			0.82
1997/98	0.00			0.00
1998/99	0.00			0.00
1999/00	0.00			0.00
2000/01	0.00			0.00
2001/02	0.00			0.00
2002/03	0.00			0.00
2003/04	0.00			0.00
2004/05	0.00			0.00
2005/06	0.43			0.43
2006/07	0.96			0.96
2007/08	0.96			0.96
2008/09	0.88			0.88
2009/10	0.60			0.60
2010/11	0.00			0.00
2011/12	0.00			0.00
2012/13	0.00			0.00
2013/14	1.25			1.25
2014/15	6.16			6.16

Table 3. Retained catch (males) in the US domestic pot fishery. Information from the Communnity Development Quota (CDQ) fisheries is included in the table for fishery years 2005/06 to the present. Number of crabs caught and harvest includes deadloss. The "Fishery Year" YYYY/YY+1 runs from July 1, YYYY to June 30, YYYY+1. The ADF&G year (in parentheses, if different from the "Fishery Year") indicates the year ADF&G assigned to the fishery season in compiled reports.

year (ADF&G year)	Total Crab (no.)	Total Harvest (lbs)	GHL/TAC (millions lbs)	Vessels (no.)	Season
1968/69 (1969)	353,300	1,008,900			
1969/70 (1970)	482,300	1,014,700			
1970/71 (1971)	61,300	166,100			
1971/72 (1972)	42,061	107,761			
1972/73 (1973)	93,595	231,668			
1973/74 (1974)	2,531,825	5,044,197			
1974/75	2,773,770	7,028,378		28	
1975/76	8,956,036	22,358,107		66	
1976/77	20,251,508	51,455,221		83	
1977/78	26,350,688	66,648,954		120	
1978/79	16,726,518	42,547,174		144	
1979/80	14,685,611	36,614,315	28-36	152	11/01-05/11
1980/81 (1981)	11,845,958	29,630,492	28-36	165	01/15-04/15
1981/82 (1982)	4,830,980	11,008,779	12-16	125	02/15-06/15
1982/83 (1983)	2,286,756	5,273,881	5.6	108	02/15-06/15
1983/84 (1984)	516,877	1,208,223	7.1	41	02/15-06/15
1984/85 (1985)	1,272,501	3,036,935	3	44	01/15-06/15
1985/86 (1986)	closed	closed	closed	closed	closed
1986/87 (1987)	closed	closed	closed	closed	closed
1987/88 (1988)	957,318	2,294,997	5.6	98	01/15-04/20
1988/89 (1989)	2,894,480	6,982,865	13.5	109	01/15-05/07
1989/90 (1990)	9,800,763	22,417,047	29.5	179	01/15-04/24
1990/91	16,608,625	40,081,555	42.8	255	11/20-03/25
1991/92	12,924,102	31,794,382	32.8	285	11/15-03/31
1992/93	15,265,865	35,130,831	39.2	294	11/15-03/31
1993/94	7,235,898	16,892,320	9.1	296	11/01-11/10, 11/20-01/01
1994/95 (1994)	3,351,639	7,766,886	7.5	183	11/01-11/21
1995/96 (1995)	1,877,303	4,233,061	5.5	196	11/01-11/16
1996/97 (1996)	734,296	1,806,077	6.2	196	11/01-11/05, 11/15-11/27
1997/98-2004/05	closed	closed	closed	closed	closed
2005/06	443,978	952,887	1.7	49	10/15-03/31
2006/07	927,086	2,122,589	3.0	64	10/15-03/31
2007/08	927,164	2,106,655	5.7	50	10/15-03/31
2008/09	830,363	1,939,571	4.3	53	10/15-03/31
2009/10	485,676	1,327,952	1.3	45	10/15-03/31
2010/11	closed	closed	closed	closed	closed
2011/12	closed	closed	closed	closed	closed
2012/13	closed	closed	closed	closed	closed
2013/14	1,426,670	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

Table 4. Total bycatch (1000's t) of Tanner crab in various fisheries. Total discard mortality was calculated assuming mortality rates of 0.321 in the crab fisheries and 0.80 in the groundfish fisheries.

Discards (1,000's t) of Tanner Crab by Fishery								Total Discard
	Tanner Crab		Snow Crab		Red King Crab		Groundfish	Mortality
Year	Male	Female	Male	Female	Male	Female	All	(1,000's t)
1973/74							17.735	14.188
1974/75							24.449	19.559
1975/76							9.408	7.526
1976/77							4.699	3.759
1977/78							2.776	2.221
1978/79							1.869	1.495
1979/80							3.397	2.718
1980/81							2.114	1.691
1981/82							1.474	1.179
1982/83							0.449	0.359
1983/84							0.671	0.537
1984/85							0.644	0.515
1985/86							0.399	0.319
1986/87							0.649	0.519
1987/88							0.640	0.512
1988/89							0.463	0.370
1989/90							0.671	0.537
1990/91							0.943	0.755
1991/92							2.545	2.036
1992/93	6.175	1.005	25.759	1.787	1.188	0.029	2.758	13.744
1993/94	3.870	1.028	14.530	1.814	2.967	0.198	1.760	9.243
1994/95	3.130	1.270	7.124	1.271	0.000	0.000	2.096	5.784
1995/96	2.762	1.760	4.797	1.759	0.000	0.000	1.524	4.776
1996/97	0.116	0.045	0.833	0.229	0.027	0.004	1.597	1.680
1997/98	0.000	0.000	1.750	0.226	0.165	0.003	1.179	1.632
1998/99	0.000	0.000	1.989	0.175	0.119	0.003	0.934	1.481
1999/00	0.000	0.000	0.695	0.145	0.076	0.004	0.630	0.800
2000/01	0.000	0.000	0.146	0.022	0.067	0.002	0.739	0.667
2001/02	0.000	0.000	0.323	0.011	0.043	0.002	1.184	1.069
2002/03	0.000	0.000	0.557	0.037	0.062	0.003	0.721	0.788
2003/04	0.000	0.000	0.193	0.026	0.056	0.003	0.422	0.427
2004/05	0.000	0.000	0.078	0.014	0.048	0.003	0.676	0.587
2005/06	0.462	0.044	0.968	0.043	0.042	0.002	0.621	0.998
2006/07	1.370	0.355	1.462	0.169	0.026	0.003	0.717	1.660
2007/08	2.041	0.097	1.872	0.102	0.056	0.009	0.694	1.896
2008/09	0.431	0.014	1.119	0.050	0.269	0.004	0.531	1.030
2009/10	0.071	0.002	1.324	0.014	0.150	0.001	0.374	0.801
2010/11	0.000	0.000	1.344	0.016	0.033	0.001	0.231	0.632
2011/12	0.000	0.000	2.119	0.014	0.017	0.000	0.203	0.852
2012/13	0.000	0.000	1.187	0.009	0.042	0.001	0.153	0.520
2013/14	0.387	0.023	1.832	0.015	0.113	0.001	0.348	1.040
2014/15	2.515	0.039	5.383	0.050	0.296	0.001	0.423	2.998

Table 5. Sample sizes from the recalculated fishery data for retained catch-at-size in the directed fishery. N = number of individuals. N` = scaled sample size used in assessment.

year	new + old shell	
	N	N'
1980/81	13,310	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

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

	N		N'	
year	males	females	males	females
1991/92	31,252	5,605	200.0	40.2
1992/93	54,836	8,755	200.0	62.8
1993/94	40,388	10,471	200.0	75.1
1994/95	5,792	2,132	42.6	15.3
1995/96	5,589	3,119	41.1	22.4
1996/97	352	168	2.6	1.2
2005/06	19,715	1,107	144.9	7.9
2006/07	24,226	4,432	178.0	31.8
2007/08	61,546	3,318	200.0	23.8
2008/09	29,166	646	200.0	4.6
2009/10	17,289	147	127.0	1.1
2013/14	17,287	710	127.0	5.2
2014/15	85,114	1,191	200.0	8.8

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

year	N		N'	
	males	females	males	females
1992/93	6,280	859	46.1	6.3
1993/94	6,969	1,542	51.2	11.3
1994/95	2,982	1,523	21.9	11.2
1995/96	1,898	428	13.9	3.1
1996/97	3,265	662	24.0	4.9
1997/98	3,970	657	29.2	4.8
1998/99	1,911	324	14.0	2.4
1999/00	976	82	7.2	0.6
2000/01	1,237	74	9.1	0.5
2001/02	3,113	160	22.9	1.2
2002/03	982	118	7.2	0.9
2003/04	688	152	5.1	1.1
2004/05	848	707	6.2	5.2
2005/06	9,792	368	72.0	2.7
2006/07	10,391	1,256	76.4	9.2
2007/08	13,797	728	101.4	5.3
2008/09	8,455	722	62.1	5.3
2009/10	11,057	474	81.2	3.5
2010/11	12,073	250	88.7	1.8
2011/12	9,453	189	69.5	1.4
2012/13	7,336	190	53.9	1.4
2013/14	12,932	356	95.0	2.6
2014/15	24,877	804	182.8	5.9

Table 8. Sample sizes from the recalculated fishery data for total bycatch-at-size in the BBRKC fishery, from crab observer sampling. N = number of individuals. N` = scaled sample size used in assessment.

year	N		N'	
	males	females	males	females
1992/93	2,056	105	15.1	0.8
1993/94	7,359	1,196	54.1	8.8
1996/97	114	5	0.8	0.0
1997/98	1,030	41	7.6	0.3
1998/99	457	20	3.4	0.1
1999/00	207	14	1.5	0.1
2000/01	845	44	6.2	0.3
2001/02	456	39	3.4	0.3
2002/03	750	50	5.5	0.4
2003/04	555	46	4.1	0.3
2004/05	487	44	3.6	0.3
2005/06	983	70	7.2	0.5
2006/07	798	76	5.9	0.6
2007/08	1,399	91	10.3	0.7
2008/09	3,797	121	27.9	0.9
2009/10	3,395	72	24.9	0.5
2010/11	595	30	4.4	0.2
2011/12	344	4	2.5	0.0
2012/13	618	48	4.5	0.4
2013/14	2,110	60	15.5	0.4
2014/15	3,110	32	22.9	0.2

Table 9. Sample sizes from the recalculated fishery data for total catch-at-size in the groundfish fisheries, from groundfish observer sampling. N = number of individuals. N` = scaled sample size used in the assessment.

year	N		N'	
	males	females	males	females
1973/74	3,155	2,277	23.2	16.7
1974/75	2,492	1,600	18.3	11.8
1975/76	1,251	839	9.2	6.2
1976/77	6,950	6,683	51.1	49.1
1977/78	10,685	8,386	78.5	61.6
1978/79	18,596	13,665	136.6	100.4
1979/80	19,060	11,349	140.1	83.4
1980/81	12,806	5,917	94.1	43.5
1981/82	6,098	4,065	44.8	29.9
1982/83	13,439	8,006	98.8	58.8
1983/84	18,363	8,305	134.9	61.0
1984/85	27,403	13,771	200.0	101.2
1985/86	23,128	12,728	170.0	93.5
1986/87	14,860	7,626	109.2	56.0
1987/88	23,508	15,857	172.7	116.5
1988/89	10,586	7,126	77.8	52.4
1989/90	59,943	41,234	200.0	200.0
1990/91	23,545	11,212	173.0	82.4
1991/92	6,817	3,479	50.1	25.6
1992/93	3,128	1,175	23.0	8.6
1993/94	1,217	358	8.9	2.6
1994/95	3,628	1,820	26.7	13.4
1995/96	3,904	2,669	28.7	19.6
1996/97	8,306	3,400	61.0	25.0
1997/98	9,949	3,900	73.1	28.7
1998/99	12,105	4,440	89.0	32.6
1999/00	11,053	4,522	81.2	33.2
2000/01	12,895	3,087	94.8	22.7
2001/02	15,788	3,083	116.0	22.7
2002/03	15,401	3,249	113.2	23.9
2003/04	9,572	2,733	70.3	20.1
2004/05	13,844	4,460	101.7	32.8
2005/06	17,785	3,709	130.7	27.3
2006/07	15,903	3,047	116.9	22.4
2007/08	16,031	3,788	117.8	27.8
2008/09	25,976	4,164	190.9	30.6
2009/10	18,760	2,588	137.9	19.0
2010/11	15,135	2,211	111.2	16.2
2011/12	16,168	4,255	118.8	31.3
2012/13	13,050	3,089	95.9	22.7
2013/14	28,862	6,081	200.0	44.7
2014/15	38,807	4,099	200.0	30.1

Table 10. Trends in mature and total Tanner crab biomass (1000's t) in the NMFS summer bottom trawl survey as derived from survey size compositions and weight-at-size regressions.

year	Rugolo and Turnock weight-at-size regressions						new regressions		
	old survey time series			new survey time series			new survey time series		
	mature males	mature females	all crab >= 25 mm CW	mature males	mature females	all crab >= 25 mm CW	mature males	mature females	all crab >= 25 mm CW
1974	212.01	55.76	267.77	--	--	--	--	--	--
1975	265.07	38.76	303.83	260.83	32.05	292.88	245.98	31.71	277.68
1976	152.09	45.99	198.08	133.45	31.78	165.23	126.18	31.44	157.61
1977	130.41	47.59	177.99	117.09	39.15	156.25	110.59	38.76	149.35
1978	80.62	26.43	107.06	81.93	26.42	108.35	77.60	26.18	103.78
1979	47.82	20.43	68.25	33.74	19.72	53.46	32.21	19.65	51.86
1980	86.33	70.42	156.76	89.87	64.40	154.27	86.15	64.16	150.31
1981	50.67	45.24	95.91	51.31	43.16	94.47	49.36	43.06	92.41
1982	49.67	64.76	114.43	50.83	64.55	115.38	48.97	64.43	113.40
1983	29.04	20.72	49.76	29.59	20.72	50.31	28.46	20.61	49.07
1984	26.15	14.72	40.87	25.18	15.12	40.30	24.17	15.01	39.18
1985	11.71	5.68	17.39	11.88	5.68	17.57	11.36	5.63	16.99
1986	13.18	3.49	16.67	13.28	3.49	16.77	12.81	3.45	16.26
1987	24.18	5.27	29.46	25.02	5.24	30.26	24.08	5.19	29.27
1988	59.51	25.57	85.08	62.95	25.75	88.69	60.43	25.47	85.90
1989	101.48	25.47	126.96	96.20	19.68	115.89	91.93	19.50	111.44
1990	103.17	36.36	139.52	101.11	38.14	139.25	96.29	37.84	134.13
1991	110.82	45.56	156.37	114.87	45.36	160.23	109.71	45.03	154.75
1992	108.12	27.76	135.88	108.35	26.66	135.02	103.22	26.47	129.69
1993	62.12	11.91	74.03	63.07	11.82	74.89	60.14	11.74	71.88
1994	44.55	10.37	54.92	44.23	10.09	54.32	42.13	10.01	52.14
1995	33.86	13.44	47.30	32.61	12.80	45.41	31.10	12.72	43.82
1996	27.32	9.80	37.12	27.53	9.87	37.40	26.26	9.80	36.05
1997	11.07	3.53	14.60	11.16	3.54	14.70	10.69	3.51	14.21
1998	10.56	2.31	12.87	10.70	2.33	13.03	10.29	2.31	12.60
1999	12.40	3.81	16.21	12.88	3.90	16.79	12.45	3.88	16.33
2000	16.45	4.17	20.63	16.83	4.22	21.04	16.15	4.18	20.33
2001	18.20	4.61	22.81	18.62	4.63	23.25	17.85	4.61	22.46
2002	18.23	4.48	22.71	18.56	4.51	23.08	17.80	4.50	22.30
2003	23.71	8.35	32.06	24.26	8.46	32.72	23.32	8.44	31.76
2004	25.56	4.70	30.26	27.33	4.92	32.25	26.35	4.90	31.25
2005	43.99	11.62	55.61	44.94	11.66	56.60	43.14	11.62	54.76
2006	66.89	15.79	82.68	66.61	15.10	81.71	64.20	15.04	79.24
2007	72.63	13.33	85.97	68.85	13.61	82.45	66.44	13.53	79.97
2008	59.70	11.33	71.03	65.39	11.79	77.18	62.71	11.73	74.44
2009	37.60	8.22	45.82	37.84	8.61	46.45	36.32	8.56	44.87
2010	36.14	5.44	41.59	39.32	5.56	44.88	37.61	5.52	43.13
2011	46.30	8.67	54.97	43.38	5.53	48.91	41.49	5.49	46.98
2012	43.15	15.83	58.97	42.61	12.56	55.17	41.18	12.50	53.68
2013	69.81	19.10	88.91	68.15	18.08	86.24	65.66	17.98	83.64
2014	87.15	15.82	102.97	82.75	15.04	97.79	79.47	14.95	94.42
2015	62.88	11.34	74.22	62.88	11.34	74.22	60.18	11.29	71.47

Table 11. Sample sizes for NMFS survey size composition data (new survey dataset). In the assessment model, an effective sample size of 200 is used for all survey-related compositional data.

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

Table 12. Effort data (1000’s potlifts) in the snow crab and BBRKC fisheries (recalculated for 1990/91-2012/13).

	Effort (1000's Potlifts)			Effort (1000's Potlifts)	
Year	BBRKC Fishery	Snow Crab Fishery	Year	BBRKC Fishery	Snow Crab Fishery
1951/52			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			
1981/82	536.646	469.091			
1982/83	140.492	287.127			
1983/84	0	173.591			
1984/85	107.406	370.082			
1985/86	84.443	542.346			

Table 13. Comparison of estimated recruitment running Model A against the incremental datasets.

Year	2014 Model	2014 Corrected	Dataset A	Dataset B	Dataset C	Dataset D
1949	62.19	61.05	63.73	59.37	58.01	59.68
1950	62.36	61.21	63.90	59.51	58.14	59.82
1951	62.75	61.59	64.30	59.86	58.47	60.16
1952	63.46	62.29	65.04	60.48	59.08	60.79
1953	64.64	63.45	66.26	61.52	60.08	61.83
1954	66.49	65.27	68.17	63.16	61.66	63.47
1955	69.36	68.09	71.16	65.71	64.13	66.02
1956	73.83	72.48	75.81	69.69	67.99	70.00
1957	80.96	79.49	83.27	76.05	74.16	76.35
1958	92.87	91.19	95.77	86.67	84.46	86.92
1959	114.43	112.35	118.54	105.80	103.03	105.92
1960	159.18	156.29	166.34	145.17	141.29	144.85
1961	273.92	268.95	290.11	245.53	238.65	243.60
1962	602.93	592.53	643.90	540.86	522.17	534.88
1963	1301.35	1282.31	1367.15	1246.18	1177.91	1244.51
1964	1807.55	1785.75	1855.97	1905.82	1758.59	1930.88
1965	1699.85	1683.44	1724.66	1888.01	1727.67	1929.26
1966	1397.57	1388.04	1421.00	1513.87	1395.88	1545.71
1967	1207.68	1204.26	1239.37	1195.77	1124.29	1214.54
1968	1161.20	1163.42	1204.89	1005.14	973.73	1015.76
1969	1196.51	1202.37	1245.47	916.42	916.66	926.12
1970	997.80	1000.34	997.65	860.08	867.67	879.66
1971	650.12	649.80	650.87	709.63	683.72	737.39
1972	542.54	542.41	551.12	549.30	518.16	572.56
1973	440.81	440.77	450.08	449.22	427.07	458.56
1974	122.18	122.66	120.89	256.98	214.99	299.76
1975	420.21	420.89	442.99	356.01	401.13	376.50
1976	919.41	918.43	964.46	1113.94	1027.08	1113.94
1977	560.43	560.16	585.74	811.16	766.13	829.22
1978	477.41	475.85	490.67	371.54	367.22	381.13
1979	118.24	117.92	121.25	125.03	125.25	126.07
1980	45.37	45.16	49.96	58.01	59.10	57.85
1981	106.97	106.34	113.65	76.50	77.57	76.54
1982	52.60	52.43	54.49	38.40	38.43	39.31
1983	372.92	370.84	383.73	273.26	270.66	275.66
1984	304.66	303.05	312.26	265.05	262.29	266.63
1985	578.41	576.00	582.02	659.23	628.88	673.12
1986	483.57	480.96	478.81	500.80	500.12	517.95
1987	438.11	433.89	435.98	471.18	457.75	485.61
1988	388.44	386.81	377.08	420.08	419.32	444.02
1989	172.35	171.12	169.50	161.23	161.85	168.66
1990	77.75	77.69	76.80	66.95	67.96	70.95
1991	36.43	36.34	36.38	38.64	38.43	40.76
1992	31.78	31.60	31.71	29.30	30.34	30.74
1993	26.66	26.55	27.51	26.69	27.31	27.74
1994	30.64	30.46	31.57	30.25	30.69	31.32
1995	45.05	44.79	46.46	40.39	40.96	41.62
1996	43.96	43.70	44.94	44.97	45.52	46.14
1997	119.75	119.06	121.14	111.04	111.96	113.81
1998	47.11	46.85	47.16	44.78	45.10	46.05
1999	147.24	146.35	148.34	138.34	138.42	140.55
2000	89.04	88.55	89.66	83.83	83.77	84.99
2001	276.17	274.46	274.67	276.13	274.91	279.15
2002	113.87	113.40	108.32	107.14	105.32	108.80
2003	202.76	201.16	197.12	185.89	182.91	185.04
2004	371.35	369.91	349.73	311.80	299.83	306.44
2005	114.16	113.89	103.71	91.58	84.98	87.26
2006	94.61	94.32	83.66	70.50	69.68	70.87
2007	66.43	66.18	58.48	48.45	51.64	52.92
2008	76.31	75.79	68.49	59.40	60.29	61.00
2009	410.40	412.22	327.13	321.53	351.07	354.63
2010	432.10	430.10	430.01	401.36	413.38	422.94
2011	216.25	216.46	231.79	246.97	241.95	251.06
2012	43.73	43.70	45.49	49.34	50.03	52.20
2013	117.42	117.27	111.17	111.88	112.77	115.80
2014	177.80	177.38	115.47	118.85	120.54	124.00
2015	--	--	72.28	76.84	78.41	80.71

Table 14. Comparison of estimated MMB-at-mating running Model A against the incremental datasets.

Year	2014 Model	2014 Corrected	Dataset A	Dataset B	Dataset C	Dataset D
1949	0.00	0.00	0.00	0.00	0.00	0.00
1950	0.01	0.01	0.01	0.01	0.01	0.01
1951	0.15	0.15	0.15	0.17	0.17	0.17
1952	1.24	1.22	1.20	1.35	1.31	1.36
1953	4.59	4.52	4.51	4.80	4.65	4.75
1954	8.82	8.68	8.84	8.85	8.60	8.66
1955	12.13	11.93	12.27	11.95	11.63	11.63
1956	14.61	14.36	14.84	14.26	13.88	13.84
1957	16.52	16.24	16.81	16.02	15.60	15.53
1958	18.08	17.77	18.42	17.45	17.00	16.92
1959	19.47	19.14	19.86	18.73	18.25	18.15
1960	20.90	20.55	21.32	20.05	19.52	19.43
1961	22.62	22.24	23.08	21.64	21.06	20.97
1962	25.03	24.61	25.55	23.89	23.23	23.15
1963	29.04	28.56	29.68	27.65	26.87	26.80
1964	37.09	36.49	38.00	35.30	34.24	34.23
1965	53.86	52.96	55.37	51.51	49.83	49.92
1966	94.82	93.32	97.44	92.81	88.80	90.17
1967	151.98	149.55	156.25	154.84	147.84	150.63
1968	225.91	222.45	231.87	239.64	226.89	233.51
1969	273.73	269.62	281.19	299.22	281.90	291.37
1970	296.50	292.39	305.04	326.08	306.72	317.01
1971	305.11	301.59	314.51	327.34	308.69	317.54
1972	310.35	307.80	320.52	315.46	299.84	305.40
1973	312.91	311.40	323.29	297.50	285.57	287.57
1974	292.48	291.68	301.81	266.17	258.10	257.21
1975	257.84	257.36	265.49	233.94	228.33	226.40
1976	195.34	195.04	201.66	177.87	176.23	171.84
1977	123.03	122.82	128.46	110.89	114.09	106.15
1978	79.23	79.04	83.87	73.34	78.05	70.30
1979	49.25	49.00	52.89	50.31	56.79	48.18
1980	34.48	34.22	35.77	32.26	39.85	31.15
1981	44.63	44.37	45.59	41.71	45.67	40.66
1982	48.67	48.45	49.16	38.55	38.91	37.88
1983	40.27	40.09	40.40	25.66	25.04	25.33
1984	24.89	24.76	24.67	12.89	12.46	12.79
1985	23.81	23.70	23.76	13.84	13.50	13.61
1986	29.58	29.45	29.60	19.42	18.95	19.12
1987	43.03	42.85	42.77	31.63	30.83	31.17
1988	59.68	59.41	59.43	49.10	48.03	48.32
1989	65.66	65.32	64.96	61.17	61.16	60.28
1990	56.02	55.56	54.87	56.12	59.21	55.10
1991	51.12	51.10	52.53	56.07	57.72	55.11
1992	43.53	43.39	44.52	48.99	49.28	48.23
1993	38.06	37.86	38.85	41.59	41.47	40.85
1994	30.58	30.40	31.41	32.11	31.84	31.48
1995	22.73	22.59	23.43	23.30	22.93	22.85
1996	17.84	17.72	18.34	17.96	17.71	17.66
1997	14.95	14.84	15.35	14.89	14.77	14.71
1998	13.43	13.33	13.76	13.31	13.24	13.22
1999	13.68	13.59	13.94	13.46	13.36	13.39
2000	15.52	15.43	15.68	15.24	15.09	15.17
2001	19.06	18.95	19.08	18.53	18.31	18.42
2002	22.71	22.59	22.68	21.71	21.42	21.49
2003	27.68	27.55	27.43	26.54	26.06	26.20
2004	34.61	34.45	34.14	33.44	32.74	32.90
2005	43.61	43.41	42.64	42.74	41.65	41.89
2006	49.90	49.65	48.60	48.09	46.67	46.77
2007	56.30	56.04	53.98	53.10	51.06	51.35
2008	67.30	67.03	63.62	61.05	58.10	58.42
2009	70.20	69.91	66.09	60.72	57.36	57.44
2010	64.36	64.11	60.09	53.92	50.77	50.95
2011	57.83	57.63	53.22	47.29	44.76	45.10
2012	58.23	58.12	52.00	47.56	45.93	46.55
2013	72.70	72.13	62.13	59.97	59.69	60.59
2014	--	--	72.58	70.43	70.82	71.57

Table 15. Parameter estimates (no devs vectors) from running Model A against the incremental datasets. flag = 1 indicates the estimate reached the upper parameter bound, flag=-1 indicates the estimate reached the lower bound.

Parameter	Limits		2014 Model			2014 Corrected			Dataset A			Dataset B			Dataset C			Dataset D		
	min	max	estimate	std. dev	flag	estimate	std. dev	flag	estimate	std. dev	flag	estimate	std. dev	flag	estimate	std. dev	flag	estimate	std. dev	flag
af1	0.4	0.7	0.70	0.000	1	0.70	0.000	1	0.70	0.000	1	0.70	0.000	1	0.70	0.000	1	0.70	0.000	1
am1	0.3	0.6	0.43	0.022	0	0.43	0.022	0	0.42	0.022	0	0.41	0.022	0	0.42	0.022	0	0.41	0.022	0
bf1	0.6	1.2	0.88	0.001	0	0.88	0.001	0	0.88	0.001	0	0.88	0.001	0	0.88	0.001	0	0.88	0.001	0
bm1	0.7	1.2	0.97	0.005	0	0.97	0.005	0	0.97	0.005	0	0.98	0.005	0	0.98	0.005	0	0.98	0.005	0
fish_disc_sel50_f	80	150	120.47	3.280	0	120.09	3.241	0	119.13	3.122	0	117.22	2.815	0	117.25	2.735	0	117.47	2.802	0
fish_disc_sel50_tf1	40	125.01	125.01	0.000	1	125.01	0.000	1	125.01	0.000	1	125.01	0.000	1	125.01	0.000	1	125.01	0.000	1
fish_disc_sel50_tf2	40	250.01	175.95	52.035	0	175.95	52.120	0	183.95	57.827	0	164.03	37.477	0	159.71	35.035	0	159.21	34.425	0
fish_disc_sel50_tf3	40	150.01	148.32	11.394	0	148.33	11.391	0	147.08	10.750	0	145.48	10.234	0	145.27	10.122	0	143.99	9.954	0
fish_disc_sel50_tm1	40	120.01	53.76	1.972	0	53.75	1.973	0	54.09	1.984	0	57.27	2.047	0	56.69	1.972	0	57.07	2.034	0
fish_disc_sel50_tm2	40	120.01	64.66	8.958	0	64.56	8.938	0	65.33	9.007	0	72.86	9.891	0	72.30	9.834	0	72.61	9.681	0
fish_disc_sel50_tm3	40	120.01	94.02	2.322	0	94.04	2.323	0	88.43	2.162	0	87.69	2.119	0	84.50	2.127	0	83.19	2.113	0
fish_disc_slope_f	0.1	0.4	0.14	0.009	0	0.14	0.009	0	0.14	0.009	0	0.14	0.008	0	0.14	0.008	0	0.14	0.008	0
fish_disc_slope_tf1	0.01	0.5	0.03	0.002	0	0.03	0.002	0	0.03	0.002	0	0.03	0.002	0	0.03	0.002	0	0.03	0.002	0
fish_disc_slope_tf2	0.005	0.5	0.01	0.005	0	0.01	0.005	0	0.01	0.005	0	0.02	0.005	0	0.02	0.005	0	0.02	0.005	0
fish_disc_slope_tf3	0.01	0.5	0.05	0.008	0	0.05	0.008	0	0.05	0.008	0	0.05	0.008	0	0.05	0.007	0	0.05	0.007	0
fish_disc_slope_tm1	0.01	0.5	0.11	0.013	0	0.11	0.013	0	0.11	0.012	0	0.11	0.011	0	0.11	0.011	0	0.11	0.011	0
fish_disc_slope_tm2	0.01	0.5	0.05	0.012	0	0.05	0.012	0	0.05	0.012	0	0.04	0.009	0	0.04	0.009	0	0.04	0.009	0
fish_disc_slope_tm3	0.01	0.5	0.07	0.004	0	0.07	0.004	0	0.08	0.004	0	0.08	0.004	0	0.08	0.004	0	0.08	0.004	0
fish_fit_sel50_mn1	85	160	138.23	0.394	0	138.22	0.394	0	138.21	0.394	0	137.82	0.364	0	137.32	0.370	0	137.67	0.355	0
fish_fit_sel50_mn2	85	160	136.86	0.303	0	136.28	0.384	0	133.16	0.484	0	133.19	0.485	0	133.09	0.495	0	133.08	0.488	0
fish_fit_slope_mn1	0.25	1.001	0.73	0.131	0	0.73	0.132	0	0.72	0.130	0	0.78	0.139	0	0.78	0.141	0	0.79	0.140	0
fish_fit_slope_mn2	0.25	2.001	0.84	0.118	0	0.64	0.077	0	0.37	0.029	0	0.37	0.029	0	0.36	0.029	0	0.37	0.030	0
fish_slope_1	0.05	0.75	0.12	0.007	0	0.12	0.007	0	0.12	0.006	0	0.11	0.007	0	0.11	0.007	0	0.11	0.007	0
fish_slope_yr_3	0.1	0.4	0.14	0.009	0	0.14	0.009	0	0.15	0.008	0	0.14	0.008	0	0.14	0.008	0	0.14	0.009	0
log_avg_sel50_3	4	5	4.83	0.009	0	4.83	0.009	0	4.83	0.008	0	4.83	0.023	0	4.87	0.010	0	4.83	0.023	0
log_sel50_dev_3[01]	-0.5	0.5	0.05	0.018	0	0.05	0.018	0	0.08	0.019	0	0.08	0.033	0	0.04	0.020	0	0.08	0.033	0
log_sel50_dev_3[02]	-0.5	0.5	0.15	0.015	0	0.14	0.015	0	0.14	0.016	0	0.13	0.029	0	0.09	0.016	0	0.13	0.029	0
log_sel50_dev_3[03]	-0.5	0.5	0.10	0.016	0	0.10	0.016	0	0.11	0.017	0	0.10	0.031	0	0.06	0.017	0	0.10	0.030	0
log_sel50_dev_3[04]	-0.5	0.5	0.10	0.021	0	0.11	0.021	0	0.15	0.020	0	0.14	0.035	0	0.09	0.021	0	0.14	0.034	0
log_sel50_dev_3[05]	-0.5	0.5	0.00	0.030	0	0.00	0.030	0	-0.01	0.033	0	-0.01	0.047	0	-0.07	0.037	0	-0.01	0.046	0
log_sel50_dev_3[06]	-0.5	0.5	-0.50	0.018	0	-0.50	0.018	0	-0.50	0.017	0	-0.44	0.297	0	0.04	0.070	0	-0.43	0.287	0
log_sel50_dev_3[07]	-0.5	0.5	-0.05	0.020	0	-0.05	0.020	0	-0.05	0.019	0	-0.05	0.030	0	-0.09	0.020	0	-0.06	0.029	0
log_sel50_dev_3[08]	-0.5	0.5	-0.05	0.020	0	-0.05	0.020	0	-0.06	0.020	0	-0.06	0.030	0	-0.10	0.020	0	-0.06	0.030	0
log_sel50_dev_3[09]	-0.5	0.5	-0.08	0.018	0	-0.08	0.018	0	-0.09	0.018	0	-0.09	0.029	0	-0.13	0.019	0	-0.09	0.028	0
log_sel50_dev_3[10]	-0.5	0.5	0.06	0.017	0	0.06	0.017	0	0.06	0.016	0	0.05	0.028	0	0.01	0.017	0	0.05	0.027	0
log_sel50_dev_3[11]	-0.5	0.5	0.23	0.021	0	0.23	0.020	0	0.23	0.019	0	0.22	0.030	0	0.18	0.020	0	0.22	0.029	0
log_sel50_dev_3[12]	-0.5	0.5	0.00	0.020	0	-0.01	0.019	0	-0.02	0.018	0	-0.02	0.029	0	-0.05	0.019	0	-0.02	0.028	0
log_sel50_dev_3[13]	-0.5	0.5	0.00	0.000	0	0.00	0.000	0	-0.04	0.015	0	-0.04	0.027	0	-0.08	0.016	0	-0.04	0.026	0
mat_big[01]	0.1	10	1.12	0.098	0	1.13	0.099	0	1.15	0.100	0	1.50	0.092	0	1.48	0.091	0	1.49	0.092	0
mat_big[02]	0.1	10	2.59	0.343	0	2.59	0.343	0	2.70	0.355	0	3.59	0.328	0	3.65	0.318	0	3.50	0.320	0
Mmult_imat	0.2	2	1.07	0.051	0	1.07	0.051	0	1.05	0.051	0	1.06	0.050	0	1.06	0.050	0	1.06	0.050	0
Mmultf	0.1	1.9	1.44	0.037	0	1.44	0.037	0	1.44	0.037	0	1.50	0.035	0	1.49	0.035	0	1.51	0.035	0
Mmultm	0.1	1.9	1.11	0.043	0	1.11	0.043	0	1.13	0.042	0	1.15	0.041	0	1.18	0.039	0	1.15	0.041	0
pAvgLnF_GTF	--	--	-4.21	0.075	0	-4.21	0.075	0	-4.26	0.075	0	-4.16	0.073	0	-4.16	0.072	0	-4.16	0.073	0
pAvgLnF_SCF	--	--	-3.80	0.132	0	-3.79	0.132	0	-3.74	0.125	0	-3.71	0.122	0	-3.68	0.120	0	-3.71	0.122	0
pAvgLnF_TCF	--	--	-1.62	0.087	0	-1.60	0.087	0	-1.59	0.086	0	-1.53	0.097	0	-1.39	0.102	0	-1.50	0.097	0
pMnLnRec	--	--	11.17	0.071	0	11.17	0.071	0	11.14	0.071	0	11.11	0.062	0	11.10	0.062	0	11.14	0.062	0
pMnLnRecEarly	--	--	11.84	0.511	0	11.83	0.511	0	11.87	0.508	0	11.79	0.517	0	11.75	0.516	0	11.80	0.518	0
rkfish_disc_sel50_f1	50	150	150.00	1.140	1	150.00	1.142	1	150.00	1.107	1	98.76	13.988	0	150.00	1.312	1	98.35	13.410	0
rkfish_disc_sel50_f2	50	150	103.08	45.740	0	103.05	45.507	0	103.83	49.048	0	103.12	43.952	0	102.70	42.903	0	103.26	44.773	0
rkfish_disc_sel50_f3	50	170	157.07	354.400	0	157.17	358.280	0	157.21	342.020	0	157.33	344.470	0	157.06	339.080	0	157.07	337.590	0
rkfish_disc_sel50_m1	95	150	150.00	0.001	1	150.00	0.001	1	150.00	0.001	1	150.00	0.001	1	150.00	0.001	1	150.00	0.001	1
rkfish_disc_sel50_m2	95	150	132.31	11.907	0	132.32	11.957	0	134.03	12.734	0	133.39	12.443	0	134.39	12.724	0	133.22	12.448	0
rkfish_disc_sel50_m3	95	150	150.00	0.001	1	150.00	0.001	1	150.00	0.001	1	150.00	0.001	1	150.00	0.001	1	150.00	0.001	1
rkfish_disc_slope_f1	0.05	0.5	0.17	0.040	0	0.17	0.040	0	0.17	0.040	0	0.24	0.131	0	0.17	0.039	0	0.24	0.132	0
rkfish_disc_slope_f2	0.05	0.5	0.18	0.173	0	0.18	0.173	0	0.18	0.171	0	0.18	0.170	0	0.18	0.172	0	0.18	0.170	0
rkfish_disc_slope_f3	0.05	0.5	0.18	0.056	0	0.18	0.056	0	0.19	0.054	0	0.18	0.054	0	0.18	0.054	0	0.18	0.054	0
rkfish_disc_slope_m1	0.01	0.5	0.11	0.011	0	0.11	0.011	0	0.11	0.011	0	0.10	0.010	0	0.10	0.010	0	0.10	0.010	0
rkfish_disc_slope_m2	0.01	0.5	0.09	0.027	0	0.09	0.027	0	0.09	0.026	0	0.09	0.026	0	0.09	0.026	0	0.09	0.027	0
rkfish_disc_slope_m3	0.01	0.5	0.08	0.007	0	0.08	0.007	0	0.08	0.007	0	0.08	0.007	0	0.08	0.007	0	0.08	0.007	0
selSCF_lnZ50_md_1	2	4.5	3.97	0.053	0	3.97	0.047	0	3.96	0.042	0	3.97	0.041	0	3.97	0.040	0	3.97	0.041	0
selSCF_lnZ50_md_2	2	4.5	3.82	0.132	0	3.82	0.132	0	3.80	0.136	0	3.81	0.133	0	3.79	0.141	0	3.80	0.136	0
selSCF_lnZ50_md_3	2	4.5	3.48	0.115	0	3.48	0.116	0	3.49	0.093	0	3.53	0.083	0	3.51	0.085	0	3.53	0.082	0
selSCF_Z50_ma_1	40	140	87.47	1.762	0	87.48	1.749	0	87.70	1.655	0	86.93	1.664	0	86.83	1.622	0	86.80	1.652	0
selSCF_Z50_ma_2	40	140	93.81	3.066	0	93.82	3.064	0	94.03	3.114	0	93.89	3.070	0	94.30	3.165	0	93.91	3.100	0
selSCF_Z50_ma_3	40	140	105.24	2.009	0	105.25	2.014	0	104.42	1.673	0	103.77	1.576	0	104.13	1.577	0	103.63	1.550	0
snowfish_disc_sel50_f_1	50	150	111.33	4.707	0	111.19	4.658	0	111.57	4.669	0	109.83	4.614	0	109.53	4.613	0	110.42	4.551	0
snowfish_disc_sel50_f_2	50	120	76.46	5.024	0	76.47	5.027	0	76.63	5.018	0	76.21	4.898	0	76.04	4.885	0	76.19	4.879	0
snowfish_disc_sel50_f_3	50	120	85.24	6.346	0	85.21	6.332	0	90.83	8.217	0	88.13	6.876	0	88.90	7.141	0	88.70	7.051	0
snowfish_disc_slope_f_1	0.05	0.5	0.05	0.000	-1	0.05	0.000	-1	0.05	0.000	-1	0.05	0.000	-1	0.05	0.000	-1	0.05	0.000	-1
snowfish_disc_slope_f_2	0.05	0.5	0.25	0.129	0	0.25	0.129	0	0.24	0.125	0	0.25	0.130	0	0.26	0.132	0	0.25	0.130	0
snowfish_disc_slope_f_3	0.05	0.5	0.16	0.053	0	0.16	0.053	0	0.13	0.039	0	0.14	0.042	0	0.13	0.041	0	0.13	0.041	0
snowfish_disc_slope_m_1	0.1	0.5	0.36	0.126	0	0.36	0.126	0	0.36	0.120	0	0.39	0.142	0	0.41	0.147	0	0.40	0.147	0
snowfish_disc_slope_m_2	0.1	0.5	0.23	0.075	0	0.23	0.075	0	0.23	0.073	0	0.23	0.074	0	0.23	0.071	0	0.23	0.074	0
snowfish_disc_slope_m_3	0.1	0.5	0.17	0.017	0	0.17	0.017	0	0.17	0.017	0	0.18	0.018	0	0.18	0.017	0	0.18	0.018	0
snowfish_disc_slope_m2_1	0.1	0.5	0.37	0.249	0	0.44	0.310	0	0.50	0.001	1	0.50	0.005	1	0.50	0.002	1	0.50	0.004	1
snowfish_disc_slope_m2_2	0.1	0.5	0.18	0.092	0	0.18	0.093	0	0.18	0.089	0	0.18	0.090	0	0.18	0.090	0	0.18	0.089	0
snowfish_disc_slope_m2_3	0.1	0.5	0.17	0.030	0	0.17	0.030	0	0.18	0.027	0	0.18	0.028	0	0.18	0.028	0	0.18	0.028	0
srv2_q	0.5	1.001	0.56	0.033	0	0.56	0.033	0	0.54	0.033	0	0.50	0.000	-1	0.50	0.000	-1	0.50	0.000	-1
srv2_qFem	0.5	1.001	0.61	0.217	0	0.61	0.219	0	0.63	0.290	0	0.50	0.000	-1	0.50	0.000	-1	0.50	0.000	-1
srv2_sel50	0	90	46.88	2.015	0	46.87	2.016	0	47.12	2.033	0	48.88	1.883	0	48.40	1.812	0	49.01	1.905	0
srv2_sel50_f	-200	100.01	57.57	18.304	0	57.60	18.446	0	61.09	24.340	0	52.97	2.842	0	51.50	2.582	0	53.63	2.859	0
srv2_seldiff	0	100	23.03	3.734	0	23.03	3.737	0	23.31	3.778	0	21.30	3.230	0	20.78	3.118	0	21.57	3.309	0
srv2_seldiff_f	0	100	55.99	29.637	0	56.11	29.843	0	61.38	35.001	0	39.03	6.596	0	35.19	5.844	0	40.82	6.712	0
srv3_q	0.2	2	0.75	0.036	0	0.76	0.036	0	0.75	0.036	0	0.80	0.035	0	0.81	0.034	0	0.78	0.035	0
srv3_qFem	0.2	1	0.56	0.039	0	0.56	0.039	0	0.55	0.038	0	0.60	0.035	0	0.61	0.034	0	0.59	0.035	0
srv3_sel50	0	69	28.43	3.289	0	28.43	3.286	0	27.79	3.451	0	32.48	2.838	0	33.01	2.851	0	32.49	2.815	0
srv3_sel50_f	-50	69	-4.11	15.461	0	-4.05	15.415	0	-9.94	17.318	0	5.57	11.464	0	6.15	11.325	0	7.10	11.252	0
srv3_seldiff	0	100	57.17	8.050	0	57.12	8.036	0	59.21	8.362	0	55.92	6.787	0	57.05	6.858	0	55.62	6.771	0
srv3_seldiff_f	0	100	100.00	0.001	1	100.00	0.001	1	100.00	0.001	1	100.00	0.001	1	100.00	0.001	1	100.00	0.001	1

Table 16. Parameter estimates (no devs vectors) from running Models A-D against Dataset D. flag = 1 indicates the estimate reached the upper parameter bound, flag=-1 indicates the estimate reached the lower bound.

Parameter	Limits		2014 Model			Model A			Model B			Model C			Model D			Description					
	min	max	est.	std. dev	flag	est.	std. dev	flag	est.	std. dev	flag	est.	std. dev	flag	est.	std. dev	flag	Category 1	Category 2	Category 3	Period	Sex	Description
af1	0.4	0.7	0.70	0.000	1	0.70	0.000	1	0.70	0.000	1	0.70	0.000	1	0.70	0.000	1	Pop. dynamics	--	growth	all	female	alpha, mean growth increment
am1	0.3	0.6	0.43	0.022	0	0.41	0.022	0	0.44	0.022	0	0.42	0.022	0	0.46	0.022	0	Pop. dynamics	--	growth	all	male	alpha, mean growth increment
bf1	0.6	1.2	0.88	0.001	0	0.88	0.001	0	0.89	0.001	0	0.88	0.001	0	0.89	0.001	0	Pop. dynamics	--	growth	all	female	beta, mean growth increment
bm1	0.7	1.2	0.97	0.005	0	0.98	0.005	0	0.97	0.005	0	0.97	0.005	0	0.97	0.005	0	Pop. dynamics	--	growth	all	male	beta, mean growth increment
Mmult_imat	0.2	2	1.07	0.051	0	1.06	0.050	0	1.05	0.049	0	1.06	0.050	0	1.06	0.049	0	Pop. dynamics	--	natural mortality	all	all	immature multiplier
Mmultf	0.1	1.9	1.44	0.037	0	1.51	0.035	0	1.59	0.036	0	1.50	0.035	0	1.60	0.036	0	Pop. dynamics	--	natural mortality	all	female	mature multiplier
Mmultm	0.1	1.9	1.11	0.043	0	1.15	0.041	0	1.29	0.039	0	1.19	0.039	0	1.24	0.039	0	Pop. dynamics	--	natural mortality	all	male	mature multiplier
mat_big[01]	0.1	10	1.12	0.098	0	1.49	0.092	0	1.65	0.089	0	1.51	0.092	0	1.57	0.089	0	Pop. dynamics	--	natural mortality	1980-84	female	multiplier
mat_big[02]	0.1	10	2.59	0.343	0	3.50	0.320	0	4.00	0.323	0	3.55	0.308	0	3.92	0.325	0	Pop. dynamics	--	natural mortality	1980-84	male	multiplier
pMnLnRecEarly	--	--	11.84	0.511	0	11.80	0.518	0	11.11	0.536	0	11.70	0.520	0	11.12	0.527	0	Pop. dynamics	--	recruitment	1949-1973	all	mean ln-scale recruitment
pMnLnRec	--	--	11.17	0.071	0	11.14	0.062	0	10.84	0.055	0	11.16	0.062	0	10.99	0.058	0	Pop. dynamics	--	recruitment	1974+	all	mean ln-scale recruitment
srv3_qFem	0.2	1	0.56	0.039	0	0.59	0.035	0	0.82	0.035	0	0.59	0.035	0	0.73	0.035	0	surveys	NMFS	catchability	1982+	female	catchability
srv2_qFem	0.5	1.001	0.61	0.217	0	0.50	0.000	-1	0.50	0.000	-1	0.50	0.000	-1	0.50	0.000	-1	surveys	NMFS	catchability	pre-1983	female	catchability
srv3_q	0.2	2	0.75	0.036	0	0.78	0.035	0	1.12	0.031	0	0.79	0.034	0	0.94	0.031	0	surveys	NMFS	catchability	1982+	male	catchability
srv2_q	0.5	1.001	0.56	0.033	0	0.50	0.000	-1	0.50	0.000	-1	0.50	0.000	-1	0.50	0.000	-1	surveys	NMFS	catchability	pre-1982	male	catchability
srv3_sel50_f	-50	69	-4.11	15.461	0	7.10	11.252	0	-1.81	10.991	0	6.55	11.348	0	6.18	10.105	0	surveys	NMFS	selectivity	1982+	female	50% selected size
srv2_sel50_f	-200	100.01	57.57	18.304	0	53.63	2.859	0	48.97	2.427	0	53.87	2.616	0	49.44	2.321	0	surveys	NMFS	selectivity	pre-1985	female	50% selected size
srv3_sel50	0	69	28.43	3.289	0	32.49	2.815	0	32.34	2.522	0	32.97	2.845	0	31.91	2.607	0	surveys	NMFS	selectivity	1982+	male	50% selected size
srv2_sel50	0	90	46.88	2.015	0	49.01	1.905	0	47.11	1.709	0	49.56	1.912	0	47.60	1.718	0	surveys	NMFS	selectivity	pre-1984	male	50% selected size
srv3_seldiff_f	0	100	100.00	0.001	1	100.00	0.001	1	100.00	0.002	1	100.00	0.001	1	100.00	0.001	1	surveys	NMFS	selectivity	1982+	female	95%-50% selectivity offset
srv2_seldiff_f	0	100	55.99	29.637	0	40.82	6.712	0	30.23	5.662	0	39.17	5.760	0	29.60	5.097	0	surveys	NMFS	selectivity	pre-1987	female	95%-50% selectivity offset
srv3_seldiff	0	100	57.17	8.050	0	55.62	6.771	0	52.91	6.014	0	56.90	6.958	0	53.44	6.488	0	surveys	NMFS	selectivity	1982+	male	95%-50% selectivity offset
srv2_seldiff	0	100	23.03	3.734	0	21.57	3.309	0	19.58	2.972	0	21.92	3.327	0	19.88	2.983	0	surveys	NMFS	selectivity	pre-1986	male	95%-50% selectivity offset

Table 16 (cont.).

Parameter	Limits		2014 Model			Model A			Model B			Model C			Model D			Description					
	min	max	est.	std. dev	flag	est.	std. dev	flag	est.	std. dev	flag	est.	std. dev	flag	est.	std. dev	flag	Category 1	Category 2	Category 3	Period	Sex	Description
pAvgLnF_TCF	--	--	-1.62	0.087	0	-1.50	0.097	0	-0.53	0.077	0	-1.36	0.086	0	-0.60	0.077	0	fisheries	TCF	mortality	1965+	male	mean ln-scale fishing mortality
fish_fit_sel50_mn2	85	160	136.86	0.303	0	133.08	0.488	0	138.67	0.412	0	135.82	0.554	0	144.19	0.985	0	fisheries	TCF	retention	1991+	male	50% selected size
fish_fit_sel50_mn1	85	160	138.23	0.394	0	137.67	0.355	0	137.20	0.353	0	138.18	0.416	0	138.79	0.483	0	fisheries	TCF	retention	pre-1991	male	50% selected size
fish_fit_slope_mn2	0.25	2.001	0.84	0.118	0	0.37	0.030	0	0.33	0.022	0	0.29	0.023	0	0.26	0.022	0	fisheries	TCF	retention	1991+	male	slope
fish_fit_slope_mn1	0.25	1.001	0.73	0.131	0	0.79	0.140	0	0.77	0.142	0	0.70	0.123	0	0.66	0.115	0	fisheries	TCF	retention	pre-1991	male	slope
fish_disc_sel50_f	80	150	120.47	3.280	0	117.47	2.802	0	119.99	1.387	0	104.81	2.335	0	114.23	1.302	0	fisheries	TCF	selectivity	all	female	50% selected size
log_avg_sel50_3	4	5	4.83	0.009	0	4.83	0.023	0	4.86	0.006	0	4.75	0.010	0	4.78	0.007	0	fisheries	TCF	selectivity	1991+	male	50% selected size
log_sel50_dev_3[01]	-0.5	0.5	0.05	0.018	0	0.08	0.033	0	0.01	0.014	0	0.09	0.026	0	0.00	0.015	0	fisheries	TCF	selectivity	1991	male	dev, 50% selected size
log_sel50_dev_3[02]	-0.5	0.5	0.15	0.015	0	0.13	0.029	0	-0.01	0.014	0	0.14	0.019	0	-0.02	0.017	0	fisheries	TCF	selectivity	1992	male	dev, 50% selected size
log_sel50_dev_3[03]	-0.5	0.5	0.10	0.016	0	0.10	0.030	0	0.00	0.013	0	0.10	0.022	0	0.00	0.015	0	fisheries	TCF	selectivity	1993	male	dev, 50% selected size
log_sel50_dev_3[04]	-0.5	0.5	0.10	0.021	0	0.14	0.034	0	0.13	0.014	0	0.18	0.030	0	0.13	0.015	0	fisheries	TCF	selectivity	1994	male	dev, 50% selected size
log_sel50_dev_3[05]	-0.5	0.5	0.00	0.030	0	-0.01	0.046	0	0.10	0.013	0	-0.06	0.061	0	0.11	0.014	0	fisheries	TCF	selectivity	1995	male	dev, 50% selected size
log_sel50_dev_3[06]	-0.5	0.5	-0.50	0.018	0	-0.43	0.287	0	0.06	0.026	0	-0.50	0.017	0	0.02	0.044	0	fisheries	TCF	selectivity	1996	male	dev, 50% selected size
log_sel50_dev_3[07]	-0.5	0.5	-0.05	0.020	0	-0.06	0.029	0	-0.08	0.019	0	-0.06	0.023	0	-0.08	0.020	0	fisheries	TCF	selectivity	2005	male	dev, 50% selected size
log_sel50_dev_3[08]	-0.5	0.5	-0.05	0.020	0	-0.06	0.030	0	-0.07	0.018	0	-0.07	0.022	0	-0.09	0.020	0	fisheries	TCF	selectivity	2006	male	dev, 50% selected size
log_sel50_dev_3[09]	-0.5	0.5	-0.08	0.018	0	-0.09	0.028	0	-0.11	0.016	0	-0.09	0.020	0	-0.11	0.018	0	fisheries	TCF	selectivity	2007	male	dev, 50% selected size
log_sel50_dev_3[10]	-0.5	0.5	0.06	0.017	0	0.05	0.027	0	0.01	0.015	0	0.03	0.021	0	0.01	0.017	0	fisheries	TCF	selectivity	2008	male	dev, 50% selected size
log_sel50_dev_3[11]	-0.5	0.5	0.23	0.021	0	0.22	0.029	0	0.11	0.014	0	0.26	0.020	0	0.13	0.019	0	fisheries	TCF	selectivity	2009	male	dev, 50% selected size
log_sel50_dev_3[12]	-0.5	0.5	0.00	0.020	0	-0.02	0.028	0	-0.04	0.016	0	-0.01	0.021	0	-0.03	0.018	0	fisheries	TCF	selectivity	2013	male	dev, 50% selected size
log_sel50_dev_3[13]	-0.5	0.5	0.00	0.000	0	-0.04	0.026	0	-0.10	0.015	0	-0.04	0.018	0	-0.08	0.016	0	fisheries	TCF	selectivity	2014	male	dev, 50% selected size
fish_disc_slope_f	0.1	0.4	0.14	0.009	0	0.14	0.008	0	0.17	0.008	0	0.16	0.011	0	0.17	0.009	0	fisheries	TCF	selectivity	all	female	slope
fish_slope_yr_3	0.1	0.4	0.14	0.009	0	0.14	0.009	0	0.16	0.010	0	0.18	0.015	0	0.20	0.016	0	fisheries	TCF	selectivity	1991+	male	slope
fish_slope_1	0.05	0.75	0.12	0.007	0	0.11	0.007	0	0.19	0.010	0	0.10	0.009	0	0.24	0.020	0	fisheries	TCF	selectivity	pre-1991	male	slope

Table 16 (cont.).

Parameter	Limits		2014 Model			Model A			Model B			Model C			Model D					Description			
	min	max	estimate	std. dev	flag	estimate	std. dev	flag	estimate	std. dev	flag	estimate	std. dev	flag	estimate	std. dev	flag	Category 1	Category 2	Category 3	Period	Sex	Description
pAvgLnF_GTF	--	--	-4.21	0.075	0	-4.16	0.073	0	-6.30	0.199	0	-3.93	0.073	0	-6.24	0.186	0	fisheries	GTF	mortality	1973+	male	mean ln-scale fishing mortality
fish_disc_sel50_tf1	40	125.01	125.01	0.000	1	125.01	0.000	1	125.01	0.000	1	125.01	0.000	1	125.01	0.000	1	fisheries	GTF	selectivity	1973-1987	female	50% selected size
fish_disc_sel50_tf2	40	250.01	175.95	52.035	0	159.21	34.425	0	162.02	27.621	0	156.12	33.065	0	154.44	26.954	0	fisheries	GTF	selectivity	1988-1996	female	50% selected size
fish_disc_sel50_tf3	40	150.01	148.32	11.394	0	143.99	9.954	0	146.05	10.410	0	145.22	10.095	0	143.84	10.000	0	fisheries	GTF	selectivity	1997+	female	50% selected size
fish_disc_sel50_tm1	40	120.01	53.76	1.972	0	57.07	2.034	0	55.57	2.008	0	57.28	2.039	0	55.51	1.995	0	fisheries	GTF	selectivity	1973-1987	male	50% selected size
fish_disc_sel50_tm2	40	120.01	64.66	8.958	0	72.61	9.681	0	104.77	16.358	0	71.85	9.813	0	93.06	14.778	0	fisheries	GTF	selectivity	1988-1996	male	50% selected size
fish_disc_sel50_tm3	40	120.01	94.02	2.322	0	83.19	2.113	0	84.59	2.255	0	84.36	2.165	0	83.08	2.206	0	fisheries	GTF	selectivity	1997+	male	50% selected size
fish_disc_slope_tf1	0.01	0.5	0.03	0.002	0	0.03	0.002	0	0.03	0.002	0	0.03	0.002	0	0.03	0.002	0	fisheries	GTF	selectivity	1973-1987	female	slope
fish_disc_slope_tf2	0.005	0.5	0.01	0.005	0	0.02	0.005	0	0.02	0.005	0	0.02	0.005	0	0.02	0.005	0	fisheries	GTF	selectivity	1988-1996	female	slope
fish_disc_slope_tf3	0.01	0.5	0.05	0.008	0	0.05	0.007	0	0.05	0.007	0	0.05	0.007	0	0.05	0.007	0	fisheries	GTF	selectivity	1997+	female	slope
fish_disc_slope_tm1	0.01	0.5	0.11	0.013	0	0.11	0.011	0	0.11	0.012	0	0.11	0.011	0	0.11	0.012	0	fisheries	GTF	selectivity	1973-1987	male	slope
fish_disc_slope_tm2	0.01	0.5	0.05	0.012	0	0.04	0.009	0	0.03	0.005	0	0.04	0.009	0	0.03	0.006	0	fisheries	GTF	selectivity	1988-1996	male	slope
fish_disc_slope_tm3	0.01	0.5	0.07	0.004	0	0.08	0.004	0	0.07	0.004	0	0.08	0.004	0	0.08	0.005	0	fisheries	GTF	selectivity	1997+	male	slope
rkfish_disc_sel50_f1	50	150	150.00	1.140	1	98.35	13.410	0	102.49	0.616	0	150.00	3.936	1	99.05	0.671	0	fisheries	RKF	selectivity	1989-1996	female	50% selected size
rkfish_disc_sel50_f2	50	150	103.08	45.740	0	103.26	44.773	0	127.47	17.467	0	150.00	8.893	1	109.64	9.618	0	fisheries	RKF	selectivity	1997-2004	female	50% selected size
rkfish_disc_sel50_f3	50	170	157.07	354.400	0	157.07	337.590	0	124.98	8.415	0	158.55	398.060	0	118.93	7.198	0	fisheries	RKF	selectivity	2005+	female	50% selected size
rkfish_disc_sel50_m1	95	150	150.00	0.001	1	150.00	0.001	1	139.02	1.340	0	150.00	0.001	1	132.27	1.197	0	fisheries	RKF	selectivity	1989-1996	male	50% selected size
rkfish_disc_sel50_m2	95	150	132.31	11.907	0	133.22	12.448	0	139.67	2.636	0	136.32	13.067	0	107.30	3.386	0	fisheries	RKF	selectivity	1997-2004	male	50% selected size
rkfish_disc_sel50_m3	95	150	150.00	0.001	1	150.00	0.001	1	150.00	0.000	1	150.00	0.001	1	146.00	1.936	0	fisheries	RKF	selectivity	2005+	male	50% selected size
rkfish_disc_slope_f1	0.05	0.5	0.17	0.040	0	0.24	0.132	0	0.50	0.000	1	0.16	0.037	0	0.50	0.000	1	fisheries	RKF	selectivity	1989-1996	female	slope
rkfish_disc_slope_f2	0.05	0.5	0.18	0.173	0	0.18	0.170	0	0.08	0.038	0	0.15	0.066	0	0.10	0.049	0	fisheries	RKF	selectivity	1997-2004	female	slope
rkfish_disc_slope_f3	0.05	0.5	0.18	0.056	0	0.18	0.054	0	0.14	0.043	0	0.18	0.052	0	0.14	0.042	0	fisheries	RKF	selectivity	2005+	female	slope
rkfish_disc_slope_m1	0.01	0.5	0.11	0.011	0	0.10	0.010	0	0.36	0.043	0	0.11	0.011	0	0.50	0.001	1	fisheries	RKF	selectivity	1989-1996	male	slope
rkfish_disc_slope_m2	0.01	0.5	0.09	0.027	0	0.09	0.027	0	0.08	0.013	0	0.09	0.024	0	0.21	0.103	0	fisheries	RKF	selectivity	1997-2004	male	slope
rkfish_disc_slope_m3	0.01	0.5	0.08	0.007	0	0.08	0.007	0	0.11	0.007	0	0.08	0.007	0	0.09	0.008	0	fisheries	RKF	selectivity	2005+	male	slope
pAvgLnF_SCF	--	--	-3.80	0.132	0	-3.71	0.122	0	-3.57	0.072	0	-2.59	0.122	0	-2.65	0.075	0	fisheries	SCF	mortality	1992+	male	mean ln-scale fishing mortality
snowfish_disc_sel50_f_1	50	150	111.33	4.707	0	110.42	4.551	0	93.49	5.584	0	109.37	4.615	0	96.19	8.365	0	fisheries	SCF	selectivity	1989-1996	female	50% selected size
snowfish_disc_sel50_f_2	50	120	76.46	5.024	0	76.19	4.879	0	99.77	4.255	0	76.16	4.878	0	99.13	4.130	0	fisheries	SCF	selectivity	1997-2004	female	50% selected size
snowfish_disc_sel50_f_3	50	120	85.24	6.346	0	88.70	7.051	0	120.00	0.000	1	88.18	6.780	0	120.00	0.000	1	fisheries	SCF	selectivity	2005+	female	50% selected size
selSCF_Z50_ma_1	40	140	87.47	1.762	0	86.80	1.652	0	88.13	2.716	0	86.90	1.595	0	87.44	2.468	0	fisheries	SCF	selectivity	1989-1996	male	ascending 50% selectivity
selSCF_Z50_ma_2	40	140	93.81	3.066	0	93.91	3.100	0	94.35	3.309	0	93.76	3.134	0	94.12	3.298	0	fisheries	SCF	selectivity	1997-2004	male	ascending 50% selectivity
selSCF_Z50_ma_3	40	140	105.24	2.009	0	103.63	1.550	0	103.13	1.409	0	103.69	1.564	0	102.33	1.426	0	fisheries	SCF	selectivity	2005+	male	ascending 50% selectivity
snowfish_disc_slope_m_1	0.1	0.5	0.36	0.126	0	0.40	0.147	0	0.31	0.142	0	0.41	0.145	0	0.34	0.154	0	fisheries	SCF	selectivity	1989-1996	male	ascending slope
snowfish_disc_slope_m_2	0.1	0.5	0.23	0.075	0	0.23	0.074	0	0.21	0.070	0	0.23	0.075	0	0.22	0.073	0	fisheries	SCF	selectivity	1997-2004	male	ascending slope
snowfish_disc_slope_m_3	0.1	0.5	0.17	0.017	0	0.18	0.018	0	0.18	0.018	0	0.18	0.018	0	0.19	0.019	0	fisheries	SCF	selectivity	2005+	male	ascending slope
selSCF_lnZ50_md_1	2	4.5	3.97	0.053	0	3.97	0.041	0	3.97	0.067	0	3.98	0.039	0	3.98	0.061	0	fisheries	SCF	selectivity	1989-1996	male	descending 50% selectivity
selSCF_lnZ50_md_2	2	4.5	3.82	0.132	0	3.80	0.136	0	3.84	0.128	0	3.81	0.149	0	3.84	0.129	0	fisheries	SCF	selectivity	1997-2004	male	descending 50% selectivity
selSCF_lnZ50_md_3	2	4.5	3.48	0.115	0	3.53	0.082	0	3.60	0.067	0	3.54	0.084	0	3.60	0.069	0	fisheries	SCF	selectivity	2005+	male	descending 50% selectivity
snowfish_disc_slope_m2_1	0.1	0.5	0.37	0.249	0	0.50	0.004	1	0.45	0.315	0	0.50	0.001	1	0.43	0.291	0	fisheries	SCF	selectivity	1989-1996	male	descending slope
snowfish_disc_slope_m2_2	0.1	0.5	0.18	0.092	0	0.18	0.089	0	0.21	0.110	0	0.16	0.085	0	0.20	0.106	0	fisheries	SCF	selectivity	1997-2004	male	descending slope
snowfish_disc_slope_m2_3	0.1	0.5	0.17	0.030	0	0.18	0.028	0	0.19	0.030	0	0.18	0.028	0	0.18	0.028	0	fisheries	SCF	selectivity	2005+	male	descending slope
snowfish_disc_slope_f_1	0.05	0.5	0.05	0.000	-1	0.05	0.000	-1	0.05	0.000	-1	0.05	0.000	-1	0.05	0.026	0	fisheries	SCF	selectivity	1989-1996	female	slope
snowfish_disc_slope_f_2	0.05	0.5	0.25	0.129	0	0.25	0.130	0	0.10	0.025	0	0.25	0.130	0	0.10	0.025	0	fisheries	SCF	selectivity	1997-2004	female	slope
snowfish_disc_slope_f_3	0.05	0.5	0.16	0.053	0	0.13	0.041	0	0.11	0.004	0	0.14	0.042	0	0.10	0.004	0	fisheries	SCF	selectivity	2005+	female	slope

Table 17. Comparison of fits to mature survey biomass (1000's t) by sex from the 2014 assessment and Models A and C using Dataset D. Columns are arranged to allow easy comparison of model predictions.

	Mature Males							Mature Females						
	2014 Assessment			Model A	Model C	Dataset D		2014 Assessment			Model A	Model C	Dataset D	
	observed		predicted	predicted	predicted	observed		observed		predicted	predicted	predicted	observed	
year	cv	value				cv	value	cv	value				cv	value
1949	--	--	--	--	--	--	--	--	--	--	--	--	--	--
1950	--	--	0.0	0.0	0.0	--	--	--	--	0.0	0.0	0.0	--	--
1951	--	--	0.1	0.1	0.1	--	--	--	--	0.2	0.1	0.1	--	--
1952	--	--	0.8	0.8	0.8	--	--	--	--	0.6	0.6	0.5	--	--
1953	--	--	3.2	2.9	2.6	--	--	--	--	1.4	1.3	1.2	--	--
1954	--	--	6.1	5.4	4.8	--	--	--	--	2.0	1.8	1.7	--	--
1955	--	--	8.4	7.2	6.5	--	--	--	--	2.5	2.3	2.1	--	--
1956	--	--	10.2	8.6	7.7	--	--	--	--	2.9	2.6	2.3	--	--
1957	--	--	11.5	9.7	8.6	--	--	--	--	3.2	2.8	2.6	--	--
1958	--	--	12.6	10.6	9.4	--	--	--	--	3.4	3.0	2.7	--	--
1959	--	--	13.6	11.3	10.1	--	--	--	--	3.7	3.2	2.9	--	--
1960	--	--	14.6	12.1	10.8	--	--	--	--	4.0	3.4	3.1	--	--
1961	--	--	15.7	13.1	11.6	--	--	--	--	4.4	3.7	3.4	--	--
1962	--	--	17.4	14.4	12.8	--	--	--	--	5.0	4.3	3.9	--	--
1963	--	--	20.2	16.7	14.8	--	--	--	--	6.2	5.3	4.8	--	--
1964	--	--	25.8	21.3	18.9	--	--	--	--	8.9	7.6	6.9	--	--
1965	--	--	38.7	32.3	28.6	--	--	--	--	15.1	13.3	12.0	--	--
1966	--	--	67.1	57.3	50.7	--	--	--	--	27.2	24.7	22.2	--	--
1967	--	--	119.9	106.2	93.0	--	--	--	--	43.8	41.4	36.7	--	--
1968	--	--	174.7	160.6	139.4	--	--	--	--	59.1	57.3	50.3	--	--
1969	--	--	217.3	204.6	175.9	--	--	--	--	68.3	66.6	58.3	--	--
1970	--	--	229.7	217.5	186.5	--	--	--	--	71.5	68.5	60.3	--	--
1971	--	--	229.8	212.8	184.1	--	--	--	--	71.6	65.9	59.0	--	--
1972	--	--	228.9	201.7	178.6	--	--	--	--	70.7	61.6	56.9	--	--
1973	--	--	228.8	189.9	174.1	--	--	--	--	68.2	57.2	54.6	--	--
1974	0.10	212.0	220.6	176.6	166.9	--	--	0.24	55.8	62.8	52.3	51.0	--	--
1975	0.10	265.1	194.0	155.1	148.9	0.14	246.0	0.20	38.8	55.0	46.4	45.6	0.15	31.7
1976	0.09	152.1	165.1	133.7	129.2	0.12	126.2	0.15	46.0	47.1	40.4	39.7	0.09	31.4
1977	0.12	130.4	124.9	102.2	100.7	0.09	110.6	0.28	47.6	39.4	34.5	34.3	0.12	38.8
1978	0.11	80.6	80.8	68.3	71.1	0.09	77.6	0.23	26.4	34.0	30.9	31.3	0.20	26.2
1979	0.09	47.8	65.5	59.0	63.1	0.07	32.2	0.23	20.4	33.6	32.2	32.9	0.19	19.7
1980	0.16	86.3	61.7	61.5	63.2	0.10	86.2	0.20	70.4	34.3	34.2	34.6	0.14	64.2
1981	0.10	50.7	48.2	46.4	46.9	0.09	49.4	0.18	45.2	31.3	28.2	28.3	0.15	43.1
1982	0.13	49.7	61.2	58.9	60.0	0.11	49.0	0.18	64.8	28.1	25.2	25.1	0.28	64.4
1983	0.13	29.0	47.9	37.3	37.5	0.08	28.5	0.19	20.7	21.7	17.2	17.2	0.23	20.6
1984	0.11	26.2	31.7	21.5	21.3	0.11	24.2	0.21	14.7	16.4	11.6	11.6	0.20	15.0
1985	0.13	11.7	21.7	13.0	12.9	0.06	11.4	0.32	5.7	13.3	8.5	8.5	0.15	5.6
1986	0.19	13.2	27.2	18.3	18.3	0.10	12.8	0.21	3.5	13.3	9.3	9.3	0.12	3.5
1987	0.13	24.2	41.4	31.6	31.4	0.07	24.1	0.25	5.3	15.5	12.3	12.2	0.17	5.2
1988	0.23	59.5	59.6	51.1	50.8	0.11	60.4	0.25	25.6	18.8	17.2	17.1	0.12	25.5
1989	0.11	101.5	78.9	77.0	76.5	0.08	91.9	0.13	25.5	22.2	22.2	22.1	0.12	19.5
1990	0.11	103.2	83.8	85.7	86.9	0.09	96.3	0.26	36.4	23.8	24.8	24.6	0.14	37.8
1991	0.17	110.8	70.4	74.5	77.9	0.09	109.7	0.21	45.6	23.3	24.6	24.4	0.12	45.0
1992	0.19	108.1	61.6	68.4	70.5	0.11	103.2	0.17	27.8	20.8	21.8	21.6	0.17	26.5
1993	0.13	62.1	46.1	50.4	51.5	0.10	60.1	0.15	11.9	16.5	16.9	16.8	0.11	11.7
1994	0.11	44.6	33.9	36.0	36.5	0.09	42.1	0.21	10.4	12.5	12.6	12.5	0.20	10.0
1995	0.15	33.9	24.8	25.9	26.1	0.11	31.1	0.23	13.4	9.4	9.2	9.2	0.17	12.7
1996	0.20	27.3	17.9	18.6	18.6	0.18	26.3	0.28	9.8	7.0	6.9	6.8	0.24	9.8
1997	0.11	11.1	14.3	14.6	14.6	0.10	10.7	0.18	3.5	5.5	5.3	5.3	0.17	3.5
1998	0.10	10.6	12.6	12.9	12.8	0.11	10.3	0.16	2.3	4.5	4.3	4.3	0.13	2.3
1999	0.16	12.4	12.4	12.6	12.5	0.10	12.5	0.28	3.8	4.0	3.9	4.0	0.13	3.9
2000	0.20	16.5	14.1	14.3	14.2	0.10	16.1	0.29	4.2	4.2	4.2	4.2	0.14	4.2
2001	0.13	18.2	17.5	17.6	17.5	0.08	17.9	0.24	4.6	4.6	4.5	4.6	0.14	4.6
2002	0.15	18.2	20.5	20.2	20.0	0.09	17.8	0.18	4.5	5.1	5.1	5.1	0.16	4.5
2003	0.15	23.7	24.7	24.4	24.1	0.09	23.3	0.17	8.3	6.0	6.0	6.0	0.14	8.4
2004	0.18	25.6	30.9	30.6	30.2	0.09	26.3	0.15	4.7	7.4	7.5	7.5	0.12	4.9
2005	0.13	44.0	39.6	39.6	39.2	0.07	43.1	0.18	11.6	8.7	8.8	8.9	0.13	11.6
2006	0.14	66.9	45.9	44.9	44.5	0.10	64.2	0.21	15.8	9.9	9.7	9.8	0.14	15.0
2007	0.20	72.6	51.7	49.3	49.2	0.10	66.4	0.26	13.3	11.5	10.8	11.1	0.13	13.5
2008	0.16	59.7	60.9	55.3	55.2	0.10	62.7	0.18	11.3	12.1	11.0	11.2	0.12	11.7
2009	0.13	37.6	63.0	53.9	53.5	0.09	36.3	0.26	8.2	11.1	9.6	9.8	0.17	8.6
2010	0.13	36.1	57.2	47.2	46.6	0.09	37.6	0.28	5.4	9.6	8.1	8.3	0.12	5.5
2011	0.17	46.3	51.5	41.9	41.1	0.08	41.5	0.16	8.7	9.1	7.8	7.8	0.12	5.5
2012	0.18	43.1	51.5	42.9	42.0	0.09	41.2	0.41	15.8	11.0	9.8	9.8	0.12	12.5
2013	0.15	69.8	65.3	57.4	56.5	0.10	65.7	0.14	19.1	14.2	13.2	13.4	0.10	18.0
2014	0.11	87.1	81.9	73.8	73.5	0.07	79.5	0.19	15.8	15.6	15.0	15.3	0.14	14.9
2015	--	--	--	72.6	72.7	0.07	60.2	--	--	--	13.8	14.1	0.14	11.3

Table 18. Comparison of time series of estimated recruitment (millions) from the 2014 assessment and Models A and C using Dataset D.

Year	2014 Assessment	Model A	Model C
1949	62.19	59.68	53.52
1950	62.36	59.82	53.64
1951	62.75	60.16	53.94
1952	63.46	60.79	54.48
1953	64.64	61.83	55.38
1954	66.49	63.47	56.80
1955	69.36	66.02	59.03
1956	73.83	70.00	62.50
1957	80.96	76.35	68.07
1958	92.87	86.92	77.35
1959	114.43	105.92	94.08
1960	159.18	144.85	128.44
1961	273.92	243.60	215.88
1962	602.93	534.88	474.18
1963	1301.35	1244.51	1096.58
1964	1807.55	1930.88	1663.33
1965	1699.85	1929.26	1637.96
1966	1397.57	1545.71	1327.10
1967	1207.68	1214.54	1087.11
1968	1161.20	1015.76	973.66
1969	1196.51	926.12	957.08
1970	997.80	879.66	938.57
1971	650.12	737.39	733.05
1972	542.54	572.56	551.92
1973	440.81	458.56	418.16
1974	122.18	299.76	338.07
1975	420.21	376.50	463.86
1976	919.41	1113.94	1105.19
1977	560.43	829.22	883.98
1978	477.41	381.13	389.15
1979	118.24	126.07	134.09
1980	45.37	57.85	61.75
1981	106.97	76.54	78.68
1982	52.60	39.31	40.05
1983	372.92	275.66	275.79
1984	304.66	266.63	264.38
1985	578.41	673.12	664.52
1986	483.57	517.95	516.81
1987	438.11	485.61	484.66
1988	388.44	444.02	449.62
1989	172.35	168.66	168.88
1990	77.75	70.95	71.85
1991	36.43	40.76	41.98
1992	31.78	30.74	31.26
1993	26.66	27.74	28.35
1994	30.64	31.32	31.73
1995	45.05	41.62	42.35
1996	43.96	46.14	47.06
1997	119.75	113.81	115.20
1998	47.11	46.05	46.50
1999	147.24	140.55	141.20
2000	89.04	84.99	84.26
2001	276.17	279.15	281.85
2002	113.87	108.80	110.45
2003	202.76	185.04	194.42
2004	371.35	306.44	311.08
2005	114.16	87.26	87.88
2006	94.61	70.87	72.23
2007	66.43	52.92	53.34
2008	76.31	61.00	61.30
2009	410.40	354.63	345.36
2010	432.10	422.94	449.87
2011	216.25	251.06	256.42
2012	43.73	52.20	53.57
2013	117.42	115.80	118.34
2014	177.80	124.00	126.93
2015	--	80.71	82.65

Table 19. Estimated mature male biomass (1000's t) at mating from the 2014 assessment and Models A and C using Dataset D.

Year	2014 Assessment	Model A	Model C
1949	0.00	0.00	0.00
1950	0.01	0.01	0.01
1951	0.15	0.17	0.16
1952	1.24	1.36	1.24
1953	4.59	4.75	4.29
1954	8.82	8.66	7.78
1955	12.13	11.63	10.44
1956	14.61	13.84	12.41
1957	16.52	15.53	13.93
1958	18.08	16.92	15.16
1959	19.47	18.15	16.26
1960	20.90	19.43	17.39
1961	22.62	20.97	18.75
1962	25.03	23.15	20.67
1963	29.04	26.80	23.91
1964	37.09	34.23	30.51
1965	53.86	49.92	44.47
1966	94.82	90.17	80.01
1967	151.98	150.63	133.47
1968	225.91	233.51	204.04
1969	273.73	291.37	251.39
1970	296.50	317.01	272.07
1971	305.11	317.54	274.85
1972	310.35	305.40	271.02
1973	312.91	287.57	264.12
1974	292.48	257.21	244.46
1975	257.84	226.40	220.10
1976	195.34	171.84	171.37
1977	123.03	106.15	110.22
1978	79.23	70.30	75.10
1979	49.25	48.18	52.89
1980	34.48	31.15	33.63
1981	44.63	40.66	41.51
1982	48.67	37.88	37.86
1983	40.27	25.33	24.74
1984	24.89	12.79	12.46
1985	23.81	13.61	13.37
1986	29.58	19.12	18.87
1987	43.03	31.17	30.92
1988	59.68	48.32	48.30
1989	65.66	60.28	62.22
1990	56.02	55.10	59.73
1991	51.12	55.11	58.15
1992	43.53	48.23	49.76
1993	38.06	40.85	41.51
1994	30.58	31.48	31.66
1995	22.73	22.85	22.83
1996	17.84	17.66	17.54
1997	14.95	14.71	14.53
1998	13.43	13.22	12.98
1999	13.68	13.39	13.13
2000	15.52	15.17	14.91
2001	19.06	18.42	18.11
2002	22.71	21.49	21.09
2003	27.68	26.20	25.67
2004	34.61	32.90	32.21
2005	43.61	41.89	41.04
2006	49.90	46.77	45.91
2007	56.30	51.35	50.78
2008	67.30	58.42	57.76
2009	70.20	57.44	56.37
2010	64.36	50.95	49.71
2011	57.83	45.10	43.77
2012	58.23	46.55	45.07
2013	72.70	60.59	58.97
2014	--	71.57	70.63

Table 20. Estimated numbers of male crab ≥ 138 mm CW (millions) in the survey from the 2014 assessment and Models A and C using Dataset D.

Year	2014 Assessment	Model A	Model C
1949	0.00	0.00	0.00
1950	0.00	0.00	0.00
1951	0.00	0.00	0.00
1952	0.09	0.10	0.09
1953	0.80	0.82	0.70
1954	2.11	1.97	1.70
1955	3.17	2.85	2.46
1956	3.95	3.50	3.01
1957	4.53	3.98	3.42
1958	4.99	4.36	3.75
1959	5.38	4.69	4.02
1960	5.76	5.00	4.28
1961	6.19	5.36	4.58
1962	6.75	5.83	4.98
1963	7.61	6.56	5.59
1964	9.17	7.89	6.72
1965	12.59	10.86	9.23
1966	20.36	17.76	14.98
1967	38.29	34.60	29.05
1968	59.50	56.14	46.20
1969	79.41	77.56	62.66
1970	85.74	85.21	67.44
1971	85.99	84.39	66.37
1972	85.55	80.13	63.97
1973	86.45	75.34	62.36
1974	176.77	70.60	61.01
1975	230.46	215.27	208.15
1976	153.64	126.34	120.37
1977	115.31	100.09	95.21
1978	64.92	60.10	56.98
1979	37.92	26.64	25.26
1980	44.32	44.07	42.94
1981	25.48	27.54	26.65
1982	31.45	34.71	34.20
1983	26.61	23.76	23.23
1984	21.17	16.43	16.02
1985	12.89	9.53	9.25
1986	12.78	9.45	9.14
1987	21.11	17.72	17.24
1988	38.16	34.47	33.66
1989	62.99	61.02	59.65
1990	75.34	73.17	71.71
1991	60.52	63.37	62.33
1992	63.39	66.97	65.80
1993	35.16	38.27	37.15
1994	26.87	28.48	27.47
1995	18.11	18.64	17.78
1996	15.11	15.73	15.00
1997	8.33	8.68	8.02
1998	6.55	6.90	6.38
1999	6.48	6.83	6.39
2000	9.67	10.00	9.61
2001	12.35	12.80	12.41
2002	13.91	14.16	13.76
2003	15.93	16.24	15.78
2004	16.46	16.96	16.39
2005	26.34	27.10	26.39
2006	32.94	32.78	31.93
2007	31.90	31.77	30.89
2008	37.30	38.65	37.69
2009	35.05	32.40	31.37
2010	34.32	32.49	31.45
2011	38.03	33.17	32.19
2012	28.65	24.72	23.73
2013	34.57	31.58	30.30
2014	52.28	48.90	47.50
2015	--	48.67	47.19

Table 21. Observed retained catch (1000's t) in the directed fishery and predicted catch from the 2014 assessment and Models A and C using Dataset D.

	2014 Assessment		Model A	Model C	Dataset D
year	observed	predicted	predicted	predicted	observed
1949	--	0.0	0.0	0.0	--
1950	--	0.0	0.0	0.0	--
1951	--	0.0	0.0	0.0	--
1952	--	0.0	0.0	0.0	--
1953	--	0.1	0.1	0.0	--
1954	--	0.1	0.1	0.1	--
1955	--	0.2	0.2	0.2	--
1956	--	0.3	0.2	0.2	--
1957	--	0.3	0.3	0.2	--
1958	--	0.3	0.3	0.3	--
1959	--	0.4	0.3	0.3	--
1960	--	0.4	0.4	0.3	--
1961	--	0.4	0.4	0.3	--
1962	--	0.5	0.4	0.4	--
1963	--	0.5	0.5	0.4	--
1964	--	0.6	0.6	0.5	--
1965	1.92	2.0	2.0	2.0	1.9
1966	2.45	2.5	2.5	2.5	2.4
1967	13.60	13.6	13.6	13.6	13.6
1968	18.00	18.0	18.0	18.0	18.0
1969	27.49	27.5	27.5	27.5	27.5
1970	25.49	25.5	25.5	25.5	25.5
1971	20.71	20.7	20.7	20.7	20.7
1972	16.91	16.9	16.9	16.9	16.9
1973	13.03	13.0	13.0	13.0	13.0
1974	15.24	15.2	15.2	15.2	15.2
1975	17.65	17.7	17.6	17.6	17.7
1976	30.02	30.0	30.0	30.0	30.0
1977	35.53	35.5	35.5	35.5	35.5
1978	21.09	21.1	21.1	21.1	21.1
1979	19.01	18.9	18.8	18.8	19.0
1980	13.43	13.5	13.4	13.4	13.4
1981	4.99	5.1	5.1	5.1	5.0
1982	2.39	2.5	2.5	2.5	2.4
1983	0.55	0.8	0.7	0.7	0.5
1984	1.43	1.5	1.5	1.5	1.4
1985	--	--	--	--	--
1986	--	--	--	--	--
1987	1.00	1.0	0.9	0.9	1.0
1988	3.18	3.1	3.0	3.1	3.2
1989	11.11	11.0	11.0	11.0	11.1
1990	18.19	18.1	18.0	18.0	18.2
1991	14.43	14.3	14.3	14.3	14.4
1992	15.92	14.5	14.8	14.9	15.9
1993	7.67	6.8	7.2	7.2	7.7
1994	3.54	3.4	3.7	3.8	3.5
1995	1.92	1.7	1.9	2.0	1.9
1996	0.82	0.4	0.5	0.7	0.8
1997	--	--	--	--	--
1998	--	--	--	--	--
1999	--	--	--	--	--
2000	--	--	--	--	--
2001	--	--	--	--	--
2002	--	--	--	--	--
2003	--	--	--	--	--
2004	--	--	--	--	--
2005	0.43	0.5	0.5	0.6	0.4
2006	0.96	0.9	1.0	1.1	1.0
2007	0.96	0.9	1.0	1.2	1.0
2008	0.88	0.9	1.0	1.0	0.9
2009	0.60	0.7	0.7	0.8	0.6
2010	--	--	--	--	--
2011	--	--	--	--	--
2012	--	--	--	--	--
2013	0.66	0.6	1.1	1.2	1.2
2014	--	--	5.0	5.5	6.2

Table 22. Total male mortality (retained+discards) in the directed fishery (1000's t) from the 2014 assessment and Models A and C using Dataset D.

	2014 Assessment		Model A	Model C	Dataset D
year	observed	predicted	predicted	predicted	observed
1949	--	0.0	0.0	0.0	--
1950	--	0.0	0.0	0.0	--
1951	--	0.0	0.0	0.0	--
1952	--	0.0	0.0	0.0	--
1953	--	0.1	0.1	0.1	--
1954	--	0.3	0.2	0.2	--
1955	--	0.4	0.3	0.2	--
1956	--	0.5	0.4	0.3	--
1957	--	0.5	0.5	0.3	--
1958	--	0.6	0.5	0.4	--
1959	--	0.6	0.5	0.4	--
1960	--	0.7	0.6	0.4	--
1961	--	0.7	0.6	0.5	--
1962	--	0.8	0.7	0.5	--
1963	--	0.9	0.8	0.6	--
1964	--	1.1	1.0	0.7	--
1965	--	3.8	3.6	3.0	--
1966	--	5.1	4.8	3.9	--
1967	--	27.9	26.6	21.7	--
1968	--	35.1	33.5	27.6	--
1969	--	50.7	48.3	40.4	--
1970	--	45.7	43.3	36.8	--
1971	--	36.7	34.6	29.6	--
1972	--	29.8	28.0	24.1	--
1973	--	22.8	21.5	18.5	--
1974	--	26.1	25.1	21.5	--
1975	--	29.9	29.2	24.9	--
1976	--	51.9	50.9	43.8	--
1977	--	65.0	65.5	59.1	--
1978	--	42.5	44.7	44.6	--
1979	--	52.0	54.3	57.3	--
1980	--	41.3	42.0	40.1	--
1981	--	10.7	9.9	8.2	--
1982	--	4.4	3.9	3.3	--
1983	--	1.2	1.1	0.9	--
1984	--	2.3	2.3	1.9	--
1985	--	--	--	--	--
1986	--	--	--	--	--
1987	--	1.8	1.7	1.4	--
1988	--	5.5	5.5	4.5	--
1989	--	20.4	20.2	16.7	--
1990	--	33.7	32.7	27.8	--
1991	--	23.0	19.5	18.9	--
1992	17.90	18.9	18.7	18.6	17.9
1993	8.91	9.5	9.3	9.2	8.9
1994	4.54	4.7	4.5	4.4	4.5
1995	2.81	3.0	3.0	2.9	2.8
1996	0.86	1.3	1.3	1.2	0.9
1997	--	--	--	--	--
1998	--	--	--	--	--
1999	--	--	--	--	--
2000	--	--	--	--	--
2001	--	--	--	--	--
2002	--	--	--	--	--
2003	--	--	--	--	--
2004	--	--	--	--	--
2005	0.58	0.9	0.8	0.8	0.6
2006	1.40	1.6	1.6	1.5	1.4
2007	1.61	1.8	1.8	1.7	1.6
2008	1.02	1.2	1.2	1.2	1.0
2009	0.63	0.7	0.8	0.8	0.6
2010	--	--	--	--	--
2011	--	--	--	--	--
2012	--	--	--	--	--
2013	0.83	1.1	1.6	1.6	1.4
2014	--	--	7.8	7.5	7.0

Table 23. Comparison of the final objective function components for the alternative models A and C, which can be compared directly. Component differences greater or less than 4 units are highlighted. Negative differences (red highlighting) indicate better fits with Model A. Positive differences (blue highlighting) indicate better fits with Model C.

Type	weight	sigma	Model A	Model C	A - C	Component Description
Total	--	--	2,049.07	2,112.49	-63.42	total
Penalties	1	1.000	2.30	2.29	0.01	recruitment penalty
	0	--	0.00	0.00	0.00	sex ratio penalty
	1	1.000	0.64	0.67	-0.03	immatures natural mortality penalty
	1	1.000	4.21	6.98	-2.77	mature male natural mortality penalty
	1	1.000	51.27	50.01	1.26	mature female natural mortality penalty
	1	1.000	1.97	1.77	0.20	survey q penalty
	1	1.000	16.35	17.01	-0.66	female survey q penalty
	1	1.000	0.90	0.90	0.00	prior on female growth parameter a
	1	1.000	0.68	0.66	0.01	prior on female growth parameter b
	1	1.000	0.57	0.21	0.36	prior on male growth parameter a
	1	1.000	0.04	0.03	0.01	prior on male growth parameter b
	1	1.000	1.41	1.40	0.01	smoothing penalty on female maturity curve
	0.5	1.414	0.16	0.16	0.00	smoothing penalty on male maturity curve
	0	--	0.00	0.00	0.00	1st difference penalty on changes in male size at 50% selectivity in directed fishery
	1	1.000	49.39	48.50	0.88	penalty on F-devs in directed fishery
	0.5	1.414	7.70	7.52	0.18	penalty on F-devs in snow crab fishery
	0	--	0.00	0.00	0.00	penalty on F-devs in BBRKC fishery
	0.5	1.414	11.69	11.67	0.03	penalty on F-devs in groundfish fishery
Size Compositions	1	1.000	194.52	222.35	-27.83	likelihood for directed fishery: retained males
	1	1.000	115.60	180.05	-64.45	likelihood for directed fishery: total males
	1	1.000	14.32	11.06	3.26	likelihood for directed fishery: discarded females
	1	1.000	49.26	50.82	-1.56	likelihood for snow crab fishery: discarded males
	1	1.000	13.95	14.09	-0.15	likelihood for snow crab fishery: discarded females
	1	1.000	24.21	24.21	0.00	likelihood for BBRKC fishery: discarded males
	1	1.000	2.68	1.94	0.74	likelihood for BBRKC fishery: discarded females
	1	1.000	135.17	128.78	6.39	likelihood for groundfish fishery
	1	1.000	280.47	278.58	1.89	likelihood for survey: immature males
	1	1.000	272.48	260.23	12.26	likelihood for survey: mature males
	1	1.000	307.31	307.19	0.12	likelihood for survey: immature females
	1	1.000	99.13	105.26	-6.13	likelihood for survey: mature females
Biomass	1	1.000	311.35	315.61	-4.26	likelihood for survey: mature survey biomass
	10	0.316	31.87	19.61	12.25	likelihood for directed fishery: male retained catch biomass
	10	0.316	18.21	11.98	6.23	likelihood for directed fishery: male total catch biomass
	10	0.316	6.64	7.62	-0.98	likelihood for directed fishery: female catch biomass
	10	0.316	10.52	10.48	0.04	likelihood for snow crab fishery: total catch biomass
	10	0.316	9.59	10.29	-0.69	likelihood for BBRKC fishery: total catch biomass
	10	0.316	2.52	2.55	-0.03	likelihood for groundfish fishery: total catch biomass
Penalties	0	--	0.00	0.00	0.00	penalty on sel50 devs for TCF

Table 24. Parameter estimates for devs vectors from Model A (Dataset D), the author's preferred model. Estimates for other parameters may be found in Table 15.

devs vector	year	estimate	std. dev.
historic recruitment devs (1949-1973)	1949	-1.496	1.627
	1950	-1.494	1.484
	1951	-1.488	1.346
	1952	-1.478	1.216
	1953	-1.461	1.095
	1954	-1.435	0.987
	1955	-1.395	0.894
	1956	-1.337	0.820
	1957	-1.250	0.767
	1958	-1.120	0.734
	1959	-0.923	0.717
	1960	-0.610	0.715
	1961	-0.090	0.725
	1962	0.697	0.729
	1963	1.541	0.720
	1964	1.980	0.702
	1965	1.980	0.700
	1966	1.758	0.703
	1967	1.517	0.698
	1968	1.338	0.689
	1969	1.246	0.685
	1970	1.194	0.669
	1971	1.018	0.609
	1972	0.765	0.575
	1973	0.543	0.584
recruitment deviations (1974+)	1974	0.781	0.415
	1975	1.009	0.323
	1976	2.094	0.126
	1977	1.799	0.138
	1978	1.022	0.186
	1979	-0.085	0.338
	1980	-0.864	0.461
	1981	-0.584	0.255
	1982	-1.250	0.385
	1983	0.698	0.104
	1984	0.664	0.160
	1985	1.590	0.107
	1986	1.328	0.134
	1987	1.264	0.133
	1988	1.174	0.120
	1989	0.206	0.172
	1990	-0.660	0.254
	1991	-1.214	0.291
	1992	-1.496	0.273
	1993	-1.599	0.250
	1994	-1.477	0.218
	1995	-1.193	0.182
	1996	-1.090	0.188
	1997	-0.187	0.098
	1998	-1.092	0.182
	1999	0.024	0.099
	2000	-0.479	0.174
	2001	0.710	0.088
	2002	-0.232	0.186
	2003	0.299	0.129
	2004	0.803	0.086
	2005	-0.453	0.197
	2006	-0.661	0.214
	2007	-0.953	0.261
	2008	-0.811	0.251
	2009	0.949	0.100
	2010	1.126	0.096
	2011	0.604	0.135
	2012	-0.966	0.369
	2013	-0.170	0.198
	2014	-0.101	0.204
	2015	-0.531	0.301

devs vector	year	estimate	std. dev.
directed fishery total mortality devs	1965	-0.518	0.498
	1966	-0.773	0.388
	1967	0.359	0.352
	1968	0.121	0.334
	1969	0.221	0.323
	1970	0.022	0.315
	1971	-0.200	0.294
	1972	-0.366	0.251
	1973	-0.570	0.187
	1974	-0.324	0.124
	1975	-0.041	0.095
	1976	0.761	0.092
	1977	1.491	0.104
	1978	1.688	0.133
	1979	2.387	0.166
	1980	2.443	0.216
	1981	0.596	0.156
	1982	-0.350	0.129
	1983	-1.277	0.265
	1984	0.097	0.176
	1987	-0.867	0.231
	1988	-0.113	0.112
	1989	0.880	0.087
	1990	1.372	0.091
	1991	1.289	0.136
	1992	1.668	0.140
	1993	0.961	0.134
	1994	0.762	0.176
	1995	-0.070	0.159
	1996	-1.228	0.198
	2005	-2.148	0.216
	2006	-1.652	0.149
	2007	-1.690	0.139
	2008	-1.753	0.167
	2009	-1.049	0.277
	2013	-1.686	0.147
	2014	-0.442	0.097
snow crab fishery discard mortality devs	1992	1.850	0.120
	1993	1.627	0.127
	1994	1.273	0.150
	1995	1.276	0.175
	1996	0.197	0.471
	1997	0.734	0.368
	1998	0.494	0.487
	1999	-0.382	0.684
	2000	-0.622	0.659
	2001	-0.580	0.630
	2002	-0.568	0.600
	2003	-0.812	0.584
	2004	-1.146	0.565
	2005	-0.649	0.503
	2006	-0.340	0.414
	2007	-0.206	0.342
	2008	-0.610	0.418
	2009	-0.486	0.421
	2010	-0.420	0.447
	2011	0.013	0.365
	2012	-0.578	0.470
	2013	-0.479	0.347
	2014	0.414	0.178

devs vector	year	estimate	std. dev.
groundfish fiesheries discard mortality devs	1973	0.845	0.115
	1974	1.273	0.086
	1975	0.461	0.082
	1976	-0.028	0.094
	1977	-0.249	0.121
	1978	-0.420	0.158
	1979	0.218	0.112
	1980	0.046	0.149
	1981	-0.071	0.191
	1982	-0.726	0.406
	1983	-0.150	0.389
	1984	0.252	0.414
	1985	-0.285	0.524
	1986	-0.368	0.409
	1987	-0.650	0.411
	1988	-1.116	0.420
	1989	-1.033	0.351
	1990	-0.716	0.290
	1991	0.392	0.146
	1992	0.686	0.135
	1993	0.556	0.175
	1994	1.068	0.154
	1995	1.115	0.188
	1996	1.473	0.180
	1997	1.374	0.234
	1998	1.066	0.332
	1999	0.531	0.498
	2000	0.658	0.390
	2001	1.003	0.244
	2002	0.367	0.367
	2003	-0.217	0.472
	2004	-0.125	0.370
	2005	-0.353	0.372
	2006	-0.289	0.326
	2007	-0.367	0.319
	2008	-0.584	0.358
	2009	-0.769	0.421
	2010	-0.881	0.480
	2011	-0.880	0.495
	2012	-1.057	0.494
	2013	-1.017	0.420
	2014	-1.030	0.391

Table 25. Estimated population size (thousands) for females on July 1 of year. from the author's preferred model, Model A.

Size bin

27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5	147.5	152.5	157.5	162.5	167.5	172.5	177.5	182.5
0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4.58E+03	1.09E+04	1.07E+04	1.01E+04	7.50E+03	4.66E+03	2.56E+03	1.28E+03	6.01E+02	2.67E+02	1.13E+02	4.65E+01	1.85E+01	7.14E+00	2.70E+00	9.96E-01	3.61E-01	1.28E-01	4.49E-02	1.54E-02	5.22E-03	1.74E-03	5.76E-04	1.88E-04	6.07E-05	1.94E-05	6.18E-06	1.95E-06	6.10E-07	1.90E-07	5.99E-08	2.33E-08
4.61E+03	1.09E+04	1.07E+04	1.05E+04	9.04E+03	7.76E+03	6.39E+03	4.73E+03	3.18E+03	1.95E+03	1.07E+03	5.15E+02	2.13E+02	7.70E+01	2.66E+01	8.44E+00	2.08E+00	4.12E-01	9.26E-02	2.71E-02	8.72E-03	2.88E-03	9.46E-04	3.09E-04	9.96E-05	3.19E-05	1.01E-05	3.19E-06	1.00E-06	3.11E-07	9.82E-08	3.82E-08
4.66E+03	1.10E+04	1.08E+04	1.06E+04	9.12E+03	7.96E+03	7.02E+03	6.19E+03	5.64E+03	5.00E+03	3.76E+03	2.37E+03	1.24E+03	5.45E+02	2.23E+02	7.68E+01	1.79E+01	2.60E+00	3.03E-01	4.92E-02	1.20E-02	3.67E-03	1.19E-03	3.88E-04	1.25E-04	4.00E-05	1.27E-05	4.01E-06	1.25E-06	3.90E-07	1.23E-07	4.79E-08
4.74E+03	1.12E+04	1.10E+04	1.07E+04	9.22E+03	8.03E+03	7.09E+03	6.36E+03	6.32E+03	6.65E+03	5.92E+03	4.48E+03	2.93E+03	1.63E+03	8.31E+02	3.40E+02	8.78E+01	1.30E+01	1.38E+00	1.58E-01	2.17E-02	4.58E-03	1.37E-03	4.41E-04	1.42E-04	4.55E-05	1.44E-05	4.55E-06	1.42E-06	4.43E-07	1.40E-07	5.43E-08
4.86E+03	1.15E+04	1.13E+04	1.09E+04	9.38E+03	8.15E+03	7.19E+03	6.48E+03	6.72E+03	7.67E+03	7.27E+03	5.82E+03	4.21E+03	2.61E+03	1.49E+03	6.75E+02	1.89E+02	2.97E+01	3.50E+00	4.32E-01	4.66E-02	6.23E-03	1.54E-03	4.84E-04	1.56E-04	4.98E-05	1.58E-05	4.98E-06	1.56E-06	4.85E-07	1.53E-07	5.95E-08
5.06E+03	1.20E+04	1.17E+04	1.13E+04	9.65E+03	8.35E+03	7.34E+03	6.64E+03	7.06E+03	8.44E+03	8.24E+03	6.78E+03	5.12E+03	3.32E+03	1.97E+03	9.26E+02	2.67E+02	4.28E+01	5.38E+00	7.04E-01	7.19E-02	7.84E-03	1.69E-03	5.18E-04	1.66E-04	5.32E-05	1.69E-05	5.32E-06	1.66E-06	5.17E-07	1.63E-07	6.34E-08
5.36E+03	1.27E+04	1.23E+04	1.18E+04	1.01E+04	8.66E+03	7.58E+03	6.85E+03	7.38E+03	9.05E+03	8.99E+03	7.49E+03	5.78E+03	3.84E+03	2.31E+03	1.10E+03	3.21E+02	5.20E+01	6.70E+00	8.95E-01	8.98E-02	9.01E-03	1.81E-03	5.49E-04	1.76E-04	5.62E-05	1.78E-05	5.62E-06	1.76E-06	5.47E-07	1.72E-07	6.70E-08
5.85E+03	1.38E+04	1.33E+04	1.27E+04	1.07E+04	9.14E+03	7.94E+03	7.15E+03	7.74E+03	9.61E+03	9.62E+03	8.07E+03	6.30E+03	4.23E+03	2.57E+03	1.23E+03	3.61E+02	5.86E+01	7.63E+00	1.03E+00	1.02E-01	9.93E-03	1.93E-03	5.81E-04	1.86E-04	5.95E-05	1.89E-05	5.95E-06	1.86E-06	5.79E-07	1.83E-07	7.09E-08
6.66E+03	1.57E+04	1.50E+04	1.41E+04	1.17E+04	9.90E+03	8.52E+03	7.60E+03	8.20E+03	1.02E+04	1.02E+04	8.60E+03	6.75E+03	4.55E+03	2.78E+03	1.34E+03	3.92E+02	6.36E+01	8.32E+00	1.13E+00	1.12E-01	1.07E-02	2.07E-03	6.22E-04	1.99E-04	6.37E-05	2.02E-05	6.37E-06	1.99E-06	6.20E-07	1.95E-07	7.59E-08
8.12E+03	1.91E+04	1.80E+04	1.65E+04	1.35E+04	1.12E+04	9.47E+03	8.33E+03	8.85E+03	1.09E+04	1.09E+04	9.16E+03	7.19E+03	4.84E+03	2.96E+03	1.42E+03	4.18E+02	6.79E+01	8.90E+00	1.21E+00	1.20E-01	1.17E-02	2.27E-03	6.83E-04	2.19E-04	7.00E-05	2.22E-05	7.00E-06	2.19E-06	6.80E-07	2.15E-07	8.34E-08
1.11E+04	2.60E+04	2.40E+04	2.11E+04	1.68E+04	1.35E+04	1.11E+04	9.56E+03	9.89E+03	1.19E+04	1.18E+04	9.85E+03	7.69E+03	5.17E+03	3.15E+03	1.52E+03	4.44E+02	7.21E+01	9.46E+00	1.28E+00	1.29E-01	1.29E-02	2.58E-03	7.84E-04	2.51E-04	8.03E-05	2.55E-05	8.03E-06	2.51E-06	7.81E-07	2.46E-07	9.57E-08
1.87E+04	4.33E+04	3.86E+04	3.20E+04	2.41E+04	1.83E+04	1.44E+04	1.19E+04	1.17E+04	1.36E+04	1.32E+04	1.08E+04	8.38E+03	5.60E+03	3.40E+03	1.63E+03	4.76E+02	7.71E+01	1.01E+01	1.38E+00	1.41E-01	1.50E-02	3.18E-03	9.74E-04	3.13E-04	1.00E-04	3.17E-05	1.00E-05	3.13E-06	9.72E-07	3.07E-07	1.19E-07
4.10E+04	9.45E+04	8.10E+04	6.22E+04	4.36E+04	3.07E+04	2.24E+04	1.71E+04	1.55E+04	1.66E+04	1.55E+04	1.25E+04	9.48E+03	6.24E+03	3.75E+03	1.79E+03	5.20E+02	8.43E+01	1.10E+01	1.51E+00	1.62E-01	1.96E-02	4.55E-03	1.42E-03	4.56E-04	1.46E-04	4.62E-05	1.46E-05	4.56E-06	1.42E-06	4.47E-07	1.74E-07
9.54E+04	2.19E+05	1.87E+05	1.41E+05	9.60E+04	6.42E+04	4.37E+04	3.09E+04	2.49E+04	2.37E+04	2.06E+04	1.59E+04	1.15E+04	7.38E+03	4.36E+03	2.05E+03	5.94E+02	9.61E+01	1.26E+01	1.77E+00	2.09E-01	3.17E-02	8.33E-03	2.64E-03	8.50E-04	2.72E-04	8.64E-05	2.72E-05	8.51E-06	2.65E-06	8.36E-07	3.24E-07
1.48E+05	3.44E+05	3.11E+05	2.61E+05	1.92E+05	1.35E+05	9.37E+04	6.54E+04	4.93E+04	4.17E+04	3.32E+04	2.39E+04	1.62E+04	9.84E+03	5.60E+03	2.57E+03	7.36E+02	1.19E+02	1.57E+01	2.29E+00	3.17E-01	6.11E-02	1.77E-02	5.68E-03	1.83E-03	5.86E-04	1.86E-04	5.87E-05	1.84E-05	5.71E-06	1.80E-06	7.00E-07
1.48E+05	3.51E+05	3.45E+05	3.34E+05	2.74E+05	2.16E+05	1.68E+05	1.27E+05	9.98E+04	8.32E+04	6.39E+04	4.39E+04	2.78E+04	1.59E+04	8.57E+03	3.80E+03	1.06E+03	1.70E+02	2.20E+01	3.22E+00	4.81E-01	1.02E-01	3.04E-02	9.81E-03	3.16E-03	1.01E-03	3.22E-04	1.01E-04	3.17E-05	9.87E-06	3.12E-06	1.21E-06
1.18E+05	2.85E+05	2.96E+05	3.11E+05	2.80E+05	2.49E+05	2.17E+05	1.84E+05	1.62E+05	1.49E+05	1.20E+05	8.47E+04	5.35E+04	2.98E+04	1.57E+04	6.77E+03	1.85E+03	2.88E+02	3.51E+01	4.76E+00	6.51E-01	1.27E-01	3.68E-02	1.17E-02	3.76E-03	1.20E-03	3.78E-04	1.19E-04	3.72E-05	1.16E-05	3.65E-06	1.42E-06
9.31E+04	2.24E+05	2.34E+05	2.50E+05	2.33E+05	2.21E+05	2.08E+05	1.94E+05	1.97E+05	2.08E+05	1.85E+05	1.39E+05	9.34E+04	5.44E+04	2.95E+04	1.29E+04	3.52E+03	5.46E+02	6.43E+01	8.10E+00	9.37E-01	1.45E-01	3.82E-02	1.20E-02	3.84E-03	1.22E-03	3.86E-04	1.21E-04	3.79E-05	1.18E-05	3.72E-06	1.45E-06
7.78E+04	1.87E+05	1.92E+05	2.01E+05	1.86E+05	1.77E+05	1.70E+05	1.68E+05	1.90E+05	2.31E+05	2.24E+05	1.82E+05	1.32E+05	8.23E+04	4.69E+04	2.12E+04	5.90E+03	9.15E+02	1.08E+02	1.33E+01	1.33E+00	1.46E-01	3.12E-02	9.38E-03	2.95E-03	9.27E-04	2.91E-04	9.11E-05	2.84E-05	8.81E-06	2.78E-06	1.08E-06
7.10E+04	1.69E+05	1.70E+05	1.73E+05	1.56E+05	1.45E+05	1.38E+05	1.37E+05	1.66E+05	2.23E+05	2.31E+05	1.97E+05	1.53E+05	1.01E+05	6.05E+04	2.83E+04	8.08E+03	1.27E+03	1.56E+02	1.97E+01	1.87E+00	1.63E-01	2.78E-02	7.95E-03	2.48E-03	7.76E-04	2.43E-04	7.59E-05	2.36E-05	7.33E-06	2.31E-06	8.97E-07
6.74E+04	1.60E+05	1.60E+05	1.59E+05	1.41E+05	1.28E+05	1.18E+05	1.15E+05	1.45E+05	2.06E+05	2.20E+05	1.93E+05	1.56E+05	1.07E+05	6.59E+04	3.16E+04	9.12E+03	1.44E+03	1.82E+02	2.36E+01	2.19E+00	1.71E-01	2.48E-02	6.79E-03	2.10E-03	6.54E-04	2.04E-04	6.38E-05	1.98E-05	6.15E-06	1.94E-06	7.51E-07
5.65E+04	1.35E+05	1.39E+05	1.44E+05	1.30E+05	1.17E+05	1.08E+05	1.04E+05	1.30E+05	1.88E+05	2.04E+05	1.80E+05	1.49E+05	1.04E+05	6.50E+04	3.15E+04	9.14E+03	1.45E+03	1.86E+02	2.45E+01	2.27E+00	1.70E-01	2.34E-02	6.28E-03	1.94E-03	6.06E-04	1.89E-04	5.90E-05	1.84E-05	5.69E-06	1.79E-06	6.96E-07
4.39E+04	1.06E+05	1.11E+05	1.19E+05	1.10E+05	1.03E+05	9.73E+04	9.52E+04	1.20E+05	1.74E+05	1.89E+05	1.67E+05	1.39E+05	9.77E+04	6.12E+04	2.97E+04	8.64E+03	1.37E+03	1.77E+02	2.35E+01	2.16E+00	1.60E-01	2.16E-02	5.80E-03	1.80E-03	5.62E-04	1.76E-04	5.49E-05	1.71E-05	5.30E-06	1.67E-06	6.48E-07
3.51E+04	8.44E+04	8.79E+04	9.34E+04	8.73E+04	8.37E+04	8.09E+04	8.20E+04	1.08E+05	1.60E+05	1.75E+05	1.55E+05	1.29E+05	9.08E+04	5.69E+04	2.76E+04	8.02E+03	1.27E+03	1.64E+02	2.17E+01	1.99E+00	1.46E-01	1.92E-02	5.15E-03	1.60E-03	5.01E-04	1.57E-04	4.90E-05	1.53E-05	4.74E-06	1.49E-06	5.79E-07
2.30E+04	5.60E+04	6.17E+04	6.99E+04	6.73E+04	6.53E+04	6.36E+04	6.60E+04	9.13E+04	1.42E+05	1.57E+05	1.41E+05	1.18E+05	8.36E+04	5.24E+04	2.55E+04	7.40E+03	1.17E+03	1.52E+02	2.00E+01	1.83E+00	1.31E-01	1.69E-02	4.49E-03	1.39E-03	4.38E-04	1.37E-04	4.30E-05	1.34E-05	4.15E-06	1.31E-06	5.08E-07
2.89E+04	6.77E+04	6.36E+04	5.87E+04	5.18E+04	4.96E+04	4.89E+04	5.18E+04	7.48E+04	1.21E+05	1.36E+05	1.23E+05	1.05E+05	7.48E+04	4.72E+04	2.29E+04	6.66E+03	1.05E+03	1.36E+02	1.79E+01	1.62E+00	1.12E-01	1.34E-02	3.47E-03	1.07E-03	3.37E-04	1.06E-04	3.30E-05	1.03E-05	3.18E-06	1.00E-06	3.88E-07
8.54E+04	1.95E+05	1.62E+05	1.16E+05	7.85E+04	5.59E+04	4.43E+04	4.23E+04	6.10E+04	1.01E+05	1.16E+05	1.06E+05	9.14E+04	6.56E+04	4.15E+04	2.02E+04	5.86E+03	9.21E+02	1.18E+02	1.56E+01	1.40E+00	9.72E-02	1.18E-02	3.05E-03	9.44E-04	2.96E-04	9.25E-05	2.89E-05	8.98E-06	2.78E-06	8.76E-07	3.39E-07
6.35E+04	1.53E+05	1.62E+05	1.71E+05	1.41E+05	1.04E+05	7.39E+04	5.62E+04	6.11E+04	8.93E+04	9.93E+04	9.00E+04	7.78E+04	5.60E+04	3.53E+04	1.70E+04	4.83E+03	7.37E+02	9.21E+01	1.19E+01	1.09E+00	9.08E-02	1.48E-02	4.10E-03	1.24E-03	3.82E-04	1.18E-04	3.65E-05	1.13E-05	3.50E-06	1.10E-06	4.27E-07
2.92E+04	7.36E+04	9.10E+04	1.16E+05	1.18E+05	1.18E+05	1.09E+05	9.36E+04	8.93E+04	1.02E+05	1.00E+05	8.40E+04	6.86E+04	4.77E+04	2.91E+04	1.35E+04	3.64E+03	5.18E+02	6.01E+01	7.31E+00	6.61E-01	5.84E-02	9.93E-03	2.63E-03	7.57E-04	2.23E-04	6.67E-05	2.03E-05	6.23E-06	1.92E-06	6.01E-07	2.33E-07
9.66E+03	2.53E+04	3.57E+04	5.19E+04	6.12E+04	7.23E+04	7.99E+04	8.54E+04	1.01E+05	1.25E+05	1.21E+05	9.76E+04	7.30E+04	4.69E+04	2.69E+04	1.17E+04	2.97E+03	3.97E+02	4.24E+01	4.81E+00	4.16E-01	3.31E-02	4.87E-03	1.20E-03	3.29E-04	9.37E-05	2.75E-05	8.24E-06	2.51E-06	7.69E-07	2.41E-07	9.31E-08
4.43E+03	1.12E+04	1.39E+04	1.89E+04	2.36E+04	3.09E+04	3.85E+04	4.88E+04	7.44E+04	1.13E+05	1.22E+05	1.05E+05	8.14E+04	5.22E+04	2.92E+04	1.22E+04	2.93E+03	3.81E+02	3.81E+01	4.02E+00	3.27E-01	1.91E-02	1.32E-03	2.02E-04	4.64E-05	1.18E-05	3.24E-06	9.32E-07	2.78E-07	8.41E-08	2.62E-08	1.01E-08
5.87E+03	1.37E+04	1.28E+04	1.18E+04	1.12E+04	1.23E+04	1.50E+04	2.13E+04	4.10E+04	7.50E+04	8.83E+04	8.13E+04	6.75E+04	4.57E+04	2.67E+04	1.15E+04	2.91E+03	4.06E+02	4.54E+01	5.40E+00	4.61E-01	2.48E-02	1.06E-03	7.70E-05	1.36E-05	3.19E-06	8.29E-07	2.31E-07	6.77E-08	2.03E-08	6.26E-09	2.35E-09
3.01E+03	7.50E+03	8.90E+03	1.07E+04	9.95E+03	8.84E+03	8.36E+03	1.04E+04	2.21E+04	4.59E+04	5.72E+04	5.51E+04	4.89E+04	3.53E+04	2.19E+04	1.02E+04	2.79E+03	4.21E+02	5.37E+01	7.16E+00	6.36E-01	3.53E-02	1.82E-03	2.39E-04	6.39E-05	1.91E-05	5.84E-06	1.80E-06	5.55E-07	1.71E-07	5.39E-08	2.09E-08
2.11E+04	4.79E+04	3.75E+04	2.35E+04	1.44E+04	1.03E+04	8.59E+03	8.62E+03	1.49E+04	2.96E+04	3.67E+04	3.55E+04	3.25E+04	2.43E+04	1.57E+04	7.56E+03	2.15E+03	3.37E+02	4.62E+01	6.51E+00	5.87E-01	3.28E-02	1.77E-03	2.53E-04	7.11E-05	2.19E-05	6.78E-06	2.11E-06	6.54E-07	2.03E-07	6.37E-08	2.45E-08
2.04E+04	4.86E+04	4.80E+04	4.62E+04	3.54E+04	2.37E+04	1.52E+04	1.10E+04	1.31E+04	2.16E+04	2.54E+04	2.40E+04	2.17E+04	1.62E+04	1.05E+04	5.12E+03	1.48E+03	2.36E+02	3.35E+01	4.86E+00	4.58E-01	3.19E-02	3.82E-03	1.01E-03	3.17E-04	1.01E-04	3.20E-05	1.01E-05	3.14E-06	9.78E-07	3.09E-07	1.20E-07
5.16E+04	1.18E+05	1.00E+05	7.49E+04	5.34E+04	4.06E+04	3.17E+04	2.40E+04	2.03E+04	2.17E+04	2.12E+04	1.83E+04	1.55E+04	1.12E+04	7.14E+03	3.45E+03	9.81E+02	1.53E+02	2.12E+01	3.00E+00	2.89E-01	2.49E-02	4.25E-03	1.22E-03	3.82E-04	1.20E-04	3.77E-05	1.18E-05	3.67E-06	1.14E-06	3.59E-07	1.39E-07
3.97E+04	9.56E+04	1.00E+05	1.05E+05	8.65E+04	6.50E+04	4.79E+04	3.67E+04	3.24E+04	3.28E+04	2.92E+04	2.26E+04	1.66E+04	1.09E+04	6.51E+03	3.06E+03	8.65E+02	1.36E+02	1.87E+01	2.69E+00	2.97E-01	3.87E-02	9.47E-03	2.97E-03	9.54E-04	3.05E-04	9.67E-05	3.04E-05	9.51E-06	2.96E-06	9.33E-07	3.62E-07
3.72E+04	8.86E+04	8.86E+04	8.94E+04	8.12E+04	7.55E+04	6.79E+04	5.72E+04	5.01E+04	4.79E+04	4.12E+04	3.13E+04	2.22E+04	1.38E+04	7.87E+03	3.55E+03	9.84E+02	1.53E+02	1.96E+01	2.69E+00	3.05E-01	4.40E-02	1.14E-02	3.60E-03	1.16E-03	3.71E-04	1.18E-04	3.71E-05	1.16E-05	3.60E-06	1.14E-06	4.41E-07
3.40E+04	8.11E+04	8.16E+04	8.23E+04	7.30E+04	6.59E+04	6.07E+04	5.74E+04	6.06E+04	6.65E+04	6.02E+04	4.59E+04	3.17E+04	1.91E+04	1.07E+04	4.81E+03	1.34E+03	2.08E+02	2.57E+01	3.34E+00	3.61E-01	4.72E-02	1.15E-02	3.60E-03	1.15E-03	3.67E-04	1.16E-04	3.65E-05	1.14E-05	3.53E-06	1.11E-06	4.32E-07
1.29E+04	3.33E+04	4.41E+04	5.89E+04	5.95E+04	5.75E+04	5.42E+04	5.15E+04	5.73E+04	7.03E+04	6.94E+04	5.71E+04	4.24E+04	2.68E+04	1.54E+04	6.96E+03	1.93E+03	3.00E+02	3.60E+01	4.50E+00	4.50E-01	4.93E-02	1.06E-02	3.21E-03	1.02E-03	3.22E-04	1.01E-04	3.17E-05	9.88E-06	3.06E-06	9.65E-07	3.75E-07
5.44E+03	1.38E+04	1.78E+04	2.44E+04	2.95E+04	3.61E+04	4.03E+04	4.29E+04	5.26E+04	6.97E+04	7.13E+04	6.03E+04	4.68E+04	3.09E+04	1.84E+04	8.58E+03	2.42E+03	3.73E+02	4.48E+01	5.55E+00	5.07E-01	4.00E-02	5.97E-03	1.63E-03	5.02E-04	1.56E-04	4.86E-05	1.51E-05	4.69E-06	1.45E-06	4.56E-07	1.77E-07
3.12E+03	7.70E+03	8.86E+03	1.09E+04	1.24E+04	1.50E+04	1.84E+04	2.41E+04	3.86E+04	6.10E+04	6.69E+04	5.86E+04	4.70E+04	3.16E+04	1.90E+04	8.79E+03	2.43E+03	3.63E+02	4.31E+01	5.30E+00	4.60E-01	2.87E-02	2.62E-03	5.74E-04	1.68E-04	5.07E-05	1.55E-05	4.78E-06	1.47E-06	4.54E-07	1.43E-07	5.52E-08
2.36E+03	5.68E+03	6.02E+03	6.61E+03	6.64E+03	7.16E+03	8.19E+03	1.12E+04	2.29E+04	4.43E+04	5.30E+04	4.93E+04	4.20E+04	2.94E+04	1.80E+04	8.38E+03	2.29E+03	3.38E+02	3.98E+01	4.88E+00	4.14E-01	2.34E-02	1.50E-03	2.53E-04	6.96E-05	2.06E-05	6.22E-06	1.90E-06	5.82E-07	1.79E-07	5.59E-08	2.16E-08
2.13E+03	5.07E+03	5.11E+03	5.22E+03	4.80E+03	4.65E+03	4.80E+03	6.38E+03	1.46E+04	3.11E+04	3.84E+04	3.64E+04	3.23E+04	2.33E+04	1.45E+04	6.71E+03	1.79E+03	2.53E+02	2.95E+01	3.63E+00	3.05E-01	1.65E-02	8.49E-04	1.07E-04	2.67E-05	7.55E-06	2.22E-06	6.64E-07	2.01E-07	6.15E-08	1.92E-08	7.38E-09
2.40E+03	5.66E+03	5.42E+03	5.11E+03	4.38E+03	3.90E+03	3.71E+03	4.58E+03	1.04E+04	2.26E+04	2.80E+04	2.65E+04	2.39E+04	1.74E+04	1.08E+04	5.01E+03	1.33E+03	1.86E+02	2.23E+01	2.84E+00	2.41E-01	1.31E-02	7.28E-04	1.05E-04	2.79E-05	8.14E-06	2.43E-06	7.38E-07	2.26E-07	6.92E-08	2.16E-08	8.34E-09
3.19E+03	7.47E+03	6.92E+03	6.16E+03	4.96E+03	4.08E+03	3.56E+03	3.93E+03	8.05E+03	1.69E+04	2.07E+04	1.95E+04	1.75E+04	1.27E+04	7.86E+03	3.60E+03	9.35E+02	1.28E+02	1.52E+01	1.91E+00	1.61E-01	9.10E-03	6.39E-04	1.20E-04	3.39E-05	1.01E-05	3.07E-06	9.40E-07	2.89E-07	8.88E-08	2.78E-08	1.07E-08
3.54E+03	8.34E+03	8.01E+03	7.51E+03	6.15E+03	4.97E+03	4.14E+03	4.03E+03	6.80E+03	1.31E+04	1.57E+04	1.46E+04	1.30E+04	9.36E+03	5.75E+03	2.62E+03	6.79E+02	9.28E+01	1.10E+01	1.39E+00	1.18E-01	7.43E-03	7.49E-04	1.79E-04	5.39E-05	1.66E-05	5.13E-06	1.59E-06	4.91E-07	1.52E-07	4.77E-08	1.84E-08
8.72E+03	2.00E+04	1.69E+04	1.27E+04	8.97E+03	6.69E+03	5.32E+03	4.75E+03	6.51E+03	1.10E+04	1.26E+04	1.15E+04	1.00E+04	7.15E+03	4.37E+03	2.00E+03	5.22E+02	7.26E+01	8.76E+00	1.12E+00	9.85E-02	7.05E-03	9.47E-04	2.56E-04	7.98E-05	2.51E-05	7.86E-06	2.46E-06	7.63E-07	2.36E-07	7.44E-08	2.88E-08
3.53E+03	9.02E+03	1.16E+04	1.48E+04	1.33E+04	1.05E+04	7.94E+03	6.38E+03	7.15E+03	1.03E+04	1.10E+04	9.60E+03	8.04E+03	5.62E+03	3.41E+03	1.56E+03	4.14E+02	5.91E+01	7.28E+00	9.53E-01	9.09E-02	8.71E-03	1.72E-03	5.18E-04	1.66E-04	5.29E-05	1.67E-05	5.26E-06	1.64E-06	5.09E-07	1.60E-07	6.20E-08
1.08E+04	2.46E+04	2.04E+04	1.50E+04	1.17E+04	1.09E+04	1.03E+04	9.25E+03	9.42E+03	1.13E+04	1.10E+04	9.08E+03	7.21E+03	4.88E+03	2.93E+03	1.34E+03	3.61E+02	5.31E+01	6.58E+00	8.61E-01	8.33E-02	8.13E-03	1.62E-03	4.92E-04	1.58E-04	5.03E-05	1.59E-05	5.00E-06	1.56E-06	4.83E-07	1.52E-07	5.87E-08
6.51E+03	1.60E+04	1.80E+04	2.02E+04	1.71E+04	1.29E+04	9.91E+03	8.69E+03	9.97E+03	1.28E+04	1.26E+04	1.02E+04	7.70E+03	5.00E+03	2.92E+03	1.33E+03	3.64E+02	5.50E+01	6.87E+00	9.09E-01	9.39E-02	1.10E-02	2.53E-03	7.90E-04	2.55E-04	8.18E-05	2.60E-05	8.19E-06	2.56E-06	7.95E-07	2.50E-07	9.71E-08
2.14E+04	4.89E+04	4.02E+04	2.87E+04	2.05E+04	1.66E+04	1.42E+04	1.19E+04	1.15E+04	1.33E+04	1.30E+04	1.08E+04	8.44E+03	5.60E+03	3.32E+03	1.53E+03	4.27E+02	6.58E+01	8.15E+00	1.06E+00	1.08E-01	1.20E-02	2.66E-03	8.25E-04	2.66E-04	8.53E-05	2.71E-05	8.54E-06	2.67E-06	8.28E-07	2.61E-07	1.01E-07
8.34E+03	2.14E+04	2.80E+04	3.59E+04	3.19E+04	2.44E+04	1.80E+04	1.44E+04	1.43E+04	1.64E+04	1.55E+04	1.23E+04	9.24E+03	6.03E+03	3.60E+03	1.70E+03	4.86E+02	7.74E+01	1.00E+01	1.36E+00	1.48E-01	1.91E-02	4.63E-03	1.46E-03	4.73E-04	1.52E-04	4.83E-05	1.52E-05	4.75E-06	1.48E-06	4.65E-07	1.80E-07
1.42E+04	3.29E+04	2.94E+04	2.54E+04	2.32E+04	2.42E+04	2.40E+04	2.13E+04	1.97E+04	2.04E+04	1.85E+04	1.47E+04	1.10E+04	7.10E+03	4.19E+03	1.96E+03	5.60E+02	8.93E+01	1.15E+01	1.55E+00	1.63E-01	1.91E-02	4.36E-03	1.36E-03	4.40E-04	1.41E-04	4.49E-05	1.42E-05	4.42E-06	1.37E-06	4.33E-07	1.68E-07
2.35E+04	5.46E+04	4.87E+04	4.04E+04	3.00E+04	2.25E+04	1.85E+04	1.78E+04	2.10E+04	2.56E+04	2.44E+04	1.92E+04	1.38E+04	8.69E+03	5.06E+03	2.36E+03	6.79E+02	1.09E+02	1.40E+01	1.88E+00	1.96E-01	2.23E-02	4.98E-03	1.55E-03	5.02E-04	1.61E-04	5.14E-05	1.62E-05	5.07E-06	1.58E-06	4.97E-07	1.93E-07
6.69E+03	1.80E+04	2.66E+04	3.78E+04	3.63E+04	3.10E+04	2.51E+04	2.05E+04	2.03E+04	2.48E+04	2.51E+04	2.14E+04	1.67E+04	1.10E+04	6.55E+03	3.07E+03	8.79E+02	1.41E+02	1.78E+01	2.37E+00	2.48E-01	2.90E-02	6.63E-03	2.08E-03	6.73E-04	2.16E-04	6.90E-05	2.18E-05	6.82E-06	2.12E-06	6.69E-07	2.60E-07
5.43E+03	1.30E+04	1.36E+04	1.55E+04	1.83E+04	2.30E+04	2.54E+04	2.48E+04	2.59E+04	2.97E+04	2.82E+04	2.29E+04	1.76E+04	1.18E+04	7.26E+03	3.52E+03	1.04E+03	1.69E+02	2.20E+01	2.96E+00	2.95E-01	2.85E-02	5.57E-03	1.69E-03	5.46E-04	1.75E-04	5.58E-05	1.76E-05	5.50E-06	1.71E-06	5.40E-07	2.10E-07
4.06E+03	9.79E+03	1.04E+04	1.13E+04	1.07E+04	1.07E+04	1.18E+04	1.48E+04	2.19E+04	3.11E+04	3.21E+04	2.68E+04	2.04E+04	1.34E+04	7.99E+03	3.81E+03	1.11E+03	1.80E+02	2.36E+01	3.18E+00	3.08E-01	2.66E-02	4.57E-03	1.35E-03	4.34E-04	1.39E-04	4.42E-05	1.39E-05	4.35E-06	1.35E-06	4.26E-07	1.66E-07
4.67E+03	1.10E+04	1.05E+04	9.95E+03	8.75E+03	8.17E+03	7.91E+03	8.57E+03	1.36E+04	2.36E+04	2.74E+04	2.52E+04	2.11E+04	1.46E+04	9.05E+03	4.36E+03	1.27E+03	2.06E+02	2.64E+01	3.48E+00	3.26E-01	2.54E-02	3.76E-03	1.07E-03	3.42E-04	1.09E-04	3.47E-05	1.09E-05	3.41E-06	1.06E-06	3.34E-07	1.30E-07
2.72E+04	6.17E+04	4.87E+04	3.10E+04	1.84E+04	1.16E+04	8.38E+03	7.54E+03	1.10E+04	1.89E+04	2.20E+04	2.04E+04	1.79E+04	1.31E+04	8.52E+03	4.28E+03	1.29E+03	2.13E+02	2.84E+01	3.86E+00	3.62E-01	2.62E-02	3.40E-03	9.27E-04	2.95E-04	9.43E-05	2.99E-05	9.39E-06	2.93E-06	9.10E-07	2.87E-07	1.11E-07
3.24E+04	7.62E+04	7.21E+04	6.51E+04	4.84E+04	3.19E+04	2.01E+04	1.33E+04	1.25E+04	1.72E+04	1.88E+04	1.71E+04	1.49E+04	1.09E+04	7.12E+03	3.60E+03	1.09E+03	1.81E+02	2.50E+01	3.54E+00	3.51E-01	3.19E-02	5.77E-03	1.71E-03	5.49E-04	1.75E-04	5.55E-05	1.75E-05	5.46E-06	1.70E-06	5.35E-07	2.08E-07
1.92E+04	4.73E+04	5.36E+04	6.18E+04	5.68E+04	4.94E+04	4.08E+04	3.14E+04	2.54E+04	2.41E+04	2.13E+04	1.70E+04	1.36E+04	9.49E+03	6.04E+03	3.02E+03	9.13E+02	1.52E+02	2.13E+01	3.08E+00	3.28E-01	3.72E-02	8.27E-03	2.57E-03	8.29E-04	2.66E-04	8.46E-05	2.67E-05	8.35E-06	2.60E-06	8.20E-07	3.19E-07
4.00E+03	1.14E+04	1.95E+04	3.13E+04	3.61E+04	3.99E+04	4.06E+04	3.87E+04	3.83E+04	3.92E+04	3.39E+04	2.51E+04	1.72E+04	1.06E+04	6.14E+03	2.90E+03	8.47E+02	1.39E+02	1.88E+01	2.67E+00	2.89E-01	3.51E-02	8.21E-03	2.57E-03	8.33E-04	2.67E-04	8.51E-05	2.68E-05	8.40E-06	2.61E-06	8.25E-07	3.21E-07
8.87E+03	2.04E+04	1.76E+04	1.48E+04	1.51E+04	1.91E+04	2.32E+04	2.72E+04	3.48E+04	4.43E+04	4.35E+04	3.50E+04	2.51E+04	1.55E+04	8.76E+03	3.97E+03	1.12E+03	1.77E+02	2.20E+01	2.85E+00	2.86E-01	3.02E-02	6.38E-03	1.97E-03	6.35E-04	2.04E-04	6.48E-05	2.04E-05	6.38E-06	1.99E-06	6.26E-07	2.43E-07
9.50E+03	2.25E+04	2.18E+04	2.05E+04	1.62E+04	1.26E+04	1.11E+04	1.31E+04	2.20E+04	3.63E+04	4.08E+04	3.64E+04	2.90E+04	1.94E+04	1.17E+04	5.52E+03	1.59E+03	2.54E+02	3.14E+01	4.00E+00	3.80E-01	3.29E-02	5.71E-03	1.69E-03	5.43E-04	1.74E-04	5.53E-05	1.74E-05	5.44E-06	1.69E-06	5.34E-07	2.07E-07
6.18E+03	1.51E+04	1.66E+04	1.87E+04	1.72E+04	1.53E+04	1.32E+04	1.20E+04	1.61E+04	2.73E+04	3.20E+04	2.99E+04	2.60E+04	1.87E+04	1.19E+04	5.88E+03	1.74E+03	2.83E+02	3.66E+01	4.85E+00	4.53E-01	3.45E-02	4.91E-03	1.37E-03	4.37E-04	1.39E-04	4.42E-05	1.39E-05	4.33E-06	1.35E-06	4.24E-07	1.65E-07

Table 26. Estimated population size (thousands) for males on July 1 of year. from the author's preferred mode, Model A.

year	Size bin																															
	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5	67.5	72.5	77.5	82.5	87.5	92.5	97.5	102.5	107.5	112.5	117.5	122.5	127.5	132.5	137.5	142.5	147.5	152.5	157.5	162.5	167.5	172.5	177.5	182.5
1949	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1950	4.58E+03	1.07E+04	1.02E+04	9.11E+03	7.01E+03	4.92E+03	3.05E+03	1.74E+03	9.51E+02	4.99E+02	2.53E+02	1.25E+02	6.05E+01	2.88E+01	1.35E+01	6.23E+00	2.85E+00	1.29E+00	5.77E-01	2.56E-01	1.13E-01	4.95E-02	2.16E-02	9.34E-03	4.01E-03	1.70E-03	7.12E-04	2.92E-04	1.17E-04	4.58E-05	1.81E-05	9.06E-06
1951	4.61E+03	1.07E+04	1.03E+04	9.30E+03	7.76E+03	6.55E+03	5.67E+03	4.66E+03	3.67E+03	2.78E+03	1.99E+03	1.35E+03	8.83E+02	5.64E+02	3.51E+02	2.13E+02	1.27E+02	7.39E+01	4.21E+01	2.34E+01	1.27E+01	6.75E+00	3.58E+00	1.89E+00	9.78E-01	4.79E-01	2.16E-01	8.59E-02	2.83E-02	6.84E-03	9.99E-04	1.58E-05
1952	4.66E+03	1.08E+04	1.04E+04	9.38E+03	7.82E+03	6.61E+03	5.81E+03	5.01E+03	4.33E+03	3.83E+03	3.42E+03	2.99E+03	2.55E+03	2.13E+03	1.73E+03	1.36E+03	1.02E+03	7.51E+02	5.35E+02	3.68E+02	2.45E+02	1.60E+02	1.04E+02	6.68E+01	4.15E+01	2.42E+01	1.29E+01	6.01E+00	2.31E+00	6.53E-01	1.09E-01	3.74E-05
1953	4.74E+03	1.10E+04	1.05E+04	9.50E+03	7.91E+03	6.68E+03	5.87E+03	5.07E+03	4.40E+03	3.92E+03	3.57E+03	3.25E+03	2.98E+03	2.77E+03	2.57E+03	2.32E+03	2.05E+03	1.82E+03	1.57E+03	1.32E+03	1.05E+03	8.20E+02	6.29E+02	4.77E+02	3.46E+02	2.34E+02	1.43E+02	7.65E+01	3.37E+01	1.10E+01	2.10E+00	1.92E-03
1954	4.86E+03	1.13E+04	1.08E+04	9.70E+03	8.06E+03	6.80E+03	5.96E+03	5.15E+03	4.47E+03	4.00E+03	3.67E+03	3.38E+03	3.16E+03	3.04E+03	2.92E+03	2.73E+03	2.50E+03	2.37E+03	2.24E+03	2.07E+03	1.81E+03	1.52E+03	1.26E+03	1.04E+03	8.26E+02	6.12E+02	4.12E+02	2.42E+02	1.18E+02	4.27E+01	9.06E+00	3.71E-02
1955	5.06E+03	1.18E+04	1.12E+04	1.00E+04	8.29E+03	6.98E+03	6.10E+03	5.26E+03	4.57E+03	4.10E+03	3.77E+03	3.50E+03	3.31E+03	3.26E+03	3.19E+03	3.03E+03	2.82E+03	2.77E+03	2.71E+03	2.61E+03	2.36E+03	2.04E+03	1.73E+03	1.46E+03	1.19E+03	9.06E+02	6.26E+02	3.78E+02	1.90E+02	7.11E+01	1.55E+01	1.60E-01
1956	5.36E+03	1.25E+04	1.18E+04	1.05E+04	8.66E+03	7.25E+03	6.32E+03	5.44E+03	4.71E+03	4.23E+03	3.90E+03	3.63E+03	3.46E+03	3.45E+03	3.42E+03	3.28E+03	3.08E+03	3.07E+03	3.07E+03	3.02E+03	2.77E+03	2.42E+03	2.07E+03	1.77E+03	1.46E+03	1.12E+03	7.82E+02	4.77E+02	2.41E+02	9.16E+01	2.02E+01	2.76E-01
1957	5.85E+03	1.36E+04	1.28E+04	1.13E+04	9.23E+03	7.68E+03	6.66E+03	5.70E+03	4.93E+03	4.41E+03	4.06E+03	3.78E+03	3.62E+03	3.63E+03	3.63E+03	3.50E+03	3.30E+03	3.33E+03	3.37E+03	3.35E+03	3.09E+03	2.72E+03	2.33E+03	2.01E+03	1.66E+03	1.28E+03	8.97E+02	5.50E+02	2.80E+02	1.07E+02	2.36E+01	3.60E-01
1958	6.66E+03	1.55E+04	1.44E+04	1.26E+04	1.02E+04	8.37E+03	7.18E+03	6.11E+03	5.25E+03	4.67E+03	4.29E+03	3.99E+03	3.82E+03	3.84E+03	3.85E+03	3.72E+03	3.51E+03	3.56E+03	3.62E+03	3.62E+03	3.35E+03	2.95E+03	2.54E+03	2.19E+03	1.82E+03	1.40E+03	9.86E+02	6.06E+02	3.09E+02	1.18E+02	2.62E+01	4.21E-01
1959	8.12E+03	1.88E+04	1.73E+04	1.48E+04	1.17E+04	9.53E+03	8.06E+03	6.77E+03	5.76E+03	5.09E+03	4.64E+03	4.29E+03	4.09E+03	4.10E+03	4.11E+03	3.97E+03	3.74E+03	3.80E+03	3.87E+03	3.87E+03	3.59E+03	3.17E+03	2.72E+03	2.35E+03	1.95E+03	1.51E+03	1.06E+03	6.52E+02	3.33E+02	1.27E+02	2.83E+01	4.68E-01
1960	1.11E+04	2.56E+04	2.31E+04	1.91E+04	1.47E+04	1.16E+04	9.61E+03	7.92E+03	6.64E+03	5.79E+03	5.21E+03	4.77E+03	4.50E+03	4.48E+03	4.46E+03	4.29E+03	4.03E+03	4.08E+03	4.15E+03	4.15E+03	3.84E+03	3.38E+03	2.90E+03	2.51E+03	2.08E+03	1.61E+03	1.13E+03	6.96E+02	3.55E+02	1.36E+02	3.02E+01	5.06E-01
1961	1.87E+04	4.29E+04	3.75E+04	2.92E+04	2.14E+04	1.62E+04	1.28E+04	1.02E+04	8.29E+03	7.05E+03	6.21E+03	5.58E+03	5.18E+03	5.07E+03	4.99E+03	4.76E+03	4.44E+03	4.46E+03	4.51E+03	4.49E+03	4.15E+03	3.64E+03	3.12E+03	2.69E+03	2.23E+03	1.72E+03	1.21E+03	7.43E+02	3.79E+02	1.45E+02	3.22E+01	5.40E-01
1962	4.10E+04	9.37E+04	7.91E+04	5.77E+04	3.96E+04	2.79E+04	2.06E+04	1.54E+04	1.20E+04	9.77E+03	8.28E+03	7.19E+03	6.47E+03	6.16E+03	5.92E+03	5.55E+03	5.11E+03	5.07E+03	5.06E+03	4.99E+03	4.58E+03	4.00E+03	3.42E+03	2.94E+03	2.43E+03	1.87E+03	1.31E+03	8.04E+02	4.10E+02	1.57E+02	3.47E+01	5.76E-01
1963	9.54E+04	2.18E+05	1.83E+05	1.31E+05	8.83E+04	6.02E+04	4.20E+04	2.98E+04	2.19E+04	1.68E+04	1.34E+04	1.10E+04	9.41E+03	8.51E+03	7.84E+03	7.13E+03	6.41E+03	6.18E+03	6.03E+03	5.84E+03	5.29E+03	4.58E+03	3.89E+03	3.32E+03	2.73E+03	2.10E+03	1.47E+03	8.95E+02	4.55E+02	1.73E+02	3.83E+01	6.20E-01
1964	1.48E+05	3.40E+05	3.01E+05	2.39E+05	1.74E+05	1.26E+05	9.11E+04	6.52E+04	4.75E+04	3.57E+04	2.74E+04	2.14E+04	1.73E+04	1.46E+04	1.27E+04	1.10E+04	9.46E+03	8.69E+03	8.12E+03	7.58E+03	6.71E+03	5.71E+03	4.78E+03	4.04E+03	3.29E+03	2.50E+03	1.73E+03	1.05E+03	5.31E+02	2.01E+02	4.43E+01	6.85E-01
1965	1.48E+05	3.44E+05	3.30E+05	2.98E+05	2.42E+05	1.93E+05	1.54E+05	1.20E+05	9.36E+04	7.36E+04	5.81E+04	4.59E+04	3.67E+04	3.03E+04	2.53E+04	2.11E+04	1.75E+04	1.52E+04	1.35E+04	1.19E+04	1.01E+04	8.39E+03	6.86E+03	5.67E+03	4.53E+03	3.39E+03	2.31E+03	1.39E+03	6.91E+02	2.58E+02	5.64E+01	7.92E-01
1966	1.18E+05	2.78E+05	2.81E+05	2.73E+05	2.38E+05	2.07E+05	1.84E+05	1.57E+05	1.32E+05	1.13E+05	9.58E+04	8.09E+04	6.84E+04	5.88E+04	5.05E+04	4.27E+04	3.56E+04	3.05E+04	2.63E+04	2.25E+04	1.85E+04	1.49E+04	1.19E+04	9.53E+03	7.42E+03	5.42E+03	3.61E+03	2.12E+03	1.03E+03	3.78E+02	8.08E+01	9.25E-01
1967	9.31E+04	2.19E+05	2.22E+05	2.18E+05	1.95E+05	1.76E+05	1.66E+05	1.50E+05	1.34E+05	1.22E+05	1.13E+05	1.03E+05	9.32E+04	8.59E+04	7.84E+04	6.98E+04	6.09E+04	5.45E+04	4.85E+04	4.25E+04	3.55E+04	2.89E+04	2.32E+04	1.87E+04	1.45E+04	1.06E+04	7.00E+03	4.07E+03	1.97E+03	7.13E+02	1.51E+02	1.36E+00
1968	7.78E+04	1.83E+05	1.82E+05	1.76E+05	1.55E+05	1.40E+05	1.33E+05	1.22E+05	1.13E+05	1.06E+05	1.03E+05	9.86E+04	9.50E+04	9.36E+04	9.11E+04	8.57E+04	7.85E+04	7.44E+04	6.95E+04	6.33E+04	5.42E+04	4.48E+04	3.66E+04	2.99E+04	2.36E+04	1.74E+04	1.16E+04	6.80E+03	3.30E+03	1.20E+03	2.53E+02	2.05E+00
1969	7.10E+04	1.66E+05	1.62E+05	1.52E+05	1.31E+05	1.16E+05	1.08E+05	9.90E+04	9.09E+04	8.65E+04	8.48E+04	8.34E+04	8.33E+04	8.64E+04	8.83E+04	8.63E+04	8.18E+04	8.15E+04	8.01E+04	7.63E+04	6.77E+04	5.74E+04	4.79E+04	4.02E+04	3.25E+04	2.45E+04	1.68E+04	1.00E+04	4.97E+03	1.84E+03	3.96E+02	3.66E+00
1970	6.74E+04	1.57E+05	1.53E+05	1.41E+05	1.20E+05	1.04E+05	9.48E+04	8.51E+04	7.71E+04	7.27E+04	7.10E+04	7.02E+04	7.13E+04	7.62E+04	8.00E+04	7.97E+04	7.67E+04	7.88E+04	7.98E+04	7.83E+04	7.06E+04	6.06E+04	5.10E+04	4.33E+04	3.55E+04	2.72E+04	1.89E+04	1.15E+04	5.78E+03	2.17E+03	4.74E+02	5.59E+00
1971	5.65E+04	1.33E+05	1.32E+05	1.27E+05	1.10E+05	9.65E+04	8.76E+04	7.81E+04	7.00E+04	6.53E+04	6.31E+04	6.22E+04	6.33E+04	6.83E+04	7.24E+04	7.27E+04	7.02E+04	7.32E+04	7.55E+04	7.51E+04	6.82E+04	5.88E+04	4.97E+04	4.25E+04	3.51E+04	2.71E+04	1.90E+04	1.16E+04	5.92E+03	2.25E+03	4.96E+02	7.06E+00
1972	4.39E+04	1.03E+05	1.05E+05	1.03E+05	9.22E+04	8.31E+04	7.80E+04	7.11E+04	6.45E+04	6.05E+04	5.86E+04	5.76E+04	5.85E+04	6.32E+04	6.71E+04	6.73E+04	6.50E+04	6.81E+04	7.05E+04	7.06E+04	6.43E+04	5.55E+04	4.69E+04	4.02E+04	3.32E+04	2.57E+04	1.81E+04	1.12E+04	5.70E+03	2.18E+03	4.83E+02	7.74E+00
1973	3.51E+04	8.26E+04	8.33E+04	8.14E+04	7.27E+04	6.63E+04	6.35E+04	5.91E+04	5.48E+04	5.27E+04	5.22E+04	5.24E+04	5.39E+04	5.88E+04	6.28E+04	6.31E+04	6.09E+04	6.39E+04	6.63E+04	6.64E+04	6.05E+04	5.22E+04	4.41E+04	3.78E+04	3.12E+04	2.42E+04	1.70E+04	1.05E+04	5.37E+03	2.06E+03	4.57E+02	7.75E+00
1974	2.30E+04	5.45E+04	5.81E+04	6.04E+04	5.58E+04	5.17E+04	4.98E+04	4.66E+04	4.35E+04	4.24E+04	4.28E+04	4.38E+04	4.61E+04	5.13E+04	5.57E+04	5.67E+04	5.52E+04	5.85E+04	6.11E+04	6.16E+04	5.63E+04	4.87E+04	4.12E+04	3.54E+04	2.93E+04	2.27E+04	1.60E+04	9.85E+03	5.04E+03	1.93E+03	4.30E+02	7.44E+00
1975	2.89E+04	6.67E+04	6.12E+04	5.22E+04	4.32E+04	3.85E+04	3.74E+04	3.56E+04	3.38E+04	3.33E+04	3.39E+04	3.50E+04	3.74E+04	4.24E+04	4.68E+04	4.80E+04	4.71E+04	5.05E+04	5.32E+04	5.39E+04	4.94E+04	4.27E+04	3.62E+04	3.11E+04	2.58E+04	2.00E+04	1.41E+04	8.69E+03	4.45E+03	1.71E+03	3.80E+02	6.62E+00
1976	8.54E+04	1.94E+05	1.59E+05	1.09E+05	7.14E+04	4.93E+04	3.77E+04	3.08E+04	2.70E+04	2.59E+04	2.66E+04	2.81E+04	3.06E+04	3.55E+04	3.97E+04	4.11E+04	4.05E+04	4.36E+04	4.61E+04	4.67E+04	4.26E+04	3.66E+04	3.09E+04	2.65E+04	2.19E+04	1.70E+04	1.20E+04	7.40E+03	3.80E+03	1.46E+03	3.25E+02	5.74E+00
1977	6.35E+04	1.50E+05	1.54E+05	1.51E+05	1.26E+05	9.86E+04	7.31E+04	5.32E+04	3.98E+04	3.18E+04	2.76E+04	2.59E+04	2.65E+04	3.00E+04	3.33E+04	3.43E+04	3.37E+04	3.62E+04	3.77E+04	3.73E+04	3.29E+04	2.74E+04	2.25E+04	1.89E+04	1.55E+04	1.18E+04	8.30E+03	5.09E+03	2.59E+03	9.90E+02	2.19E+02	3.77E+00
1978	2.92E+04	7.09E+04	8.43E+04	9.84E+04	9.68E+04	9.30E+04	9.02E+04	8.09E+04	6.94E+04	5.86E+04	4.90E+04	4.14E+04	3.66E+04	3.53E+04	3.48E+04	3.30E+04	3.03E+04	3.02E+04	2.92E+04	2.65E+04	2.15E+04	1.66E+04	1.29E+04	1.04E+04	8.25E+03	6.19E+03	4.25E+03	2.56E+03	1.28E+03	4.77E+02	1.03E+02	1.51E+00
1979	9.66E+03	2.41E+04	3.25E+04	4.27E+04	4.69E+04	5.12E+04	5.71E+04	5.83E+04	5.73E+04	5.67E+04	5.63E+04	5.46E+04	5.24E+04	5.10E+04	4.87E+04	4.41E+04	3.83E+04	3.44E+04	2.98E+04	2.43E+04	1.81E+04	1.32E+04	9.72E+03	7.46E+03	5.64E+03	4.04E+03	2.65E+03	1.52E+03	7.28E+02	2.60E+02	5.40E+01	5.76E-01
1980	4.43E+03	1.08E+04	1.28E+04	1.55E+04	1.74E+04	2.04E+04	2.49E+04	2.79E+04	3.01E+04	3.31E+04	3.67E+04	3.95E+04	4.20E+04	4.53E+04	4.70E+04	4.54E+04	4.14E+04	3.78E+04	3.25E+04	2.60E+04	1.97E+04	1.49E+04	1.14E+04	8.73E+03	6.37E+03	4.27E+03	2.55E+03	1.31E+03	5.45E+02	1.64E+02	2.87E+01	8.78E-02
1981	5.87E+03	1.35E+04	1.23E+04	1.05E+04	8.97E+03	8.69E+03	9.55E+03	1.05E+04	1.17E+04	1.35E+04	1.59E+04	1.81E+04	2.04E+04	2.31E+04	2.51E+04	2.55E+04	2.44E+04	2.33E+04	2.10E+04	1.80E+04	1.51E+04	1.26E+04	1.07E+04	8.96E+03	7.06E+03	5.06E+03	3.20E+03	1.71E+03	7.37E+02	2.27E+02	4.00E+01	3.77E-02
1982	3.01E+03	7.25E+03	8.31E+03	9.25E+03	8.53E+03	7.48E+03	6.61E+03	5.94E+03	5.61E+03	5.80E+03	6.43E+03	7.27E+03	8.36E+03	9.94E+03	1.14E+04	1.22E+04	1.23E+04	1.28E+04	1.28E+04	1.24E+04	1.15E+04	1.04E+04	9.41E+03	8.50E+03	7.28E+03	5.73E+03	4.04E+03	2.47E+03	1.24E+03	4.62E+02	1.01E+02	4.87E-01
1983	2.11E+04	4.77E+04	3.71E+04	2.26E+04	1.31E+04	8.50E+03	6.76E+03	5.78E+03	5.10E+03	4.67E+03	4.41E+03	4.31E+03	4.42E+03	4.88E+03	5.41E+03	5.71E+03	5.80E+03	6.27E+03	6.67E+03	6.95E+03	6.79E+03	6.43E+03	6.00E+03	5.62E+03	4.99E+03	4.08E+03	2.99E+03	1.91E+03	1.00E+03	3.94E+02	9.03E+01	1.62E+00
1984	2.04E+04	4.77E+04	4.60E+04	4.15E+04	3.26E+04	2.37E+04	1.59E+04	1.04E+04	7.09E+03	5.28E+03	4.41E+03	3.96E+03	3.73E+03	3.73E+03	3.78E+03	3.71E+03	3.57E+03	3.67E+03	3.80E+03	3.93E+03	3.84E+03	3.63E+03	3.39E+03	3.18E+03	2.84E+03	2.35E+03	1.75E+03	1.13E+03	6.07E+02	2.44E+02	5.68E+01	1.62E+00
1985	5.16E+04	1.18E+05	9.79E+04	6.95E+04	4.76E+04	3.49E+04	2.79E+04	2.22E+04	1.75E+04	1.36E+04	1.03E+04	7.65E+03	5.78E+03	4.60E+03	3.88E+03	3.38E+03	3.01E+03	2.87E+03	2.77E+03	2.67E+03	2.46E+03	2.21E+03	1.97E+03	1.78E+03	1.54E+03	1.24E+03	9.00E+02	5.72E+02	3.02E+02	1.19E+02	2.75E+01	8.63E-01
1986	3.97E+04	9.34E+04	9.52E+04	9.26E+04	7.74E+04	6.08E+04	4.58E+04	3.40E+04	2.59E+04	2.07E+04	1.74E+04	1.48E+04	1.26E+04	1.09E+04	9.25E+03	7.72E+03	6.32E+03	5.34E+03	4.59E+03	4.02E+03	3.44E+03	2.92E+03	2.50E+03	2.21E+03	1.87E+03	1.47E+03	1.06E+03	6.64E+02	3.46E+02	1.36E+02	3.09E+01	8.51E-01
1987	3.72E+04	8.69E+04	8.45E+04	7.86E+04	6.81E+04	6.07E+04	5.64E+04	4.96E+04	4.21E+04	3.53E+04	2.90E+04	2.37E+04	1.96E+04	1.68E+04	1.46E+04	1.28E+04	1.11E+04	9.92E+03	8.81E+03	7.74E+03	6.54E+03	5.41E+03	4.46E+03	3.76E+03	3.02E+03	2.26E+03	1.53E+03	9.17E+02	4.57E+02	1.71E+02	3.76E+01	8.32E-01
1988	3.40E+04	7.95E+04	7.78E+04	7.25E+04	6.21E+04	5.39E+04	4.87E+04	4.34E+04	3.91E+04	3.64E+04	3.45E+04	3.22E+04	2.95E+04	2.71E+04	2.45E+04	2.15E+04	1.85E+04	1.62E+04	1.43E+04	1.24E+04	1.05E+04	8.63E+03	7.13E+03	6.03E+03	4.87E+03	3.64E+03	2.48E+03	1.48E+03	7.30E+02	2.71E+02	5.87E+01	8.17E-01
1989	1.29E+04	3.18E+04	4.06E+04	5.00E+04	4.94E+04	4.65E+04	4.38E+04	3.95E+04	3.55E+04	3.27E+04	3.08E+04	2.92E+04	2.80E+04	2.76E+04	2.72E+04	2.59E+04	2.41E+04	2.29E+04	2.14E+04	1.93E+04	1.66E+04	1.38E+04	1.14E+04	9.55E+03	7.61E+03	5.62E+03	3.76E+03	2.20E+03	1.07E+03	3.91E+02	8.34E+01	1.02E+00
1990	5.44E+03	1.33E+04	1.63E+04	2.02E+04	2.22E+04	2.50E+04	2.88E+04	2.97E+04	2.91E+04	2.84E+04	2.79E+04	2.72E+04	2.64E+04	2.65E+04	2.65E+04	2.55E+04	2.39E+04	2.33E+04	2.23E+04	2.06E+04	1.79E+04	1.50E+04	1.25E+04	1.08E+04	8.77E+03	6.58E+03	4.47E+03	2.65E+03	1.29E+03	4.71E+02	9.99E+01	9.68E-01
1991	3.12E+03	7.47E+03	8.27E+03	9.19E+03	9.48E+03	1.03E+04	1.20E+04	1.33E+04	1.46E+04	1.64E+04	1.87E+04	2.03E+04	2.15E+04	2.28E+04	2.38E+04	2.35E+04	2.22E+04	2.17E+04	2.05E+04	1.84E+04	1.54E+04	1.25E+04	1.03E+04	8.84E+03	7.16E+03	5.34E+03	3.61E+03	2.12E+03	1.03E+03	3.71E+02	7.81E+01	7.93E-01
1992	2.36E+03	5.55E+03	5.69E+03	5.71E+03	5.36E+03	5.32E+03	5.76E+03	6.18E+03	6.66E+03	7.63E+03	9.06E+03	1.06E+04	1.22E+04	1.43E+04	1.64E+04	1.74E+04	1.74E+04	1.82E+04	1.80E+04	1.69E+04	1.44E+04	1.18E+04	9.71E+03	8.33E+03	6.71E+03	4.99E+03	3.37E+03	1.99E+03	9.72E+02	3.54E+02	7.50E+01	6.50E-01
1993	2.13E+03	4.97E+03	4.87E+03	4.59E+03	4.03E+03	3.71E+03	3.72E+03	3.79E+03	3.90E+03	4.37E+03	5.18E+03	6.17E+03	7.07E+03	8.46E+03	9.98E+03	1.08E+04	1.10E+04	1.21E+04	1.26E+04	1.23E+04	1.07E+04	8.78E+03	7.14E+03	6.11E+03	4.84E+03	3.55E+03	2.40E+03	1.43E+03	7.14E+02	2.66E+02	5.79E+01	4.28E-01
1994	2.40E+03	5.57E+03	5.21E+03	4.56E+03	3.76E+03	3.25E+03	3.06E+03	2.96E+03	2.92E+03	3.16E+03	3.68E+03	4.32E+03	4.82E+03	5.67E+03	6.70E+03	7.26E+03	7.37E+03	8.21E+03	8.71E+03	8.63E+03	7.52E+03	6.10E+03	4.93E+03	4.29E+03	3.42E+03	2.52E+03	1.73E+03	1.05E+03	5.33E+02	2.04E+02	4.53E+01	6.00E-01
1995	3.19E+03	7.36E+03	6.68E+03	5.55E+03	4.34E+03	3.52E+03	3.08E+03	2.78E+03	2.59E+03	2.67E+03	2.98E+03	3.39E+03	3.66E+03	4.19E+03	4.88E+03	5.25E+03	5.30E+03	5.91E+03	6.30E+03	6.27E+03	5.46E+03	4.40E+03	3.53E+03	3.06E+03	2.39E+03	1.73E+03	1.16E+03	7.00E+02	3.55E+02	1.36E+02	3.05E+01	5.15E-01
1996	3.54E+03	8.21E+03	7.69E+03	6.72E+03	5.40E+03	4.37E+03	3.68E+03	3.14E+03	2.76E+03	2.65E+03	2.75E+03	2.96E+03	3.04E+03	3.32E+03	3.75E+03	3.95E+03	3.92E+03	4.28E+03	4.48E+03	4.38E+03	3.76E+03	3.02E+03	2.45E+03	2.19E+03	1.76E+03	1.28E+03	8.73E+02	5.28E+02	2.69E+02	1.03E+02	2.31E+01	4.54E-01
1997	8.72E+03	1.99E+04	1.66E+04	1.18E+04	8.04E+03	5.83E+03	4.64E+03	3.83E+03	3.27E+03	2.98E+03	2.89E+03	2.89E+03	2.81E+03	2.91E+03	3.13E+03	3.19E+03	3.10E+03	3.31E+03	3.44E+03	3.36E+03	2.93E+03	2.39E+03	1.97E+03	1.77E+03	1.44E+03	1.07E+03	7.30E+02	4.44E+02	2.26E+02	8.71E+01	1.95E+01	3.90E-01
1998	3.53E+03	8.65E+03	1.08E+04	1.28E+04	1.18E+04	9.77E+03	7.63E+03	5.82E+03	4.55E+03	3.81E+03	3.43E+03	3.22E+03	3.03E+03	3.01E+03	3.07E+03	3.01E+03	2.85E+03	2.96E+03	3.00E+03	2.92E+03	2.56E+03	2.12E+03	1.76E+03	1.58E+03	1.29E+03	9.68E+02	6.67E+02	4.06E+02	2.07E+02	7.96E+01	1.78E+01	3.53E-01
1999	1.08E+04	2.45E+04	2.00E+04	1.39E+04	9.81E+03	8.19E+03	8.00E+03	7.49E+03	6.72E+03	5.93E+03	5.18E+03	4.53E+03	3.97E+03	3.66E+03	3.48E+03	3.25E+03	2.98E+03	2.98E+03	2.96E+03	2.85E+03	2.51E+03	2.11E+03	1.77E+03	1.56E+03	1.28E+03	9.67E+02	6.68E+02	4.07E+02	2.07E+02	7.90E+01	1.76E+01	3.28E-01
2000	6.51E+03	1.55E+04	1.69E+04	1.77E+04	1.53E+04	1.22E+04	9.21E+03	7.02E+03	5.75E+03	5.25E+03	5.19E+03	5.16E+03	5.01E+03	4.90E+03	4.72E+03	4.36E+03	3.91E+03	3.73E+03	3.55E+03	3.32E+03	2.90E+03	2.43E+03	2.02E+03	1.75E+03	1.43E+03	1.08E+03	7.45E+02	4.52E+02	2.29E+02	8.71E+01	1.93E+01	3.30E-01
2001	2.14E+04	4.86E+04	3.95E+04	2.68E+04	1.79E+04	1.35E+04	1.17E+04	1.01E+04	8.65E+03	7.35E+03	6.23E+03	5.37E+03	4.80E+03	4.64E+03	4.60E+03	4.47E+03	4.26E+03	4.30E+03	4.29E+03	4.14E+03	3.70E+03	3.16E+03	2.65E+03	2.27E+03	1.84E+03	1.38E+03	9.49E+02	5.71E+02	2.86E+02	1.07E+02	2.35E+01	3.60E-01
2002	8.34E+03	2.05E+04	2.58E+04	3.10E+04	2.84E+04	2.31E+04	1.75E+04	1.29E+04	9.95E+03	8.34E+03	7.55E+03	7.00E+03	6.54E+03	6.26E+03	5.93E+03	5.43E+03	4.87E+03	4.69E+03	4.59E+03	4.46E+03	4.05E+03	3.52E+03	3.01E+03	2.61E+03	2.17E+03	1.67E+03	1.17E+03	7.18E+02	3.66E+02	1.40E+02	3.09E+01	4.34E-01
2003	1.42E+04	3.26E+04	2.84E+04	2.26E+04	1.86E+04	1.76E+04	1.85E+04	1.76E+04	1.57E+04	1.36E+04	1.14E+04	9.50E+03	8.13E+03	7.41E+03	6.95E+03	6.45E+03	5.94E+03	5.85E+03	5.76E+03	5.57E+03	5.04E+03	4.36E+03	3.70E+03	3.15E+03	2.58E+03	1.97E+03	1.37E+03	8.30E+02	4.20E+02	1.60E+02	3.53E+01	5.81E-01
2004	2.35E+04	5.39E+04	4.73E+04	3.69E+04	2.70E+04	2.00E+04	1.55E+04	1.27E+04	1.13E+04	1.11E+04	1.14E+04	1.14E+04	1.12E+04	1.09E+04	1.03E+04	9.35E+03	8.27E+03	7.73E+03	7.33E+03	6.94E+03	6.21E+03	5.36E+03	4.54E+03	3.88E+03	3.19E+03	2.45E+03	1.72E+03	1.05E+03	5.34E+02	2.03E+02	4.50E+01	6.71E-01
2005	6.69E+03	1.70E+04	2.42E+04	3.21E+04	3.13E+04	2.75E+04	2.30E+04	1.84E+04	1.48E+04	1.22E+04	1.05E+04	9.38E+03	8.95E+03	9.23E+03	9.57E+03	9.57E+03	9.30E+03	9.49E+03	9.53E+03	9.30E+03	8.45E+03	7.33E+03	6.21E+03	5.24E+03	4.26E+03	3.23E+03	2.23E+03	1.35E+03	6.77E+02	2.55E+02	5.59E+01	8.53E-01
2006	5.43E+03	1.28E+04	1.29E+04	1.30E+04	1.35E+04	1.54E+04	1.83E+04	1.88E+04	1.78E+04	1.63E+04	1.48E+04	1.32E+04	1.19E+04	1.13E+04	1.08E+04	1.01E+04	9.26E+03	9.30E+03	9.50E+03	9.60E+03	9.01E+03	8.04E+03	7.00E+03	6.09E+03	5.09E+03	3.97E+03	2.80E+03	1.73E+03	8.81E+02	3.37E+02	7.47E+01	1.04E+00
2007	4.06E+03	9.56E+03	9.82E+03	9.81E+03	8.85E+03	8.16E+03	8.07E+03	8.27E+03	8.84E+03	9.97E+03	1.13E+04	1.22E+04	1.28E+04	1.33E+04	1.34E+04	1.28E+04	1.18E+04	1.15E+04	1.13E+04	1.10E+04	1.01E+04	8.82E+03	7.56E+03	6.49E+03	5.37E+03	4.15E+03	2.92E+03	1.80E+03	9.19E+02	3.53E+02	7.86E+01	1.36E+00
2008	4.67E+03	1.08E+04	1.01E+04	8.83E+03	7.36E+03	6.49E+03	6.18E+03	5.83E+03	5.53E+03	5.54E+03	5.85E+03	6.42E+03	7.35E+03	8.88E+03	1.02E+04	1.08E+04	1.09E+04	1.17E+04	1.22E+04	1.23E+04	1.15E+04	1.02E+04	8.84E+03	7.60E+03	6.28E+03	4.83E+03	3.38E+03	2.06E+03	1.05E+03	3.98E+02	8.79E+01	1.44E+00
2009	2.72E+04	6.15E+04	4.82E+04	2.98E+04	1.72E+04	1.04E+04	7.24E+03	5.61E+03	4.78E+03	4.54E+03	4.65E+03	4.95E+03	5.53E+03	6.65E+03	7.62E+03	8.02E+03	8.08E+03	9.06E+03	1.01E+04	1.09E+04	1.07E+04	9.81E+03	8.70E+03	7.70E+03	6.53E+03	5.16E+03	3.69E+03	2.30E+03	1.18E+03	4.57E+02	1.02E+02	1.61E+00
2010	3.24E+04	7.51E+04	6.94E+04	5.90E+04	4.46E+04	3.19E+04	2.14E+04	1.40E+04	9.45E+03	6.86E+03	5.54E+03	5.00E+03	5.07E+03	5.81E+03	6.53E+03	6.81E+03	6.80E+03	7.64E+03	8.58E+03	9.39E+03	9.27E+03	8.58E+03	7.64E+03	6.78E+03	5.76E+03	4.54E+03	3.24E+03	2.02E+03	1.04E+03	4.07E+02	9.18E+01	1.81E+00
2011	1.92E+04	4.59E+04	5.03E+04	5.36E+04	4.86E+04	4.23E+04	3.66E+04	3.00E+04	2.39E+04	1.88E+04	1.45E+04	1.12E+04	9.12E+03	8.18E+03	7.69E+03	7.16E+03	6.63E+03	7.03E+03	7.64E+03	8.23E+03	8.08E+03	7.47E+03	6.66E+03	5.92E+03	5.04E+03	3.98E+03	2.85E+03	1.78E+03	9.22E+02	3.60E+02	8.12E+01	1.76E+00
2012	4.00E+03	1.06E+04	1.74E+04	2.57E+04	2.84E+04	2.98E+04	3.12E+04	2.99E+04	2.74E+04	2.51E+04	2.28E+04	2.03E+04	1.81E+04	1.63E+04	1.46E+04	1.27E+04	1.08E+04	9.95E+03	9.43E+03	9.10E+03	8.34E+03	7.36E+03	6.37E+03	5.54E+03	4.64E+03	3.62E+03	2.57E+03	1.59E+03	8.21E+02	3.19E+02	7.17E+01	1.56E+00
2013	8.87E+03	2.03E+04	1.71E+04	1.30E+04	1.13E+04	1.22E+04	1.50E+04	1.66E+04	1.75E+04	1.84E+04	1.92E+04	1.95E+04	1.94E+04	1.95E+04	1.91E+04	1.80E+04	1.64E+04	1.55E+04	1.47E+04	1.37E+04	1.21E+04	1.04E+04	8.67E+03	7.26E+03	5.85E+03	4.41E+03	3.02E+03	1.82E+03	9.10E+02	3.43E+02	7.53E+01	1.38E+00
2014	9.50E+03	2.21E+04	2.09E+04	1.84E+04	1.45E+04	1.13E+04	8.93E+03	7.76E+03	7.60E+03	8.46E+03	9.95E+03	1.14E+04	1.30E+04	1.50E+04	1.64E+04	1.68E+04	1.65E+04	1.70E+04	1.73E+04	1.71E+04	1.57E+04	1.37E+04	1.17E+04	9.96E+03	8.14E+03	6.20E+03	4.28E+03	2.58E+03	1.29E+03	4.85E+02	1.06E+02	1.39E+00
2015	6.18E+03	1.47E+04	1.57E+04	1.62E+04	1.46E+04	1.29E+04	1.15E+04	9.91E+03	8.43E+03	7.43E+03	6.92E+03	6.95E+03	7.71E+03	9.47E+03	1.11E+04	1.20E+04	1.22E+04	1.35E+04	1.47E+04	1.54E+04	1.47E+04	1.32E+04	1.16E+04	1.02E+04	8.56E+03	6.68E+03	4.71E+03	2.89E+03	1.47E+03	5.60E+02	1.24E+02	1.75E+00

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Table 27. OFL and ABC values for the progression of datasets from the 2014 assessment dataset to the final 2015 dataset, Dataset D. These values are presented only to illustrate the effect of incremental changes in the data used for the assessment on the OFL and ABC.

Model	Dataset	Snow Crab Model	Projection Approach	Average Recruitment	B	Fmsy	Bmsy	B/Bmsy	OFL	ABC P-star	ABC (20% buffer)
2014 Model	Base	--	2014	187.90	63.80	0.61	29.82	2.14	31.48	31.43	25.18
2014 Model	2014 Corrected	--	2014	187.07	63.56	0.60	29.75	2.14	31.25	31.20	25.00
Model A	Dataset A	Preferred	2014	178.62	55.16	0.61	27.70	1.99	28.15	28.11	22.52
Model A	Dataset B	Preferred	2014	174.18	52.57	0.63	27.06	1.94	27.54	27.50	22.03
Model A	Dataset C	Preferred	2014	173.45	51.41	0.72	26.01	1.98	28.66	28.62	22.93
Model A	Dataset D	Preferred	2014	179.37	52.80	0.64	26.79	1.97	27.73	27.70	22.19

Table 28. OFLs and ABCs from the 2014 assessment (model Alt4b) and based on 2015 candidate models A and C run against Dataset D, using several approaches to compute the OFL. The author's preferred version is highlighted in yellow: his preferred model is Model A, his preferred approach to calculating the OFL for 2015/16 is based on Turnock's preferred snow crab model, as of Sept. 10, 2015 and the 2014 projection approach. Note that this table has been superseded (see Appendices C and D).

Model	Snow Crab Model	Projection Approach	Average Recruitment	B	Fmsy	Bmsy	B/Bmsy	OFL	ABC P-star	ABC (20% buffer)
2014 Model	--	2014	187.90	63.80	0.61	29.82	2.14	31.48	31.43	25.18
Model A	Preferred	2014	179.37	52.80	0.64	26.79	1.97	27.73	27.70	22.19
Model A	Preferred	new (1)	179.37	52.80	0.64	26.79	1.97	27.73	27.70	22.19
Model A	Preferred	new (2)	179.37	55.91	0.44	26.79	2.09	24.78	24.75	19.82
Model A	2014	2014	179.37	53.02	0.62	26.79	1.98	27.60	27.56	22.08
Model A	2014	new (1)	179.37	53.02	0.62	26.79	1.98	27.60	27.56	22.08
Model A	2014	new (2)	179.37	56.02	0.43	26.79	2.09	24.76	24.72	19.80
Model C	Preferred	2014	180.95	54.53	0.44	25.62	2.13	26.27	26.24	21.02
Model C	2014	2014	180.95	54.88	0.41	25.62	2.14	26.15	26.12	20.92

Figures

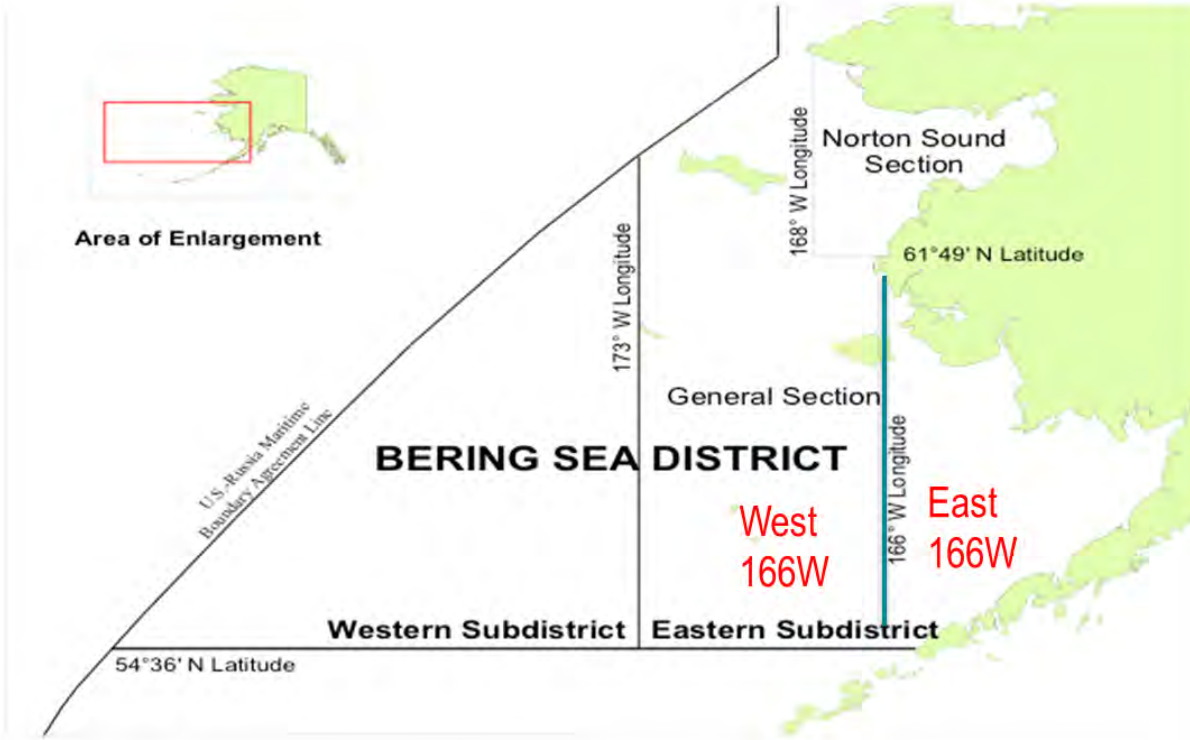


Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008).

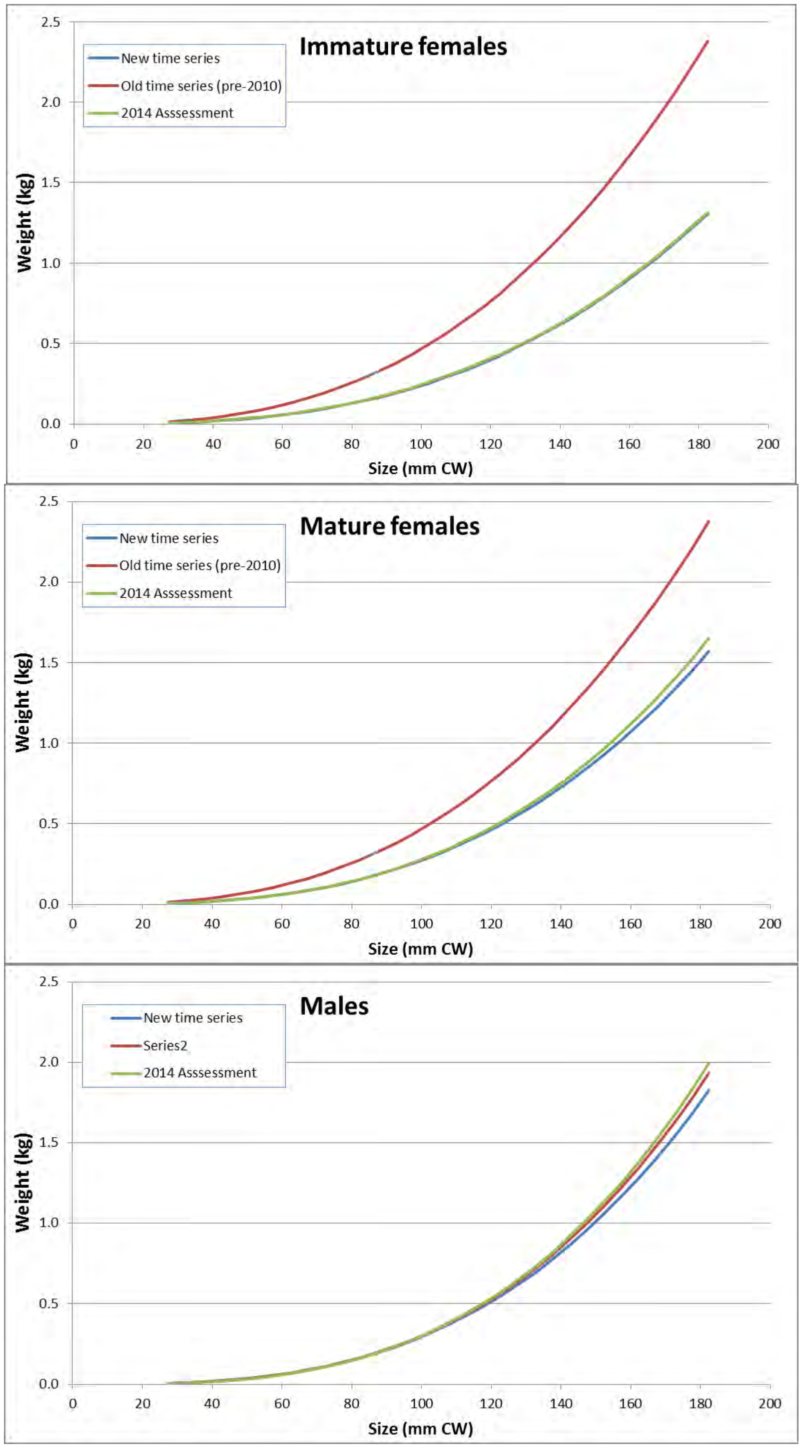


Figure 2. Comparison of weight-at-size relationships for Tanner crab used for the new survey time series (and this assessment; in blue), the old survey time series (in red), and previous assessments (in green).

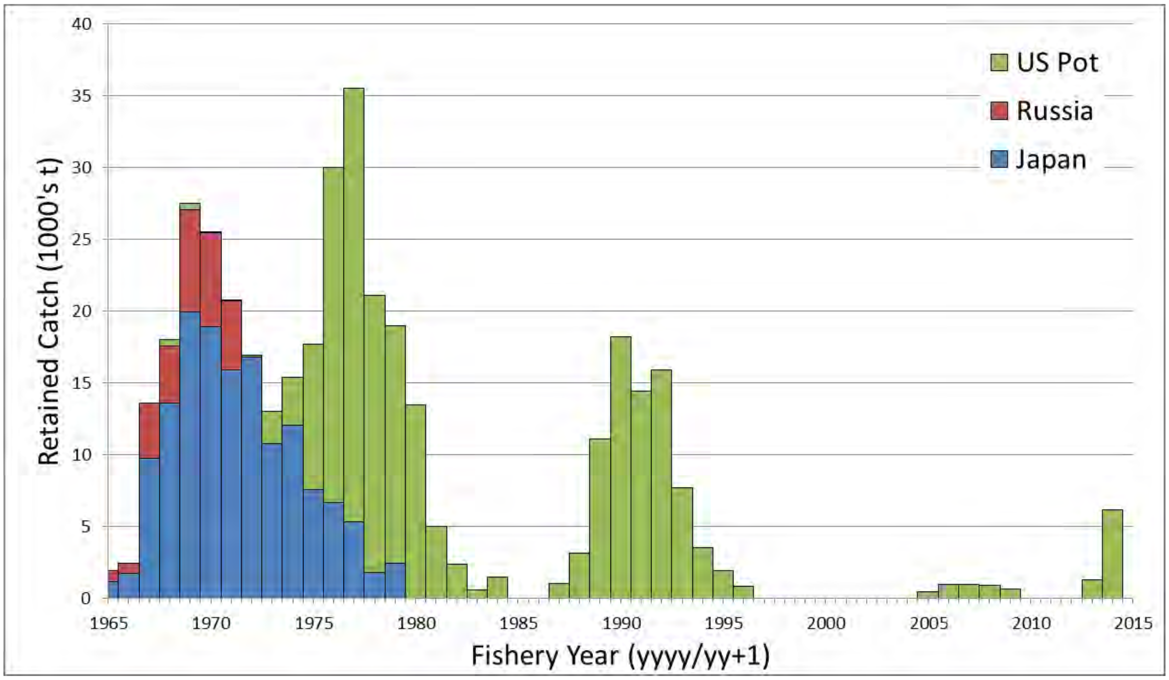


Figure 3. Retained catch (males, 1000's t) in the directed fisheries (US pot fishery [green bars], Russian tangle net fishery [red bars], and Japanese tangle net fisheries [blue bars]) for Tanner crab since 1965/66.

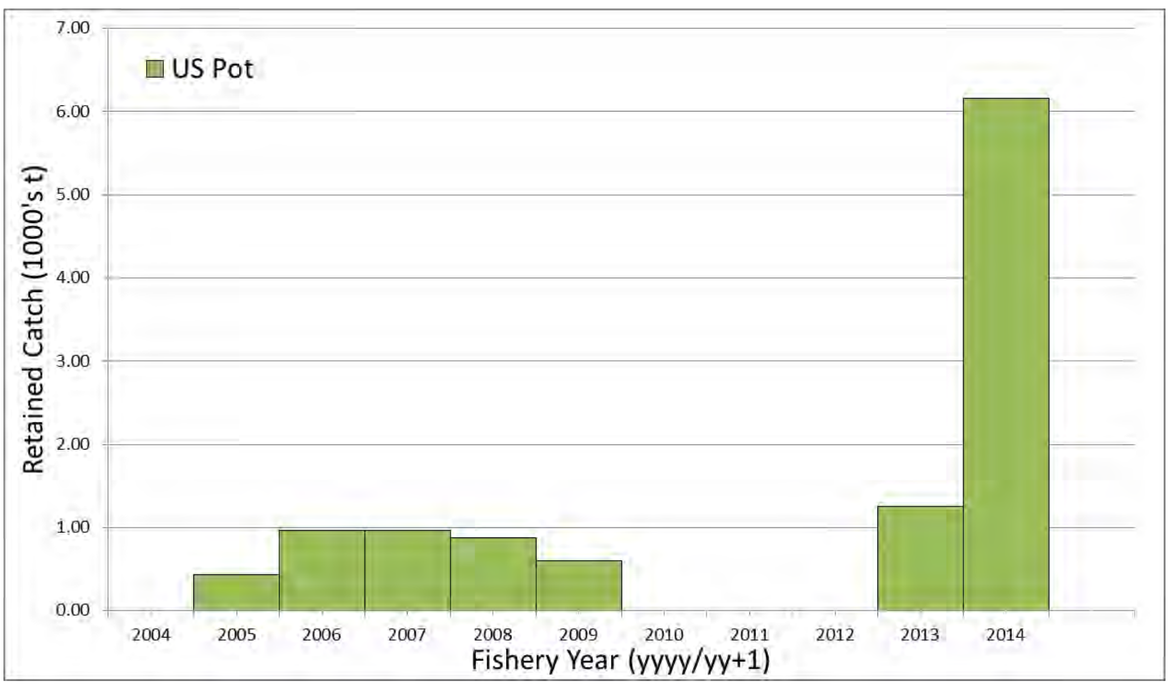


Figure 4. Retained catch (males, 1000's t) in directed fishery for Tanner crab since 2001/02. The directed fishery was closed from 1996/97 to 2004/05 and from 2010/11 to 2012/13.

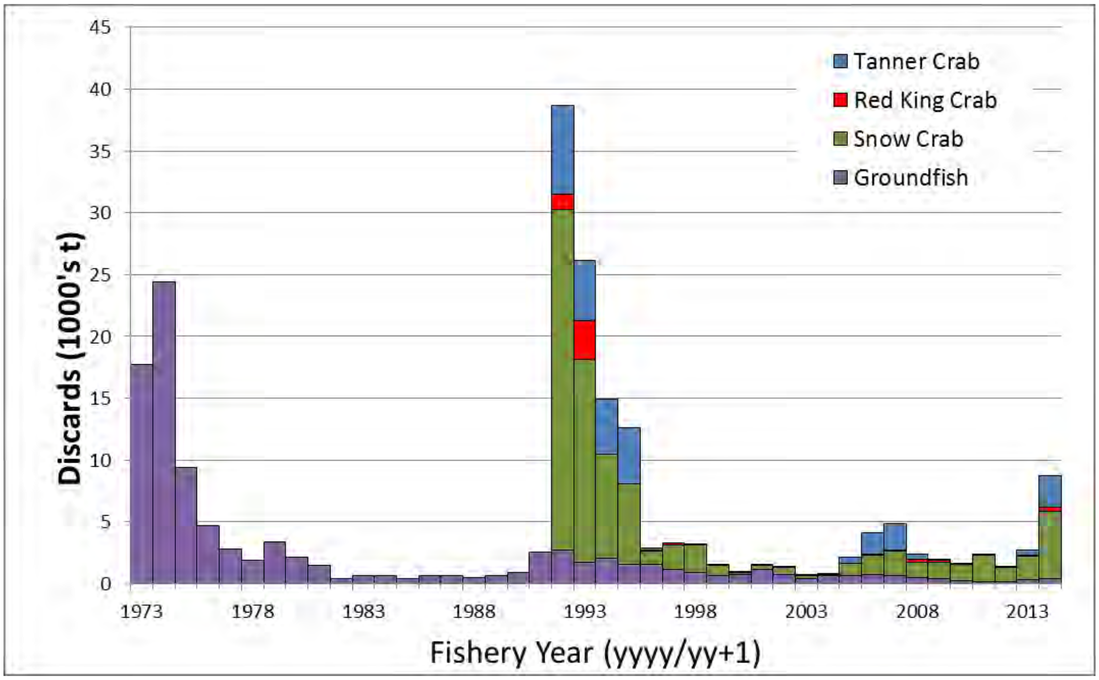


Figure 5. Tanner crab discards (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Discard reporting began in 1973 for the groundfish fisheries and in 1992 for the crab fisheries.

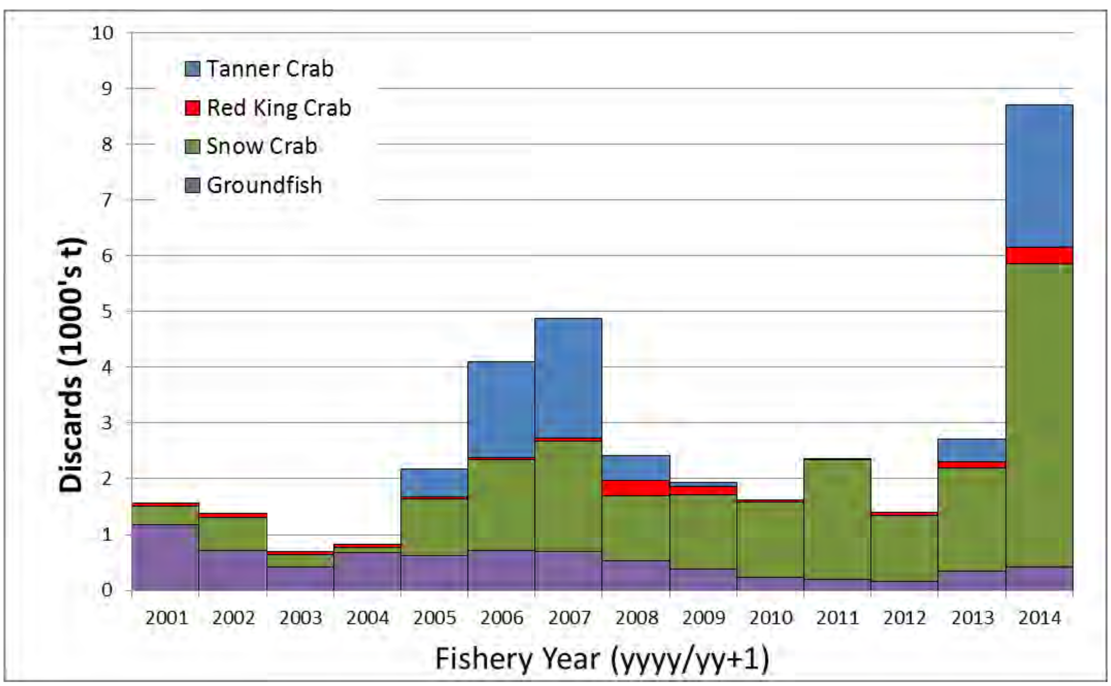


Figure 6.Tanner crab discards (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries since 2001.

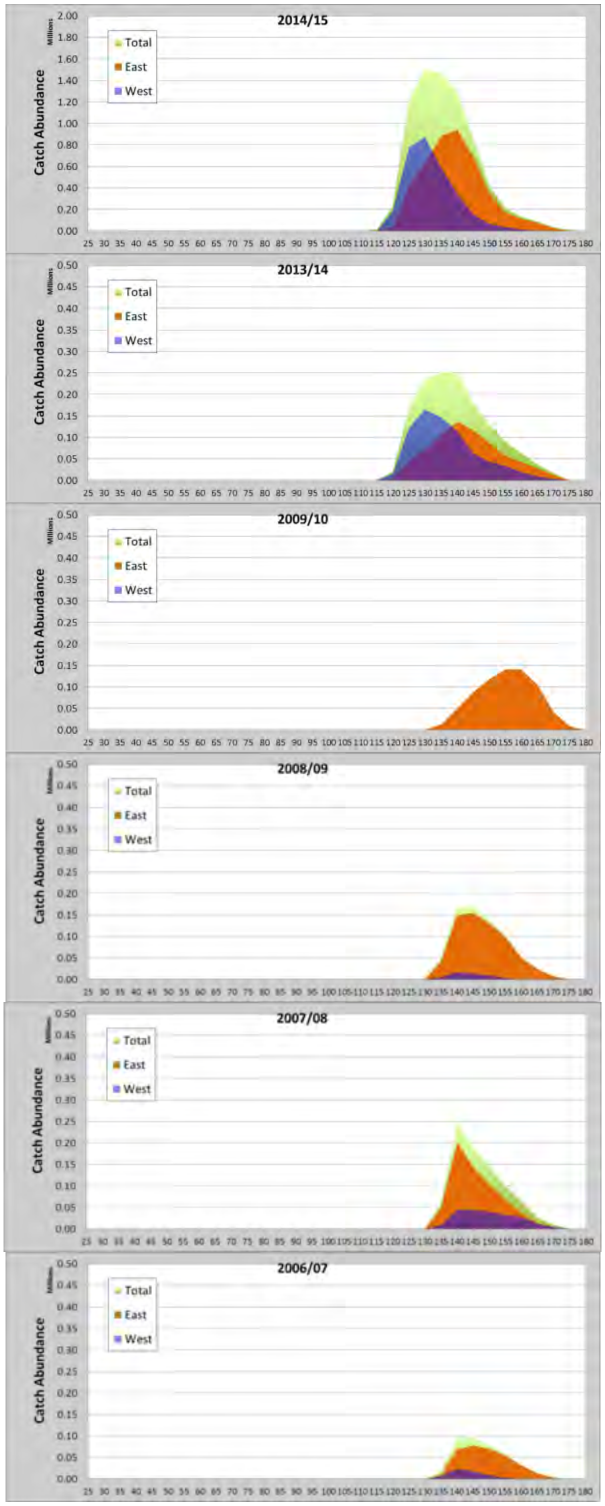


Figure 7. Size compositions, by 5 mm CW bins and expanded to total retained catch, for retained (male) crab in the directed Tanner crab pot fisheries since 2006/07, from dockside crab fishery observer sampling. Fishing occurred only east of 166°W in 2009/10. The entire fishery was closed in 2010/11-2012/13.

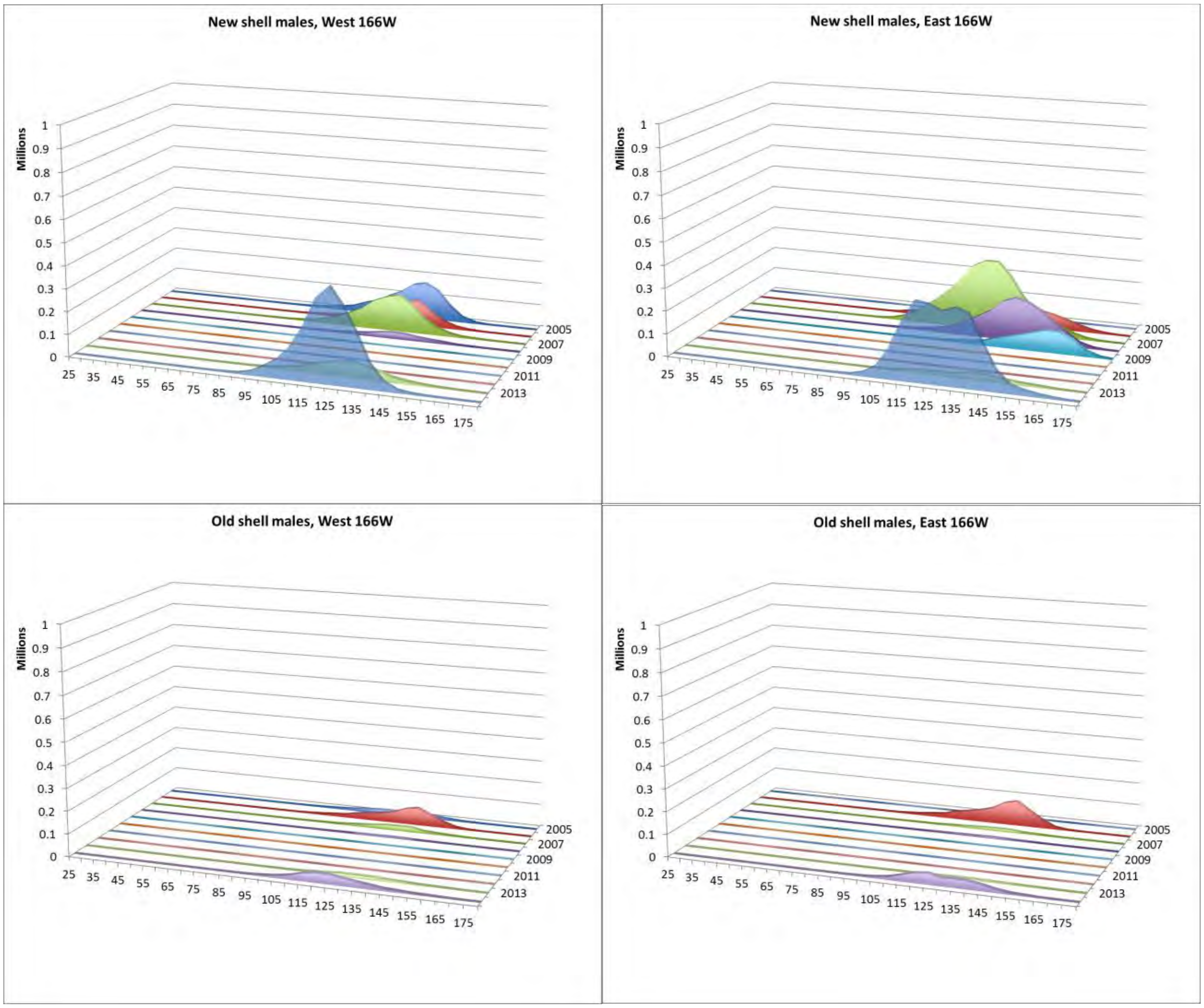


Figure 8. Male Tanner crab catch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling.

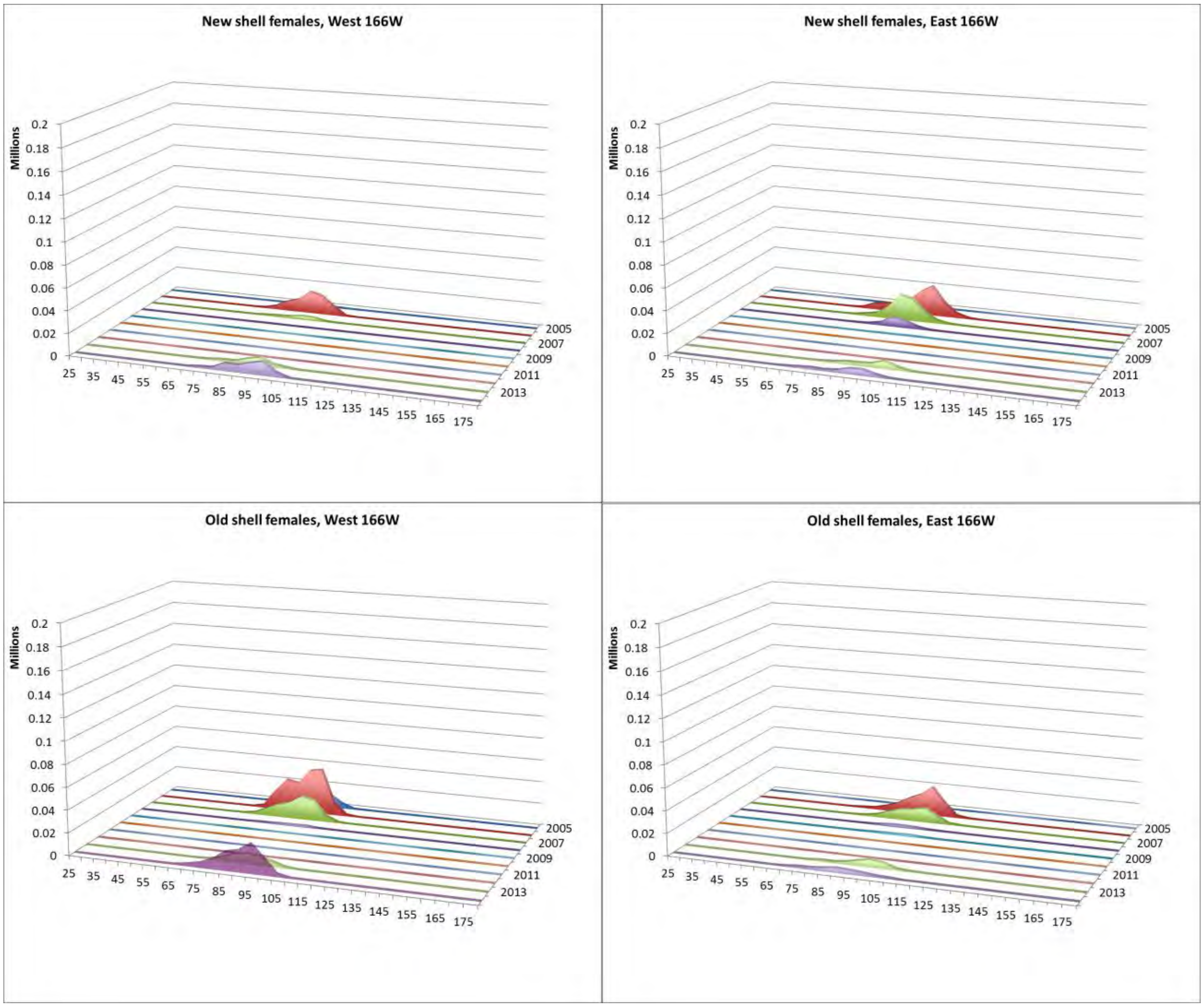


Figure 9. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling.

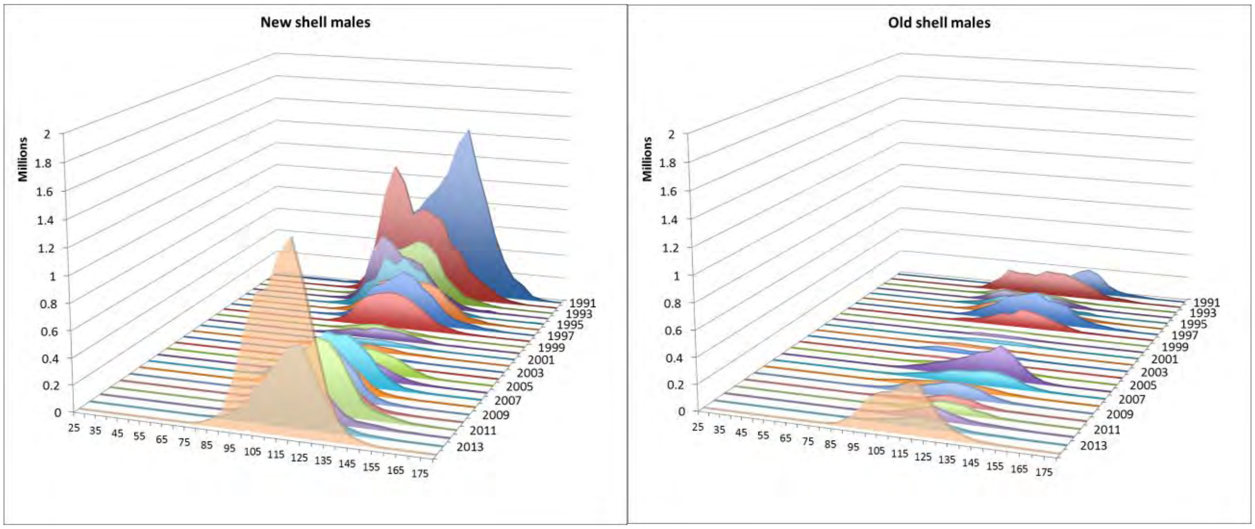


Figure 10. Male Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the snow crab pot fishery, from at-sea crab fishery observer sampling.

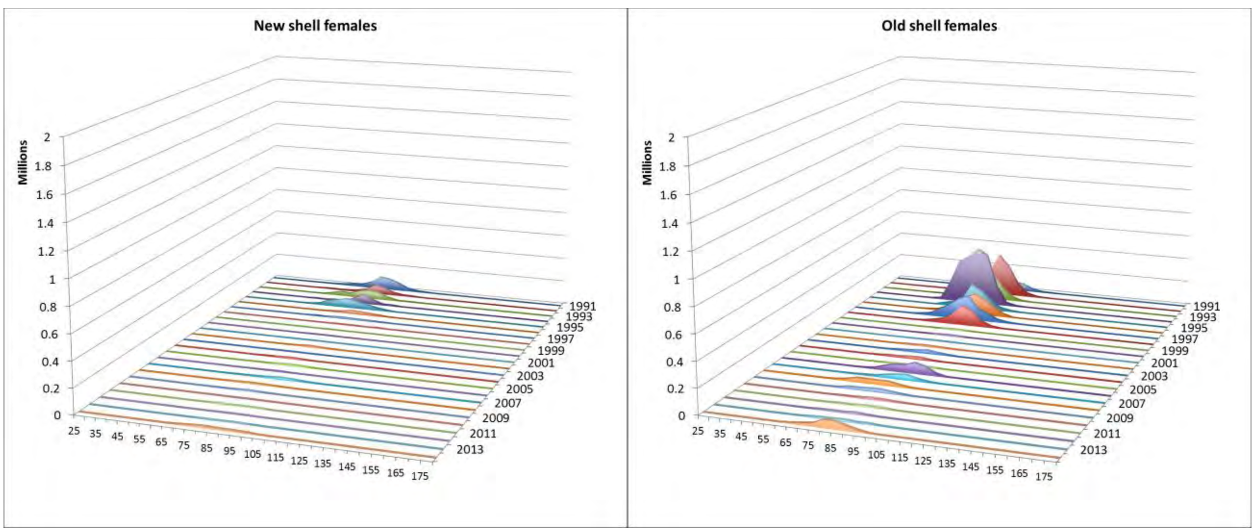


Figure 11. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the snow crab pot fishery, from at-sea crab fishery observer sampling.

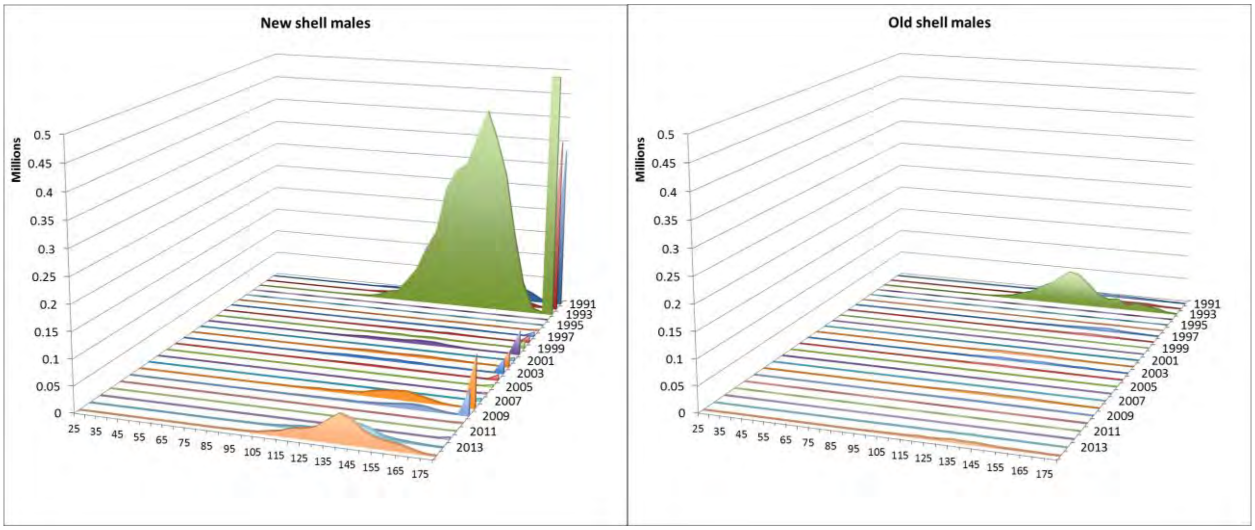


Figure 12. Male Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the BBRKC pot fishery, from at-sea crab fishery observer sampling.

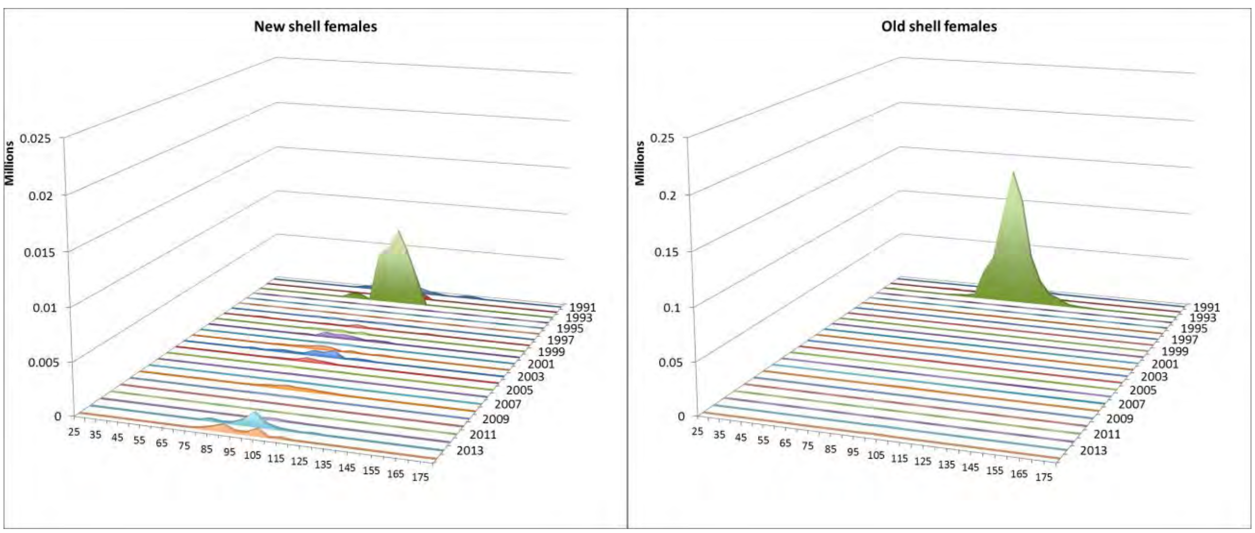


Figure 13. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the BBRKC pot fishery, from at-sea crab fishery observer sampling.

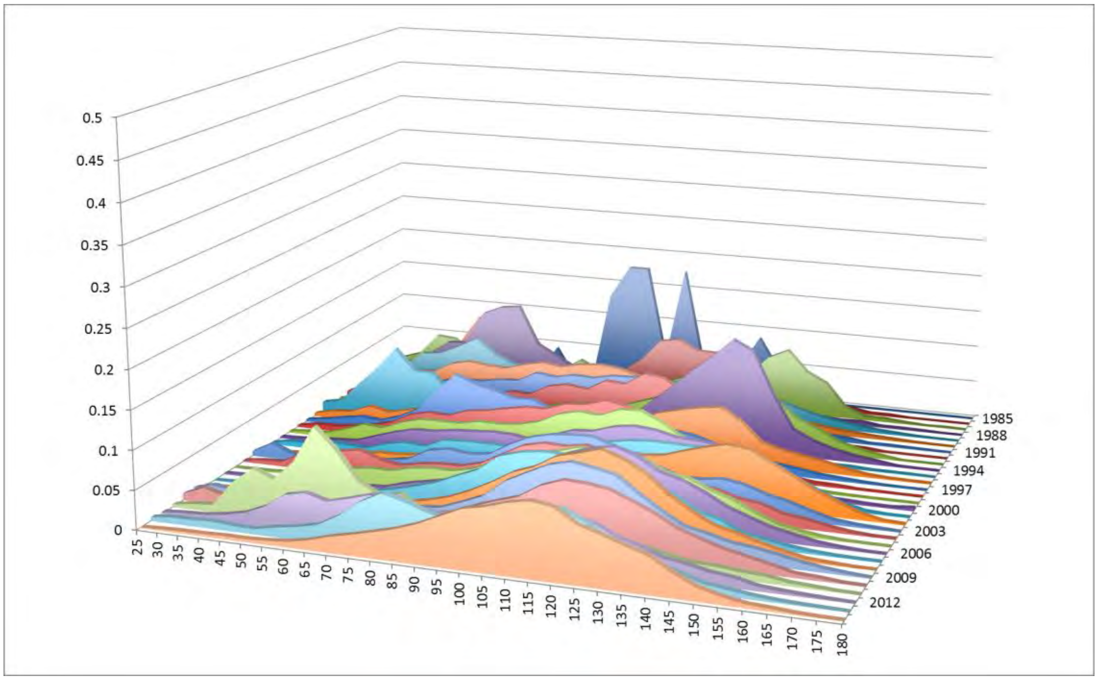


Figure 14. Normalized male Tanner crab bycatch size compositions in the groundfish fisheries, from groundfish observer sampling. Size compositions have been normalized to sum to 1 for each year.

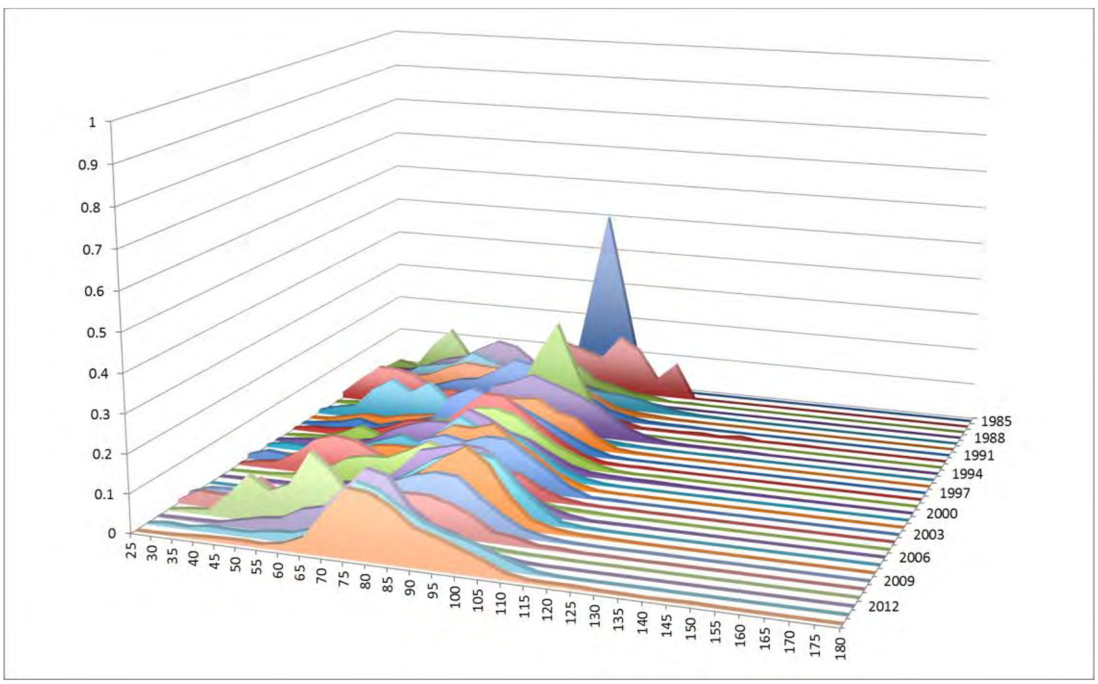


Figure 15. Normalized female Tanner crab bycatch size compositions in the groundfish fisheries, from groundfish observer sampling. Size compositions have been normalized to sum to 1 for each year.

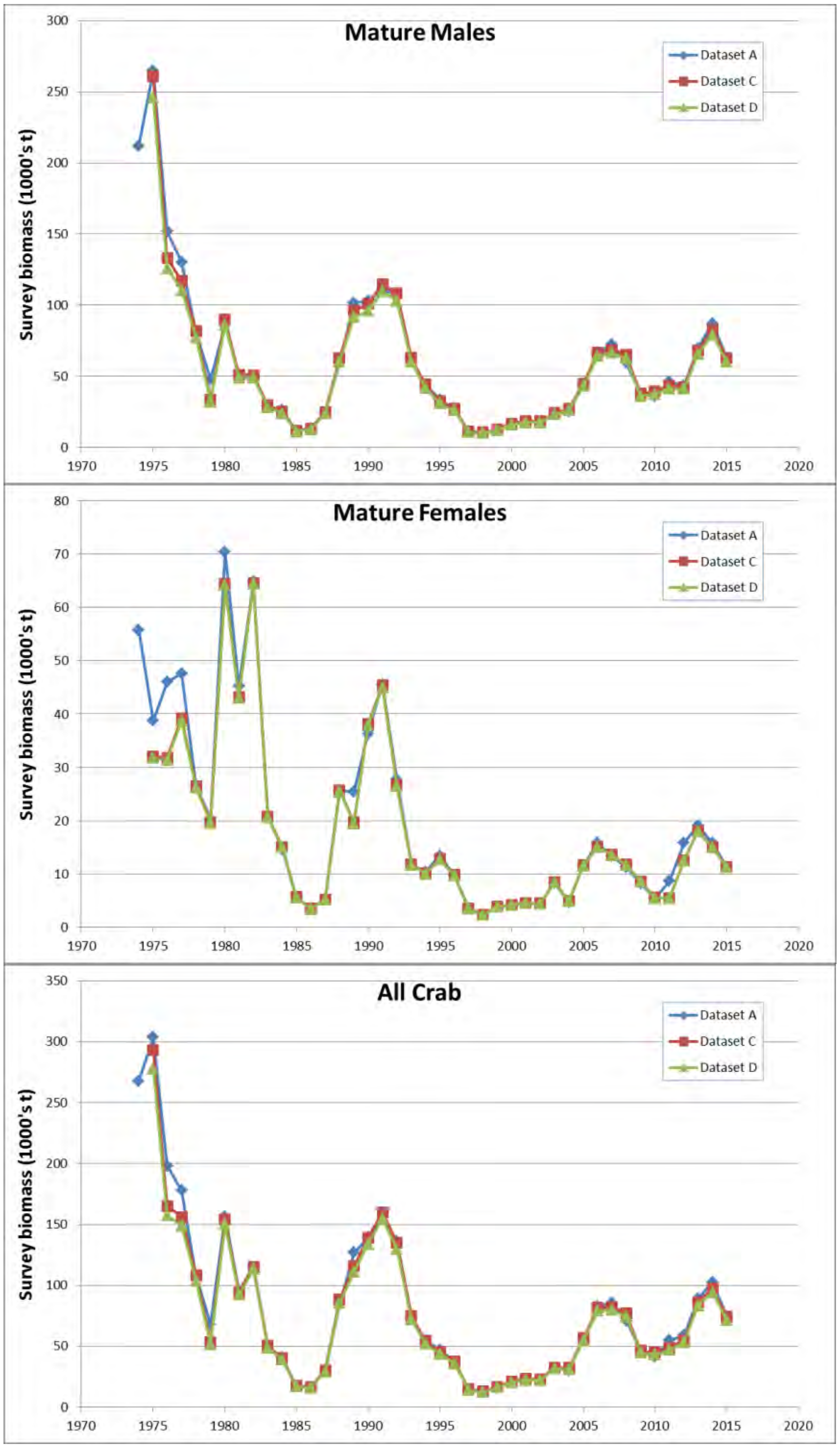


Figure 16. Trends in mature Tanner crab biomass based on size compositions from the NMFS bottom trawl survey. Datasets A and C use the Rugolo and Turnock (2012a) weight-at-size regressions; Datset D uses the new standardized regressions. Dataset A uses the old trawl survey stations/hauls, Datasets C and D use the new standardized stations/hauls.

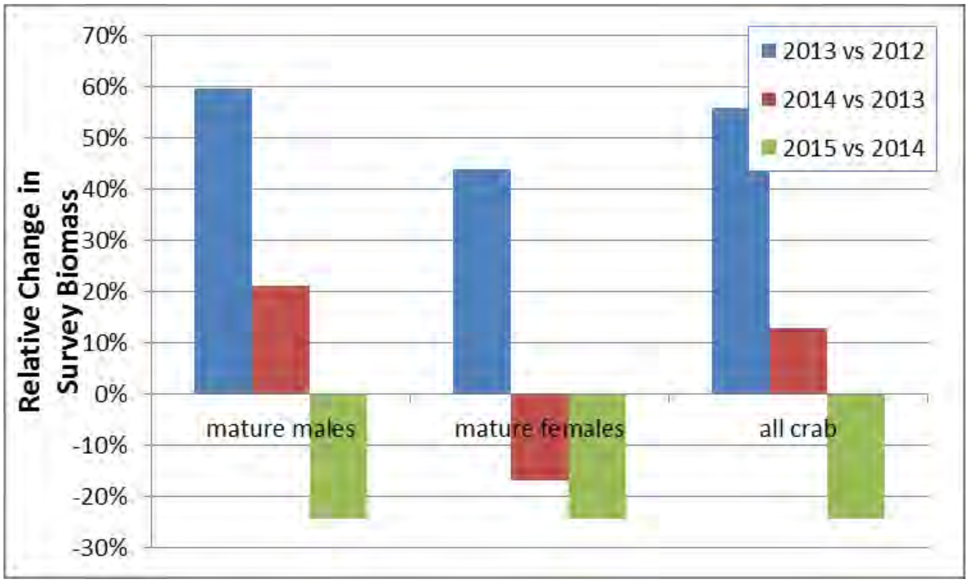
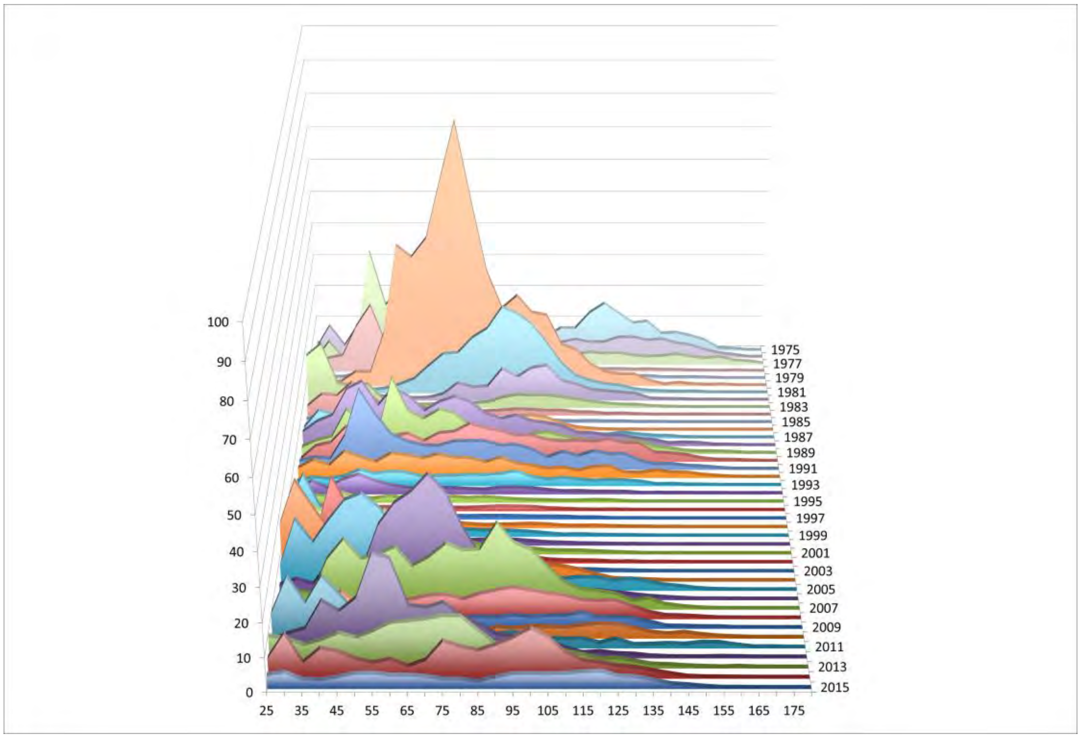


Figure 17. Percent change in mature male biomass, mature female biomass, total mature biomass and biomass of all crab observed in the NMFS bottom trawl survey during the past 3 years.

West of 166° W



East of 166° W

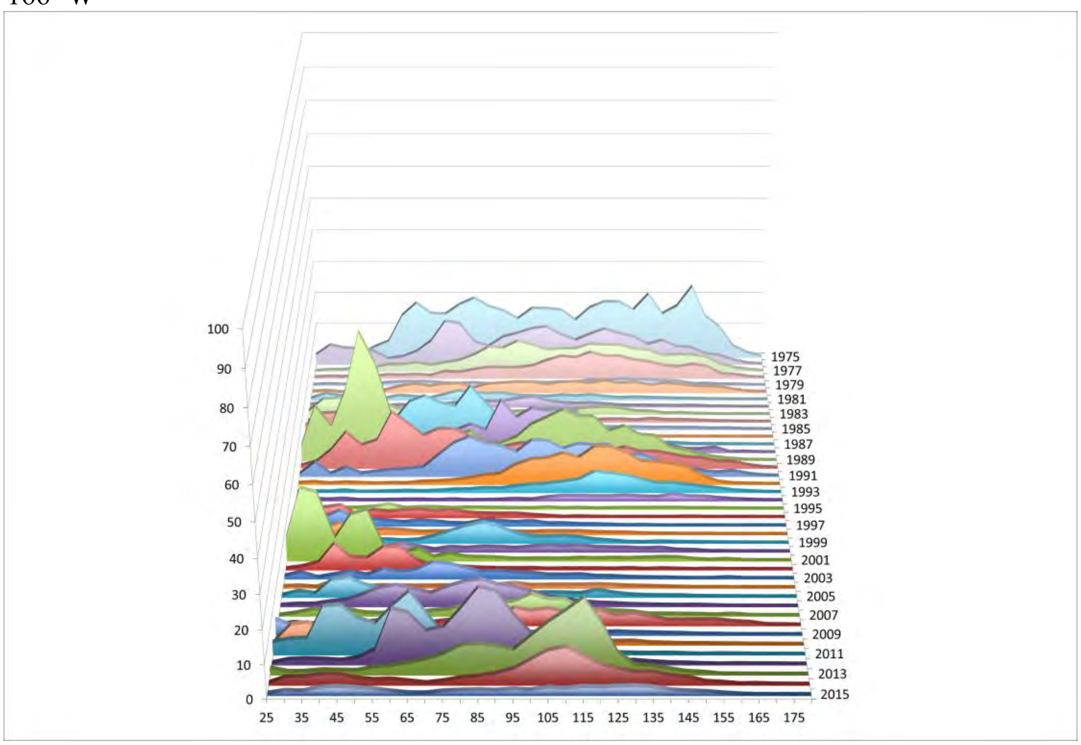
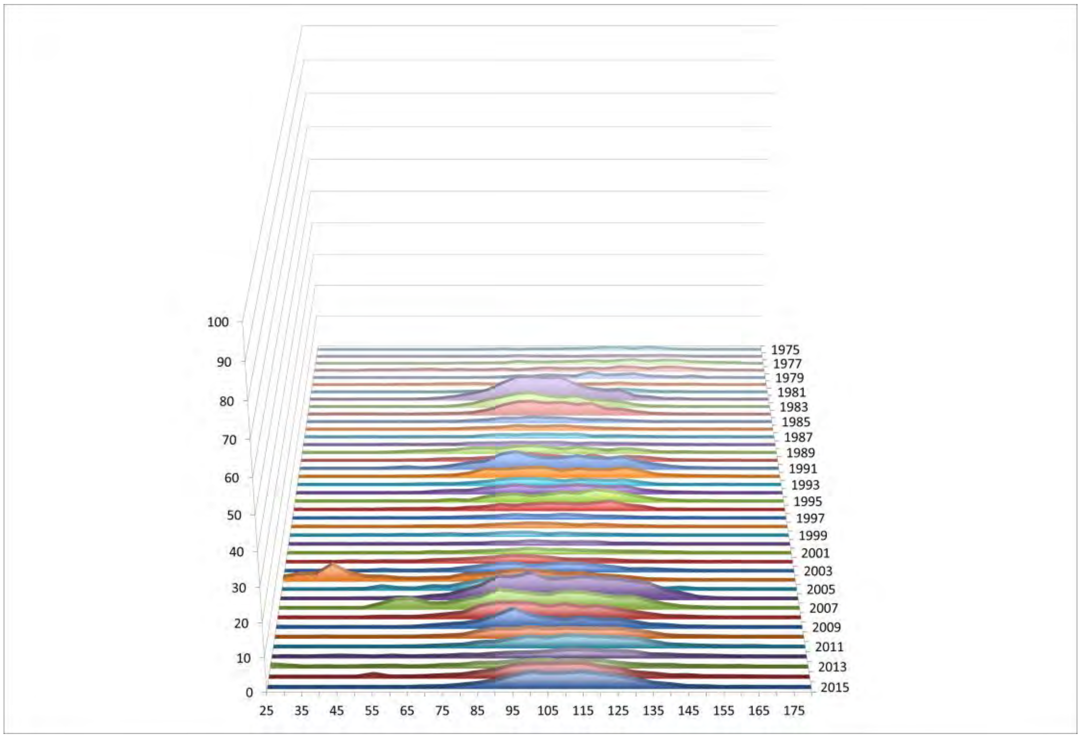


Figure 18a. Numbers at size (millions) by area for new shell male Tanner crab in the NMFS summer bottom trawl survey (new time series), binned by 5 mm CW.

West of 166° W



East of 166° W

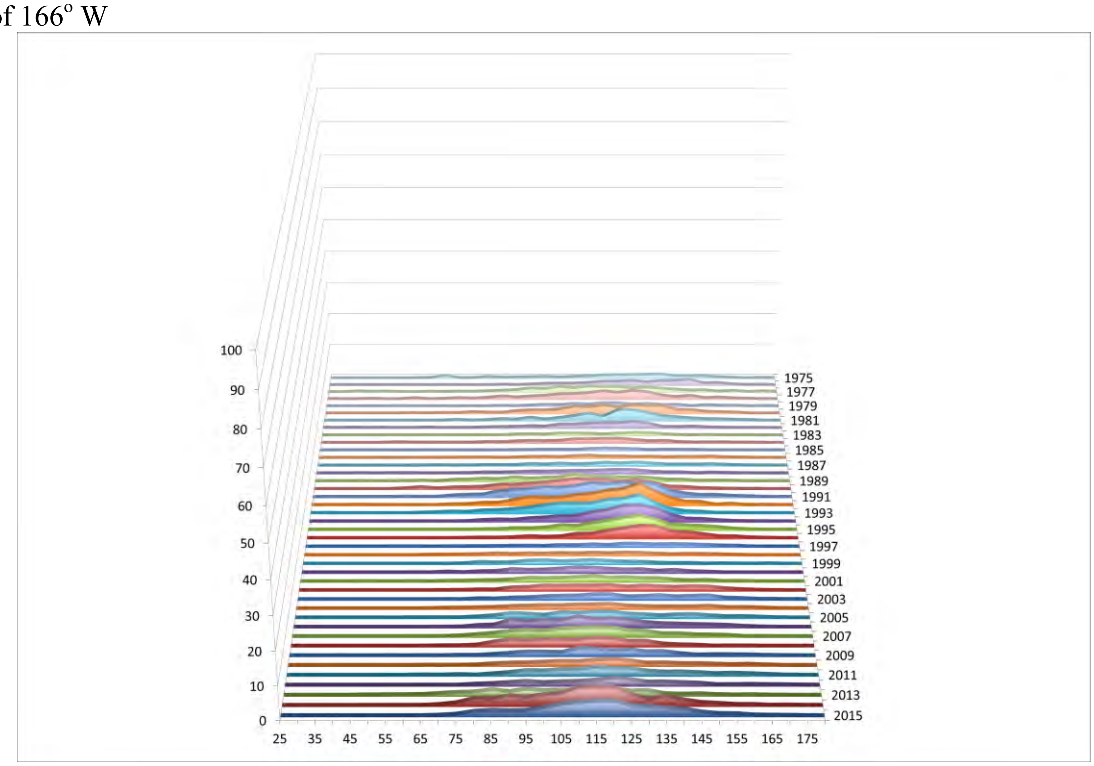
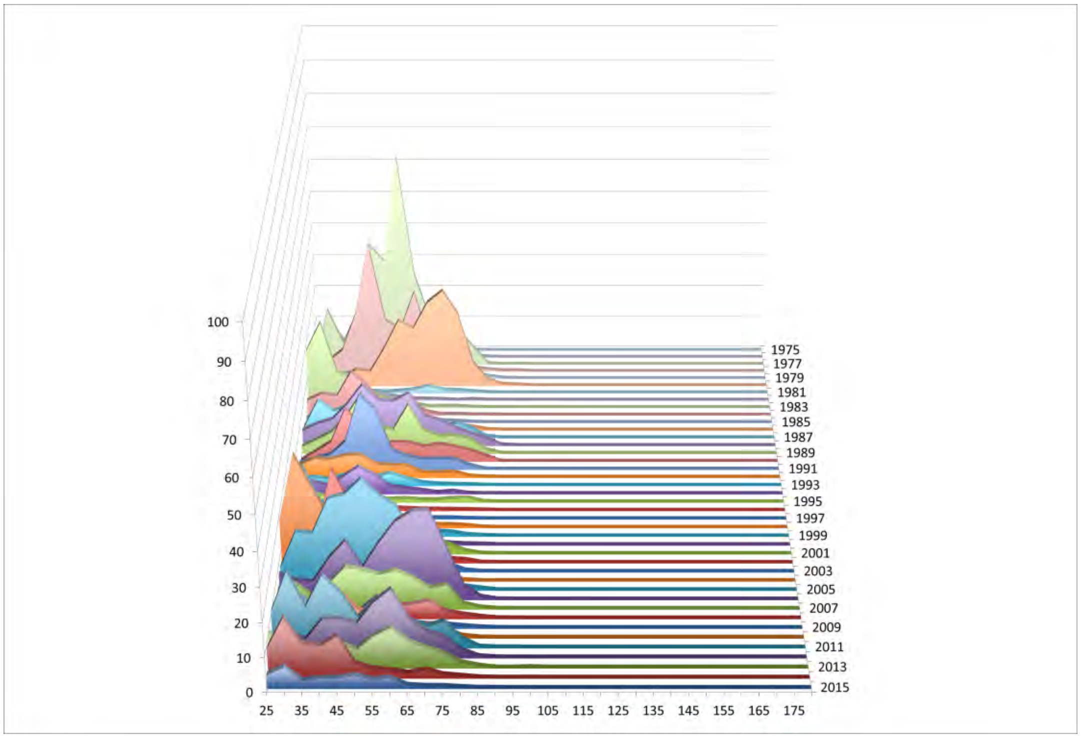


Figure 18b. Numbers at size (millions) by area for old shell male Tanner crab in the NMFS summer bottom trawl survey (new time series), binned by 5 mm CW.

West of 166° W



East of 166° W

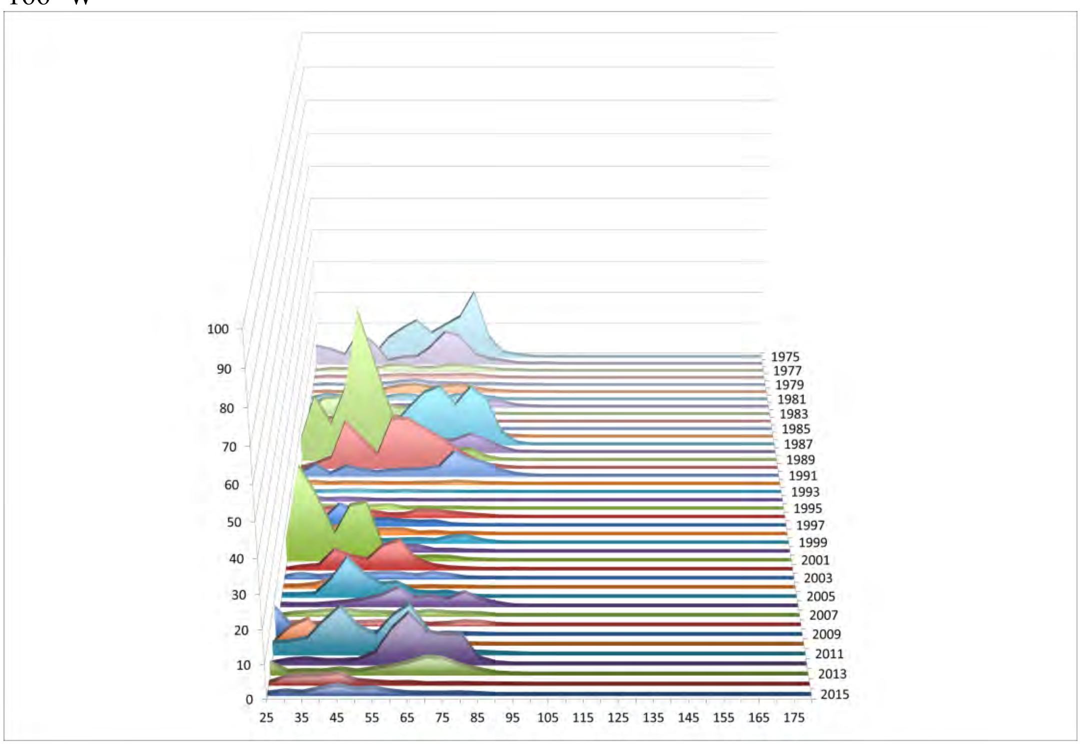
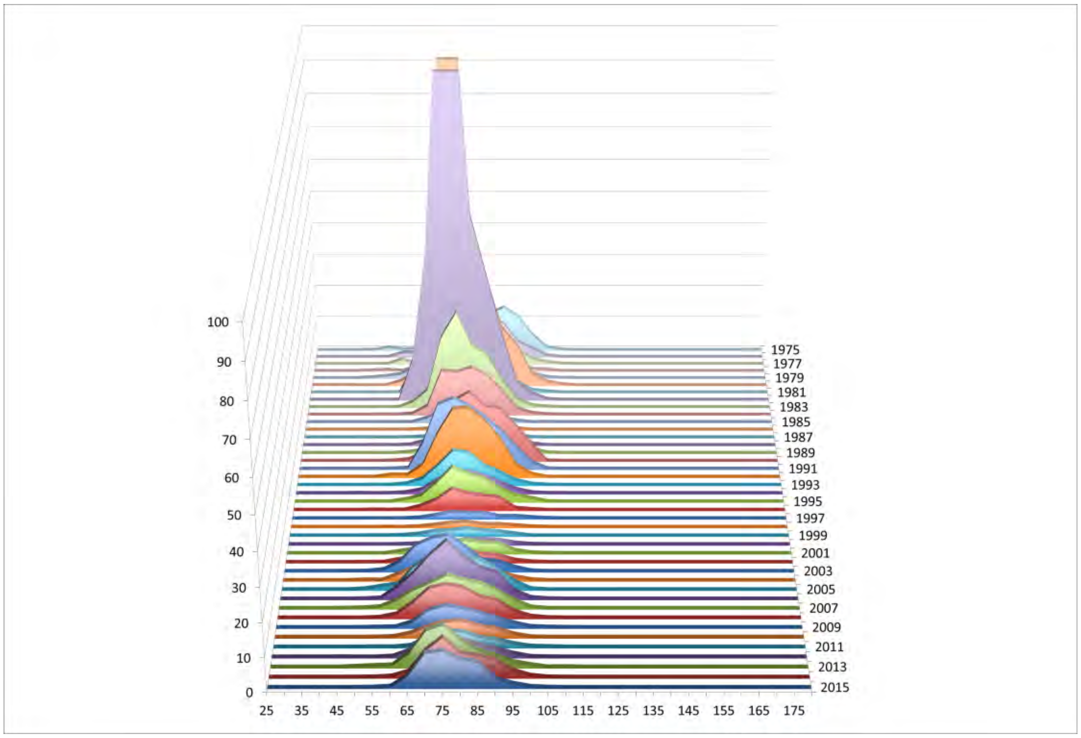


Figure 19a. Numbers at size (millions) by area for immature female Tanner crab in the NMFS summer bottom trawl survey (new time series), binned by 5 mm CW.

West of 166° W



East of 166° W

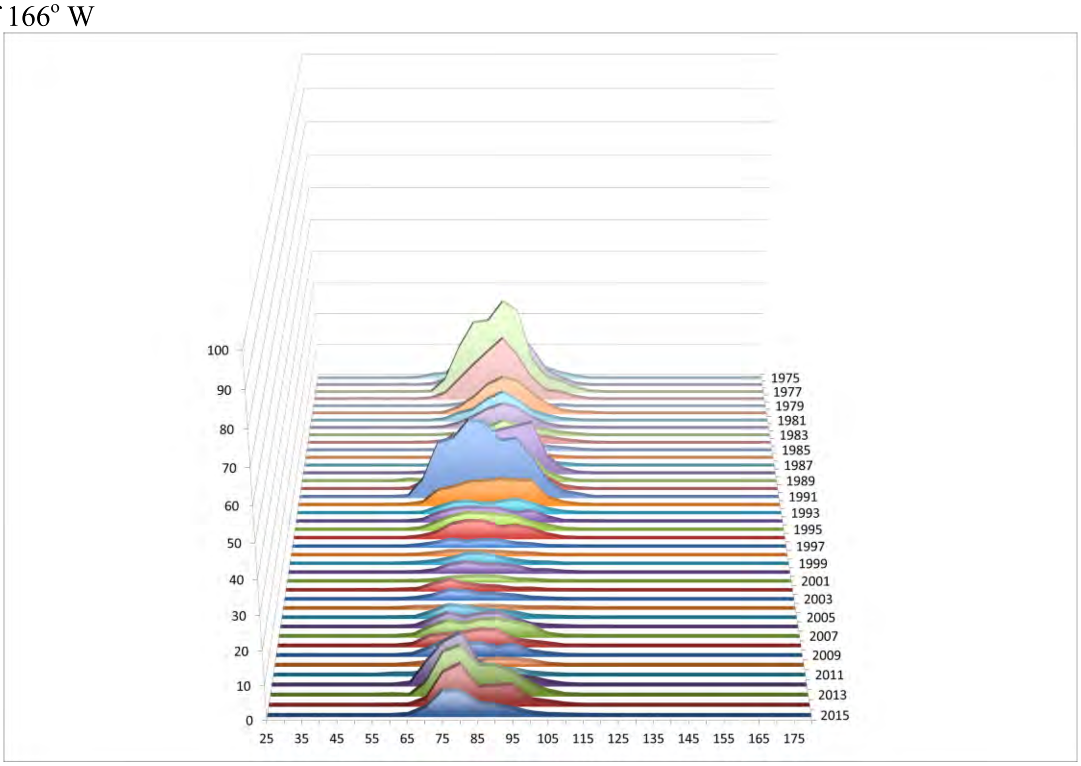


Figure 19b. Numbers at size (millions) by area for mature female Tanner crab in the NMFS summer bottom trawl survey (new time series), binned by 5 mm CW.

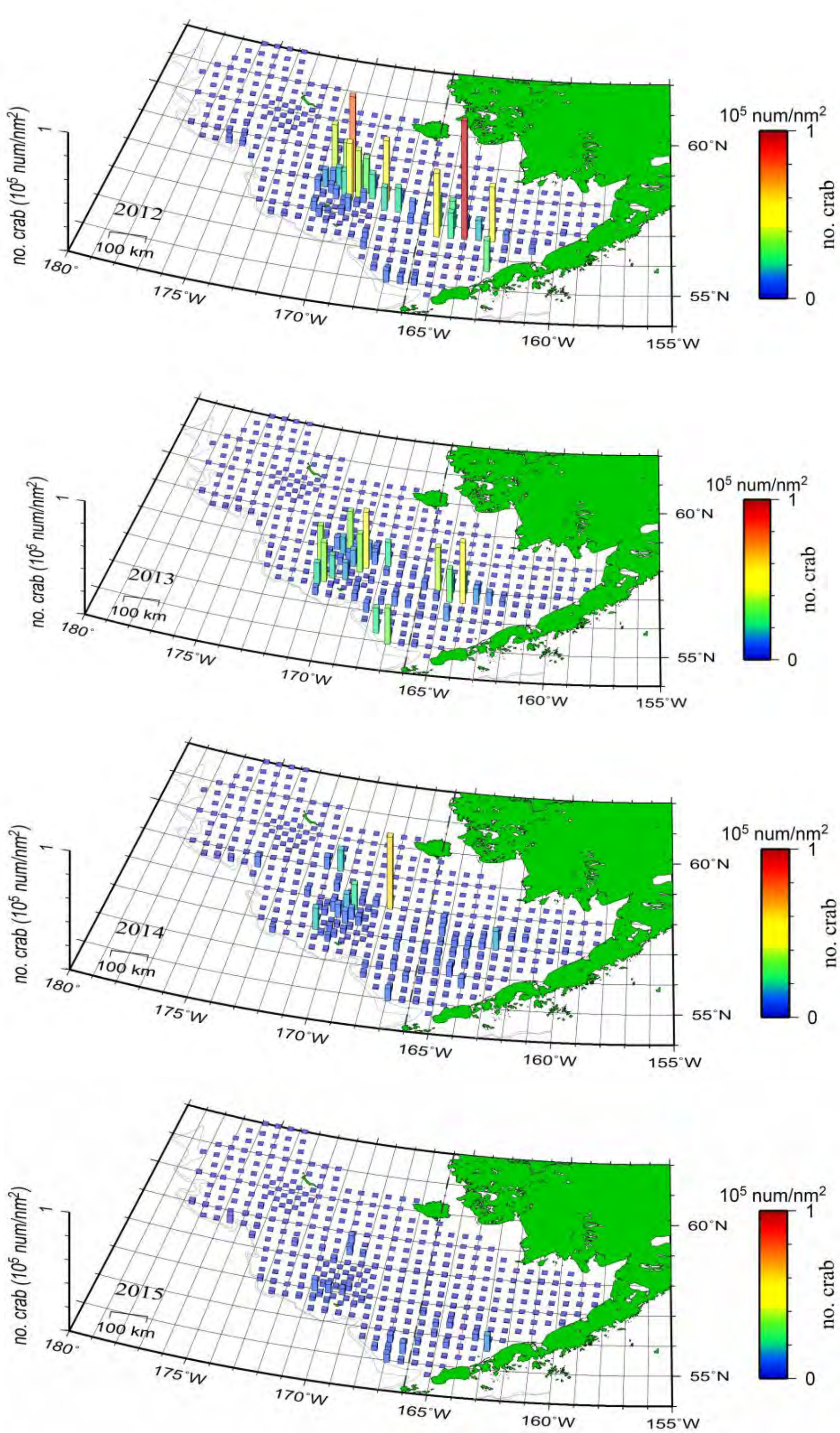


Figure 20. Distribution of immature males (number/ sq. nm) in the summer trawl survey for 2012-15.

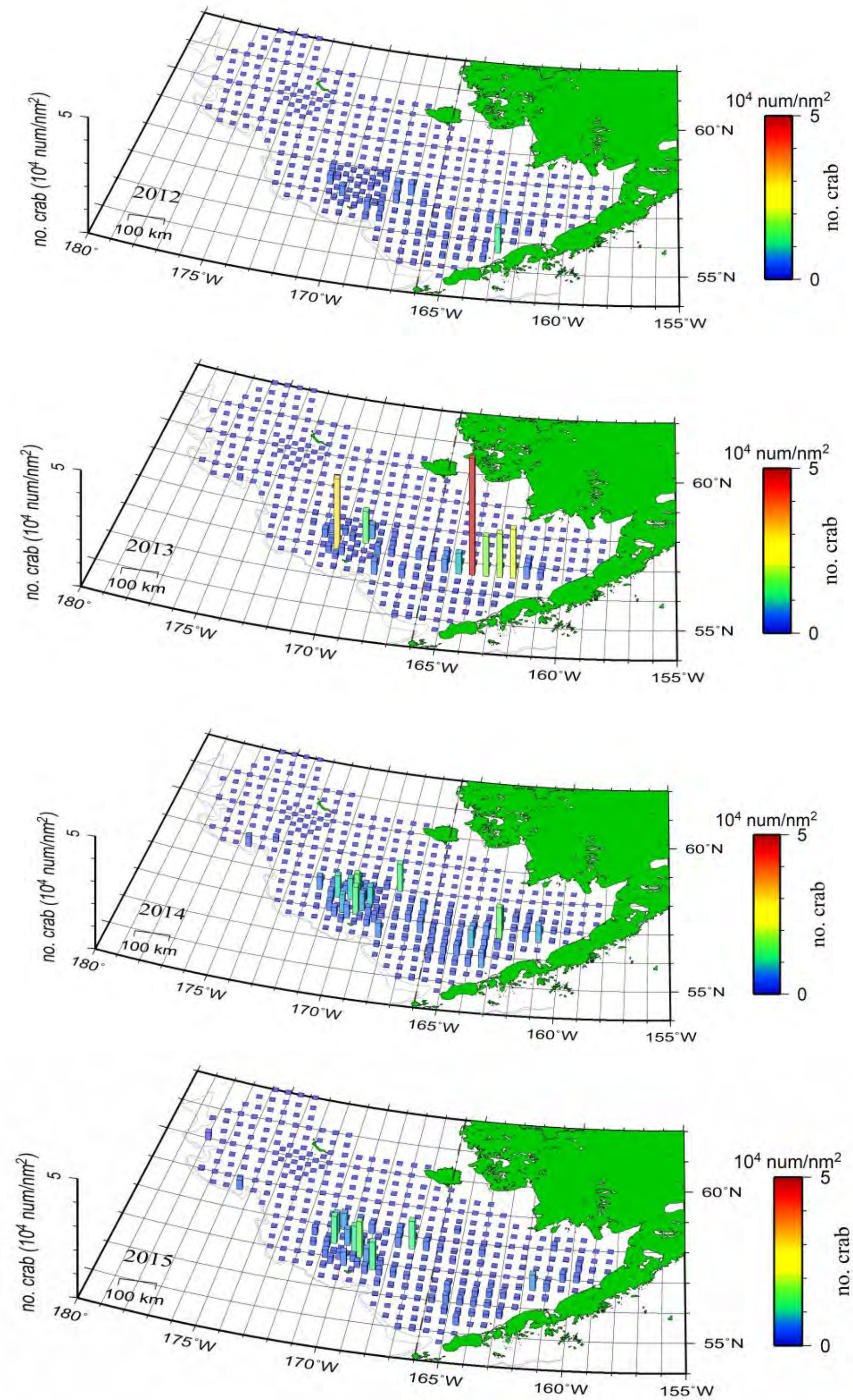


Figure 21. Distribution of mature males (number/ sq. nm) in the summer trawl survey for 2012-15.

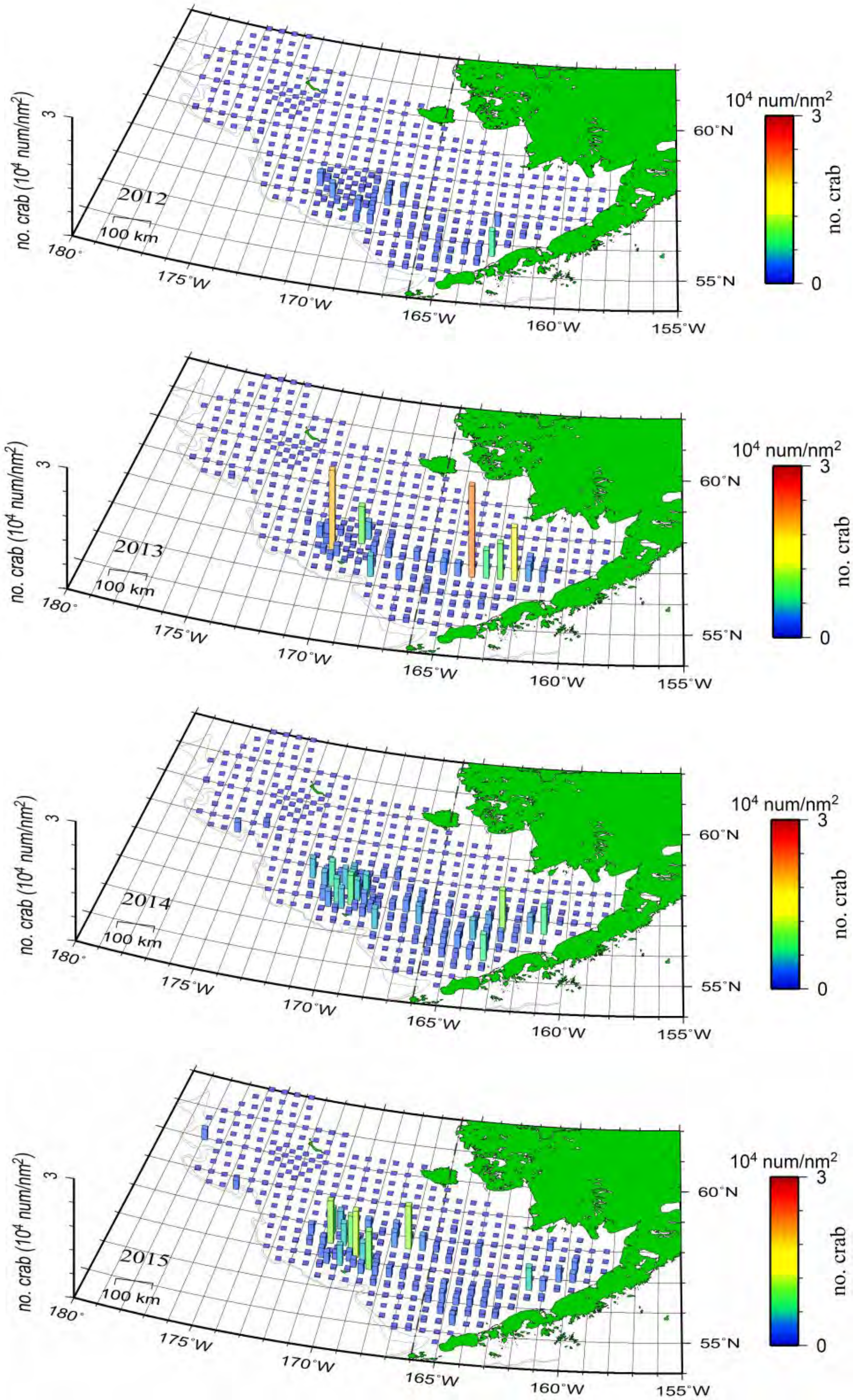


Figure 22. Distribution of legal males (≥ 110 mm CW west of 166°W, ≥ 120 mm CW east of 166°W; number/ sq. nm) in the summer trawl survey for 2012-15.

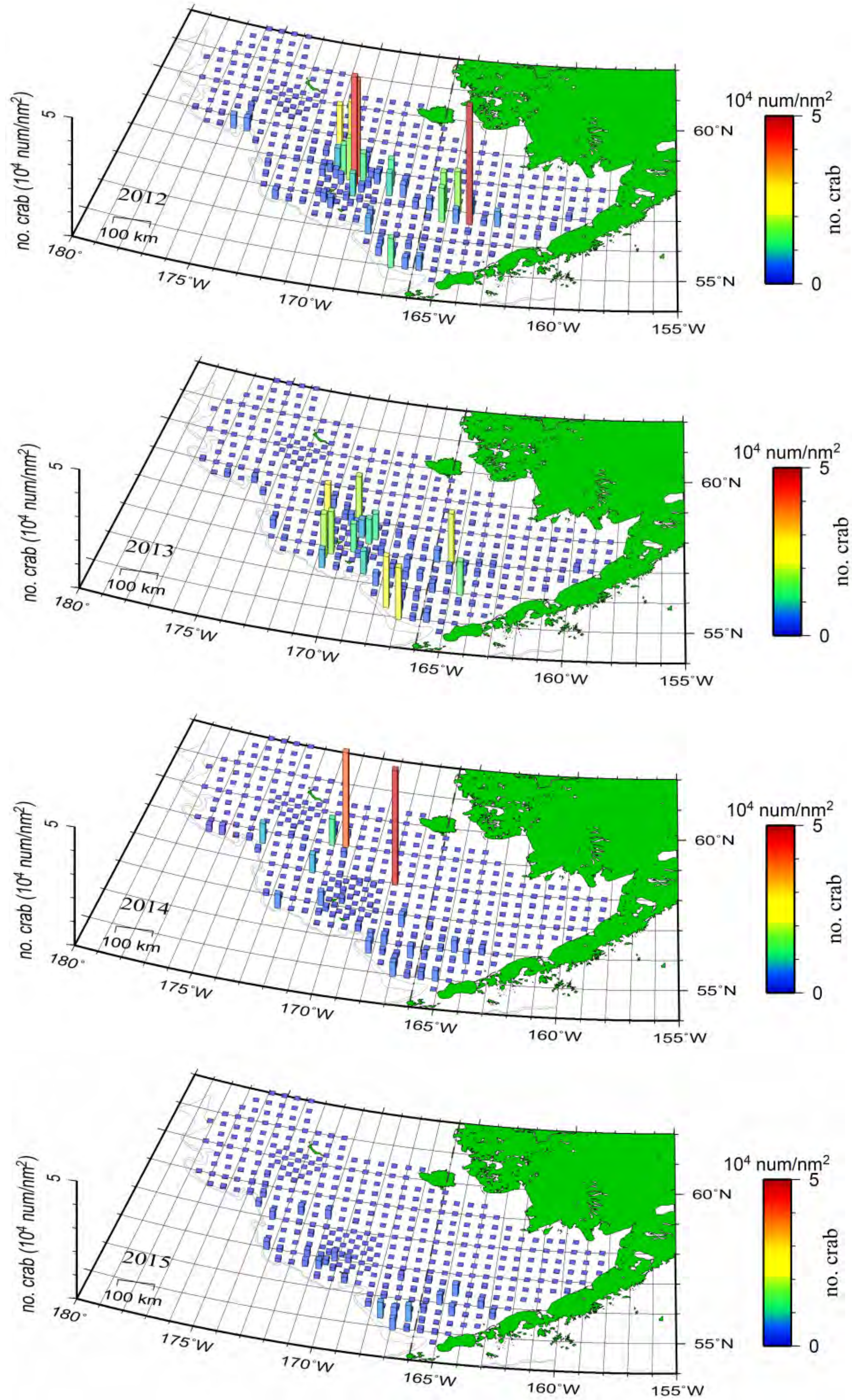


Figure 23. Distribution of immature females (number/ sq. nm) in the summer trawl survey for 2012-15.

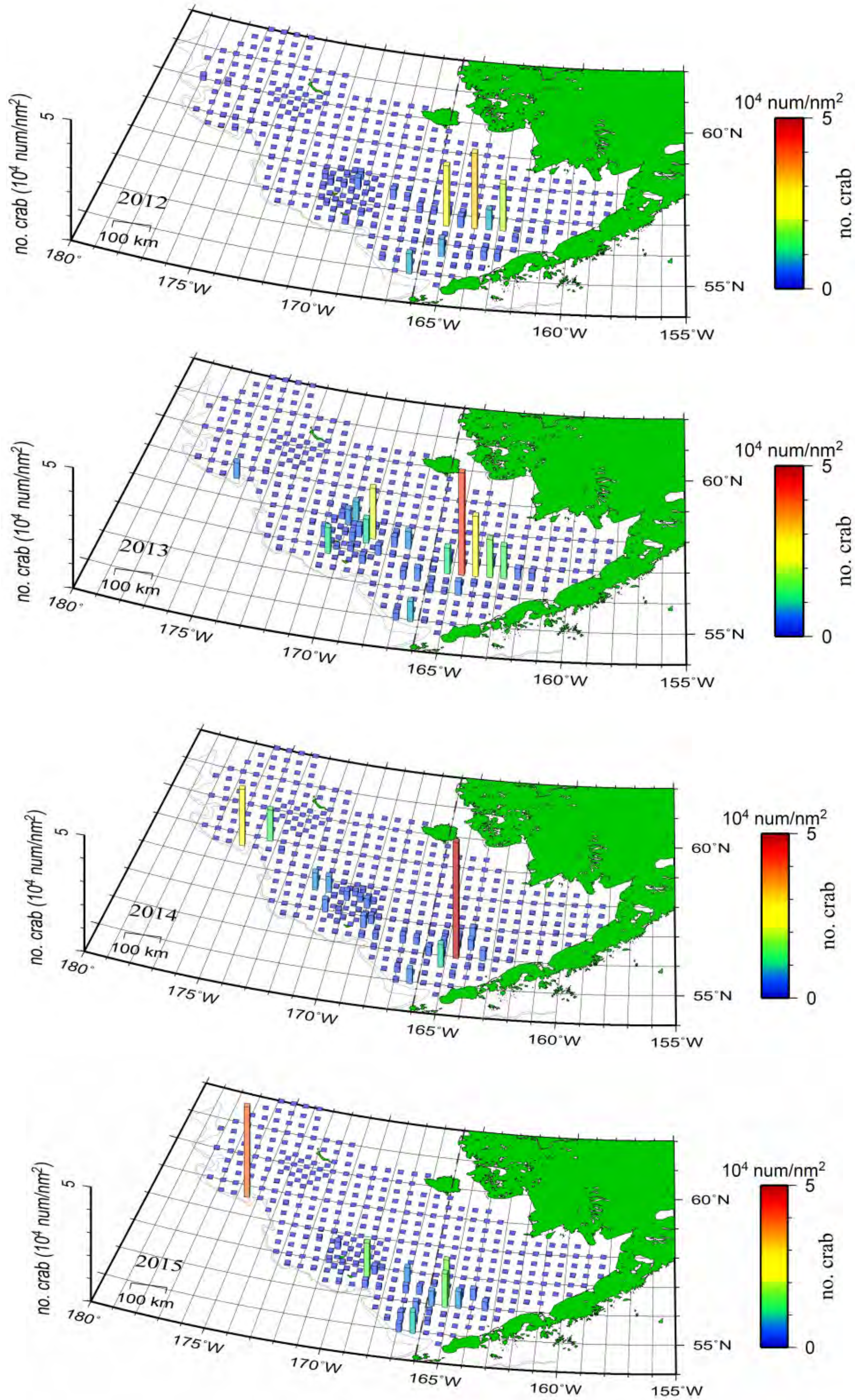
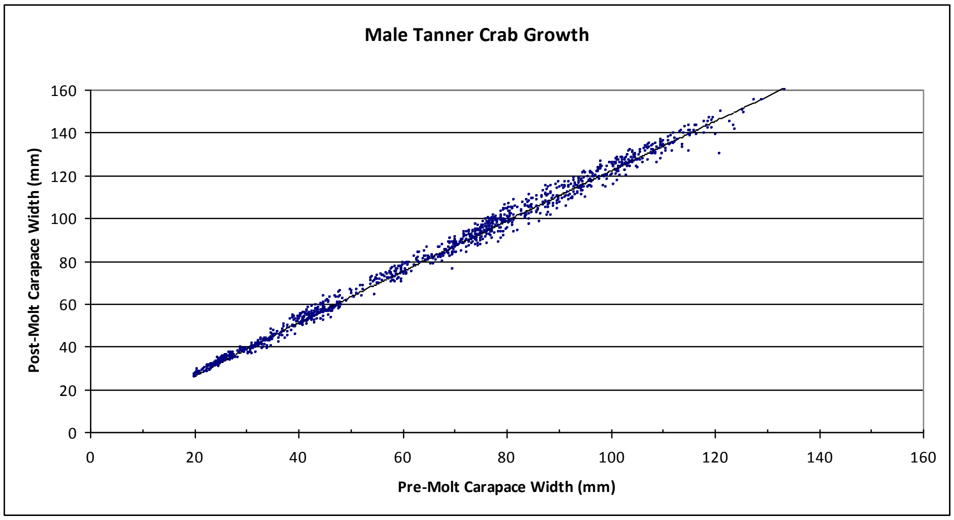


Figure 24. Distribution of mature females (number/ sq. nm) in the summer trawl survey for 2012-15.

(a)



(b)

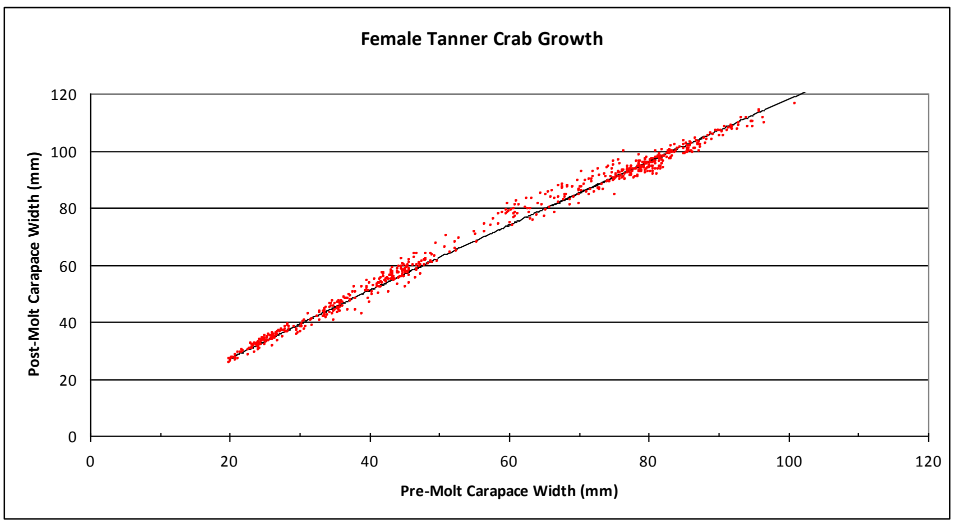


Figure 25. Growth of male (a) and female (b) Tanner crab as a function of premolt size. Estimated by Rugolo and Turnock (2010) based on data from Gulf of Alaska Tanner crab (Munk, unpublished data).

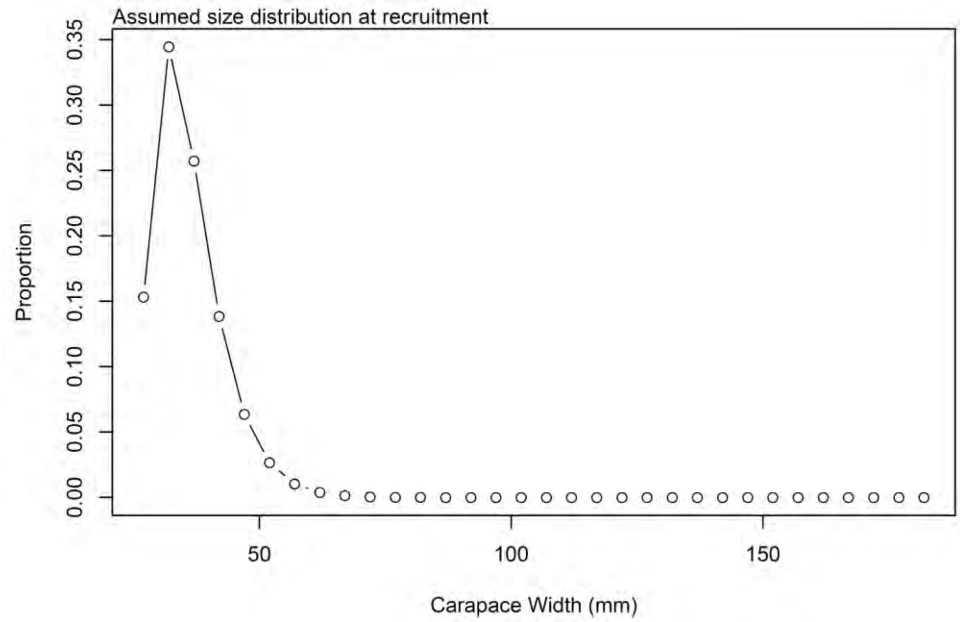


Figure 26. Assumed size distribution for recruits entering the population.

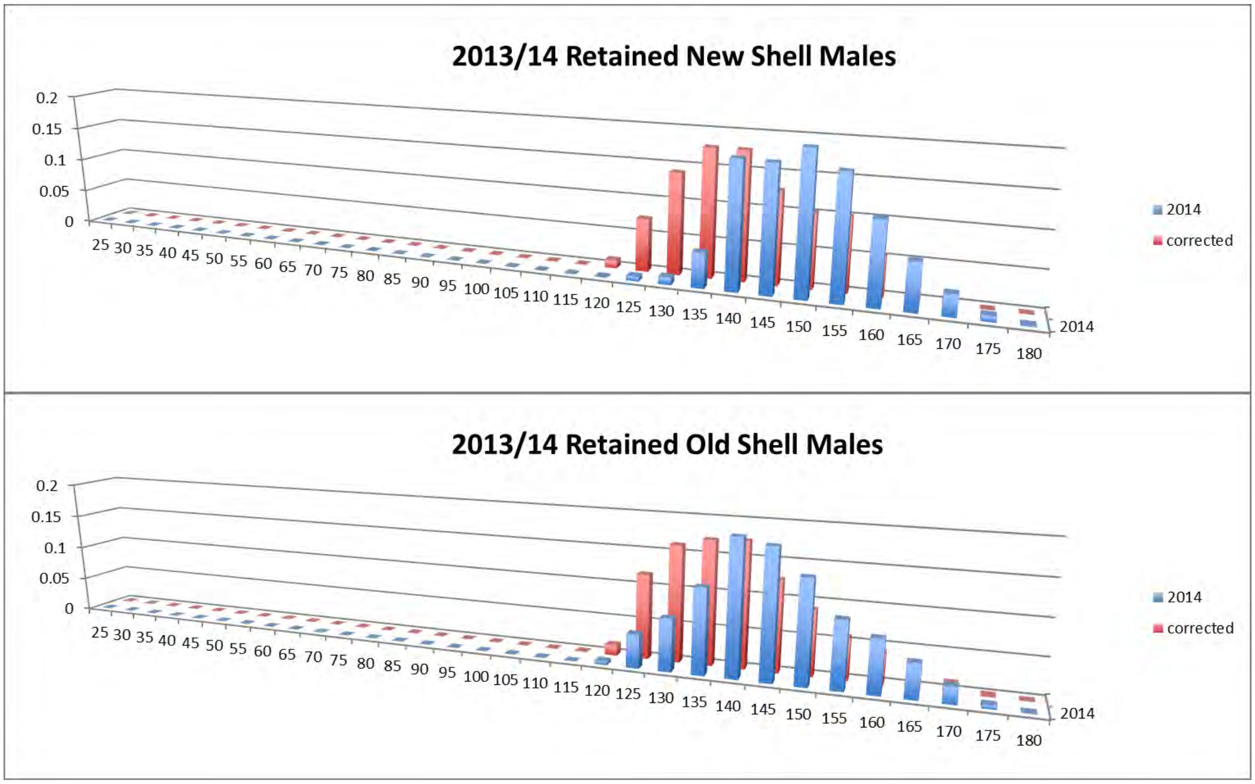


Figure 27. Comparison of 2013/14 size compositions by shell condition for retained males in the directed fishery: blue bars: those used in the 2014 assessment; red bars: corrected versions.

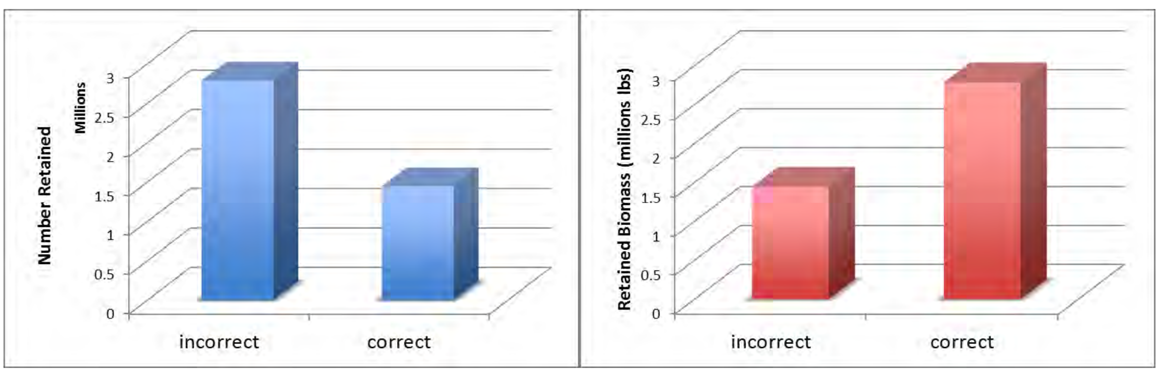


Figure 28. Comparison of 2013/14 retained numbers and biomass used in the 2014 assessment ("incorrect") and the correct values.

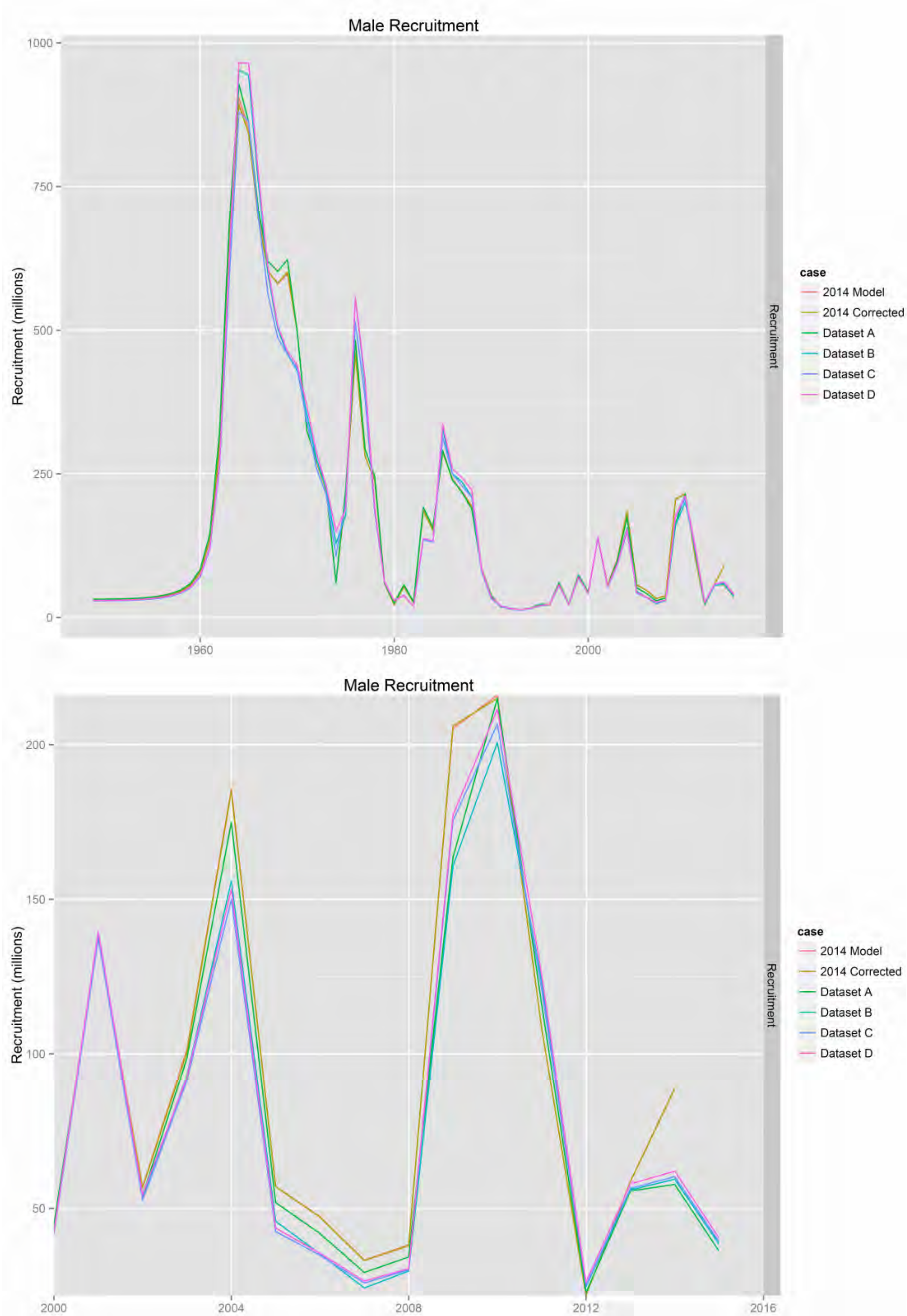
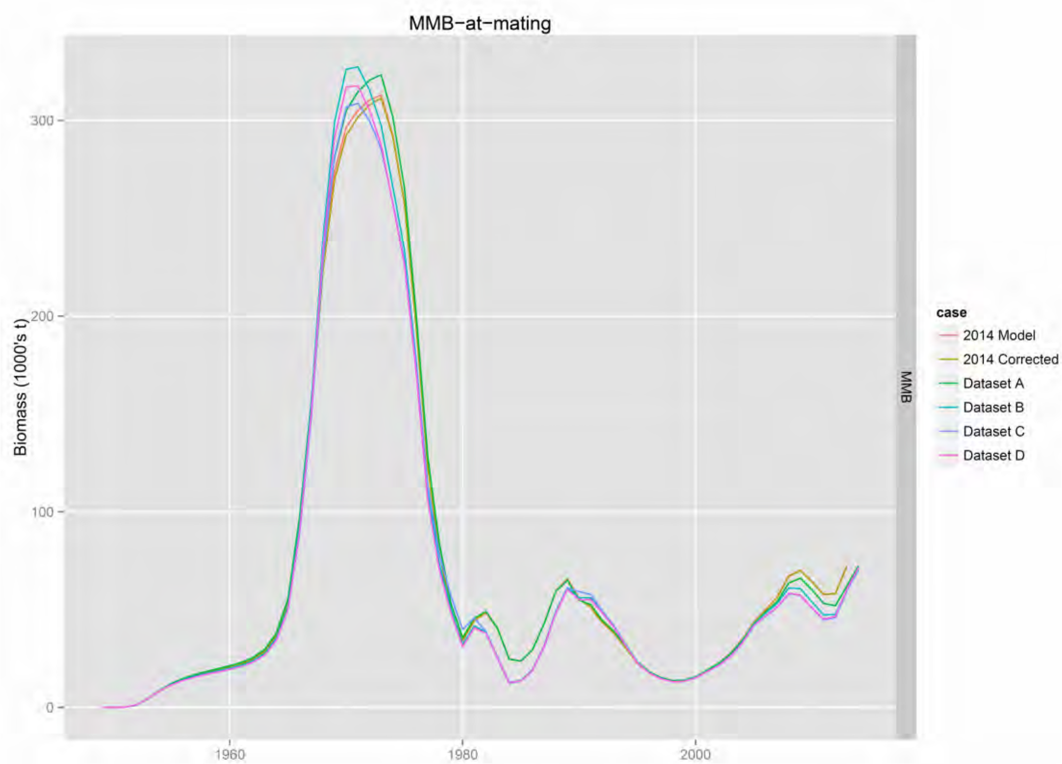


Figure 29. Estimated time series for male recruitment from running Model A on the six datasets considered in the assessment, showing the incremental progression of data changes on model results. Upper graph: entire model time period. Lower graph: 2000-present.



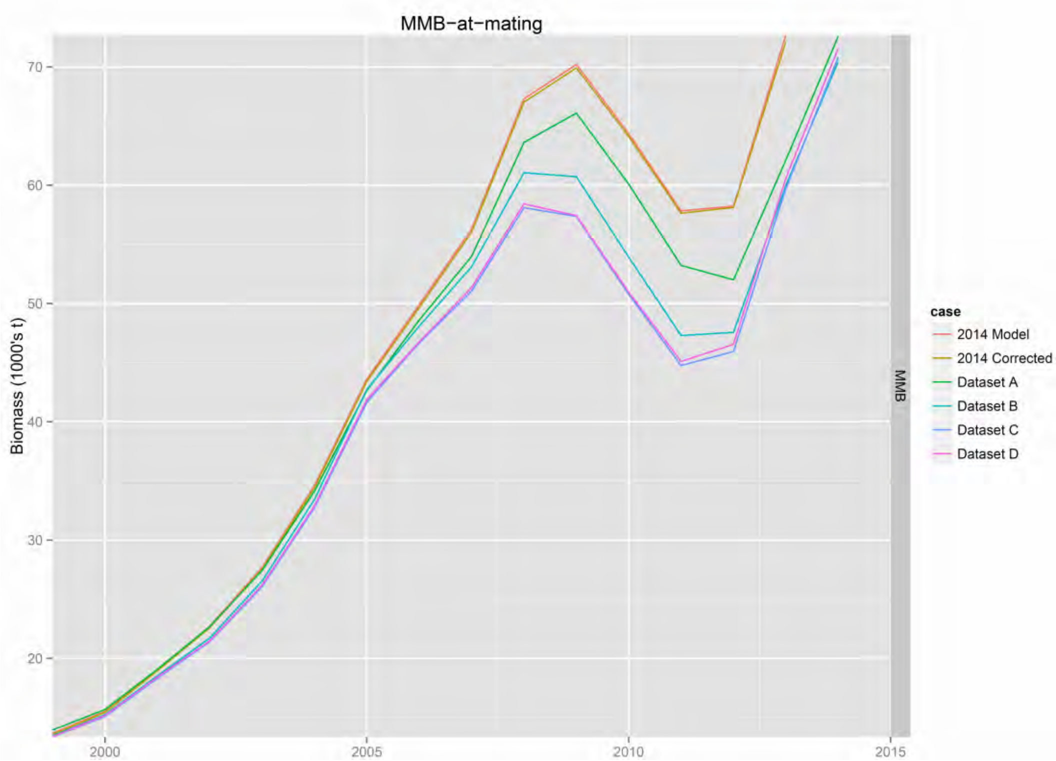


Figure 30. Estimated time series for MMB-at-mating from running Model A on the six datasets considered in the assessment, showing the incremental progression of data changes on model results. Upper graph: entire model time period. Lower graph: 1999-present.

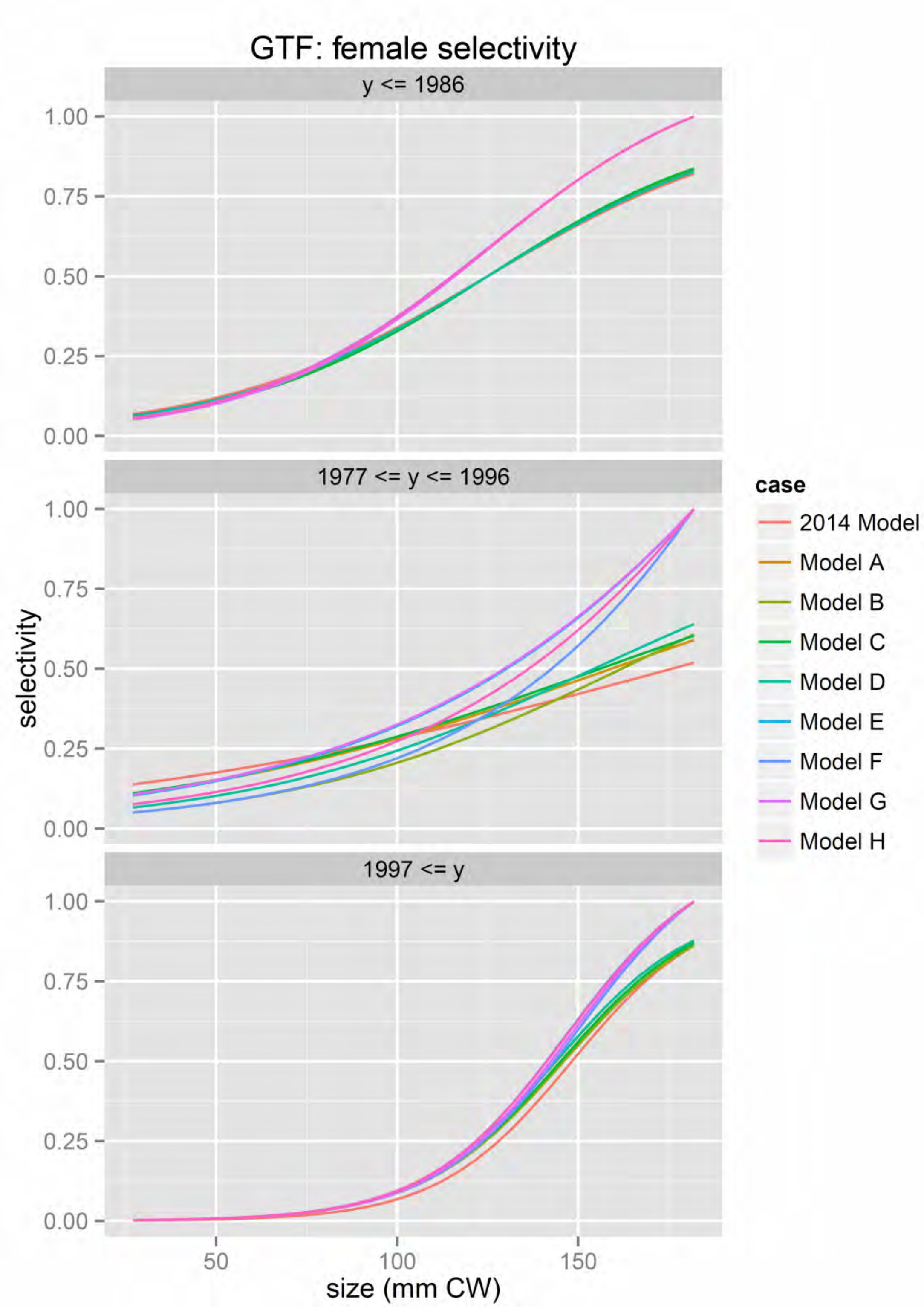


Figure 31. Comparison of estimated logistic curves for female bycatch selectivity in the groundfish trawl fisheries, illustrating the effects of forcing asymptotic selectivity to 1 in the largest model size bin.

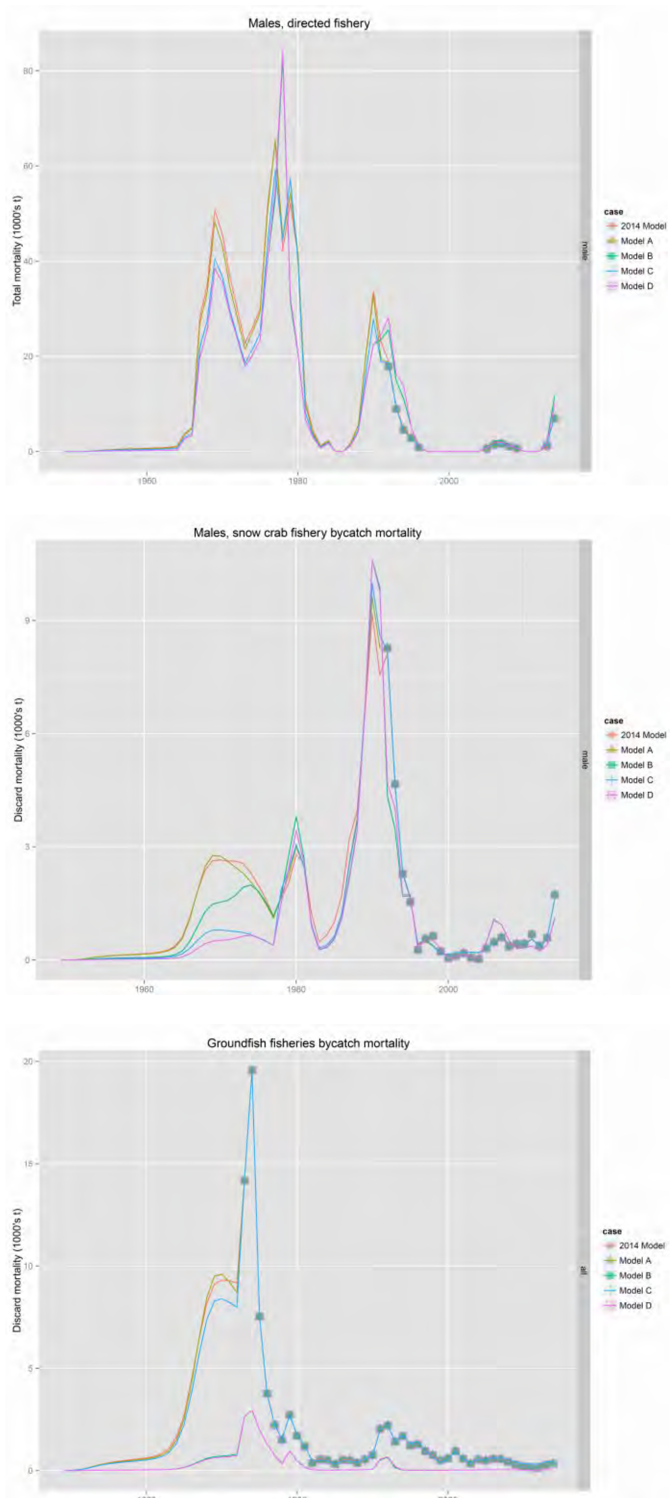


Figure 32. Comparison of fits to bycatch mortality time series in the directed fishery (top graph), the snow crab fishery (center graph) , and the groundfish fisheries (bottom graph) from the 2014 assessment and the alternative models A-D run against Dataset D.

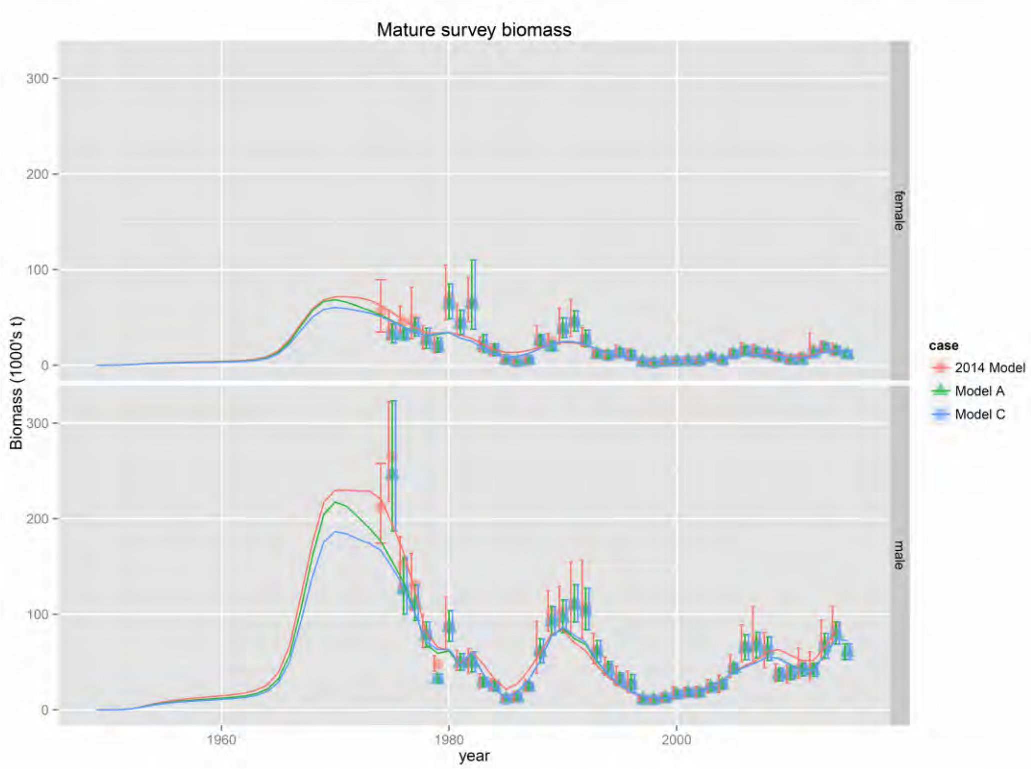


Figure 33. Comparison for fits to mature survey biomass from the 2014 assessment and Models A and C run against Dataset D. Error bars represent 80% confidence intervals based on cv's for survey biomass. They have also been offset slightly horizontally so they don't overlap completely.

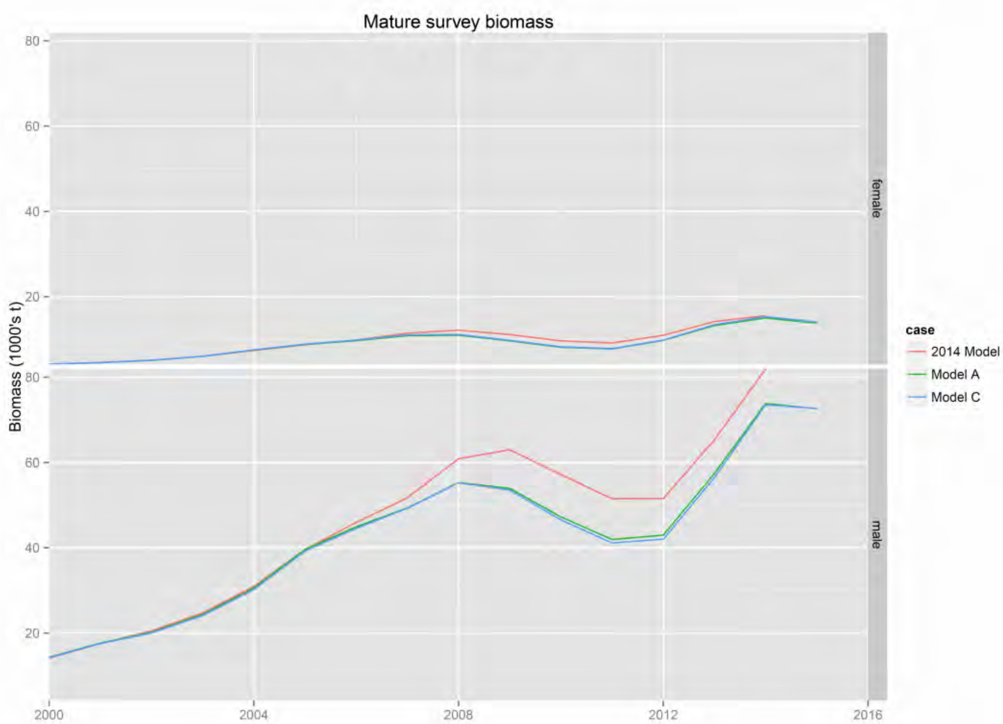


Figure 34. Estimates of mature survey biomass from the 2014 assessment and Models A and C run against Dataset D since 2000.

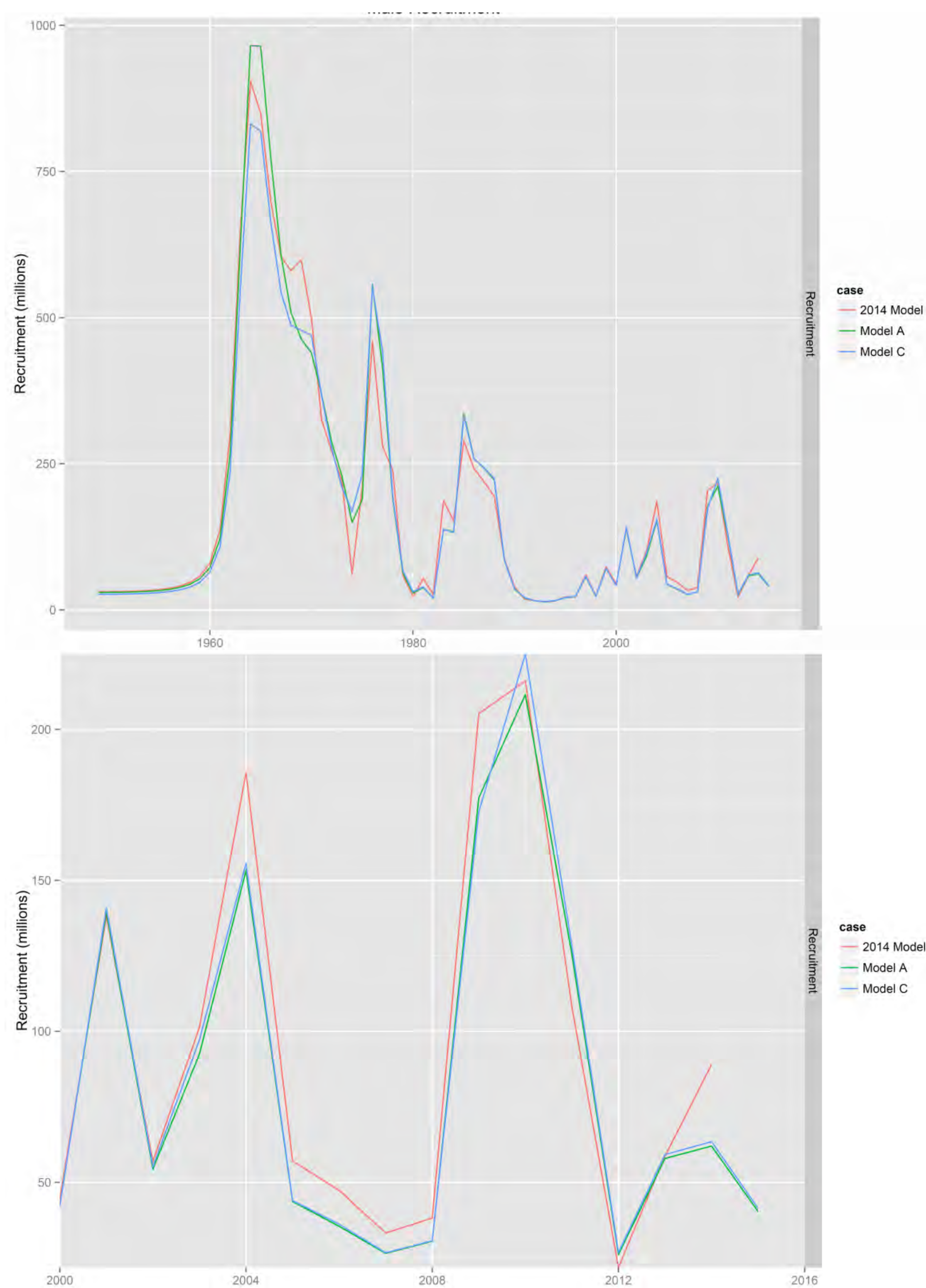


Figure 35. Estimates of male recruitment from the 2014 assessment and Models A and C run against Dataset D since 2000.

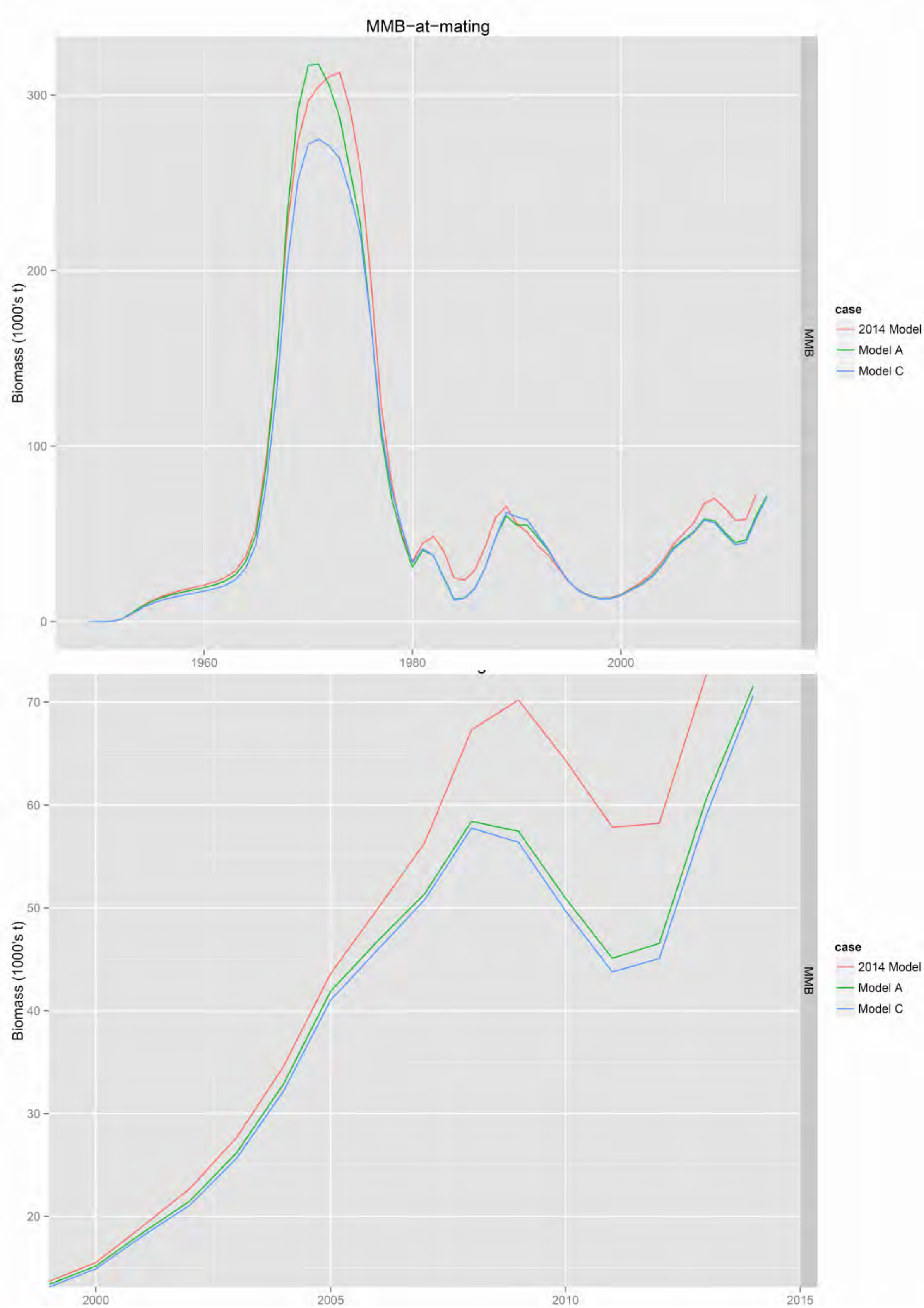


Figure 36. Estimates of MMB-at-mating from the 2014 assessment and Models A and C run against Dataset D since 2000.

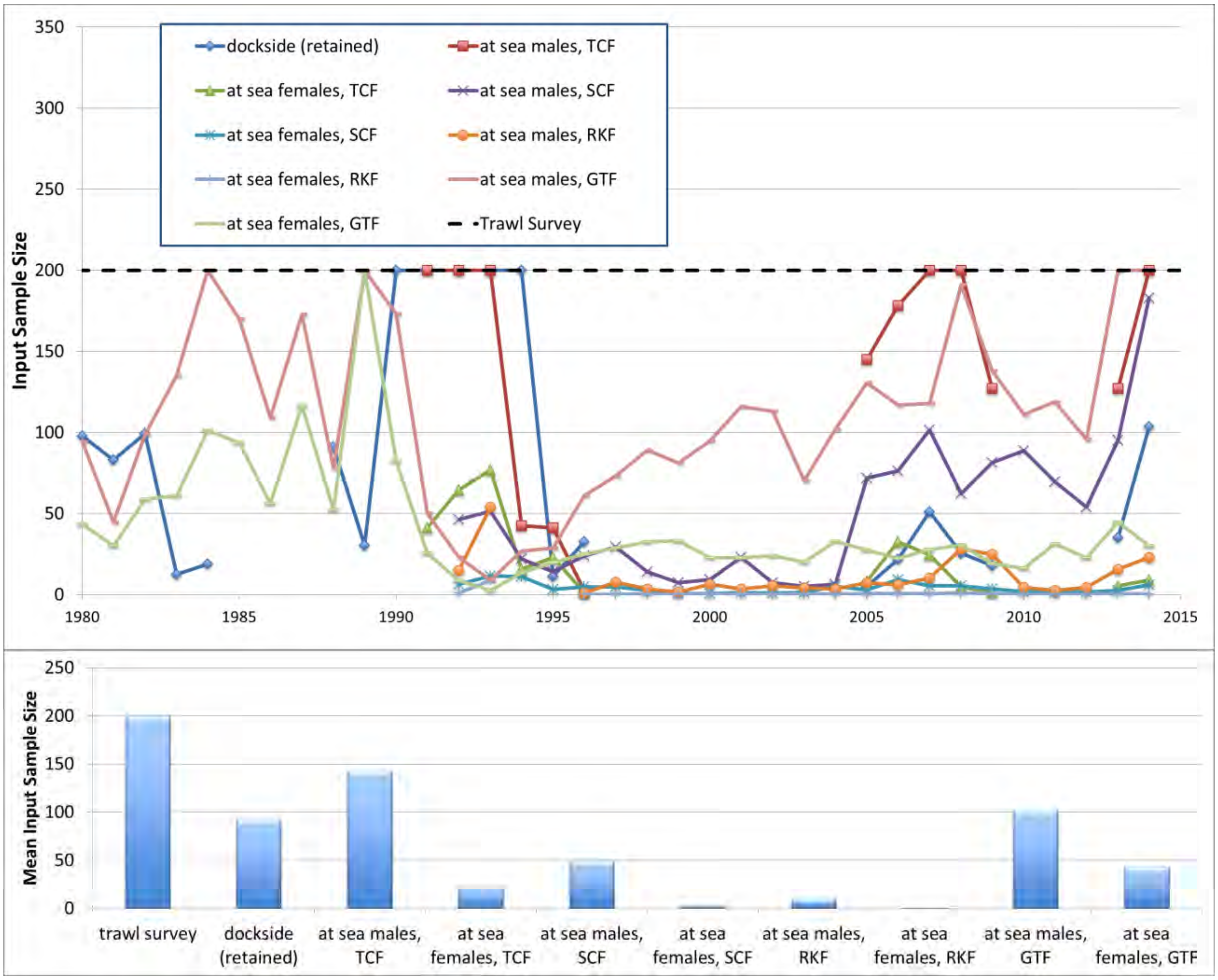


Figure 37. Input sample sizes for by size composition in Dataset D. Upper graph: by year. Lower graph: mean values.

Figure 38.Objective function penalties for Model C, relative to Model A (Model C – Model A). Positive values indicate Model A has a smaller penalty than Model C.

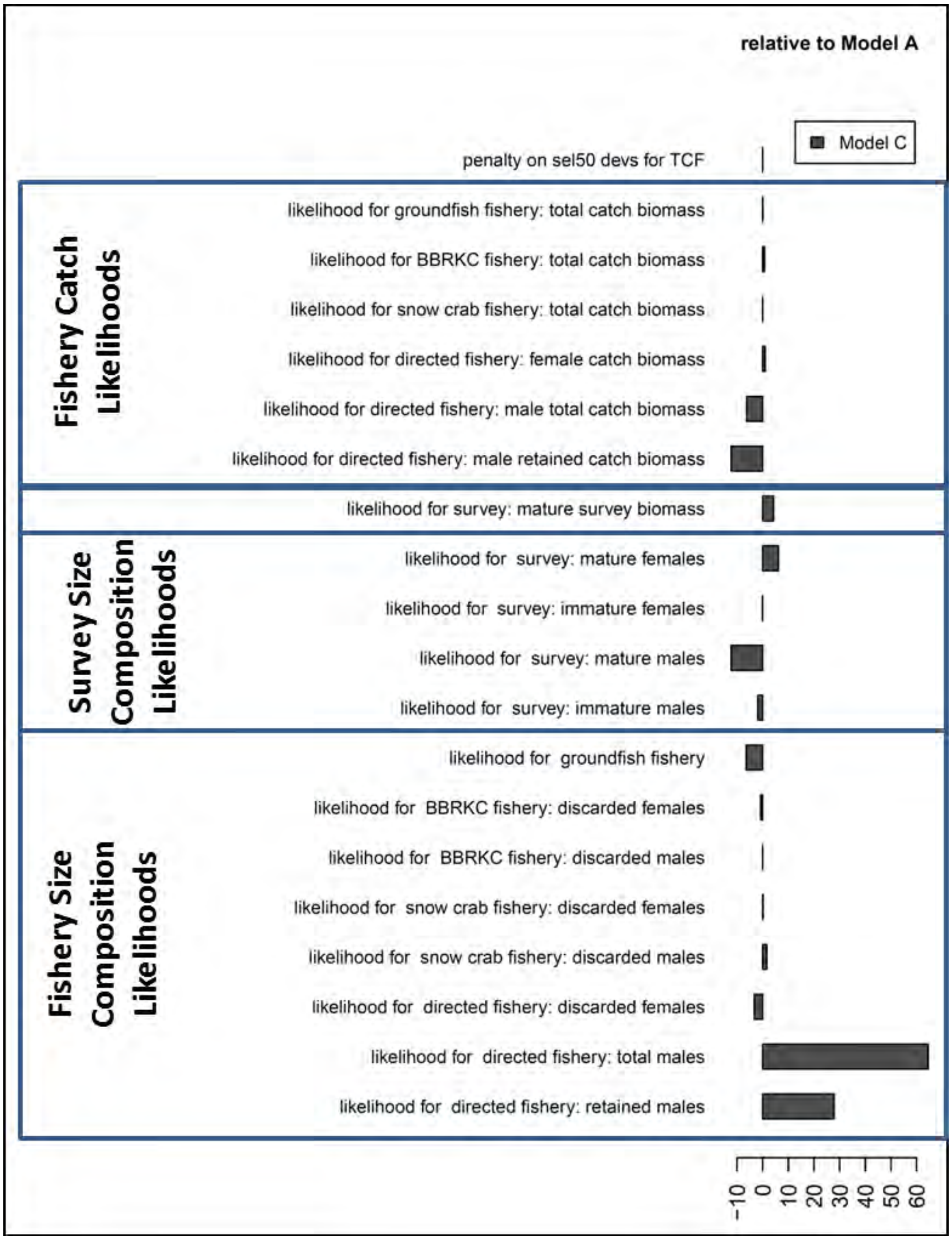


Figure 39.Objective function penalty and data (weighted negative log-likelihood) components for Model C relative to Model A (Model C – Model A). Positive values indicate Model A has a smaller penalty or fits the data better than Model C (this convention is opposite to that used in Table 23).

Model A Model C

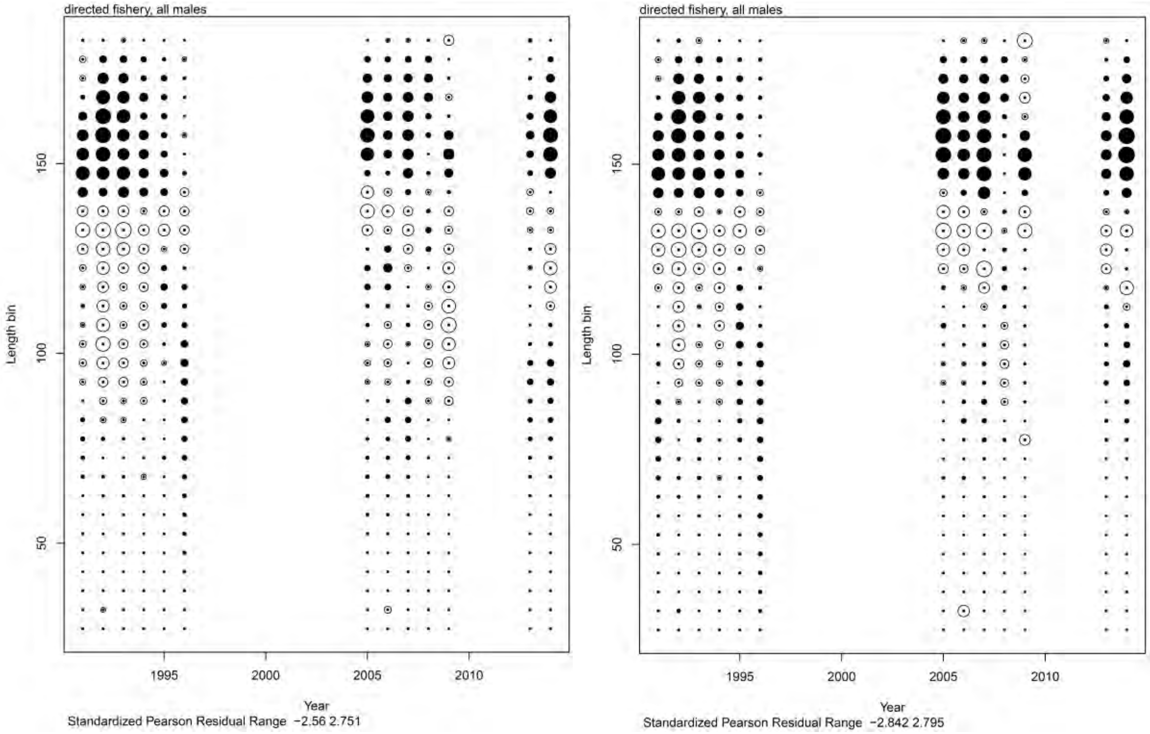


Figure 40.Comparison of Pearson's residuals from the fits to total male catch size compositions in the directed fishery for Models A (left) and C (right). Scales for Model C are slightly larger than for A.

Model A Model C

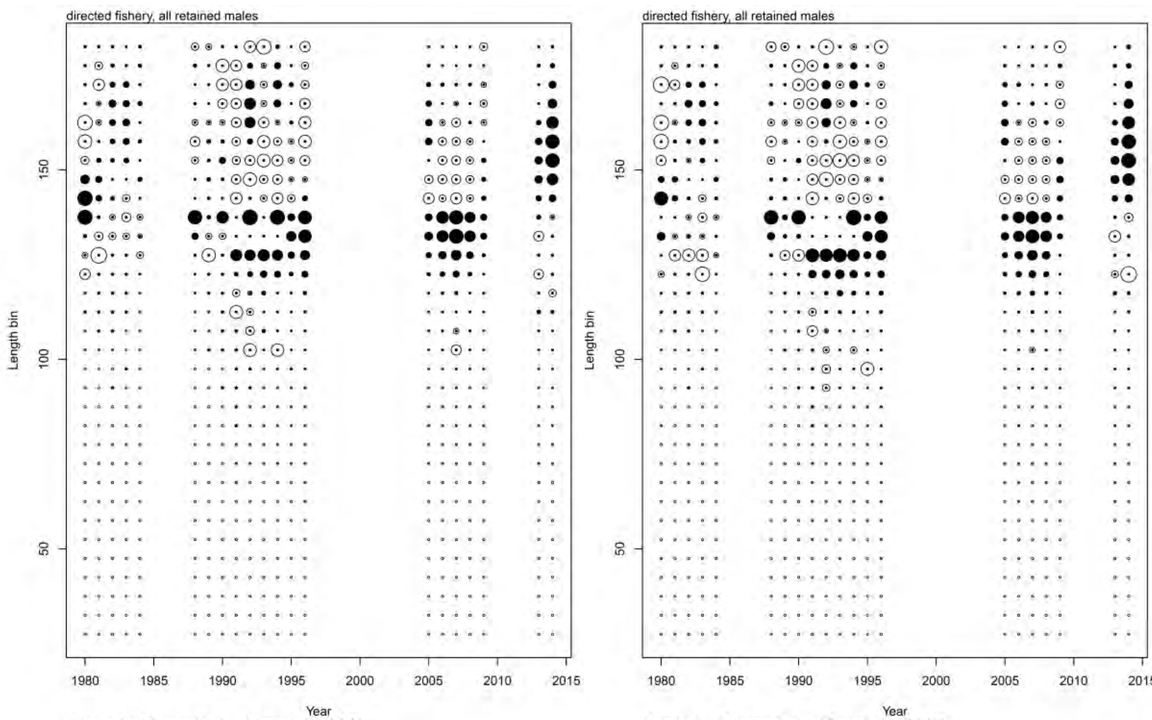


Figure 41.Comparison of Pearson's residuals from the fits to retained catch size compositions for Models A (left) and C (right). Note: the scales are not quite identical.

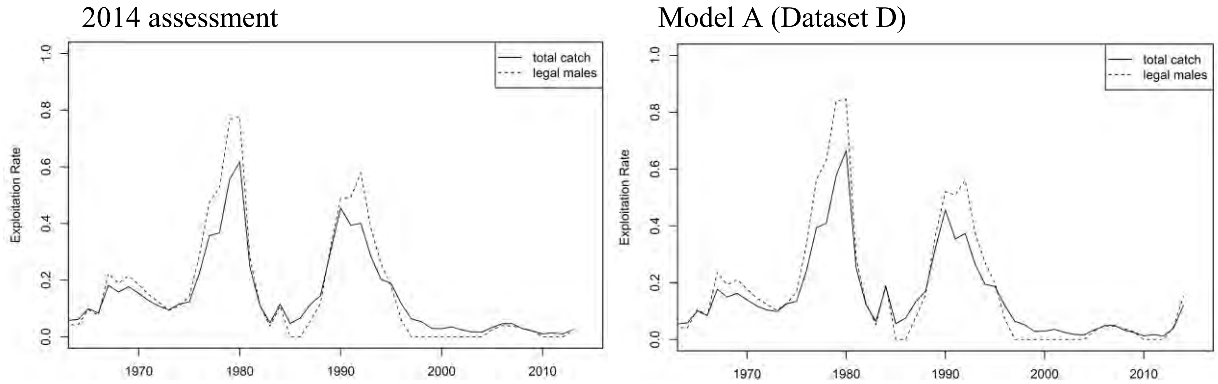


Figure 42. Estimated exploitation rates in the directed fishery for total catch and males ≥ 138 mm CW from the 2014 assessment and the author's preferred model.

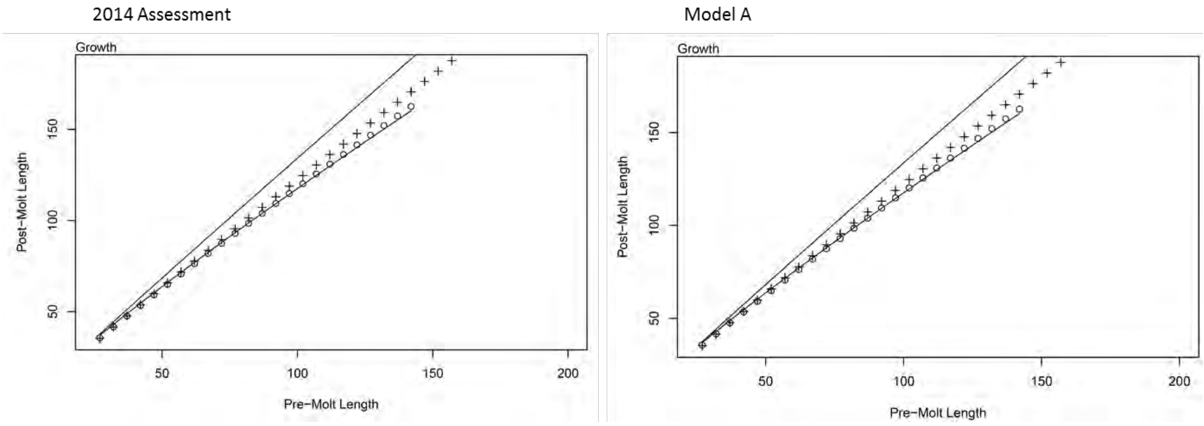


Figure 43. Comparison of mean growth curves from the 2014 assessment and Model A (Dataset D). Solid lines: model estimates (upper = males, lower=females). Symbols: empirical curves ("+": males, "o"=females) developed from Tanner crab growth data near Kodiak Island in the Gulf of Alaska (Courtesy of E. Munk, AFSC Kodiak).

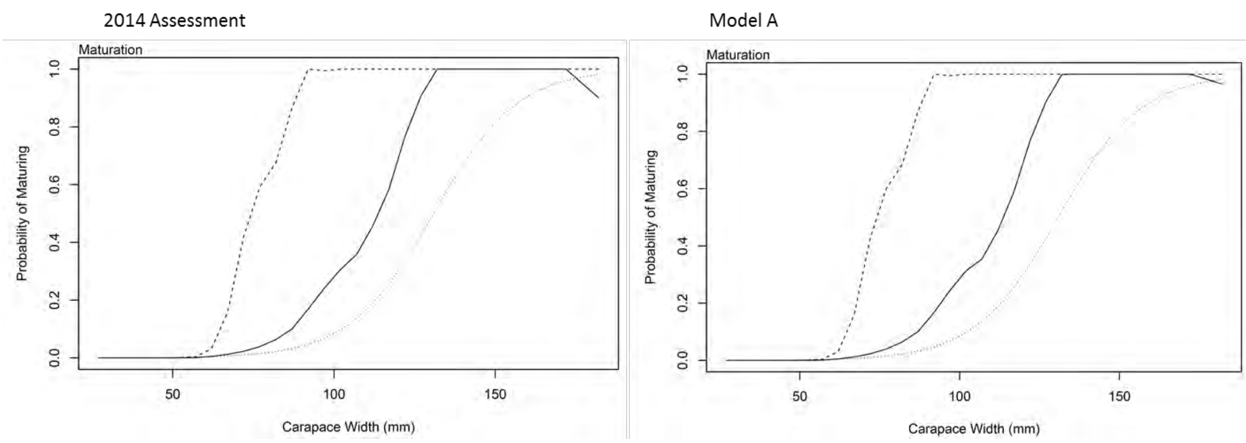


Figure 44. Comparison of probability of maturing from the 2014 assessment and Model A (Dataset D). Solid lines: males, dashed lines=females. The dotted line was used in the analysis for Amendment 24.

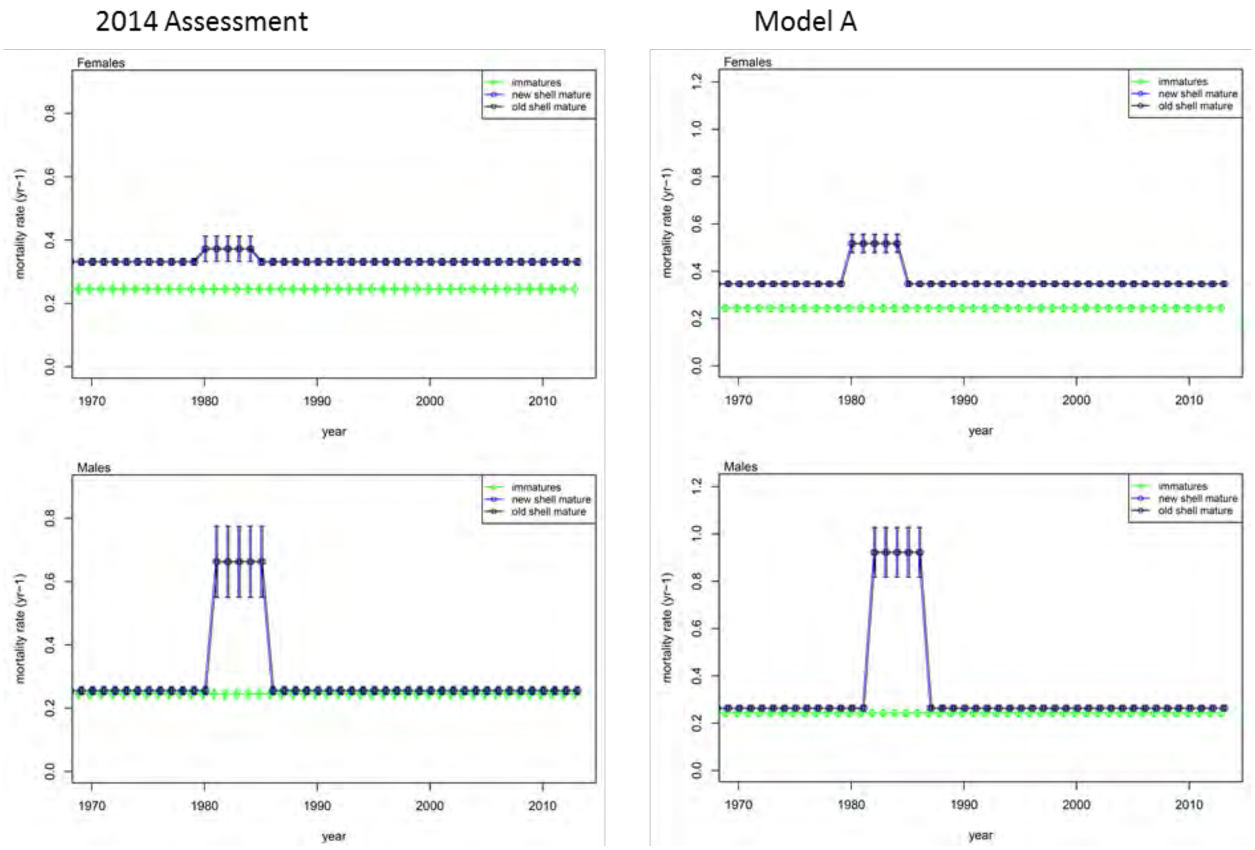


Figure 45. Estimated natural mortality for immature (single time period: 1949-2013) and mature (two time periods: 1949-1979+2005-2013 and 1980-1984) crab by sex (upper graph: females; lower graph: males).

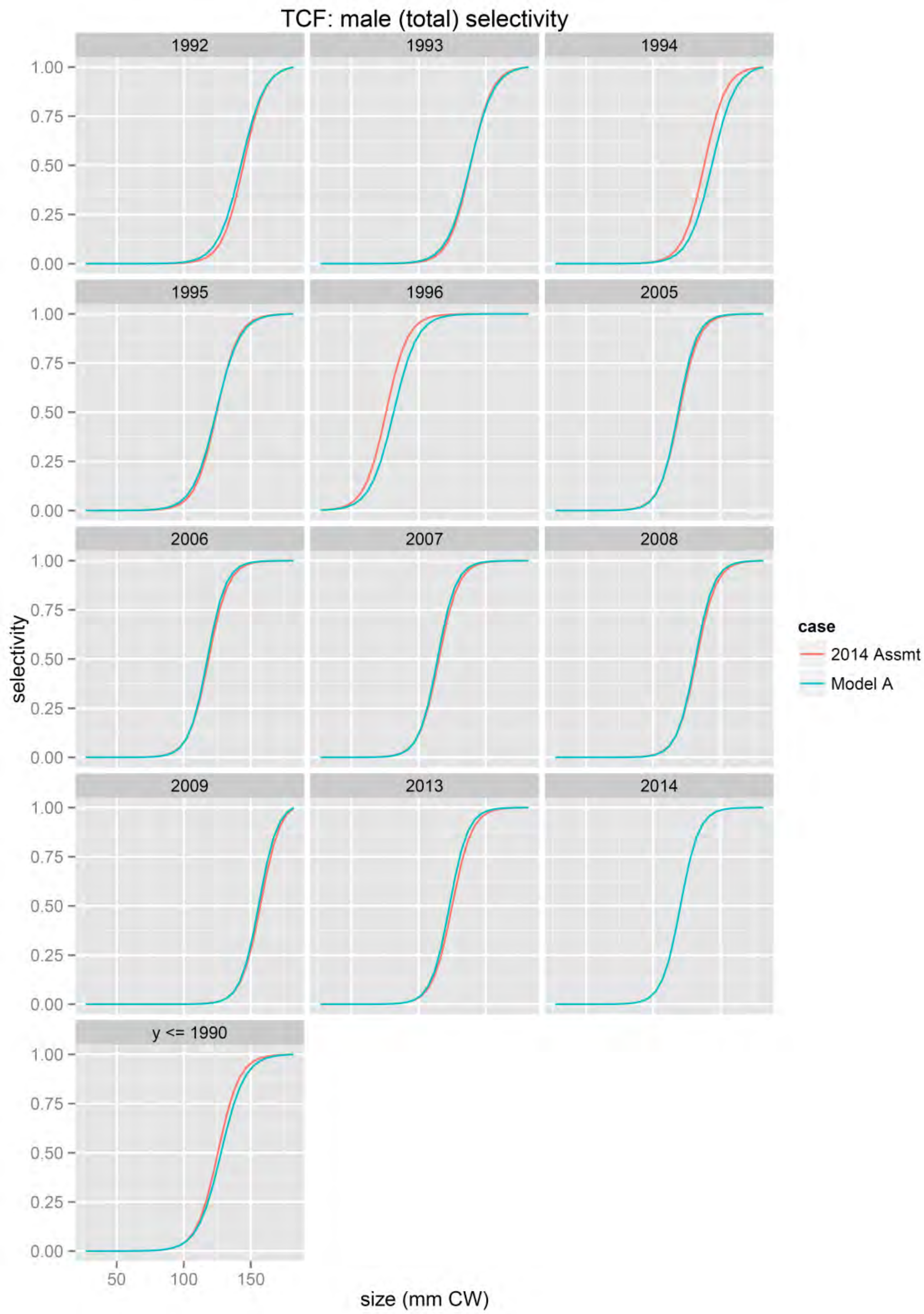


Figure 46. Comparison of estimated total male fishing mortality selectivity curves in the directed fishery.

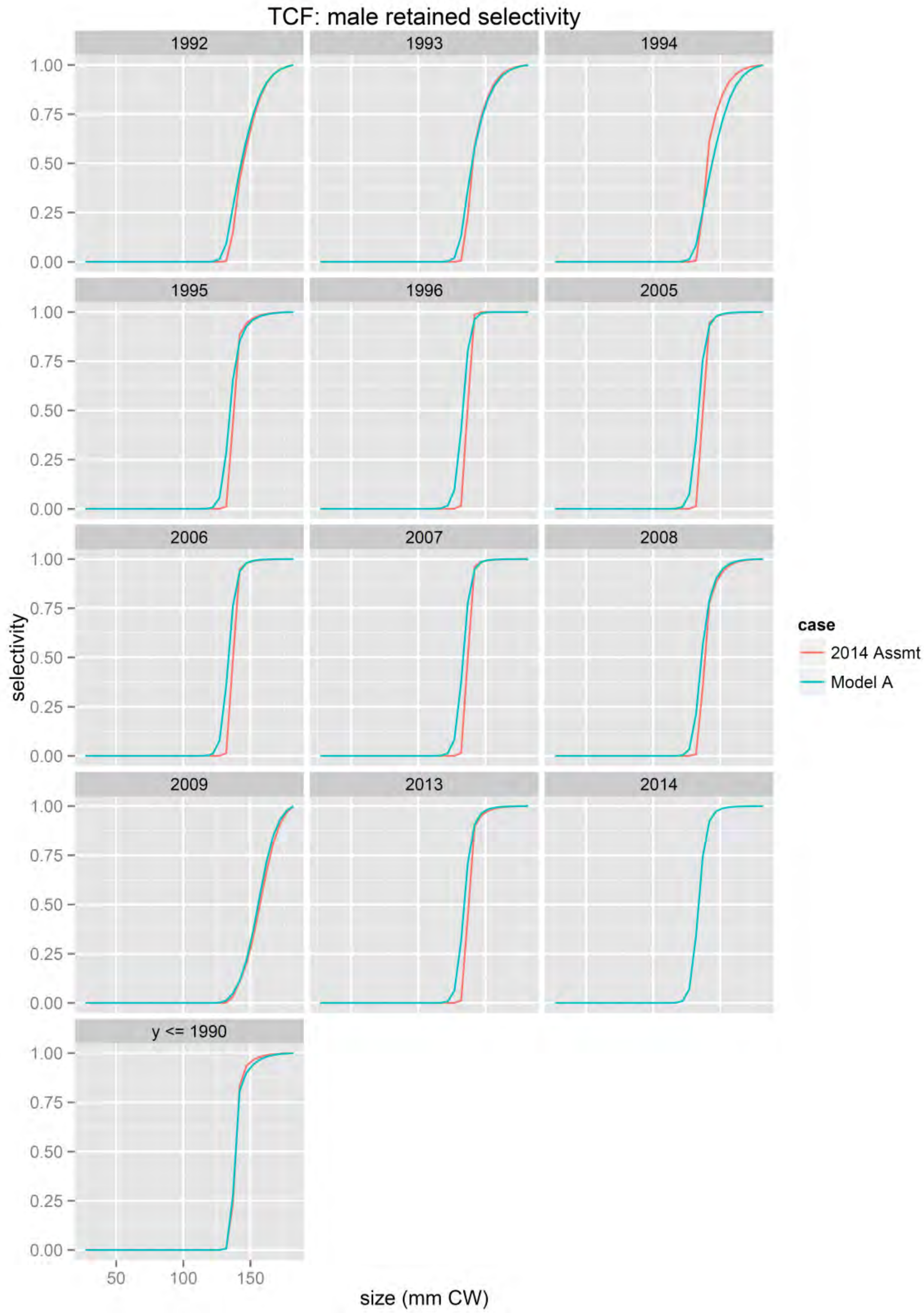


Figure 47. Comparison of estimated male retained mortality selectivity curves in the directed fishery (TCF = Tanner crab fishery).

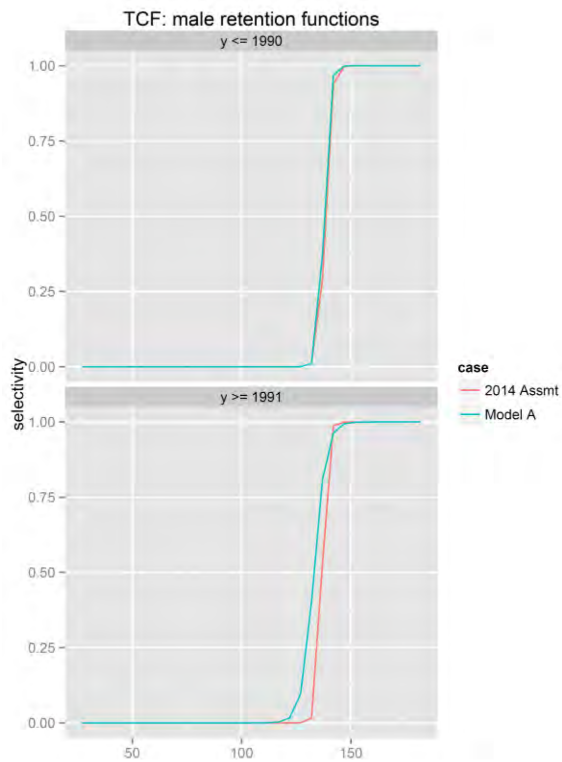


Figure 48. Comparison of retention curves in the directed Tanner crab fishery (TCF).

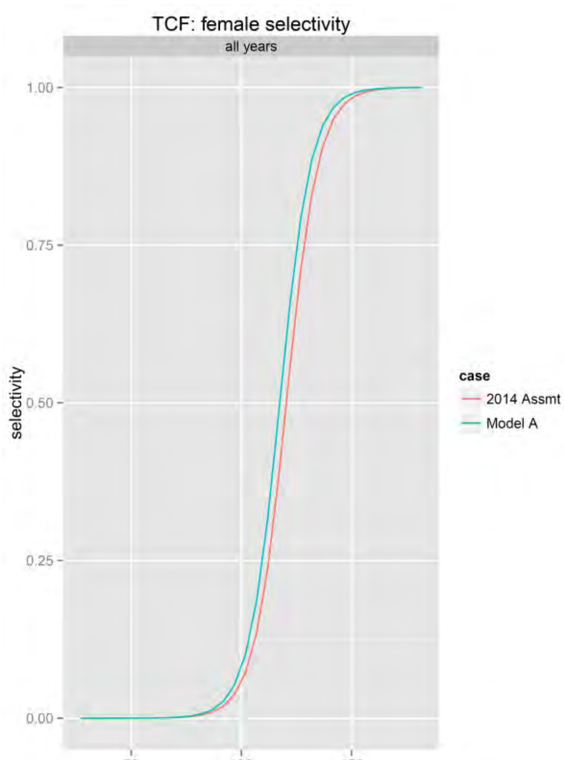


Figure 49. Comparison of estimated female bycatch selectivity in the directed Tanner crab fishery (TCF).

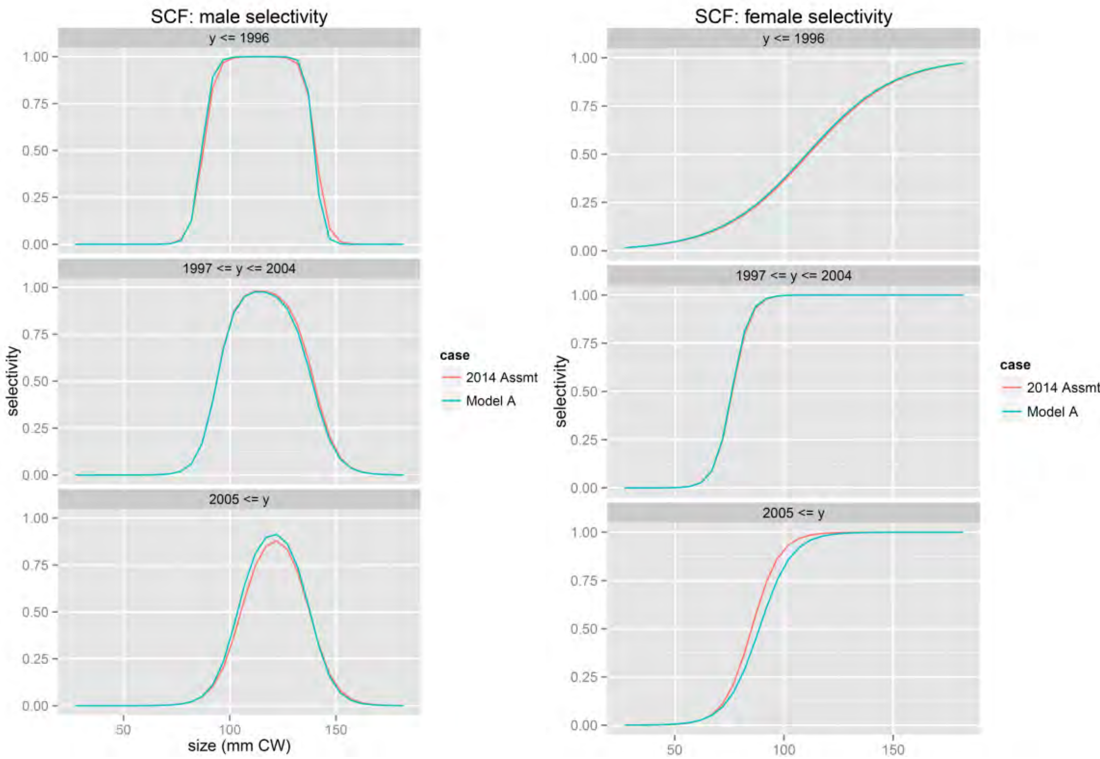


Figure 50. Estimated sex-specific bycatch selectivity functions in the snow crab fishery (SCF).

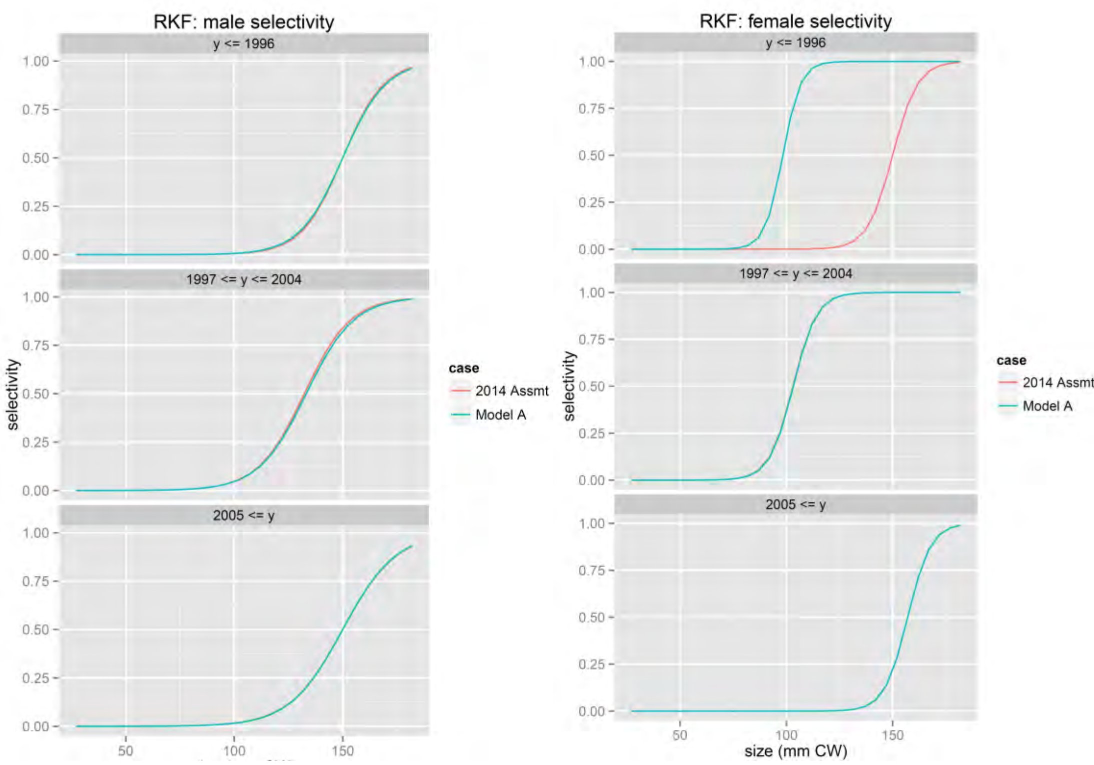


Figure 51. Estimated bycatch selectivity functions in theBBRKC fishery (RKF).

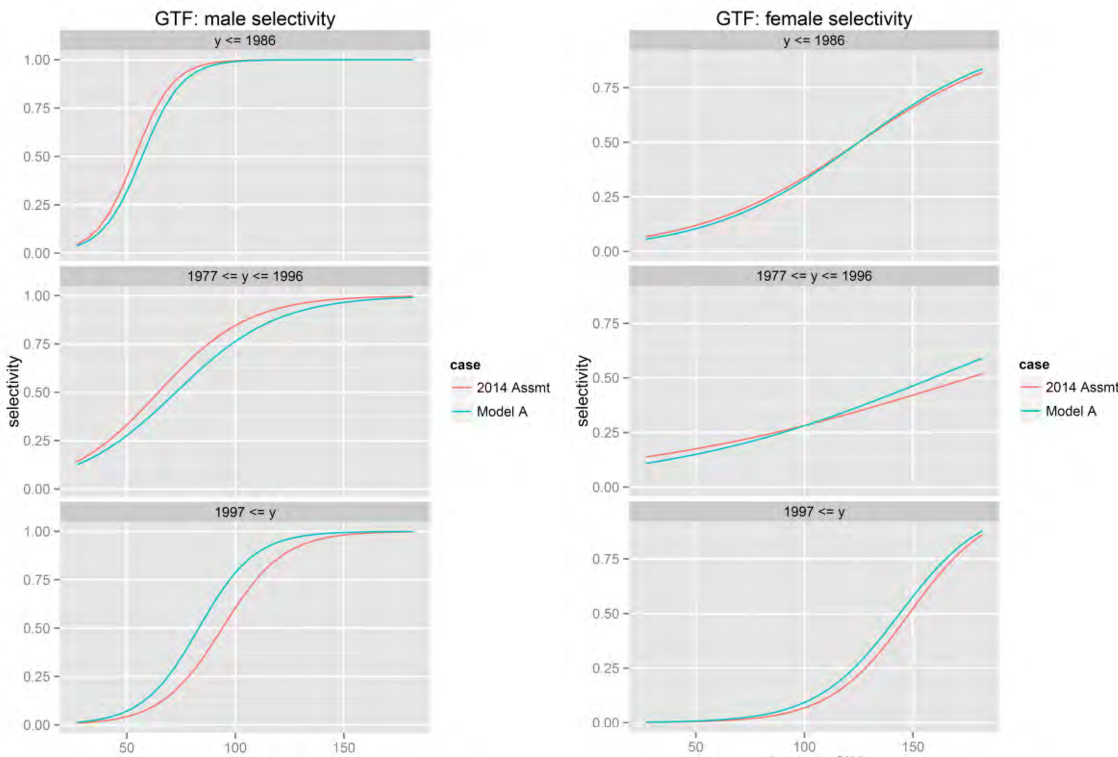


Figure 52. Estimated bycatch selectivity in the groundfish fisheries (GTF).

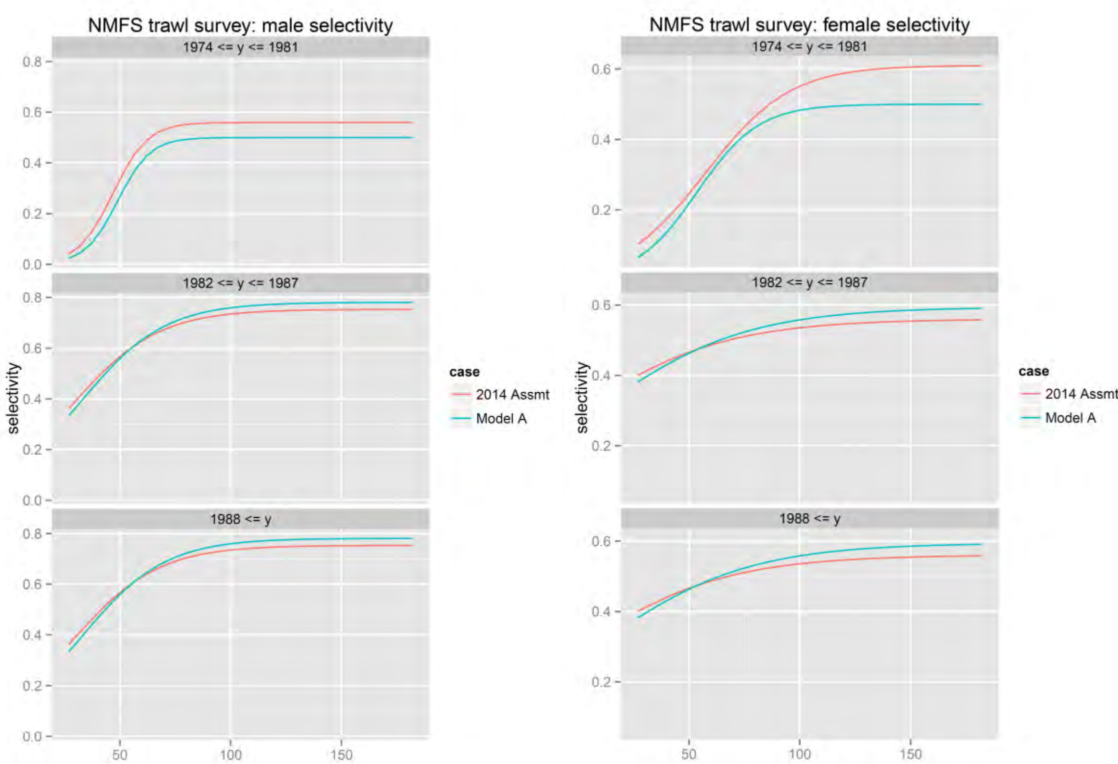


Figure 53. Estimated NMFS trawl survey selectivities, scaled by sex-specific catchability.

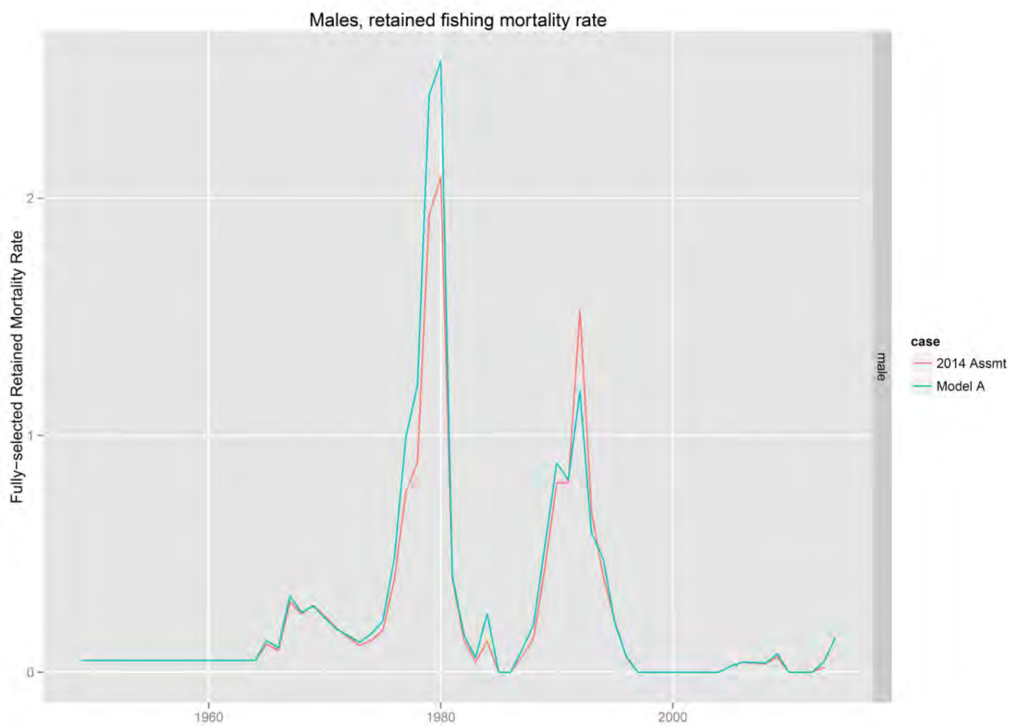


Figure 54. Comparison of estimated fully-selected fishing mortality rate on males in the directed fishery.

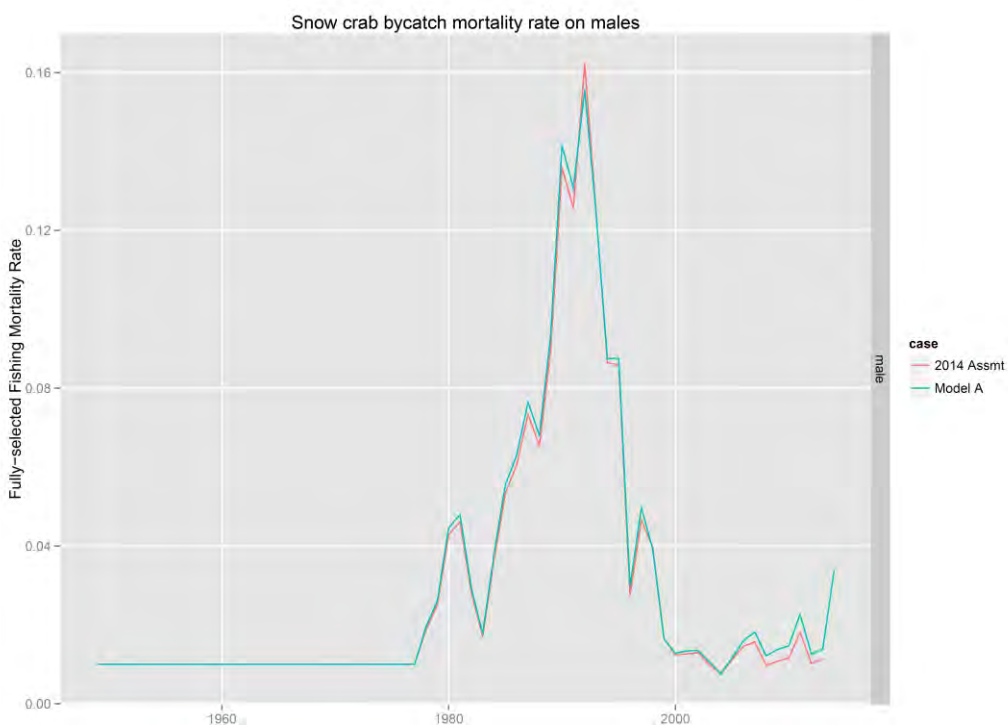


Figure 55. Comparison of estimated fully-selected bycatch mortality rate on males in the snow crab fishery.

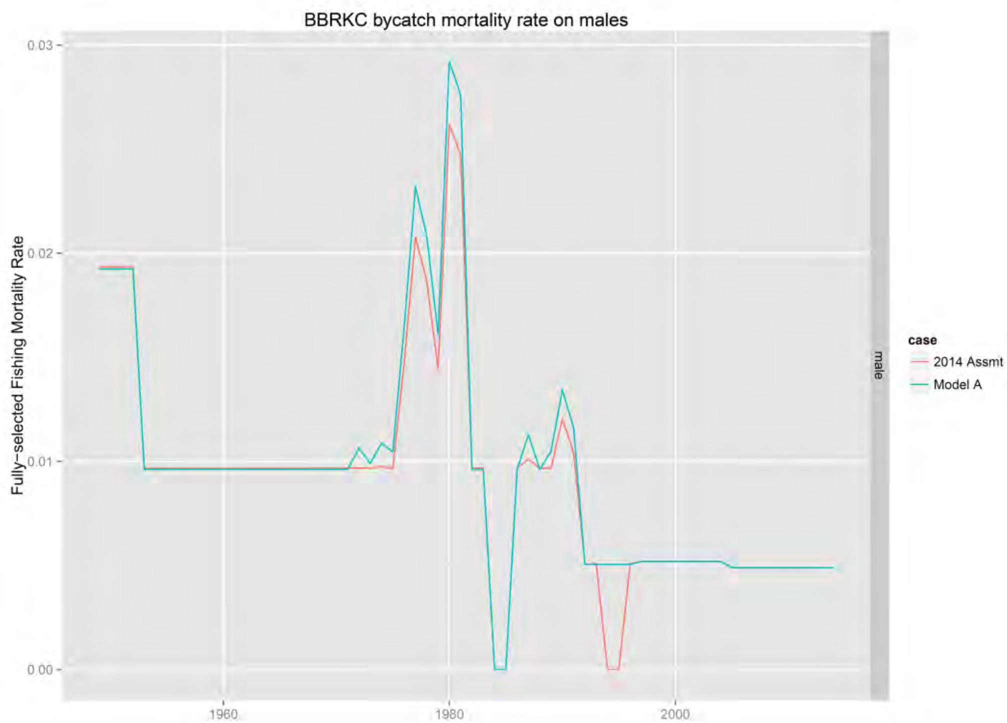


Figure 56. Comparison of estimated fully-selected bycatch mortality rate on males in the BBRKC fishery.

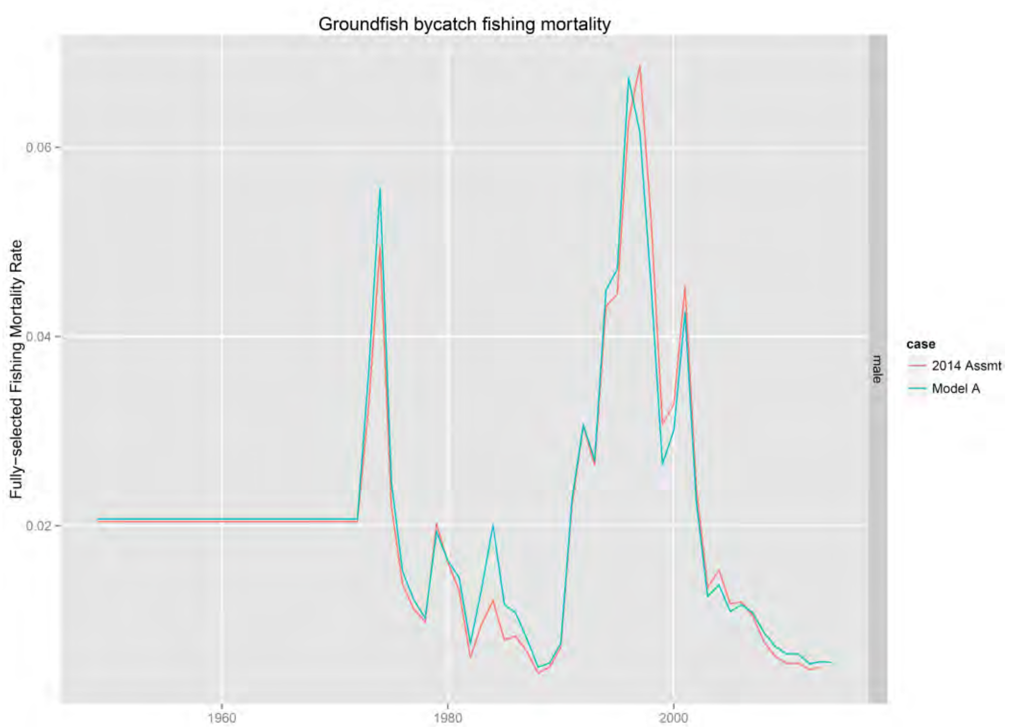


Figure 57. Comparison of estimated fully-selected bycatch mortality rate on males in the groundfish fisheries.

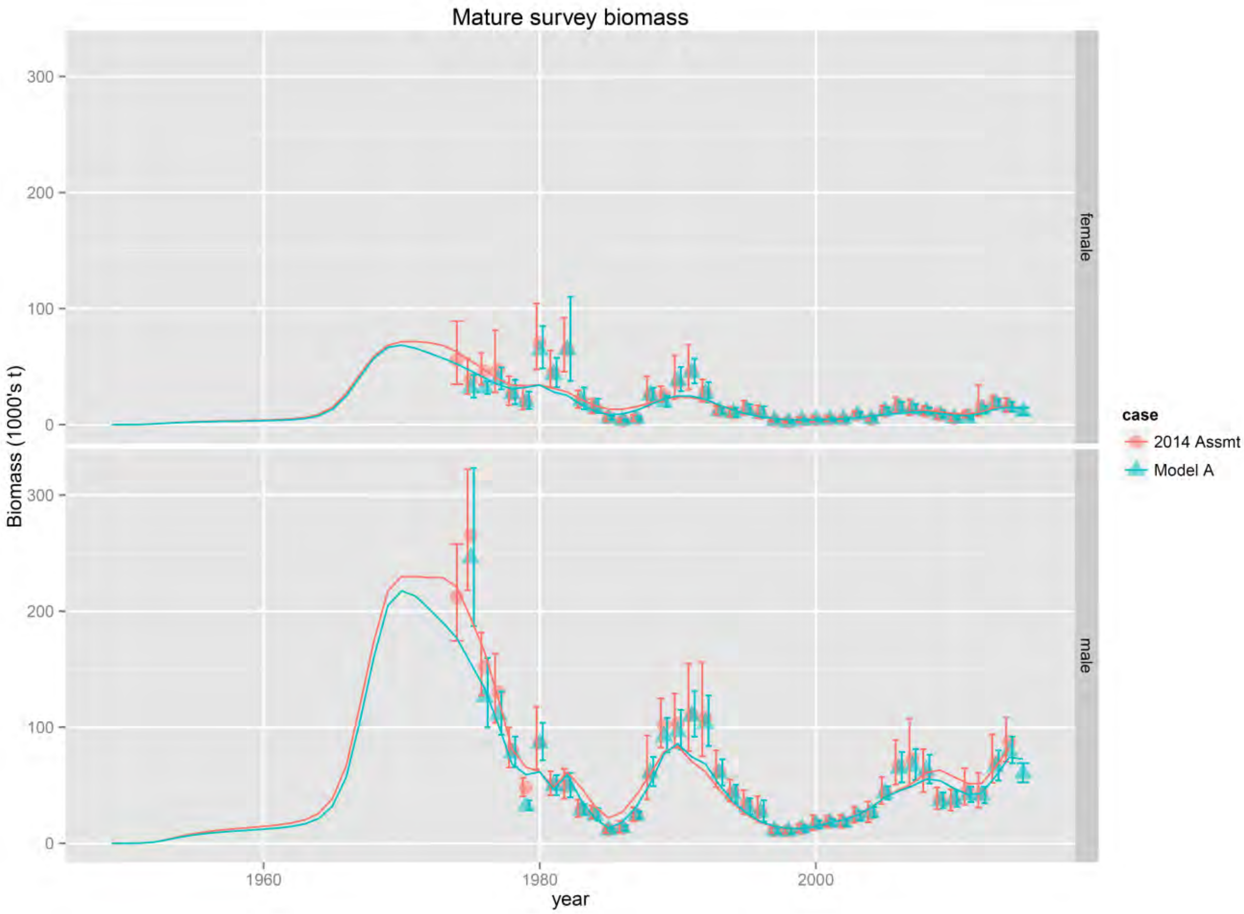


Figure 58. Comparison of time series of mature survey spawning biomass from the 2014 assessment and Model A (Dataset D). Error bars are 80% confidence intervals, and are slightly offset to prevent overlap.

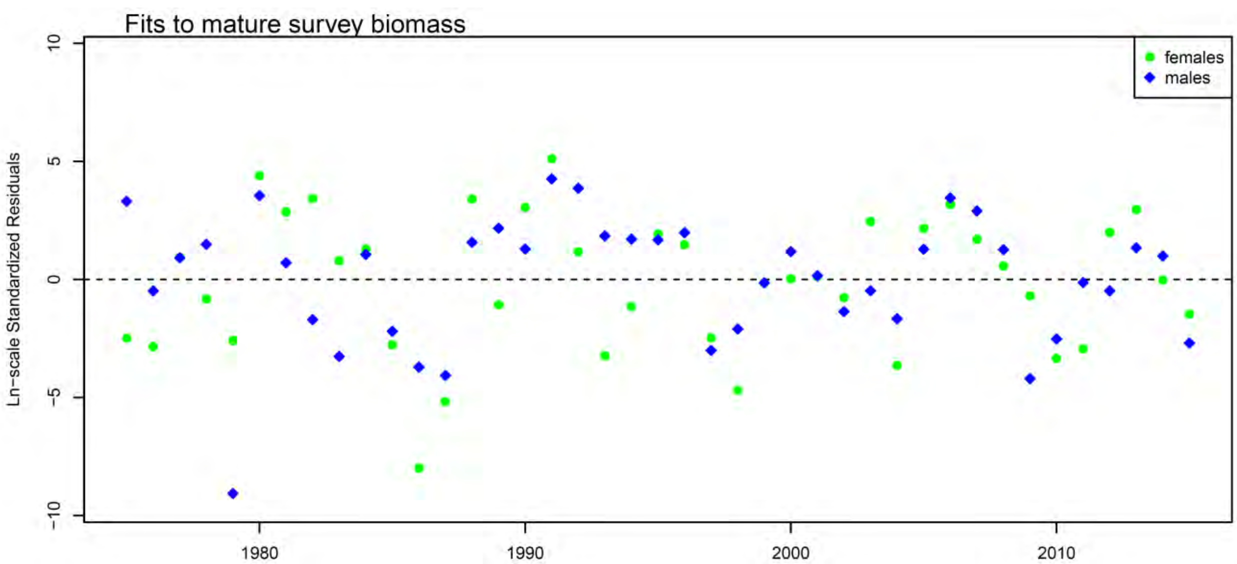


Figure 59.Residuals from the sex-specific fits to mature survey spawning biomass for Model A (Dataset D).

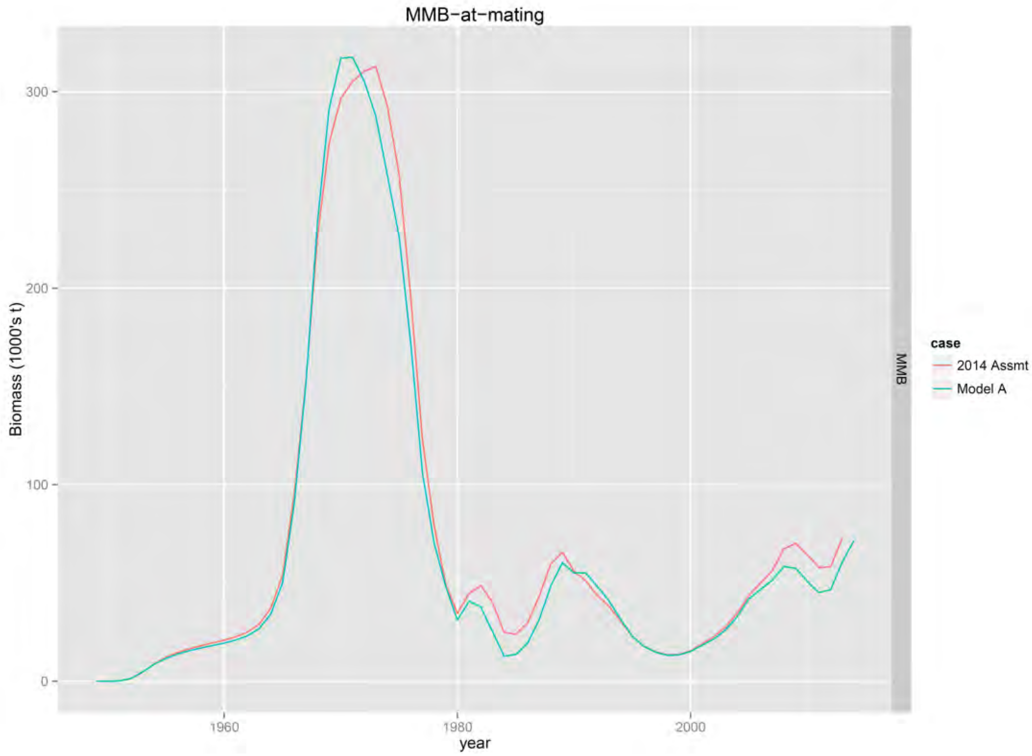


Figure 60. Comparison of time series of estimated MMB-at-mating from the 2014 assessment and Model A (Dataset D).

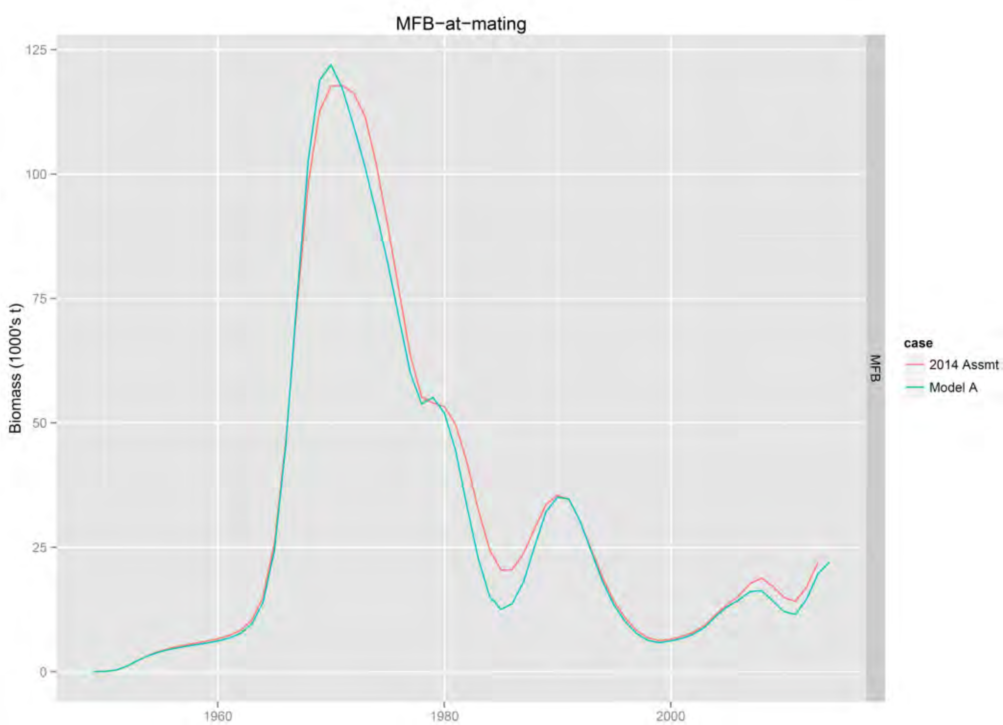
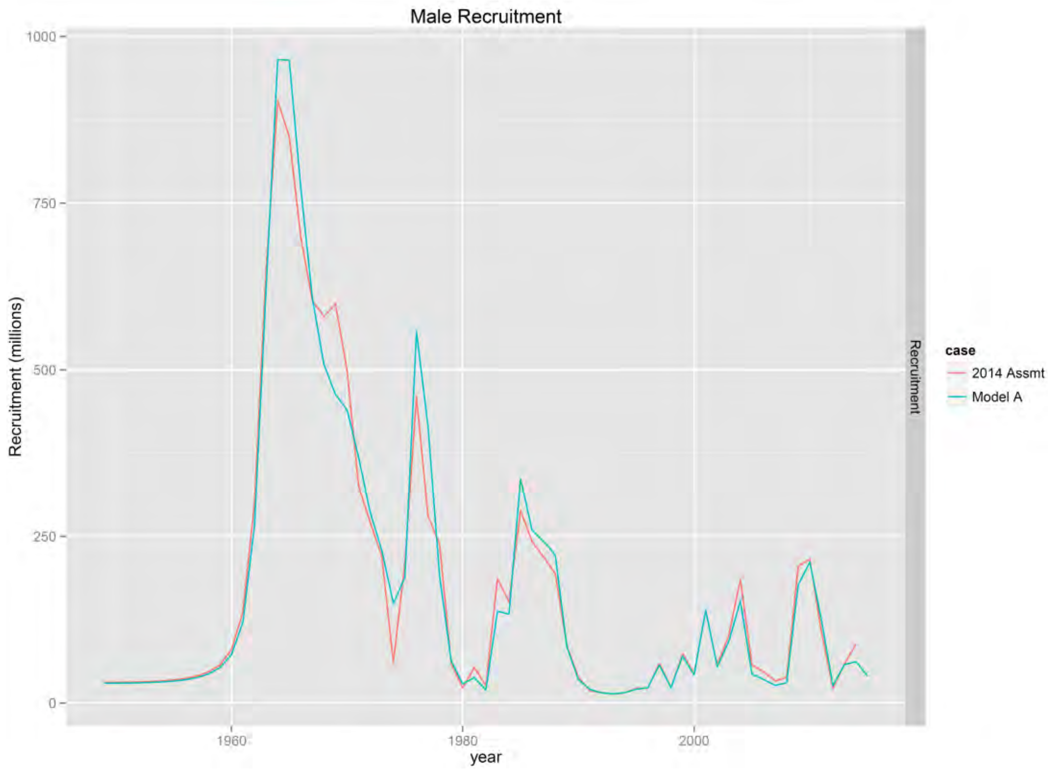
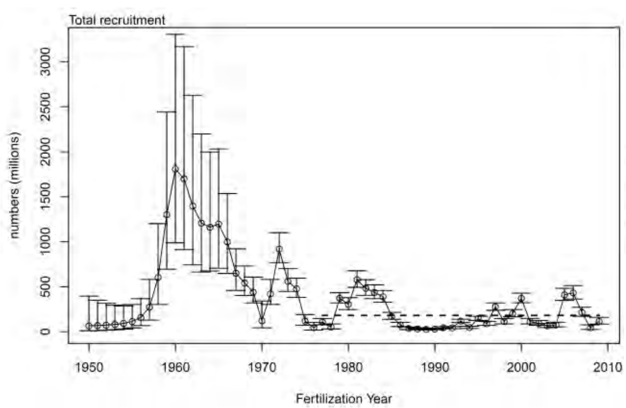


Figure 61. Comparison of time series of estimated mature female biomass-at-mating from the 2014 assessment and Model A (Dataset D).



2014 Assessment Model



Model A

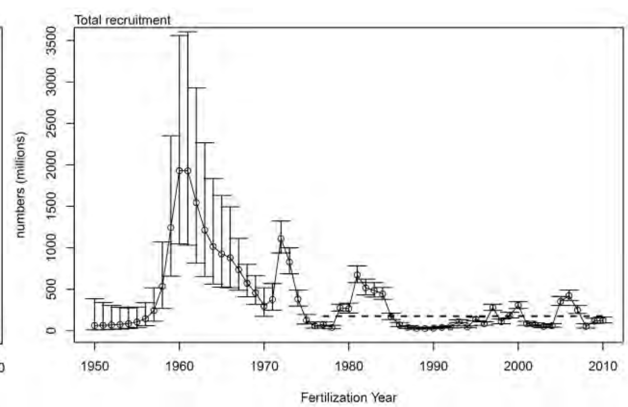


Figure 62. Comparison of model-estimated time series for (male) recruitment from the 2014 assessment and Model A (Dataset D).

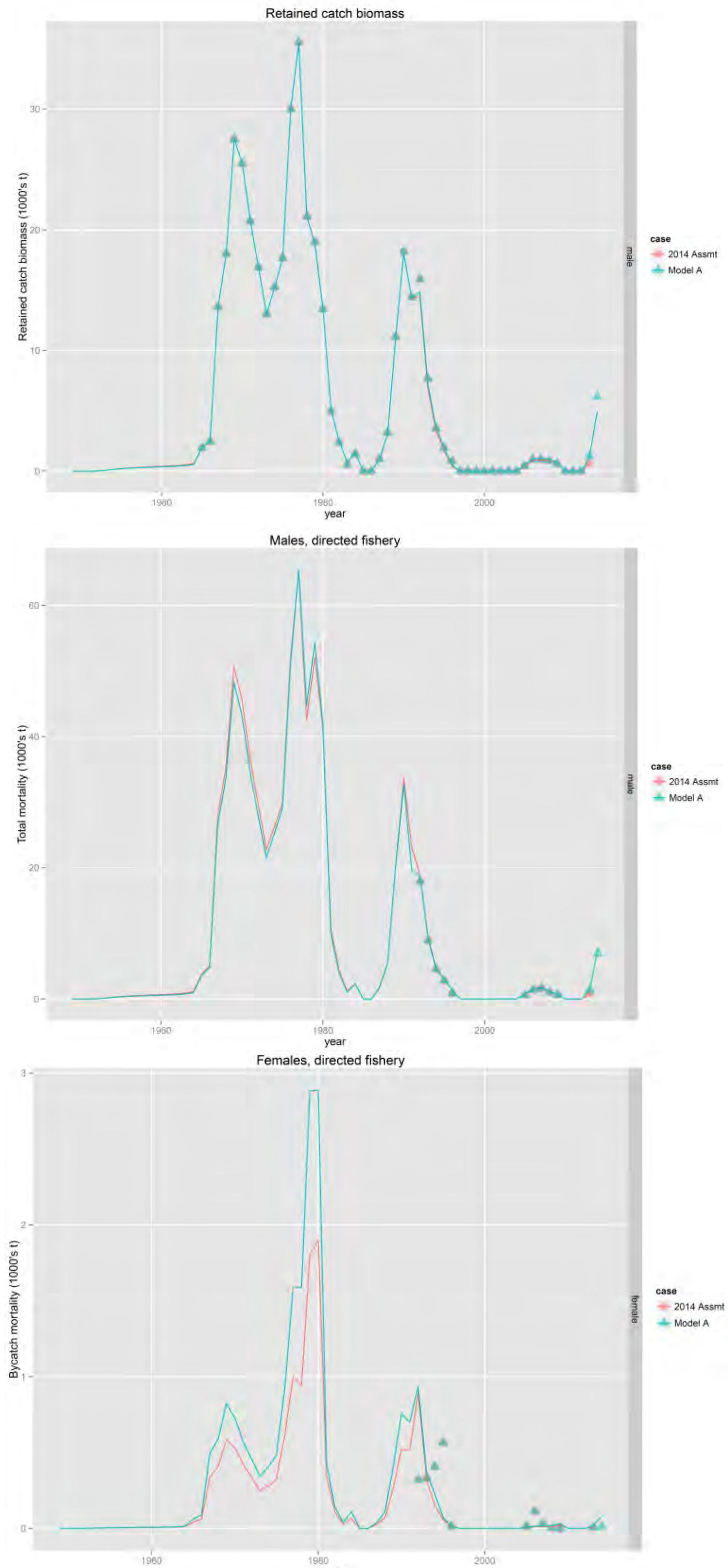
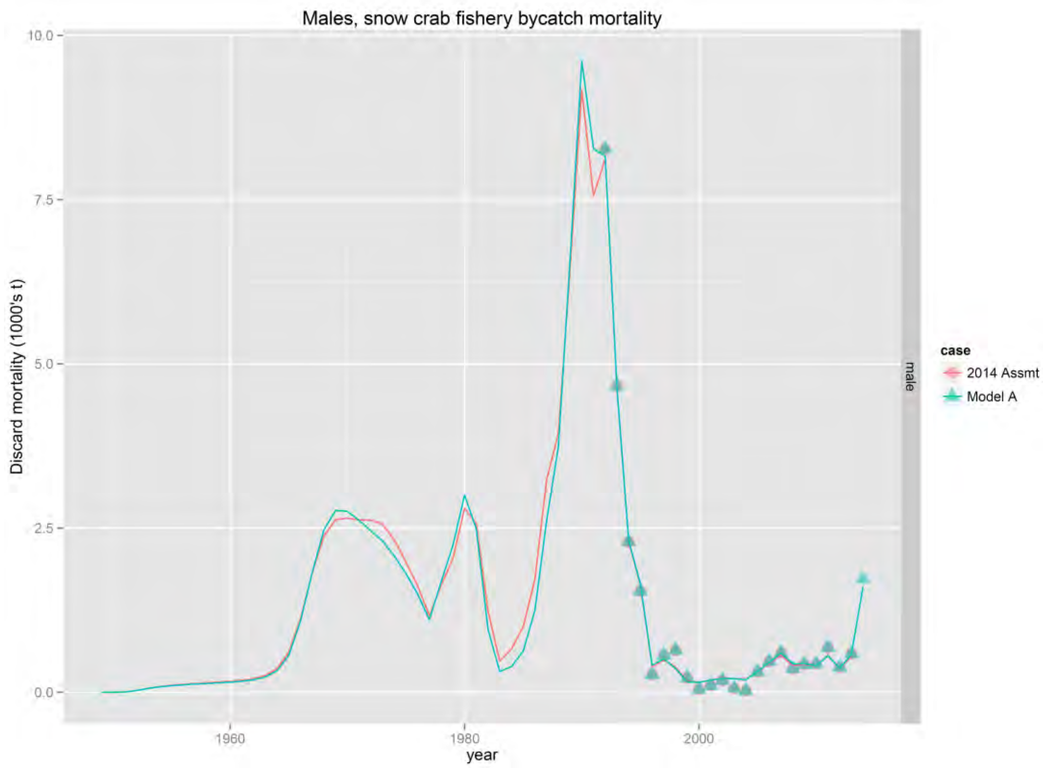


Figure 63 Comparison of model-estimated time series for fits to data from the directed fishery: 1) retained catch (upper graph), 2) total male mortality (retained + discard), and 3) female discard mortality (lower graph).



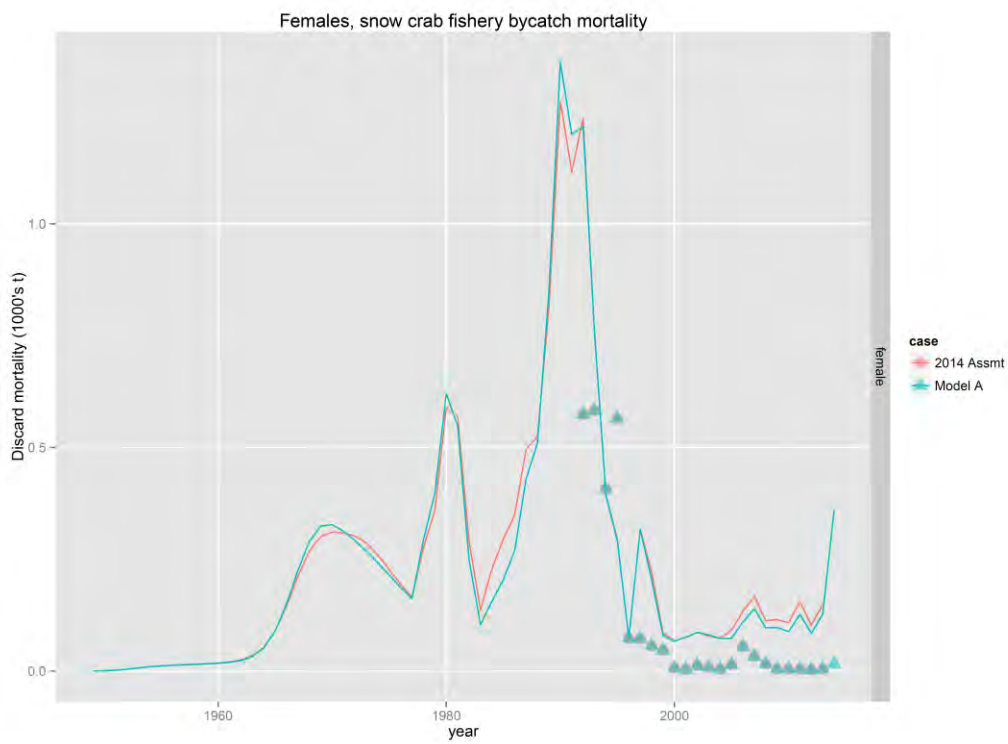


Figure 64. Comparison of model-estimated time series for fits to data for bycatch mortality in the snow crab fishery for the 2014 assessment Model A (Dataset D). Upper graph: males. Lower graph: females.

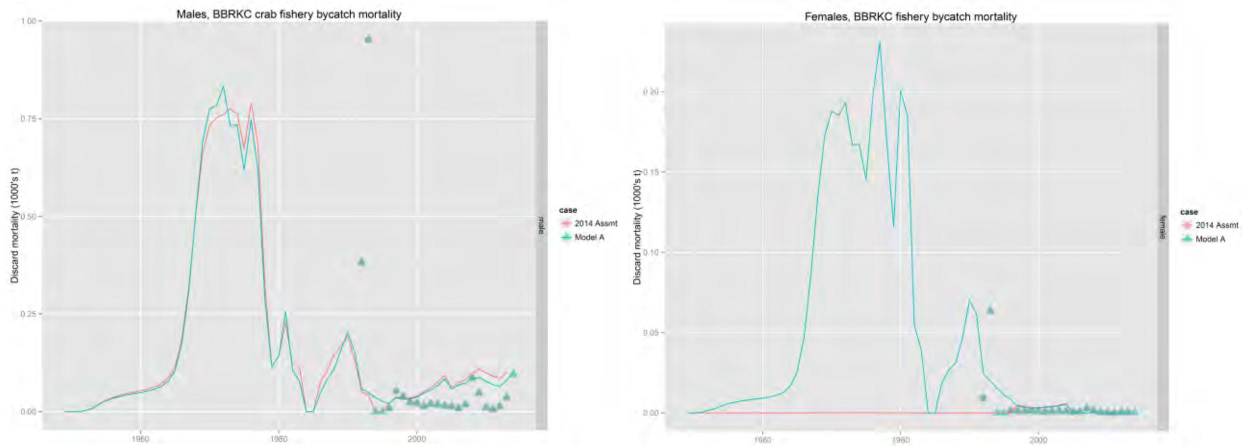


Figure 65. Comparison of fits to discard mortality time series in the BBRKC fishery from the 2014 assessment and Model A (Dataset D).

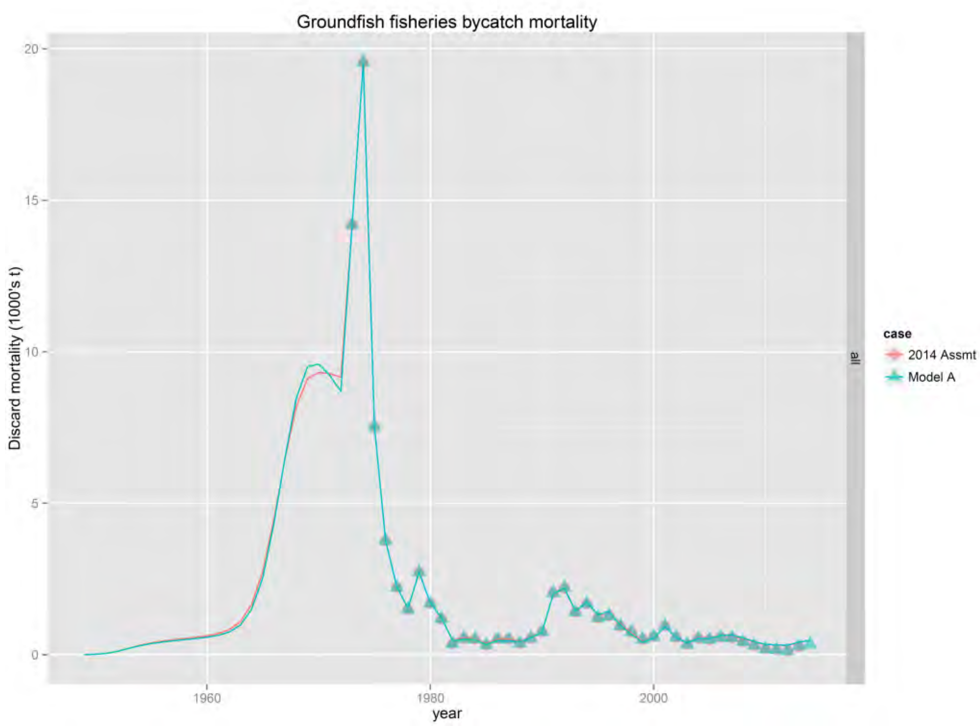


Figure 66. Comparison of fits to discard mortality in the groundfish fisheries from the 2014 assessment and Model A (Dataset D).

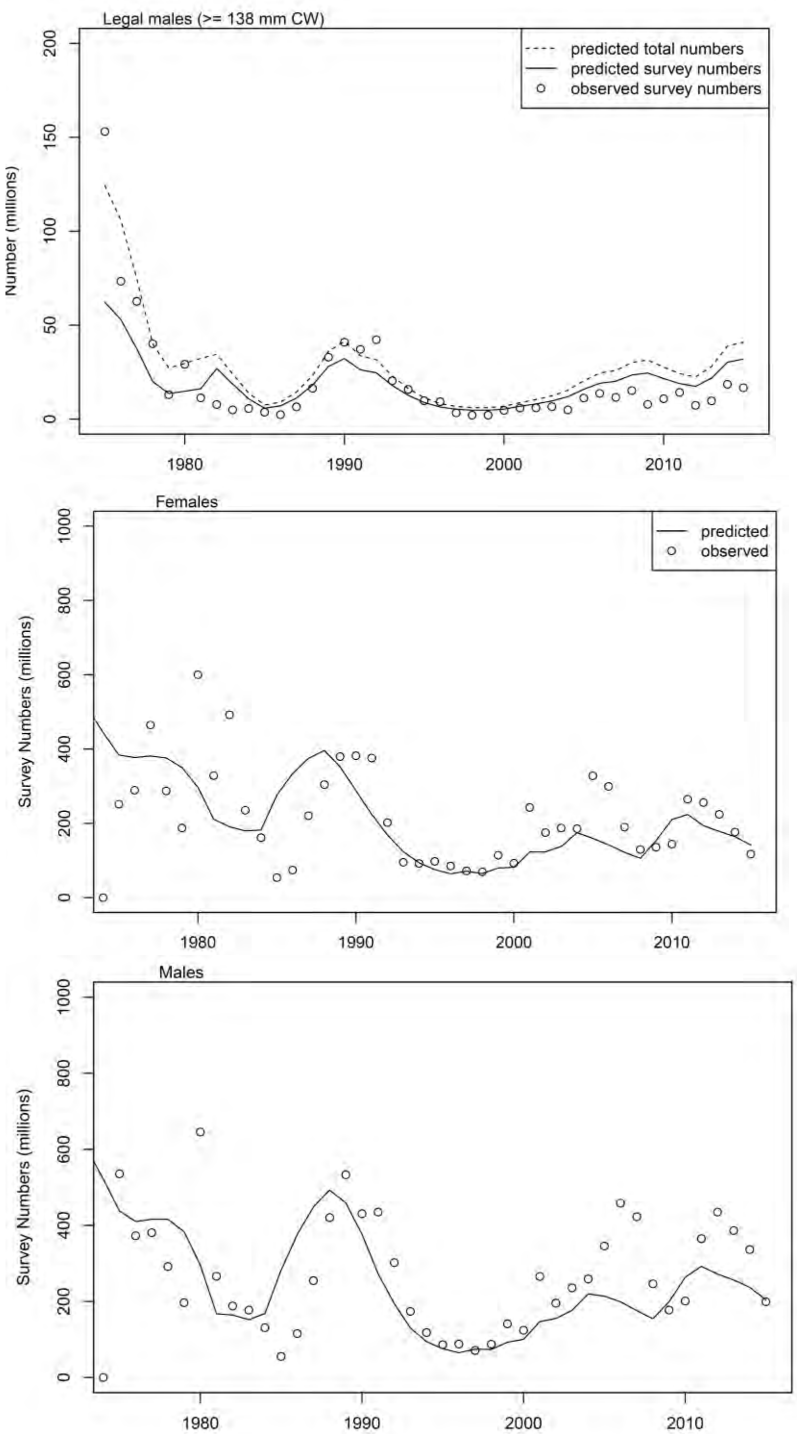


Figure 67. Comparison of observed numbers (circles) from the survey for large males, females, and males with corresponding predictions (lines) from Model A (Dataset D). Note that these data are not directly fit in the model.

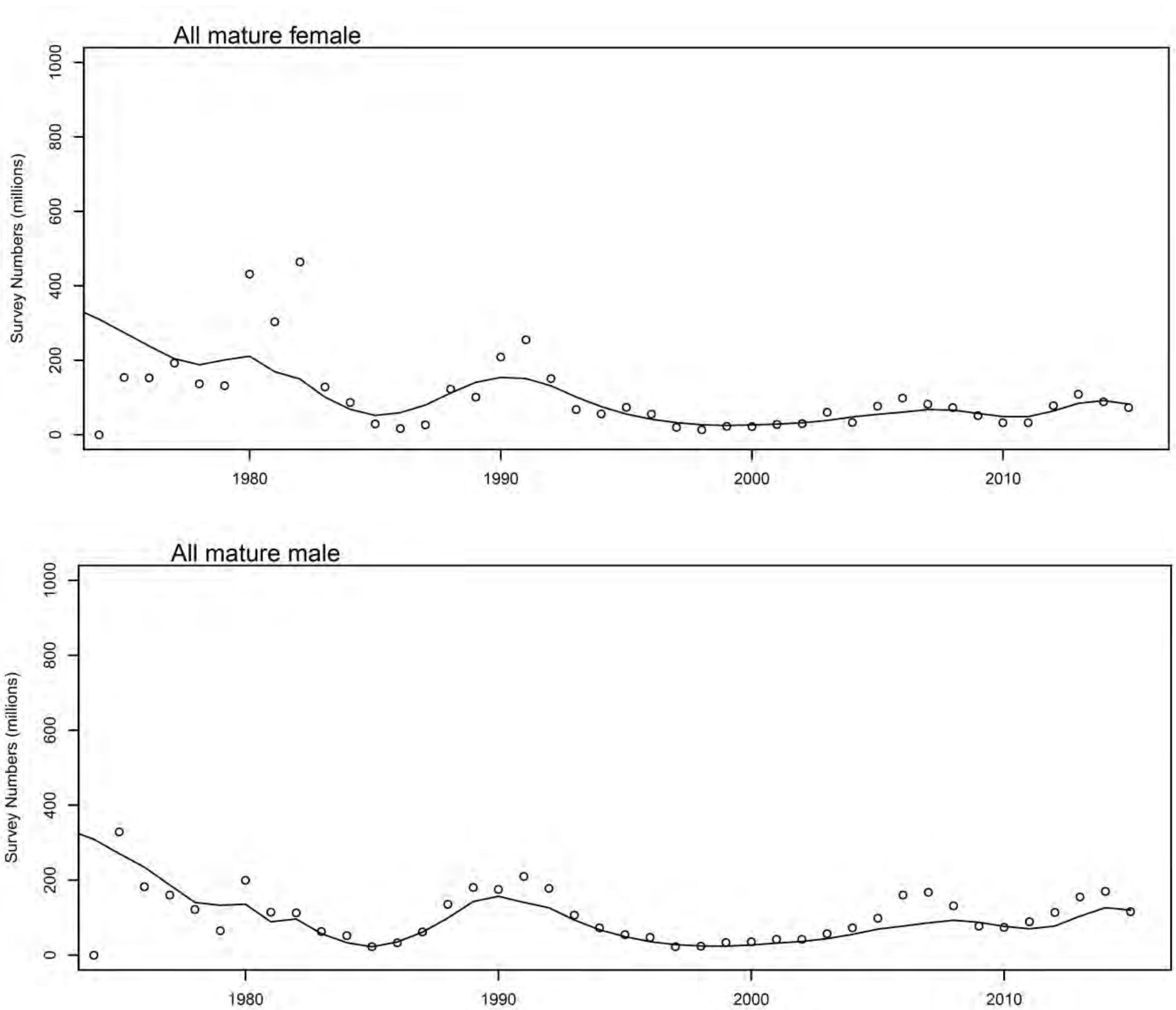
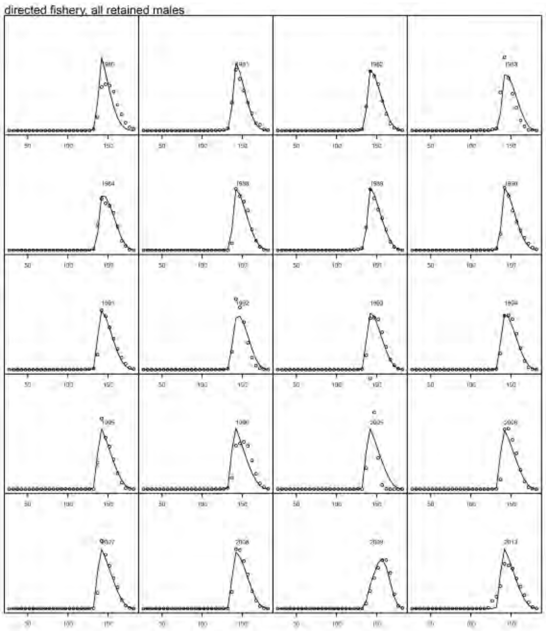


Figure 68. Comparison of observed numbers (circles) from the survey for mature females and males with corresponding predictions (lines) from Model A (Dataset D). Note that these data are not directly fit in the model.

2014 assessment



Model A (Dataset D)

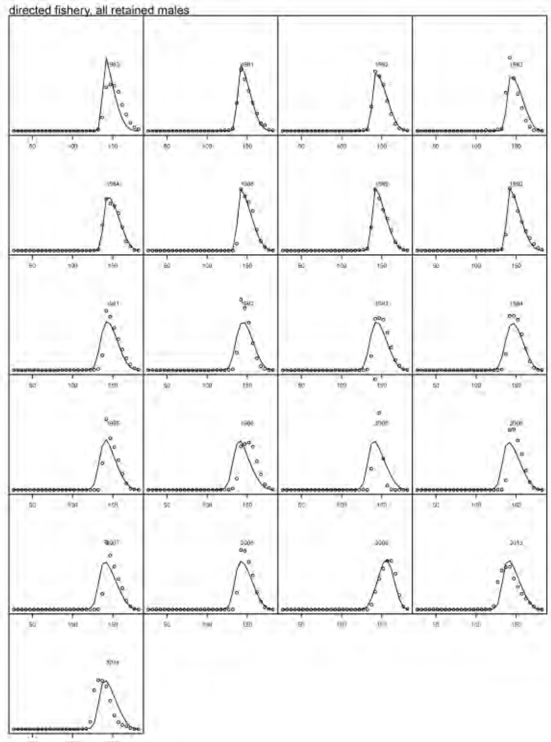
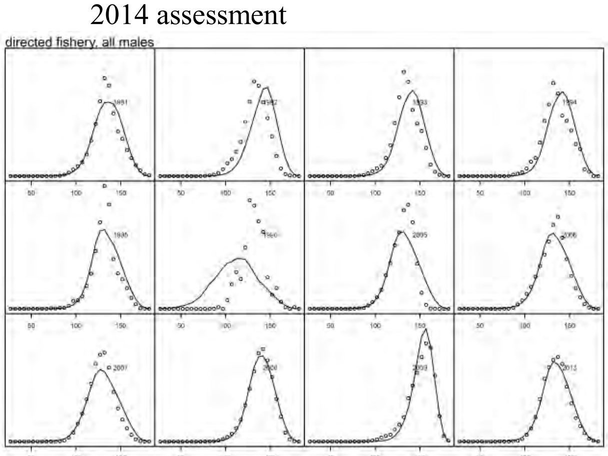


Figure 69.F its to retained catch size compositions from the 2014 assessment and Model A (Dataset D).

2014 assessment



Model A (Dataset D)

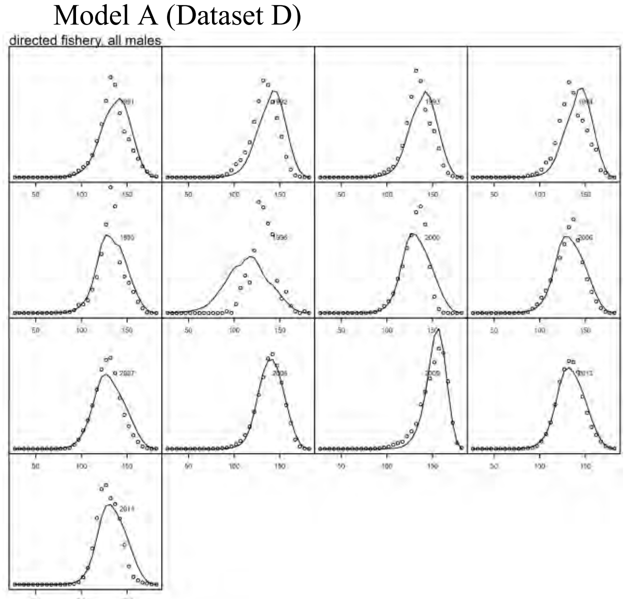


Figure 70. Fits total male catch size compositions in the directed fishery from the 2014 assessment and Model A (Dataset D).

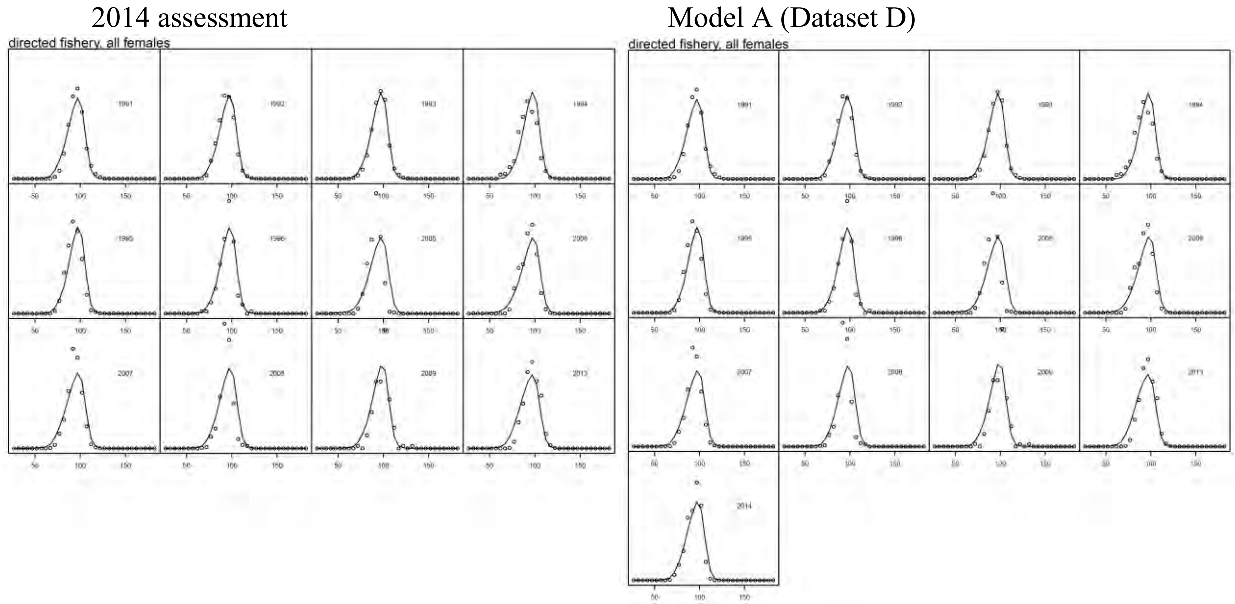


Figure 71. Fits to female bycatch size compositions in the directed fishery from the 2014 assessment and Model A (Dataset D).

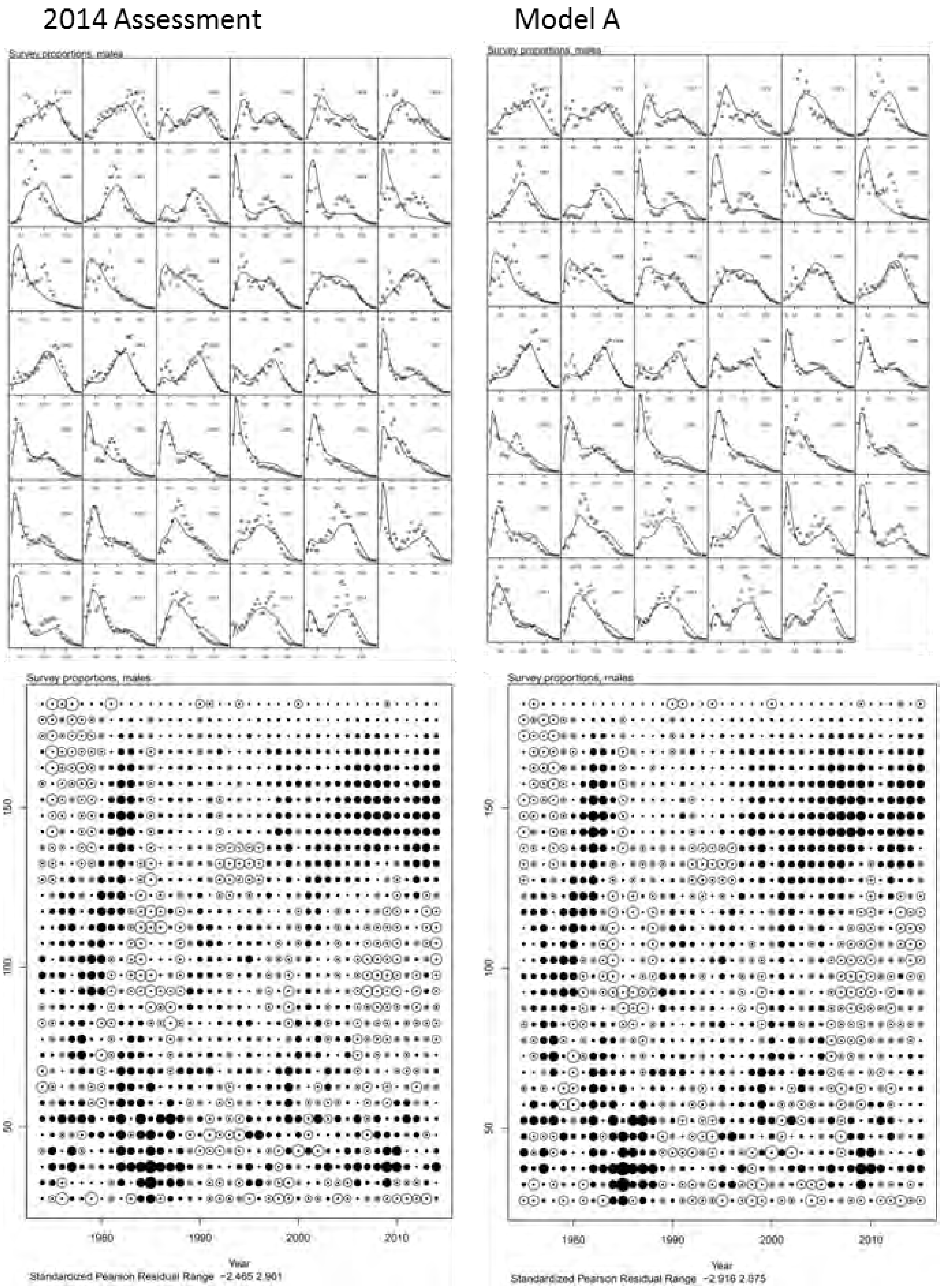


Figure 72.Fits to male size compositions in the NMFS trawl survey.

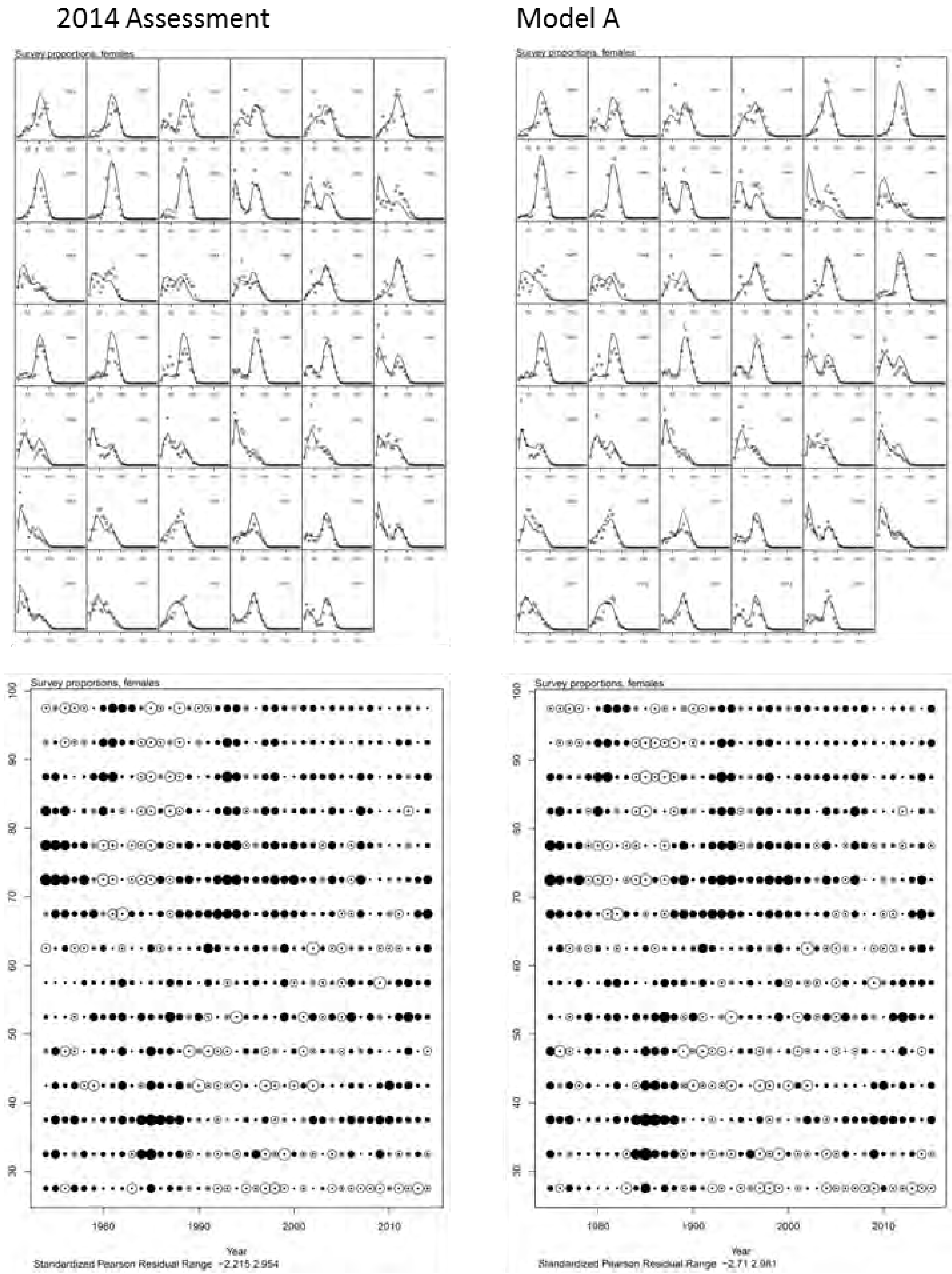


Figure 73. Alt4b model fits to female size compositions in the NMFS trawl survey.

2014 assessment Model A (Dataset D)

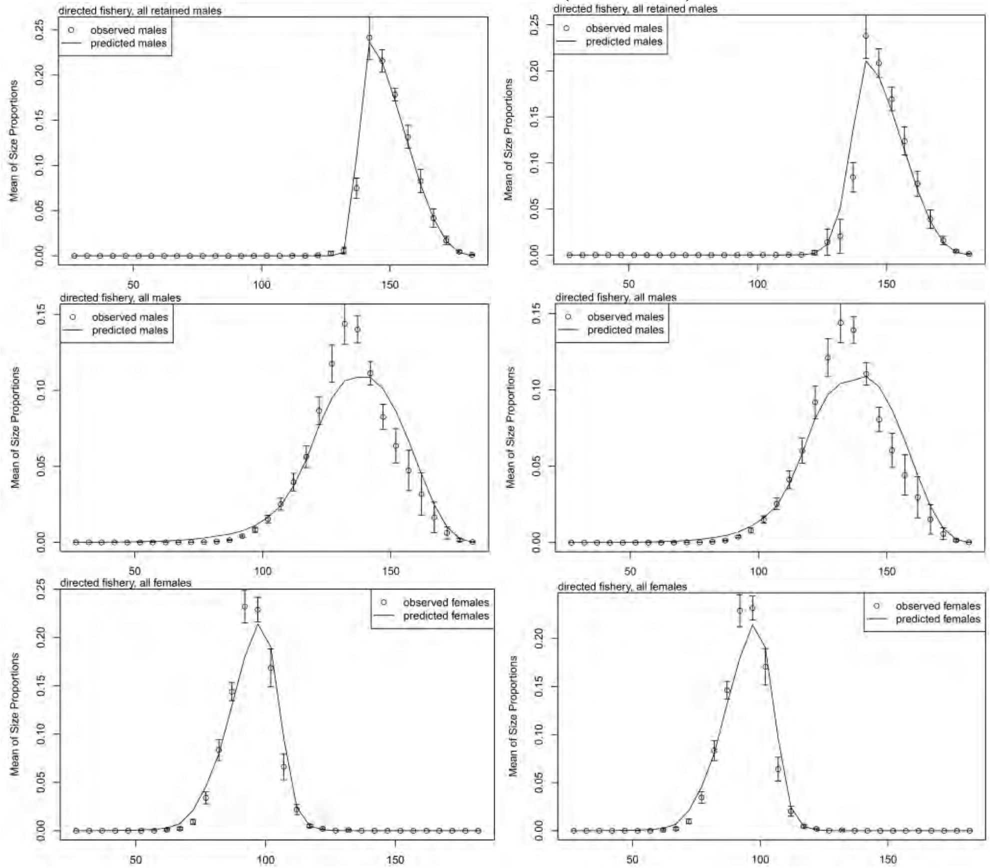


Figure 74. Comparison of marginal size compositions in the directed fishery. Circles with error bars are based on observer sampling.

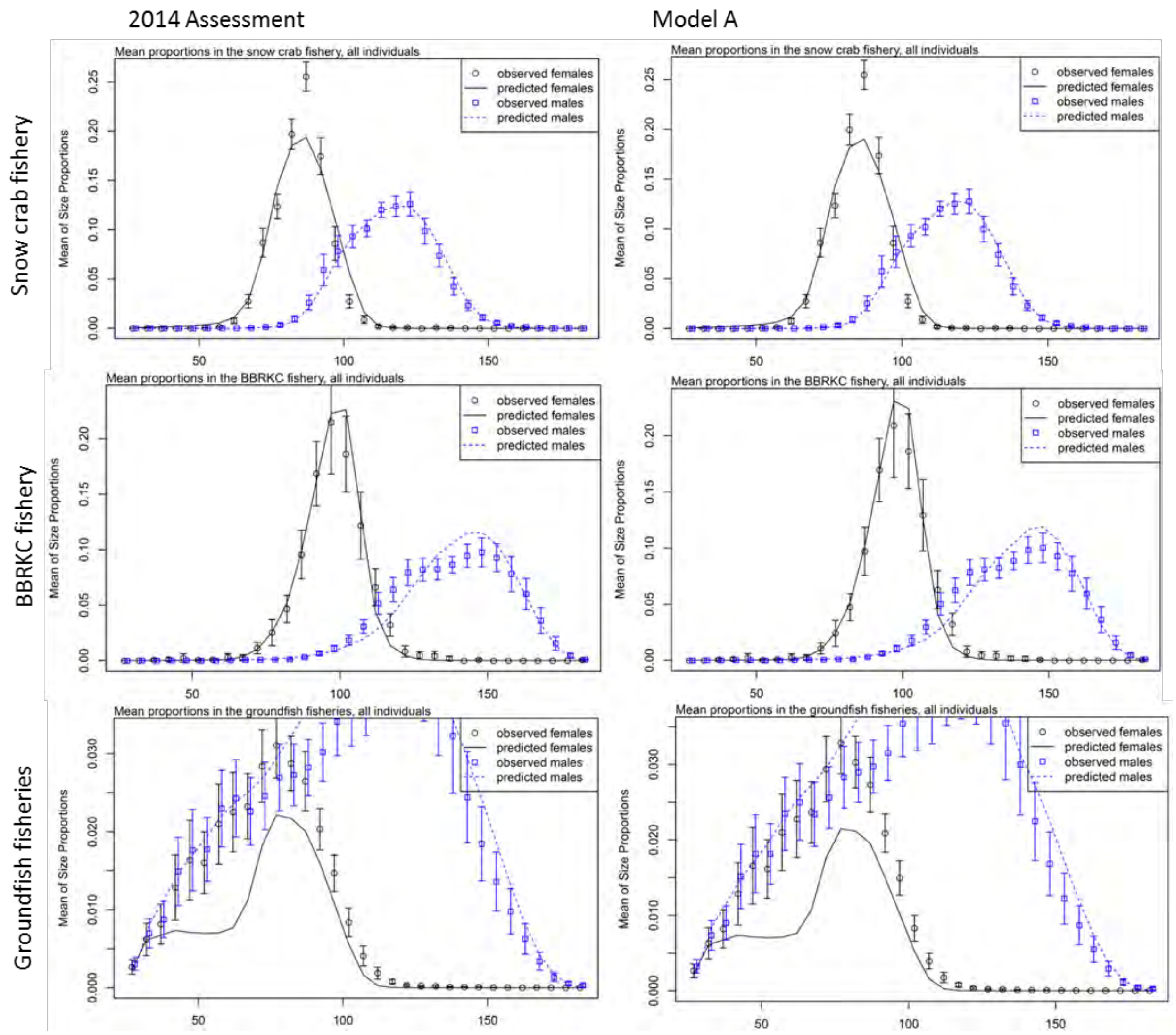


Figure 75. Comparison of marginal size compositions in the bycatch fisheries. Circles with error bars are based on observer sampling.

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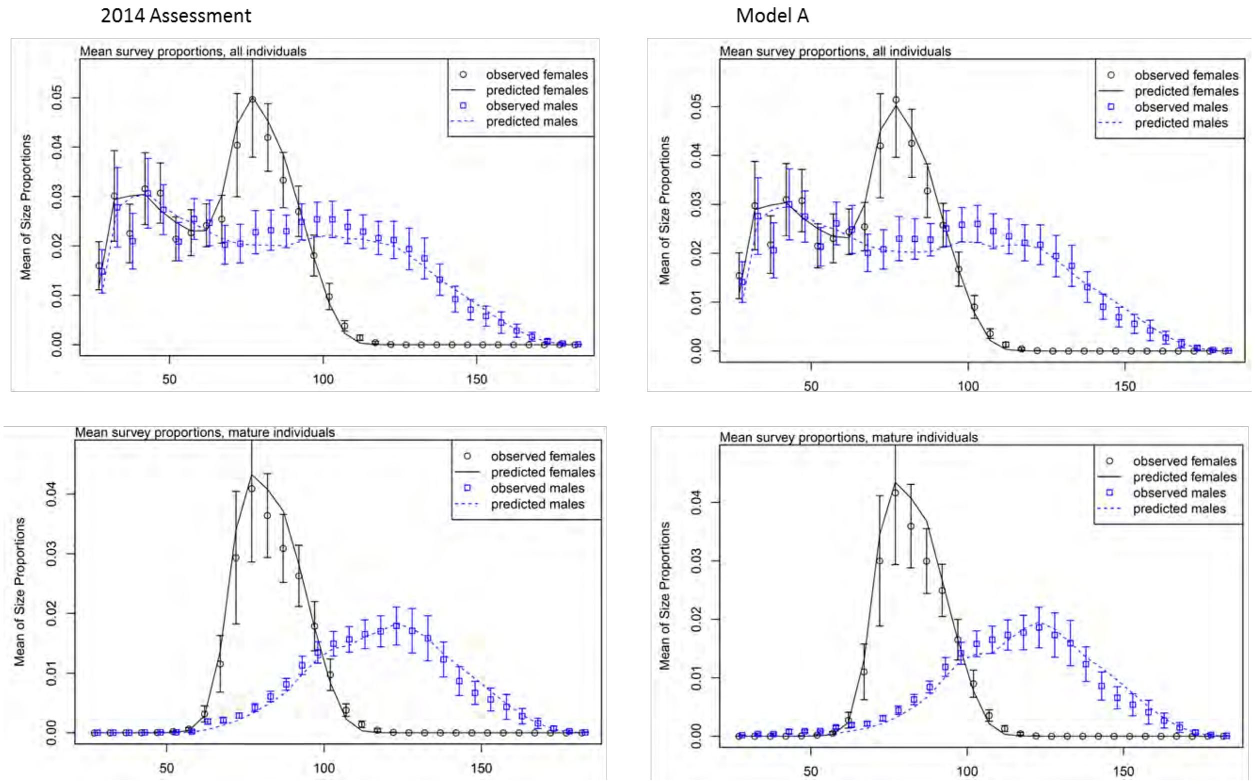

Figure 76. Comparison of marginal size compositions in the NMFS trawl survey.

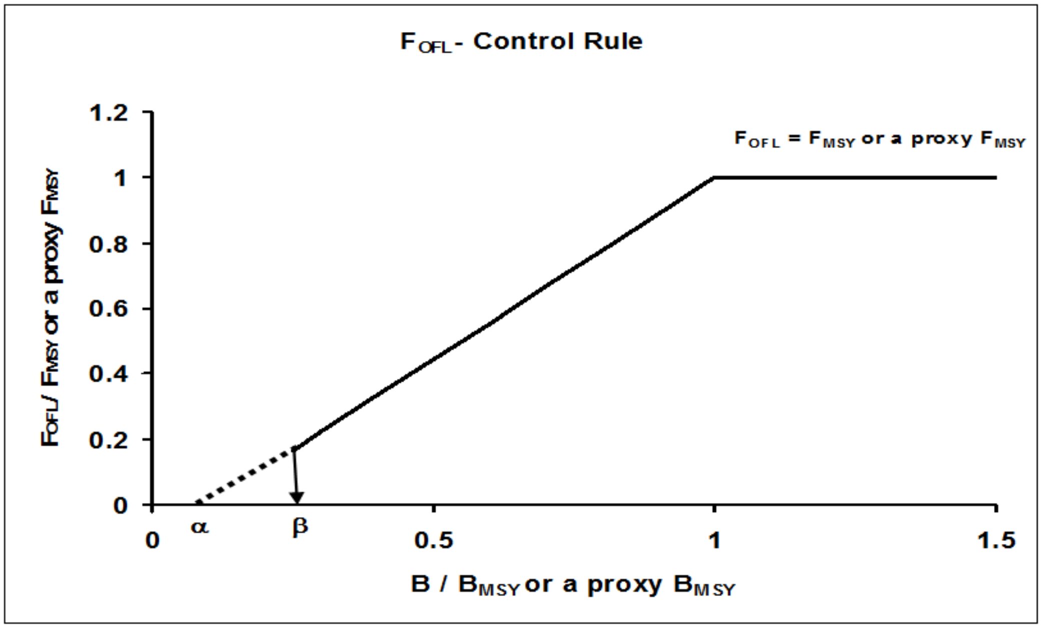

Figure 77. The F_{OFL} harvest control rule. For Tier 3 stocks such as EBS Tanner crab, F_{MSY} and B_{MSY} are based on spawning biomass per recruit proxies, where $F_{MSY} = F_{35\%}$, $B_{MSY}Y = B_{35\%}$, and MMB at mating time is used as a surrogate for egg production/spawning biomass.

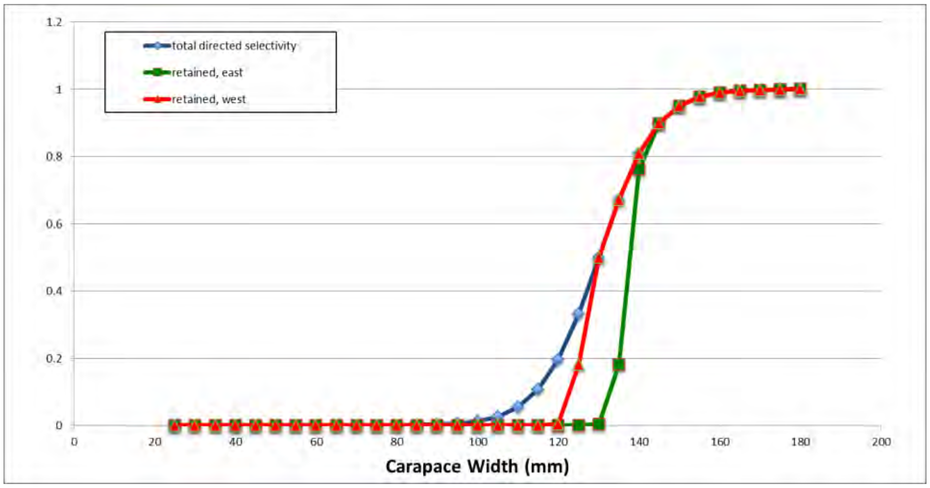

Figure 78. Selectivity functions for males in the directed fishery using the 2014 projection approach.

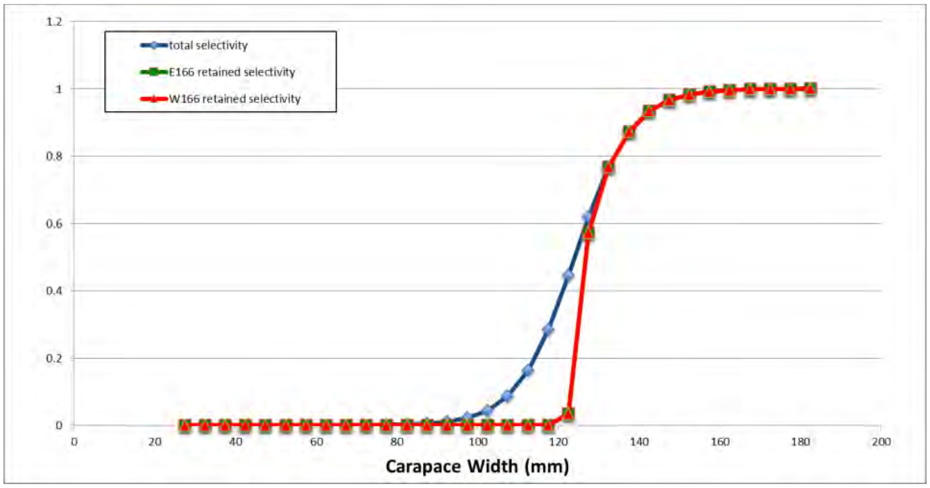

Figure 79. Selectivity functions for males in the directed fishery using the new (1) projection approach.

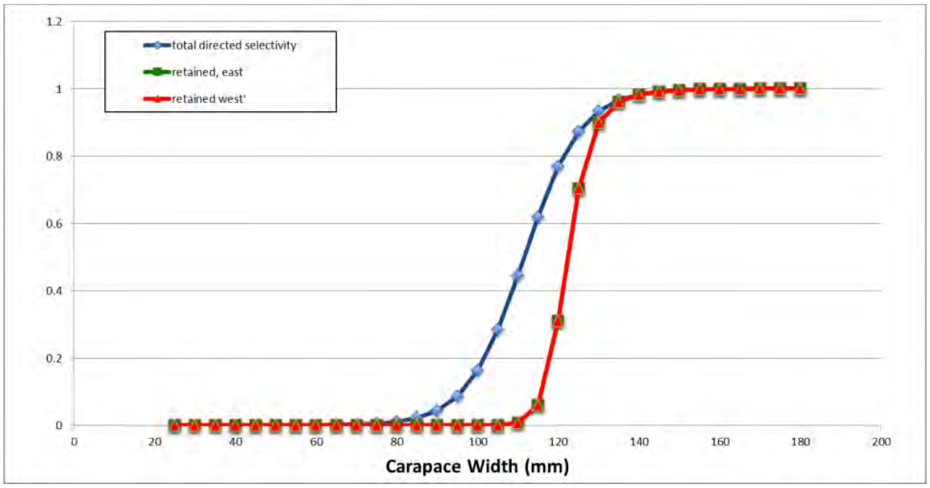

Figure 80. Selectivity functions for males in the directed fishery using the new (2) projection approach.

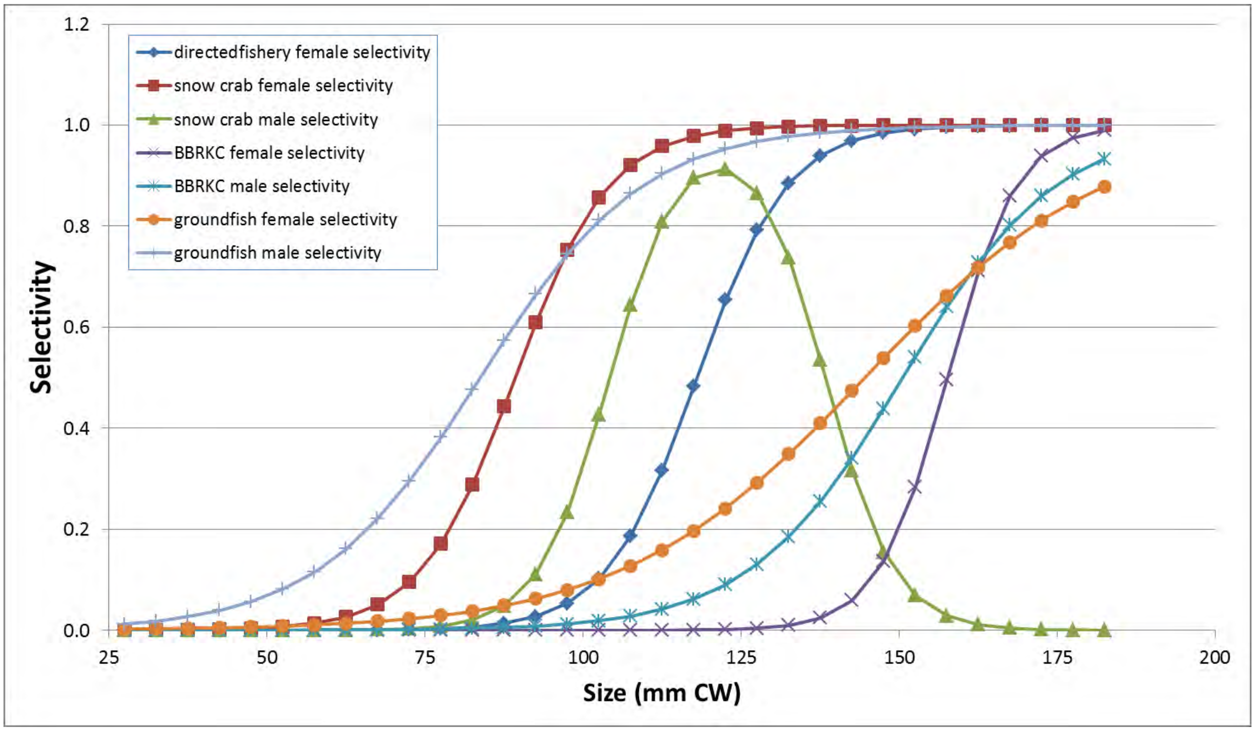

Figure 81. Selectivity curves for bycatch fisheries used in the Model A, Dataset D projection model.

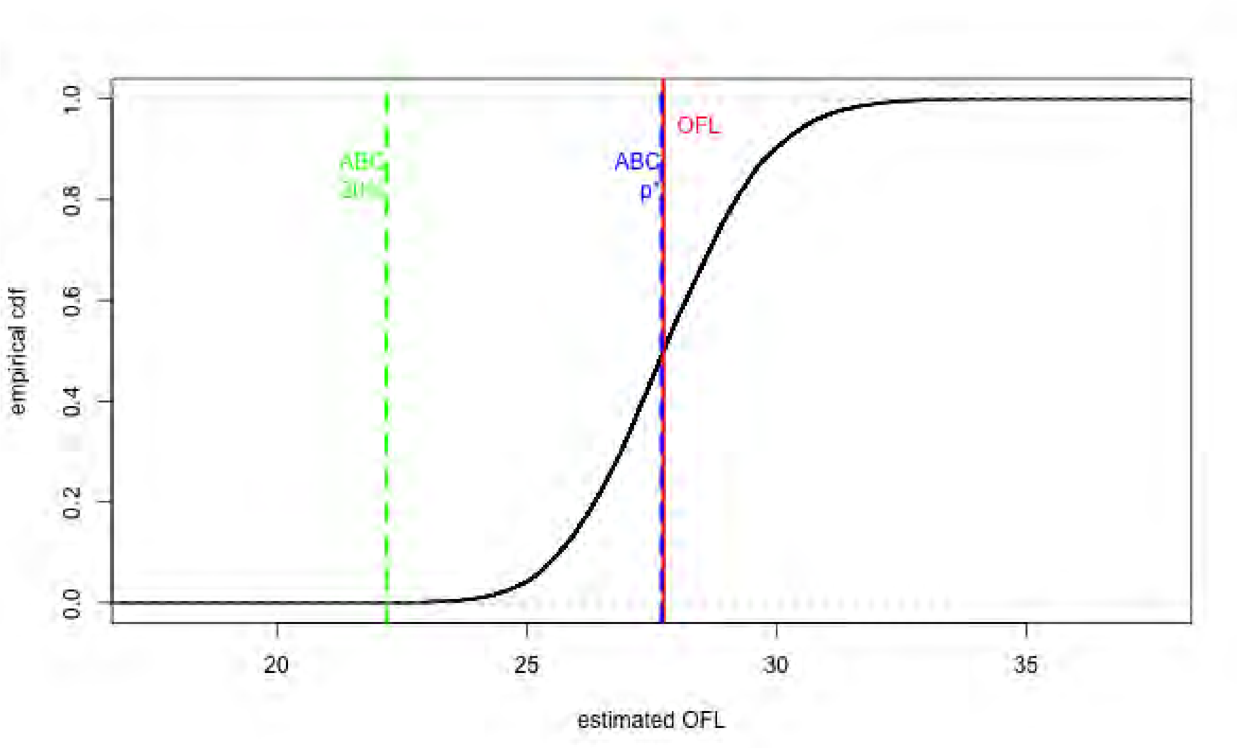

Figure 82. Distribution of OFL, illustrating the estimated p* ABC and 20%-buffer ABC, for scenario Model A (Dataset D), based on Turnock's preferred snow crab model and the 2014 projection approach.

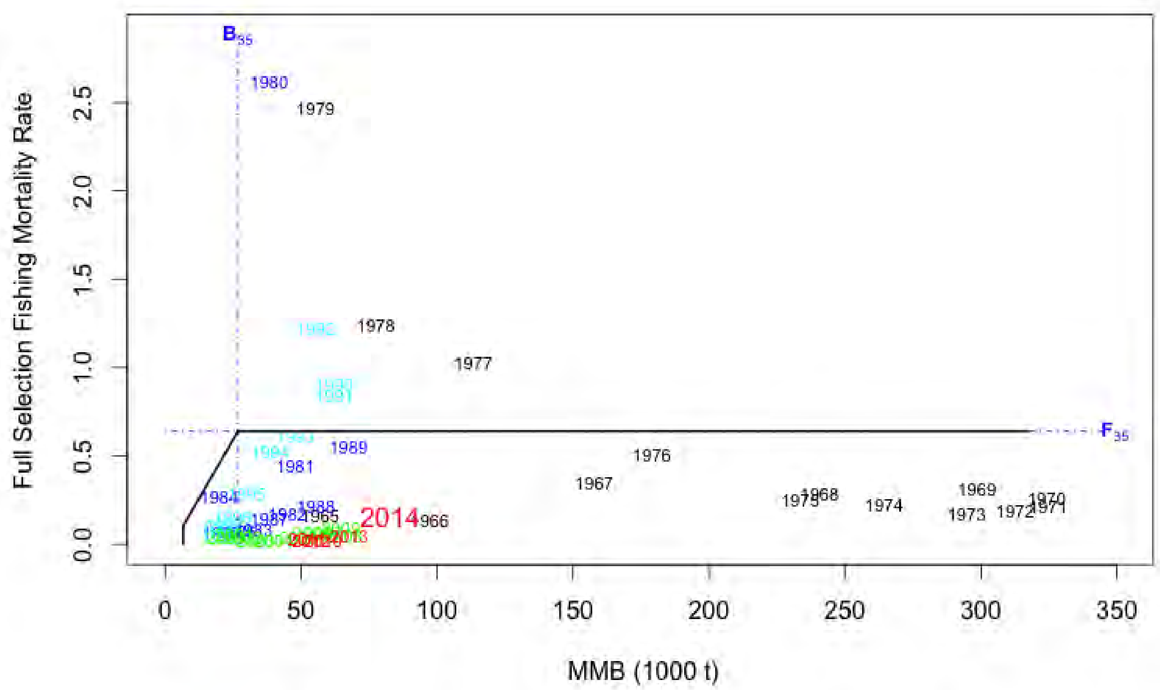

Figure 83. Tier 3 quad plot for the author's preferred model, Model A (Dataset D). Colors indicate different time periods. Black: 1965-1979; blue: 1980-1989; cyan: 1990-1999; green: 2000-2009; red: 2010-2014.

Appendix A: Fishing mortality model

Introduction

The “retention curve” estimated in TCSAM2013 using its standard fishing mortality model does not directly reflect the on-deck process of sorting crab into retained and discarded components. However, the alternative fishing mortality model used in Gmacs does reflect this process. This has implications for what can (and cannot) be done using TCSAM2013’s projection model, because the projection model is based on the TCSAM2013 fishing mortality model. Specifically, adjusting the “retention curve” to reflect changes in preference for the size of retained crab does NOT result in changes to the OFL—contrary to one’s expectation (and as it would if the projection model were based on the Gmacs fishing mortality model).

Fishing mortality models

“Standard” TCSAM

The “standard” TCSAM fishing mortality model (used since the 2012 assessment, “TCSAM2013” here) is based on the assumption that the rate of mortality on crab due to retaining them in the directed fishery is proportional to the rate of total fishing *mortality* (retained +discarded mortality) in that fishery (see Stockhausen, 2014, Appendix 3 for details). Using a slightly simplified description, TCSAM2013 models the rate of fishing mortality on male crab of size *z* due to retention, $r_{y,z}$, as

$$r_{y,z} = r_z \cdot F_{y,z} \tag{1}$$

where $F_{y,z}$ is the total fishing mortality rate (retained + discard mortality) in year *y* on male crabs of size *z* and r_z is the size-specific “retention function”, which takes values between 0 (no retention) and 1 (complete retention). The retention function r_z is modeled using an increasing 2-parameter logistic function (retention is 0 for “small” crab and 100% for “large” crab), and the two parameters are estimated as part of the model fitting process. $F_{y,z}$ is expressed (again, a simplification) as

$$F_{y,z} = S_z \cdot f_y \tag{2}$$

where S_z is the size-specific total fishery selectivity and f_y is the year-specific fully-selected total fishing mortality rate. Parameters associated with r_z, S_z and f_y are estimated by fitting to retained and total (retained + discard) fishing mortality in the directed fishery. This is fine, as far as it goes, because it simply represents a somewhat non-standard model for retained fishing mortality.

However, the expectation has been that r_z reflects the process of sorting and retaining legal crab on deck, and thus it represents the fraction of crab caught at size *z* that were retained. If this *were* the case, r_z would be independent of handling mortality because what’s retained is not affected by what’s discarded (rather it’s the other way around: what’s discarded is simply what’s left over after crab to be retained have been selected). However, **this is not the correct interpretation of $\boldsymbol{r_z}$** as it is used in TCSAM2013 and Eq. 1 above. Rather, as illustrated in Fig. 1, r_z simply reflects the fraction of crab killed at size *z* that were killed *because* they were retained, as opposed to being killed as part of the discard process. As such, it is actually a function of the assumed handling mortality on discarded crab whereas the function that describes the on-deck sorting process is not.

As an illustration to make this last point, if handling mortality were 0 then all fishing mortality $F_{y,z}$ would be due to retention ($r_{y,z} = F_{y,z}$) and r_z would be identically 1 irrespective of any sorting process that occurred on deck (e.g., all sub-legals being discarded). In Fig. 1, this would be equivalent to the “fishing mortality pie” shrinking in size but turning completely red, while the only change to the “fishing capture pie” would be that the discard mortality slice turns blue (all discards survive). The fraction of the latter pie representing retention would not change.

Gmacs-style

In Gmacs, the size-specific fishing mortality rate in the directed fishery is modeled using:

$$F_{y,z} = (h \cdot [1 - \rho_z] + \rho_z) \cdot \phi_{y,z} \tag{3}$$

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

$$r_{y,z} = \rho_z \cdot \phi_{y,z} \tag{4}$$

which looks identical to Eq. 1, but is not because $\phi_{y,z}$ in Eq. 4 represents the *capture rate* while $F_{y,z}$ in Eq. 1 is the *total mortality rate*. The fishery capture rate $\phi_{y,z}$ in the revised model is treated in the same fashion that $F_{y,z}$ is treated in TCSAM2013: it is modeled as a separable function of size and year

$$\phi_{y,z} = \phi_y \cdot S_z \tag{5}$$

where ϕ_y is the "fully-selected" capture rate in year y and S_z is the size-specific capture selectivity. ϕ_y is also parameterized in a similar fashion to the fully-selected fishing mortality rate F_y in TCSAM2013. The capture selectivity S_z and retention function ρ_z are also parameterized in the same way as selectivity and the retention function r_z in TCSAM2013. The parameters associated with ρ_z, S_z, and ϕ_y can be fit using the same data (retained catch and discard mortality) used to fit the standard TCSAM model.

Note that, for the Gmacs-style fishing mortality model, the total fishing mortality rate $F_{y,z}$ in Eq. 3 is a derived quantity dependent on the estimated retention rate ρ_z, whereas in the standard TCSAM approach $F_{y,z}$ is itself an estimated quantity (essentially) and is independent of r_z.

Another aspect of this model is that the *total* fishing mortality $F_{y,z}$ is independent of the "retention curve" r_z. As a consequence, changing r_z does not change the OFL (as calculated using the TCSAM Projection Model, which uses this fishing mortality model). The OFL only depends on $F_{y,z}$. Changing r_z only changes the *proportion* of the OFL that is accounted for by retention. Thus, changing r_z to reflect changes in preferred crab size (without also changing $F_{y,z}$) does not lead to a change in the OFL (contrary to one's expectation).

Figures

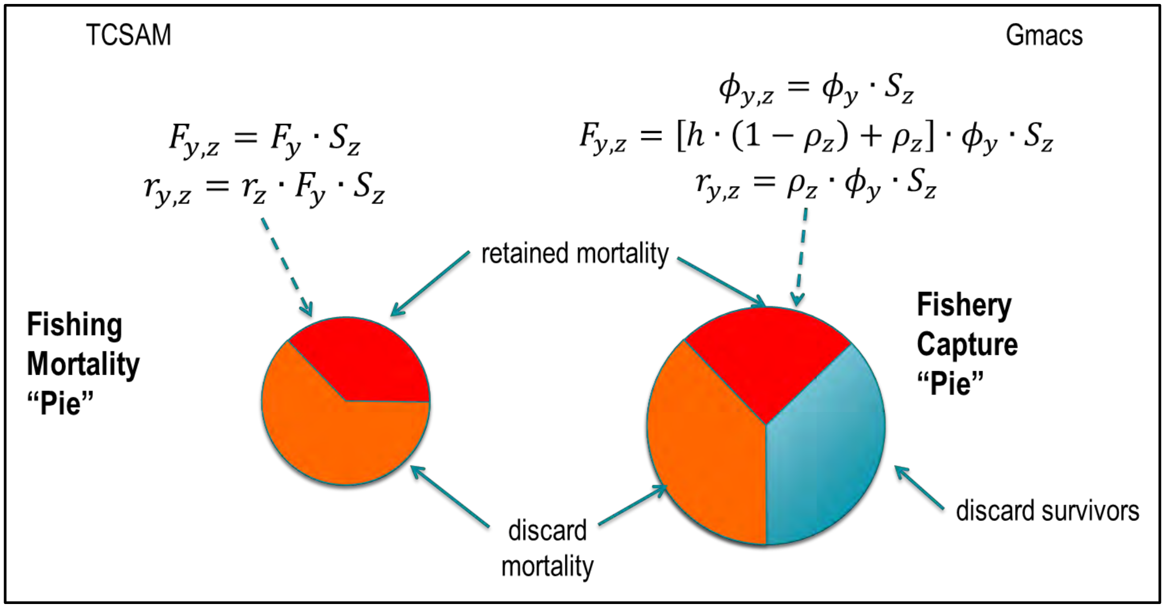

Figure A1. Comparison of models for fishing mortality in TCSAM2013 (left) and Gmacs (right). The *areas* associated with retained mortality and discard mortality are the same in both pies. r_z is the fraction of the fishing mortality pie related to retained crab. ρ_z is the fraction of the fishery capture pie related to retained crab.

Appendix B: Projection model strategies for dealing with changes in preferred sizes

Introduction

The Tanner crab stock in the eastern Bering Sea is partitioned by the State of Alaska (SOA) into two fishery regions (east and west of 166^{o}W longitude) for management purposes, with separate legal size limits and separate harvest strategies. In particular, until 2015/16, the SOA has used a minimum preferred male crab size of 125 mm CW (not including lateral spines) for the western area TAC calculations and a minimum preferred size of 138 mm CW in the eastern area. The TCSAM2013 assessment model, however, currently ignores the spatial aspects of the directed fishery and estimates a directed fishery total mortality selectivity curve and a retention curve for the entire stock. In the projection model used to determine OFL, however, an attempt has been made to incorporate the effect of the differences in TAC setting between the two areas on the OFL. In particular, the projection model assumes that total (retained+discards) directed fishing mortality on males is the same in both areas and, but that retention functions for the two areas will be different—with the western region retaining smaller crab. In practice, this was implemented in the projection model by assuming that 1) the most recent 4-year average of total selectivity on all males in the directed fishery, as estimated in the assessment model, could be applied to the entire stock in the future, 2) that the future retention curve in the eastern area was the same as the most recent 4-year average from the assessment model, 3) that the future retention curve in the western area was simply that in the eastern area, but shifted to smaller sizes by 10 mm (reflecting the smaller preferred size), and 4) that the proportion of crab caught at a given size in the east vs the west would be equal to the same proportion of crab caught in the NMFS bottom trawl survey. This strategy has been possible to implement because it was based on information available from the assessment model.

For 2015/16, the State of Alaska has modified its TAC-setting calculations from prior years. In particular, the minimum size of "preferred" male crab used in these calculations will now be the same in both fishery areas (125 mm CW, not including the lateral spines) whereas in previous years a larger minimum size was used to set the TAC in the east region (138 mm CW). To "correctly" calculate the OFL for 2015/16, one needs to predict how this will change current selectivity and retention patterns in the east and west regions from those estimated by the assessment model. As it turns out, this does not appear to be possible using the TCSAM2013 fishing mortality model as the basis for the projection model

Projection model description

The projection model used to determine the OFL associated with a model is based on the TCSAM2013 fishing mortality model (Appendix A). For each fishery, TCSAM2013 models the rate of fishing mortality, $F_{y,xz}$, on crab of sex *x* and size *z* in year *y* as

$$F_{y,x,z} = S_{x,z} \cdot f_{y,x} \tag{1}$$

where $S_{x,z}$ is the sex/size-specific total fishery selectivity function and $f_{y,x}$ is a sex/year-specific fully-selected total fishing mortality rate (except for bycatch in the groundfish fisheries, where *f* is not sex-specific). In the directed fishery, *S* also varies by year. For males in the directed Tanner crab fishery (TCF), the retained mortality rate $r_{y,z}$ (i.e., the mortality rate associated with being retained, rather than discarded), is expressed as

$$r_{y,z} = r_z \cdot F^{TCF}_{y,male,z} = r_z \cdot S^{TCF}_{y,male,z} \cdot f^{TCF}_{y,male} \tag{2}$$

where r_z is the size-specific "retention function", which takes values between 0 (no retention) and 1 (complete retention).

The OFL appropriate to a given assessment model is determined in the projection model using an iterative process to find the value for the fully-selected total fishing mortality rate on males in the directed fishery,

$f^{TCF}_{\cdot,male}$ or (more conventionally) F_{MSY}, that reduces stock biomass to B_{MSY} when fished at $f^{TCF}_{\cdot,male}$ (F_{MSY}) in the long term. In doing so, it is assumed that (in the long term) bycatch rates in the snow crab fishery will be as if it were fished at its F_{OFL}, the BBRKC fishery and groundfish fisheries will be fished at rates similar to those in the recent past (based on a four year average), and female bycatch rates in the directed fishery will be similar to those in the recent past (based on four-year average). Selectivity functions for all fisheries in the projection model are the same as those estimated in the assessment model, except that a 4-year average is used for total male selectivity and retention functions in the directed fishery.

Equations 1 and 2 in the projection model for fishing mortality are identical in form to those used in the TCSAM2013 assessment model. However, the equations are *used* in the projection model in one importantly different aspect from those in the assessment model: they are prognostic (they tell us what *will* happen) in the projection model whereas they are diagnostic (they tell us what *did* happen) in the assessment model. If one anticipates changes in fishing behavior, such as new discard procedures that will change handling mortality or a gear that will change fishery selectivity or a change in consumer habits that will change the retention curve, the projection model should be able to accommodate such changes.

The assessment model handles changes that have already occurred quite well, assuming data is available, because it *estimates* their effects on total (retained + discard) and retained fishing mortality. Unfortunately, as currently formulated using the TCSAM2013 fishing mortality model, it is not possible to consider *future* changes in either handling mortality rates or retention characteristics. First, future changes in handling mortality rates cannot be incorporated in the framework of Equations 1 and 2 because they are independent of handling mortality! Handling mortality is not an explicit parameter in the equations, even as an assumed value—it is applied to the *observed* discards in the assessment model to calculate observed total fishing mortality, which is then fit to estimate the components to $F_{y,x,z}$, $S_{x,z}$ and $f_{y,x}$. Consequently, the OFL calculated by the projection model is independent of projected changes in handling mortality. Second, the OFL calculated by the projection model is independent of the retention function r_z. The OFL depends on the total size-specific fishing mortality rate in each fishery, but it doesn't depend on the proportion of retained to discard mortality. Consequently, projected changes in the retention function affect the proportion of the OFL that is retained, but not the OFL itself.

It should be noted that these observations do not apply to a projection model formulated using the Gmacs fishing mortality model (Appendix A). This is because the Gmacs fishing mortality model is really a size-specific fishery capture (what's landed on deck) model, which is then partitioned into retained mortality and discards (what's thrown overboard), the latter of which is partitioned into discard mortality and discard survivors using an (assumed) handling mortality rate. One can postulate future changes in handling mortality (adjust the rate) or retention (adjust the retention ogive) without postulating changes in the way the fishery captures crab: the OFL will change because the characteristics of fishing mortality changes, even if the characteristics of the fishery capture process do not.

Appendix C: An Update to the 2015 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

William T. Stockhausen
Alaska Fisheries Science Center
10 September 2015

The preferred snow crab assessment model was recently updated (Sept. 7, 2015). Because the Tanner crab OFL and ABC calculations depend on the snow crab OFL, I have recalculated the values reported in the Tanner crab SAFE chapter released to the CPT and provide updated tables here.

The following updates Table 28 in the SAFE chapter and provides the snow crab F_{OFL} and effective *F* for Tanner crab bycatch used in the Tanner crab projection model. The row highlighted in yellow is based on the new preferred snow crab model (J. Turnock's Model 5, see Snow Crab SAFE):

Model	Snow Crab Model	Snow Crab Fofl	Efffective Snow Crab F	Projection Approach	Average Recruitment	B	Fmsy	Bmsy	B/Bmsy	OFL	ABC P-star	ABC (20% buffer)
2014 Mode	--			2014	187.90	63.80	0.58	29.82	2.14	31.48	31.43	25.18
Model A	Model 5	1.26	0.0344	2014	179.37	53.35	0.60	26.79	1.99	27.40	27.36	21.92
Model A	Preferred	0.89	0.0123	2014	179.37	52.80	0.64	26.79	1.97	27.73	27.70	22.19
Model A	Preferred	0.89	0.0123	new (1)	179.37	52.80	0.64	26.79	1.97	27.73	27.70	22.19
Model A	Preferred	0.89	0.0123	new (2)	179.37	55.91	0.44	26.79	2.09	24.78	24.75	19.82
Model A	2014	1.01	0.0212	2014	179.37	53.02	0.62	26.79	1.98	27.60	27.56	22.08
Model A	2014	1.01	0.0212	new (1)	179.37	53.02	0.62	26.79	1.98	27.60	27.56	22.08
Model A	2014	1.01	0.0212	new (2)	179.37	56.02	0.43	26.79	2.09	24.76	24.72	19.80
Model C	Preferred	1.01	0.0123	2014	180.95	54.53	0.44	25.62	2.13	26.27	26.24	21.02
Model C	2014	0.89	0.0212	2014	180.95	54.88	0.41	25.62	2.14	26.15	26.12	20.92

The following tables would update the "Management Performance" tables in the Executive Summary, if Snow Crab Model 5 were selected by the CPT:

Units in 1000's t.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2011/12	11.40	58.59	0.00	0.00	1.24	2.75	2.48
2012/13	16.77	59.35	0.00	0.00	0.71	19.02	8.17
2013/14	16.98	72.70	1.41	1.26	2.78	25.35	17.82
2014/15	13.40	71.57	6.85	6.16	9.16	31.48	25.18
2015/16		53.35				27.40	21.92

Units in millions lbs.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2011/12	25.13	129.17	0.00	0.00	2.73	6.06	5.47
2012/13	36.97	130.84	0.00	0.00	1.57	41.93	18.01
2013/14	37.43	160.28	3.11	2.78	6.14	55.89	39.29
2014/15	29.53	157.78	15.10	13.58	20.19	69.40	55.51
2015/16		117.61				60.40	48.32

The following tables would update the “Basis for the OFL” tables in the Executive Summary, if Snow Crab Model 5 were selected by the CPT

Biomass units in 1000’s t.

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2012/13	3a	33.45	58.59	1.75	0.61 yr^{-1}	1982-2012	0.23 yr^{-1}
2013/14	3a	33.54	59.35	1.77	0.73 yr^{-1}	1982-2013	0.23 yr^{-1}
2014/15	3a	29.82	63.80	2.14	0.61 yr^{-1}	1982-2014	0.23 yr^{-1}
2015/16	3a	26.79	53.35	1.99	0.60 yr^{-1}	1982-2015	0.23 yr^{-1}

Biomass units in millions lbs.

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	Natural Mortality
2012/13	3a	73.74	129.17	1.75	0.61 yr^{-1}	1982-2012	0.23 yr^{-1}
2013/14	3a	73.94	130.84	1.77	0.73 yr^{-1}	1982-2013	0.23 yr^{-1}
2014/15	3a	65.74	140.66	2.14	0.61 yr^{-1}	1982-2014	0.23 yr^{-1}
2015/16	3a	59.06	117.61	1.99	0.60 yr^{-1}	1982-2015	0.23 yr^{-1}

Appendix D: Another Update to the 2015 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
15 September 2015

The CPT selected Model 0 from the snow crab assessment today (Sept. 15, 2015) for setting OFL. Because the Tanner crab OFL and ABC calculations depend on the snow crab OFL, I have (again) recalculated the values reported in the Tanner crab SAFE chapter and provide updated tables here.

The following updates Table 28 in the SAFE chapter and provides the snow crab F_{OFL} and effective *F* for Tanner crab bycatch used in the Tanner crab projection model. The row highlighted in yellow is based on the CPT-selected snow crab model (J. Turnock's Model 0, see the Snow Crab SAFE):

Model	Snow Crab Model	Snow Crab Fofl	Efffective Snow Crab F	Projection Approach	Average Recruitment	B	Fmsy	Bmsy	B/Bmsy	OFL	ABC P-star	ABC (20% buffer)
2014 Model	--			2014	187.90	63.80	0.58	29.82	2.14	31.48	31.43	25.18
Model A	Model 0	1.32	0.049	2014	179.37	53.70	0.58	26.79	2.00	27.19	27.15	21.75
Model A	Model 5	1.26	0.034	2014	179.37	53.35	0.60	26.79	1.99	27.40	27.36	21.92
Model A	Preferred	0.89	0.012	2014	179.37	52.80	0.64	26.79	1.97	27.73	27.70	22.19
Model A	Preferred	0.89	0.012	new (1)	179.37	52.80	0.64	26.79	1.97	27.73	27.70	22.19
Model A	Preferred	0.89	0.012	new (2)	179.37	55.91	0.44	26.79	2.09	24.78	24.75	19.82
Model A	2014	1.01	0.021	2014	179.37	53.02	0.62	26.79	1.98	27.60	27.56	22.08
Model A	2014	1.01	0.021	new (1)	179.37	53.02	0.62	26.79	1.98	27.60	27.56	22.08
Model A	2014	1.01	0.021	new (2)	179.37	56.02	0.43	26.79	2.09	24.76	24.72	19.80
Model C	Preferred	1.01	0.012	2014	180.95	54.53	0.44	25.62	2.13	26.27	26.24	21.02
Model C	2014	0.89	0.021	2014	180.95	54.88	0.41	25.62	2.14	26.15	26.12	20.92

The following tables update the "Management Performance" tables in the Executive Summary:

Units in 1000's t.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2011/12	11.40	58.59	0.00	0.00	1.24	2.75	2.48
2012/13	16.77	59.35	0.00	0.00	0.71	19.02	8.17
2013/14	16.98	72.70	1.41	1.26	2.78	25.35	17.82
2014/15	13.40	71.57	6.85	6.16	9.16	31.48	25.18
2015/16		53.70				27.19	21.75

Units in millions lbs.

Year	MSST	Biomass (MMB)	TAC (East + West)	Retained Catch	Total Catch Mortality	OFL	ABC
2011/12	25.13	129.17	0.00	0.00	2.73	6.06	5.47
2012/13	36.97	130.84	0.00	0.00	1.57	41.93	18.01
2013/14	37.43	160.28	3.11	2.78	6.14	55.89	39.29
2014/15	29.53	157.78	15.10	13.58	20.19	69.40	55.51
2015/16		118.38				59.94	47.95

The following tables update the "Basis for the OFL" tables in the Executive Summary.

Biomass units in 1000's t.

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

Biomass units in millions lbs.

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

2015 Stock assessment and fishery evaluation report for the Pribilof Island red king crab fishery of the Bering Sea and Aleutian Islands regions (DRAFT)

C.S. Szuwalski, R.J. Foy, B.J. Turnock
Alaska Fishery Science Center
National Marine Fishery Service
National Oceanic and Atmospheric Administration

Executive summary

1. Stock: Pribilof Islands red king crab, *Paralithodes camtschaticus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been increasing in recent years, but are still low relative to the OFL.
3. Stock biomass:
    a. According to a 3-year running average, mature male biomass decreased from 2007 to 2010 and increased during 2011 through 2015.
    b. According to an integrated length-based assessment, mature male biomass increased from 2007 to 2009 and decreased from 2010 through 2015.
4. Recruitment: Recruitment is episodic for PIRKC and has been low since 2001.
5. Recent management statistics:

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	2,255	2,754[A]	0	0	4.2	349	
2011/12	2,571	2,775[B*]	0	0	5.4	393	307
2012/13	2,609	4,025[C**]	0	0	13.1	569	455
2013/14	2,582	4,679 [D**]	0	0	2.25	903	718
2014/15	2,871	8894	0	0	1.06	1359	1019

Units are in tonnes.

Year	MSST	Biomass (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2010/11	4.97	6.07[A]	0	0	0.009	0.77	
2011/12	5.67	6.12[B*]	0	0	0.011	0.87	0.68
2012/13	5.75	8.87[C**]	0	0	0.029	1.25	1.00
2013/14	5.66	10.32[D**]	0	0	0.005	1.99	1.58
2014/15	6.33	19.60	0	0	0.002	3.00	2.25

Units are in millions of lbs. The OFL is the total catch OFL for each year. The stock was above MSST in 2013/2014 according to both a 3-year average and a length-based assessment method and is hence not overfished.

Notes:

A – Based on survey data available to the Crab Plan Team in September 2010 and updated with 2010/2011 catches
B – Based on survey data available to the Crab Plan Team in September 2011 and updated with 2011/2012 catches
C – Based on survey data available to the Crab Plan Team in September 2012 and updated with 2012/2013 catches
D – Based on survey data available to the Crab Plan Team in September 2013
* – 2011/12 estimates based on 3 year running average
** –estimates based on weighted 3 year running average using inverse variance

6. 2015/2016 OFL projections:

Tier	Assessment Method	OFL	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	γ	Years to define B_{MSY}	F_{MSY}	P*	ABC
4	Running Average	2119	5649	13685	2.42	1.0	1991/1992-2013/2014 (MMB)	0.18	0.49	1467
4	Integrated assessment	458	3887	3180	0.82	1.0	1991/1992-2013/2014 (MMB)	0.18	0.49	339
3	Integrated assessment	1015	1363	3180	2.62	1.0	1991/1992-2013/2014 (MMB)	0.45	0.49	752
4	Integrated assessment (males only)	741	4345	5161	1.19	1.0	1991/1992-2013/2014 (MMB)	0.18	0.49	528
3	Integrated assessment (males only)	1608	1560	5161	3.31	1.0	1983-present (recruitment)	0.44	0.49	1143

Units are in tonnes

Tier	Assessment Method	OFL	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	γ	Years to define B_{MSY}	F_{MSY}	P*	ABC
4	Running Average	4.68	12.45	30.17	2.42	1.0	1991/1992-2013/2014 (MMB)	0.18	0.49	3.24
4	Integrated assessment	1.01	8.57	7.01	0.82	1.0	1991/1992-2013/2014 (MMB)	0.18	0.49	0.75
3	Integrated assessment	2.23	3.00	7.01	2.62	1.0	1983-present (recruitment)	0.45	0.49	1.66
4	Integrated assessment (males only)	1.63	9.58	11.38	1.19	1.0	1991/1992-2013/2014 (MMB)	0.18	0.49	1.16
3	Integrated assessment (males only)	3.54	3.44	11.38	3.31	1.0	1983-present (recruitment)	0.44	0.49	2.52

Units are in millions of pounds.

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. The posterior of the OFL from the integrated assessment was used as the distribution for the OFL from which ABCs were calculated.
8. Basis for ABC: ABCs were identified as the 49th percentile of the distributions of the OFL given a p-star of 0.49.

Summary of Major Changes:

1. Management: None.
2. Input data: Survey (2015) and bycatch (2014) data were incorporated into the assessment. Methodology for calculating estimates of numbers from the survey data changed between 2014 and 2015.
3. Assessment methodology: A comparison of output when the only data for males is fit is presented based on concerns of 2014 model fits to survey estimates. Fishery selectivity is borrowed from BBRKC rather than knife-edge and incorporates discard mortality of 20%.
4. Assessment results: MMB estimates from the 3-year running average are the highest on record, but conflict with a lack of recruitment since the early 2000s.

CPT May 2015 requests (and SSC comments)

In response to the SSC comments about poor fits to male numbers from the survey data from 1990 forward, the CPT suggested a model run forcing a fit to the higher survey years and exploration of time-varying processes. The SSC also suggested truncating the time series to exclude the low abundances in the 1970s and 1980s.

The poor fits to survey numbers result from two data conflicts. First, males and females have opposite trends in recent years (apart from 2015; Figure 19): females are declining and males are increasing. Recruitment and catchability were identical for females and males in the 2014 integrated assessment, so the neither the male nor female numbers data were well fit for recent years. A model fitting to only males is presented here and fits male numbers (marginally) better than the 2014 assessment (Figure 27). Excluding the low abundances from the data (1970s-1980s) does not change the fits to the data starting in the 1990s. Forcing a fit to the high survey estimates during the 1990s results in large overestimates of numbers in the 2000s and after (i.e. the model can fit either the high abundances or the low, with a constant M or q because there is no fishing mortality; Figure 39). Large swings in abundance between the 1990s and 2000s are still poorly fit because the specified natural mortality and the inferred fishing mortality are not large enough to allow for such large yearly changes in abundance.

The second data conflict is apparent in the length frequencies, recruitment, and the most recent estimated MMB. Estimated MMB from the 3-year running average was the highest on record this year, but there has been no recruitment since the early 2000s (as seen through the length frequencies). This suggests that either catchability is varying or there has been large-scale immigration by large male crab.

The CPT also suggested time-blocking M and allowing time-varying selectivity or catchability to address the poor fits.

A switch allowing time-varying catchability was coded in the assessment method. Model fits to male numbers were much better when catchability was freely estimated (as expected; Figure 37), but there was no clear relationship between catchability and temperature (sea surface or bottom). Time-varying catchability analyses were only done when fitting males because: 1) trends in estimates of numbers are opposite for females and males in recent years and 2) male biomass (via survey numbers) are the important quantity to estimate for management.

The CPT suggested borrowing the total fishery selectivity from BBRKC for use with PIRKC so that some discard mortality could be applied when calculating target fishing mortalities.

This was incorporated and resulted in a reduction in $F_{35\%}$ by 0.08 (from 0.53 to 0.45) when both males and females were fit.

The SSC supports the author's suggestions to further investigate model sensitivity of different size bins on growth and management specifications.

A simulation framework was built to explore biases observed in 2014 by moving to 10mm length bins (Szuwalski, in press). Assessment methods using 5mm size bin data returned unbiased estimates of MMB, but 10mm size bins produced biased estimates of MMB. So, the estimates of MMB from the assessment method using 5mm size bins presented in 2014 are likely more reliable than the 10mm data. The bias was caused by the way the integral representing the probability of molting from one size to another was approximated. Assessment methods with 5mm length bins were used in all scenarios presented here based on the unbiased estimates of MMB in simulation.

Include more detail on the model
The code is now available on Github (github.com/szuwalski/PIRKC) and Appendix A (describing the model) is more detailed.

Unaddressed comments
Incorporate a mean-unbiased log normal likelihood for survey numbers
Next time.

Discuss the poisson vs. negative binomial for survey estimates of abundance and CVs
Currently all of the data in the model are those that are passed from Bob Foy and the Kodiak lab, but given the over-dispersion in the data, a negative binomial (or something similar) might be more appropriate, particularly for estimates of variance. The CVs sent by Bob are used in the assessment, but bootstrapped variances are much larger.

Consider ADFG pot survey data and retained catch size frequency data
These data area not yet incorporated, but may be useful in exploring the mechanics of time-varying catchability.

Employ an iterative reweighting scheme for setting the length frequency weights.
To be addressed.

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

Two survey time series' (with accompanying CVs--both updated through 2014) are first presented for comparison (Figure 5). A change in the methodology used to produce estimates of biomass and numbers at length within these time series' produced small changes in some of the data used in the assessment methodology. The updated survey time series (through 2015) is used to present the final OFL and ABC.

The standard groundfish discards time series data (updated through 2014) were used in this assessment. The crab fishery retained and discard catch time series were updated with 2014/2015 data. The following sources and years of data are available:

Data source	Years available	Used in integrated assessment?
NMFS trawl survey	1975-2015	Yes
Retained catch	1993-2014	Yes
Trawl bycatch	1991-2014	Yes
Fixed gear bycatch	1991-2014	No
Pot discards	1998-2014	No

2.1 Retained catch

Red king crab were targeted in the Pribilof Islands District from the 1993/1994 season to 1998/1999. Live and deadloss landings data and effort data are available during that time period (Tables 1 and 2), but no retained catch has been allowed since 1999.

2.2 Bycatch and discards

Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers. Catch weight was calculated by first determining the mean weight (g) for crabs in each of three categories: legal non-retained, sublegal, and female. Length to weight parameters were available for two time periods: 1973 to 2009 (males: A=0.000361, B=3.16; females: A=0.022863, B=2.23382) and 2010 to 2013 (males: A=0.000403, B=3.141; ovigerous females: A=0.003593, B=2.666; non-ovigerous females: A=0.000408, B=3.128). The average weight for each category was multiplied by the number of crabs at that CL, summed, and then divided by the total number of crabs (equation 2).

$$\text{Weight (g)} = A * \text{CL(mm)}^{B} \qquad (1)$$

$$\text{Mean Weight (g)} = \sum(\text{weight at size} * \text{number at size}) / \sum(\text{crabs}) \qquad (2)$$

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.

Historical non-retained catch data are available from 1998/1999 to present from the snow crab, golden king crab (*Lithodes aequispina*), and Tanner crab fisheries (Table 3) although data may be incomplete for some of these fisheries. Limited observer data exists prior to 1998 for catcher-processor vessels only so non-retained catch before this date is not included here. In 2013/2014, there were no Pribilof Islands red king crab incidentally caught in the crab fisheries (Table 3).

2.3 Groundfish pot, trawl, and hook and line fisheries

The 2013/2014 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 for 2012/2013 catches, 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 1991data 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.

The new time series resulted in different estimates of red king crab bycatch biomass in 2009/2010-2012/2013 (Table 3). In 2012/2013, using the new database estimation, 16.46 t of male and female red king crab were caught in fixed gear (0.23 t) and trawl gear (16.23 t) groundfish fisheries which is 51% greater than was caught in 2011/2012 pot, trawl, and hook and line groundfish fisheries. The catch was mostly in non-pelagic trawls (99%) followed by longline (1%), and pot (<1%) fisheries (Table 4). The targeted species in these fisheries were Pacific cod (3%), flathead sole (18%), yellowfin sole (77%), and traces <1% found in the rockfish fisheries. Unlike previous years no bycatch was observed in Alaska plaice fisheries in 2011/2012 or 2012/2013.

2.4 Catch-at-length
Catch-at-length data are not available for this fishery.

2.5 Survey biomass and length frequencies
The 2015 NOAA Fisheries EBS bottom trawl survey results (Daly et al. in press) are included in this SAFE report. Data available for estimating the abundance of crab around the Pribilof Islands are relatively sparse. Red king crab have been observed at 35 unique stations in the Pribilof District (22 stations on the 400 nm^2 grid). The number of stations at which at least one crab was observed in a given year ranges from 0-14 over the period from 1975-present (Figure 6). Weight (equation 1) and maturity (equation 3) schedules are applied to calculated abundances and summed to calculate mature male, female, and legal male biomass for the Tier 4 analysis.

$$\text{Proportion mature male} = 1/(1 + (5.842 * 10^{14}) * e^{((CL(mm)+2.5) * -0.288)})$$
$$\text{Proportion mature female} = 1/(1 + (1.416 * 10^{13}) * e^{((CL(mm)+2.5) * -0.297)}) \qquad (3)$$

Historical survey data are available from 1975 to the present (Tables 5 and 6), and survey data analyses were standardized in 1980 (Stauffer, 2004). Male and female abundance varies widely over the history of the survey time series' (Figure 7) and uncertainty around area-swept estimates of abundance are large due to relatively low sample sizes (Figure 6). Male crabs were observed at 9 of 35 stations in the Pribilof District during the 2015 NMFS survey (Figure 8); female crabs were observed at 5 (Figure 9). Two (possibly three) cohorts can be seen moving through the length frequencies over time (Figure 10 and Figure 11). Numbers at length vary dramatically from year to year, but the cohorts can nonetheless also be discerned in these data (Figure 12 and Figure 13). Methodologies for calculating estimated numbers at length and biomass changed slightly from 2014 to 2015 (see Daly et al., in press for description).

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 length frequencies used in the 2014 assessment were calculated from the survey data for use in the integrated assessment. Occasionally, several hauls were taken at a single survey station (here a 'haul' does not refer to the high density sampling in which the 'corners' of a station are trawled—'haul' refers to multiple samples from a given location). Treating multiple hauls as independent measurements may introduce bias when calculating the population-wide length frequencies. Therefore, whenever multiple hauls were taken at a station, their contribution to the overall length frequency was weighted by the average number of individuals caught in a haul at that station. The length frequencies used in 2015 were provided by the Kodiak lab and exhibited only minor differences to 2014 input data.

3. Analytical approaches

3.1 History of modeling

An inverse-variance weighted 3-year running average of mature male biomass 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). A catch survey analysis has been used for assessing the stock in the past, although the data are not currently used in this assessment. This year (2015), biomass and derived management quantities are estimated both by a running-average method and by an integrated length-based assessment method (developed in 2014). Tier 3 and tier 4 harvest control rules (HCRs) are applied to the integrated assessment output and are compared to the OFLs calculated by a tier 4 HCR applied to the running-average estimates of MMB.

3.2 Model descriptions

3.2.1. Running average

A 3 year running average of mature male biomass (runAvg) was calculated using the function 'weighted.mean' in the R programming languages as:

for(t in 2:(length(MMB)-1))
runAvg[t]<-weighted.mean(MMB[(t-1):(t+1)],w=1/σ²[(t-1):(t+1)]) (4)

Where,

MMB	Estimated mature male biomass from the survey data
σ^2	The variance associated with the estimate of MMB at time t

σ_t^2 is calculated from the CVs of the estimates of MMB from the survey provided by the Kodiak lab as:

$$\sigma_t^2 = \ln((CV_t^{MMB})^2 + 1) \tag{5}$$

Where,

CV_t^{MMB}	Coefficient of variation associated with the estimate of MMB at time t

3.2.2 Integrated assessment

A length-based integrated assessment method [coded in ADMB (Fournier et al. 2012)] was used to estimate trends in recruitment, fishing mortality (directed and bycatch in the non-pelagic trawl fishery) and male and female numbers in the survey (see appendix A for the model description, likelihood weightings, and estimated and fixed parameters). The assessment is initiated 5 years before data are available to avoid estimating initial numbers at length for both sexes. Males and females are tracked by 5 mm length bins ranging from 37.5-207.5mm in the base model. Fishing mortality from the directed fishery during 1993-1998 and bycatch in the non-pelagic trawl fishery from 1991-2013 were accounted for in the model, but discards from the pot fisheries for crab and the fixed gear fishery for cod are not incorporated into the model. The magnitude of the mortality imposed by discards on the population is very small compared to the directed fishery, so the impact of excluding them from the model should be relatively small. Samples were drawn from the posterior distributions for some quantities important in management (e.g. the OFL and MMB) using MCMC to characterize the uncertainty in parameter estimates and derived quantities. This involved conducting 5,000,000 cycles of the MCMC algorithm, implementing a 20% burn-in period and saving every 2000th draw. Several diagnostic statistics (e.g. checking for lack of autocorrelation and calculating Geweke statistics) were used to check for evidence of non-convergence of the MCMC algorithm.

Growth was estimated within the integrated assessment because there are no targeted studies on growth of Pribilof Island red king crab. The presence of a single, large cohort that established the population during the mid-1980s and then was subsequently relatively lightly fished (or not at all in the case of females) makes estimating growth tractable. The modes of the length frequency distributions were well fit by a linear relationship when translated to growth per molt (Figure 14).

Sensitivities to the bin width were performed in 2014 by fitting the assessment method with 10 mm length bins. Estimates of quantities important in management and model fits were not identical between 10 and 5 mm size bin scenarios. Fits to numbers at length and length frequencies were visually similar, but estimated MMB for 2014 was 16% higher when using the 10mm data. A simulation study was undertaken to explore these differences and showed that an assessment method with bin sizes of 5mm estimates MMB without bias (when the data were generated from the underlying population dynamics model), but the estimates from the assessment method fit data binned at 10mm exhibit positive biases compared to the true quantities (Figure 15). The details of this simulation study were presented at the CAPAM symposium on growth and have been accepted for publication in the special issue (Szuwalski, in press). As a result of this study, the assessment methods presented here use 5mm length bins.

The fits of the 2014 integrated assessment in the recent past were poor for both females and males (Figure 16). Male numbers were underestimated; female numbers were overestimated. An additional assessment method that fits only to male numbers and length frequencies in the survey is presented for comparison given the poor fits. An assessment method in which only males are fit and catchability is allowed to vary in each year is also presented to explore relationships between estimated catchability and environmental variables. Finally, an assessment method that decreases the CVs of the survey numbers during the 1990s (i.e. the first large cohort that produced large estimates of survey numbers) to force the model predictions to fit the 1990s data is presented.

4. Model Selection and Evaluation

The running average method with a tier 4 HCR was selected in 2014 by the SSC as the model to determine the TAC based on concerns around different trends in the last decade for the integrated model and the running average. This year (2015) three assessment methods are presented for comparison: a running average with a tier 4 HCR, an integrated assessment with tier 3 HCR, an integrated assessment with a tier 4 HCR. Each of these methods was fit to the new time series of estimated numbers from the summer survey. Data scenarios in which methods were fit to data for both sexes and data for only males are also presented.

There are trade-offs between using the running average method and the integrated assessment to estimate MMB. The running average methodology is simple to perform and interpret, but estimates of biomass can be sensitive to measurement errors, particularly when relatively few stations report observations of crab or very large tows are taken at a small number of stations. An integrated assessment can smooth over some of the error introduced by imperfect measurement, but it also smoothes over process error (e.g. time-varying population processes) that may be captured by a running average. Integrated assessments are also relatively data-hungry and some assumptions must be made about the underlying population processes (e.g. selectivity of the different fleets).

Non-convergence of the integrated models was checked for by examining the maximum gradient components and the ability to invert the Hessian matrix.

5. Results

5.1 Mature biomass

Estimated MMB from the integrated assessment peaked during 1992 at 5282 t using the 2015 survey data and fitting both males and females (Figure 17); estimates of MMB (i.e. carapace width >120mm) from a 3-year moving average peaked during 2015 at 13685 t. Estimated MMB in the year 2015 when only males were fit in the integrated assessment was 62% higher (5161 vs. 3180 t) than when females were also fit (Figure 17). MMB is higher for the data calculated using the new methodology because the survey estimates for females increased (Figure 5), estimated recruitment increased to compensate, and MMB is linked to FMB through recruitment.

Female mature biomass peaked during 2001 at 1541 t using the 2014 survey data; whereas estimates of FMB from the 3-year moving average peaked during 1994 at 5179 t. Estimated trajectories of biomass from the models are similar in that a large pulse of recruitment in the early 1980s translates to an initial rise in biomass which is fished down through the 1990s. However, estimates of biomass from the integrated assessment methods rebound to levels as high as or higher than the early 1990s levels after fishing pressure is ceased. Estimates from the 3-year moving average for MMB have recently returned to levels exceeding those estimated during the early 1990s. Given the similarities in mature biomass estimates between the 2015 and 2014 survey methodologies, only the results for the updated survey methodologies and the 2015 survey data will be presented from here forward.

5.2 Integrated assessment model fits

5.2.1 Both females and males fit

Estimated male survey numbers peaked during 1991 at 1.84 million (Figure 18), corresponding to an estimated mature male biomass at 5282 t. Estimated female survey numbers peaked during 1992 at 1.60 million, corresponding to an estimated mature female biomass of 2014 t. Catch and bycatch in the non-pelagic trawl fishery were well fit by the assessment method (Figure 18). Given a relatively low natural mortality, a short series of years in which there was a directed fishery, and the selectivity of the fishery, the assessment method was unable to track large year-to-year swings in estimated survey abundance. It is possible that yearly swings in estimates of abundance were attributable to sampling error, given the few data points available to inform these estimates. This was somewhat corroborated by noting the number of observations available to inform the estimates increased over time (Figure 6) and the extreme estimates of biomass were less often observed after the year 2000 (though 2014 and 2015 may be exceptions to this observation). The differences in interannual variability of estimates of mature biomass and numbers between the integrated assessment and running average represent a tradeoff between following data influenced by low sample sizes (running average) and the smoothing effects of assuming a constant natural mortality and catchability (integrated assessment).

Large estimated recruitment events during the mid-1980s translated to a large increase in mature biomass, but estimated recruitment events since that period have been much smaller (Figure 20). Estimated recruitment was very poor during recent years (2003-present) and there did not seem to be a relationship between female mature biomass and recruitment at 4, 5, or 6 year lags (Figure 22). Estimated fishing mortality peaked in 1993 (the first year of the directed fishery) at 0.38, which does not exceed the calculated $F_{35\%}$ of 0.44. Estimated survey selectivity gradually increased until ~150 mm length at which point 95% of crab are selected in the survey gear (Figure 20) and survey catchability is fixed at 1. The negative log likelihood decreases as survey catchability (q) increased, even beyond a value of 1 (Figure 23). However, catchability higher than 1 is difficult to justify, so fixing q at 1 was a reasonable practice here. Fishery selectivity was not estimated as there are no catch at length or discard at length data available.

Two (possibly three) cohorts moved through the male size classes throughout the history of the fishery and the resulting survey length frequencies are better fit in the 1980s than during the late 1990s and early 2000s (Figure 24 and Figure 25). During 1999 and 2001, two large peaks in small crab appeared but did not carry through to larger size classes. The appearance (1999), disappearance (2000), and reappearance (2001) of a “cohort” influenced the ability of the assessment method to fit the length frequencies in the 2000s. Capping the samples sizes at 200 provided slightly better fits to the length frequencies, but did not completely eliminate the poor fits. Female length frequencies were fit better than the male frequencies (table A3, Figure 25), but also displayed 'disappearing' crab (e.g. the year 2000).

The estimated growth relationships were similar to estimates for other red king crab in the EBS. For example, a 50 mm female would molt to 68 mm on average given the estimates produced here. Weber (1967) estimated the post-molt length for a 50 mm female at 63.5 and then 67.5 in 1974. An 80 mm female would molt to 93.8 mm given estimates from the integrated assessment which is less than Weber's estimates (96m m and 97.5 mm), but corroborated the observation that female growth increment decreases compared to males as size increases. A 50 mm male would molt to 65 mm given the estimates from the assessment and an 80 mm male would molt to 99.5 mm. Posteriors for the growth parameters suggest growth was relatively well estimated (Figure 26). Estimated variability around the growth curve was larger for males than it was for females (1.12 vs. 0.30) and was apparent in the spread of the length frequencies throughout the 1990s (Figure 24 vs. Figure 25). There were slight changes in the estimated growth parameters from 2014 to 2015 due to changes in survey data methodologies.

5.2.2 Only males fit

Estimated male survey numbers peaked during 2009 at 2.2 million when fitting to only data for male crab, corresponding to an estimated mature male biomass at 7294 t, which is also the peak MMB (Figure 18 and Figure 27). Both of these figures are larger than the estimates when females were also fit and occur at a later time in the time series (2009 vs. 1992). Consequently, estimated recruitment was scaled up, but maintained similar patterns. Catch and bycatch in the non-pelagic trawl fishery were well fit by the assessment method. Estimated fishing mortality peaked in 1993 (the first year of the directed fishery) at 0.47, which was higher than the two sex model (Figure 28). Fits to the length frequencies were very similar to when both females and males were fit (Figure 29). Estimated survey selectivity shifted to the left slightly when males only are fit (sel95% = 147 and 145; both sexes and males only, respectively).

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 a 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.

$$F_{OFL} = \begin{cases} Bycatch\ only & if\ \dfrac{B_{cur}}{B_{MSY\ proxy}} \leq \beta \\ \dfrac{\gamma M\left(\dfrac{B_{cur}}{B_{MSY\ proxy}} - \alpha\right)}{1-\alpha} & if\ \beta < \dfrac{B_{cur}}{B_{MSY\ proxy}} < 1 \\ \gamma M & if\ B_{cur} > B_{MSY\ proxy} \end{cases} \qquad (4)$$

Where,

B_{cur}	Current estimated mature male biomass
$B_{MSY\ proxy}$	Average mature male biomass over the years 1991-present
M	Natural mortality
α	Determines the slope of the descending limb of the HCR (0.1)
β	Fraction of $B_{MSY\ proxy}$ below which directed fishing mortality is zero (here set to 0.25)

The F_{OFL} calculated from equation 4 was applied to the legal male population surviving to the time of the fishery (October 15).

6.2 Tier 3 OFL, $F_{35\%}$, and $B_{35\%}$

Proxies for biomass and fishing mortality reference points were calculated using spawner-per-recruit methods (e.g. Clarke, 1991) in the tier 3 HCR. After fitting the assessment model to the data and estimating population parameters, the model was projected forward 100 years using the estimated parameters under no exploitation to find virgin mature male biomass per recruit. Projections were repeated (again for 100 years) to determine the level of fishing mortality that reduced the mature male biomass per recruit to 35% of the virgin level (i.e. $F_{35\%}$ and $B_{35\%}$, respectively) by using the bisection method for identifying the target fishing mortality.

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

$$F_{OFL} = \begin{cases} Bycatch\ only & if\ \dfrac{B_{cur}}{B_{35\%}} \le \beta \\ \dfrac{F_{35\%}\left(\dfrac{B_{cur}}{B_{35\%}} - \alpha\right)}{1-\alpha} & if\ \beta < \dfrac{B_{cur}}{B_{35\%}} < 1 \\ F_{35\%} & if\ B_{cur} > B_{35\%} \end{cases} \tag{5}$$

Where,

B_{cur}	current estimated mature male biomass
$B_{35\%}$	mature male biomass at the time of mating resulting from fishing at $F_{35\%}$
$F_{35\%}$	Fishing mortality that reduce the spawners per recruit (measured here as mature male biomass at the time of mating) to 35% of the unfished level
α	Determines the slope of the descending limb of the HCR (0.05)
β	Fraction of $B_{35\%}$ below which directed fishing mortality is zero (here set to 0.25)

6.3 Acceptable biological catches

An acceptable biological catch (ABC) was 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 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.

6.5 Tier 3 and integrated assessment: Reference points and OFL

6.5.1 Fitting males and females

A large year class recruited to the survey gear during 1985 and, lagged to the year of fertilization, would have been produced near the timing of the late 1970s shift in environmental conditions in the North Pacific (Overland et al., 2008). Consequently, $B_{35\%}$ was calculated using only estimates of recruitment from 1983 forward to reflect current environmental conditions (DOC, 2007) and corresponds to a MMB of 1363 t. The corresponding $F_{35\%}$ was 0.45 and, given a ratio of the current biomass to $B_{35\%}$ of 2.62, the calculated F_{OFL} was also 0.45 which resulted in an OFL of 1015 t. $F_{35\%}$ was relatively high compared to natural mortality because a large fraction of MMB is protected by the 138mm size limit; $F_{35\%}$ in 2015 was less than the calculated value in 2014 (0.53) because discard mortality borrowed from BBRKC was incorporated into the assessment method. When only males were fit, $B_{35\%}$ was calculated as an MMB of 1560 t. The corresponding $F_{35\%}$ was 0.44 and, given a ratio of the current biomass to $B_{35\%}$ of 3.31, the calculated F_{OFL} was also 0.44 which resulted in an OFL of 1608 t.

The traces of the MCMCs performed were stationary for all data scenarios with sufficient burn-ins and thinning. The 90% credibility interval of the posterior distribution of $B_{current}/B_{35\%}$ when both males and females were fit ranged from 2.42 to 2.79; the 90% credibility interval for the posterior for $F_{35\%}$ ranged from .449 to 0.457; and the 90% credibility interval for the OFL ranged from 894 to 1126 t (Figure 31). The 90% credibility interval of the posterior distribution of $B_{current}/B_{35\%}$ when only males were fit ranged from 3.07 to 4.38; the 90% credibility interval for the posterior for $F_{35\%}$ ranged from 0.438 to 0.445; and the 90% credibility interval for the OFL ranged from 1269 to 2050 t (Figure 32).

5.4 Tier 4 Reference points and OFL

Tier 4 reference points and management quantities were calculated simultaneously in the integrated assessment with the tier 3 reference points. B_{MSY} (based on the MMB over the years 1991-present) was calculated as 3887 t when fitting both males and females. F_{MSY} was set equal to natural mortality (0.18) and the resulting OFL was 458 t. The 90% credibility interval of the posterior distribution of B_{MSY} for the tier 4 control rule ranged from 3572 to 4238 t, and the 90% credibility interval for the OFL ranged from 403 to 508 t (Figure 33). B_{MSY} (based on the MMB over the years 1991-present) was calculated as 4345 t when fitting only males; the associated 90% credibility interval of the posterior distribution ranged from 3478 to 5196 t, and the 90% credibility interval for the OFL ranged from 585 to 947 t (Figure 34).

B_{MSY} and current MMB calculated from the 3-year running averages were substantially higher than the estimates from the integrated assessment when both males and females were fit (e.g. MMB equal to 13685 vs 3180t for 3-year average and integrated assessment fit to males and females, respectively). Consequently, the calculated OFL was also much higher—2119 t. The OFL for the 3-year running average was the highest OFL from all methods, due to its reliance on the most recent survey estimate of male numbers and biomass, which is the highest estimate in the observed time series. The 90^{th} quantiles of the bootstrapped distribution for the OFL ranged from 604 to 6581 t (Figure 35).

5.5 Recommended ABCs

All of the following ABCs are reported using a pstar of 0.49 and an additional buffer of 25%. Based on the distributions of the OFL calculated using the running-average method, the ABC for the tier 4 HCR was 1563 t. For the models in which both males and females were fit, the ABC for the tier 4 HCR using the posterior of the OFL from the integrated assessment was 339 t; the ABC for the tier 3 HCR was 752 t. For the models in which only males were fit, the ABC for the tier 4 HCR/integrated assessment and a p-star of 0.49 was 528 t; the ABC for the tier 3 HCR/integrated assessment was 1143 t.

5.6 Variables related to scientific uncertainty in the OFL probability distribution

Uncertainty in estimates of stock size and OFL for Pribilof Islands red king crab was relatively high due to small sample sizes. The coefficient of variation for the estimate of male abundance for 2015 was 0.72

and has ranged between 0.36 and 0.92 since the 1991 peak in numbers. These CVs were calculated by assuming the data are Poisson distributed, but the data are overdispersed. Using a negative binomial (or other distribution that can allow for overdispersion) would increase the CVs. Growth and survey selectivity were estimated within the integrated assessment (and therefore uncertainty in both processes is accounted for in the posterior distributions), but maturity, survey catchabillity, fishery selectivity, and natural mortality were fixed. F_{MSY} was assumed to be equal to natural mortality and B_{MSY} was somewhat arbitrarily set to the average MMB over a predetermined range of years for tier 4 HCRs; both of which were assumptions that had a direct impact on the calculated OFL. Sources of mortality from discard in the crab pot fishery and the fixed gear fishery were not included in the integrated assessment because of a lack of length data to apportion removals correctly. Including these sources of mortality may alter the estimated MMB.

A simulation test in which the assessment method was fit to data generated by the population dynamics model within the assessment method and subject to the same measurement error showed that the assessment method was capable of returning unbiased estimates of MMB band other quantities and parameters important in management when size bins were 5mm (Szuwalski, in press). Retrospective analyses have not yet been performed for the presented integrated assessment, but should be considered.

6. Author Recommendation

In the foreseeable future, low sample size will be a problem for the Pribilof Island red king crab, so extra precaution should be taken given the uncertainty associated with MMB estimates. In this respect, the tier 4 HCR is more precautionary in that it sets a higher MSST and a lower $F_{OFL,}$ OFL, and ABC for a given MMB. However, when used in concert with a running average method to estimate MMB, it can be less conservative than the tier 3 HCR that uses estimates from the integrated assessment. If there is a particularly high estimate of MMB from the survey (which are often uncertain–see 2015 for an example), the OFL can be much higher for the tier 4/running average combination than the tier3/integrated assessment combination. The integrated assessment can be useful in these years because it smoothes over fluctuations in estimates of biomass and numbers, which often appear to be the result of measurement error. Incorporating length frequency information in the integrated assessment (which is ignored in the running average) can provide information on trends of biomass and numbers—for example, if no recruitment has been observed for 15 years, one would not expect estimated numbers to increase. The integrated assessment method also provides increased biological realism, allows for the incorporation of multiple data streams into the assessment, and facilitates the use of MCMC to characterize uncertainty in management quantities. MCMC is a cleaner way to account for uncertainty than arbitrarily inflating the variance around survey estimates, particularly when data are available to inform estimation of important population processes.

Females and male experienced similar increases in abundance in the early 1990s, and only in recent years did trends in their abundances deviate from previously correlated trajectories. This suggests that some population process (e.g. natural mortality or catchability) has changed for males or females, but it is difficult to say if the change in trends was a result of a population process for females or for males (or both) changing. It is generally inadvisable to invoke time-varying population processes within an assessment for the sake of improving fits without a hypothesis behind the changes and data to corroborate it. Consequently, it is difficult to make a recommendation on which data scenario to use—the male only scenario did fit the male data better, but that should be expected.

Although it is inadvisable to invoke time-varying processes to produce estimates of MMB without some underlying mechanism, allowing survey catchability to vary in each year can be useful in looking for relationships between estimated catchability and environmental variables (to find such a mechanism). An assessment method fit to only males and allowing catchability to vary yearly improved fits to the male numbers (as expected; Figure 37). The utility of this exercise is not to fit the data better, but compare the variability in estimated catchability and environmental variables (Figure 36). However, no relationship was apparent between sea surface temperature at the Pribilof Islands during winter or summer bottom temperature (Figure 38). More in-depth analyses incorporating temperature observations at specific stations for which large hauls occurred may be useful in further exploring how catchability may vary with environmental conditions. For the most recent cohorts, catchability seems to increase as the cohort begins to die out. For example, during 2015 the 3-year average estimated the largest biomass in the history of the time series, but there has been no recruitment since the early 2000s (as seen through the length frequencies). So, either there has been immigration of large crab (less likely given the distribution of large crab in Bristol Bay) or there has been a change in catchability. This suggests another potential avenue of research to understand changes in catchability over time (in addition to temperature mediated response); a relationship between density of crab and their movement or preferred habitat may exist. An increasing biomass estimate as a cohort ages and dies off through natural mortality may suggest higher mobility or a change in habitat preference as population density decreases. Although considering time-varying catchability is potentially interesting, ultimately the small sample sizes used to produce estimates of biomass will continue to make precise assessment for PIRKC difficult.

Forcing the model to fit the high estimates of survey numbers during the 1990s (the first cohort seen in the length frequencies) results in a trajectory that is completely unable to fit the most recent numbers estimates (i.e. cohorts 2 and 3; Figure 39).

7. Data gaps and research priorities

The largest data gap is the number of observations from which the population size and biomass is extrapolated. Catch-at-length data for the trawl fishery would allow trawl fishery selectivity to be estimated and discard mortality specific to PIRKC to be incorporated into the model. Simulation studies designed to prioritize research on population processes for which additional information would be beneficial in achieving more accurate estimates of management quantities could be useful for this stock (e.g. Szuwalski and Punt, 2012). Research on the probability of molting at length for males would allow the use of data specific to PIRKC in specifying molting probability in the assessment. Research aimed at the catchability and availability of PIRKC may shed some light on divergent changes in male and female abundance in recent years.

7. Ecosystem Considerations

The impact of a directed fishery for Pribilof Islands red king crab on the population of Pribilof island blue king crab will likely continue to be the largest ecosystem consideration facing this fishery and preclude the possibility of a directed fishery for red king crab. Linking changes in productivity as seen in the 1980s with environmental influences is a potential avenue of research useful in selecting management strategies for crab stocks around the Pribilof Islands (e.g. Szuwalski and Punt, 2013a). It is possible that the large year class in the mid-1980s reflected changing environmental conditions, similar to proposed relationships between the Pacific Decadal Oscillation snow crab recruitment in the EBS (Szuwalski and Punt, 2013b). Ocean acidification also appears to have a large detrimental effect on red king crab (Long et al., 2012), which may impact the productivity of this stock in the future.

All code for this assessment can be found at github.com/szuwalski/pirkc.

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8. Appendix 1: Population dynamics model for the integrated assessment

An integrated length-based assessment that tracks biannual dynamics of numbers of male and female Pribilof Island red king crabs is used here to provide estimates for quantities used in management. See table A1 for a list of estimated and fixed parameters, table A2 for a list of estimates of parameters, and table A3 for contributions of likelihood components to the objective function and their relative weights. The mode date of the hauls performed in the NMFS trawl survey was June 15th, so this date is used as the beginning of the 'model year'. Survey to fishery dynamics are described by equation A1:

$$N_{s,y,l} = N_{s,y,l}e^{-3M/12} \tag{A1}$$

where $N_{s,y,l}$ is the number of animals of sex *s* in length-class *l* at time step *y*, and $-3M/12$ decrements the population by three months of natural mortality. A pulse fishery is modeled three month after the survey (the fishery lasted on average two weeks, so a pulse fishery is a reasonable assumption) in which numbers are updated as in equation A2. Historically, the fishery occurred in September, but the opening day for all crab fisheries is October 15th now. Consequently, the calculated OFL is based on numbers at length decremented by 4 months of natural mortality.

$$N_{s,y,l} = N_{s,y,l}e^{-(F_{dir,y,l}+F_{trawl,y,l})} \tag{A2}$$

Molting, growth, and recruitment occur after the fishery (in that order, equation A3):

$$N_{s,y,l} = \begin{cases} \Omega_l N_{s,y,l} \mathrm{X}_{l,l'} \\ (1-\Omega_l)N_{s,y,l} + Pr_l R_y \end{cases} \tag{A3}$$

Where Ω_l is the probability of an animal molting at length *l*, $N_{s,y,l}$, is the number of animals in sex *s* in length-class *l* at time step *y*, $\mathrm{X}_{l,l'}$ is the size transition matrix, R_y is recruitment during year *y* and Pr_l is the proportion recruiting to length-class *l*.

Mature biomass at the time of mating (which is used in calculation of reference points) is calculated by decrementing the population by 5 months of natural mortality after the fishery. The remaining 4 months of natural mortality are applied to the population between the mating and the survey:

$$N_{s,y+1,l} = N_{s,y,l}e^{-4M/12} \tag{A4}$$

Fishing mortality and selectivity

Historical fishing mortality was primarily caused by landings in the directed fishery. No length frequency data are available to allocate discards from the directed fishery, so discard mortality is assumed to be zero and knife-edge selectivity is specified for the fishery with the 'edge' occurring at the minimum legal size—138mm carapace length (Figure 21). Fishing mortality is calculated by:

$$F_{dir,y,l} = S_{l,dir}e^{\overline{F_{dir}}+n_y} \tag{A5}$$

where $S_{l,dir}$ is the selectivity of the fishery on animals in length-class l, $\overline{F_{dir}}$ is the average (over time) ln-scale fully-selected fishing mortality, and n_y is the ln-scale deviation in fishing mortality for year y from the average fishing mortality. Average fishing mortality and the yearly deviations are estimated parameters.

Fishery selectivity is assumed to be a logistic function of size and constant over time:

$$S_{l,dir} = \left(1 + \exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,dir}\right)}{L_{95,dir} - L_{50,dir}}\right)\right)^{-1} \quad \text{(A6)}$$

where $L_{50,\mathrm{dir}}$ is the length at which 50% of animals are selected, $\bar{L}_l$ is the midpoint of length-class l, and $L_{95,\mathrm{dir}}$ is the length at which 95% of animals are selected.

A switch that allows mortality due to discarding in the fishery to be modeled based on the Bristol Bay red king crab assessment (Zheng et al., 2014) is included in the code. Discard selectivity, $S_{l,disc}$ is defined as:

$$S_{l,disc} = \vartheta + \varphi * L_l \qquad if\ L_l \le 138 \quad \text{(A7)}$$
$$S_{l,disc} = S_{l-1,disc} + 5 * \delta \qquad if\ L_l > 138 \quad \text{(A8)}$$
$$S_{l,disc} = 0 \qquad if\ S_{l,disc} < 0 \quad \text{(A9)}$$

Where θ, φ, and δ are parameters borrowed from the 2014 BBRKC assessment and L_l is the carapace width of an individual crab. Discard mortality is assumed to be 0.2.

Bycatch in the non-pelagic trawl for groundfish is the second largest historical source of mortality, but it only comprised 3% (on average) of the catch when the directed fishery was operating. Fishing mortality at length attributed to bycatch in the trawl fishery is modeled by equation A7:

$$F_{trawl,y,l} = S_{l,trawl} e^{\overline{F_{trawl}} + n_y} \quad \text{(A10)}$$

Selectivity, $S_{l,trawl}$, in the non-pelagic trawl fishery for groundfish is assumed to be a logistic function of size and constant over time:

$$S_{l,trawl} = \left(1 + \exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,trawl}\right)}{L_{95,trawl} - L_{50,trawl}}\right)\right)^{-1} \quad \text{(A11)}$$

where $L_{50,\mathrm{trawl}}$ is the length at which 50% of animals are selected, $\bar{L}_l$ is the midpoint of length-class l, and $L_{95,\mathrm{trawl}}$ is the length at which 95% of animals are selected. Parameters are fixed to those reported in the Bristol Bay red king crab assessment because there are no length frequency data available to inform estimation for Pribilof Island red king crab (Figure 21).

Survey selectivity is assumed to be a logistic function of size and constant over time. :

$$S_{l,surv} = Surv_q * \left(1 + \exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,surv}\right)}{L_{95,surv} - L_{50,surv}}\right)\right)^{-1} \quad \text{(A12)}$$

where $Surv_q$, is the catchability coefficient for the survey gear, $L_{50,\mathrm{surv}}$ is the length at which 50% of animals are selected, $\bar{L}_l$ is the midpoint of length-class l, and $L_{95,\mathrm{surv}}$ is the length at which 95% of animals are selected. Survey selectivity parameters are estimated, except for $Surv_q$, which is fixed to a value of 1. A switch has been added to the code to allow $Surv_q$ to be estimated annually. This is to be used as an exploratory tool, not to provide estimated of numbers during the survey.

Survey numbers at length

The model prediction of the number of male crab at length at the time of the survey, $\hat{N}^{surv}_{s,y,l}$, is given by:

$$\hat{N}^{surv}_{s,y,l} = S_{l,surv} N_{s,y,l} \quad \text{(A13)}$$

Catch

The model prediction of the directed catch at length is given by:

$$\hat{C}^{dir}_{y,l} = S_{l,dir} N_{s,y=fishtime,l}(1 - e^{-F_{y,l}}) \quad \text{(A14)}$$

where $\hat{C}^{dir}_{y,l}$ is the model estimate of the total catch of animals in length-class *l* during year *y* in numbers, $N_{s,y=fishtime,l}$ is the number of animals of sex *s* in length-class *l* when the fishery occurs during year *y*. ($1-e^{-F_{y,l}}$) is the proportion of crab taken by the fishery during year *y*.

Growth

Molting and growth occur before the survey. Female crab are assumed to molt every year, but the probability of molting for male crab is a declining logistic function of length. The parameters are fixed based on Powell (1967) such that the probability of molting is 1 until approximately the age of maturity at which time it steadily declines (Figure 21):

$$P_l = 1 - \left(1 + \exp\left(-\frac{\log(19)\left(\bar{L}_l - L_{50,molt}\right)}{L_{95,molt} - L_{50,molt}}\right)\right)^{-1} \quad \text{(A15)}$$

where $L_{50,molt}$ is the length at which 50% of animals molt, and $L_{95,molt}$ is the length at which 95% of animals molt. The growth increment for animals that do molt is based on a gamma distribution, i.e.:

$$X_{l,l'} = Y_{l,l'} / \sum_{l'} Y_{l,l'} \quad \text{(A16)}$$

$$Y_{l,l'} = (\Delta_{l,l'})^{(L_l - (\bar{L}_l - 2.5))/\beta} e^{-\Delta_{l,l'}/\beta} \quad \text{(A17)}$$

where L_l is the expected length for an animal in length-class *l* given that it moults:

$$L_l = \delta_1 + \delta_2 \bar{L}_l \quad \text{(A18)}$$

δ_1, δ_2 are the parameters of the relationship between length and growth increment, $\Delta_{l,l'}$ is the difference in length between midpoints of length-classes *i* and *j*:

$$\Delta_{l,l'} = \bar{L}_{l'} + 2.5 - \bar{L}_l \quad \text{(A19)}$$

β is the parameter which defines the variability in growth increment and was set to 0.75 for this analysis. The constant “2.5” is half a length bin’s length. The size transition matrix can be seen in Figure 21.

Recruitment

The fraction of the annual recruitment in an area which recruits to length-class *l* is based on a gamma function, i.e.:

$$Pr_l = (\Delta_{l,l'})^{\mu_1/\mu_2} e^{-\Delta_{l,l'}/\mu_2} / \sum_{l'} (\Delta_{l,l'})^{\mu_1/\mu_2} e^{-\Delta_{l,l'}/\mu_2} \quad \text{(A20)}$$

Where μ_1 and μ_2 are the parameters that define the recruitment fractions. Mean recruitment, annual recruitments and fraction recruiting are treated as estimable parameters, resulting 42 total estimated parameters related to recruitment (Table A1). The fraction recruiting was estimated and changes depending on whether both males and females are fit or if only males are fit (compare Figure 21 and Figure 30).

Likelihood components

The model is fit to survey length frequencies (L1, A21), a survey index of abundance (L2, A22), directed catch (L3, A23) and non-pelagic trawl bycatch (L4, A24).

$$L_1 = \begin{cases} \sum_s \sum_y \sum_l -\gamma_y p^{obs}_{surv,l,y,s} \ln\left(p^{pred}_{surv,l,y,s} + \kappa\right) & if \;\; p^{obs}_{surv,l,y,s} \geq 0.01 \\ 0 & if \;\; p^{obs}_{surv,l,y,s} < 0.01 \end{cases} \qquad \text{(A21)}$$

where L_1 is the contribution to the objective function of the fit to survey length frequencies; γ_y is the sample size for year y, $p^{pred}_{surv,l,y,s}$ is the model-estimate of the length-frequency for sex s for length-class l in year y; $p^{obs}_{surv,l,y,s}$ is the observed survey length-frequency for sex s for length-class l during year y; κ is a small number (0.001 here) added to all log calculations. Fits to the observed length frequencies only contribute to the objective function if the observed proportion is greater than 0.01. The reported number of samples used to calculate the length frequencies were used to weight the survey length frequency likelihoods unless they exceeded 200, at which point they were set to 200.

$$L_2 = \sum_s \sum_y \frac{\left(\ln\left(N^{pred}_{y,s} + \kappa\right) - \ln\left(N^{obs}_{y,s} + \kappa\right)\right)^2}{\ln\left(\left(CV_{y,s}\right)^2 + 1\right)} \qquad \text{(A22)}$$

where $N^{pred}_{y,s}$ is the model-estimate of the number of crab of sex s caught in the survey in during year y, $N^{obs}_{y,s}$ is the observed number of crab of sex s in the survey in during year y, and $CV_{y,s}$ is the observed coefficient of variation for $N^{obs}_{y,s}$. κ is a small number (equal to 0.001 here) added to avoid taking the log of zero. Historically calculated CVs were used to fit the survey numbers

$$L_3 = \sum_y \frac{\left(\ln\left(C^{pred}_y + \kappa\right) - \ln\left(C^{obs}_y + \kappa\right)\right)^2}{\ln\left(\left({CV_y}^{cat}\right)^2 + 1\right)} \qquad \text{(A23)}$$

where C^{pred}_y is the catch in numbers predicted by the model for year y, C^{obs}_y is the observed catch in numbers for year y, ${CV_y}^{cat}$ is the assumed coefficient of variation for the observed data for year y, and κ is a small number added to avoid taking the log of zero when catches do not occur (here 0.001 is used).

$$L_3 = \sum_y \frac{\left(\ln\left(\sum_s byC^{pred}_{y,s} + \kappa\right) - \ln\left(byC^{obs}_{y,s} + \kappa\right)\right)^2}{\ln\left(\left({CV_y}^{bycatch}\right)^2 + 1\right)} \qquad \text{(A24)}$$

where $byC^{pred}_{y,s}$ is the bycatch in tonnes of sex s from the non-pelagic trawl fishery predicted by the model for year y, byC^{obs}_y is the observed bycatch in tonnes for during year y, ${CV_y}^{bycatch}$ is the assumed coefficient of variation for the observed data for year y, and κ is a small number added to avoid taking the log of zero when catches do not occur (here 0.001 is used).

Penalty components

A penalty is placed on the between year deviations in estimated recruitment deviates and fishing mortality deviates (both directed and trawl) of the form:

$$P_2 = \gamma_w \sum_l (\ln(\eta_l) - \ln(\eta_{l-1})) \text{ ^2} \qquad \text{(A25)}$$

where, η_l, is the quantity in question (e.g. recruitment deviations) and γ_w is the weighting factor (equal to 1 in the assessment presented for all quantities).

9. 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 2014/2015	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
1999-2013/14	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). **** NEW 2013 calculation of bycatch using AKRO Catch Accounting System with data reported from State of Alaska reporting areas that encompass the Pribilof Islands red king crab district.**

	Crab pot fisheries			Groundfish fisheries	
Year	Legal male (t)	Sublegal male (t)	Female (t)	All fixed (t)	All trawl (t)
1991/1992				0.48	45.71
1992/1993				16.12	175.93
1993/1994				0.60	131.87
1994/1995				0.27	15.29
1995/1996				4.81	6.32
1996/1997				1.78	2.27
1997/1998				4.46	7.64
1998/1999	0.00	0.91	11.34	10.40	6.82
1999/2000	1.36	0.00	8.16	12.40	3.13
2000/2001	0.00	0.00	0.00	2.08	4.71
2001/2002	0.00	0.00	0.00	2.71	6.81
2002/2003	0.00	0.00	0.00	0.50	9.11
2003/2004	0.00	0.00	0.00	0.77	9.83
2004/2005	0.00	0.00	0.00	3.17	3.52
2005/2006	0.00	0.18	1.81	4.53	24.72
2006/2007	1.36	0.14	0.91	6.99	21.35
2007/2008	0.91	0.05	0.09	1.92	2.76
2008/2009	0.09	0.00	0.00	1.64	6.94
2009/2010	0.00	0.00	0.00	0.33	2.45
**2009/2010				0.19	1.05
2010/2011	0.00	0.00	0.00	0.30	3.87
**2010/2011				0.45	6.25
2011/2012	0.00	0.00	0.00	0.62	4.78
**2011/2012				0.35	4.47
**2012/2013	0.00	0.00	0.00	0.12	12.98
2013/2014	0.00	0.00	0.00	0.25	1.99
2014/2015	0.00	0.00	0.00	0.82	0.24

Table 4. Proportion 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	68	32	0	0	439

Table 5. 2016 Pribilof Islands District red king crab male abundance, male biomass, and female biomass estimated based on the NMFS annual EBS bottom trawl survey with no running average.

Year	Total Male Abundance	Total males at survey (t)	Total females at survey (t)
1975/1976	0	0	11
1976/1977	50778	165	102
1977/1978	228477	213	148
1978/1979	367140	1250	52
1979/1980	279707	556	93
1980/1981	400513	1269	262
1981/1982	80928	312	35
1982/1983	352166	1482	933
1983/1984	144735	553	309
1984/1985	64331	317	112
1985/1986	16823	61	0
1986/1987	38419	138	79
1987/1988	18611	54	31
1988/1989	1963775	525	836
1989/1990	1844076	1720	2251
1990/1991	6354076	8019	2723
1991/1992	3100675	4979	5032
1992/1993	1861538	3361	3432
1993/1994	3787997	10156	6478
1994/1995	3669755	9538	3964
1995/1996	7693368	18417	5149
1996/1997	683611	2378	2007
1997/1998	3155556	7254	1962
1998/1999	1192015	2655	1719
1999/2000	9102898	5751	5418
2000/2001	1674067	4477	995
2001/2002	6157584	10186	5774
2002/2003	1910263	7037	787
2003/2004	1506201	5373	2269
2004/2005	2196795	3622	1292
2005/2006	302997	1262	3118
2006/2007	1459278	7097	2183
2007/2008	1883489	5371	1811
2008/2009	1721467	5603	3017
2009/2010	923133	2545	826
2010/2011	927825	4449	840
2011/2012	1052228	3878	817
2012/2013	1609444	4753	663
2013/2014	1831377	7854	169
2014/2015	3036807	12129	1093
2015/2016	3662609	15252	3859

Table 6. 2016 Pribilof Islands District male red king crab abundance CV and total male and female biomass CVs estimated from the NMFS annual EBS bottom trawl survey data.

Year	Total Male Abundance CV	Total male at survey (t) CV	Total female at survey (t) 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

Table 9. Estimated recruitment (numbers), female mature biomass (t), male mature biomass (t), total female abundance and total male abundance (1000s) from the integrated assessment method when females and males are fit.

Year	Recruitment	FMB (t)	MMB (t)	Female abundance	Male abundance
1975	14878	85	145	91.6	89.6
1976	15602	127	255	114.5	121.1
1977	18528	157	372	128.1	144.3
1978	10050	168	443	131.7	151.5
1979	6575	168	458	127.5	144.3
1980	7715	162	440	119	130.6
1981	16246	154	411	108.6	116.5
1982	72094	144	379	97.7	103.7
1983	413692	132	345	88.7	93.1
1984	142532	120	310	90.1	92
1985	4598343	112	278	103.3	96.3
1986	835610	127	259	225.7	209.6
1987	241773	193	306	441.4	354.3
1988	498254	425	522	777.6	614
1989	197221	1114	1108	1158.6	1055
1990	112964	1734	3547	1450.5	1582.3
1991	130316	1966	5035	1591.7	1876
1992	1080215	2014	5282	1596.5	1837.3
1993	578885	1780	3775	1527.7	1674.1
1994	312839	1526	3030	1321.9	1159.1
1995	2179664	1304	2425	1173.1	941.7
1996	1067346	1315	2259	1113.8	899.4
1997	78360	1232	2241	1179.2	1016.4
1998	28431	1233	2324	1219.7	1085.5
1999	38865	1545	2707	1308.6	1205.3
2000	212285	1852	3819	1411.1	1430.8
2001	362669	1936	4681	1417	1540.2
2002	1797022	1859	4779	1348.3	1463.4
2003	1045487	1733	4471	1279.7	1334.1
2004	270685	1624	4059	1254.2	1234.8
2005	122624	1600	3714	1294.8	1217.1
2006	151155	1769	3650	1373.8	1307.3
2007	286966	1974	4339	1432	1467.3
2008	317137	2024	4957	1431.2	1560.1
2009	115741	1948	5040	1374.1	1506.5
2010	43303	1832	4771	1286.8	1374.2
2011	29841	1727	4411	1189.7	1240.1
2012	16937	1632	4105	1088.9	1129.8
2013	13945	1519	3859	981.8	1027
2014	13267	1380	3548	871.5	915.1
2015	13267	1233	3180	762.2	795.1

Table 10. Estimated recruitment (numbers), female mature biomass (t), male mature biomass (t), total female abundance and total male abundance (1000s) from the integrated assessment method when males are fit.

Year	Recruitment	MMB (t)	Male abundance
1975	14681	95	53.7
1976	21030	208	85.1
1977	12543	296	105
1978	8614	341	109.7
1979	9146	347	103.9
1980	15132	332	94.1
1981	48544	310	84.4
1982	323491	288	76.2
1983	178587	265	70.8
1984	4823576	241	66.3
1985	650956	218	95.6
1986	435730	202	125.1
1987	617317	223	193.6
1988	232138	354	346.6
1989	118534	829	654.4
1990	154506	2794	1136
1991	1157155	4169	1496.9
1992	571461	4486	1535.6
1993	433932	3070	1416.5
1994	2875288	2433	939.5
1995	1226401	1914	749.5
1996	132122	1797	673.7
1997	64580	1747	760.3
1998	92980	1839	828
1999	430421	2289	956.2
2000	761735	3487	1242.5
2001	2580435	4505	1455.9
2002	3152752	4756	1458.7
2003	605901	4536	1350.9
2004	244048	4185	1253.8
2005	256801	3940	1257.7
2006	622266	4054	1414.6
2007	676978	5058	1743.3
2008	229647	6578	2093.1
2009	116479	7294	2205.2
2010	99699	7188	2074.2
2011	61775	6768	1883
2012	50875	6391	1728.6
2013	47031	6100	1600.2
2014	45958	5689	1453.9
2015	45958	5161	1281.8

Table 11. Estimates of female and male abundance (1000s individuals) and female and male biomass (t) from a 3-year running average. NAs result from years in which no individuals were captured of a given sex.

Year	Female abundance	Male abundance	Female biomass	Male biomass
1977	113	230	87	585
1978	105	244	92	648
1979	96	352	157	1042
1980	85	287	153	850
1981	238	331	441	1060
1982	219	178	416	691
1983	192	163	366	679
1984	NA	89	NA	368
1985	NA	56	NA	211
1986	NA	27	NA	95
1987	861	739	NA	107
1988	1891	1468	NA	609
1989	2688	3482	1452	961
1990	3658	3901	3150	2526
1991	3716	3880	3630	3133
1992	4237	2760	5051	5172
1993	3486	2866	4759	6597
1994	3523	4596	5179	13423
1995	2341	2383	3618	7350
1996	1886	2429	2800	6816
1997	1200	1368	1791	2955
1998	3176	3176	1589	3783
1999	3089	2507	1283	3614
2000	4167	3868	2023	5298
2001	1164	2411	1634	5614
2002	1352	2753	2053	6853
2003	916	1834	1200	5194
2004	1425	1101	1938	3283
2005	1261	1236	1958	4805
2006	1052	1154	2320	5190
2007	1179	1559	2282	6086
2008	882	1433	1652	4642
2009	781	1462	1410	4333
2010	428	1248	820	3779
2011	482	1412	754	4292
2012	322	1511	525	5350
2013	315	2097	550	7455
2014	603	2718	1260	11235
2015	778	3349	2453	13685

Table A1. List of estimated and fixed parameters.

Fixed parameters (14)	Number
Natural mortality	1
Molting probability	3
Fishery selectivity	2
Discard selectivity	3
Weight	4
Survey catchability	1
Estimated parameters (89)	
Growth	6
Proportion recruiting	2
Log recruitment deviations	46
Log average fishing mortality (directed)	1
Log fishing mortality deviations (directed)	6
Log average fishing mortality (trawl)	1
Log fishing mortality deviations (trawl)	26
Survey selectivity	2

Table A2. List of estimated parameter values from 2014 and 2015.

Parameter	2014	2015
srv_q	1	1
fish_sel50	138	138
fish_sel95	138.05	138.05
srv_sel50	102.15	100.3
srv_sel95	141.06	147.88
log_avg_fmort_dir	-0.98	-1.72
log_avg_fmort_trawl	-4.88	-5.5
mean_log_rec	11.21	11.62
A_f (growth)	25.42	25.3
A_m (growth)	9.77	7.76
B_f (growth)	0.86	0.86
B_m (growth)	1.13	1.15
growth_beta_males	0.72	1.12
alpha_rec	0.86	5.56
beta_rec	0.16	1.53

Table A3. Likelihood component contribution to the likelihood and associated weights for males and female and males only.

Likelihood component	negLogLike (both)	negLogLike (males only)	Weighting
Survey numbers (males)	185.9	52.7	.36 -1 (CVs)
Survey numbers (females)	178.6	n/a	.36-1 (CVs)
Survey length frequencies (male)	9175.2	9218.9	18-200 (sample size)
Survey length frequencies (female)	5824.9	n/a	18-200 (sample size)
Catch	1.9	0.4	.005(CV)
Trawl	206.5	206.6	.05 (CV)
Smoothness penalties			
Trawl fishing mortality	28.9	28.9	1 (CV)
Fishing mortality	4.3	4.2	1 (CV)
Recruitment	57.1	49.6	1 (CV)

10. Figures

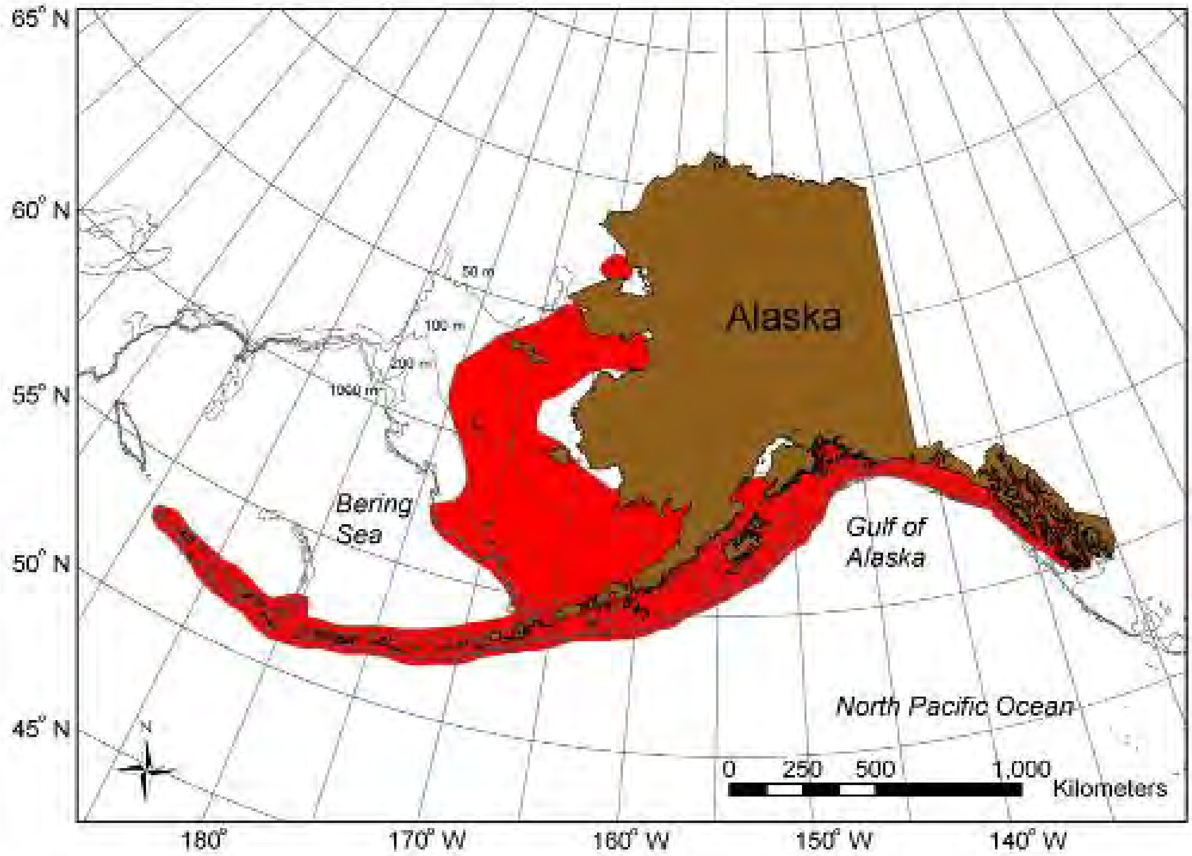

Figure 1. Red king crab distribution.

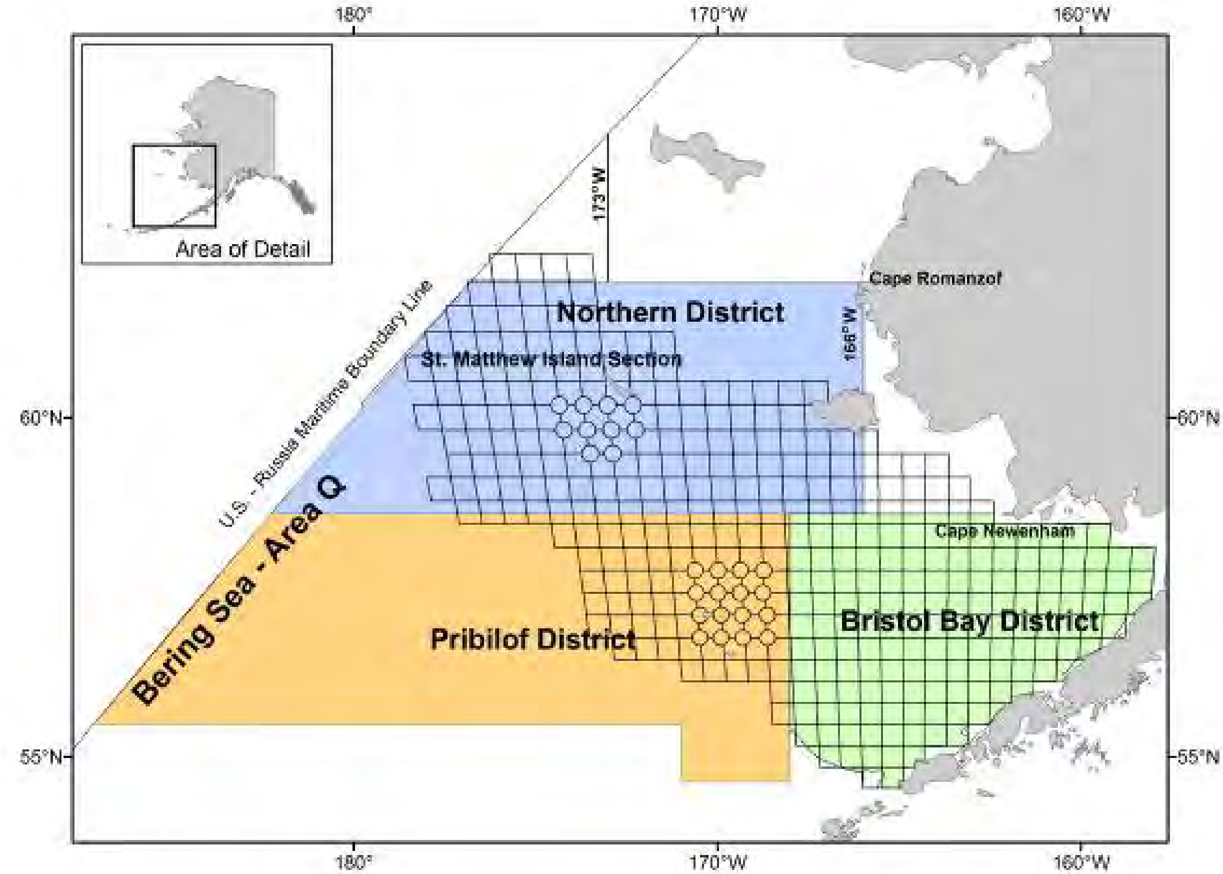

Figure 2. King crab registration area Q (Bering Sea) showing the Pribilof District.

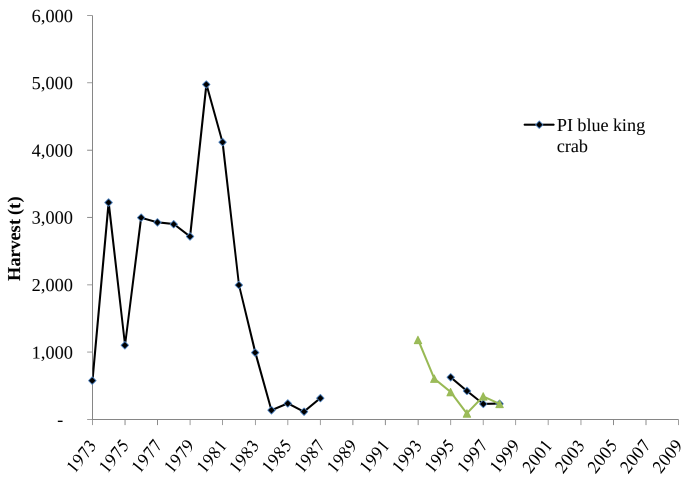

Figure 3. Historical harvests and GHLs for Pribilof Island blue (diamonds) and red king crab (triangles) (Bowers et al. 2011).

Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area.

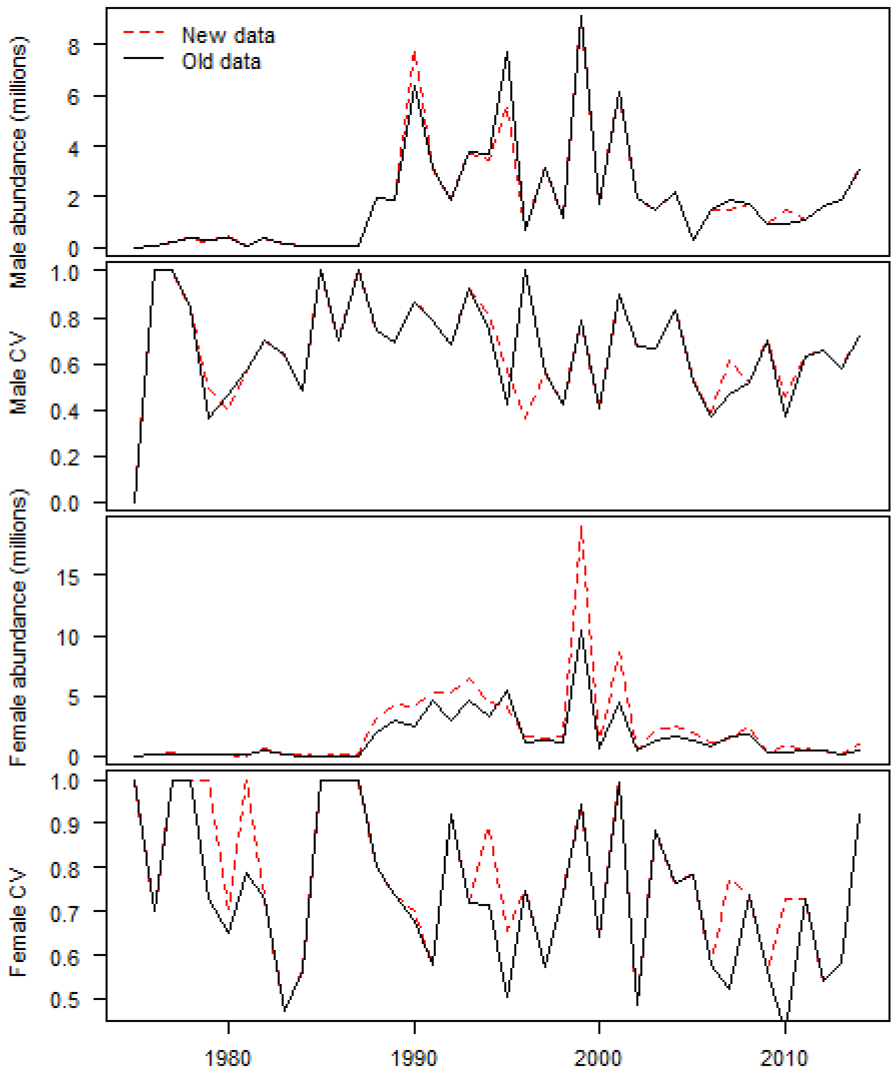

Figure 5. Comparison of data calculated using 2014 and 2015 methodologies.

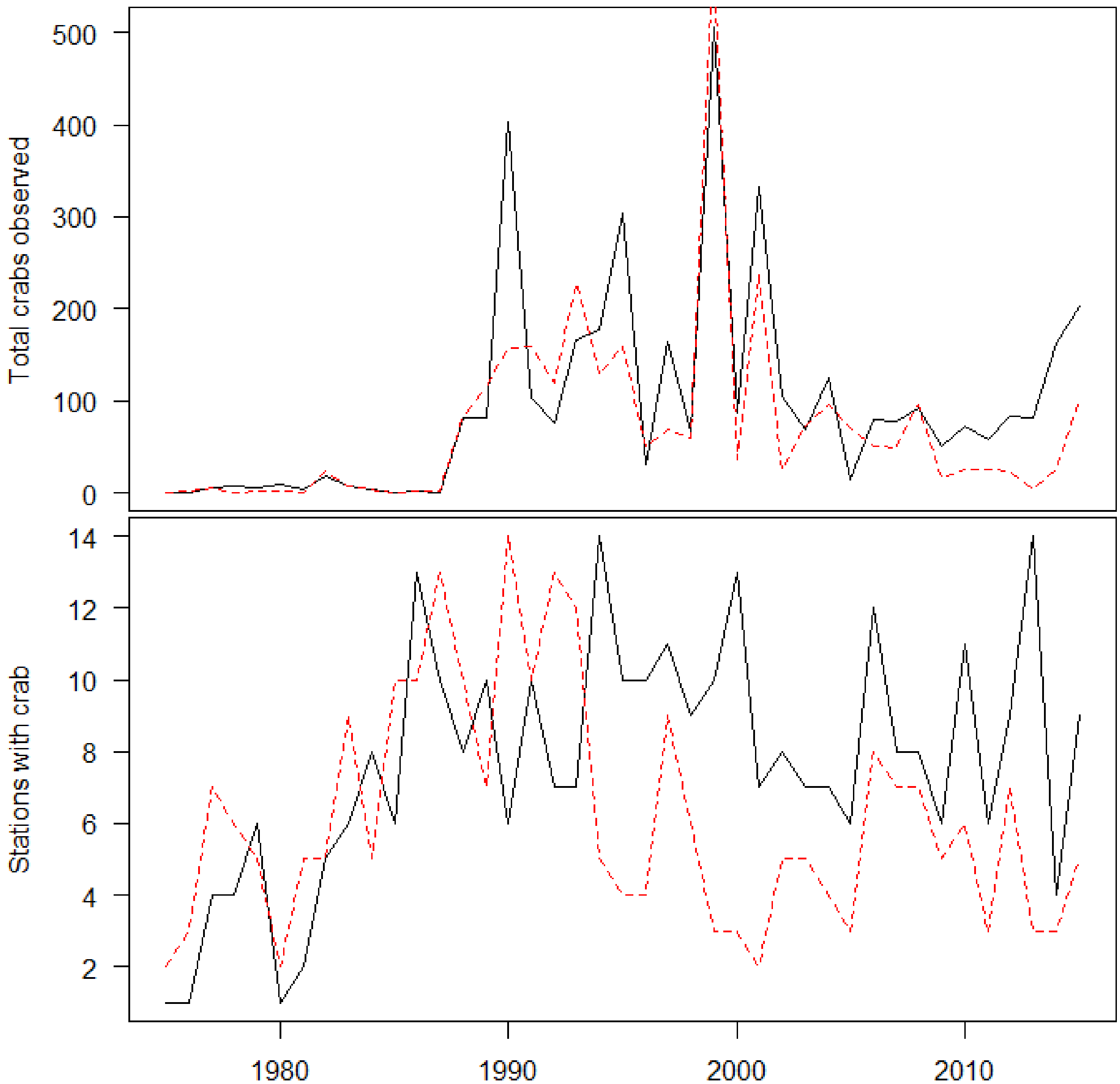

Figure 6. Total number of observed crab (top) and the number of stations that reported observations of crab (female = dashed line, male = solid line) from 1975-2014.

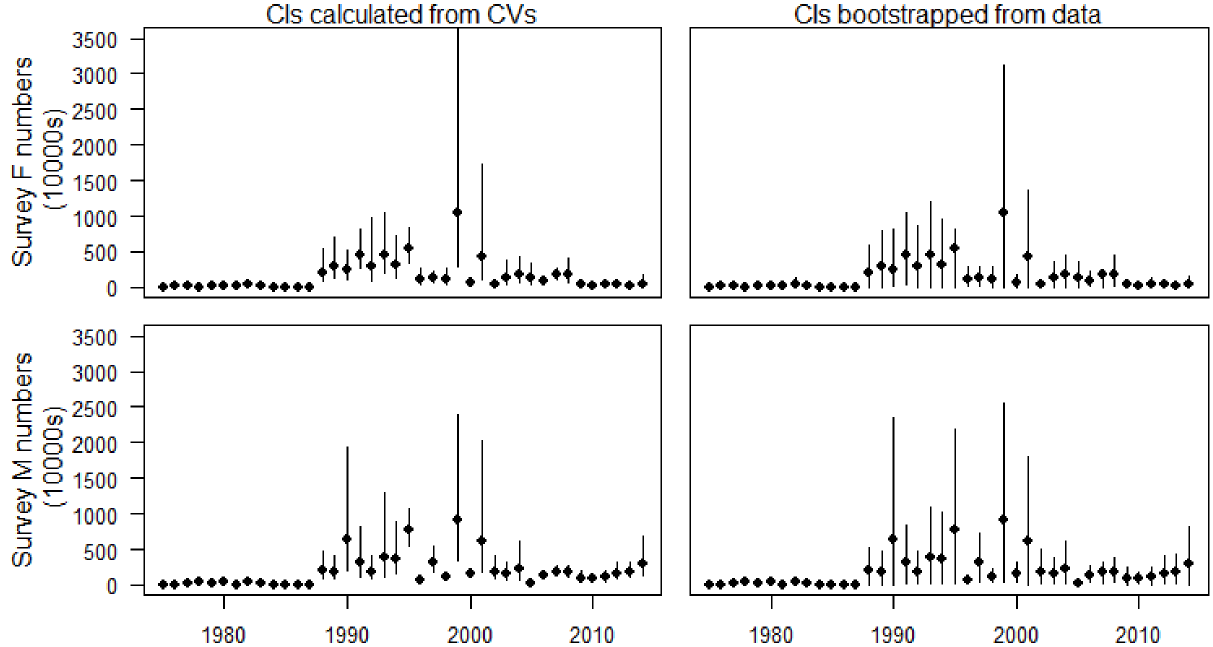

Figure 7. Time series of Pribilof Islands red king crab estimated from the NMFS annual EBS bottom trawl survey. CIs for the left column are based on back calculations from the CVs provided from Kodiak, CIs in the right column are based on bootstraps from the NMFS.

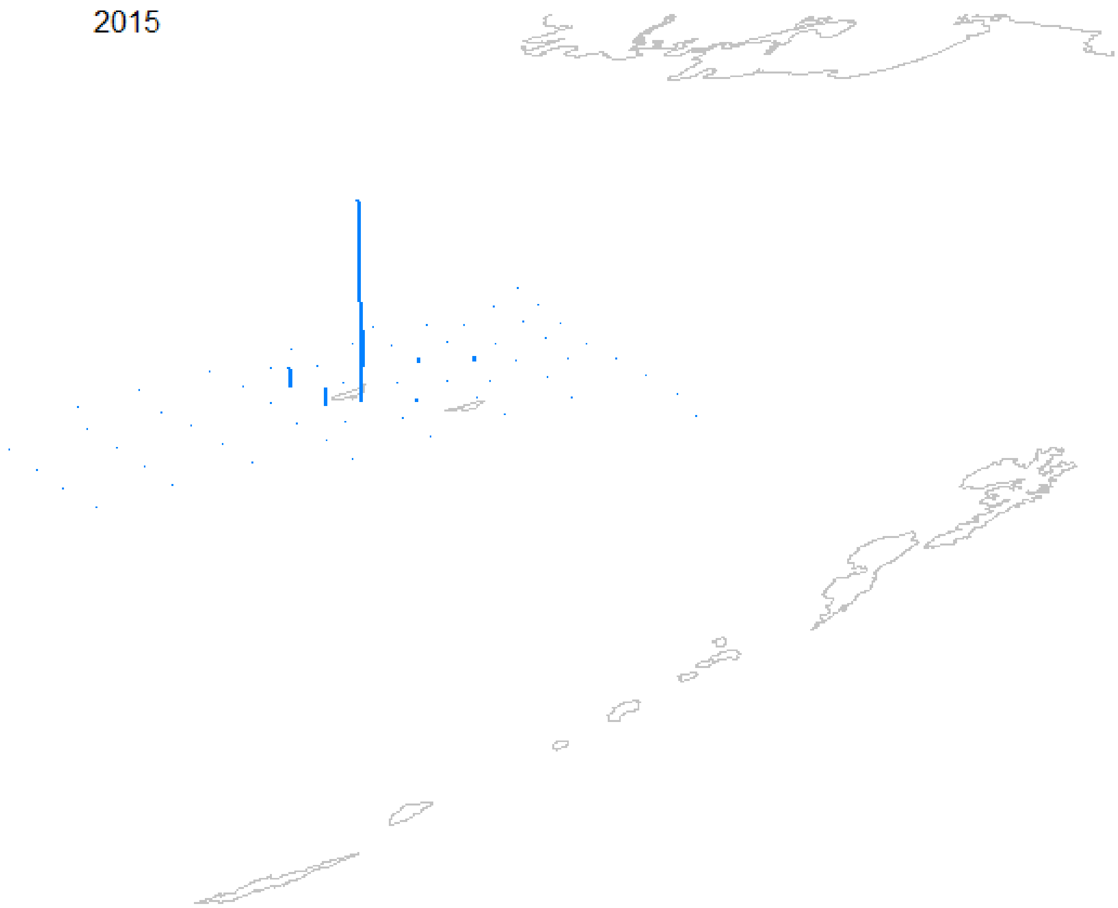

Figure 8. Male red king crab relative density by station in the Pribilof Island district in 2015. Blue bars represent the relative magnitude of the density calculated from the NMFS trawl survey.

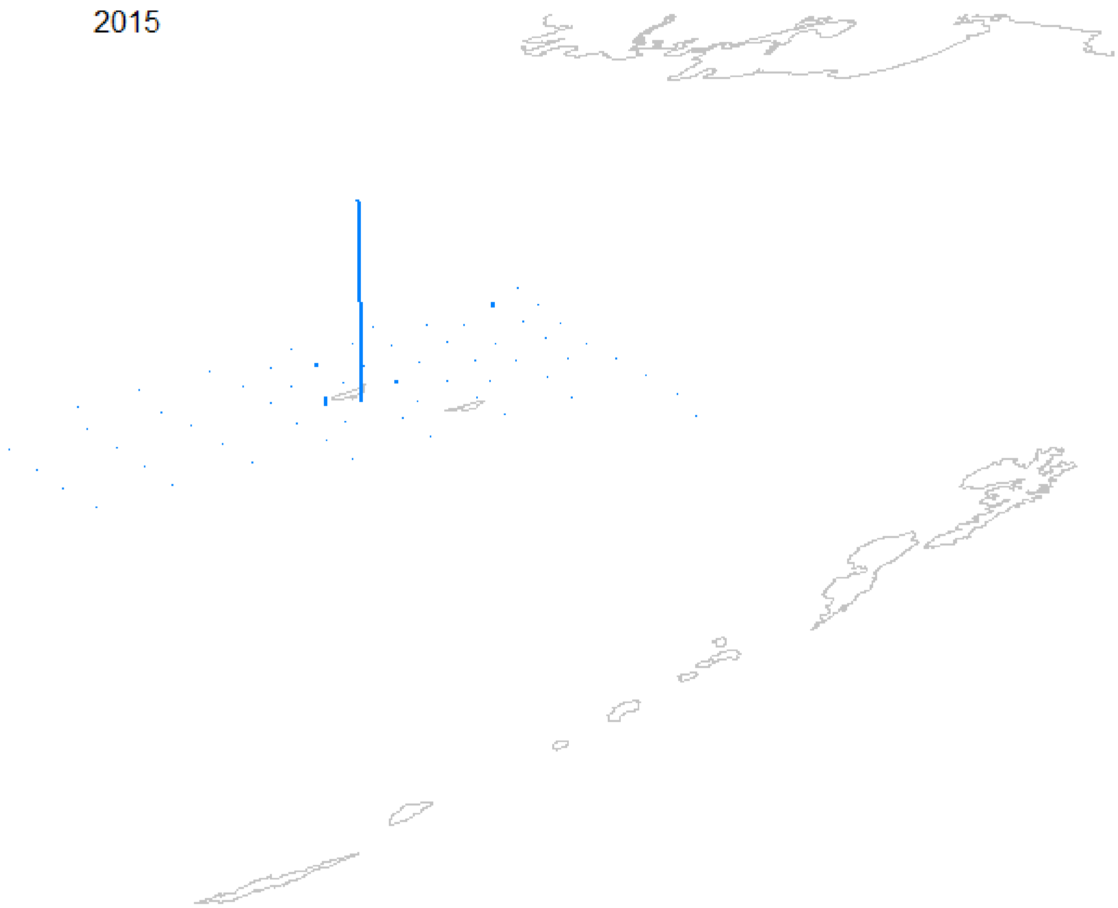

Figure 9. Female red king crab relative density by station in the Pribilof Island district in 2015. Blue bars represent the relative magnitude of the density calculated from the NMFS trawl survey.

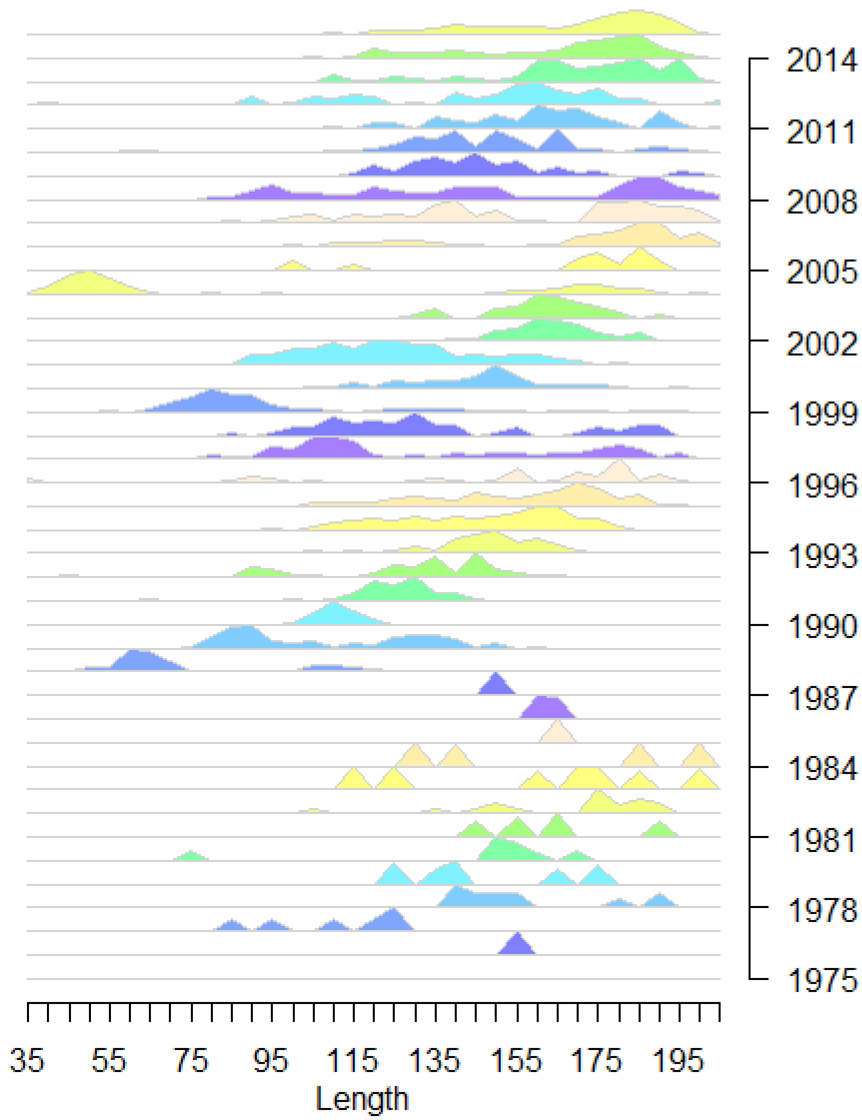

Figure 10. Observed length frequencies by 5 mm length classes of Pribilof Islands male red king crab (Paralithodes camtschaticus) from 1975 to 2015.

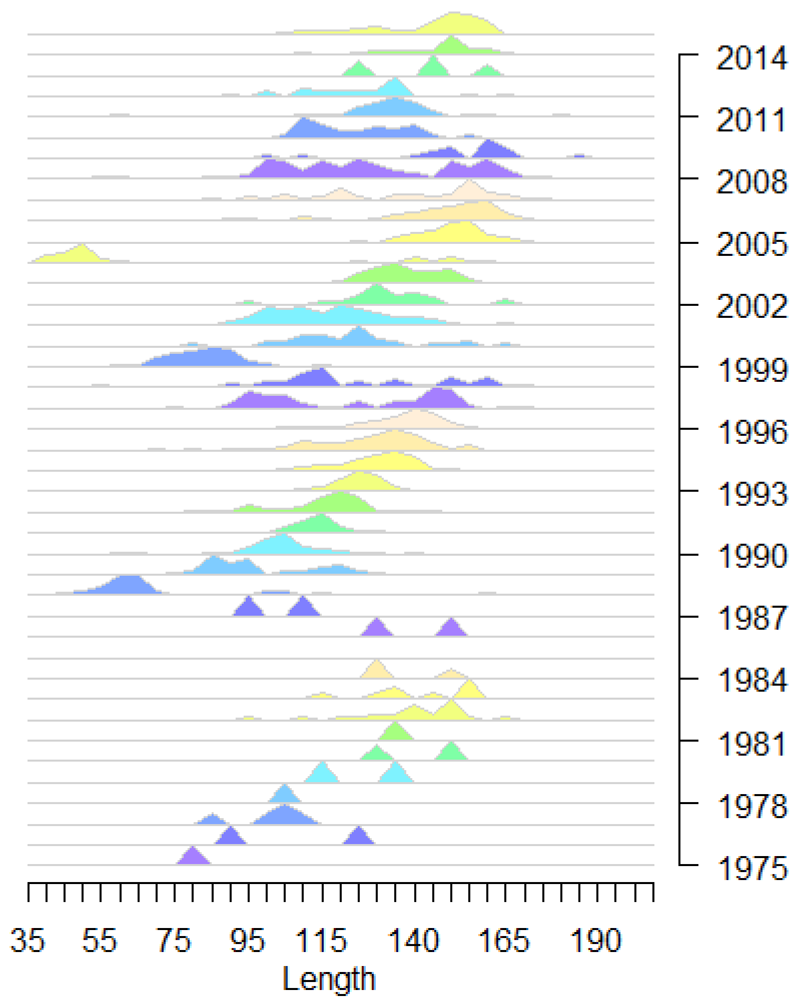

Figure 11. Observed length frequencies by 5 mm length classes of Pribilof Islands female red king crab (Paralithodes camtschaticus) from 1975 to 2015.

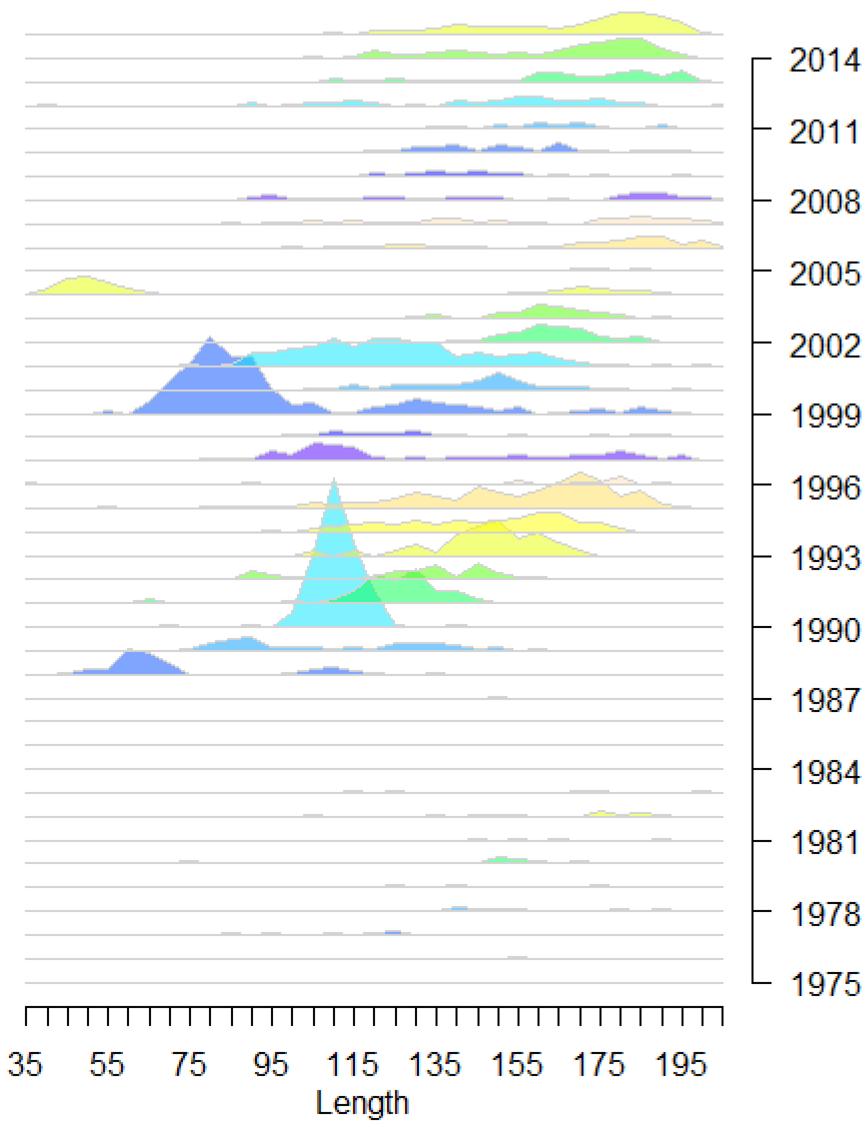

Figure 12. Observed numbers at length by 5 mm length classes of Pribilof Islands male red king crab (Paralithodes camtschaticus) from 1975 to 2015.

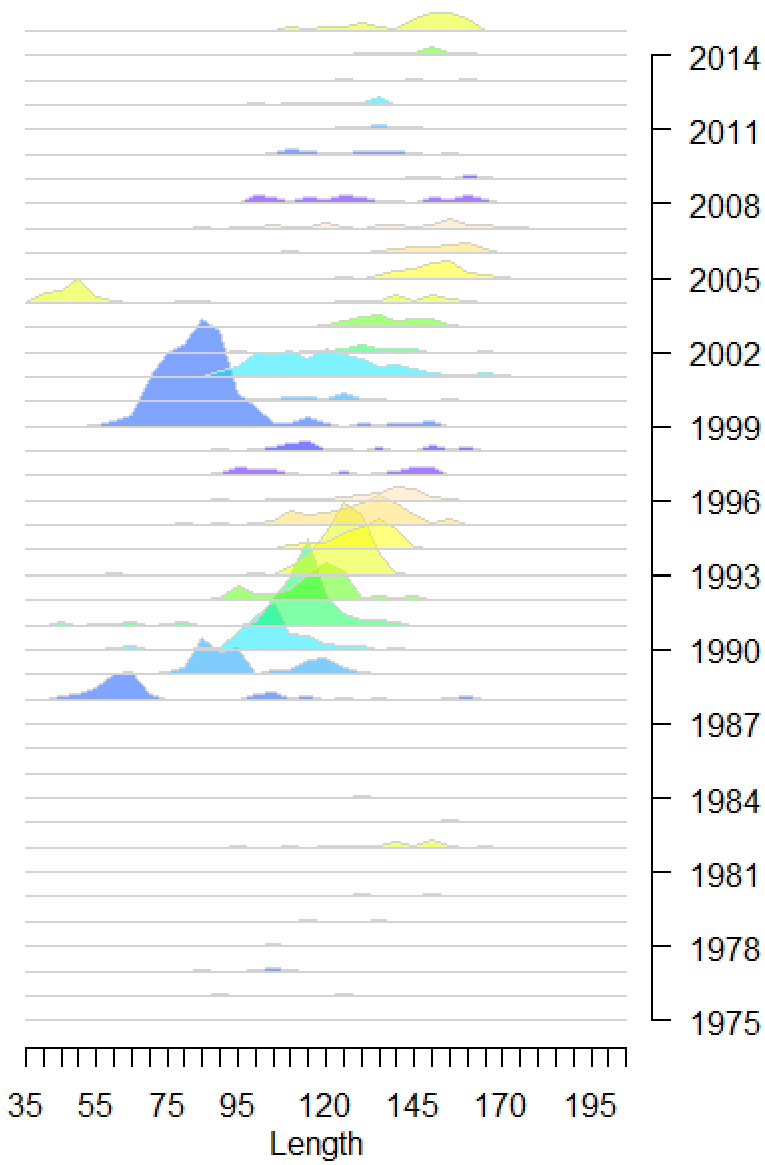

Figure 13. Observed numbers at length by 5 mm length classes of Pribilof Islands female red king crab (Paralithodes camtschaticus) from 1975 to 2015.

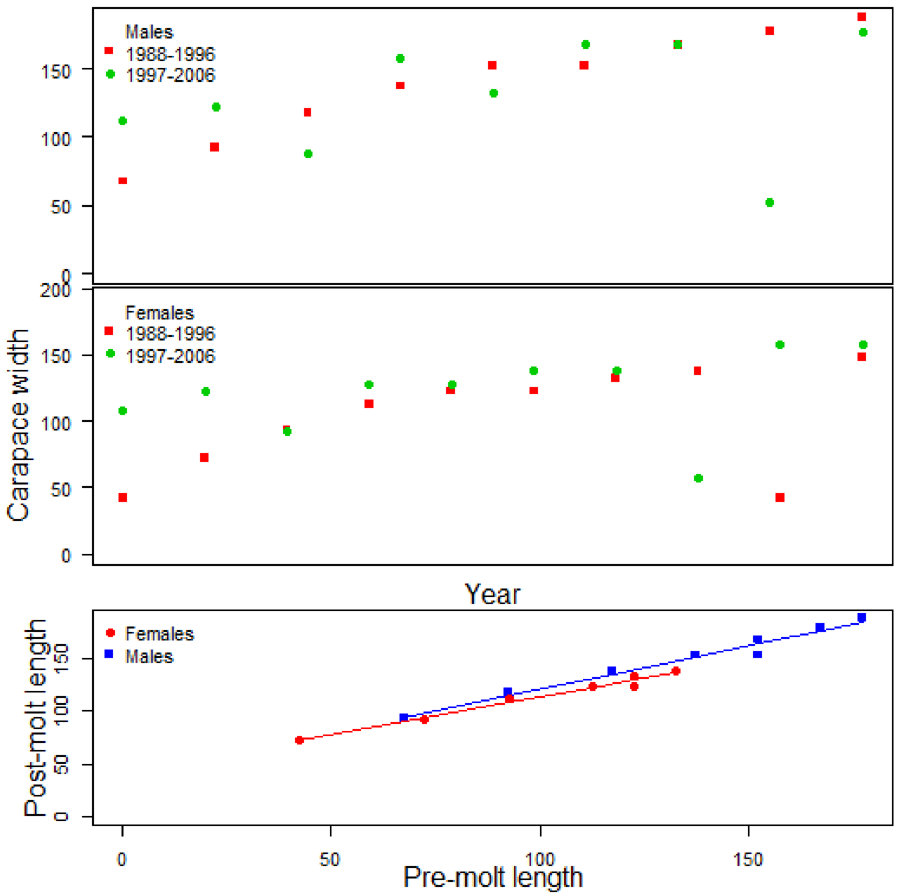

Figure 14. Modes of the length frequency distribution for males and females plotted for two time periods over which two cohorts were observed to move through the population. Growth per molt calculated from the modes from the length frequencies with fitted linear relationship (bottom).

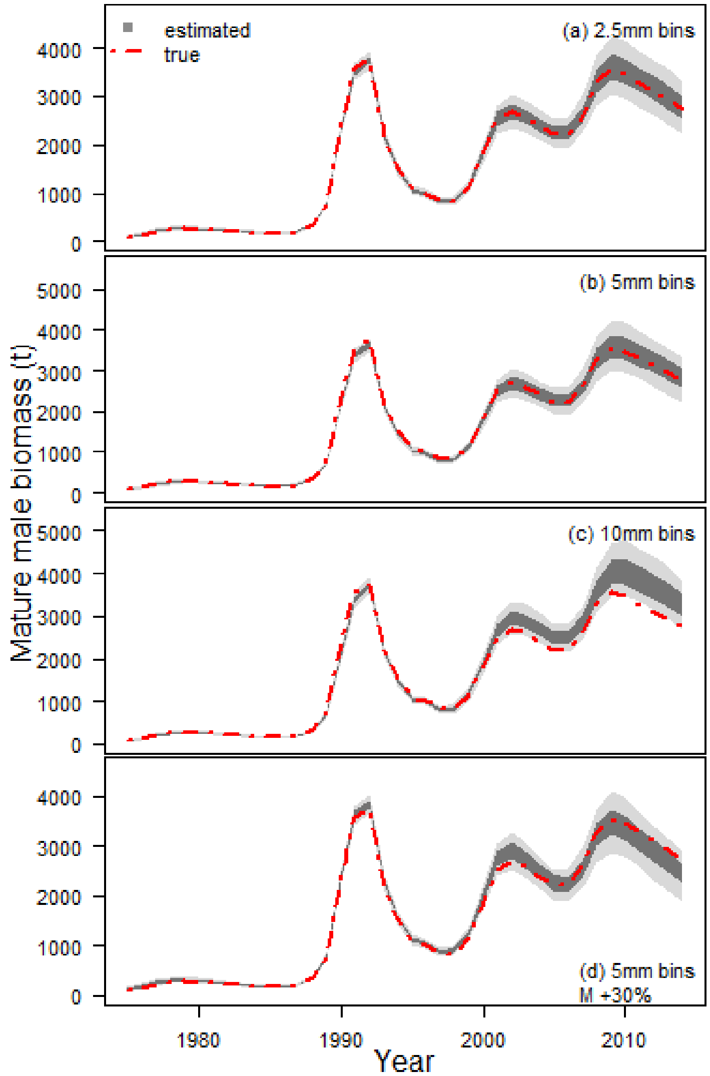

Figure 15. Estimates of MMB in simulation aimed at the testing of the integrated assessment method when binning data into different size bins. Panel (d) shows a case in which M was mis-specified. Red dashed lines are the true quantity; grey shading indicates the intersimulation quantiles for estimated MMB.

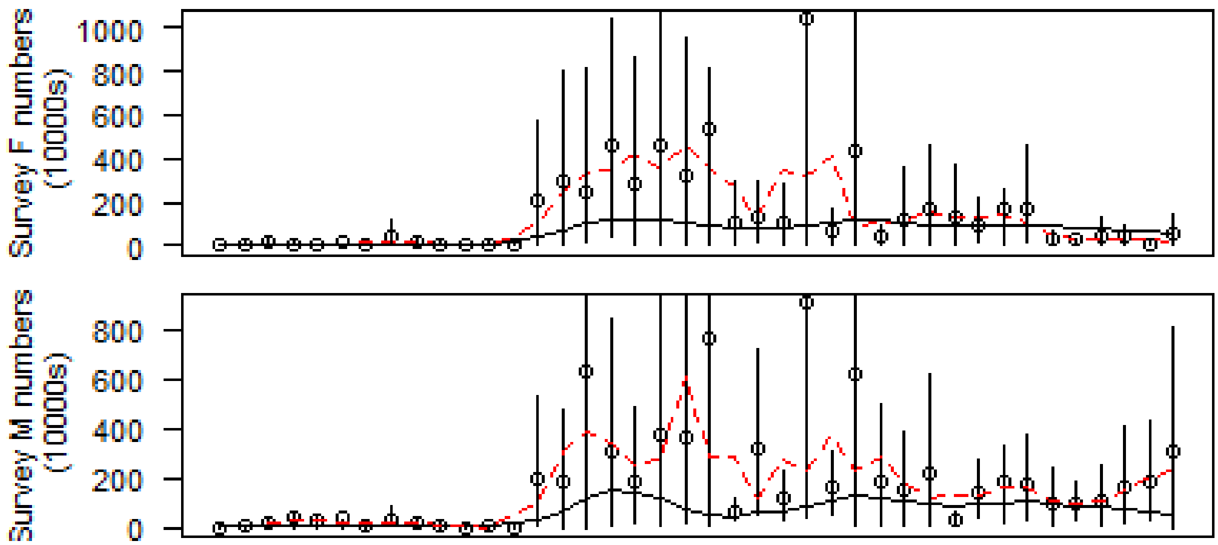

Figure 16. Fits to male and female survey numbers from 2014. Black line is integrated assessment method, dashed red is a 3-year running average.

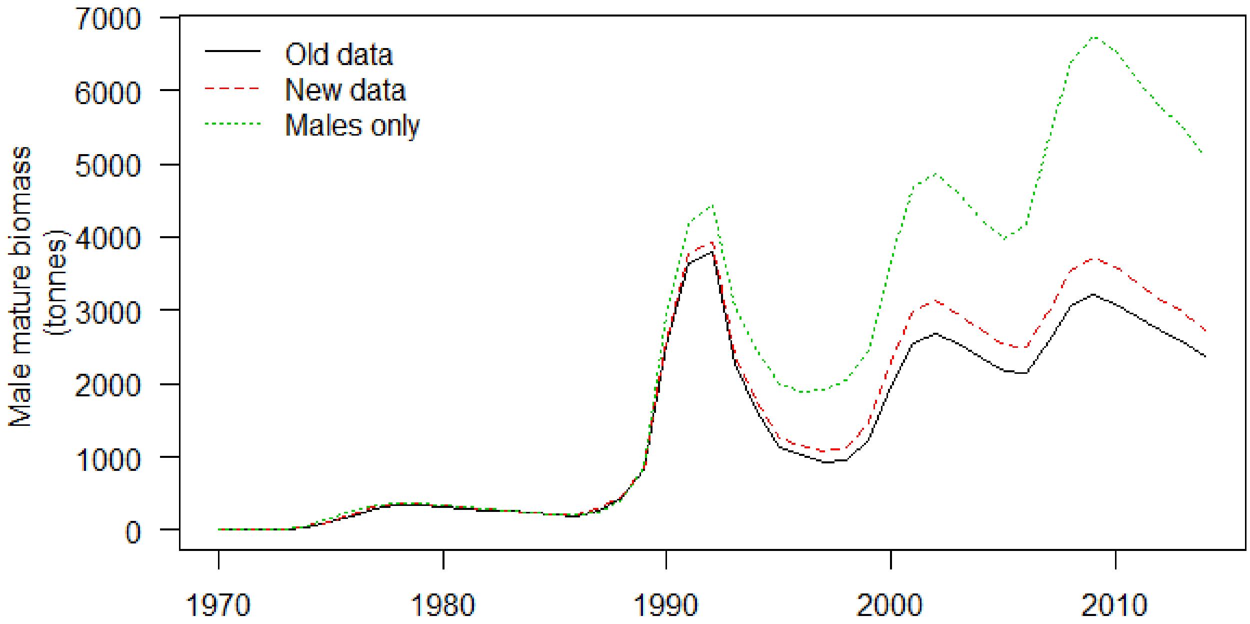

Figure 17. Comparison of estimated MMB using survey data from 1975-2014 using the new and old methodologies for calculating survey numbers and while fitting males only with the new methodology.

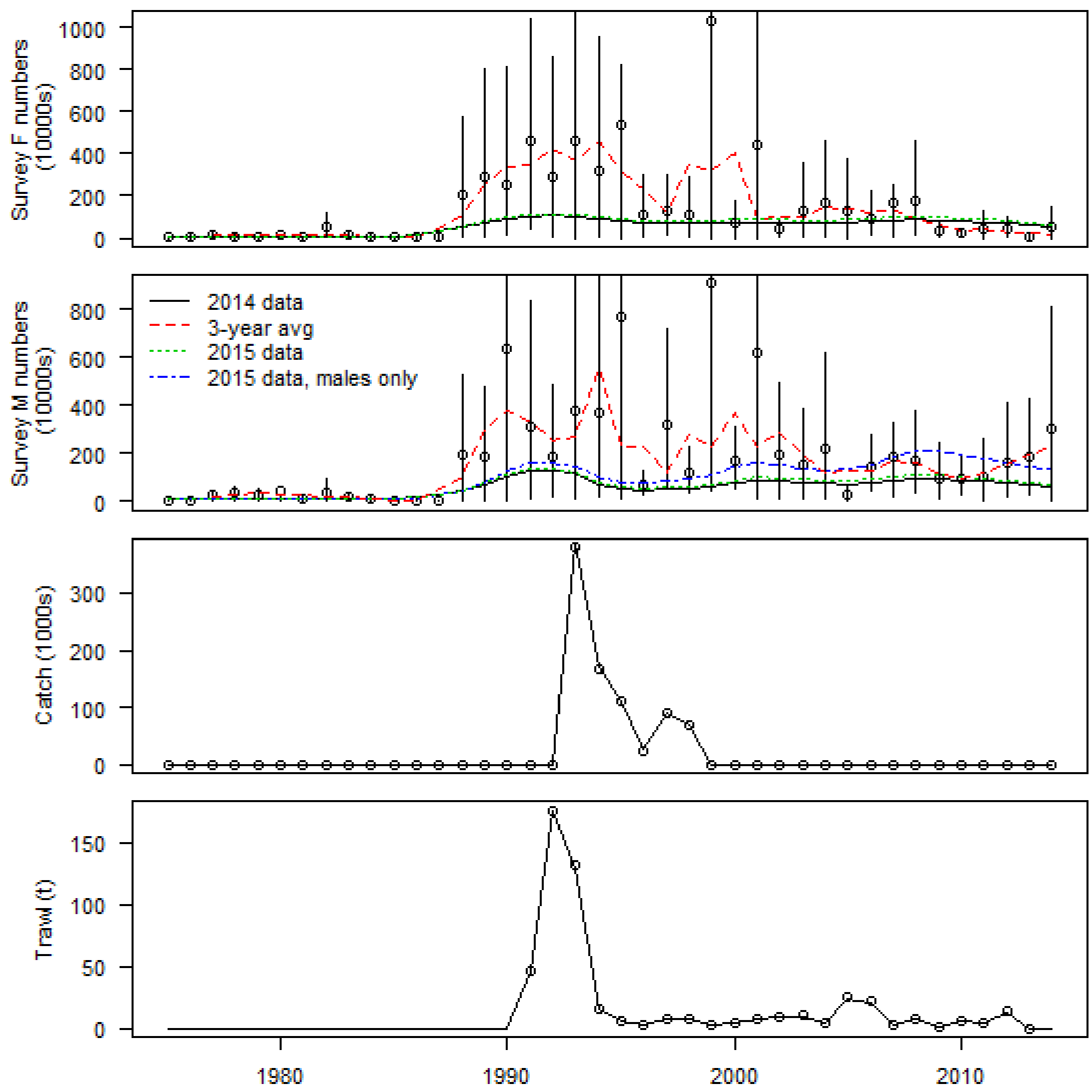

Figure 18. Model fits (black line) to observed survey numbers (black dots) with 95% bootstrapped CIs for females (top) and males (2nd row). Model fits (black line) to observed catches in the directed fishery (dots) in numbers caught (3rd row) and bycatch in the non-pelagic trawl fishery (4th row). Survey data are updated through year 2014, '2015' indicates the new survey methodology here.

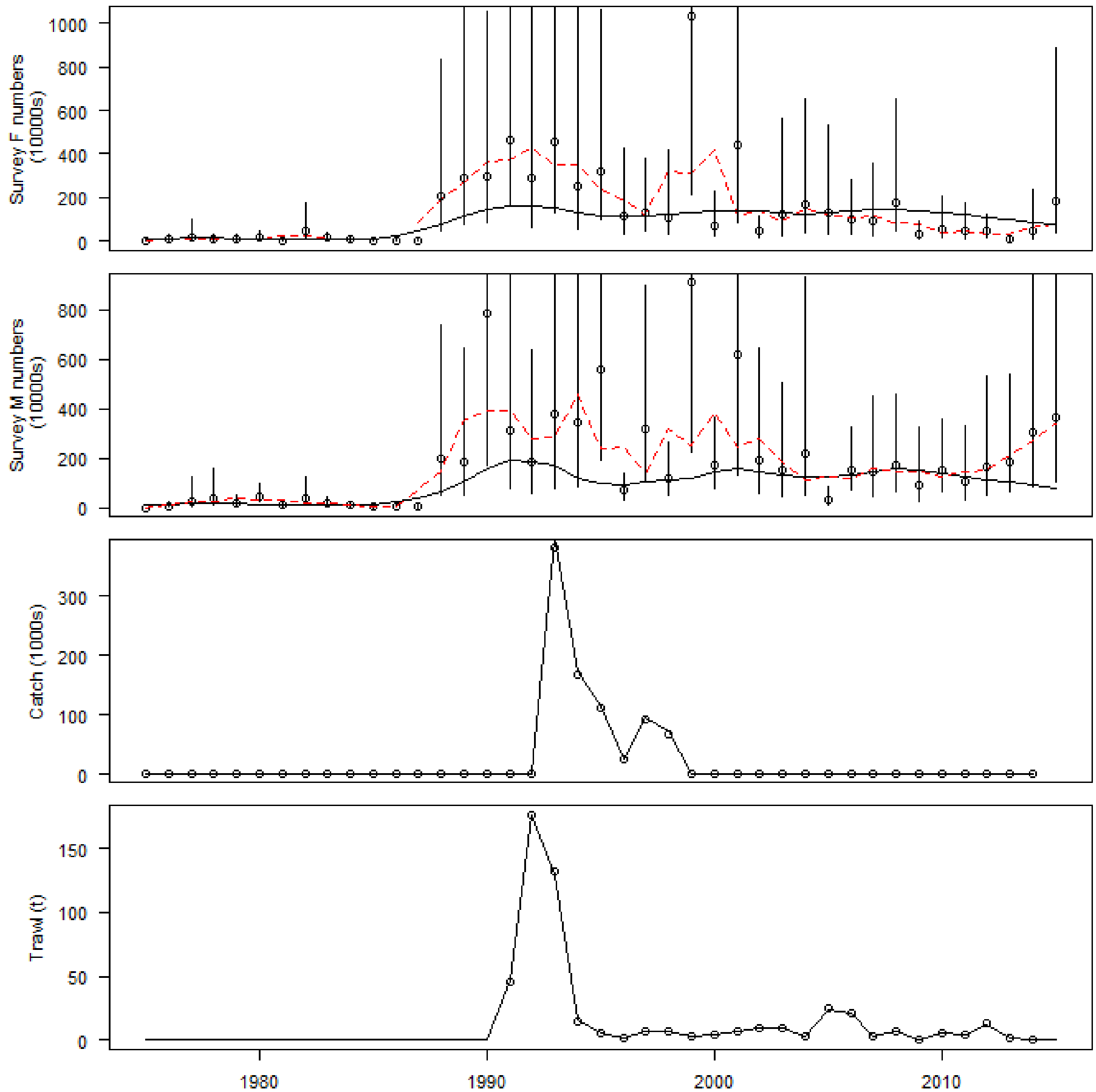

Figure 19. Model fits (black line) to observed survey numbers (black dots) with 95% Poisson CIs (provided by Kodiak lab) for females (top) and males (2nd row). Model fits (black line) to observed catches in the directed fishery (dots) in numbers caught (3rd row) and bycatch in the non-pelagic trawl fishery (4th row).

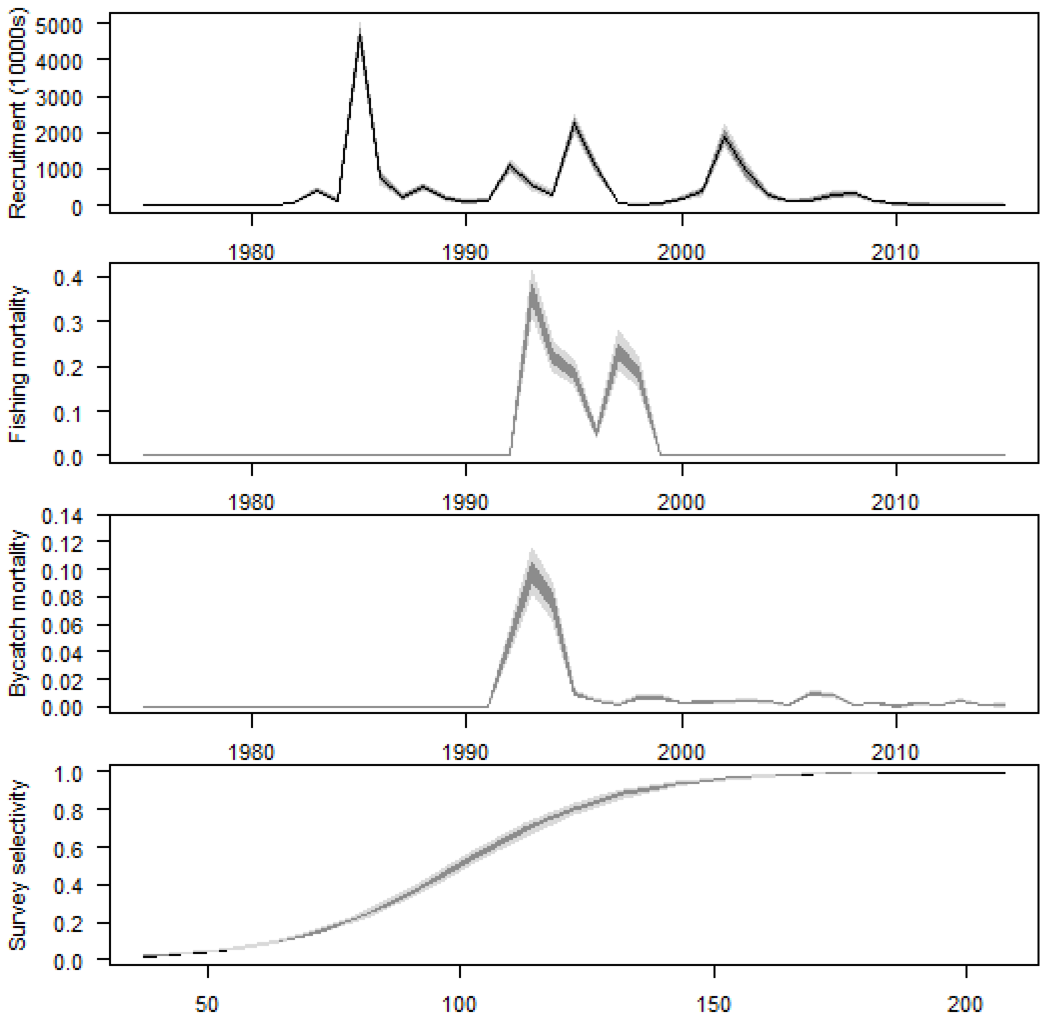

Figure 20. Estimated recruitment (top), fishing mortality in the directed fishery (2nd row), fishing mortality in the non-pelagic trawl (3rd row) and survey selectivity (bottom). Light grey areas indicate the 90% credibility interval and darker grey are the 50% credibility interval. Assessment method uses the 2015 data and fits both females and males.

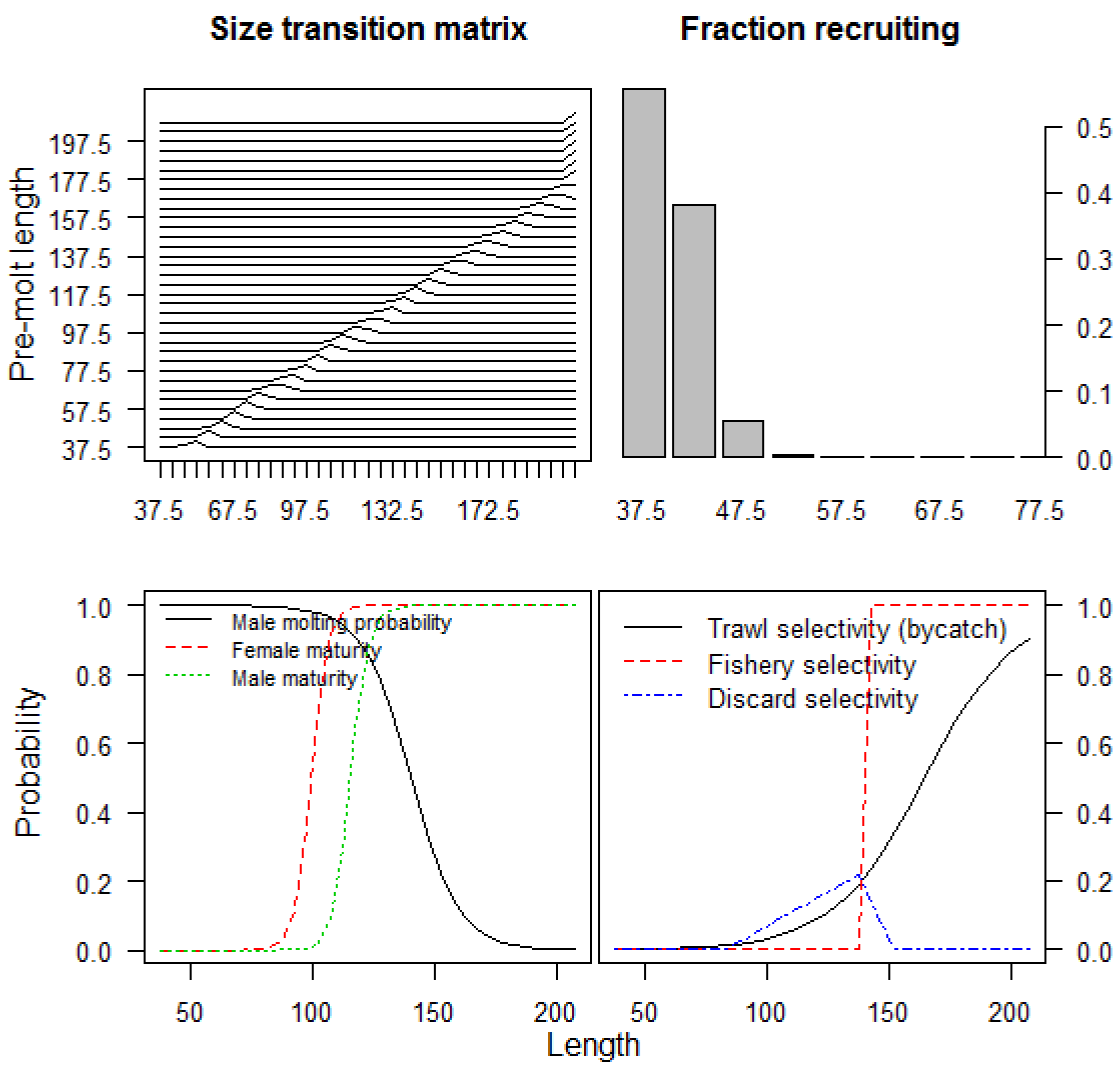

Figure 21. Size transition matrix (topleft), fraction recruiting to a given size class (top right), probability of molting (males only) and maturing (females and males; bottom left), probability of being selected in the directed and trawl fisheries (bottom right). Blue line indicates the discard selectivity from the directed fishery. All from the assessment method fit to both males and females.

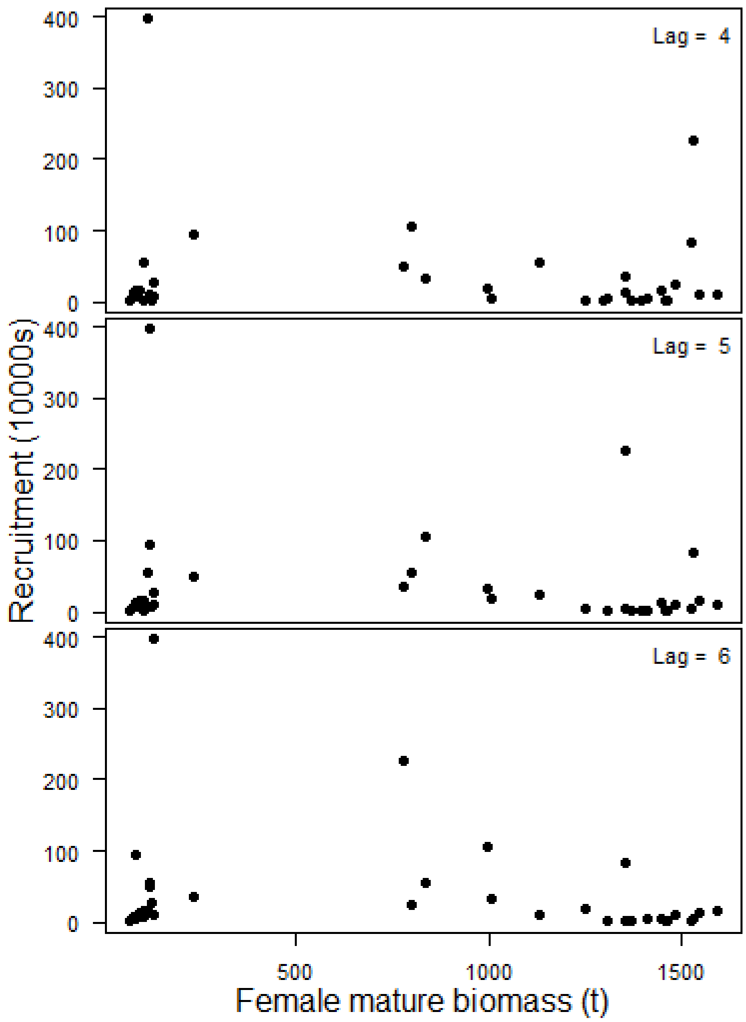

Figure 22. Recruitment vs. estimated female mature biomass at lags of 4, 5, and 6 years.

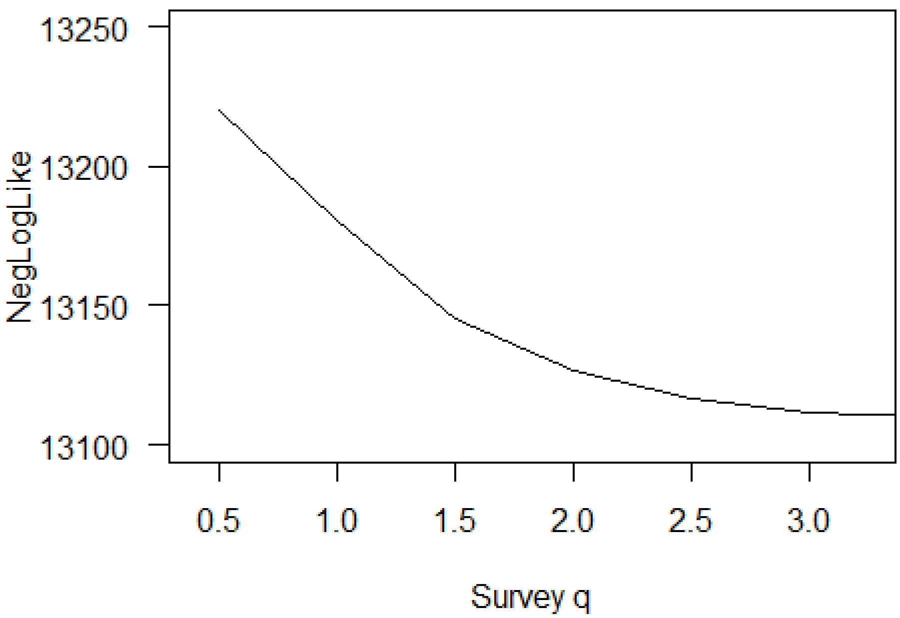

Figure 23. Likelihood profile for the catchability coefficient (q) in the survey.

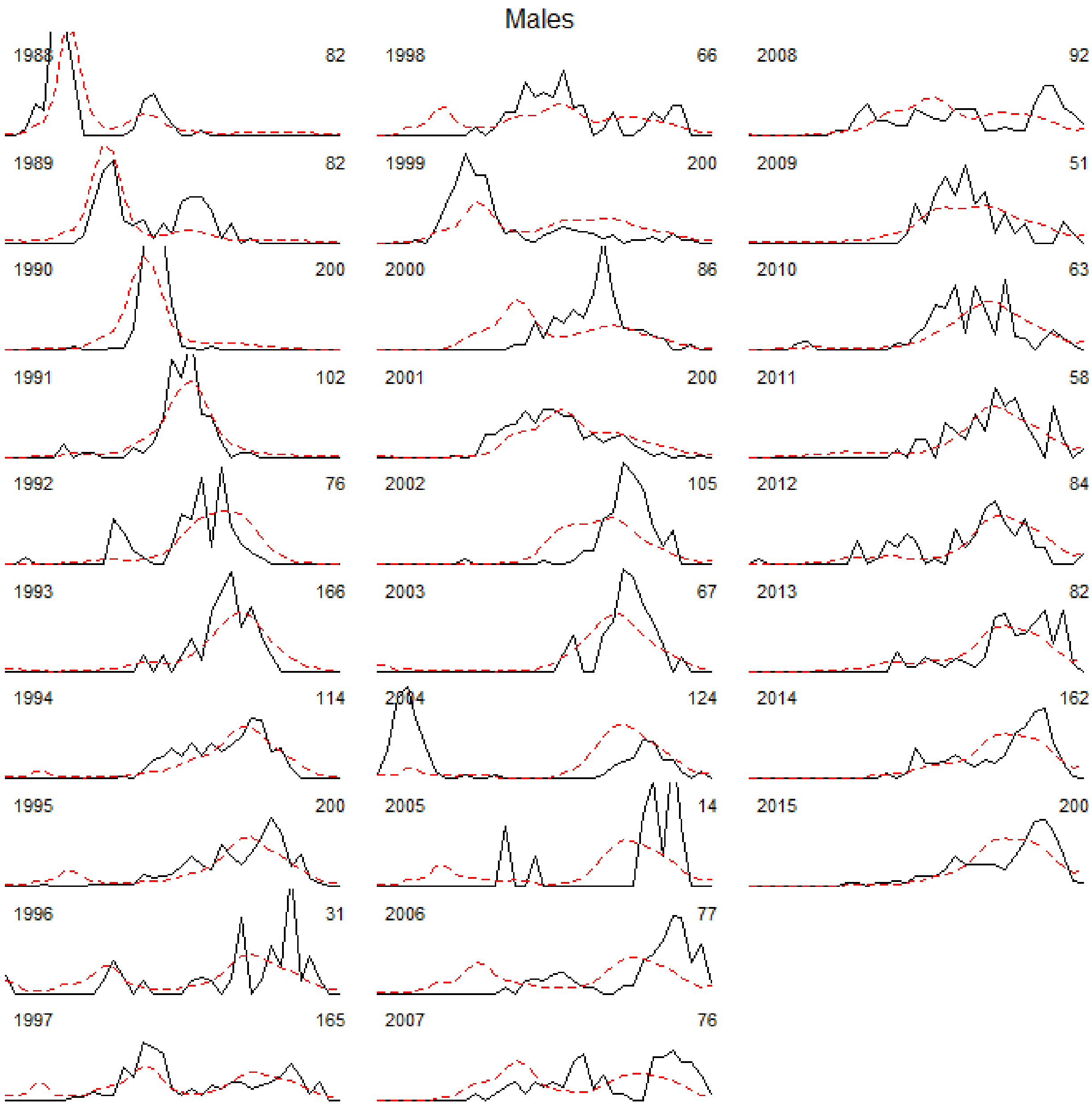

Figure 24. Model fits (red dashed line) to observed male length frequencies in the survey (solid line) by year using 5 mm length bins and fitting males and females. Sample size is noted in the top right hand corner of each plot. Length frequencies for the years 1975-1987 are not shown because the associated sample sizes were <=18 and therefore held very little information.

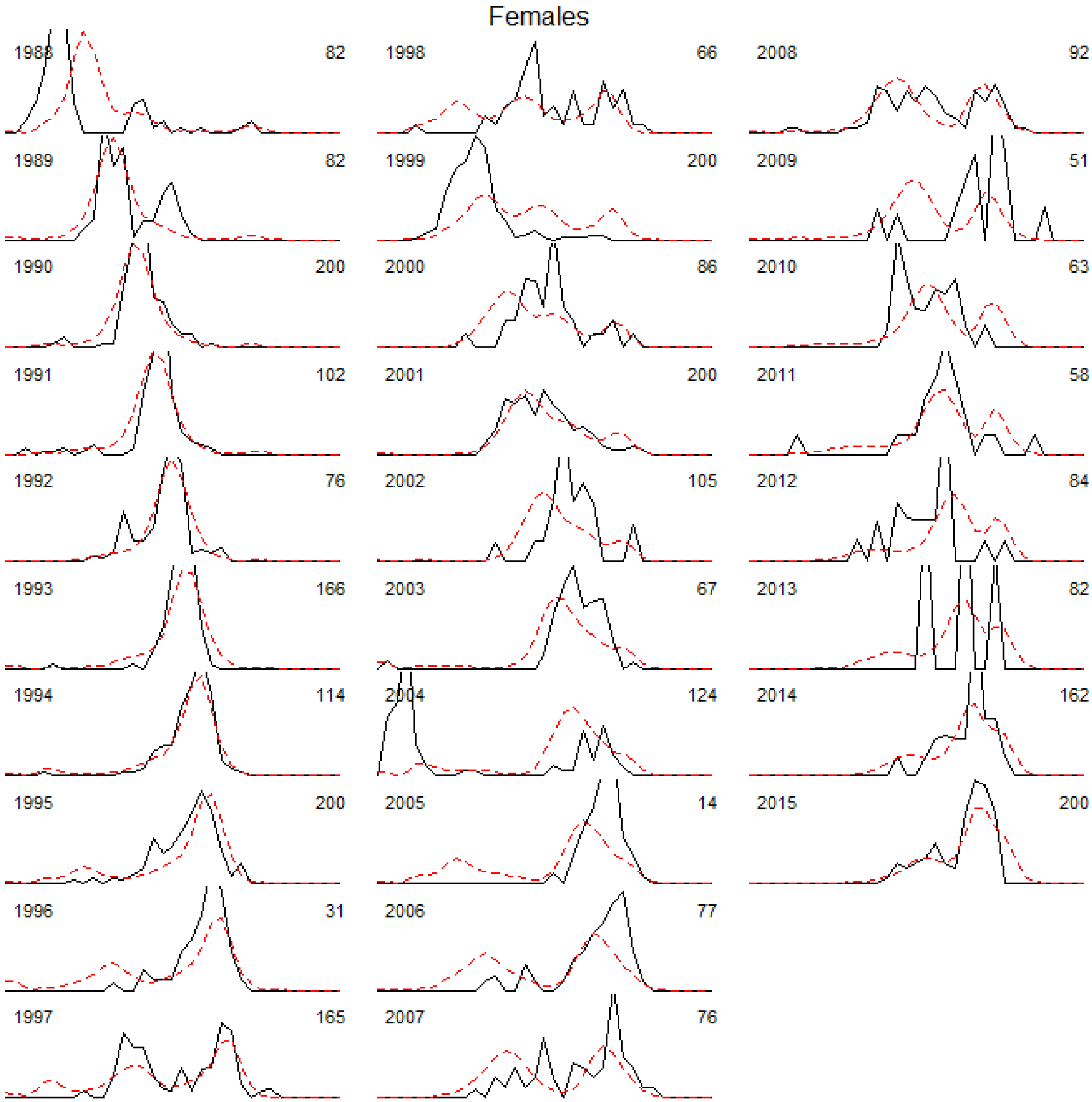

Figure 25. Model fits (red dashed line) to observed female length frequencies in the survey (solid line) by year using 5 mm length bins. Sample size is noted in the top right hand corner of each plot. Length frequencies for the years 1975-1987 are not shown because the associated sample sizes were <=18 and therefore held very little information.

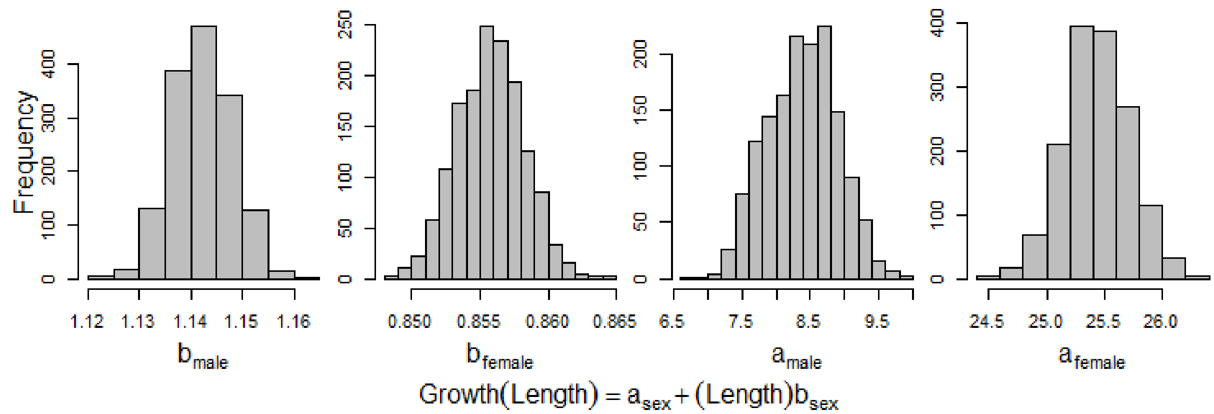

Figure 26. Posterior distributions of estimated growth parameters.

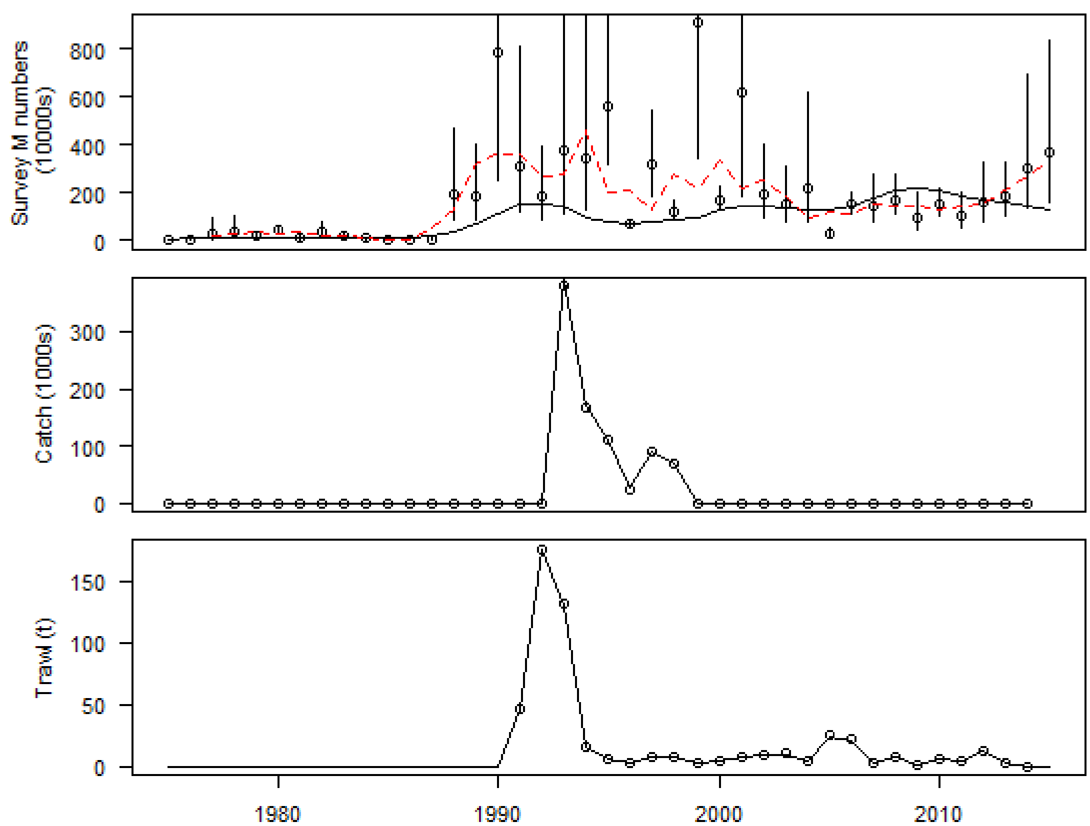

Figure 27. Male only model fits (black line) to observed survey numbers (black dots) with Poisson CIs for males (top row). Model fits (black line) to observed catches in the directed fishery (dots) in numbers caught (2rd row) and bycatch in the non-pelagic trawl fishery (3th row).

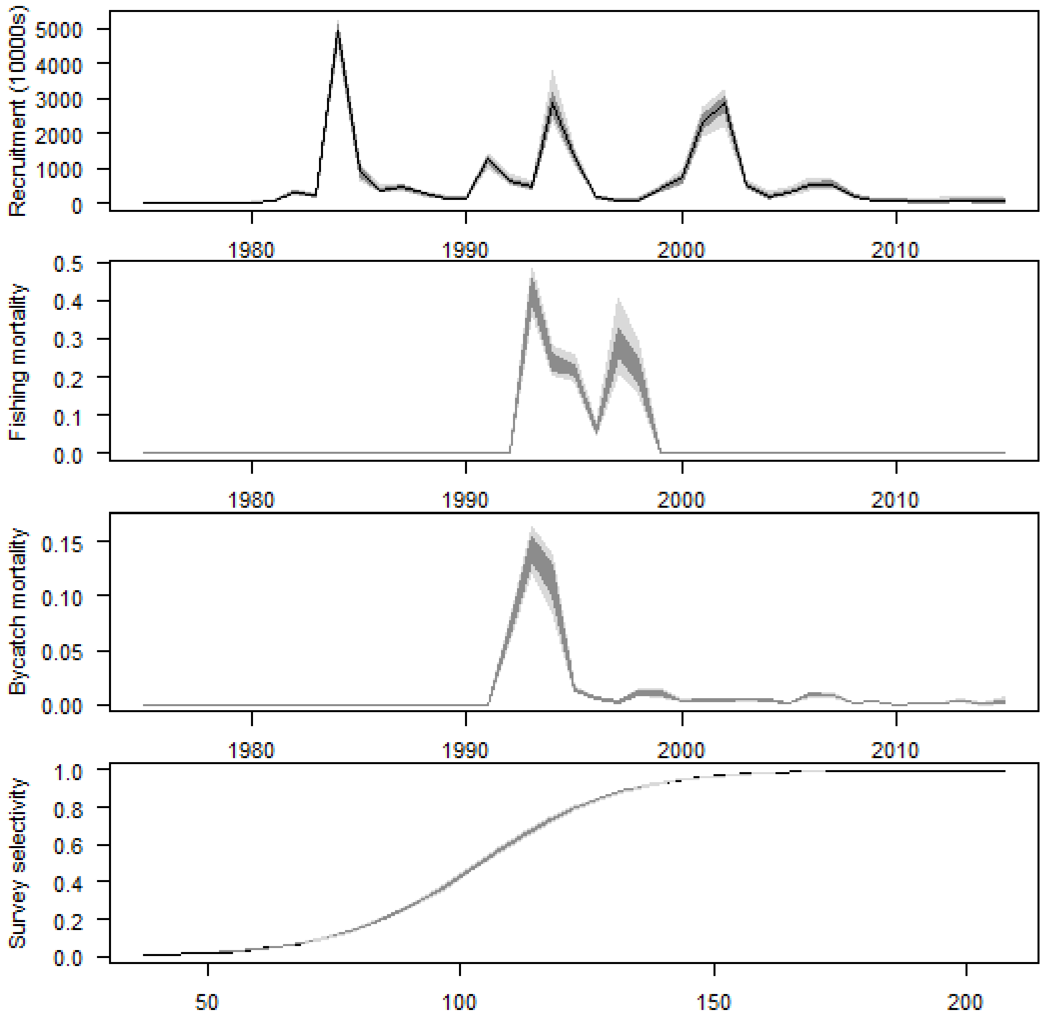

Figure 28. Estimated recruitment (top), fishing mortality in the directed fishery (2nd row), fishing mortality in the non-pelagic trawl (3rd row) and survey selectivity (bottom). Light grey areas indicate the 90% credibility interval and darker grey are the 50% credibility interval. Assessment method uses the 2015 data and fits males.

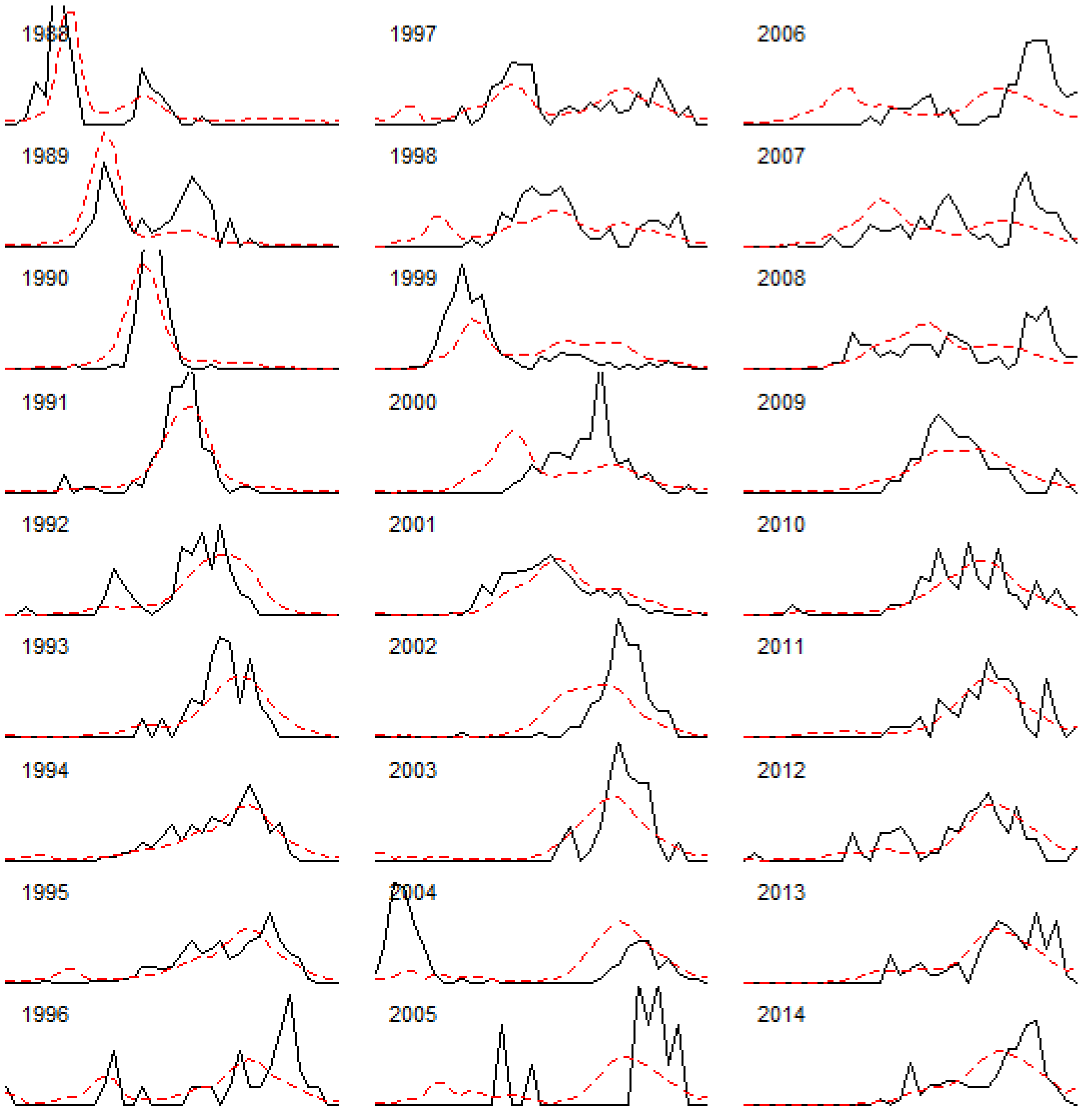

Figure 29. Model fits (red dashed line) to observed male length frequencies in the survey (solid line) by year using 5 mm length bins and fitting only males. Sample size is noted in the top right hand corner of each plot. Length frequencies for the years 1975-1987 are not shown because the associated sample sizes were <=18 and therefore held very little information.

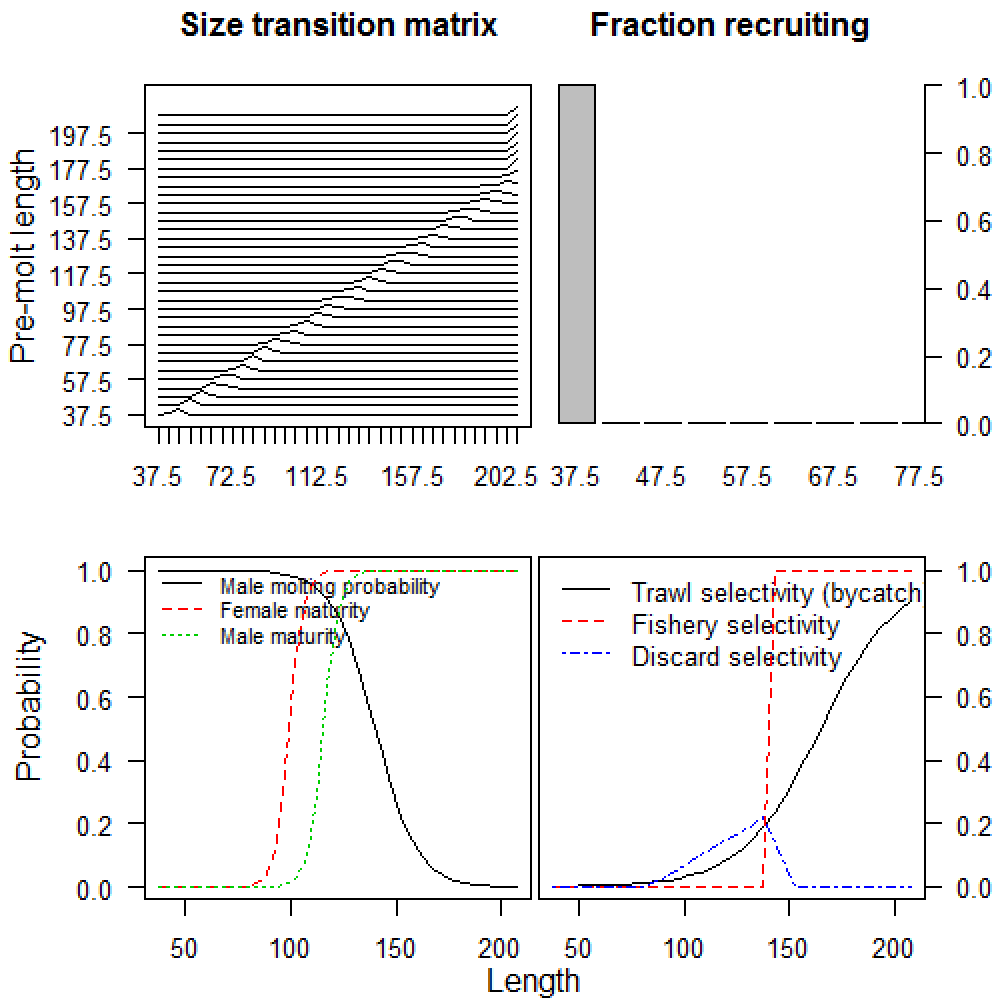

Figure 30. Size transition matrix (topleft), fraction recruiting to a given size class (top right), probability of molting (males only) and maturing (females and males; bottom left), probability of being selected in the directed and trawl fisheries (bottom right). Blue line indicates the discard selectivity from the directed fishery. All from the assessment method fit to both males and females.

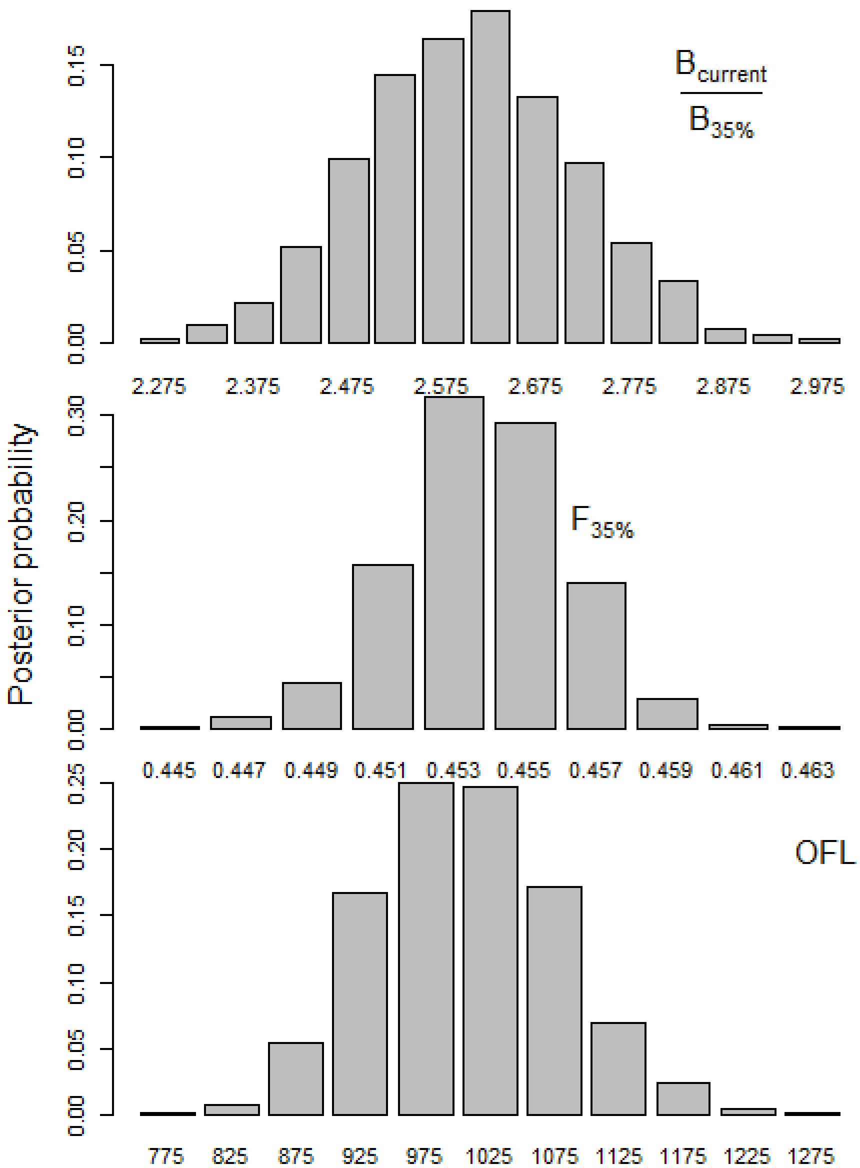

Figure 31. Posterior distributions for the ratio of the current biomass to the target biomass (top), F35% (middle) and the overfishing level (bottom) for an MCMC in which both the male and female 2015 data were fit to.

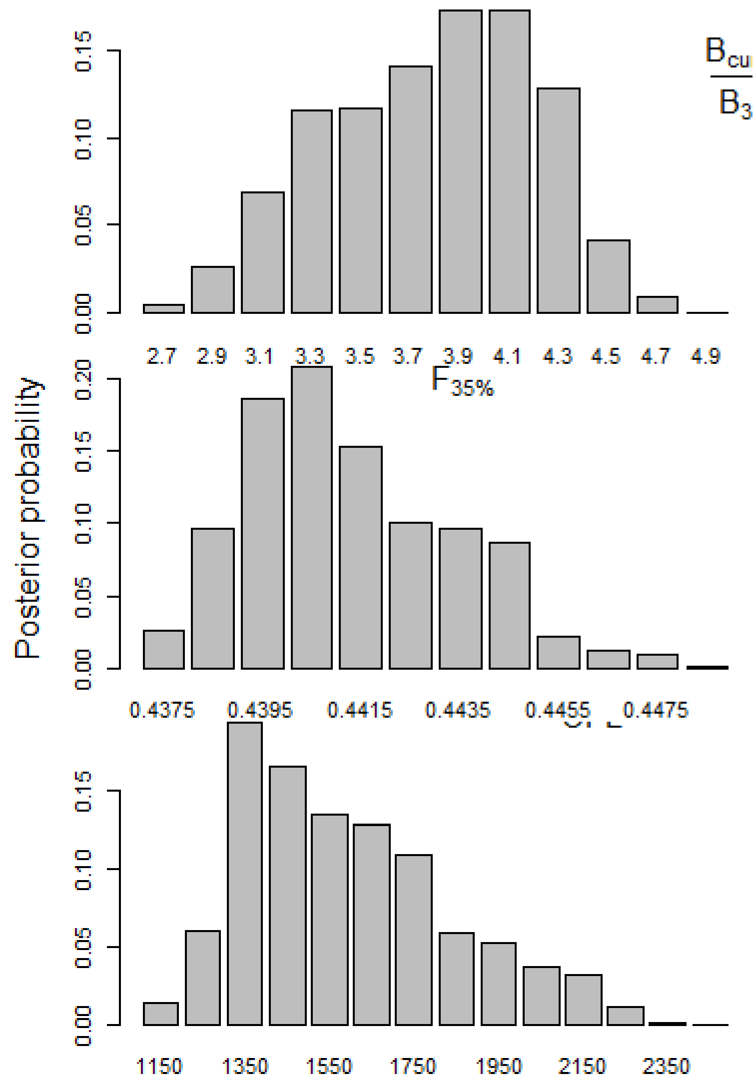

Figure 32. Posterior distributions for the ratio of the current biomass to the target biomass (top), F35% (middle) and the overfishing level (bottom) for an MCMC in which the 2015 data were fit to and only males were fit.

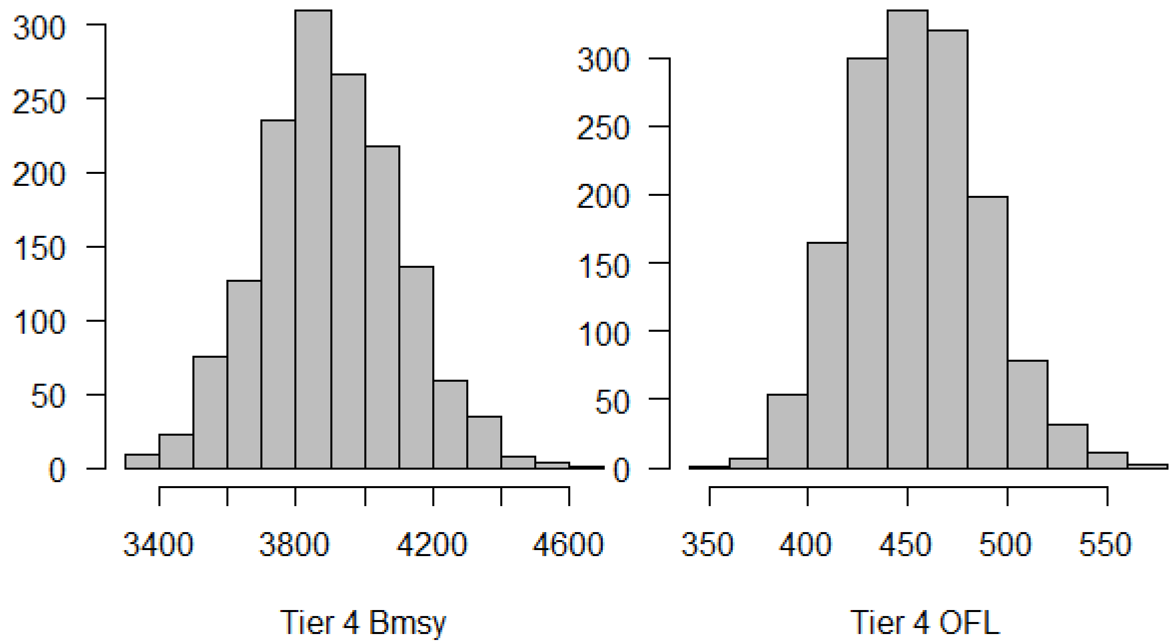

Figure 33. Posterior distribution for Tier 4 BMSY and OFL (in tonnes) from the integrated assessment when both males and females were fit using the 2015 data..

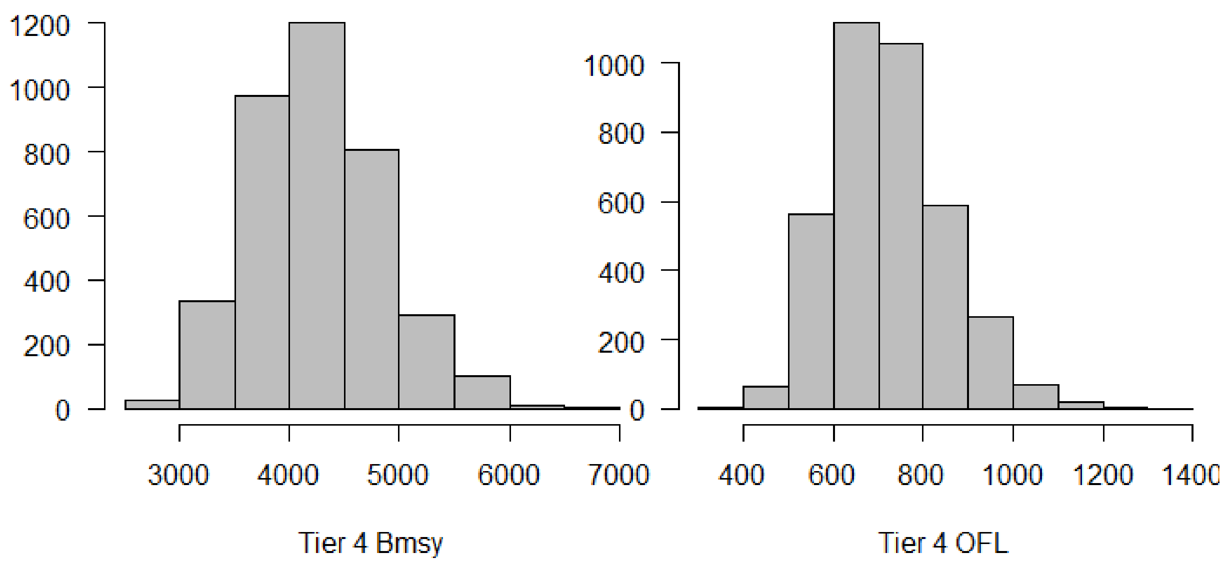

Figure 34. Posterior distribution for Tier 4 BMSY and OFL (in tonnes) from the integrated assessment when only males were fit from the 2015 data..

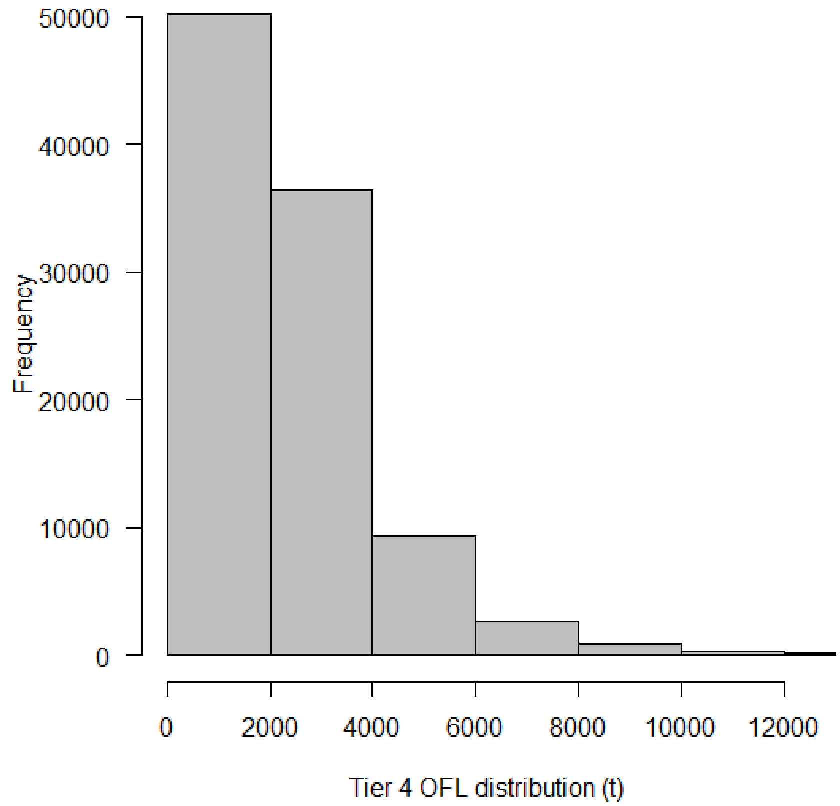

Figure 35. Distribution of tier 4 OFL generated by bootstrapping values of MMB from a 3-year, inverse-variance weighted, running average with an additional sigma of 0.3.

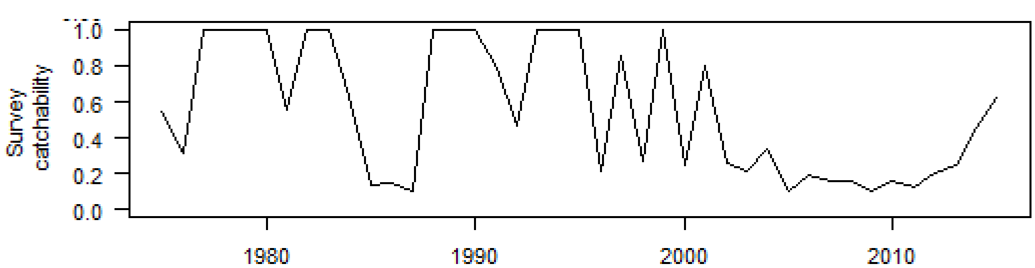

Figure 36. Estimated survey catchability when only males were fit by the integrated assessment method.

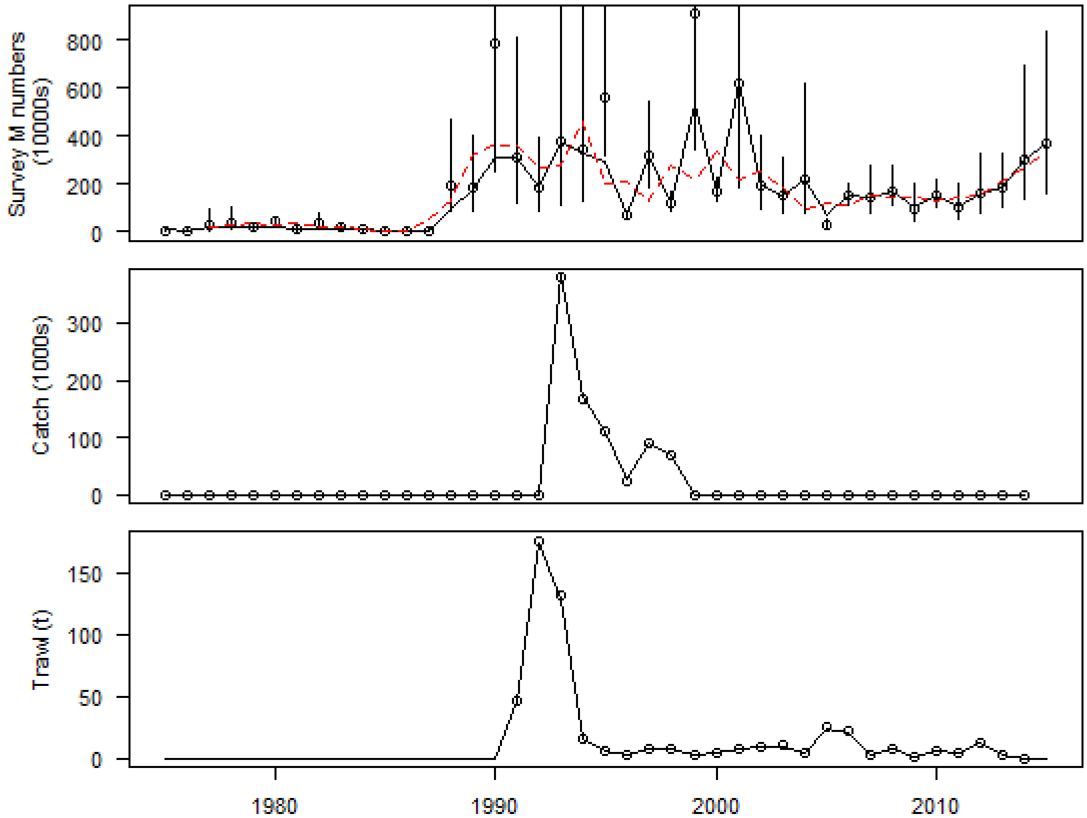

Figure 37. Fits to male numbers with time-varying survey catchabilty.

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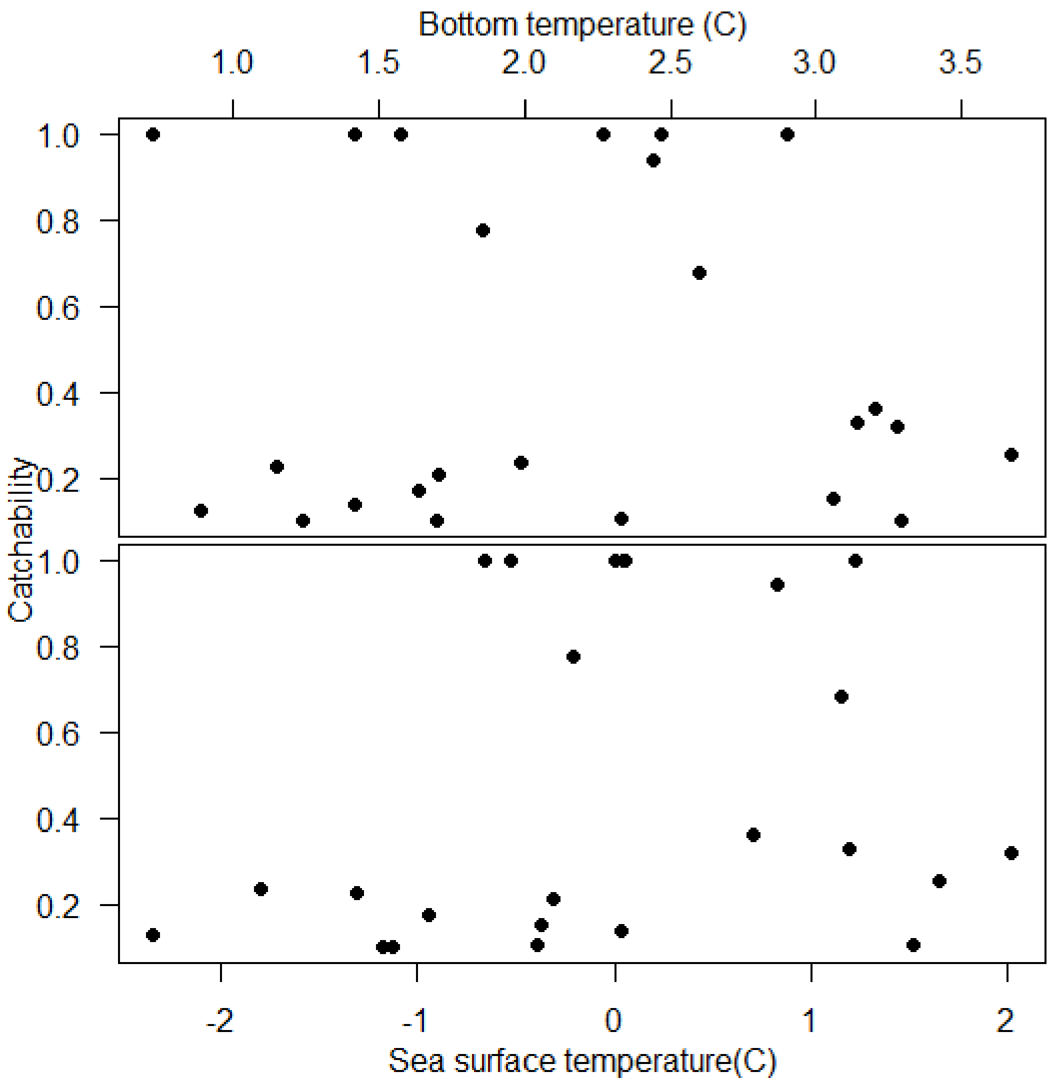

Figure 38. Relationship between estimated yearly catchability for males during the years 1992-2015 and sea surface temperature and bottom temperature around the Pribilof Islands.

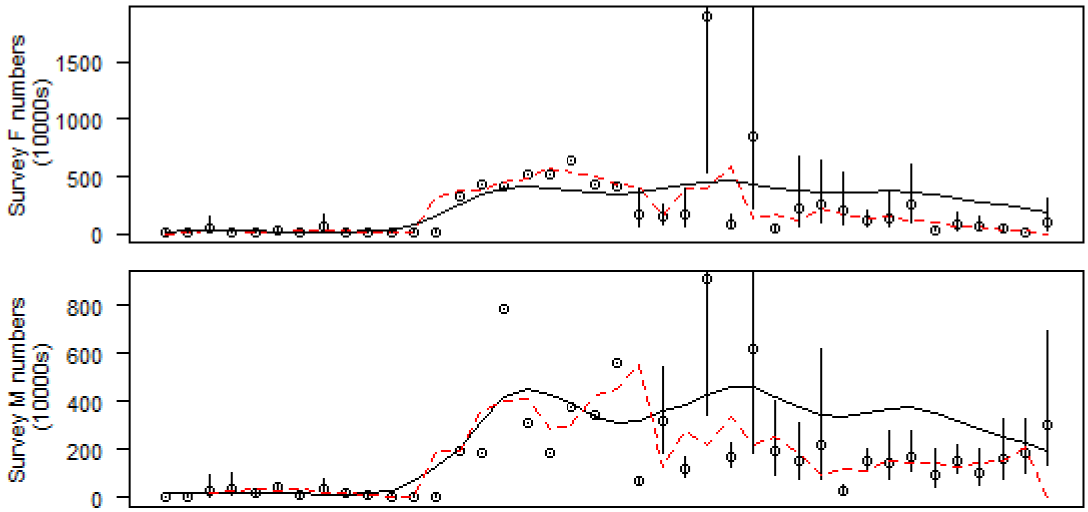

Figure 39. Estimated survey numbers when the CVs for the large numbers estimates in the 1990s are decreased to 0.001.

2015 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions

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September 20, 2015

Executive Summary

1. Stock: Pribilof Islands blue king crab (PIBKC), *Paralithodes platypus*
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been relatively small in recent years, with most bycatch mortality occurring in the BSAI groundfish trawl fisheries (5-year average: 0.09 t [0.0002 million lbs]) and pot fisheries (5-year average: 0.03 t [0.0001 million lbs]). In 2014/15, the estimated crab bycatch mortality was zero in the groundfish trawl fisheries and 0.07 t (< 0.0002 million lbs) in the groundfish pot fisheries. The estimated bycatch mortality for Pribilof Islands blue king crab in other crab fisheries was zero in 2014/15.
3. Stock biomass: Stock biomass decreased between the 1995 and 2008 surveys, and continues to fluctuate at low abundance 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 blue king crab. Pre-recruits have remained consistently low in the past 10 years, although these may not be well assessed with the survey.
5. Management performance: The stock is below MSST and consequently is overfished. Overfishing did not occur during the 2014/2015 fishing year. [Note: MSST changed somewhat 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}]. The following results are based on calculating BMSY by averaging the MMB-at-mating time series estimated using the "raw" survey data and on determining current MMB-at-mating using the inverse variance-smoothed approach.

All units are tons of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2011/12	2,247 [A]	365 [A]	0	0	0.36	1.16	1.04
2012/13	1,994 [A]	579 [A]	0	0	0.61	1.16	1.04
2013/14	2,001 [A]	225 [A]	0	0	0.03	1.16	1.04
2014/15	2,506 [A]	320 [A]	0	0	0.07	1.16	0.87
2015/16	--	318 [B]	--	--	--	1.16	0.87

All units are million pounds of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2011/12	4.95 [A]	0.80 [A]	0	0	0.0008	0.003	0.002
2012/13	4.39 [A]	1.09 [A]	0	0	0.0013	0.003	0.002
2013/14	4.41 [A]	0.50 [A]	0	0	0.0001	0.003	0.002
2014/15	5.52 [A]	0.71 [A]	0	0	0.0002	0.003	0.002
2015/16	--	0.70 [B]	--	--	--	0.003	0.002

Notes:
A – Based on data available to the Crab Plan Team at the time of the assessment following the end of the crab fishing year.
B – Based on data available to the Crab Plan Team at the time of the assessment for the crab fishing year.

6. Basis for the 2014/2015 OFL: The OFL was determined following Tier 4 considerations. The ratio of the estimate of current (2015/16) 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 a consequence, the OFL is based on a Tier 5 calculation of average bycatch mortalities between 1999/2000 and 2005/2006 to adequately reflect the conservation needs associated with this stock and to acknowledge existing non-directed catch mortality. Using this approach, the OFL was determined to be 1.16 t (0.0003 million lbs) for 2015/16. [Note: MSST changed somewhat 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}]. The following results are based on calculating BMSY by averaging the MMB-at-mating time series estimated using the "raw" survey data and on determining current MMB-at-mating using the inverse variance-smoothed approach.

   All weights in t.

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2011/12	4c	4,209	365	0.09	1	1975/76-1984/85 &1990/91-1997/98	0.18	10% buffer
2012/13	4c	4,494	496	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	3,988	278	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	4,002	218	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2015/16	4c	5,012	318	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

All weights in million lbs.

Year	Tier	B_{MSY}	Current MMB_{mating}	B/B_{MSY} (MMB_{mating})	γ	Years to define B_{MSY}	Natural Mortality	P*
2011/12	4c	9.28	0.80	0.09	1	1975/76-1984/85 &1990/91-1997/98	0.18	10% buffer
2012/13	4c	9.91	1.09	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	8.79	0.61	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	8.82	0.48	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2015/16	4c	11.05	0.70	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

7. Probability density function for the OFL: Not applicable for this stock.
8. The ABC_{max} was calculated using a 25% buffer, as in the 2014 assessment. The ABC_{max} is thus 0.87 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.

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 closes the Pribilof Islands Habitat Conservation Zone to pot fishing for Pacific cod is 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.
2. Input data: Retained and discard catch time series were updated with 2014/2015 data from the crab and groundfish fisheries. Following review by the CPT and approval by the SSC, abundance, biomass and size frequencies estimated from the NMFS crab and groundfish summer bottom trawl survey were recalculated for the entire time series based on a new set of standardized stations and hauls selected to improve sampling design and consistency across the 40-plus year dataset.
3. Assessment methodology: No changes. The Tier 4 approach based on inverse-averaged survey biomass estimates used in this assessment for status determination is identical to that used last year (Stockhausen, 2014). An alternative Tier 4 approach using a random effects/Kalman filter

model was developed and is discussed in this chapter. It was not, however, used for status determination because it has not been reviewed and approved by the CPT and SSC.

4. Assessment results: Total catch mortality in 2014/2015 was 0.07 t. The projected MMB for 2015/16 decreased slightly from that in 2013/14 and remained below the MSST. Consequently, the stock remains overfished and a directed fishery is prohibited in 2015/16. The OFL, based on average catch, and ABC are identical to last year's values.

B. Responses to SSC and CPT Comments

CPT comments May 2014:

Specific remarks pertinent to this assessment

none

SSC comments June 2014:

Specific remarks pertinent to this assessment

none

CPT comments September 2014:

Specific remarks pertinent to this assessment

The CPT expressed interest in seeing information about whether the amount of observer coverage has changed since the new groundfish observer program was implemented in 2013.

The CPT would like to see the spatial distribution of bycatch by State statistical area.

Responses to CPT Comments: These requests will be addressed at the May 2016 CPT meeting.

SSC comments October 2014:

Specific remarks pertinent to this assessment

none

CPT comments May 2015:

Specific remarks pertinent to this assessment

none

SSC comments June 2015:

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 (Somerton 1985; Armstrong et al 1985, 1987).

   During the years when the fishery was active (1973-1989, 1995-1999), the Pribilof Islands blue king crab (PIBKC) were managed under the Bering Sea king crab Registration Area Q Pribilof District. The southern boundary of this District is formed by a line from 54° 36' N lat., 168° W long., to 54° 36' N lat., 171° W long., to 55° 30' N lat., 171° W. long., to 55° 30' N lat., 173° 30' E long., while its northern boundary is a line at the latitude of Cape Newenham (58° 39' N lat.), its eastern boundary is a line from 54° 36' N lat., 168° W long., to 58° 39' N lat., 168° W long., to Cape Newenham (58° 39' N lat.), and its western boundary is the United States-Russia Maritime Boundary Line of 1991 (ADF&G 2008) (Figure 2). In the Pribilof District, blue king crab occupied the waters adjacent to and northeast of the Pribilof Islands (Armstrong et al. 1987).

3. **Stock structure** - Stock structure of blue king crabs in the North Pacific is largely unknown. Samples were collected in 2009-2011 to support a genetic study on blue king crab population structure by a graduate student at the University of Alaska. 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.

   The potential for species interactions between blue king crab and red king crab as a potential reason for PIBKC shifts in abundance and distribution were addressed in a previous assessment (Foy, 2013). Foy (2013) compared the spatial extent of both speices in the Pribilof Islands from 1975 to 2009 and found that, in the early 1980's when red king crab first became abundant, blue king crab males and females dominated the 1 to 7 stations where the species co-occurred in the Pribilof Islands District. Spatially, the stations with co-occurance were all dominated by blue king crab and broadly distributed around the Pribilof Islands. In the 1990's, the red king crab population biomass increased substantially as the blue king crab population biomass decreased. During this time period, the number of stations with co-occurance remained around a maximum of 8, but they were equally dominated by both blue king crab and red king crab—sugggesting a direct overlap in distribution at the scale of a survey station. During this time period, the stations dominated by red king crab were dispersed around the Pribilof Islands. Between 2001 and 2009 the blue king crab population decreased dramatically while the red king crab fluctuated. The number of stations dominated by blue king crab in 2001-2009 was similar to that for stations dominated by red king crab for both males and females, suggesting continued competition for similar habitat. The only stations dominated by blue king crab in the latter period are to the north and east of St. Paul Island. Although blue king crab protection measures also afford protection for the red king crab in this region, red king crab stocks continue to fluctuate (more so than simply accounted for by the uncertainty in the survey).

4. **Life History** - Blue king crab are similar in size and appearance, except for color, to the more widespread red king crab, but are typically biennial spawners with lesser fecundity and somewhat larger sized (*ca.* 1.2 mm) eggs (Somerton and Macintosh 1983; 1985; Jensen et al. 1985; Jensen and Armstrong 1989; Selin and Fedotov 1996). Blue king crab fecundity increases with size, from approximately 100,000 embryos for a 100-110 mm CL female to approximately 200,000 for a female >140-mm CL (Somerton and MacIntosh 1985). Blue king crab have a biennial ovarian cycle with embryos developing over a 12 or 13-month period depending on whether or not the female is primiparous or multiparous, respectively (Stevens 2006a). Armstrong et al. (1985, 1987), however, estimated the embryonic period for Pribilof blue king crab at 11-12 months, regardless of previous reproductive history. Somerton and MacIntosh (1985) placed development at 14-15 months. It may not be possible for large female blue king crabs to support the energy requirements for annual ovary development, growth, and egg extrusion due to limitations imposed by their habitat, such as poor quality or low abundance of food or reduced feeding activity due to cold water (Armstrong et al. 1987, Jensen and Armstrong 1989). Both the large size reached by Pribilof Islands blue king crab and the generally high productivity of the Pribilof area, however, argue against such environmental constraints. Development of the fertilized embryos occurs in the egg cases attached to the pleopods beneath the abdomen of the female crab and hatching occurs February through April (Stevens 2006b). After larvae are released, large female Pribilof blue king crab will molt, mate, and extrude their clutches the following year in late March through mid April (Armstrong et al. 1987).

   Female crabs require an average of 29 days to release larvae, and release an average of 110,033 larvae (Stevens 2006b). Larvae are pelagic and pass through four zoeal larval stages which last about 10 days each, with length of time being dependent on temperature: the colder the temperature the slower the development and vice versa (Stevens et al 2008). Stage I zoeae must find food within 60 hours as starvation reduces their ability to capture prey (Paul and Paul 1980) and successfully molt. Zoeae consume phytoplankton, the diatom *Thalassiosira* spp. in particular, and zooplankton. The fifth larval stage is the non-feeding (Stevens et al. 2008) and transitional glaucothoe stage in which the larvae take on the shape of a small crab but retain the ability to swim by using their extended abdomen as a tail. This is the stage at which the larvae searches for appropriate settling substrate, and upon finding it, molts to the first juvenile stage and henceforth remains benthic. The larval stage is estimated to last for 2.5 to 4 months and larvae metamorphose and settle during July through early September (Armstrong et al. 1987, Stevens et al. 2008).

   Blue king crab molt frequently as juveniles, growing a few mm in size with each molt. Unlike red king crab juveniles, blue king crab juveniles are not known to form pods. Female king crabs typically reach sexual maturity at approximately five years of age while males may reach maturity one year later, at six years of age (NPFMC 2003). Female size at 50% maturity for Pribilof blue king crab is estimated at 96-mm carapace length (CL) and size at maturity for males, as estimated from size of chela relative to CL, is estimated at 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 for all king crab species was adopted in the federal crab fishery management plan for the BSAI areas (Siddeek et. al 2002).

5. **Management history -** The king crab fishery in the Pribilof District began in 1973 with a reported catch of 590 t by eight vessels (Fig. 3). Landings increased during the 1970s and peaked at a harvest of 5,000 t in the 1980/81 season (Fig. 3), with an associated increase in effort to 110 vessels (ADF&G 2008). The fishery occurred September through January, but usually lasted less than 6 weeks (Otto and Cummiskey 1990, ADF&G 2008). The fishery was male only, and legal size was >16.5 cm carapace width (NPFMC 1994). Guideline harvest levels (GHL) were 10 percent of the abundance of mature males or 20 percent of the number of legal males (ADF&G 2006).

   Blue king crab in the Pribilof District have occurred as bycatch in the eastern Bering Sea snow crab (*Chionoecetes opilio*) fishery, the eastern Bering Sea Tanner crab (*Chionoecetes bairdi*) fishery, the Bering Sea hair crab (*Erimacrus isenbeckii*) fishery, and the Pribilof red and blue king crab fisheries. In addition, blue king crab are taken as bycatch in flatfish, sablefish, halibut, pollock, and Pacific cod fisheries.

   Amendment 21a to the BSAI Groundfish FMP prohibits the use of trawl gear in the Pribilof Islands Habitat Conservation Area (Fig. 4; subsequently renamed the Pribilof Islands Habitat Conservation Zone in Amendment 43), which the amendment also established (NPFMC, 1994). The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from the impact from trawl gear.

   Declines in the stock after 1995 resulted in a closure of directed fishing from 1999 to the present. The Pribilof Islands blue king crab 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 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 King and Tanner Crab Fishery Management Plan (FMP) and Amendment 103 to the BSAI Groundfish FMP to rebuild the PIBKC stock were adopted by the Council in 2012 and approved by the Secretary of Commerce in early 2015. Amendment 103 closes the Pribilof Islands Habitat Conservation Zone (Fig. 4) to pot fishing for Pacific cod is 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 2014/15 from ADFG data (no retained catch, no discard mortality; Tables 1 and 2). The time series of discards in the groundfish pot and trawl fisheries (Tables 2-4) were updated for 2013/14 and calculated for the 2014/15 crab fishery season (July 1-June 30) using the NMFS Alaska Regional Office (AKRO) estimates obtained from the AKFIN database (as updated on Aug. 17, 2015).

   Results from the 2015 NMFS EBS bottom trawl survey were added to the assessment (Table 5). The (old) standard NMFS survey time series data, including an additional (as of 2013) 20 nm strip on the eastern portion of the Pribilof District, were recalculated and updated through the 2015 summer bottom trawl survey (Table 6). Additionally, a suite of similar time series was calculated using the newly-standardized set of survey stations and hauls (Table 7). This new standardization improves sampling consistency and strata definitions across the 40-plus years the annual NMFS summer crab and groundfish trawl survey has been conducted and includes data from the 20 nm strip adjacent to the Pribilof District identified in the Environmental Assessment as an area to include in defining the stock area. Time series based on this new standardization will be referred to as "new" survey time series, while those based on the old selection of stations and hauls will be referred to as "old" survey time series. The new standardization primarily affects survey time series values in the early portions of these series. Recent results (e.g., 2013-2015) are based on the same set of hauls and stations in both the "new" and "old" time series.

2. *a. Total catch:*

<u>Crab pot fisheries</u>

Retained pot fishery catches (live and deadloss landings data) are provided for 1973/74 to 2012/13 (Table 1, Fig. 3), including the 1973/74 to 1987/88 and 1995/96 to 1998/99 seasons when blue king crab were targeted in the Pribilof Islands District. In the 1995/96 to 1998/99 seasons, blue king crab and red king crab were fished under the same Guideline Harvest Level (GHL). Total allowable catch (TAC) for a directed fishery has been set at zero since 1999/2000; there was no retained catch in the 2014/15 crab fishing season.

b. Bycatch and discards:

<u>Crab pot fisheries</u>

Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males (≤138 mm CL), legal males (>138 mm CL), and females based on data collected by onboard observers in the crab fisheries (Table 2). Catch weight was calculated by first determining the mean weight (in grams) for crabs in each of three categories: legal non-retained, sublegal, and female. The average weight for each category was then calculated from length frequency tables, where the carapace length (*z*; in mm) was converted to weight (*w*; in g) using the following equation:

$$w = \alpha \cdot z^{\beta} \qquad (1)$$

Values for the length-to-weight conversion parameters α and β were applied across two time periods: 1973-2009 (males: α =0.000329, β =3.175; females: α =0.114389, β =1.9192) and 2010-present (both sexes: α =0.000508, β =3.106). [Note: these coefficients should be updated next year based on the new NMFS EBS trawl survey weight-at-size relationships and catch weights should be recalculated, if possible, for the entire time series.] Average weights ($\overline{W}$) for each category were calculated using the following equation:

$$\overline{W} = \frac{\sum_z W_z \cdot n_z}{\sum_z n_z} \qquad (2)$$

where w_z is crab weight-at-size *z* (i.e., carapace length) using Eq. 1 and n_z is the number of crabs observed at that size in the category.

Finally, estimated total non-retained weights for each crab fishery were the product of average weight ($\overline{W}$), CPUE based on observer data, and total effort (pot lifts) in each fishery. A 50% handling mortality rate was applied to the bycatch estimates to estimate non-retained crab mortality in these pot fisheries.

Historical non-retained catch data are available from 1996/97 to present from the snow crab general, snow crab CDQ, and Tanner crab fisheries (Table 2, Bowers et al. 2011), although data may be incomplete for some of these fisheries. Prior to 1998/99, limited observer data exists (for catcher-processor vessels only), so non-retained catch before this date is not included here.

In 2014/15, no PIBKC were incidentally caught in the crab fisheries (Table 2).

Groundfish pot, trawl, and hook and line fisheries

AKRO estimates of non-retained catch from all groundfish fisheries in 2014/15, as available through the AKFIN database (updated Aug. 17, 2015), are included in this report (Tables 2-4). Updated estimates for 2009/10-2013/14 were also obtained through the AKFIN database.

Prior to 1991, groundfish bycatch data are available only in INPFC reports and are not included in this assessment. Non-retained crab catch data in the groundfish fisheries are available from 1991/92 to present. Between 1991 and December 2001, bycatch was estimated using the "blend method". From January 2003 to December 2007, bycatch was estimated using the Catch Accounting System (CAS), based on substantially different methods than the "blend". Starting in January 2008, the groundfish observer program changed the method in which they speciate crab to better reflect their hierarchal sampling method and to account for broken crab that in the past were only identified to genus. In addition, the haul-level weights collected by observers were used to estimate the crab weights through CAS instead of applying an annual (global) weight factor to convert numbers to biomass. Spatial resolution was at the NMFS statistical area. Beginning in January 2009, ADF&G statistical areas (1^{o} longitude x 0.5^{o} latitude) were included in groundfish production reports and allowed an increase in the spatial resolution of bycatch estimates from the NMFS statistical areas to the state statistical areas. Bycatch estimates (2009-present) based on the state statistical areas were first provided in the 2013 assessment, and improved methods for aggregating observer data were used in 2014 (see Stockhausen, 2014). The estimates obtained this year are based on the same methods as those used in 2014.

To assess crab mortalities in the groundfish fisheries, an 80% handling mortality rate was applied to estimates of bycatch in trawl fisheries and a 50% handling mortality rate was applied to fisheries using pot and hook and line gear (Table 2, 3).

In 20114/15, as in 2013/14, bycatch of Pribilof Islands blue king crab occurred almost exclusively in fisheries targeting Pacific cod (*Gadus macrocephalus*; 99.4% by weight, Table 3). In 2012/13, fisheries targeting Pacific cod accounted for 20% of the bycatch while those targeting yellowfin sole (*Limanda aspera*) accounted for 77.2%. The flathead sole (*Hippoglossoides elasodon*) fishery also accounted for a substantial fraction of the bycatch in 2010/11 (59%).

Since the 2009/10 crab fishing season, Pribilof Islands blue king crab have been taken as bycatch in the groundfish fisheries only by hook and line and non-pelagic trawl gear (Table 4). In 2013/14 and 2014/15, hook and line gear accounted for the total bycatch of Pribilof Islands blue king crab. In the previous year, it accounted for only 20% of the bycatch (by weight), whereas non-pelagic trawl gear accounted for 80%. Although this appears to be a large change, the actual bycatch amounts involved are small and interannual variability is consequently expected to be rather high.

c. Catch-at-length: NA

d. Survey biomass:

The 2015 NMFS EBS bottom trawl survey was conducted between May and August of this year. Survey results for PIBKC are based on the stock area first defined in the 2013 assessment (Foy, 2013), which includes the Pribilof District (Fig. 2) and a 20 nm strip adjacent to the eastern edge of the District (not shown in Fig. 2). This new area was defined as a result of the new rebuilding plan and the concern that crab outside the Pribilof District were not being accounted for in the assessment.

In 2015, the survey caught 28 blue king crab in 86 tows/stations across the stock area (Table 5a). Out of the 86 tows, immature males were caught in 2, mature males were caught in 8, immature females were caught in none, and mature females were caught in 4. In 2014, the survey caught only 15 crab in 86 tows across the stock area (Table 5b). Of the crab caught in 2015, 17 were male (4 immature, 13 mature, and 7 legal-sized) while 11 were female (all mature). Swept-area estimates of abundance in the stock area at the time of the 2015 survey, with 95% normal confidence intervals, were 234,000 (± 168,000) mature males, 76,000 (± 113,000) immature males, 125,000 (± 109,000) legal-sized males, 202,000 (± 260,000) mature females, and 0 immature females. Swept-area estimates of biomass were 622 t (± 480 t) for mature males, 82 t (±120 t) for immature males, 428 t (± 325 t) for legal-sized males, 160 t (± 207 t) for mature females, and 0 t for immature females.

The 2015 estimates of survey biomass represent seemingly large increases relative to the 2014 estimates for mature males (166%), legal males (83%), and mature females (76%), while immature males decreased slightly (1%) and immature females decreased substantially (100%, but this results from one less immature female being caught in 2015 than in 2014). However, given the large confidence intervals associated with these estimates, none of the changes are statistically significant. To better determine temporal trends, it is necessary to consider the entire survey time series.

During the two past years, and involving considerable effort, the set of stations and hauls constituting the "standard" dataset for calculating crab-related trends in abundance, biomass and size compositions from the annual NMFS EBS bottom trawl survey was redefined for each crab stock to improve sampling design and consistency across the 40-plus year dataset (R. Foy, verbal report to the CPT, May 2015). The "old" dataset included stations with multiple hauls associated with special projects and "re-tows", as well as somewhat inconsistent strata definitions across the time series. The new dataset consists of a single haul per station and strata definitions are temporally consistent. In conjunction with this effort, the size-weight regressions used to convert crab abundance to biomass were also revised. As such, new survey biomass and abundance time series have been calculated from the 1975-2015 annual survey results and incorporated into this assessment (Table 7, Fig. 5). For comparison purposes, survey time series based on the "old" survey dataset have also been updated with the results of the 2015 bottom trawl survey (Table 6, Fig.s 6-9).

While the new and old time series exhibit some large differences in the earliest part of the time series (e.g., prior to 1985), they show substantial agreement in the latter part of the time series (e.g., post-1985), although some differences are still apparent (Fig.s 6-9). In both time series, the mature portion of the population was highest in the late 1970's and early 1980's, declined in the mid-1980's into the early 1990's, recovered somewhat in the mid-1990's, then declined again through the 2000's to the present. The uncertainties associated with individual estimates are quite large, due to the patchiness of the stock, and trends can be more easily discerned by smoothing the time series in some fashion (Table 8, Fig. 10). The smoothed time series suggest that the stock reached its minimum size during the 2003-2009 period (~100-200 t) and may have increased slightly since then (to ~300 t).

Size frequencies for males by shell condition from the 3 most recent surveys (2013-2015) are illustrated in Figure 11. Size frequencies for all males across the time series are shown in Fig. 12 for both the new time series and the old time series. Fig. 11 suggests a recent trend toward larger sizes, with little evidence for recruitment in 2014 or 2015. However, given the sampling error associated with this stock, it is hard to draw any firm conclusions regarding such a trend.

Size frequencies for females by shell condition are presented in Fig. 13 for the 3 most recent surveys (2013-2015). Size frequencies for all females are shown in Fig. 14, contrasting the new and old time series.

Spatial patterns found in the 2015 survey are contrasted with those from the 2014 and 2013 surveys in Figures 15 and 16.

E. Analytic Approach

1. *History of modeling approaches*

   A catch survey analysis has been used for assessing the stock in the past, although it is not currently in use. In October 2013, the SSC concurred with the CPT that the PIBKC stock falls under Tier 4 for status determination but it recommended that the OFL be calculated using a Tier 5 approach, with ABC based on a 10% buffer.

   In the previous two assessments (Foy, 2013; Stockhausen, 2014), "current" MMB-at-mating has been 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. This approach was also followed in this assessment. An alternative approach to smoothing based on a Random Effects/Kalman Filter model (see Appendix A) is also presented.

2. *Model Description: Not applicable.*
3. *Model Selection and Evaluation: Not applicable*
4. *Results: Not applicable*

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 2008).

   In Tier 4, stock status is based on the ratio of "current" spawning stock biomass (B) to B_{MSY} (or a proxy thereof, B_{MSY}^{proxy}, also referred to as B_{REF}). MSY (maximum sustained yield) is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions. The fishing mortality that, if applied over the long-term, would result in MSY is F_{MSY}. B_{MSY} is the long-term average stock size when fished at F_{MSY}, and is based on mature male biomass at the time of mating (MMB_{mating}), which serves as an approximation for egg production. MMB_{mating} is used as a basis for B_{MSY} because of the complicated female crab life history, unknown sex ratios, and male only fishery. Although B_{MSY} cannot be calculated for a Tier 4 stock, a proxy value (B_{MSY}^{proyx} or B_{REF}) is defined as the average biomass over a specified time period that satisfies the conditions under which B_{MSY} would occur (i.e., equilibrium biomass yielding MSY under an applied F_{MSY}).

   The time period for establishing B_{MSY}^{proxy} is assumed to be representative of the stock being fished at an average rate near F_{MSY} and fluctuating around B_{MSY}. The SSC has endorsed using the time periods 1980-84 and 1990-97 to calculate B_{MSY}^{proxy} for Pribilof Islands blue king crab to avoid time periods of low abundance possibly caused by high fishing pressure. Alternative time periods (e.g., 1975 to 1979) have also been considered but rejected (Foy, 2013). Considerations for choosing the current time periods included:

   A. Production potential

      1) Between 2006 and 2013 the stock does appears to be below a threshold for responding to increased production based on the lack of response of the adult stock biomass to slight fluctuations in recruitment (male crab 120-134 mm) (Figure 20).
      2) An estimate of surplus production (ASP = $\mathrm{MMB}_{t+1} - \mathrm{MMB}_t$ + total catch_t) suggested that only meaningful surplus existed 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 and 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 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 $F_{\mathrm{MSY}}^{proxy} = M$ is 0.18, so time periods with greater exploitation rates should not be considered to represent a period with an average rate of fishery removals.

C. Subsequent to increases in exploitation rates in the late 1980s and 1990s, the quantity ln(recruits/MMB) dropped, suggesting that exploitation rates at the levels of $F_{\mathrm{MSY}}^{proxy} = M$ were not sustainable.

Thus, MMB_{mating} is the basis for calculating B_{MSY}^{proxy}. The formulas used to calculate MMB_{mating} from MMB at the time of the survey (MMB_{survey}) are documented in Appendix A. For this stock, B_{MSY}^{proxy} was calculated using “raw” (unsmoothed) estimates for MMB_{survey} from the new survey time series in the formula for MMB_{mating}. B_{MSY}^{proxy} is the average of MMB_{mating} for the years 1980-84 and 1990-97 (see Table 7) and was calculated as 5,012 t.

In this assessment, “current *B*” is the MMB_{mating} projected for 2015/16. Details of this calculation are provided in Appendix A. For 2015/16, current B = 318 t.

Overfishing is defined as any amount of fishing in excess of a maximum allowable rate, F_{OFL}, which would result in a total catch greater than the OFL. For Tier 4 stocks, a minimum stock size threshold (MSST) is specified as 0.5 B_{MSY}^{proxy} and if current B drops below the MSST, the stock is considered to be overfished.

2. *List of parameter and stock sizes:*

- B_{MSY}^{proxy} (B_{REF}) = 5,012 t
- M = 0.18 yr^{-1}
- Current B = 318 t

3. *OFL specification:*

a. In the Tier 4 OFL-setting approach, the “total catch OFL” and the “retained catch OFL” are calculated by applying the F_{OFL} to all crab at the time of the fishery (total catch OFL) or to the mean retained catch determined for a specified period of time (retained catch OFL).

The Tier 4 F_{OFL} is derived using the F_{OFL} Control Rule (Figure 17), where the Stock Status Level (level a, b or c; equations 4-6) is based on the relationship of current B to B_{MSY}^{proxy}:

Stock Status Level:	F_{OFL}:	
a. $B/B_{\mathrm{MSY}}^{\mathrm{prox}} > 1.0$	$F_{\mathrm{OFL}} = \gamma \cdot M$	(4)
b. $\beta < B/B_{\mathrm{MSY}}^{\mathrm{prox}} \leq 1.0$	$F_{\mathrm{OFL}} = \gamma \cdot M\,[(B/B_{\mathrm{MSY}}^{\mathrm{prox}} - \alpha)/(1 - \alpha)]$	(5)

c. $B/B_{\mathrm{MSY}}^{\mathrm{prox}} \leq \beta$ $F_{\mathrm{directed}} = 0;\ F_{\mathrm{OFL}} \leq F_{\mathrm{MSY}}$ (6)

When $B/B_{\mathrm{MSY}}^{\mathrm{proxy}}$ 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 $B/B_{\mathrm{MSY}}^{\mathrm{proxy}}$ 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 2008).

b. The basis for projecting MMB from the survey to the time of mating is discussed in detail in Appendix A.

c. Specification of F_{OFL}, OFL and other applicable measures:

The following tables are based on the new survey time series.

All weights in t.

Year	Tier	B_{MSY}	Current $\mathrm{MMB}_{\mathrm{mating}}$	B/B_{MSY} ($\mathrm{MMB}_{\mathrm{mating}}$)	γ	Years to define B_{MSY}	Natural Mortality	P*
2011/12	4c	4,209	365	0.09	1	1975/76-1984/85 &1990/91-1997/98	0.18	10% buffer
2012/13	4c	4,494	496	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	3,988	278	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	4,002	218	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2015/16	4c	5,012	318	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

All weights in million lbs.

Year	Tier	B_{MSY}	Current $\mathrm{MMB}_{\mathrm{mating}}$	B/B_{MSY} ($\mathrm{MMB}_{\mathrm{mating}}$)	γ	Years to define B_{MSY}	Natural Mortality	P*
2011/12	4c	9.28	0.80	0.09	1	1975/76-1984/85 &1990/91-1997/98	0.18	10% buffer
2012/13	4c	9.91	1.09	0.11	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2013/14	4c	8.79	0.61	0.07	1	1980/81-1984/85 &1990/91-1997/98	0.18	10% buffer
2014/15	4c	8.82	0.48	0.05	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer
2015/16	4c	11.05	0.70	0.06	1	1980/81-1984/85 &1990/91-1997/98	0.18	25% buffer

4. *Specification of the retained catch portion of the total catch OFL:*

   a. The retained portion of the catch for this stock is zero (0 t).

5. *Recommendations:*

For 2015/2016, B_{MSY}^{proxy} *= 5,012 t, derived as the mean* MMB_{mating} *from 1980 to 1984 and 1990 to 1997 using the new 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 2015/16 was estimated at 318 t for B_{MSY}^{proxy}. The B/B_{MSY}^{proxy} ratio corresponding to the biomass reference is 0.06. B/B_{MSY}^{proxy} is < β, therefore the ***stock status level is c, $F_{directed}$ = 0, and $F_{OFL} \leq F_{MSY}$*** (as determined in the Pribilof Islands District blue king crab rebuilding plan). Total catch OFL calculations were explored in 2008 to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality (NPFMC 2008). 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 2015/16, 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 $\sigma_{\text{total}} = \sqrt{\sigma_b^2 + \sigma_w^2}$. For the PIBKC stock, the CPT has recommended, and the SSC has approved, using a constant buffer of 25% is applied 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 0.70 and has ranged between 0.17 and 0.80 since the 1980 peak in biomass.

3. *List of additional uncertainties considered for alternative σ_b applications to the ABC.*

Several sources of uncertainty are not included in the measures of uncertainty reported as part of the stock assessment:

- Survey catchability and natural mortality uncertainties are not estimated but rather are pre-specified.

- F_{MSY} is assumed to be equal to γM when applying the OFL control rule, where the proportionality constant γ is assumed to be equal to 1 and M is assumed to be known.

- The coefficients of variation for the survey estimates of abundance for this stock are very high.

- B_{MSY} is assumed to be equivalent to average mature male biomass. However, stock biomass has fluctuated greatly and targeted fisheries only occurred from 1973-1987 and 1995-1998 so considerable uncertainty exists with this estimate of B_{MSY}.

4. *Recommendations:*

For 2015/2016, $F_{directed} = 0$ and the total catch OFL is based on catch biomass would maintain the conservation needs with this stock and acknowledge the existing non-directed catch mortality. In this case, the ***ABC_{max}* based on a 25% buffer of the average catch between 1999/2000 and 2005/2006 would be 0.87 t.**

All units are tons of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2011/12	2,247 ^{A}	365 ^{A}	0	0	0.36	1.16	1.04
2012/13	1,994 ^{A}	579 ^{A}	0	0	0.61	1.16	1.04
2013/14	2,001 ^{A}	225 ^{A}	0	0	0.03	1.16	1.04
2014/15	2,506 ^{A}	320 ^{A}	0	0	0.07	1.16	0.87
2015/16	--	318 ^{B}	--	--	--	1.16	0.87

All units are million pounds of crab and the OFL is a total catch OFL for each year:

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch Mortality	OFL	ABC
2011/12	4.95 ^{A}	0.80 ^{A}	0	0	0.0008	0.003	0.002
2012/13	4.39 ^{A}	1.09 ^{A}	0	0	0.0013	0.003	0.002
2013/14	4.41 ^{A}	0.50 ^{A}	0	0	0.0001	0.003	0.002
2014/15	5.52 ^{A}	0.71 ^{A}	0	0	0.0002	0.003	0.002
2015/16	--	0.70 ^{B}	--	--	--	0.003	0.002

Notes:
A – Based on data available to the Crab Plan Team at the time of the assessment following the end of the crab fishing year.
B – Based on data available to the Crab Plan Team at the time of the assessment for the crab fishing year.

H. Rebuilding Analyses

Rebuilding analyses results summary: A revised rebuilding plan analysis was submitted to the 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 will protect the main concentration of the stock from the fishery with the highest observed rates of bycatch (NPFMC, 2014a). The area has been closed to trawling since 1995.

I. Data Gaps and Research Priorities

Given the large CVs associated with the survey abundance and biomass estimates for the Pribilof Islands blue king crab stock, assessment of this species might benefit from additional surveys using alternative gear at finer spatial resolution. Further data gaps include a lack of understanding regarding processes apparently preventing successful recruitment to the Pribilof District.

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Figure 16. Size class distribution of blue king crab in the Pribilof District during the 2013 (upper), 2014 (center), and 2015 (lower) EBS bottom trawl surveys.

Figure 17. 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).

Tables

Table 1. Total retained catches from directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2011; D. Pengilly, ADF&G, personal communications).

Year	Retained Catch		Avg. CPUE
	Abundance	Biomass (t)	legal crabs/pot
1973/1974	174,420	579	26
1974/1975	908,072	3224	20
1975/1976	314,931	1104	19
1976/1977	855,505	2999	12
1977/1978	807,092	2929	8
1978/1979	797,364	2901	8
1979/1980	815,557	2719	10
1980/1981	1,497,101	4976	9
1981/1982	1,202,499	4119	7
1982/1983	587,908	1998	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 - 2014/2015	0	0	--

Table 2. Total non-retained catch (bycatch/discard) mortalities from directed and non-directed fisheries for Pribilof Islands District blue king crab. Handling mortalities (pot and hook/line= 0.5, trawl = 0.8) were applied to estimates of non-retained catch based on observer data in the crab and groundfish fisheries. Crab bycatch data is not available prior to 1996/1997 (Bowers et al. 2011; D. Pengilly ADF&G). Gear-specific groundfish fishery data is not available prior to 1991/1992 (J. Mondragon, NMFS).

Year	Crab pot fisheries			Groundfish fisheries	
	Non-retained legal male (t)	Sublegal male (t)	Female (t)	Fixed gear (t)	Trawl gear (t)
1991/1992	NA	NA	NA	0.03	4.96
1992/1993	NA	NA	NA	0.44	48.63
1993/1994	NA	NA	NA	0.00	27.39
1994/1995	NA	NA	NA	0.02	5.48
1995/1996	NA	NA	NA	0.05	1.03
1996/1997	0	0.4	0	0.02	0.05
1997/1998	0	0	0	0.73	0.10
1998/1999	1.15	0.23	1.86	9.90	0.06
1999/2000	1.75	2.15	0.99	0.40	0.02
2000/2001	0	0	0	0.06	0.02
2001/2002	0	0	0	0.42	0.02
2002/2003	0	0	0	0.04	0.24
2003/2004	0	0	0	0.17	0.18
2004/2005	0	0	0	0.41	0.00
2005/2006	0	0	--	0.18	1.07
2006/2007	0	0	--	0.07	0.06
2007/2008	0	0	--	2.00	0.11
2008/2009	0	0	--	0.07	0.38
2009/2010	0	0	--	0.11	0.17
2010/2011	0	0.09	--	0.02	0.05
2011/2012	0	0	--	0.06	0.01
2012/2013	0	0	0	0.08	0.54
2013/2014	0	0	0	0.03	0.00
2014/2015	0	0	0	0.07	0.00

Table 3. Proportion by weight of the Pribilof Islands blue king crab bycatch in the groundfish fisheries among trip targets For the 2003/2004-2008/2009 crab fishing seasons, these were calculated using bycatch from NMFS Statistical Area 513. For 2009/10-2014/15, these were calculated using the AKRO Catch Accounting System, with data reported from State of Alaska statistical areas that encompass the Pribilof Islands Blue King Crab District. Groundfish fishery target species that caught blue king crab but made up less than 1% of the blue king crab bycatch across all years are not shown in the table. These include pollock-bottom trawl, pollock-midwater trawl, halibut, Greenland turbot, and arrowtooth flounder.

Crab Fishery Year	% bycatch (biomass) by trip target					total bycatch (# crabs)
	yellowfin sole %	Pacific cod %	flathead sole %	rocksole %	sablefish %	
2003/2004	47.0	22.0	31.0	< 1	< 1	252
2004/2005	< 1	100.0	< 1	< 1	< 1	259
2005/2006	< 1	97.0	3.0	< 1	< 1	757
2006/2007	54.0	20.0	< 1	26.0	< 1	96
2007/2008	3.0	96.0	1.0	< 1	< 1	2,950
2008/2009	77.0	23.0	< 1	< 1	< 1	295
2009/2010	30.5	51.1	16.8	< 1	< 1	281
2010/2011	< 1	38.5	59.0	< 1	< 1	48
2011/2012	< 1	99.8	< 1	< 1	< 1	62
2012/2013	77.2	20.0	2.9	< 1	< 1	410
2013/2014	< 1	99.4	< 1	< 1	< 1	39
2014/2015	< 1	99.4	< 1	< 1	< 1	64

Table 4. Proportion by weight of the Pribilof Islands blue king crab bycatch in the groundfish fisheries among gear types. For the 2003/2004-2008/2009 crab fishing seasons, these were calculated using bycatch from NMFS Statistical Area 513. For 2009/10-2014/15, these were calculated using the AKRO Catch Accounting System, with data reported from State of Alaska statistical areas that encompass the Pribilof Islands Blue King Crab District.

Crab Fishery Year	% bycatch (biomass) by gear type				total bycatch (# crabs)
	hook and line %	non-pelagic trawl %	pot %	pelagic trawl %	
2003/04	21	79	0	0	252
2004/05	99	1	0	0	259
2005/06	18	3	79	0	757
2006/07	20	20	0	0	96
2007/08	1	3	95	0	2,950
2008/09	23	77	0	0	295
2009/10	7	49	44	0	281
2010/11	41	59	0	0	48
2011/12	94	6	0	0	62
2012/13	20	80	0	0	410
2013/14	100	0	0	0	39
2014/15	100	0	0	0	64

Table 5. Summaries of the a) 2015 and b) 2014 NMFS annual EBS bottom trawl surveys for Pribilof Islands District blue king crab by stock component.

a) 2015 survey results.

Stock Component	Number of tows in District	Tows with crab	Number of crab measured	Number of crab caught	Abundance (millions)		Biomass (mt)	
					estimate	95% CI	estimate	95% CI
Immature male	86	2	4	4	0.076	0.113	82	120
Mature male	86	8	13	13	0.234	0.168	622	480
Legal male	86	5	7	7	0.125	0.109	428	385
Immature female	86	0	0	0	0.000	0.000	0	0
Mature female	86	4	11	11	0.202	0.260	160	207

b) 2014 survey results.

Stock Component	Number of tows in District	Tows with crab	Number of crab measured	Number of crab caught	Abundance (millions)		Biomass (mt)	
					estimate	95% CI	estimate	95% CI
Immature male	86	3	5	5	0.091	0.105	83	102
Mature male	86	2	5	5	0.092	0.128	233	320
Legal male	86	2	5	5	0.092	0.128	233	320
Immature female	86	1	1	1	0.028	0.054	16	32
Mature female	86	3	4	4	0.074	0.088	91	108

Table 6. Time series for Pribilof Islands blue king crab abundance and biomass based on the old standardization for the NMFS annual EBS bottom trawl survey.

Year	@ time of survey					@ mating time
	Mature male abundance	Mature male biomass (t)	Legal male biomass (t)	Total male biomass (t)	Total female biomass (t)	Mature male biomass (t)
1975/76	14,955,818	33,862	24,037	41,292	12,172	29,449
1976/77	3,568,103	9,573	8,585	13,333	5,770	5,795
1977/78	13,043,983	38,756	36,706	42,137	13,573	32,133
1978/79	6,140,638	15,798	12,291	18,315	6,492	11,489
1979/80	5,232,918	12,974	10,843	14,275	4,097	9,118
1980/81	5,432,065	14,253	12,163	16,050	63,713	8,146
1981/82	3,921,734	10,744	9,686	13,014	9,911	5,794
1982/83	2,344,203	6,691	6,241	7,740	9,376	4,140
1983/84	1,851,301	4,919	4,069	5,795	10,248	3,493
1984/85	674,376	1,761	1,446	1,860	2,580	1,453
1985/86	428,076	959	687	995	523	637
1986/87	480,198	1,368	1,340	1,372	2,431	1,121
1987/88	903,180	2,659	2,529	2,833	913	2,095
1988/89	237,868	766	766	921	717	690
1989/90	239,948	752	752	1,914	1,745	677
1990/91	1,738,237	3,259	1,549	5,376	3,811	2,934
1991/92	2,014,086	4,266	3,025	5,521	2,776	3,838
1992/93	1,935,278	3,995	2,761	5,635	2,649	3,574
1993/94	1,875,500	4,144	2,913	5,136	2,092	3,718
1994/95	1,263,447	3,028	2,491	3,578	4,858	2,724
1995/96	3,139,328	7,753	6,365	8,616	4,844	6,390
1996/97	1,712,015	4,221	3,522	4,899	5,585	3,399
1997/98	1,201,296	2,940	2,515	3,288	3,028	2,429
1998/99	967,097	2,545	2,283	3,175	2,182	2,063
1999/00	617,258	1,573	1,297	1,719	2,868	1,414
2000/01	725,050	1,902	1,588	2,005	1,462	1,712
2001/02	522,239	1,454	1,329	1,533	1,817	1,309
2002/03	225,476	618	588	618	1,401	556
2003/04	228,897	638	610	656	1,307	574
2004/05	47,905	97	44	130	123	87
2005/06	91,932	313	313	610	847	281
2006/07	50,638	137	115	210	558	123
2007/08	100,295	254	170	417	257	228
2008/09	18,256	42	42	235	672	38
2009/10	248,626	452	170	684	625	407
2010/11	138,787	322	202	420	440	290
2011/12	165,525	461	399	461	37	415
2012/13	272,233	644	459	809	237	580
2013/14	104,361	250	190	265	166	225
2014/15	91,856	233	233	317	108	210
2015/16	233,630	622	428	703	160	--

Table 7. Time series for Pribilof Islands blue king crab abundance and biomass based on the new standardization for the NMFS annual EBS bottom trawl survey.

Year	@ time of survey					@ mating time
	Mature male abundance	Mature male biomass (t)	Legal male biomass (t)	Total male biomass (t)	Total female biomass (t)	Mature male biomass (t)
1975/76	15,288,169	38,054	27,016	46,395	12,442	33,223
1976/77	4,782,105	14,059	12,649	18,188	5,792	9,834
1977/78	13,043,983	42,618	40,366	46,332	13,572	35,611
1978/79	6,140,638	17,370	13,517	20,135	6,492	12,904
1979/80	4,107,868	10,959	9,040	11,021	1,189	7,304
1980/81	7,842,342	23,553	20,679	25,637	212,303	16,519
1981/82	3,834,431	11,628	10,554	13,332	6,484	6,590
1982/83	2,353,813	7,389	6,893	8,541	9,377	4,769
1983/84	1,851,301	5,409	4,474	6,371	10,248	3,934
1984/85	770,643	2,216	1,824	2,345	3,085	1,862
1985/86	428,076	1,055	756	1,094	525	723
1986/87	480,198	1,505	1,473	1,508	2,431	1,244
1987/88	903,180	2,923	2,781	3,115	913	2,333
1988/89	237,868	842	842	1,012	718	758
1989/90	239,948	828	828	2,102	1,746	745
1990/91	1,470,419	3,078	1,514	5,082	2,929	2,771
1991/92	2,014,086	4,690	3,326	6,067	2,776	4,220
1992/93	1,935,278	4,391	3,035	6,192	2,649	3,930
1993/94	1,875,500	4,556	3,203	5,644	2,092	4,089
1994/95	1,294,263	3,410	2,806	4,029	4,893	3,068
1995/96	3,101,712	8,360	6,787	9,328	4,279	6,937
1996/97	1,712,015	4,641	3,873	5,386	5,585	3,776
1997/98	1,201,296	3,233	2,765	3,614	3,028	2,692
1998/99	967,098	2,798	2,510	3,490	2,182	2,291
1999/00	617,258	1,729	1,426	1,890	2,868	1,555
2000/01	725,051	2,091	1,746	2,205	1,462	1,883
2001/02	522,239	1,599	1,461	1,686	1,817	1,439
2002/03	225,476	680	647	680	1,401	612
2003/04	228,897	702	671	721	1,307	632
2004/05	47,905	107	48	143	123	96
2005/06	91,932	344	344	670	847	309
2006/07	55,579	166	139	253	576	149
2007/08	110,080	306	206	503	282	275
2008/09	18,256	46	46	258	672	41
2009/10	248,626	497	187	751	625	447
2010/11	130,465	303	190	395	394	273
2011/12	165,525	461	399	461	37	415
2012/13	272,233	644	459	809	237	579
2013/14	104,361	250	190	265	166	225
2014/15	91,856	233	233	317	108	210
2015/16	233,630	622	428	703	160	--

Table 8. Estimates of mature male biomass (MMB) at the time of mating for Pribilof Islands blue king crab using three methods for smoothing MMB at the time of the survey to reduce estimation error: 1) Unaveraged (no smoothing); 2) smoothing using a three-year centered Inverse Variance Average, and 3) , smoothing using a Random Effects Model.

year	Unaveraged (t)		Inverse-Variance Averaging (t)		Random Effects Model (t)	
	old time series	new time series	old time series	new time series	old time series	new time series
1975/76	29,449	33,223	--	--	18,718	23,196
1976/77	5,795	9,834	7,317	12,755	10,656	15,114
1977/78	32,133	35,611	7,142	11,425	13,440	16,395
1978/79	11,489	12,904	9,522	8,057	11,344	12,551
1979/80	9,118	7,304	9,732	8,956	9,581	9,435
1980/81	8,146	16,519	5,776	5,944	7,089	9,372
1981/82	5,794	6,590	3,652	4,158	5,507	6,407
1982/83	4,140	4,769	3,711	4,228	4,189	4,822
1983/84	3,493	3,934	1,448	2,068	3,173	3,640
1984/85	1,453	1,862	1,133	1,289	1,617	1,980
1985/86	637	723	881	1,005	858	988
1986/87	1,121	1,244	912	1,010	1,158	1,289
1987/88	2,095	2,333	753	854	1,293	1,437
1988/89	690	758	813	892	1,192	1,284
1989/90	677	745	794	819	1,377	1,438
1990/91	2,934	2,771	1,127	1,140	2,391	2,343
1991/92	3,838	4,220	3,382	3,653	3,239	3,431
1992/93	3,574	3,930	3,702	4,073	3,447	3,742
1993/94	3,718	4,089	3,209	3,571	3,544	3,885
1994/95	2,724	3,068	3,272	3,619	3,289	3,614
1995/96	6,390	6,937	2,759	3,112	3,607	3,862
1996/97	3,399	3,776	2,738	3,023	3,218	3,547
1997/98	2,429	2,692	2,431	2,695	2,508	2,773
1998/99	2,063	2,291	1,723	1,916	1,989	2,208
1999/00	1,414	1,555	1,754	1,926	1,617	1,777
2000/01	1,712	1,883	1,525	1,679	1,503	1,654
2001/02	1,309	1,439	857	945	1,036	1,139
2002/03	556	612	592	651	641	706
2003/04	574	632	123	136	447	494
2004/05	87	96	120	132	224	250
2005/06	281	309	106	119	212	239
2006/07	123	149	153	185	176	202
2007/08	228	275	60	65	181	206
2008/09	38	41	51	56	173	189
2009/10	407	447	62	70	252	266
2010/11	290	273	322	308	292	291
2011/12	415	415	327	310	342	341
2012/13	580	579	303	303	371	371
2013/14	225	225	240	240	331	331
2014/15	210	210	288	288	344	344
2015/16	--	--	--	--	--	--

Figures

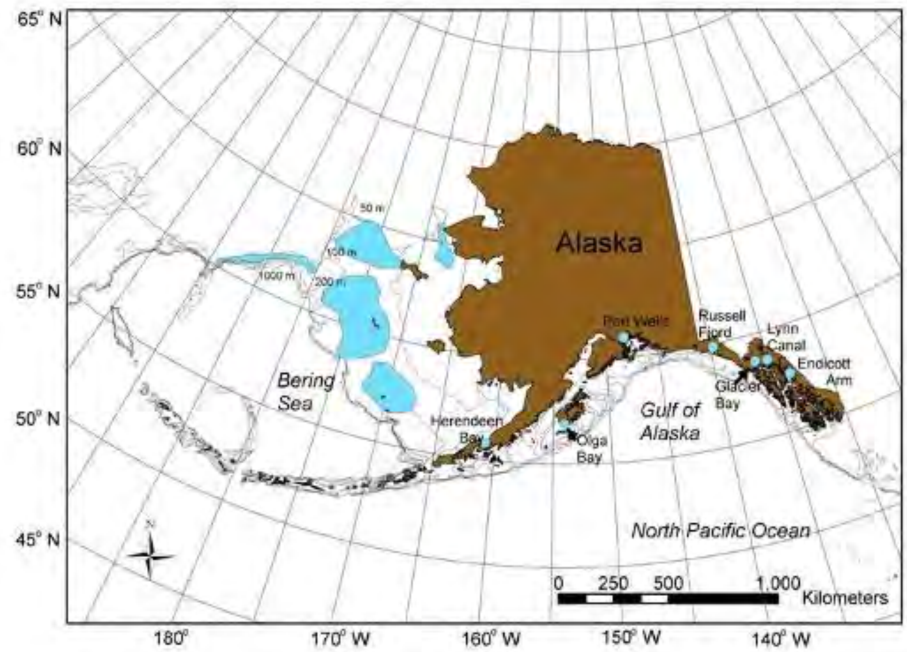


Figure 1. Distribution of blue king crab (*Paralithodes platypus*) in Alaskan waters.

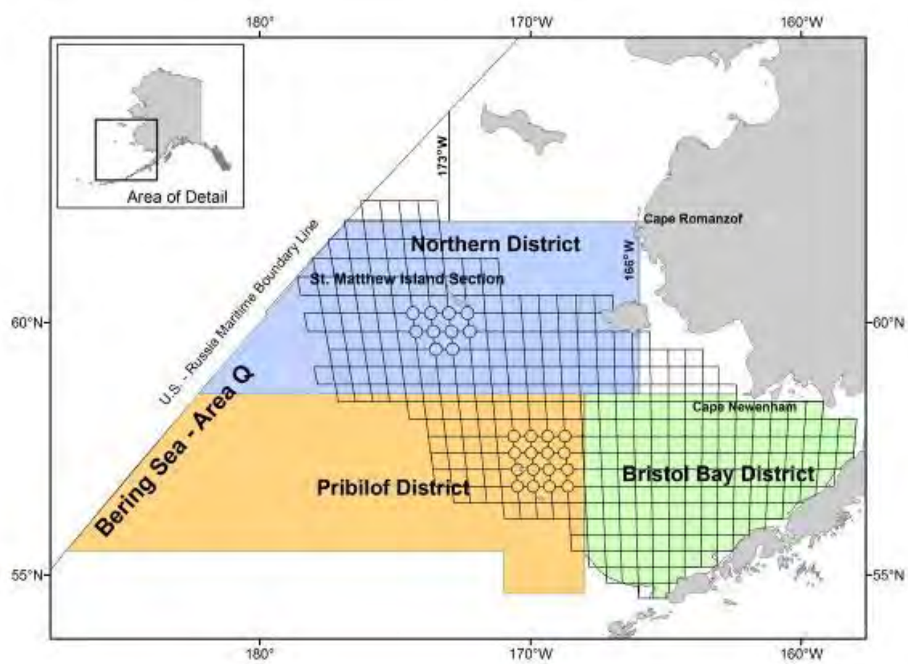


Figure 2. King crab Registration Area Q (Bering Sea) showing the Pribilof District. This figure does not show the additional 20 nm strip considered starting in 2013 year for biomass and catch data in the Pribilof District.

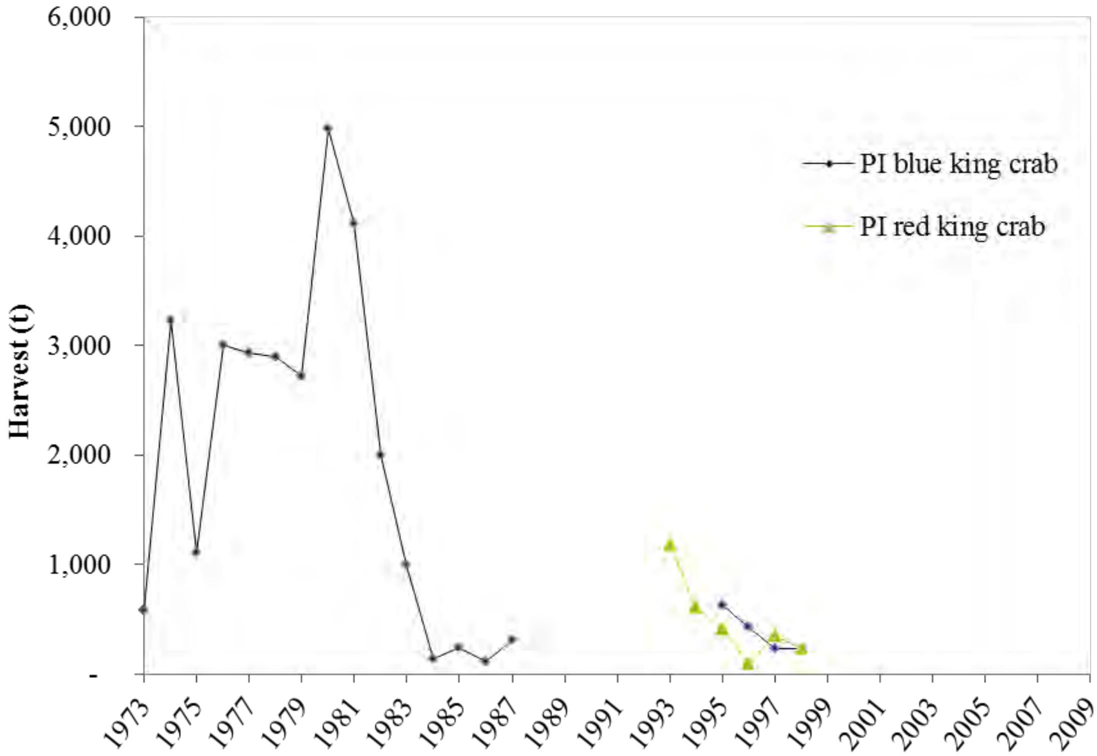


Figure 3. Historical harvests (t) and GHLs for Pribilof Island blue and red king crab (Bowers et al. 2011).

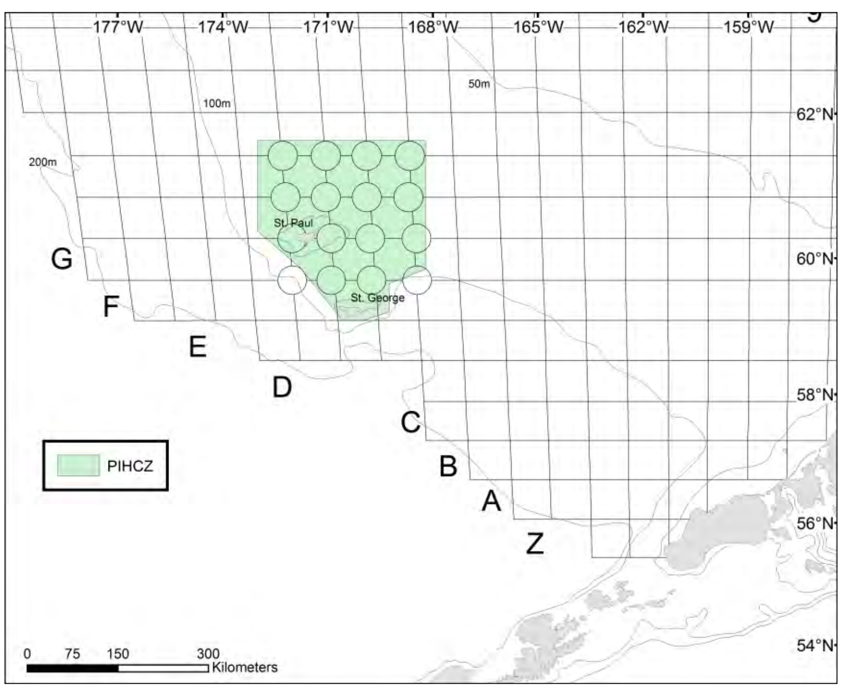
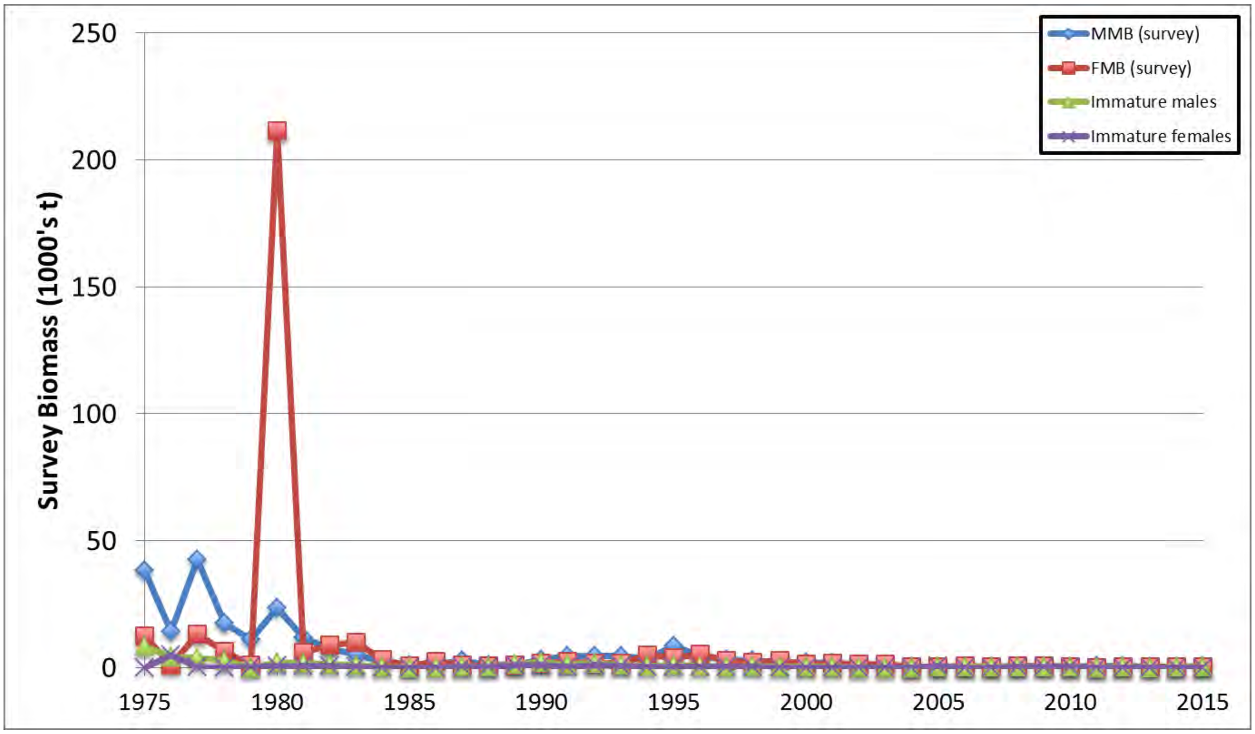


Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation Zone (PIHCZ). Trawl fishing is prohibited year-round in this zone (as of 1995), as is pot fishing for Pacific cod (as of 2015). Also shown is a portion of the NMFS annual EBS bottom trawl survey grid.



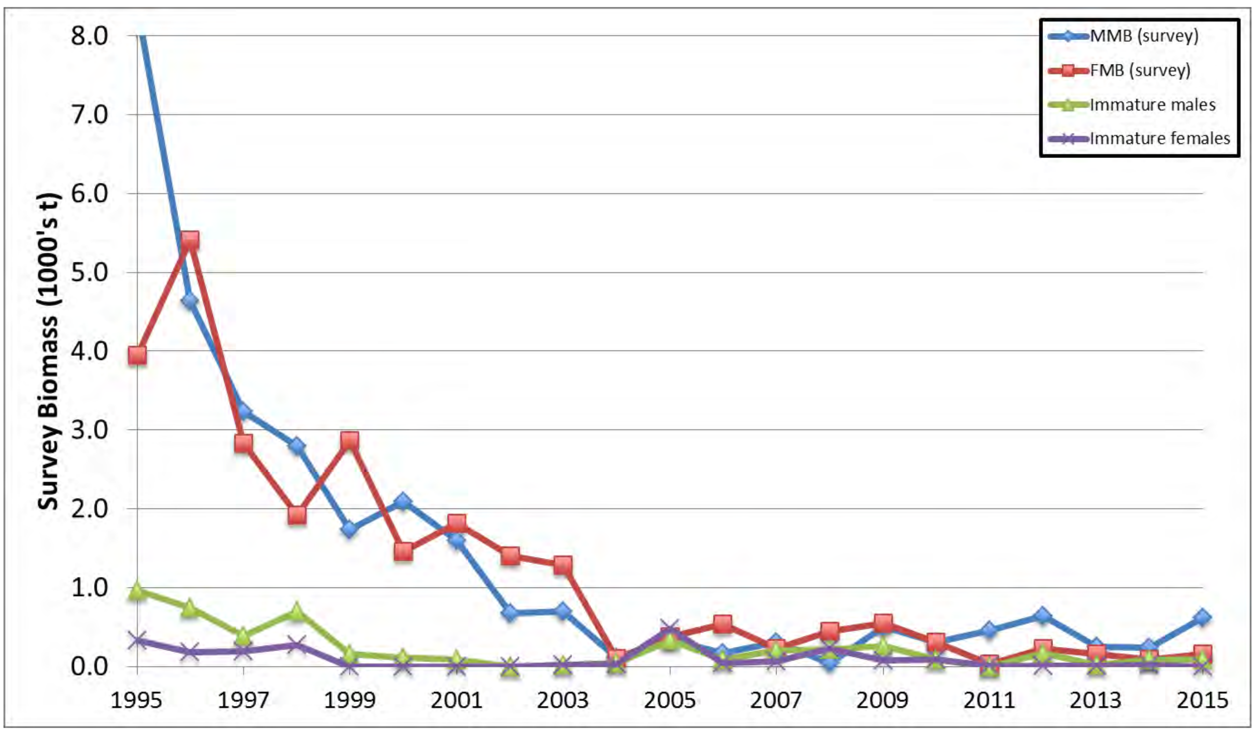
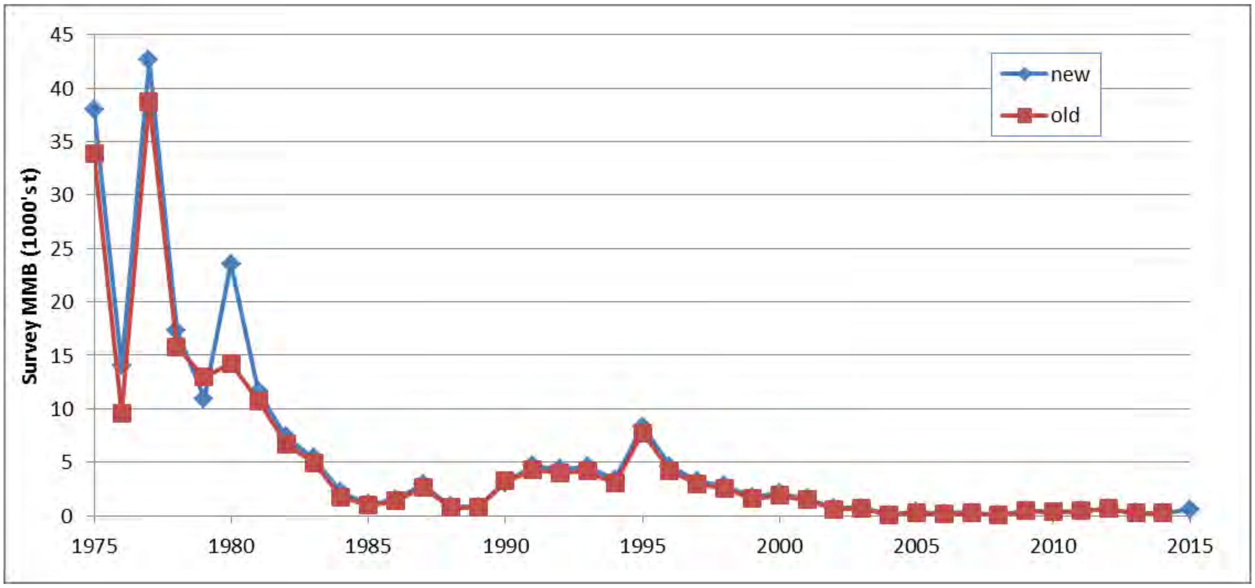


Figure 5. Time series for various stock components of Pribilof Islands blue king crab estimated using the new standardization for the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2015. Lower graph: 2000-2015.



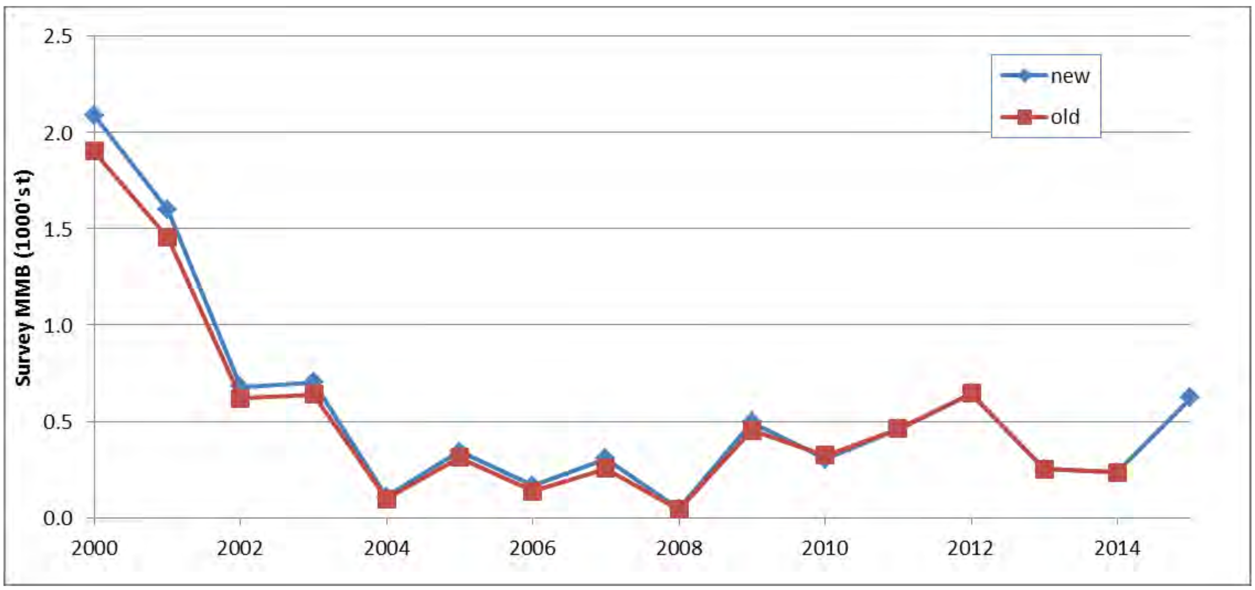


Figure 6. Comparison of time series for survey mature male biomass (MMB) estimated using the new and old standardizations for the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2015. Lower graph: 2000-2015. New standardization in blue, old standardization in red.

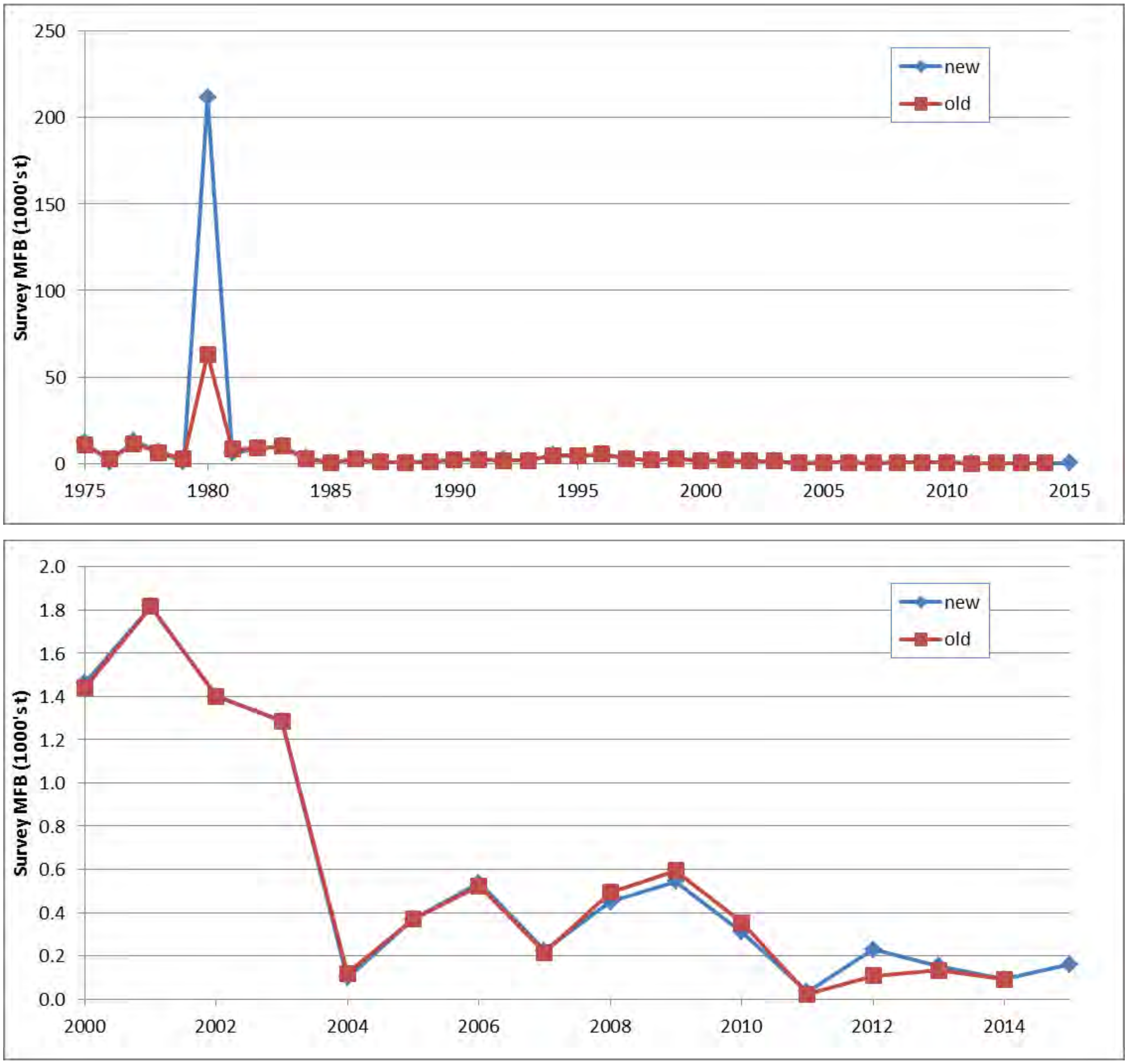


Figure 7. Comparison of time series for survey maturefe male biomass (MFB) estimated using the new and old standardizations for the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2015. Lower graph: 2000-2015. New standardization in blue, old standardization in red.

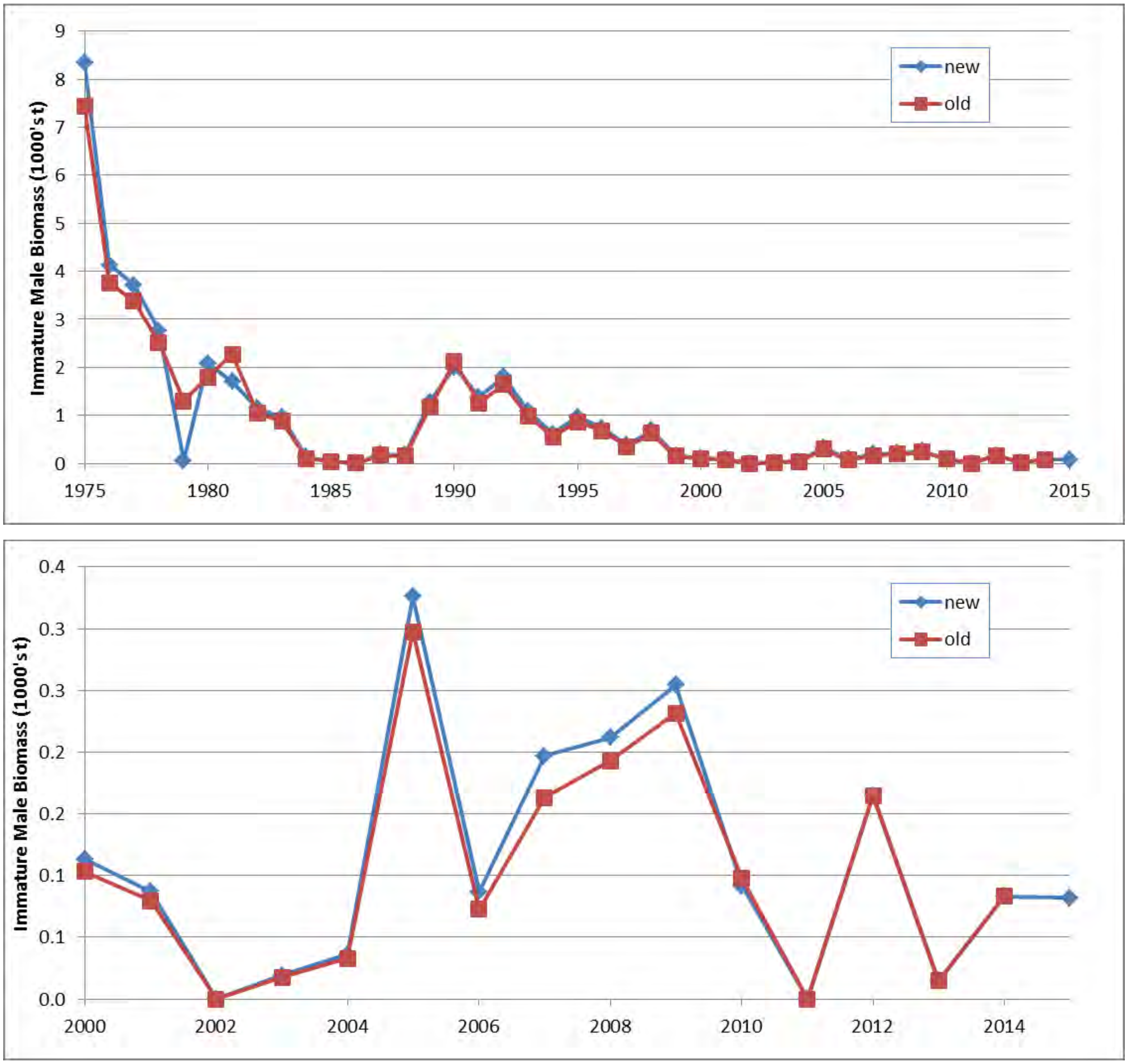
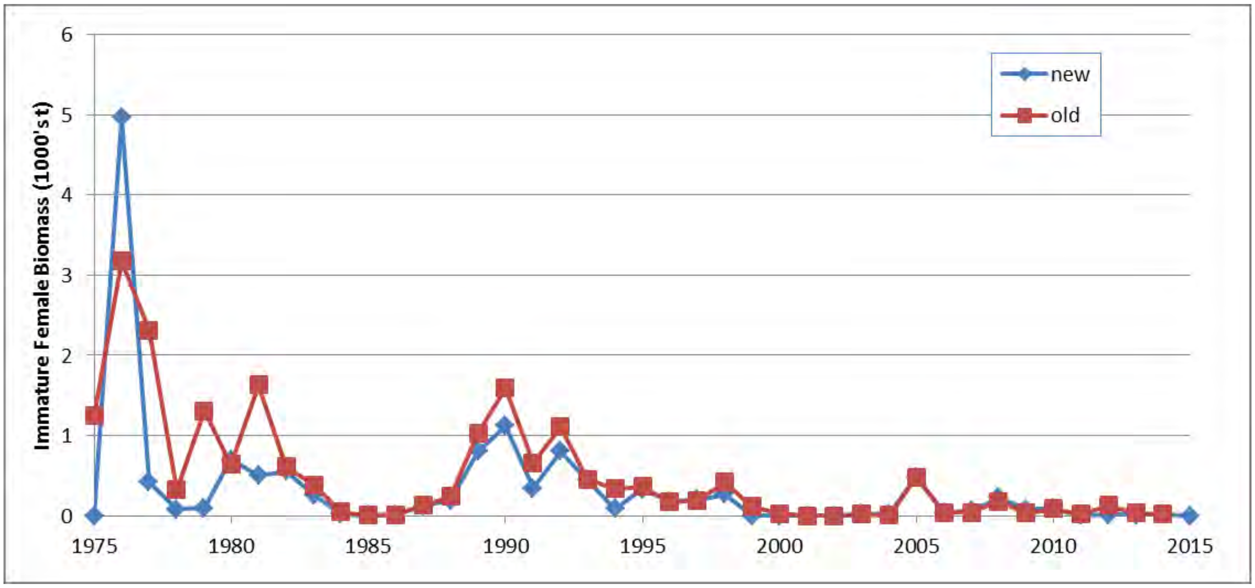


Figure 8. Comparison of time series for immature male biomass at the time of the survey estimated using the new and old standardizations for the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2015. Lower graph: 2000-2015. New standardization in blue, old standardization in red.



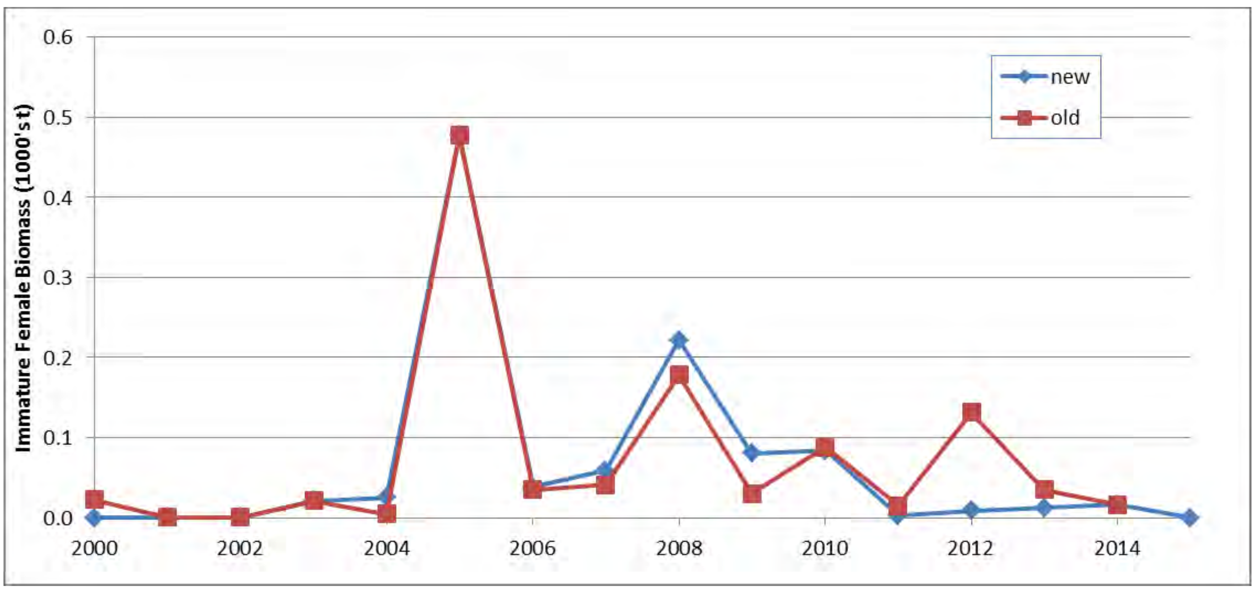


Figure 9. Comparison of time series for survey mature male biomass (MMB) estimated using the new and old standardizations for the NMFS annual EBS bottom trawl survey. Upper graph: 1975-2015. Lower graph: 2000-2015. New standardization in blue, old standardization in red.

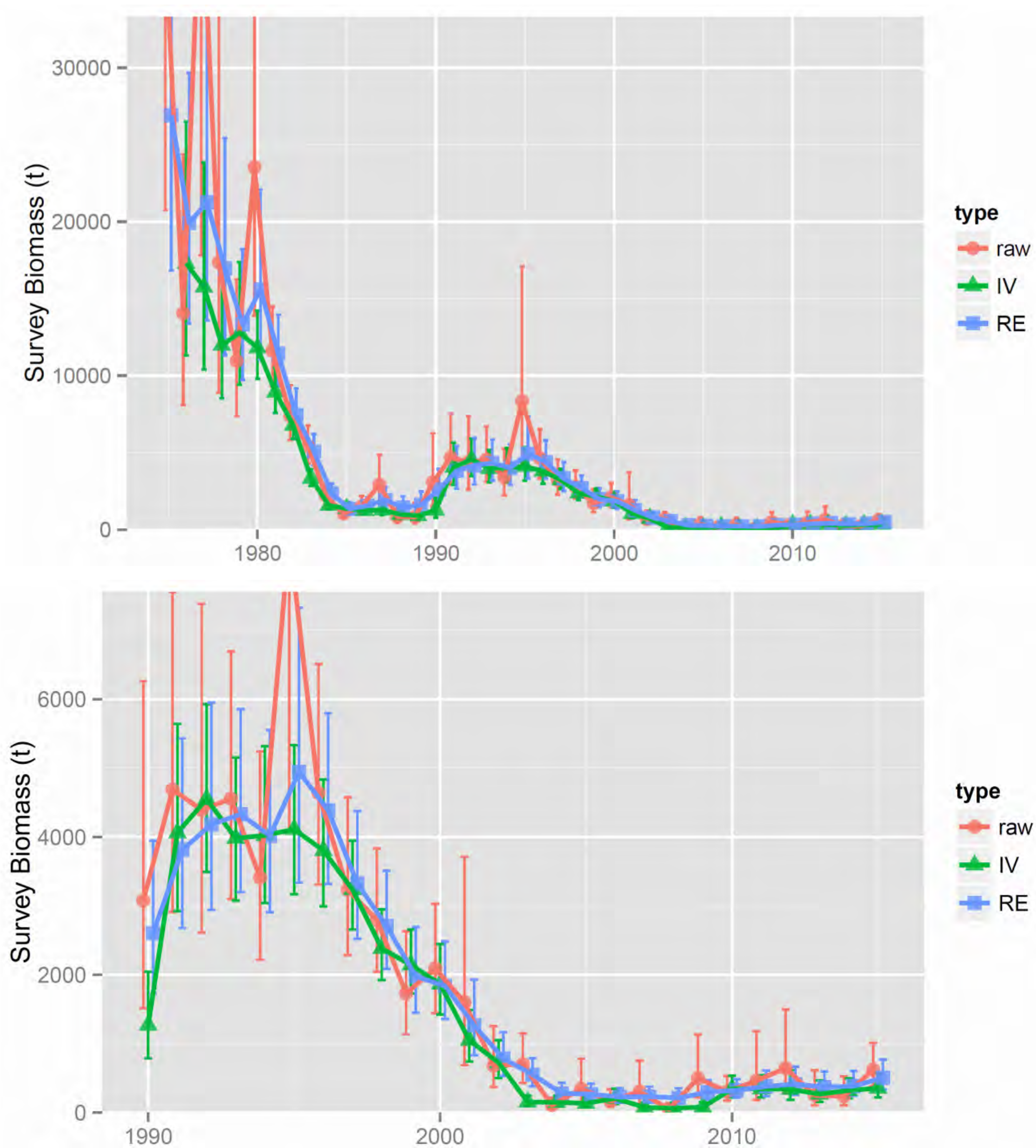


Figure 10. Time series for MMB at the time of the survey estimated from the NMFS annual EBS bottom trawl survey using the new standardization. Upper graph: 1975-2015. Lower graph: 1990-2015. Red line: "raw" time series. Green line: 3-year center-averaged smoothed series using inverse-variance (IV) weighting. Blue line: random effects (RE) model results. Error bars show 80% CIs.

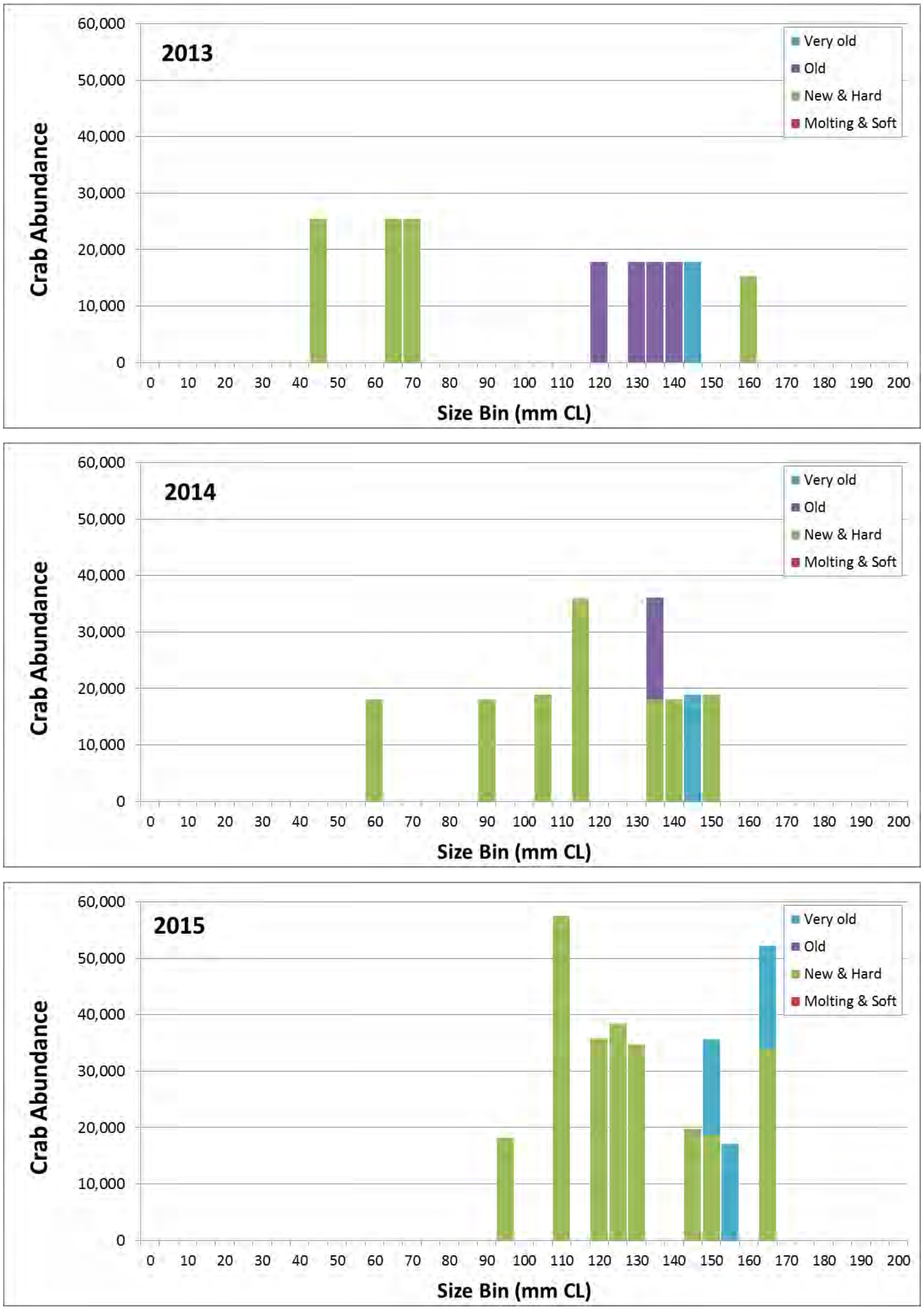


Figure 11. Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from the last 3 surveys.

old standardization new standardization

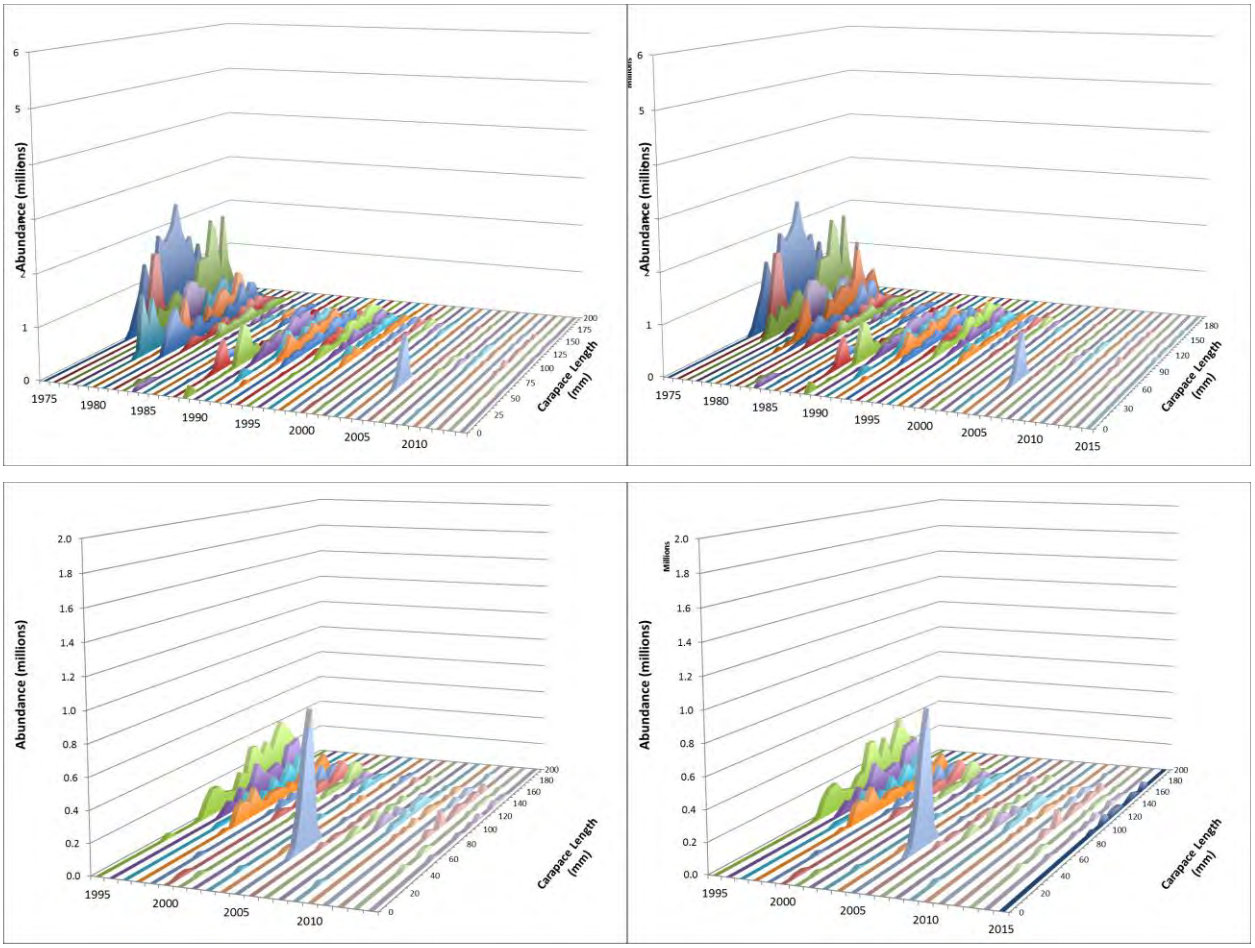


Figure 12. Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islands blue king crab by 5 mm length bins. Results using the old standardization are shown in the lefthand column for comparison with those from the new standardization. The top row shows the entire time series, the bottom shows the size compositions since 1995.

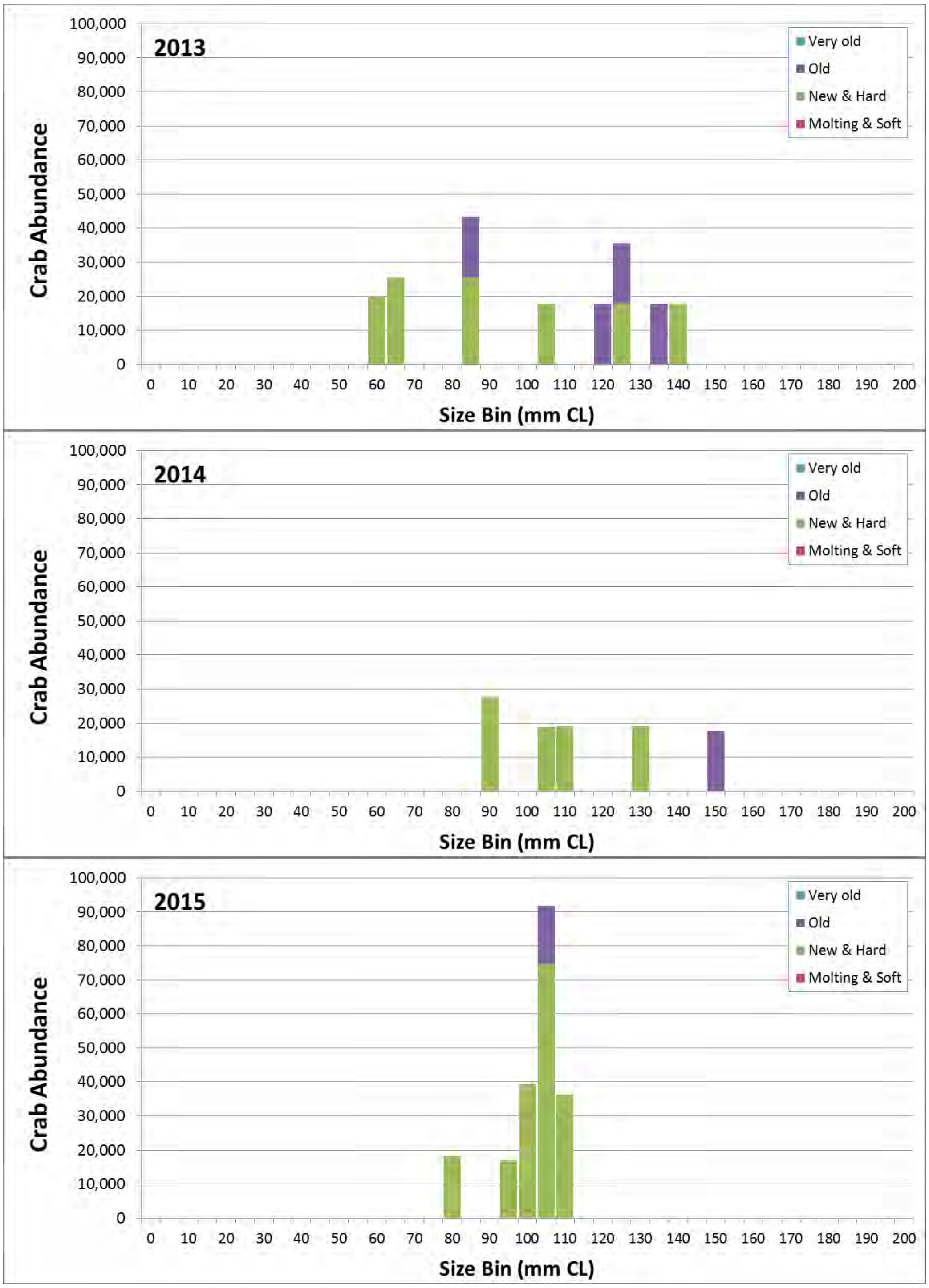


Figure 13. Size-frequencies by shell condition for female Pribilof Island blue king crab by 5 mm length bins from the last three NMFS bottom trawl surveys.

old standardization new standardization

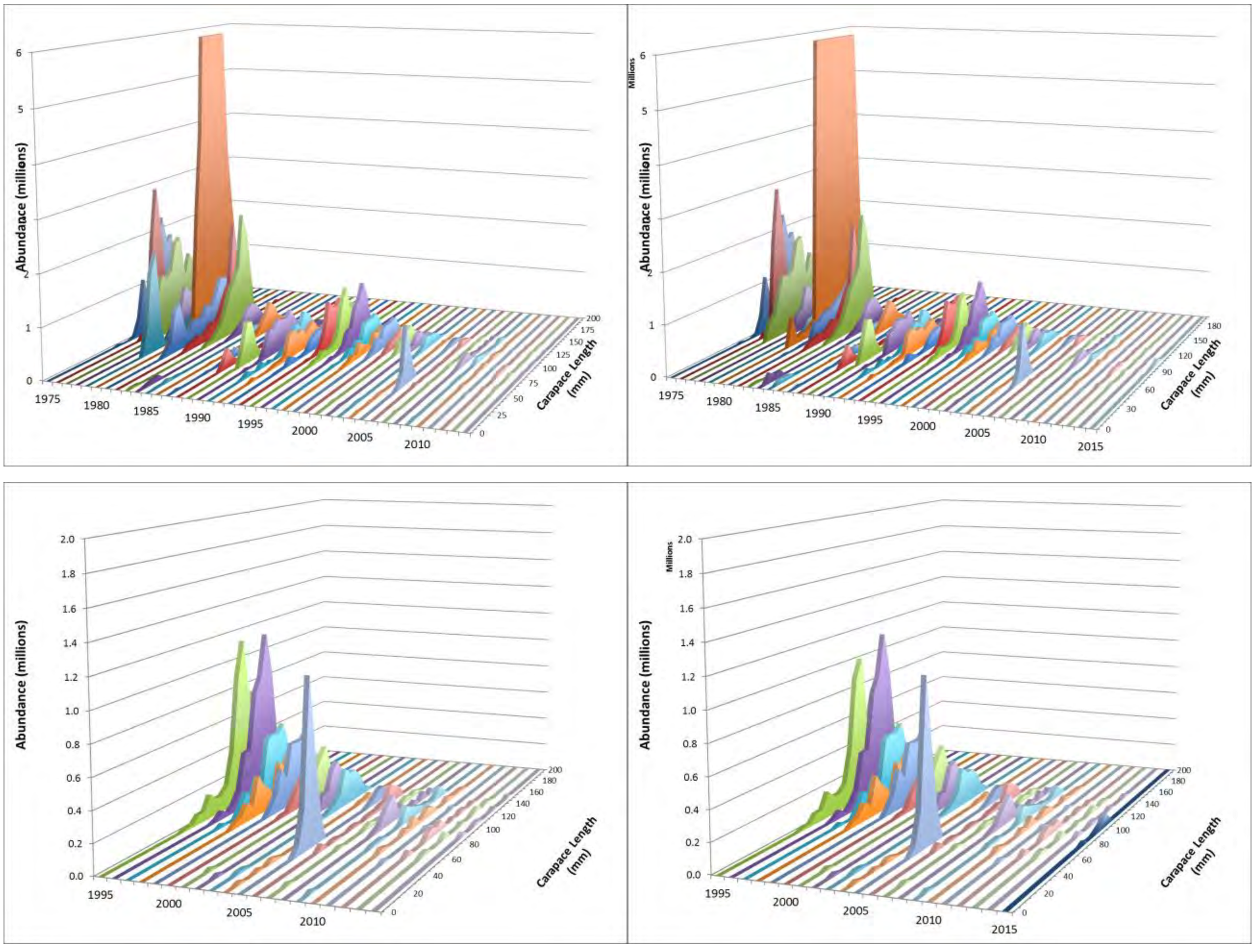
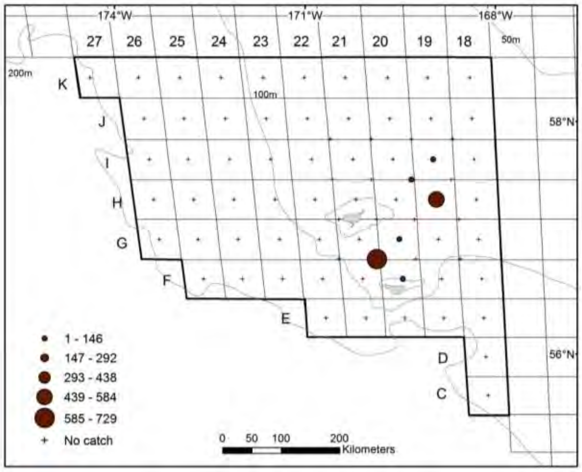
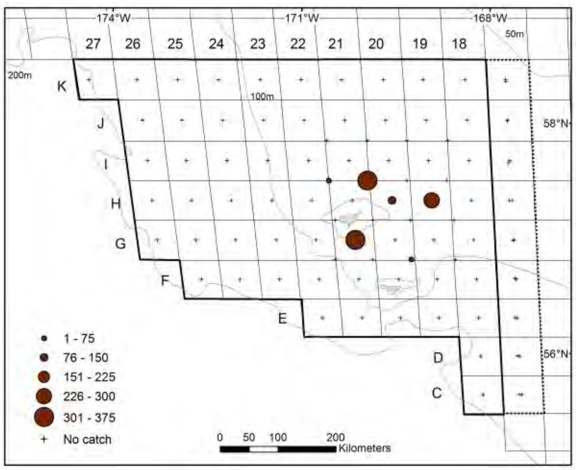


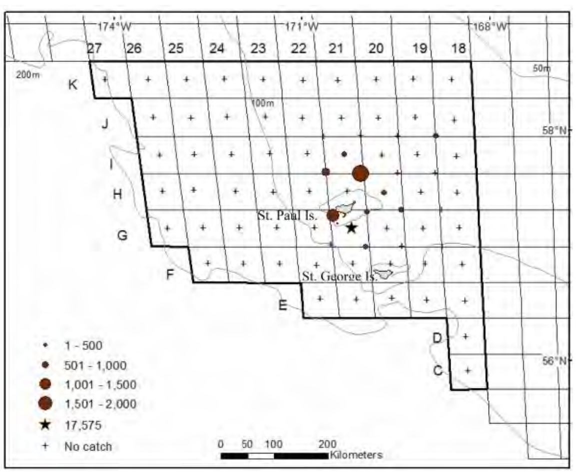
Figure 14. Size frequencies from the annual NMSF bottom trawl survey for female Pribilof Islands blue king crab by 5 mm length bins. Results using the old standardization are shown in the lefthand column for comparison with those from the new standardization. The top row shows the entire time series, the bottom shows the size compositions since 1995.



2013

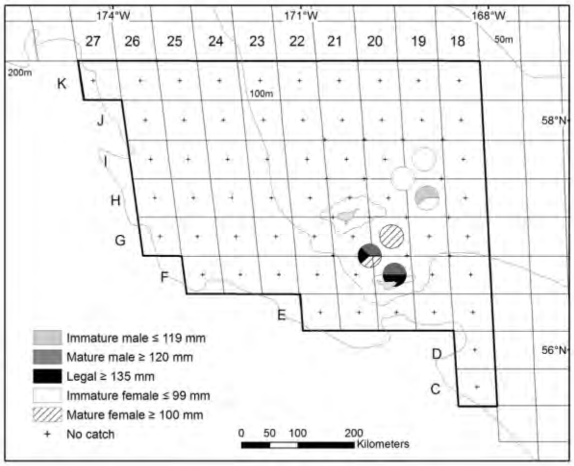


2014

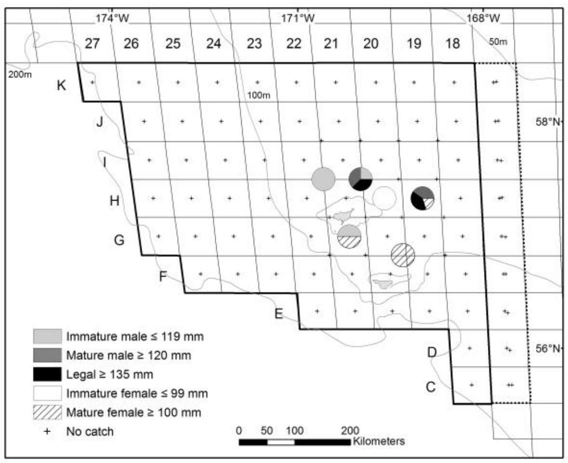


2015

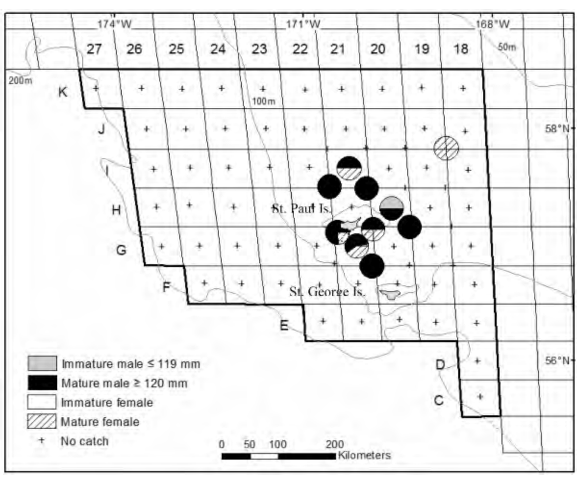
Figure 15. Total density (number/nm^2) of blue king crab in the Pribilof District in the 2013 (upper), 2014 (center), and 2015 (lower) EBS bottom trawl surveys.



2013



2014



2015

Figure 16. Size class distribution of blue king crab in the Pribilof District during the 2013 (upper), 2014 (center), and 2015 (lower) EBS bottom trawl surveys.

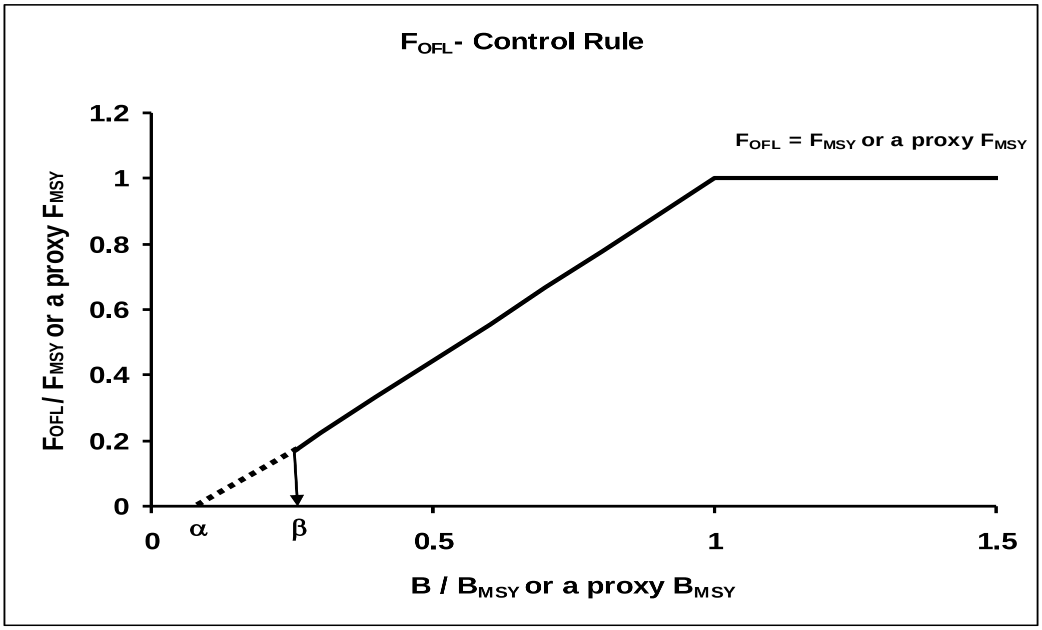


Figure 17. F_{OFL} Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below β (= 0.25).

Appendix A: PIBKC 2015 Status Determination and OFL Setting (using the new survey time series)

William Stockhausen

September 20, 2015

Introduction

This is an appendix to the 2015 stock assessment chapter for the Pribilof Islands blue king crab stock (PIBKC). It presents results for current status determination (is overfishing occurring?, is the stock overfished?) for the current year and the overfishing limit (OFL) for the upcoming year using the rPIBKC R package developed by the assessment author. The rPIBKC package (source code and R package) is available under source control at https://github.com/wStockhausen/rPIBKC.git.

This appendix is the result of processing an R Markdown document to create a Word document. Markdown is a simple formatting syntax for authoring HTML, PDF, and MS Word documents that can encapsulate R code. Following changes to the fishery and/or survey data used for this assessment, the R Markdown document can be re-evaluated to produce an updated version of this appendix using one mouse click. For more details on using R Markdown see http://rmarkdown.rstudio.com.

Status Determination and OFL calculations

For all crab stocks managed by the NPFMC, overfishing is evaluated by comparing the previous year's catch mortality (retained + discard mortality) to the previous year's OFL: if the former is greater than the latter, then overfishing is occurring. Overfished status is assessed with respect to B_{MSY}, i.e. spawning stock biomass fished at maximum sustainable yield (MSY), such that the stock is overfished if $B/B_{MSY} < 0.5$, where B is "current"" spawning stock biomass. 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.

PIBKC falls into Tier 4 for status determination and OFL setting. For Tier 4 stocks, it is not possible to determine B_{MSY} directly. Instead, average mature male biomass (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 $B_{MSY_{proxy}}$ 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. 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

In order to determine overfished status for PIBKC, one needs to determine "current" B and $B_{MSY_{proxy}}$, both of which are based on MMB.

Survey MMB

MMB at the time of the annual NMFS trawl survey is calculated from annual survey data using:

$$MMB_s = \sum_z w_z \cdot P_z \cdot n_z$$

where w_z is weight at size z (CL), P_z is the probability of maturity at size z, and n_z is survey-estimated male abundance at size z.

MMB-at-mating

MMB-at-mating (MMB_m) is calculated from survey MMB (MMB_s) by accounting for natural and fishing mortality from the time of the survey to mating. For a year y prior to the assessment year, MMB_{m_y} is given by

1. $MMB_{f_y} = MMB_{s_y} \cdot e^{-M \cdot t_{sf}}$
2. $MMB_{m_y} = [MMB_{f_y} - (RM_y + DM_y)] \cdot e^{-M \cdot t_{fm}}$

where MMB_{f_y} is the MMB in year y just prior to the fishery, M is natural mortality, RM is retained mortality on MMB in the directed fishery, DM is discard mortality on MMB (NOT all crab) in all fisheries, t_{sf} is the time between the survey and the fishery, and t_{fm} is the time between the fishery and mating.

For the assessment year, the fishery has not occurred, so RM and DM are unknown. The amount of fishing mortality presumably depends on the (as yet-to-be-determined) overfishing limit, so an iterative procedure is used to estimate MMB-at-mating for the fishery year. This procedure involves:

1. "guess" a value for F_{OFL}, the directed fishing mortality rate that yields OFL ($F_{OFL_{max}} = \gamma \cdot M$ is used).
2. determine the OFL corresponding to fishing at F_{OFL} using the following equations:
   - $MMB_f = MMB_s \cdot e^{-M \cdot t_{sf}}$
   - $RM_{OFL} = (1 - e^{-F_{OFL}}) \cdot MMB_s \cdot e^{-M \cdot t_{sf}}$
   - $DM_{OFL} = \theta \cdot \frac{MMB_f}{p_{male}}$
   - $OFL = RM_{OFL} + DM_{OFL}$
3. project MMB-at-mating from the "current" survey MMB and the OFL:
   - $MMB_m = [MMB_f - (RM_{OFL} + p_{male} \cdot DM_{OFL})] \cdot e^{-M \cdot t_{fm}}$
4. use the harvest control rule to determine the F_{OFL} corresponding to the projected MMB-at-mating.
5. update the "guess" in 1. for the result in 4.
6. repeat steps 2-5 until the process has converged, yielding self-consistent values for F_{OFL} and MMB-at-mating.

where p_{male} is the assumed fraction of overall discard mortality represented by 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 θ/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_y}) 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.

Survey smoothing

For PIBKC, the variances associated with annual survey estimates of MMB are so large that, prior to estiamting "current" MMB-at-mating, the survey MMB time series is first smoothed in some fashion to reduce overall variability.

Inverse-variance averaging

In recent assessments, inverse-variance (IV) averaging using a centered, 3-year window has been used to smooth the survey MMB time series using:

$$< MMB_s \underset{y}{>} = \frac{[\sum_{-1\le i\le 1} w_{y+i}\cdot MMB_{s_{y+i}}]}{\sum_{-1\le i\le 1} w_{y+i}}$$

where $w_y = \frac{1}{\sigma_{s_y}^2}$ and $\sigma_{s_y}^2$ is the variance associated with MMB_{s_y}. One should note, however, that it is not possible to use a centered, 3-year averaging window to obtain a smoothed value for the "current" survey MMB because the survey subsequent to the assessment year has not been conducted yet. Instead, a non-centered 2-year window is used to obtain a smoothed estimate of "current' survey MMB.

Random effects smoothing

As an alternative to IV averaging, I implemented a random effects (RE) model in ADMB, based on code developed by Jim Ianelli (NOAA/NMFS/AFSC). This is a statistical approach which models annual log-scale changes in "true" survey MMB as a random walk process using

$$< ln(MMB_s) \underset{y}{>} = < ln(MMB_s) \underset{y-1}{>} + \varepsilon_y, \text{where } \varepsilon_y \sim N(0,\phi^2)$$

as the state equation and

$$ln(MMB_{s_y}) = < ln(MMB_s) \underset{y}{>} + \eta_y, \qquad \text{where } \eta_y \sim N(0,\sigma_{s_y}^2)$$

as the observation equation, where $< ln(MMB_s) >_y$ is the estimated "true" log-scale survey MMB in year y, ε_y represents normally-distributed process error in year y with standard deviation ϕ, MMB_{s_y} is the observed survey MMB in year y, η_y represents normally-distributed ln-scale observation error, and σ_{s_y} is the log-scale survey MMB standard deviation in year y. The MMB_s's and σ_s's are observed quantities, the $< ln(MMB_s) >$'s and ϕ are estimated parameters, and the ε's are random effects (essentially nuisance parameters) that are integrated out in the solution.

Parameter estimates are obtained by minimizing the objective function

$$\Lambda = \sum_{y}[\, ln(2\pi\phi) + (\frac{< ln(MMB_s) \underset{y}{>} - < ln(MMB_s) \underset{y-1}{>}}{\phi})^2] + \sum_{y}(\frac{ln(MMB_{s_y}) - < ln(MMB_s) \underset{y}{>}}{\sigma_{s_y}})^2$$

Averaging Results

For comparison, the raw, IV-averaged, and RE-smoothed survey MMB time series are shown in Fig.s

A.1-A.3 on both arithmetic and natural log scales.

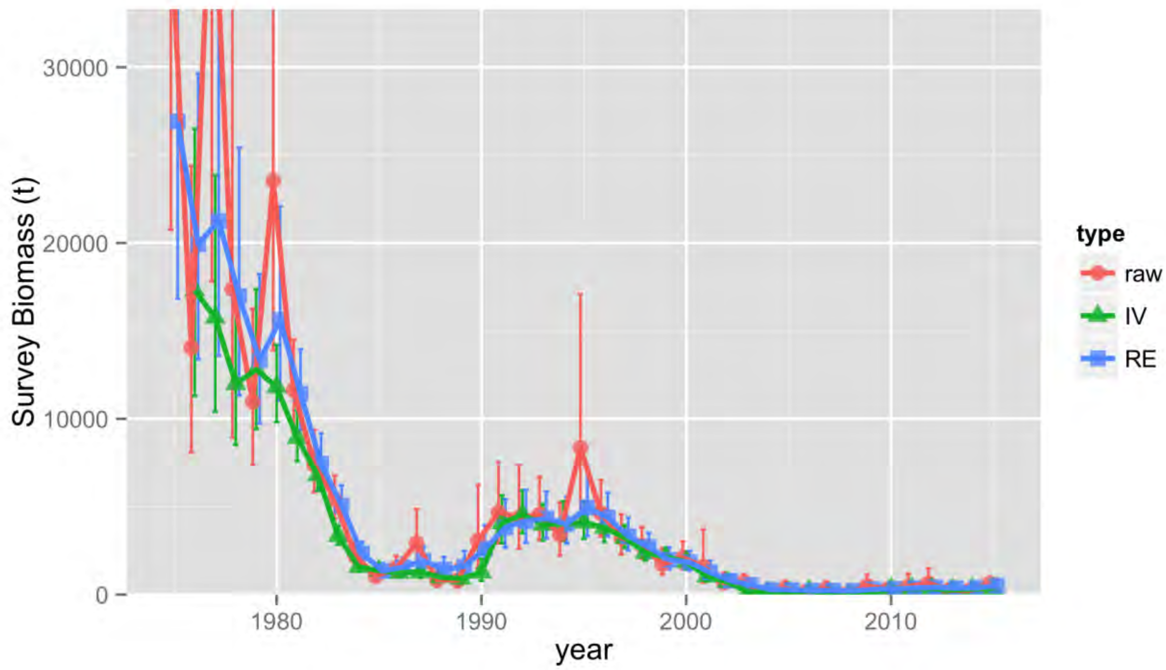


Fig. A.1. Arithmetic-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions.

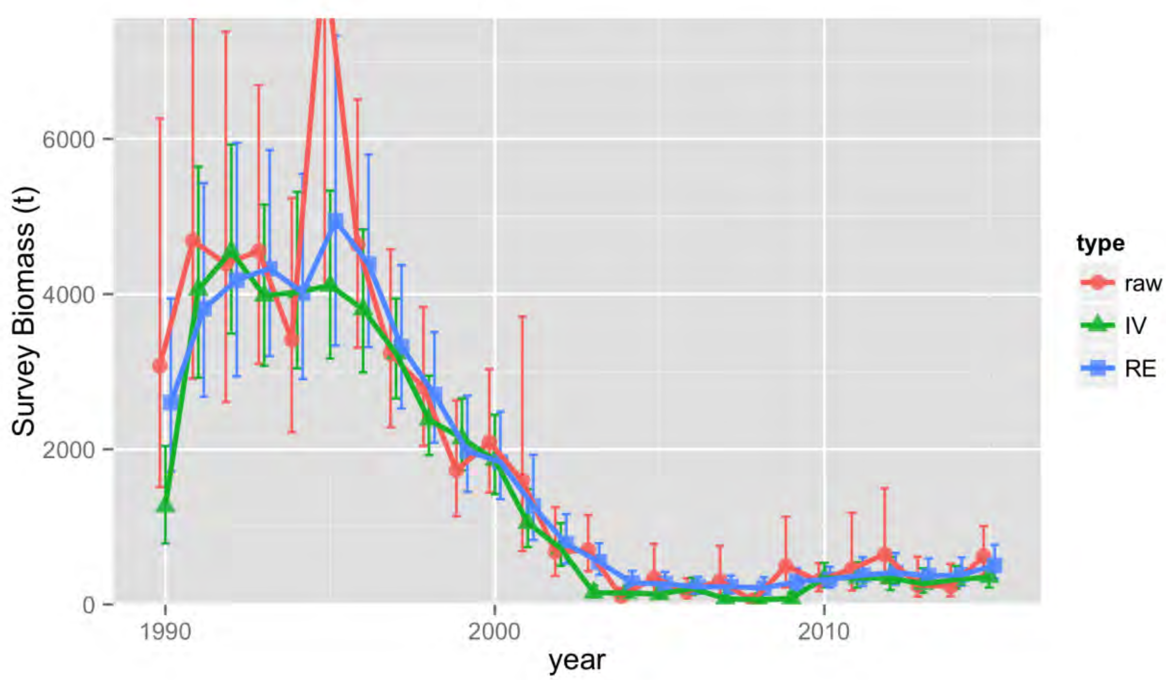


Fig. A.2. Arithmetic-scale raw and smoothed survey MMB time series, since 1990. Confidence intervals shown are 80% CIs, assuming lognormal error distributions.

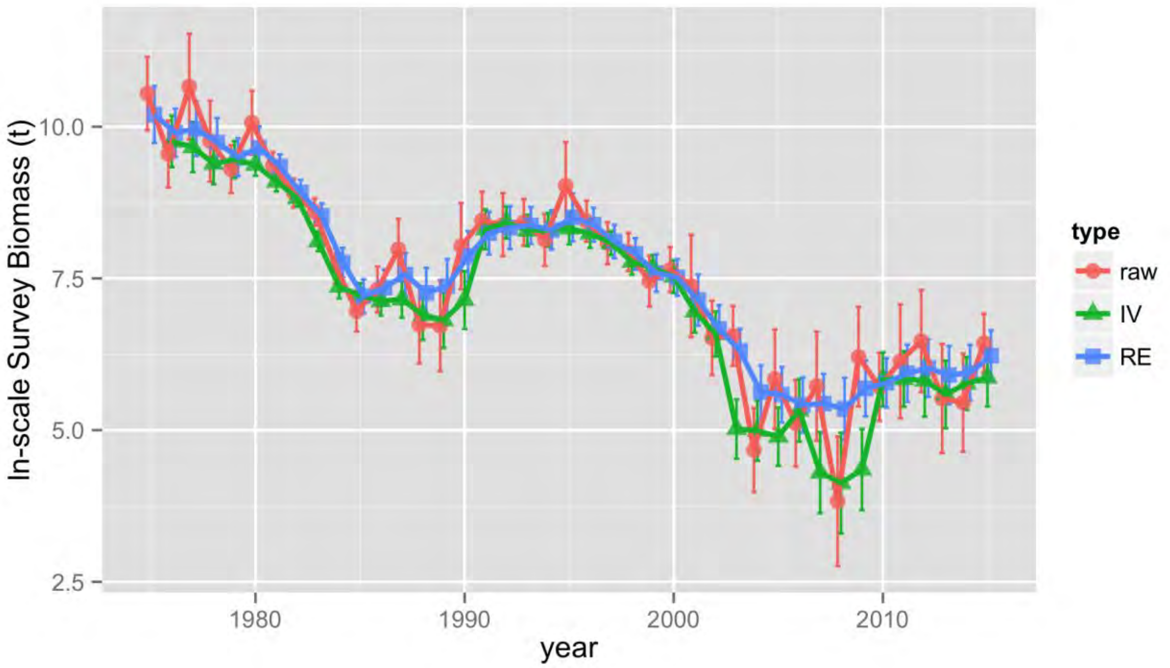


Fig. A.3. Log-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80% CIs, assuming lognormal error distributions.

Status determination and OFL calculations

Overfishing status

For PIBKC, the total fishing mortality in 2014/15 was 0.071 t while the OFL was 1.16 t. Thus, overfishing did not occur in 2014/15.

OFL calculations and overfished status

MMB-at-mating

For comparison, I calculated time series of MMB-at-mating using the raw (unsmoothed) survey MMB time series, the IV-averaged survey MMB time series, and the RE-smoothed survey MMB time series (Fig.s A.4-6).

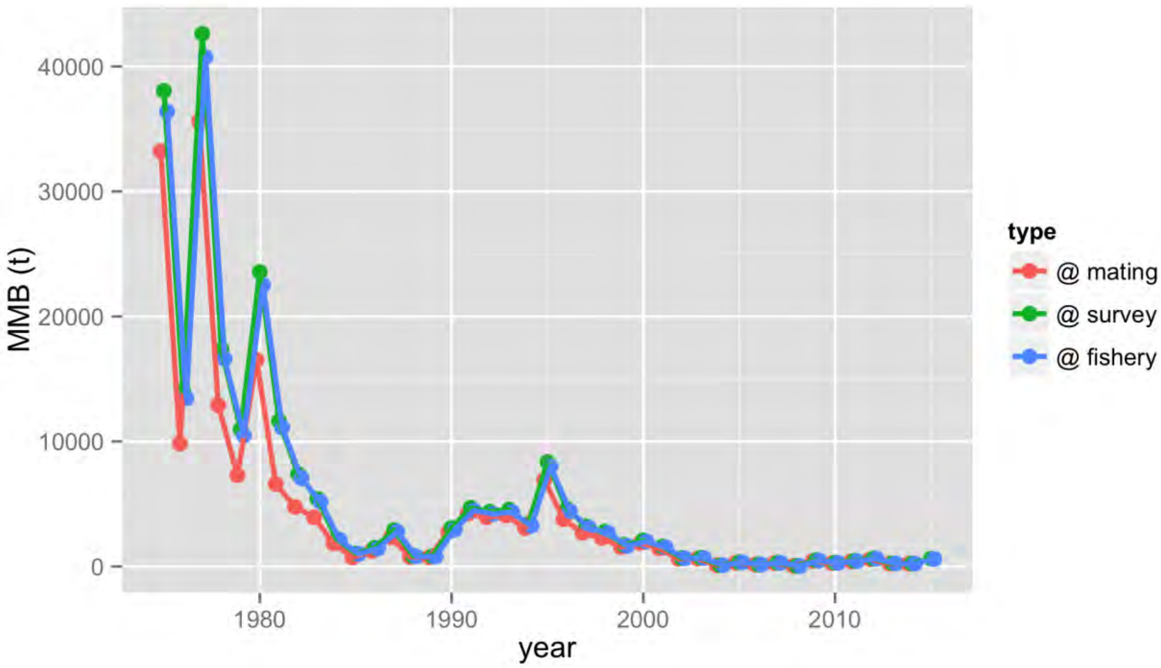


Fig. A.4. Estimated time series for MMB at the time of the survey (no smoothing), at the time of the fishery, and at the time of mating.

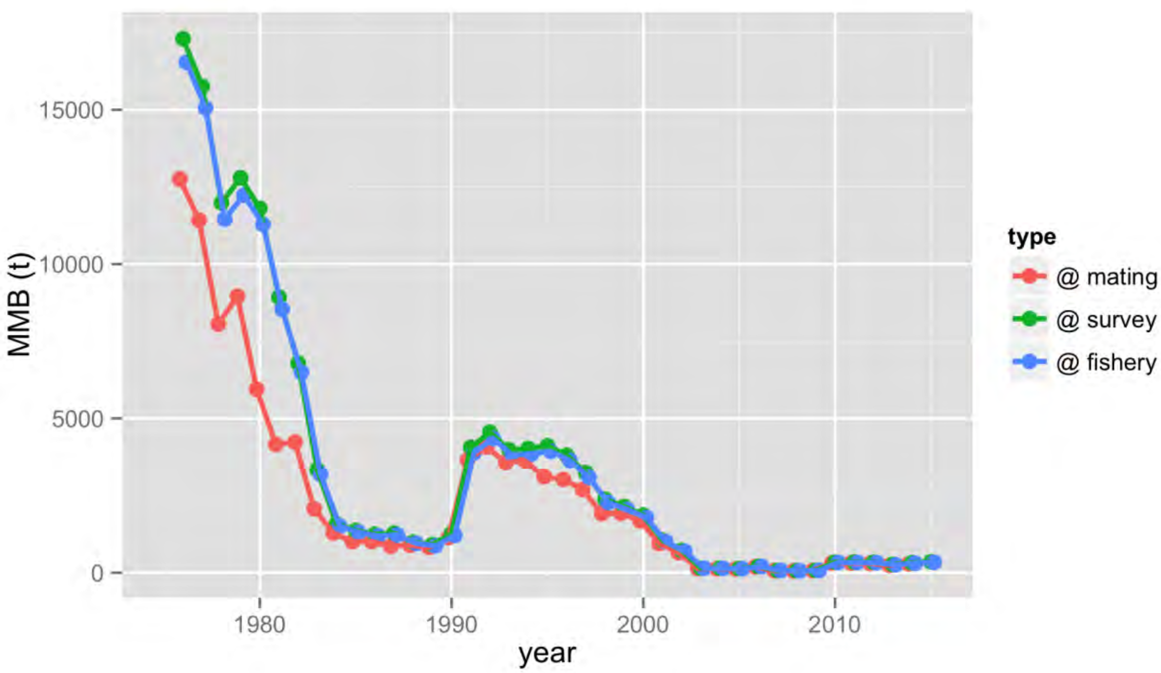


Fig. A.5. Estimated time series for MMB using IV method at the time of the survey (the inverse-averaged time series), at the time of the fishery, and at the time of mating.

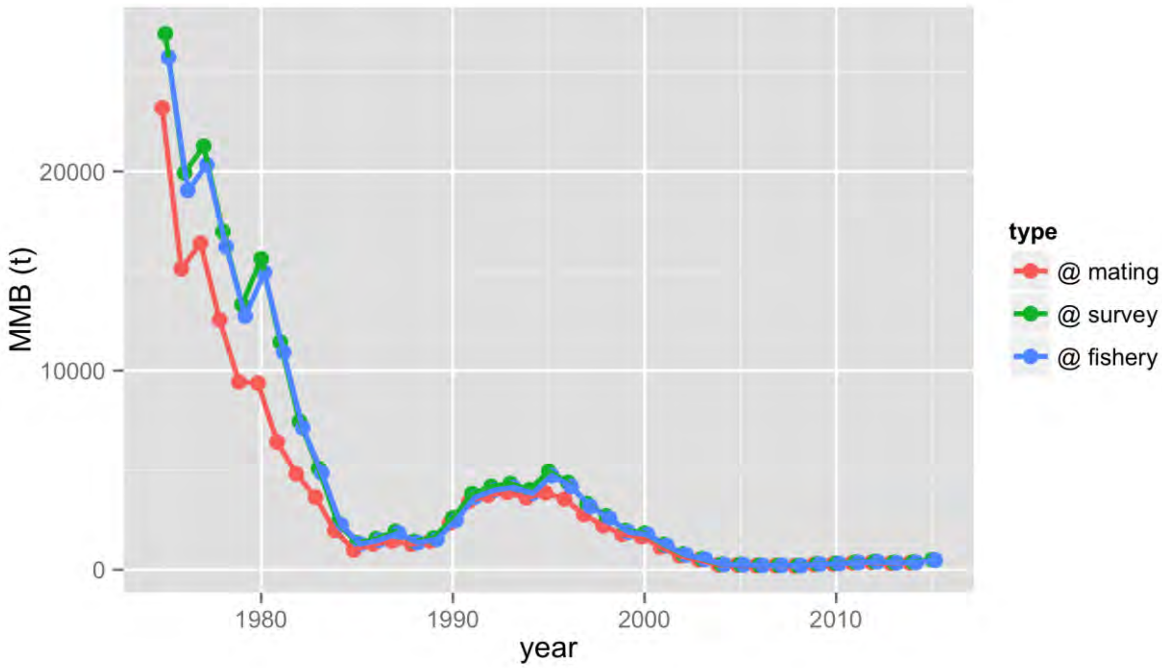


Fig. A.6. Estimated time series for MMB using the RE method at the time of the survey (the random effects time series), at the time of the fishery, and at the time of mating.

Values for $B_{MSY_{proxy}}$, obtained by averaging estimated MMB-at-mating over the period [1980-1984,1990-1997], as well as the estimated current (2015/16) MMB at the time of the survey from the raw survey data, the IV-averaged results, and the RE-smoothed results, are:

Type	current survey MMB (t)	$B_{MSY_{proxy}}$ (t)
Raw	621.7	5012.1
IV	352.9	3274.9
RE	505.5	4109.1

The values above for $B_{MSY_{proxy}}$ using the IV and RE methods are shown for illustration only. The $B_{MSY_{proxy}}$ used to determine overfished status and calculate the OFL is based on averaging the MMB-at-mating calculated from the raw survey MMB (i.e., 5,012.1 t).

Values for θ, used in the projected MMB calculations, representing the average value from the previous 3 years as calculated from the IV and RE methods are:

Type	θ
IV	3.7943658×10^{-4}
RE	3.0898071×10^{-4}

The results of the iterative status determination and OFL setting procedure described above, for the new NMFS EBS trawl survey standardization, are:

quantity	units	IV	RE
Projected MMB	t	317.6040582	454.940123
B_{MSY}	t	5012.1154242	5012.1154242
stock status		overfished	overfished
F_{OFL}	$year^{-1}$	0	0
RM_{OFL}	t	0	0
DM_{OFL}	t	0.2560223	0.2986122
OFL	t	0.2560223	0.2986122

Because the PIBKC stock is under a rebuilding plan, the OFL(s) calculated above are illustrative and will not be used for management this stock. As discussed in Section F5 of the main chapter, the OFL is based on historical average catch levels.

For comparison purposes, these procedures were also applied using survey time series calculated using the old standardization approach. The results are summarized in the following table:

quantity	units	IV	RE
Projected MMB	t	317.2714406	455.3479237
B_{MSY}	t	4002.4982102	4002.4982102
stock status		overfished	overfished
F_{OFL}	$year^{-1}$	0	0
RM_{OFL}	t	0	0
DM_{OFL}	t	0.2558485	0.2987104
OFL	t	0.2558485	0.2987104

Using the new survey standardization results in a 25% higher estimate for B_{MSY} with respect to the old standardization, while the projected MMB and OFL are quite similar (when the same survey smoothing method is used) because the old and new survey standardization methods yield almost identical results for the most recent surveys.

Saint Matthew Island Blue King Crab Stock Assessment for Fall 2015

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Executive Summary

1. Stock: Blue king crab, *Paralithodes platypus*, Saint Matthew Island (SMBKC), Alaska.

2. Catches: Peak historical harvest was 9.454 million pounds (4,288 t) in 1983/84. 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 0.461 million pounds (209 t), less than half the 1.167 million pound (529.3 t) TAC. Following three more years of modest harvests supported by a fishery 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 0.655 million pounds (300 t), but the fishery performance was relatively poor with the retained catch of 0.309 million pounds (140 t).

3. Stock biomass: Following a period of low numbers after the stock was declared overfished in 1999, trawl-survey indices of SMBKC stock abundance and biomass generally increased in subsequent years, with survey estimated mature male biomass reaching 20.98 million pounds (9,516 t; CV == 0.55) in 2011, the second highest in the 37-year time series used in this assessment. Survey mature male biomass then declined to 12.46 million pounds (5,652 t; CV = 0.33) in 2012 and to 4.459 million pounds (2,202 t; CV = 0.22) in 2013 before going back up to 12.06 million pounds (5,472 t; CV = 0.44) in 2014 and 11.32 million pounds (5,134 t; CV = 0.76).

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

5. Management performance: In recent assessments, estimated total male catch has been determined as the sum of fishery-reported retained catch, estimated male discard mortality in the directed fishery, and estimated male bycatch mortality in the groundfish fisheries, as these have been the only sources of non-negligible fishing mortality to consider.

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

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Male Catch	OFL	ABC

2011/12	1.50[A]	5.03[A]	1.15	0.85	0.95	1.70	1.54
2012/13	1.80[B]	2.85[B]	0.74	0.73	0.82	1.02	0.92
2013/14	1.50[C]	3.01[C]	0	0	0.0003	0.56	0.45
2014/15	1.86[D]	2.48[D]	0.30	0.14	0.15	0.43	0.34
2015/16		2.45[D]				0.28	0.22

The stock was above MSST in 2014/15 and is hence not overfished. Overfishing did not occur.

Status and catch specifications (million lbs) (scenario 1):

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Male Catch	OFL	ABC
2011/12	3.4[A]	11.09[A]	2.539	1.881	2.10	3.74	3.40
2012/13	4.0[B]	6.29[B]	1.630	1.616	1.81	2.24	2.02
2013/14	3.4[C]	6.64[C]	0	0	0.0006	1.24	0.99
2014/15	4.1[D]	5.47[D]	0.655	0.309	0.329	0.94	0.75
2015/16		5.40[D]				0.62	0.49

Notes:

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2012
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2013
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2014
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2015

6. <u>Basis for the OFL</u>: Estimated Feb 15 mature-male biomass (MMB_{mating}) is used as the measure of biomass for this Tier 4 stock, with males measuring 105 mm CL or more considered mature. The B_{MSY} proxy is obtained by averaging estimated MMB_{mating} over a specific reference time period, and current CPT/SSC guidance recommends using the full assessment time frame as the default reference time period.

Basis for the OFL: All table values are in 1000 t (Scenario 1):

Year	Tier	B_{MSY}	B (MMB_{mating})	B/B_{MSY}	F_{OFL}	γ	Basis for B_{MSY}	Natural Mortality
2011/12	4a	3.11	7.17	2.31	0.18	1	1989-2010	0.18
2012/13	4a	3.56	5.63	1.56	0.18	1	1978-2012	0.18
2013/14	4b	3.06	3.01	0.98	0.18	1	1978-2013	0.18
2014/15	4b	3.28	2.71	0.82	0.14	1	1978-2014	0.18
2015/16	4b	3.71	2.45	0.66	0.11	1	1978-2015	0.18

Basis for the OFL: All table values are in million lbs (Scenario 1):

Year	Tier	B_{MSY}	B (MMB_{mating})	B/B_{MSY}	F_{OFL}	γ	Basis for B_{MSY}	Natural Mortality
2011/12	4a	6.85	15.80	2.31	0.18	1	1989-10	0.18
2012/13	4a	7.93	12.41	1.56	0.18	1	1978-12	0.18
2013/14	4b	6.76	6.64	0.98	0.18	1	1978-2013	0.18
2014/15	4b	7.24	5.98	0.82	0.14	1	1978-2014	0.18
2015/16	4b	8.18	5.40	0.66	0.11	1	1978-2015	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

All time series used in the assessment have been updated to include the most recent fishery and survey results. This assessment makes use of an updated full trawl-survey time series supplied by R. Foy in August 2015 (new time series), updated groundfish bycatch estimates based on 1999-2014 NMFS AKRO data also supplied by R. Foy, and the ADF&G pot survey data in 2015.

Spatial trawl survey and bottom temperatures from 1978 to 2015 are used in this assessment as well.

Changes in Assessment Methodology

This assessment employs the 3-stage length-based assessment model first presented in May 2011 by Bill Gaeuman and accepted by the CPT in May 2012. The model was developed to replace a similar 4-stage model used prior to 2011. During the assessment in May 2015 and this assessment, many combinations of molting probability and trawl survey selectivities were evaluated to address the residual bias problems in the previous model. We also considered bottom temperature data and spatial abundance density in station R-24 in the assessment in May 2015. In September 2015, twenty scenarios were investigated. The detailed changes to the model parameters are described in details in §E (Analytic Approach).

Changes in Assessment Results

Changes in assessment results depend on model scenarios. Many model scenarios in this assessment have satisfactorily addressed the problems of biased residual patterns on ????.

B. Responses to SSC and CPT Comments

CPT and SSC Comments on Assessments in General

Spring 2015 CPT and SSC

<u>Comments</u>: *all final assessments consider stepwise changes to data and individual model runs, such that the effects of a single change to the model structure or data elements on estimates of stock status and catch recommendations can be evaluated.*

<u>Response</u>: Many model scenarios were created in this assessment to compare stepwise changes in the data and model structures.

CPT and SSC Comments Specific to SMBKC Stock Assessment

Fall 2014 CPT

Comment: *The CPT requested further investigation of the time-varying selectivity, including further explanation/investigation of plausible explanations. Research needs include better molting probability information for the two smaller stages (of the three used in the model).*

Response: See following author response to Fall 2014 SSC comments.

Spring 2015 CPT

Comments: (1) *Drop all current models from further consideration, and (2) develop new model scenarios incorporating the following elements: (i) data weighting, (ii) additional variance, (iii) revised survey time series, (iv) selectivity (various time-blocks), and (v) molting probability (various time-blocks). The above elements should be added singly to model scenarios building from the base (2014 assessment model) to more easily discern the effects of the individual changes. In addition, the author should try to achieve parsimony in the final models.*

Response: Twenty model scenarios were examined to address these comments.

Fall 2014 SSC

Comment: *The CPT had a number of recommendations for future model explorations and the SSC agrees with these recommendations. The SSC appreciates the author providing a likelihood profile on the natural mortality rate and recommends further model explorations on model fit to each data component as natural mortality rate changes. The SSC also requests the author explore the inclusion of potential environmental variables such as nearshore temperature data as an explanation for the temporally patterned residuals in the survey composition data. The mechanism might be environmentally-driven changes in biological factors such as growth or mortality or simply changes in the availability of different life stages to the survey. Any available data that might distinguish these phenomena should be examined.*

Response: The authors agree with the comments made by the CPT and SSC and think that addressing these issues is important to improve the model.

Near-shore bottom temperatures from NMFS summer surveys are obtained to create an annual temperature index during 1978-2015. Spatial NMFS survey data are examined and are used to estimate distribution centers for different stages of crab. The patterns of crab distribution centers and temperature index over time are examined, and the association between the crab distribution centers and temperature index is investigated. It appears that crab distributions are somewhat affected by the temperatures, but the association is generally weak.

In May 2015, a scenario that the annual trawl survey catachability was estimated from the near-shore bottom temperatures using the approach of Wilderbuer et al. (2013): $Q = \exp(-a+b*T)$, where a and b are parameters and T is temperature. However, the fit did not improve with this approach. The scenario was not repeated in this report.

We also investigated the "data method" similar to Schirippa et al. (2009) to estimate trawl survey selectivities with temperature data. However, the systematic residual patterns for stage-composition data cannot be corrected by this approach. The main problem is that the temperature data do not show such systematic patterns. To save space for other scenarios, we do not present the results in this report.

Doug Pengilly has examined the crab spatial patterns from NMFS trawl surveys and ADF&G pot surveys and their associations with bottom temperatures in a great detail. He presented his findings to the CPT in May 2015. His work shows the impacts of bottom temperatures on crab availability are complex. Unfortunately we do not have annual spatial temperature data very close to the island to develop a relationship to use temperature data to estimate annual trawl survey selectivities. His study also shows that the change of area-swept estimates in Station R-24 over time may be part of the reasons for the temporally patterned residuals in the survey composition data. We used pot survey data to estimate the high density area in station R-24 and developed an adjustment factor to reduce the biased area-swept estimates in station R-24.

Both trawl survey selectivity and molting probability may be implicated as reasons for the systematic residual patterns in the models presented in 2014. Based on the results of Model ST with trawl survey selectivities and the random walk approach on molting probability, a reasonable approach is to have different selectivities and molting probabilities for two different periods separated in about 2000, after the 1999 crash.

The systematic residual patterns for stage-composition data can be satisfactorily addressed with one to four additional parameters from Model T, far fewer parameters than Model ST. However, the biological reasons for the big differences in molting probabilities or trawl survey selectivities between two periods are still unclear. The model retrospective patterns of biomass could also not be satisfactorily addressed in this assessment; the patterns are primarily caused by the two or three high abundance tows. It is difficult to deal with the high abundance tows in a three stage model. Future investigation may include development of a five or six stage model, like Norton Sound red king crab model, to see whether it can improve the model retrospective patterns.

Spring 2015 SSC
Comments: None

C. Introduction

Scientific Name

The blue king crab is a lithodid crab, *Paralithodes platypus* (Brant 1850).

Distribution

Blue king crab are sporadically distributed throughout the North Pacific Ocean from Hokkaido, Japan, to southeastern Alaska (Figure 1). In the eastern Bering Sea small populations are distributed around St. Matthew Island, the Pribilof Islands, St. Lawrence Island, and Nunivak Island. Isolated populations also exist in some other cold water areas of the Gulf of Alaska (NPFMC 1998). The St. Matthew Island Section for blue king crab is within Area Q2 (Figure 2), which is the Northern District of the Bering Sea king crab registration area and includes the waters north of Cape Newenham (58°39’ N. lat.) and south of Cape Romanzof (61°49’ N. lat.).

Stock Structure

The Alaska Department of Fish and Game (ADF&G) Gene Conservation Laboratory division has detected regional population differences between blue king crab collected from St. Matthew

Island and the Pribilof Islands[1]. 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 lithodid 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 70m (NPFMC 1998). The reproductive cycle appears to be annual for the first two reproductive cycles and biennial thereafter (cf. Jensen and Armstrong, 1989) and mature crab seasonally migrate inshore where they molt and mate. Unlike red king crab, juvenile blue king crab do not form pods, but instead rely on cryptic coloration for protection from predators and require suitable habitat such as cobble and shell hash. Somerton and MacIntosh (1983) estimated SMBKC male size at sexual maturity to be 77.0 mm carapace length (CL). Paul et al. (1991) found that spermatophores were present in the vas deferens of 50% of the St. Matthew Island blue king crab males examined with sizes of 40–49 mm CL and in 100% of the males at least 100 mm CL. Spermataphore diameter also increased with increasing CL with an asymptote at ~ 100 mm CL. They noted, however, that although spermataphore presence indicates physiological sexual maturity, it may not be an indicator of functional sexual maturity. For purposes of management of the St. Matthew Island blue king crab fishery, the State of Alaska uses 105 mm CL to define the lower size bound of functionally mature males (Pengilly and Schmidt 1995). Otto and Cummiskey (1990) report an average growth increment of 14.1 mm CL for adult SMBKC males.

Management History

The SMBKC fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990). Ten U.S. vessels harvested 1.202 million pounds in 1977, and harvests peaked in 1983 when 164 vessels landed 9.454 million pounds (Fitch et al. 2012; Table 1). 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 11.0 million pounds as defined by the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner crabs (NPFMC 1999). Zheng and Kruse (2002) hypothesized a high level of SMBKC natural mortality from 1998 to 1999 as an explanation for the low catch per unit effort (CPUE) in the 1998/99 commercial fishery and the low numbers across all male crab size groups caught in the annual NMFS eastern Bering Sea trawl survey from 1999 to 2005 (Table 2). In Nov 2000, Amendment 15 to the FMP for Bering Sea/Aleutian Islands king and Tanner crabs was approved to implement a rebuilding plan for the SMBKC stock (NPFMC 2000). The rebuilding plan included a regulatory harvest strategy (5 AAC 34.917), area closures, and gear modifications. In addition, commercial crab fisheries near St. Matthew Island were scheduled in fall and early winter to reduce the potential for bycatch mortality of vulnerable molting and mating crab.

[1] NOAA grant Bering Sea Crab Research II, NA16FN2621, 1997.

NMFS declared the stock rebuilt on Sept 21, 2009, and the fishery was reopened after a 10-year closure on Oct 15, 2009 with a TAC of 1.167 million pounds, closing again by regulation on Feb 1, 2010. Seven participating vessels landed a catch of 460,859 pounds with a reported effort of 10,697 pot lifts and an estimated CPUE of 9.9 retained number of crab per pot lift. The fishery remained open the next three years with modest harvests and similar CPUE, but large declines in the NMFS trawl-survey estimate of stock abundance raised concerns about the health of the stock, prompting ADF&G to close the fishery again for the 2013/14 season. Due to abundance above thresholds, the fishery was reopen for the 2014/15 season with a low TAC 0.655 million pounds.

Though historical observer data are limited due to very limited samplings, 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 twice or more 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 3), with total male discard mortality in the 2012/13 directed fishery estimated at about 12% (0.193 million pounds) of the reported retained catch weight, assuming 20% handling mortality. On the other hand, these same data suggest a significant reduction in the bycatch of females, which may be attributable to the later timing of the contemporary fishery[2]. Some bycatch of discarded blue king crab has also been observed historically in the eastern Bering Sea snow crab fishery, but in recent years it has generally been negligible, and observers recorded no bycatch of blue king crab in sampled pot lifts during 2013/14. The St. Matthew Island golden king crab fishery, the third commercial crab fishery to have taken place in the area, typically occurred in areas with depths exceeding blue king crab distribution. NMFS observer data suggest that variable but mostly limited SMBKC bycatch has also occurred in the eastern Bering Sea groundfish fisheries (Table 5).

D. Data

Summary of New Information

Data used in this assessment have been updated to include the most recently available fishery and survey numbers. In addition, this assessment makes use an updated trawl-survey time series provided by R. Foy in August 2015 (new time series), as well as updated 1993-2014 groundfish bycatch estimates based on AKRO data also supplied by R. Foy. The new and old time series of trawl survey area-swept estimates were compared in May 2015 and only the new time series was used in this assessment.

Major Data Sources

Major data sources used in this assessment are annual directed-fishery retained-catch statistics from fish tickets (1978/79-1998/99, 2009/10-2012/13, and 2014/15; Table 1); results from the annual NMFS eastern Bering Sea trawl survey (1978-2015; Table 2); results from the triennial ADF&G SMBKC pot survey (every third year during 1995-2013) and 2015 pot survey (Table 4);

[2] D. Pengilly, ADF&G, pers. comm.

size-frequency information from ADF&G crab-observer pot-lift sampling (1990/91-1998/99, 2009/10-2012/13, and 2014/15; Table3); and NMFS groundfish-observer bycatch biomass estimates (1992/93-2014/15; Table 5). Figure 3 maps stations from which SMBKC trawl-survey and pot-survey data were obtained. Further information concerning the NMFS trawl survey as it relates to commercial crab species is available in Daly et al. (2014); see Gish et al. (2012) for a description of ADF&G SMBKC pot-survey methods. It should be noted that the two surveys cover different geographic regions and that each has in some years encountered proportionally large numbers of male blue king crab in areas where the other is not represented (Figure 4). Crab-observer sampling protocols are detailed in the crab-observer training manual (ADF&G 2013). Groundfish SMBKC bycatch data come from NMFS Bering Sea reporting areas 521 and 524 (Figure 5). Note that for this assessment the newly available NMFS groundfish observer data reported by ADF&G statistical area was not used.

Other Data Sources

The alternative model configuration developed for this assessment makes use of a growth transition matrix based on Otto and Cummiskey (1990). Other relevant data sources, including assumed population and fishery parameters, are presented in Appendix A, which provides a detailed description of the base-model configuration used for the 2012 and 2013 assessments.

Major Excluded Data Sources

Groundfish bycatch size-frequency data available for selected years, though used in the model-based assessment in place prior to 2011, play no direct role in this analysis. This is because these data tend to be severely limited: for example, 2012/13 data include a total of just 4 90-mm+ CL male blue king crab from reporting areas 521 and 524.

E. Analytic Approach

History of Modeling Approaches for this Stock

A four-stage catch-survey-analysis (CSA) assessment model was used before 2011 to estimate abundance and biomass and prescribe fishery quotas for the SMBKC stock (2010 SAFE; Zheng et al. 1997). The four-stage CSA is similar to a full length-based analysis, the major difference being coarser length groups, which are more suited to a small stock with consistently low survey catches. In this approach, the abundance of male crab with a CL of 90 mm or above is modeled in terms of four crab stages: stage 1: 90-104 mm CL; stage 2: 105-119 mm CL; stage 3: newshell 120-133 mm CL; and stage 4: oldshell $\geq$ 120 mm CL and newshell $\geq$ 134 mm CL. Motivation for these stage definitions comes from the fact that for management of the SMBKC stock, male crab measuring at least 105 mm CL are considered mature, whereas 120 mm CL is considered a proxy for the legal size of 5.5 in carapace width, including spines. Additional motivation for these stage definitions derives 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 CPT and SSC recommendations that included development of an alternative model with provisional assessment based on survey biomass or some other index of abundance. An alternative 3-stage model was proposed to the CPT in May 2011 but was requested to proceed with a survey-based approach for the Fall 2011 assessment. In May 2012 the CPT approved a slightly revised and better documented version of the alternative model for assessment.

Assessment Methodology

The current SMBKC stock assessment model, first used in Fall 2012, is a variant of the previous four-stage SMBKC CSA model (2010 SAFE; Zheng et al. 1997) and similar in complexity to that described by Collie et al. (2005). Like the earlier model, it considers only male crab at least 90 mm in CL, but it combines stages 3 and 4 of the earlier model resulting in just three stages (male size classes) determined by carapace length 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. A detailed description of the base model and its implementation in the software AD Model Builder (Fournier et al. 2012) is presented in t Appendix A .

Model Selection and Evaluation

In May 2015, eight model scenarios were considered. In this (September 2015) assessment, twenty scenarios are examined:

T. Model T from September 2014.

0. Effective sample sizes are determined differently from scenario T. With scenario T, effective sample sizes are equal to **min(N, observed values)**, where N is 50 for trawl surveys and 100 for pot surveys and pot fishery bycatch. The drawback with this approach is that some observed values are 1-to-1 to effective sample size and some observed values are more than 10 to 1. Also, effective sample sizes for the pot fishery bycatch should not be 100% more than those of the trawl surveys, since the observer coverages are not very representative for this fishery, especially for the early data. An approach modified from The Bristol Bay red king crab approach is used here: **effective sample size = min(N, 0.5*observed values)** for the surveys and **= min(N, 0.1*observed values)** for the pot fishery observer data, where N is 50 for the trawl surveys, N is 50 for the observer data, and N is 100 for the pot surveys. Besides effective sample sizes, length composition likelihood is computed by the robust normal approximation. There are only three stages, and stage 3 has about 50% of stage compositions. The robust normal approximation is preferred over the multinomial by the authors, although the difference between them is small.

   The second change is to convert the weights to catch and discard biomass likelihoods into CVs.

   The third change is to reduce the mean weights for legals (stage 3) based on the trawl survey data and retained catch mean weights. In scenario T, annual mean retained catch weights were used for legal males. However, mean retained catch weights are always higher than the mean legal male weights. With scenario 0, the annual mean weight is the product of the ratio of mean legal male weight to retained catch weight and the annual mean retained catch weight.

Scenario 0 is the same as scenario T except for above three changes. The first change is a major change and the last two changes are for housekeeping purpose.

00. Scenario 0 plus reduction of penalty weights for groundfish fisheries bycatch fishing mortality. The weight changes from 1 to 0.01. Higher weights result in more constant fishing mortalities over time. Since the groundfish fisheries bycatch varied greatly over time, a small weight should be used.

1. Scenario 00 plus changes in the effective sample sizes for pot fishery observer length composition data and use of pot fishery discarded biomass. In scenario T, the maximum effective sample size is the same over time for the pot fishery observer length composition data. However, before 2005, the observer coverage was very limited, and the observer data came from a small segment of the fleet and a very small amount of pots. The observer data after 2005 were from 100% coverage of the fleet and a large sampling of pots. The maximum effective sample size before 2005 (25) is set as 50% of that after 2005 for scenario 1 (50).

   In scenario T, the pot fishery discard biomass is not used to compute the likelihood. With scenario 1, the discarded biomass is used to compute the likelihood and a CV of 0.2 is set for the biomass after 2005 and 0.6 for biomass before 2005. The trawl survey CVs are generally higher than 0.2 and lower than 0.6.

2. Scenario 1 plus estimating an additional CV for the pot survey CPUE.

3. Scenario 2 plus estimating a molting probability for stage 1. The molting probability for stage 2 is based on the ratio (0.6923) of the molting probabilities between stage 1 and 2 from the tagging data (Otto and Cummiskey 1990). The transition matrix is estimated from the growth matrix after molting and molting probability. In scenario T, the transition matrix (including molting probability and growth matrix) was fixed.

4. Scenario 3 plus estimating trawl survey selectivities for two periods (before 2000 and 2000-present).

5. Scenario 3 plus estimating molting probabilities for two periods (before 2000 and 2000-present).

6. Scenario 4 plus estimating molting probabilities for two periods (before 2000 and 2000-present).

7. The same as scenario 4 except molting probabilities are 0.91 and 0.63 for respective stages 1 and 2 based on tagging data (Otto and Cummiskey 1990).

8. The same as scenario 5 except without estimating an additional CV for the pot survey CPUE and the molting probabilities during the period (1978-1999) are based on tagging data (0.91 and 0.63 for stages 1 and 2).

9. Scenario 7 plus estimating two pot survey selectivities for two periods (before 2000 and 2000-present).

10. The same as scenario 9 except without estimating an additional CV for the pot survey CPUE.

11. The same as scenario 10 except estimating annual trawl selectivity for stage 1 with a random walk approach (penalty weight = 50 for annual change):

$S_{1,t} = S_{1,t-1}$ exp(ε_t), and $S_{2,t} = S_{2,t-1}$ exp(ε_t). The penalty is $L_{pen} = 50 \sum(\varepsilon_t * \varepsilon_t)$. The weight of 50 results in relatively smooth annual estimates of the selectivities.

10-4. The same as scenario 10 except reducing station R-24 trawl CPUE by multiplying a factor of 0.4*(401-25)/401, or 37.51%. The 401 is total square nautical miles of a station, the 25 is the approximate square nautical miles of land in station R-24, and the 0.4 means the high density area is 40% of the area with water in station R-24.

10-3. The same as scenario 10-4 except reduction factor is 0.3*(401-25)/401, or 28.13%.

10-2. The same as scenario 10-4 except reduction factor is 0.2*(401-25)/401, or 18.75%.

10-0. The same as scenario 10-4 except assuming no trawl survey occurred in station R-24.

9-4. The same as scenario 9 except reducing station R-24 trawl CPUE by multiplying a factor of 0.4*(401-25)/401, or 37.51%.

9-0. The same as scenario 9-4 except assuming no trawl survey occurred in station R-24.

Results

Additional results are presented for model scenarios 3, 8, 10, 11, and 10-4, as these scenarios represent different approaches. We recommend scenario 10-4 to be used for the overfishing determination in 2015, based on the fit of the data, plausibility of parameter estimates, and quality of area-swept abundance estimates.

a. Trawl survey station R-24.

NMFS summer trawl surveys normally did not catch many crab in station R-24 except during the 1990s and recent 10 years (Table 6). The extremely high survey catch in station R-24 during recent years merits a close examination whether there are any sampling problems. The high temporal variation and high catch rates during some periods make station R-24 be an outlier relative to the two strata (Table 6). Station R-24 makes up a high proportion of area-swept estimates of abundance in recent years.

There are four sets of pot survey data in trawl survey station R-24: 10 pot stations in 1998 and 2013, and 20 pot stations in 2013 and 2015. These pot surveys are with systematic sampling, equally covering the 401 square nautical miles. We ranked the catch by pot stations and summarized the data in Table 7. Clearly, high catch occurred only in a small area of R-24, and this area is close to the shore. The northeastern part of R-24 had low catch or no catch. The trawl survey area in R-24 is within the high density area (Figure 6). From the four pot surveys, the top 40% of the pot survey stations by CPUE caught about 85% to 95% of males >89 mm CL (Table 7).

We propose that the trawl CPUE in station R-24 should be applied to the high density area only. Based on the pot survey data, we define the high density area to be about 40% of R-24. With about 25 square nautical miles in R-24 being land, the reduction factor is 0.4*(401-25)/401, or 37.51%. Alternatively, we also examine the high density area as 30% and 20% and without using the trawl CPUE in R-24. Figure 7 illustrates the area-swept abundance estimates of males >89 mm CL with and without 37.51% reduction applied to station R-24.

b. Effective sample sizes.

Observed and estimated effective sample sizes are compared in Table 8.

c. Tables of estimates.

Model parameter estimates are summarized in Table 9 for six scenarios. Negative log likelihood values and management measures for 18 scenarios are compared in Table 10. Estimated abundances by stage and mature male biomasses are listed in Table 11 for four scenarios.

Generally speaking, scenarios with different molting probabilities or survey selectivities for two periods fit the data better. Scenarios with additional CV for the pot survey CPUE fit the trawl survey data better and result in higher abundance and biomass estimates in most recent years. Like the results in May 2015, large differences exist for estimated molting probabilities or survey selectivities during the two periods. Plausible biological reasons have not yet been found to explain large differences in molting probabilities. Estimated trawl survey selectivities > 1.0 for both stages 1 and 2 during 2000-2015 are also troublesome, but might be possible due to changes in crab spatial distributions, based on the examination on pot survey data presented by Doug Pengilly to the CPT in May 2015. Differences of estimated trawl survey selectivities between two periods decrease with scenarios 10-4, 10-3, 10-2, and 10-0. The high estimated trawl survey selectivities imply that the catchability of trawl surveys during recent years is greater than the assumed value of 1.0.

d. Graphs of estimates

Estimated trawl survey selectivities are compared in Figure 8 and molting probabilities are shown in Figure 9. The fits of total male (>89mm CL) trawl survey biomass are compared in Figure 10, and the fits of pot survey CPUE are contrasted in Figures 11a and 11b for 18 scenarios. Standardized residuals of total male trawl survey biomass are plotted in Figure 12, and bubble plots of stage compositions for trawl survey, pot survey, and commercial observer data are shown in Figure 13 for scenarios 3, 8, 10, 10-4 and 11. Fits to retained catch biomass and bycatch death biomass are shown for scenario 10 in Figure 14. The fits of catch and bycatch biomasses for other scenarios are not shown in the report because the differences of fits are very small among scenarios. Estimated recruitment and mature male biomass are compared in Figures 15 and 16, respectively.

Estimated trawl survey selectivities with scenario 11 (random walk approach) show strong temporal trends (Figure 8); estimated selectivities start to increase in mid-1990s and accelerate after 1999 to a peak in 2010 and the values decrease somewhat during the last four years. With the trawl survey gear change in 1982 and relatively high estimated selectivities during 1978-1980 (Figure 8), it would be reasonable to estimate trawl survey selectivities separately during 1978-1981. We did run a scenario for this, but the fit did not improve with statisticalsignificance over scenario 10, so we did not report the scenario.

Estimated trawl survey selectivities and molting probabilities are generally confounded. For example, the estimated lower molting probabilities after 1999 are associated with lower trawl survey selectivity estimates for scenario 8, and the assumed higher molting probabilities result in higher estimated trawl survey selectivities for scenario 10 (Figures 8 and 9; Table 9). To reduce the confounding, molting probabilities are fixed at the values estimated from tagging data during the same period for scenarios 9, 10, and 11.

e. Graphic evaluation of the fit to the data.

Model estimated relative survey biomasses depend on scenarios. Scenarios T, 0, 00, and 1 have relatively high biomass in the early period and during recent years (Figure 10). Scenarios 2 and 3 with constant molting probabilities and trawl survey selectivities over time and with an additional CV for the pot survey CPUE result in much higher biomass estimates in recent years; the trend of the biomass estimates also differ from other scenarios (Figure 10). Estimated pot survey CPUEs are also dependent on scenarios, and the difference among scenarios are very similar to the relative survey biomasses (Figure 11).

There are strong temporal patterns for residuals of total trawl survey biomass and stage composition data for scenarios T, 0, 00, 1, 2, and 3 (showing only scenario 3), and no apparent residual patterns occur for other scenarios with two levels of trawl selectivities or molting probabilities over time (Figures 12 and 13). The stage compositions for observer data were not fit very well before 2000 for all scenarios, because the data are low quality and effective sample size is assumed small accordingly. The absolute values of standardized residuals of survey biomass are relatively smaller for scenarios 10-4, 10-3, 10-2, and 10-0 than those for scenario 10 (Figure 12). All scenarios fit well to retained catch biomass and fits to bycatch biomass are generally well. All fits are not shown in this document, but as an example scenario 10 fits are shown in Figure 14.

Estimated recruitments to the model vary greatly over time (Figure 15). Estimated recruitments during recent years are generally low except for scenarios 2 and 3. Estimated mature male biomasses on Feb. 15 also fluctuate strongly over time; the high biomass estimates in recent years for scenarios 2 and 3 show an opposite trend from the other scenarios (Figure 16).

f. Retrospective and historic analyses.

Retrospective results of mature male biomass (Figure 17) and legal male abundance (Figure 18) with scenarios 10 and 10-4 are very good except during 2010-2012. Both scenarios 10 and 10-4, as well as all other scenarios, could not account for the high abundances mainly due to two or three extremely high abundance tows during these years. These results generally perform better than Model ST in the SAFE report of September 2014. Scenario 10-4 performs slightly better than scenario 10.

g. Uncertainty and sensitivity analyses.

Estimated standard deviations of parameters are summarized in Table 9 for six scenarios. Probabilities for mature male biomass and OFL in 2015 are illustrated in the section "F. Calculation of the OFL"

h. Comparison of alternative model scenarios.

Among the 20 scenarios, scenario T was used in 2014 and scenarios 0, 00, and 1 have some corrections and some modifications to scenario T. The results among scenarios T, 0, 00 and 1 do not have large differences, and strong temporal residual patterns occur for both survey biomass and stage composition data. Scenarios 2 and 3 are similar, and with an additional CV for the pot survey CPUE, these two scenarios result in not only strong temporal residual patterns but also an opposite trend of biomass relative to the pot survey CPUE during recent years. Scenarios 4 - 7 have either different molting probabilities or trawl survey selectivities for two periods, thus solving the problems of temporal residual patterns. However, with an additional CV for the pot survey CPUE, scenarios 4-7 also down weight the pot survey data and result in biomass estimates quite different from the pot survey CPUE during recent years. With the poor performance of the commercial fishery during 2014/15 season and the trawl survey issue in station R-24 in 2015, the low pot survey CPUE in 2015 seems to be more reasonable than the high abundance estimated by the trawl survey in 2015. Scenario 9 has the same problem with scenarios 4 - 7, but with different pot survey selectivities for two periods, it fits the pot survey data better than scenarios 4 - 7.

Considering all the problems for scenarios T - 7 and 9 above, we would consider only the remaining scenarios for overfishing/overfished determination. With two different molting probabilities for two periods and without an additional CV for the pot survey CPUE, Scenario 8 has no temporal residual pattern issue and fits the data reasonable well. If we think that change in molting probability between two periods is real, then our choice will be scenario 8. However, it seems easier to explain the change in survey selectivities than molting probability over time and scenario 10 fits the data better than scenario 8 (Table 10). Therefore, scenario 10 is a better choice than scenario 8. Scenario 11 shows the annual change in trawl survey selectivities over time and fits the data well. Considering there are 35 more estimated parameters with scenario 11 than with scenario 10, statistically, scenario 10 fits the data better than scenario 11 (Table 10).

Scenarios 10-4, 10-3, 10-2 and 10-0 provide interesting options to adjust the trawl survey CPUE in station R-24. Estimated trawl survey biomass and mature male biomass over time are very close among these four scenarios and scenario 10 (Figures 19 and 20). With the reduction of trawl survey CPUE in station R-24, the estimated trawl survey biomasses are closer to the observed values with these four scenarios than scenario 10 (Figure 19).

We also used scenario 9 to show the impact with an additional CV for the pot survey CPUE. The reduction of trawl survey CPUE in station R-24 results in lower biomass estimates during recent years with scenarios 9-4 and 9-0 than with scenario 9 (Figures 21 and 22).

Among scenarios 10-4, 10-3, 10-2 and 10-0, completely throwing out the data in R-24 provides an interesting comparison but seems not a valid option. Therefore, we will eliminate scenario 10-0 for consideration for overfishing/overfished determination. Choice among scenarios 10-4, 10-3, and 10-2 depends on high density area definition in station R-24. Based on Table 7, it seems more reasonable to define 40% of pot survey stations as high density area rather than 20% or 30%. So, we select scenario 10-4 as an option to compare with scenario 10. Estimates of biomass and OFL are almost the same between these two scenarios, primarily due to the pot survey data in 2015 and change in trawl survey biomass CV estimates between them. Without the pot survey in 2015, the difference exists as shown in the retrospective analysis (Figures 17 and 18). The fit to data other than the trawl survey data is slightly better with scenario 10-4 than with scenario 10 (Table 10). Estimated trawl survey selectivities during 2000-2015 are lower for scenario 10-4 than scenario 10 (Figures 8 and 9; Table 9). Although both scenario 10 and 10-4 are a good choice for using for overfishing/overfished determination, we would prefer scenario 10-4 over scenario 10, based on the reasons above.

The remaining question is what reasons cause the trawl survey selectivities greater than 1 when selecting scenario 10 or scenario 10-4. Since we assume trawl survey catchability to be 1, the trawl survey selectivities are a combination of the catchability and selectivities. If the catchability is greater than 1, then selectivities can be less than 1. Trawl survey catchability was estimated to be greater than 1 in the past for this stock (Collie et al. 2005). During our past modeling experience with this stock, the catchability would be greater than 1 if estimated in the model like Collie et al. (2005). The spatial distribution of blue king crab around the island and the systematic design of survey stations may be the reason for catchability greater than 1. The area-swept estimate of abundance in station R-24 is an example for abundance overestimation. Much more field work may be needed to completely answer this question.

In summary, we recommend scenario 10-4 be used for overfishing/overfished determination for this stock in 2015. The CPT selected scenario 1 in September 2015.

F. Calculation of the OFL and ABC

The overfishing level (OFL) is the fishery-related mortality biomass associated with fishing mortality F_{OFL}. The SMBKC stock is currently managed as Tier 4 (2013 SAFE), and only a Tier 4 analysis is presented here. Thus given stock estimates or suitable proxy values of B_{MSY} and F_{MSY}, along with two additional parameters α and β, F_{OFL} is determined by the control rule

$$a)\quad F_{OFL} = F_{MSY}\text{, } when\ \ B/B_{MSY} > 1;$$

$$b)\quad F_{OFL} = F_{MSY}\,(B/B_{MSY} - \alpha)/(1-\alpha),\ when\ \ \beta < B/B_{MSY} \le 1;$$

$$c)\quad F_{OFL} < F_{MSY}\ \ with\ directed\ \ fishery\ F = 0,\ when\ \ B/B_{MSY} \le \beta\ ,$$

where B is quantified as mature-male biomass MMB_{mating}, at mating with time of mating assigned a nominal date of Feb 15. Note that as B itself is a function of the fishing mortality F_{OFL}, in case b) numerical approximation of F_{OFL} is required. As implemented for this assessment, all calculations proceed according to the model equations given in Appendix A. In particular, the OFL catch is computed using equations [A3], [A4], and [A5], with F_{OFL} 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 -2015, to define a B_{MSY} proxy in terms of average estimated MMB_{mating} and to put $\gamma = 1.0$ 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, and MMB in 2015 for 18 scenarios are summarized in Table 10. Figures 23 and 24 illustrate respectively the MMB and OFL probabilities in 2015 for scenarios 10 and 10-4 using the mcmc appproach. ABC is 80% of the OFL.

OFL, ABC, retained catch and bycatches for 2015 are summarized for scenarios 10 and 10-4 below:

	OFL	ABC	Ret. catch	Pot male bycatch	Groundfish bycatch
Scen. 1 (1000t):	0.2799	0.2239	0.2661	0.0137	0.0002
(million lbs):	0.6171	0.4936	0.5866	0.0301	0.0005
Scen. 10 (1000t):	0.1560	0.1248	0.1495	0.0064	0.0001
(million lbs):	0.3440	0.2752	0.3296	0.0141	0.0003
Scen.10-4 (1000t):	0.1616	0.1292	0.1545	0.0069	0.0001
(million lbs):	0.3562	0.2849	0.3407	0.0152	0.0003

G. Rebuilding Analysis

This stock is not currently subject to a rebuilding plan.

H. Data Gaps and Research Priorities

1. Growth increments and molting probabilities as a function of size.
2. Trawl survey catchability and selectivities.
3. Temporal changes in spatial distributions near the island.
4. Natural mortality.

I. Projections and Future Outlook

With the decline of estimated population biomass during recent years, outlook for this stock is not promising. If the decline continues, the stock will fall to depleted status soon.

J. Acknowledgements

We thank the Crab Plan Team, Joel Webb and Shareef Siddeek for reviewing the earlier draft of this manuscript. Some materials in the report are from the SAFE report prepared by Bill Gaeuman in 2014.

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Table 1. The 1978/79 – 2014/15 directed St. Matthew Island blue king crab pot fishery. Source: Fitch et al. 2012; ADF&G Dutch Harbor staff, pers. comm.

			Harvest[b]					
season	dates	GHL/TAC[a]	crab	pounds	pot lifts	CPUE[c]	avg wt[d]	avg CL[e]
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	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	10/15-12/05	0.66	69,109	308,582	10,133	7	4.5	132.3

[a] Guideline Harvest Level/Total Allowable Catch in millions of pounds.
[b] Includes deadloss.
[c] Harvest number/pot lift.
[d] Harvest weight/harvest number, in pounds.
[e] Average CL of retained crab in millimeters, from dockside sampling of delivered crab.

Table 2a. NMFS EBS trawl-survey area-swept estimates of male crab abundance (10^6 crab) and of mature male biomass (10^6 lbs). Total number of captured male crab ≥ 90 mm CL is also given. Source: R.Foy, NMFS. The "+" refers to plus group.

	abundance					biomass		
year	stage 1 (90-104mm CL)	stage 2 (105-119mm CL)	stage 3 (120mm+ CL)	Total	CV	Total (90mm+ CL)	CV	number of crab
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
1999	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

Table 2b. NMFS EBS trawl-survey area-swept estimates of male crab abundance (10^6 crab) and of mature male biomass (10^6 lbs). Total number of captured male crab ≥ 90 mm CL is also given. The CPUE in station R-24 is reduced by a factor 0.4*(401-25)/401, or 37.51%. Source: Doug Pengilly, ADF&G.. The "+" refers to plus group. The table corresponds to the data used in scenarios 9-4 and 10-4.

	abundance					biomass		
year	stage 1 (90-104mm CL)	stage 2 (105-119mm CL)	stage 3 (120mm+ CL)	Total	CV	Total (90mm+ CL)	CV	number of crab
1978	1.975	1.753	1.348	5.075	0.430	13.360	0.410	157
1979	3.035	2.256	1.808	7.099	0.476	17.519	0.466	178
1980	2.833	2.430	2.474	7.738	0.588	21.311	0.523	185
1981	0.483	1.213	2.247	3.943	0.370	14.389	0.403	140
1982	1.669	2.431	5.865	9.965	0.402	35.696	0.345	271
1983	1.061	1.651	3.345	6.057	0.332	21.240	0.298	231
1984	0.435	0.475	1.452	2.362	0.176	8.920	0.181	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	0.307	0.613	0.696	1.616	0.308	4.857	0.297	71
1988	0.385	0.791	0.932	2.109	0.290	6.751	0.256	81
1989	2.169	1.154	1.766	5.089	0.315	13.878	0.273	208
1990	1.053	1.013	2.229	4.295	0.308	14.393	0.279	170
1991	1.128	1.568	2.155	4.851	0.263	14.714	0.252	197
1992	1.040	1.175	2.153	4.368	0.186	14.412	0.180	220
1993	1.439	1.729	3.128	6.297	0.179	20.005	0.160	324
1994	0.823	1.239	2.138	4.200	0.179	13.730	0.170	211
1995	0.969	1.114	1.648	3.731	0.181	11.844	0.168	178
1996	0.995	1.556	2.952	5.503	0.230	19.021	0.226	285
1997	0.873	1.566	3.185	5.624	0.228	19.366	0.217	296
1998	0.591	1.266	2.317	4.175	0.299	14.315	0.277	243
1999	0.206	0.222	0.558	0.986	0.194	3.492	0.183	52
2000	0.282	0.248	0.703	1.232	0.309	4.356	0.317	61
2001	0.399	0.482	0.899	1.779	0.246	5.975	0.248	91
2002	0.111	0.184	0.640	0.935	0.318	3.689	0.328	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	0.262	0.281	0.414	0.957	0.398	3.121	0.364	42
2006	0.862	0.642	1.240	2.744	0.345	8.506	0.337	126
2007	1.752	1.509	1.010	4.271	0.250	11.003	0.238	250
2008	1.316	0.693	1.403	3.411	0.294	9.710	0.288	167
2009	1.398	1.724	1.288	4.410	0.187	12.010	0.187	251
2010	2.082	2.174	2.155	6.411	0.337	17.585	0.287	388
2011	1.070	1.968	2.208	5.245	0.365	15.764	0.343	318
2012	0.517	1.473	1.517	3.507	0.214	10.890	0.203	193
2013	0.294	0.411	0.766	1.471	0.201	4.684	0.206	74
2014	0.500	0.997	1.420	2.917	0.339	9.809	0.304	181
2015	0.492	0.711	0.997	2.200	0.577	6.747	0.567	153

Table 2c. NMFS EBS trawl-survey area-swept estimates of male crab abundance (10^6 crab) and of mature male biomass (10^6 lbs). Total number of captured male crab ≥ 90 mm CL is also given. Assuming that no tows were made in station R-24. Source: Doug Pengilly, ADF&G. The "+" refers to plus group?? The table corresponds to the data used in scenarios 9-0 and 10-0.

	abundance					biomass		
	stage 1	stage 2	stage 3			Total		number
year	(90-104mm CL)	(105-119mm CL)	(120mm+ CL)	Total	CV	(90mm+ CL)	CV	of crab
1978	1.831	1.609	1.244	4.685	0.463	12.338	0.440	127
1979	3.020	2.240	1.808	7.068	0.477	17.462	0.467	176
1980	2.820	2.350	2.434	7.605	0.598	20.887	0.534	175
1981	0.483	1.213	2.237	3.933	0.370	14.356	0.404	139
1982	1.669	2.431	5.854	9.954	0.402	35.656	0.344	270
1983	1.061	1.651	3.345	6.057	0.332	21.240	0.298	231
1984	0.435	0.463	1.452	2.349	0.177	8.887	0.181	104
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	0.387	46
1987	0.296	0.602	0.685	1.583	0.314	4.757	0.302	68
1988	0.371	0.776	0.917	2.064	0.296	6.625	0.260	78
1989	2.169	1.154	1.754	5.077	0.316	13.820	0.274	207
1990	1.053	1.002	2.164	4.218	0.314	14.126	0.284	163
1991	1.116	1.509	2.108	4.734	0.269	14.352	0.258	187
1992	1.019	1.051	2.070	4.140	0.190	13.675	0.183	198
1993	1.389	1.670	3.040	6.099	0.182	19.377	0.162	304
1994	0.787	1.203	2.066	4.057	0.183	13.318	0.173	199
1995	0.936	1.069	1.592	3.598	0.186	11.405	0.172	166
1996	0.850	1.354	2.885	5.089	0.236	17.985	0.232	248
1997	0.698	1.168	2.822	4.688	0.190	16.535	0.192	216
1998	0.550	1.029	1.998	3.577	0.308	12.352	0.281	185
1999	0.195	0.222	0.558	0.975	0.196	3.478	0.184	51
2000	0.282	0.226	0.681	1.188	0.318	4.195	0.327	57
2001	0.387	0.470	0.875	1.732	0.251	5.815	0.253	87
2002	0.111	0.157	0.640	0.908	0.327	3.610	0.334	37
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	0.227	0.264	0.362	0.853	0.434	2.821	0.391	36
2006	0.829	0.642	1.240	2.711	0.349	8.459	0.338	123
2007	1.292	1.203	0.901	3.395	0.183	9.045	0.194	170
2008	1.294	0.628	1.370	3.293	0.303	9.380	0.297	156
2009	1.293	1.462	1.214	3.969	0.179	10.880	0.182	209
2010	0.968	1.526	1.973	4.467	0.221	13.411	0.218	217
2011	0.631	1.195	1.608	3.434	0.199	10.761	0.205	161
2012	0.404	1.175	1.343	2.922	0.171	9.222	0.166	136
2013	0.269	0.386	0.742	1.398	0.206	4.468	0.212	68
2014	0.367	0.618	1.186	2.171	0.300	7.718	0.275	114
2015	0.191	0.376	0.408	0.976	0.344	3.020	0.293	47

Table 3. Observed proportion of crab by size class during ADF&G crab observer pot-lift sampling. Source: ADF&G Crab Observer Database.

year	pot lifts (sampled/total)	number of crab (90 mm+ CL)	stage 1 (90-104 mm CL)	stage 2 (105-119 mm CL)	stage 3 (120 mm+ CL)
1990/91	10/26,264	150	0.113	0.393	0.493
1991/92	125/37,104	3,393	0.133	0.177	0.690
1992/93	71/56,630	1,606	0.191	0.268	0.542
1993/94	84/58,647	2,241	0.281	0.210	0.510
1994/95	203/60,860	4,735	0.294	0.271	0.434
1995/96	47/48,560	663	0.148	0.212	0.640
1996/97	96/91,085	489	0.160	0.223	0.618
1997/98	133/81,117	3,195	0.182	0.205	0.613
1998/99	135/91,826	1,322	0.193	0.216	0.591
1999-2008			**FISHERY CLOSED**		
2009/10	989/10,484	19,802	0.141	0.324	0.535
2010/11	2,419/29,356	45,466	0.131	0.315	0.553
2011/12	3,359/48,554	58,666	0.131	0.305	0.564
2012/13	2,841/37,065	57,298	0.141	0.318	0.541
2013/14			**FISHERY CLOSED**		
2014/15	895/10,133	9,906	0.094	0.228	0.679

Table 4. Size-class and total CPUE (90 mm+ CL) and estimated CV and total number of captured crab (90 mm+ CL) from the 96 common stations surveyed during the six triennial ADF&G SMBKC pot surveys. Source: D.Pengilly and R.Gish, ADF&G.

year	stage 1 (90-104mm CL)	stage 2 (105-119mm CL)	stage 3 (120mm+ CL)	Total CPUE	CV	number of crab
1995	1.919	3.198	6.922	12.042	0.13	4,624
1998	0.964	2.763	8.804	12.531	0.06	4,812
2001	1.266	1.737	5.487	8.477	0.08	3,255
2004	0.112	0.414	1.141	1.667	0.15	640
2007	1.086	2.721	4.836	8.643	0.09	3,319
2010	1.326	3.276	5.607	10.209	0.13	3,920
2013	0.878	1.398	3.367	5.643	0.19	2,167
2015	0.198	0.682	1.924	2.805	0.18	1,077

Table 5. Groundfish SMBKC male bycatch biomass (10^3 pounds) estimates. Source: J. Zheng, ADF&G, and author estimates based on data from R. Foy, NMFS. AKRO estimates used after 2008/09.

year	bycatch: trawl[a]	bycatch: fixed gear	total mortality[b]
1991/92	7.8	0.1	6.3
1992/93	4.4	5.0	6.0
1993/94	3.4	0.0	2.7
1994/95	0.7	0.2	0.7
1995/96	1.4	0.3	1.3
1996/97	0.0	0.1	0.1
1997/98	0.0	0.4	0.2
1998/99	0.0	2.0	1.0
1999/00	0.0	3.0	1.5
2000/01	0.0	0.0	0.0
2001/02	0.0	1.9	1.0
2002/03	1.6	0.9	1.7
2003/04	2.2	2.5	3.0
2004/05	0.2	1.4	0.9
2005/06	0.0	1.3	0.7
2006/07	6.2	3.2	6.6
2007/08	0.1	153.7	76.9
2008/09	0.6	14.6	7.8
2009/10	1.4	16.6	9.4
2010/11	0.8	21.1	11.2
2011/12	0.4	1.3	1.0
2012/13	1.3	0.0	1.0
2013/14	0.4	0.6	0.6
2014/15	0.0	0.3	0.2

[a] Trawl, pelagic trawl, and non-pelagic trawl gear types.
[b] Assuming handling mortalities of 0.8 for trawl and 0.5 for fixed gear.

Table 6. Density (number of crab per sq-nm) of male blue king crab ≥ 90 mm CL in trawl station R-24 relative to the single-tow and multi-tow strata averages.

	R-24	SM single-tow stratum (without R-24)				SM multi-tow stratum			
Year	Density	N tows	Average density	Sample Std Dev	(R-24 - Avg)/(St. D.)	N tows	Average density	Sample Std Dev	(R-24 - Avg)/(St. D.)
1978	2,531.8	38	299.7	855.5	2.61	0	-	-	-
1979	202.6	36	489.6	1,402.0	-0.20	0	-	-	-
1980	883.4	37	512.6	1,864.9	0.20	0	-	-	-
1981	64.3	36	265.3	589.1	-0.34	0	-	-	-
1982	73.7	39	636.5	1,598.2	-0.35	0	-	-	-
1983	0.0	26	60.8	220.4	-0.28	27	751.3	1,411.0	-0.53
1984	85.3	26	49.8	111.3	0.32	27	253.6	251.4	-0.67
1985	-	26	11.1	33.5	-	27	243.3	286.7	-
1986	0.0	26	17.9	77.7	-0.23	27	116.2	294.6	-0.39
1987	219.4	28	8.4	32.6	6.47	23	206.2	327.1	0.04
1988	294.9	28	9.4	36.3	7.87	26	271.4	428.2	0.05
1989	79.8	28	13.2	69.6	0.96	27	682.9	1,148.9	-0.52
1990	507.7	28	24.2	128.1	3.78	24	546.8	878.9	-0.04
1991	778.7	28	77.1	148.1	4.74	25	535.9	855.0	0.28
1992	1,510.8	28	52.7	145.0	10.05	27	491.6	519.6	1.96
1993	1,312.8	28	20.7	73.4	17.61	27	812.8	789.8	0.63
1994	950.2	28	22.4	74.4	12.48	26	527.1	511.6	0.83
1995	886.8	28	88.4	202.0	3.95	27	361.0	368.4	1.43
1996	2,753.0	28	16.4	48.8	56.05	26	679.5	845.1	2.45
1997	6,218.4	28	37.6	124.2	49.75	27	591.0	612.6	9.19
1998	3,971.3	28	24.2	82.7	47.73	27	457.9	782.8	4.49
1999	69.2	28	10.3	32.7	1.80	26	119.1	126.1	-0.40
2000	296.3	28	5.7	29.9	9.71	27	155.8	268.2	0.52
2001	316.8	28	0.0	0.0	-	27	239.9	312.7	0.25
2002	182.0	28	7.1	20.9	8.36	27	114.7	211.2	0.32
2003	0.0	28	0.0	0.0	-	27	165.4	343.0	-0.48
2004	0.0	28	4.7	25.1	-0.19	27	130.2	260.7	-0.50
2005	691.8	28	29.7	145.3	4.56	26	72.0	144.7	4.28
2006	218.3	28	15.2	56.6	3.59	27	351.9	675.8	-0.20
2007	5,821.9	28	22.4	54.2	106.93	27	435.6	440.6	12.23
2008	788.3	28	9.5	23.7	32.87	27	441.4	716.2	0.48
2009	2,929.6	28	53.0	139.8	20.58	27	467.4	465.6	5.29
2010	12,920.7	28	57.5	118.6	108.47	27	529.4	687.4	18.03
2011	12,041.2	28	62.3	204.5	58.57	27	378.8	379.9	30.70
2012	3,894.9	28	57.3	125.5	30.57	27	315.7	303.8	11.78
2013	487.1	28	24.5	54.1	8.56	27	155.6	190.5	1.74
2014	4,958.0	28	0.0	0.0	-	27	300.8	468.6	9.94
2015	8,140.7	28	2.3	12.3	661.43	27	131.6	241.2	33.20

Table 7. Pot survey station rank within trawl survey station R-24, male catch (>89 mm CL) in each station, and cumulative percentage of catch in 1998, 2013 and 2015. Two pot surveys were conducted in 2013, one with 10 stations and another with 20 stations. The highlighted is top 40% of total pot stations.

Station	1998		2013		2013		2015	
rank	Catch	Cumu.%	Catch	Cumu.%	Catch	Cumu.%	Catch	Cumu.%
1	43	43.88%	76	45.51%	63	18.86%	105	35.12%
2	27	71.43%	43	71.26%	53	34.73%	66	57.19%
3	8	79.59%	33	91.02%	48	49.10%	25	65.55%
4	7	86.73%	7	95.21%	38	60.48%	17	71.24%
5	4	90.82%	6	98.80%	30	69.46%	12	75.25%
6	4	94.90%	1	99.40%	30	78.44%	10	78.60%
7	2	96.94%	1	100.00%	22	85.03%	10	81.94%
8	2	98.98%	0	100.00%	19	90.72%	8	84.62%
9	1	100.00%	0	100.00%	11	94.01%	7	86.96%
10	0	100.00%	0	100.00%	5	95.51%	7	89.30%
11					3	96.41%	6	91.30%
12					2	97.01%	5	92.98%
13					2	97.60%	4	94.31%
14					2	98.20%	3	95.32%
15					2	98.80%	3	96.32%
16					2	99.40%	3	97.32%
17					1	99.70%	3	98.33%
18					1	100.00%	2	99.00%
19					0	100.00%	2	99.67%
20					0	100.00%	1	100.00%
Total	98		167		334		299	
Mean	9.8		16.7		16.7		14.95	

Table 8. Observed and effective sample sizes for trawl survey, pot survey, and observer data of the directed pot fishery.

	Observed Sample Sizes			Effective Sample Sizes							
				Scenario T			Scen. 0-11		Scen. 0, 00	Scen. 1-11	
Year	Trawl	Pot	Observer	Trawl	Pot	Observer	Trawl	Pot	Observer	Observer	
1978	157			50			50				
1979	178			50			50				
1980	185			50			50				
1981	140			50			50				
1982	271			50			50				
1983	231			50			50				
1984	105			50			50				
1985	93			50			46.5				
1986	46			46			23				
1987	71			50			35.5				
1988	81			50			40.5				
1989	208			50			50				
1990	170		150	50		100	50		15	15	
1991	197		3393	50		100	50		50	25	
1992	220		1606	50		100	50		50	25	
1993	324		2241	50		100	50		50	25	
1994	211		4735	50		100	50		50	25	
1995	178	4624	663	50	100	100	50	100	50	25	
1996	285		489	50		100	50		48.9	25	
1997	296		3195	50		100	50		50	25	
1998	243	4812	1323	50	100	100	50	100	50	25	
1999	52			50			26				
2000	61			50			30.5				
2001	91	3255		50	100		45.5	100			
2002	38			38			19				
2003	65			50			32.5				
2004	48	640		48	100		24	100			
2005	42			42			21				
2006	126			50			50				
2007	250	3319		50	100		50	100			
2008	167			50			50				
2009	251		19802	50		100	50		50	50	
2010	388	3920	45466	50	100	100	50	100	50	50	
2011	318		58667	50		100	50		50	50	
2012	193		57282	50		100	50		50	50	
2013	74	2167		50	100		37	100			
2014	181		9906	50		100	50		50	50	
2015	153	1077		50	100		50	100			

Table 9(T & 1). Model parameter estimates and standard deviations for scenarios T and 1. Ranges are given for log recruit, log fishing mortality and log trawl-survey selectivity deviations.

	Scenario T		Scenario 1	
parameter	estimate	standard dev.	estimate	standard dev.
1998/99 natural mortality	0.875	0.118	0.938	0.120
pot-survey catchability	4.416	0.352	3.987	0.317
trawl-survey stage-1 selectivity (1978-2015)	0.696	0.047	0.656	0.049
trawl-survey stage-2 selectivity (1978-2015)	0.944	0.055	0.913	0.054
pot-survey stage-1 selectivity	0.301	0.043	0.347	0.051
pot-survey stage-2 selectivity	0.732	0.072	0.720	0.064
pot-fishery stage-1 selectivity (1978-1998)	0.341	0.033	0.416	0.067
pot-fishery stage-2 selectivity (1978-1998)	0.518	0.041	0.658	0.061
pot-fishery stage-1 selectivity (2009-2014)			0.327	0.068
pot-fishery stage-2 selectivity (2009-2014)			0.807	0.100
log initial stage-1 abundance	8.212	0.203	8.238	0.170
log initial stage-2 abundance	7.779	0.227	7.791	0.197
log initial stage-3 abundance	7.428	0.243	7.426	0.219
mean log recruit abundance	6.735	0.051	6.815	0.050
mean log recruit abundance deviations (37)	[-1.92, 1.56]	[0.15, 0.54]	[-1.91, 1.53]	[0.16, 0.49]
mean log pot-fishery fishing mortality	-1.388	0.057	-1.436	0.055
log pot-fishery fishing mortality dev. (26)	[-3.18, 1.31]	[0.08, 0.27]	[-3.14, 1.29]	[0.07, 0.24]
mean log GF trawl-gear fishing mortality	-10.454	0.220	-11.016	0.479
log GF trawl-gear fishing mortality dev. (24)	[-1.73, 1.69]	[0.70, 0.72]	[-4.45, 3.86]	[1.06, 3.65]
mean log GF fixed-gear fishing mortality	-9.584	0.215	-9.764	0.322
log GF fixed-gear fishing mortality dev. (24)	[-2.27, 2.60]	[0.69, 0.70]	[-5.64, 6.00]	[0.08, 3.23]

Table 9(8 & 11). Model parameter estimates and standard deviations for scenarios 8 and 11. Ranges are given for log recruit, log fishing mortality and log trawl-survey selectivity deviations.

	Scenario 8		Scenario 11	
parameter	estimate	standard dev.	estimate	standard dev.
1998/99 natural mortality	1.131	0.115	1.234	0.141
pot-survey catchability	3.779	0.290	3.697	0.292
trawl-survey stage-1 selectivity (1978-2015)	0.454	0.037		
trawl-survey stage-2 selectivity (1978-2015)	0.636	0.039		
initial trawl-survey stage-1 selectivity			1.112	0.174
Initial trawl-survey stage-2 selectivity			1.344	0.203
trawl-survey stage-1 & 2 selectivity deviations (37)			[-2.01, 1.40]	[0.15, 0.53]
pot-survey stage-1 selectivity (1995-2015)	0.154	0.025		
pot-survey stage-2 selectivity (1995-2015)	0.398	0.037		
pot-survey stage-1 selectivity (1995-1998)			0.253	0.070
pot-survey stage-2 selectivity (1995-1998)			0.382	0.064
pot-survey stage-1 selectivity (2001-2015)			0.413	0.066
pot-survey stage-2 selectivity (2001-2015)			0.919	0.087
pot-fishery stage-1 selectivity (1978-1998)	0.375	0.057	0.385	0.062
pot-fishery stage-2 selectivity (1978-1998)	0.540	0.051	0.549	0.054
pot-fishery stage-1 selectivity (2009-2014)	0.154	0.035	0.446	0.095
pot-fishery stage-2 selectivity (2009-2014)	0.363	0.049	0.839	0.105
molting probability for stage 1 (2000-2015)	0.416	0.030		
log initial stage-1 abundance	8.137	0.204	7.943	0.187
log initial stage-2 abundance	7.746	0.222	7.632	0.219
log initial stage-3 abundance	7.333	0.242	7.650	0.241
mean log recruit abundance	6.966	0.058	6.744	0.048
mean log recruit abundance deviations (37)	[-1.49, 1.30]	[0.17, 0.52]	[-1.79, 1.38]	[0.16, 0.42]
mean log pot-fishery fishing mortality	-1.274	0.059	-1.344	0.059
log pot-fishery fishing mortality dev. (26)	[-2.98, 1.44]	[0.08, 0.29]	[-3.16, 1.53]	[0.08, 0.25]
mean log GF trawl-gear fishing mortality	-11.296	0.477	-11.074	0.460
log GF trawl-gear fishing mortality dev. (24)	[-4.34, 3.64]	[1.06, 3.57]	[-4.68, 3.41]	[0.95, 3.33]
mean log GF fixed-gear fishing mortality	-10.107	0.318	-9.856	0.298
log GF fixed-gear fishing mortality dev. (24)	[-5.40, 5.11]	[1.00, 3.56]	[-4.79, 5.40]	[0.90, 3.55]

Table 9(10 & 10-4). Model parameter estimates and standard deviations for scenarios 10 and 10-4. Ranges are given for log recruit, log fishing mortality and log trawl-survey selectivity deviations.

	Scenario 10		Scenario 10-4	
parameter	estimate	standard dev.	estimate	standard dev.
1998/99 natural mortality	1.150	0.129	1.146	0.127
pot-survey catchability	3.740	0.291	3.745	0.274
trawl-survey stage-1 selectivity (1978-1999)	0.460	0.039	0.446	0.038
trawl-survey stage-2 selectivity (1978-1999)	0.604	0.042	0.575	0.040
trawl-survey stage-1 selectivity (2000-2015)	1.418	0.137	1.290	0.124
trawl-survey stage-2 selectivity (2000-2015)	1.551	0.130	1.427	0.119
pot-survey stage-1 selectivity (1995-1998)	0.240	0.066	0.235	0.065
pot-survey stage-2 selectivity (1995-1998)	0.368	0.060	0.375	0.061
pot-survey stage-1 selectivity (2001-2015)	0.420	0.069	0.436	0.073
pot-survey stage-2 selectivity (2001-2015)	0.968	0.092	0.939	0.089
pot-fishery stage-1 selectivity (1978-1998)	0.375	0.058	0.378	0.058
pot-fishery stage-2 selectivity (1978-1998)	0.538	0.051	0.534	0.050
pot-fishery stage-1 selectivity (2009-2014)	0.437	0.093	0.445	0.094
pot-fishery stage-2 selectivity (2009-2014)	0.817	0.100	0.836	0.101
log initial stage-1 abundance	8.062	0.172	8.039	0.172
log initial stage-2 abundance	7.650	0.191	7.627	0.190
log initial stage-3 abundance	6.904	0.232	6.833	0.235
mean log recruit abundance	6.711	0.047	6.719	0.044
mean log recruit abundance deviations (37)	[-1.88, 1.54]	[0.17, 0.50]	[-1.83, 1.51]	[0.16, 0.50]
mean log pot-fishery fishing mortality	-1.265	0.059	-1.247	0.058
log pot-fishery fishing mortality dev. (26)	[-2.99, 1.45]	[0.08, 0.30]	[-2.96, 1.48]	[0.08, 0.31]
mean log GF trawl-gear fishing mortality	-11.059	0.458	-11.063	0.458
log GF trawl-gear fishing mortality dev. (24)	[-4.69, 3.42]	[0.96, 3.51]	[-4.67, 3.93]	[0.95, 3.55]
mean log GF fixed-gear fishing mortality	-9.844	0.297	-9.848	0.296
log GF fixed-gear fishing mortality dev. (24)	[-5.78, 5.38]	[0.89, 3.56]	[-5.77, 5.36]	[0.90, 3.20]

Table 10a. Comparisons of negative log-likelihood values and management measures for eighteen model scenarios. Note that scenarios 10-0, 10-2, 10-3, and 10-4 are the same as scenario 10 except using different adjustments for station R-24. Biomass and OFL are in million lbs.

Model Scenario

Neg.log.LL	T	0	00	1	2	3	4	5	6	7	8	9	10	11	10-0	10-2	10-3	10-4
Ret catch	0.595	0.497	0.449	0.638	0.462	0.462	0.415	0.416	0.418	0.420	0.436	0.425	0.445	0.458	0.458	0.460	0.459	0.458
Trawl bio	37.937	37.182	37.387	38.233	36.852	36.759	25.698	25.687	25.496	26.043	31.565	25.194	29.993	25.610	25.190	26.945	27.699	28.255
Pot CPUE	69.541	69.812	69.200	67.202	1.388	1.383	-0.322	-0.498	-0.579	-0.276	37.535	-0.755	30.644	33.196	29.943	31.353	31.382	31.290
Trawl length	1925.87	-132.49	-133.36	-128.50	-144.98	-144.84	-160.56	-161.25	-162.55	-160.72	-158.63	-161.75	-160.16	-163.02	-159.09	-161.15	-161.37	-161.42
Pot length	688.46	-47.82	-47.82	-45.58	-48.14	-48.23	-45.16	-45.63	-46.56	-44.97	-44.28	-48.99	-47.53	-48.31	-48.38	-48.12	-48.03	-47.95
Obser length	1307.40	-60.51	-60.78	-53.56	-53.93	-53.96	-53.64	-54.48	-54.38	-53.58	-54.24	-53.87	-53.73	-54.04	-54.54	-54.42	-54.36	-54.27
Obser Bio1				19.519	19.581	19.475	18.393	17.563	17.742	18.893	18.213	18.080	18.116	18.341	18.778	18.562	18.486	18.423
Obser Bio2				0.597	0.612	0.611	0.679	0.699	0.706	0.681	0.735	0.703	0.742	0.722	0.801	0.758	0.750	0.747
Trawl byc bio	17.495	17.503	0.171	0.171	0.167	0.167	0.171	0.171	0.172	0.171	0.174	0.173	0.178	0.176	0.177	0.177	0.177	0.178
Fix-g. byc bio	17.752	17.909	0.348	0.345	0.162	0.174	0.092	0.087	0.087	0.092	0.087	0.087	0.087	0.087	0.089	0.088	0.088	0.088
Select. Pen														8.524				
Rec Pen	13.747	13.667	13.776	13.009	10.671	10.614	12.885	8.825	9.677	12.897	11.595	13.686	17.933	15.513	18.474	17.421	17.401	17.470
Direct F pen	0.012	0.012	0.012	0.012	0.013	0.013	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.013	0.011	0.011	0.011	0.011
Trawl by F pen	13.545	13.557	0.961	0.966	0.946	0.948	0.972	0.973	0.974	0.970	0.987	0.984	1.053	1.043	1.045	1.048	1.049	1.050
Fix-g by F pen	16.136	16.302	0.869	0.868	0.891	0.893	0.873	0.811	0.822	0.874	0.780	0.863	0.863	0.862	0.854	0.856	0.857	0.858
Total	4108.48	-54.39	-118.78	-86.09	-175.30	-175.53	-199.49	-206.61	-207.96	-198.49	-155.02	-205.16	-161.36	-160.83	-166.18	-166.01	-165.40	-164.81
Total est para	126	126	126	128	129	130	132	131	133	131	129	133	132	167	132	132	132	132
Bmsy (mill.lbs)	8.146	8.081	8.069	8.185	8.457	8.402	7.743	8.138	7.997	8.0235	8.288	7.863	7.62	7.925	7.343	7.497	7.527	7.543
MMB2015	5.139	5.132	5.117	5.396	11.131	11.086	6.775	7.901	7.409	7.001	5.604	6.349	3.922	4.091	3.564	3.932	3.968	3.966
OFL2015	0.532	0.558	0.554	0.617	1.986	1.986	1.094	1.182	1.098	1.103	0.53	0.929	0.344	0.357	0.289	0.352	0.357	0.356
Fofl	0.106	0.107	0.107	0.112	0.18	0.18	0.155	0.174	0.165	0.155	0.115	0.141	0.083	0.083	0.077	0.085	0.085	0.085
ABC2015	0.426	0.446	0.443	0.494	1.589	1.589	0.875	0.946	0.878	0.882	0.424	0.743	0.275	0.286	0.231	0.282	0.286	0.285

Table 10b. Comparisons of differences of negative log-likelihood values and number of parameters between different model scenarios.

	Model Scenario											
Neg.log.LL	2 - 1	3 - 2	4 - 3	5 - 4	6 - 4	7 - 4	8 - 5	9 - 7	10 - 9	10 - 7	8 - 10	11 - 10
Ret catch	-0.176	0.000	-0.047	0.001	0.003	0.005	0.019	0.005	0.020	0.025	-0.010	0.013
Trawl bio	-1.381	-0.092	-11.061	-0.011	-0.202	0.345	5.878	-0.849	4.799	3.950	1.572	-4.383
Pot CPUE	-65.814	-0.004	-1.705	-0.176	-0.257	0.046	38.033	-0.479	31.399	30.920	6.890	2.552
Trawl length	-16.480	0.148	-15.725	-0.688	-1.984	-0.160	2.622	-1.026	1.587	0.561	1.533	-2.863
Pot length	-2.557	-0.097	3.076	-0.469	-1.408	0.190	1.350	-4.027	1.466	-2.561	3.252	-0.782
Obser length	-0.362	-0.038	0.320	-0.834	-0.732	0.062	0.242	-0.289	0.137	-0.152	-0.502	-0.305
Obser Bio1	0.062	-0.106	-1.083	-0.830	-0.650	0.500	0.650	-0.813	0.036	-0.777	0.096	0.225
Obser Bio2	0.015	-0.001	0.068	0.020	0.028	0.002	0.036	0.021	0.040	0.061	-0.007	-0.020
Trawl byc bio	-0.004	0.000	0.004	0.000	0.000	0.000	0.003	0.002	0.005	0.007	-0.004	-0.001
Fix-g. byc bio	-0.183	0.012	-0.082	-0.005	-0.005	-0.001	0.000	-0.004	0.000	-0.004	0.000	-0.001
Select pen	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	8.524
Rec Pen	-2.338	-0.056	2.271	-4.060	-3.208	0.012	2.770	0.788	4.247	5.036	-6.338	-2.420
Direct F pen	0.000	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
Trawl by F pen	-0.020	0.002	0.024	0.001	0.002	-0.002	0.014	0.014	0.070	0.083	-0.066	-0.011
Fix-g by F pen	0.023	0.001	-0.019	-0.063	-0.052	0.001	-0.031	-0.011	0.000	-0.011	-0.083	-0.001
Total	-89.213	-0.231	-23.961	-7.115	-8.464	1.000	51.584	-6.668	43.804	37.136	6.333	0.529
Diff para.	1	1	2	-1	1	-1	-2	2	-1	1	-3	35

Table 11(1). Population abundances (N) by crab stage in millions of crab, mature male biomasses at survey (MMB) in millions of pounds on Feb. 15 for scenario 1. All abundances are at time of survey.

Year	N1	N2	N3	MMB
1978	3.782	2.419	1.678	10.058
1979	4.842	2.943	2.203	13.877
1980	4.219	3.805	3.266	20.947
1981	1.756	3.734	4.604	21.430
1982	1.876	2.217	4.780	15.587
1983	1.013	1.760	3.410	9.631
1984	0.866	1.107	2.021	6.761
1985	1.279	0.838	1.499	6.231
1986	1.896	0.998	1.282	6.272
1987	1.865	1.418	1.372	7.529
1988	1.653	1.538	1.646	8.454
1989	2.649	1.455	1.889	9.711
1990	1.719	2.009	2.082	10.700
1991	2.467	1.643	2.390	9.989
1992	2.717	1.931	2.163	10.338
1993	2.970	2.176	2.269	11.233
1994	1.745	2.394	2.399	11.099
1995	1.848	1.752	2.432	10.826
1996	2.151	1.619	2.311	9.926
1997	1.306	1.747	2.144	8.600
1998	0.852	1.284	1.800	4.240
1999	0.456	0.415	0.691	3.579
2000	0.479	0.405	0.785	3.914
2001	0.479	0.416	0.859	4.218
2002	0.215	0.419	0.926	4.478
2003	0.454	0.266	0.983	4.343
2004	0.293	0.354	0.954	4.435
2005	0.656	0.290	0.974	4.365
2006	0.970	0.481	0.958	4.740
2007	0.717	0.727	1.040	5.493
2008	1.252	0.647	1.205	6.058
2009	1.130	0.947	1.329	6.666
2010	1.058	0.968	1.483	6.220
2011	0.896	0.920	1.432	5.410
2012	0.582	0.803	1.231	4.643
2013	0.682	0.586	1.062	5.379
2014	0.619	0.594	1.180	5.472
2015	0.496	0.557	1.218	5.396

Table 11(8&11). Population abundances (N) by crab stage in millions of crab, mature male biomasses at survey (MMB) in millions of pounds on Feb. 15 for scenarios 8 and 11. All abundances are at time of survey.

	Scenario 8				Scenario 11			
Year	N1	N2	N3	MMB	N1	N2	N3	MMB
1978	3.214	2.056	1.033	6.743	2.815	2.063	2.100	10.925
1979	4.375	2.682	1.412	10.642	3.809	2.487	2.329	13.255
1980	4.143	3.732	2.385	17.446	3.682	3.309	3.062	19.040
1981	1.814	3.978	3.709	18.658	1.587	3.534	4.077	19.052
1982	1.887	2.535	4.023	13.377	1.820	2.241	4.133	13.180
1983	0.933	2.028	2.847	7.879	1.021	1.886	2.813	7.448
1984	0.804	1.246	1.609	5.508	0.861	1.248	1.521	5.172
1985	1.219	0.918	1.179	5.063	1.235	0.949	1.104	4.814
1986	1.568	1.070	1.022	5.440	1.705	1.087	0.973	5.284
1987	1.694	1.356	1.155	6.564	1.763	1.445	1.121	6.628
1988	1.565	1.539	1.391	7.519	1.538	1.612	1.403	7.724
1989	2.441	1.524	1.627	8.840	2.485	1.534	1.670	9.030
1990	1.572	2.072	1.849	9.986	1.551	2.102	1.889	10.203
1991	2.382	1.718	2.160	9.261	2.391	1.716	2.208	9.443
1992	2.581	2.070	1.953	9.853	2.597	2.074	1.992	10.012
1993	2.952	2.328	2.096	10.886	3.015	2.339	2.131	11.051
1994	2.174	2.643	2.255	11.114	2.215	2.686	2.290	11.342
1995	2.212	2.262	2.351	11.654	2.067	2.302	2.400	11.935
1996	2.457	2.169	2.422	11.601	2.470	2.093	2.481	11.662
1997	2.161	2.289	2.439	11.045	2.145	2.270	2.454	11.065
1998	1.609	2.126	2.243	5.699	1.215	2.108	2.247	5.295
1999	0.816	0.672	0.840	4.733	0.488	0.519	0.751	4.044
2000	0.952	0.761	1.016	5.608	0.417	0.498	0.870	4.450
2001	1.113	0.747	1.012	5.558	0.474	0.446	0.960	4.672
2002	0.824	0.785	1.005	5.618	0.217	0.463	1.011	4.901
2003	1.065	0.725	1.007	5.488	0.375	0.307	1.060	4.731
2004	0.858	0.757	0.996	5.521	0.282	0.349	1.029	4.709
2005	2.050	0.718	0.994	5.423	0.602	0.306	1.022	4.587
2006	2.615	1.037	0.984	6.113	0.832	0.492	0.997	4.912
2007	2.537	1.397	1.043	7.121	0.812	0.705	1.062	5.588
2008	3.361	1.589	1.162	8.058	1.096	0.762	1.203	6.314
2009	2.645	1.955	1.310	8.911	0.871	0.970	1.360	6.835
2010	2.297	1.966	1.415	8.286	0.913	0.895	1.489	6.087
2011	1.540	1.856	1.325	7.196	0.594	0.880	1.375	5.125
2012	1.092	1.562	1.097	5.923	0.342	0.667	1.138	4.018
2013	1.096	1.255	0.897	6.289	0.440	0.438	0.899	4.423
2014	0.925	1.095	1.018	6.017	0.316	0.438	0.956	4.279
2015	0.912	0.943	1.021	5.604	0.315	0.357	0.939	4.091

Table 11(10&10-4). Population abundances (N) by crab stage in millions of crab, mature male biomasses at survey (MMB) in millions of pounds on Feb. 15 for scenarios 10 and 10-4. All abundances are at time of survey.

	Scenario 10				Scenario 10-4			
Year	N1	N2	N3	MMB	N1	N2	N3	MMB
1978	3.173	2.101	0.996	6.697	3.100	2.053	0.928	6.317
1979	4.313	2.669	1.400	10.574	4.221	2.600	1.318	10.143
1980	4.174	3.688	2.369	17.285	4.297	3.604	2.269	16.712
1981	1.767	3.981	3.675	18.537	1.801	4.028	3.552	18.177
1982	1.947	2.506	3.995	13.210	1.979	2.541	3.912	12.963
1983	0.948	2.054	2.811	7.787	0.937	2.083	2.756	7.619
1984	0.803	1.263	1.590	5.473	0.810	1.265	1.556	5.345
1985	1.189	0.923	1.170	5.039	1.179	0.926	1.141	4.925
1986	1.572	1.053	1.018	5.383	1.564	1.047	0.995	5.282
1987	1.682	1.353	1.143	6.510	1.651	1.345	1.121	6.408
1988	1.555	1.530	1.380	7.456	1.542	1.508	1.358	7.323
1989	2.475	1.515	1.613	8.764	2.502	1.498	1.584	8.611
1990	1.550	2.089	1.833	9.965	1.540	2.100	1.801	9.869
1991	2.395	1.710	2.154	9.223	2.348	1.707	2.132	9.130
1992	2.576	2.075	1.945	9.834	2.618	2.044	1.924	9.689
1993	2.972	2.326	2.091	10.865	2.989	2.340	2.061	10.773
1994	2.223	2.655	2.251	11.124	2.230	2.669	2.231	11.082
1995	2.088	2.296	2.353	11.736	2.086	2.304	2.343	11.719
1996	2.510	2.105	2.439	11.524	2.374	2.106	2.435	11.514
1997	2.249	2.299	2.424	11.007	2.203	2.216	2.422	10.814
1998	1.285	2.182	2.235	5.677	1.345	2.125	2.196	5.539
1999	0.395	0.591	0.831	4.512	0.381	0.599	0.812	4.459
2000	0.347	0.466	0.970	4.757	0.365	0.460	0.958	4.698
2001	0.374	0.390	1.029	4.803	0.379	0.399	1.016	4.777
2002	0.185	0.379	1.042	4.827	0.194	0.386	1.035	4.819
2003	0.345	0.256	1.047	4.563	0.364	0.264	1.045	4.575
2004	0.266	0.311	0.994	4.490	0.269	0.326	0.996	4.533
2005	0.571	0.282	0.976	4.355	0.614	0.289	0.984	4.404
2006	0.785	0.464	0.947	4.659	0.811	0.493	0.958	4.766
2007	0.816	0.665	1.007	5.292	0.783	0.692	1.030	5.440
2008	1.111	0.750	1.140	6.046	1.155	0.740	1.171	6.142
2009	0.873	0.975	1.302	6.628	0.918	0.999	1.323	6.762
2010	0.933	0.898	1.442	5.930	0.863	0.935	1.471	6.112
2011	0.592	0.893	1.337	5.021	0.598	0.862	1.378	5.100
2012	0.320	0.670	1.113	3.937	0.330	0.664	1.134	3.994
2013	0.411	0.426	0.880	4.322	0.395	0.430	0.894	4.384
2014	0.281	0.415	0.935	4.146	0.304	0.407	0.948	4.177
2015	0.278	0.326	0.910	3.922	0.278	0.338	0.917	3.966

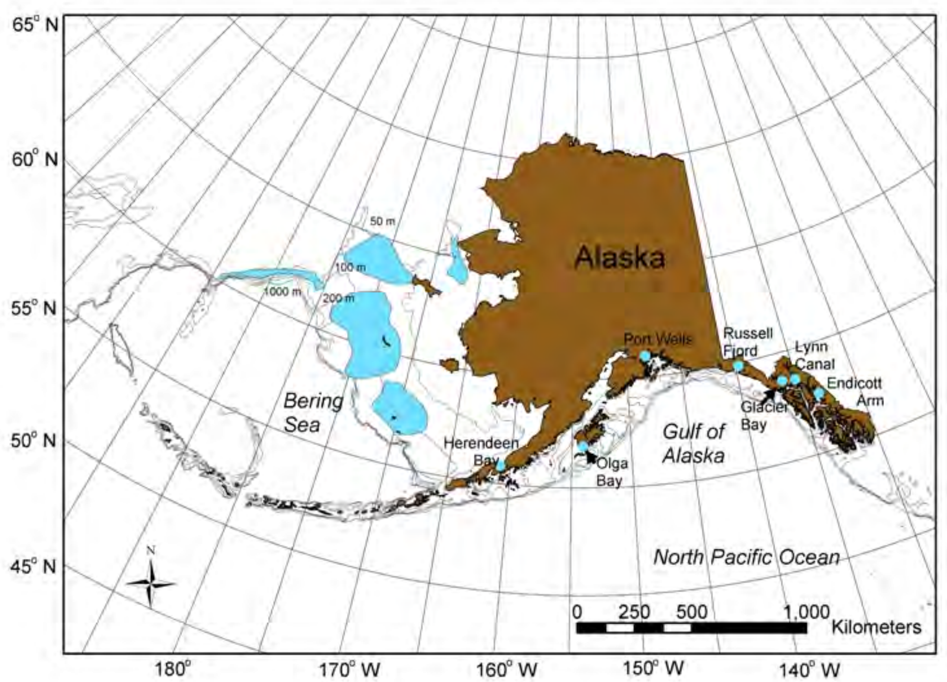


Figure 1. Distribution of blue king crab *Paralithodes platypus* in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters. Shown in blue.

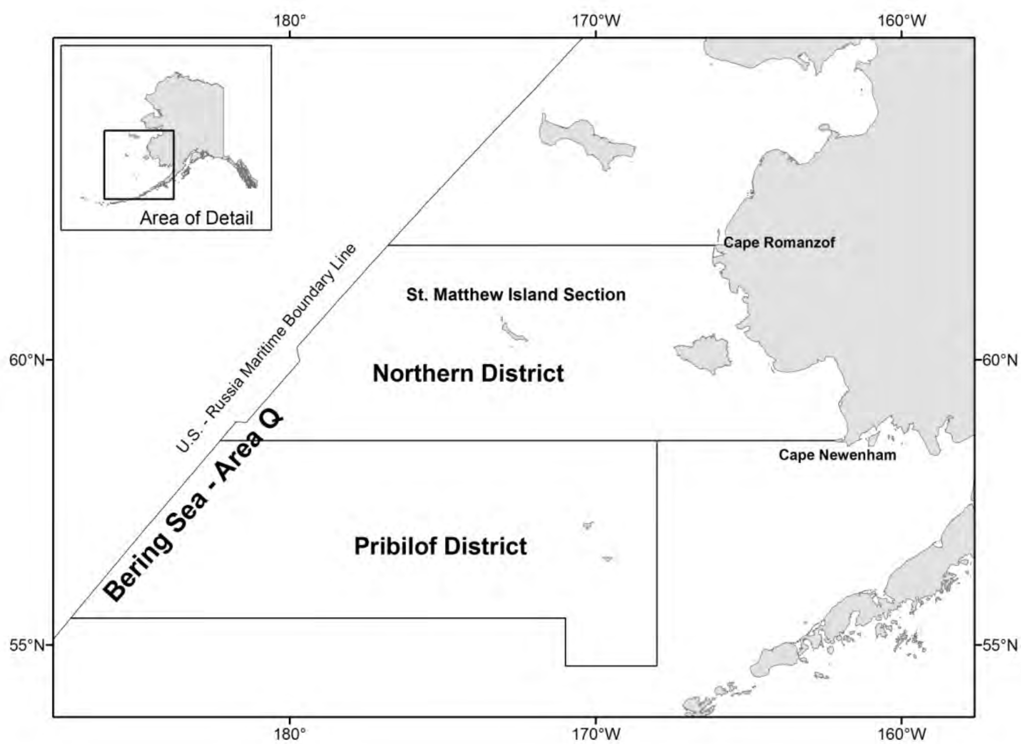


Figure 2. King crab Registration Area Q (Bering Sea).

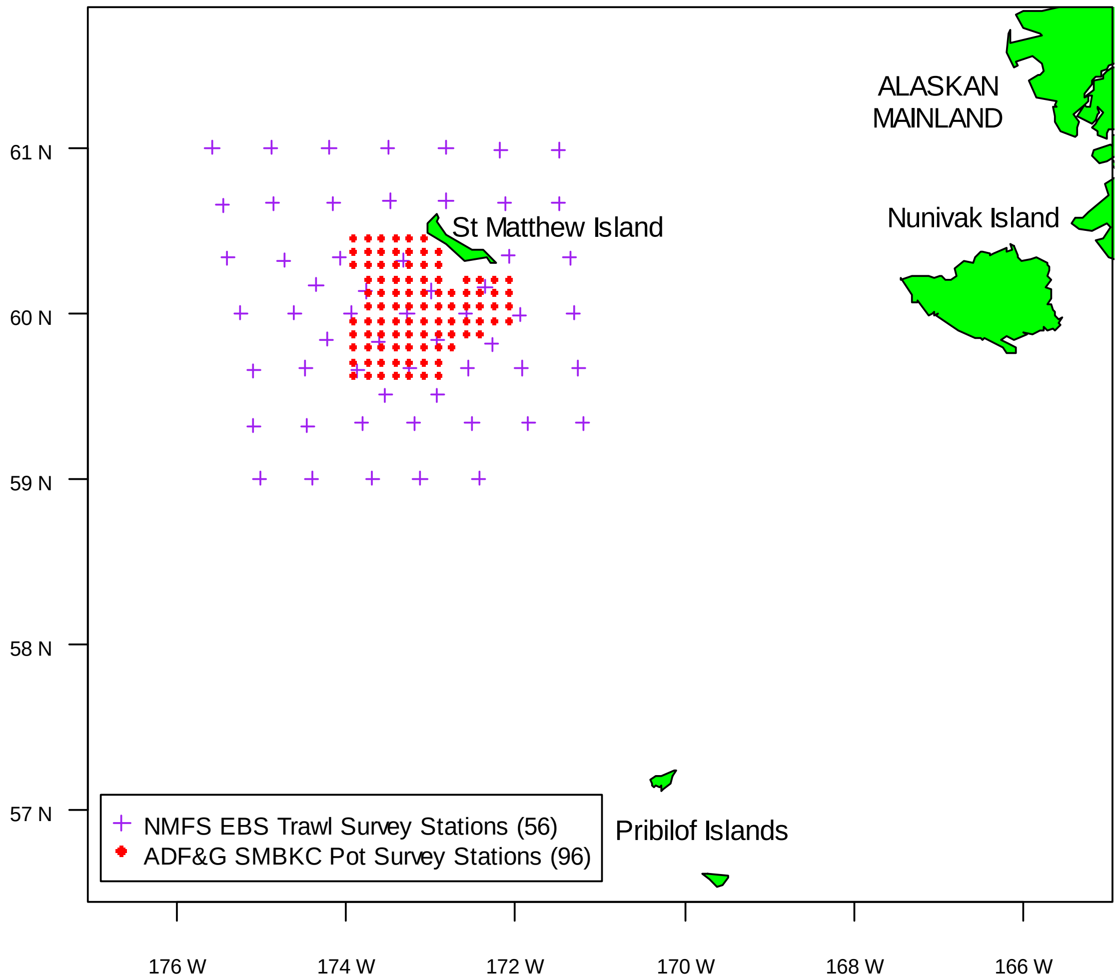


Figure 3. Trawl and pot-survey stations used in the SMBKC stock assessment.

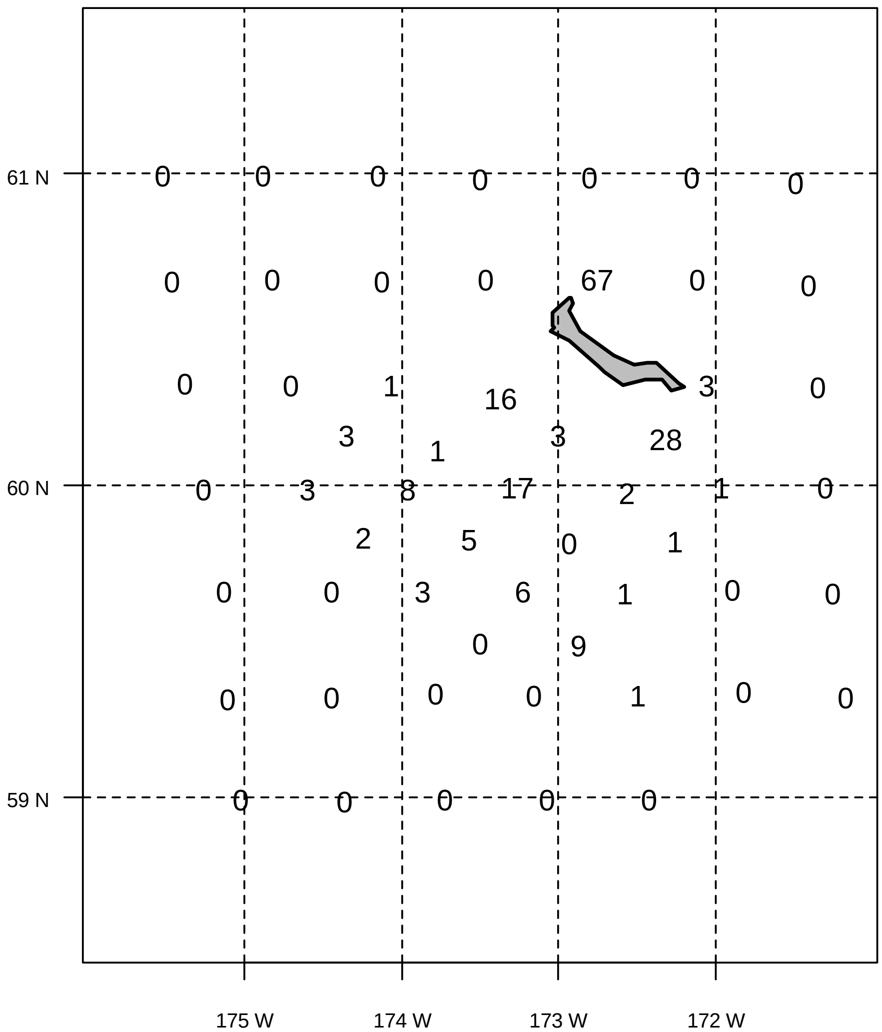


Figure 4. Catches of 181 male blue king crab measuring at least 90 mm CL from the 2014 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock. Note that the area north of St. Matthew Island, which includes the large catch of 67 crab at station R-24, is not represented in the ADF&G pot-survey data used in the assessment.

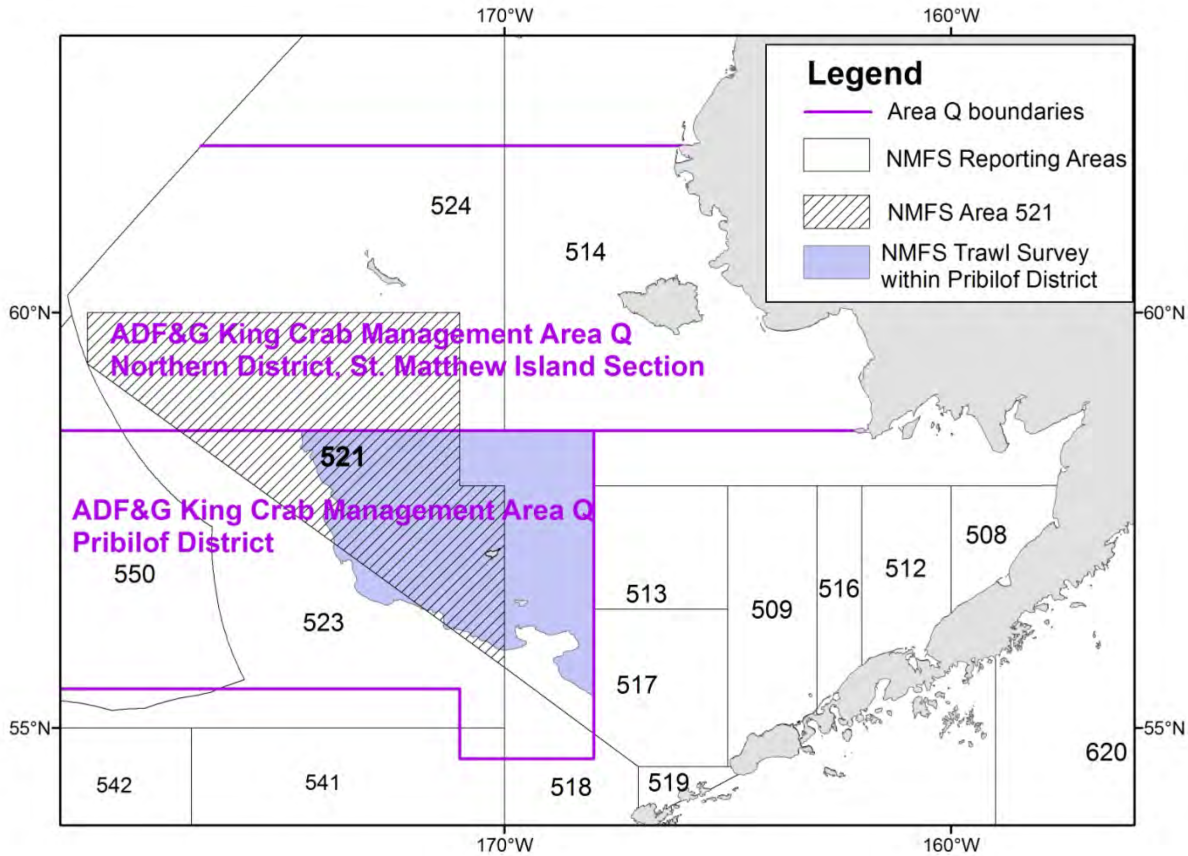


Figure 5. NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.

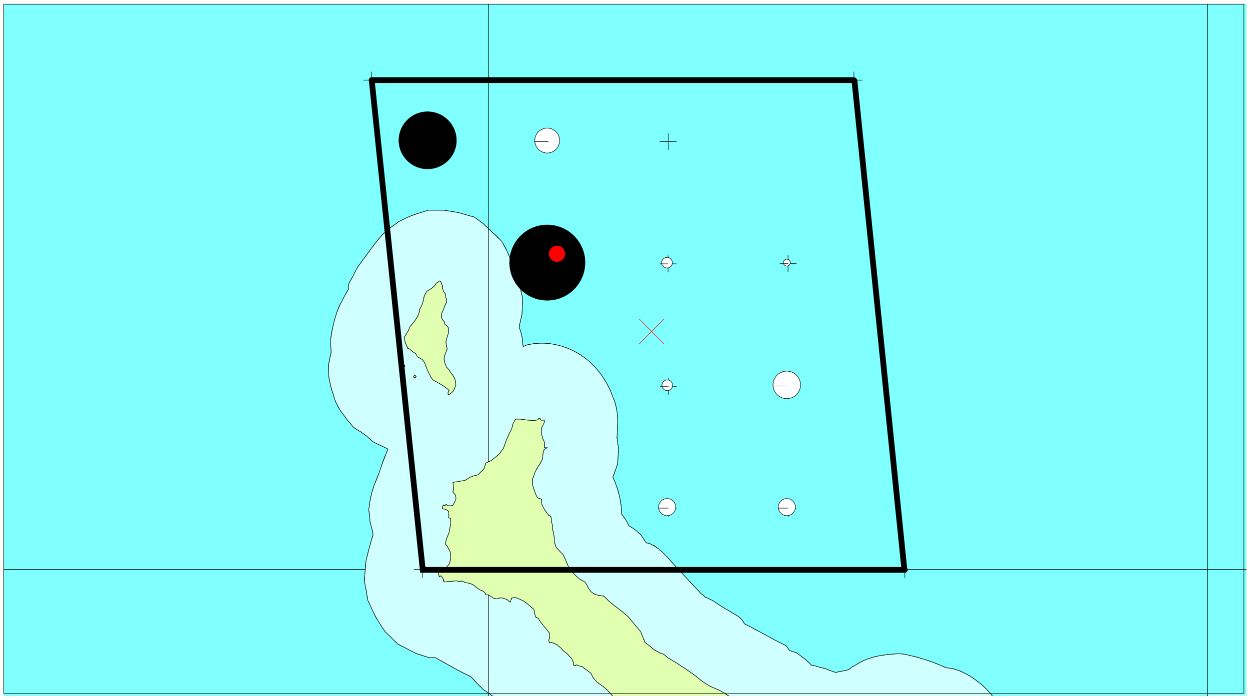


Figure 6a. ADF&G 1998 pot survey catch of male blue king crab ≥ 90 mm CL for the 10 standard (Stratum 1) stations fished during 17–19 August 1998 within NMFS trawl survey station R-24. Size (area) of circle is proportional to catch (largest = 43 crab). Black circles denote catch at a station was greater than the average catch for the 10 stations (10 crab); white circles denote catch at a station was less than the average catch for the 10 stations. Red circle is the centroid (‘center of gravity”) of distribution computed from the 10 stations. Red X is midpoint of the NMFS trawl survey tow performed in R-24 on 20 July 1998.

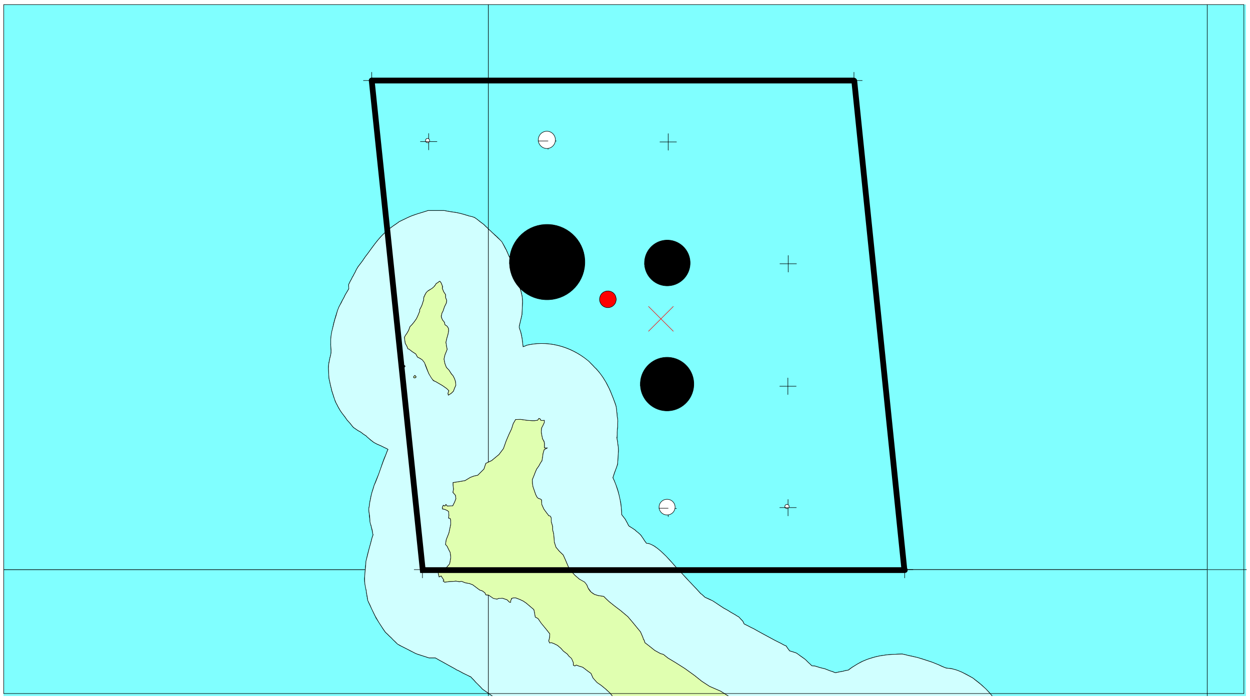


Figure 6b. ADF&G 2013 pot survey catch of male blue king crab ≥ 90 mm CL for the 10 standard (Stratum 1) stations fished during 21–25 September 2013 within NMFS trawl survey station R-24. Size (area) of circle is proportional to catch (largest = 76 crab). Black circles denote catch at a station was greater than the average catch for the 10 stations (17 crab); white circles denote catch at a station was less than the average catch for the 10 stations. Red circle is the centroid (‘center of gravity”) of distribution computed from the 10 stations. Red X is midpoint of the NMFS trawl survey tow performed in R-24 on 12 July 2013.

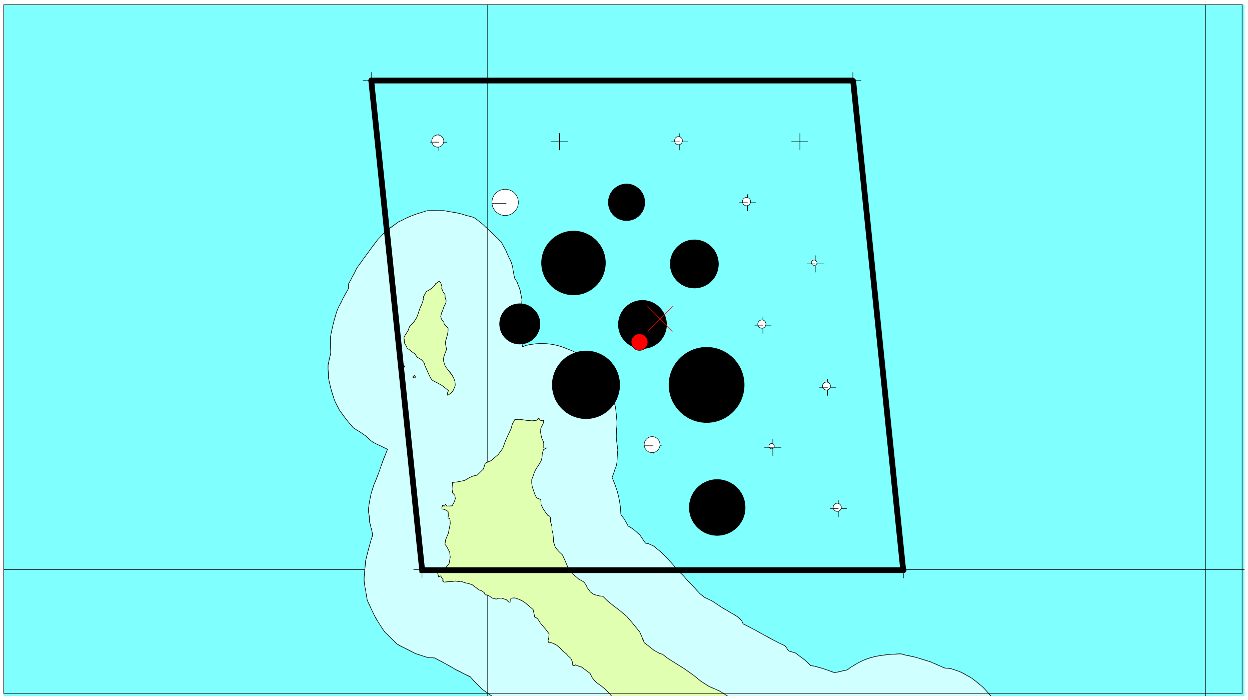


Figure 6c. ADF&G 2013 pot survey catch of male blue king crab ≥ 90 mm CL for the 20 special (Stratum 2) stations fished during 20–25 September 2013 within NMFS trawl survey station R-24. Size (area) of circle is proportional to catch (largest = 63 crab). Black circles denote catch at a station was greater than the average catch for the 20 stations (17 crab); white circles denote catch at a station was less than the average catch for the 20 stations. Red circle is the centroid ('center of gravity") of distribution computed from the 20 stations. Red X is midpoint of the NMFS trawl survey tow performed in R-24 on 12 July 2013.

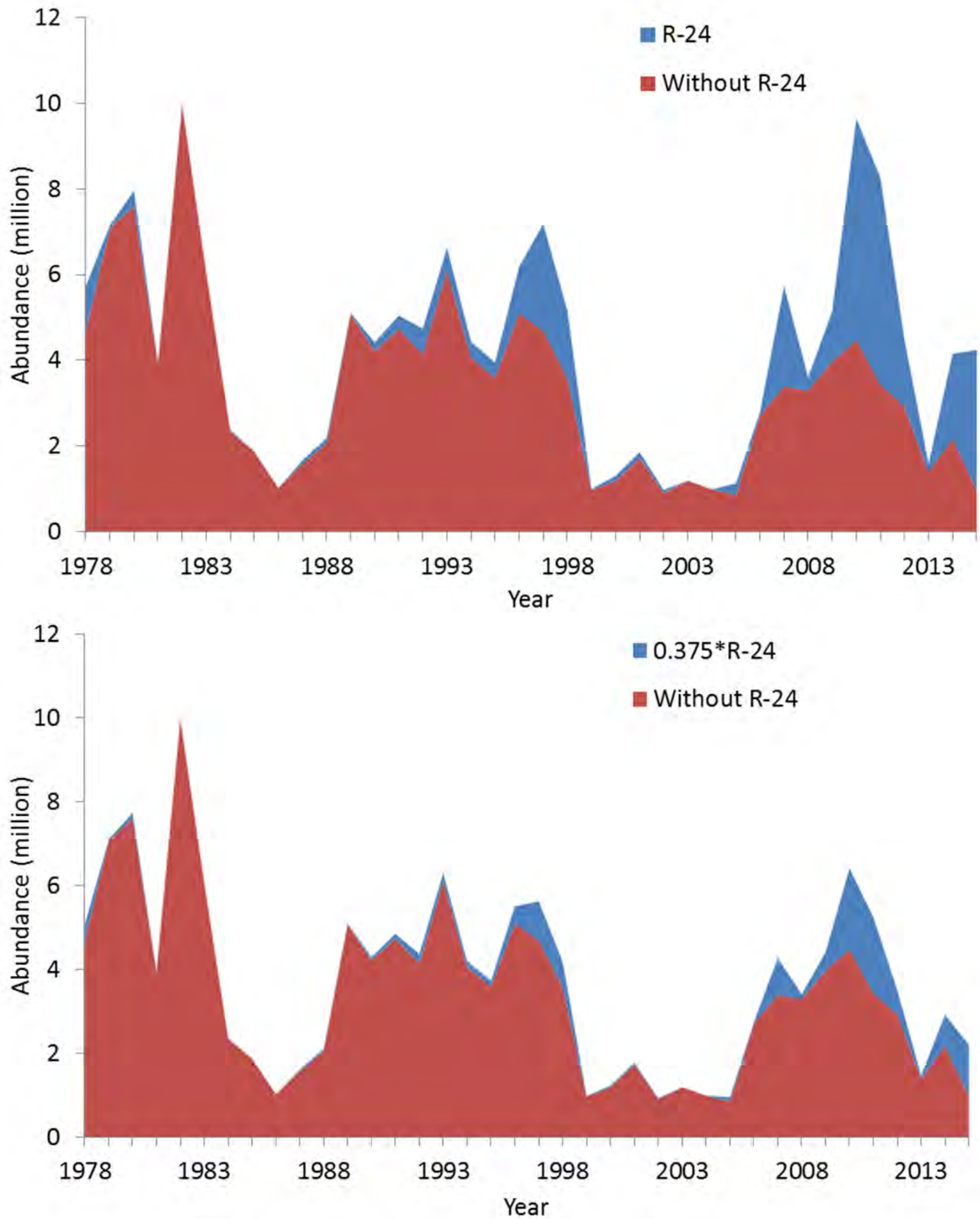


Figure 7. Comparisons of area-swept estimates of male (>89 mm CL) abundance without trawl survey station R-24, with reduction factor of 0.4*(401-25)/401, or 37.5%, applied to station R-24, and without reduction factor applied to station R-24 for St. Matthew Island blue king crab.

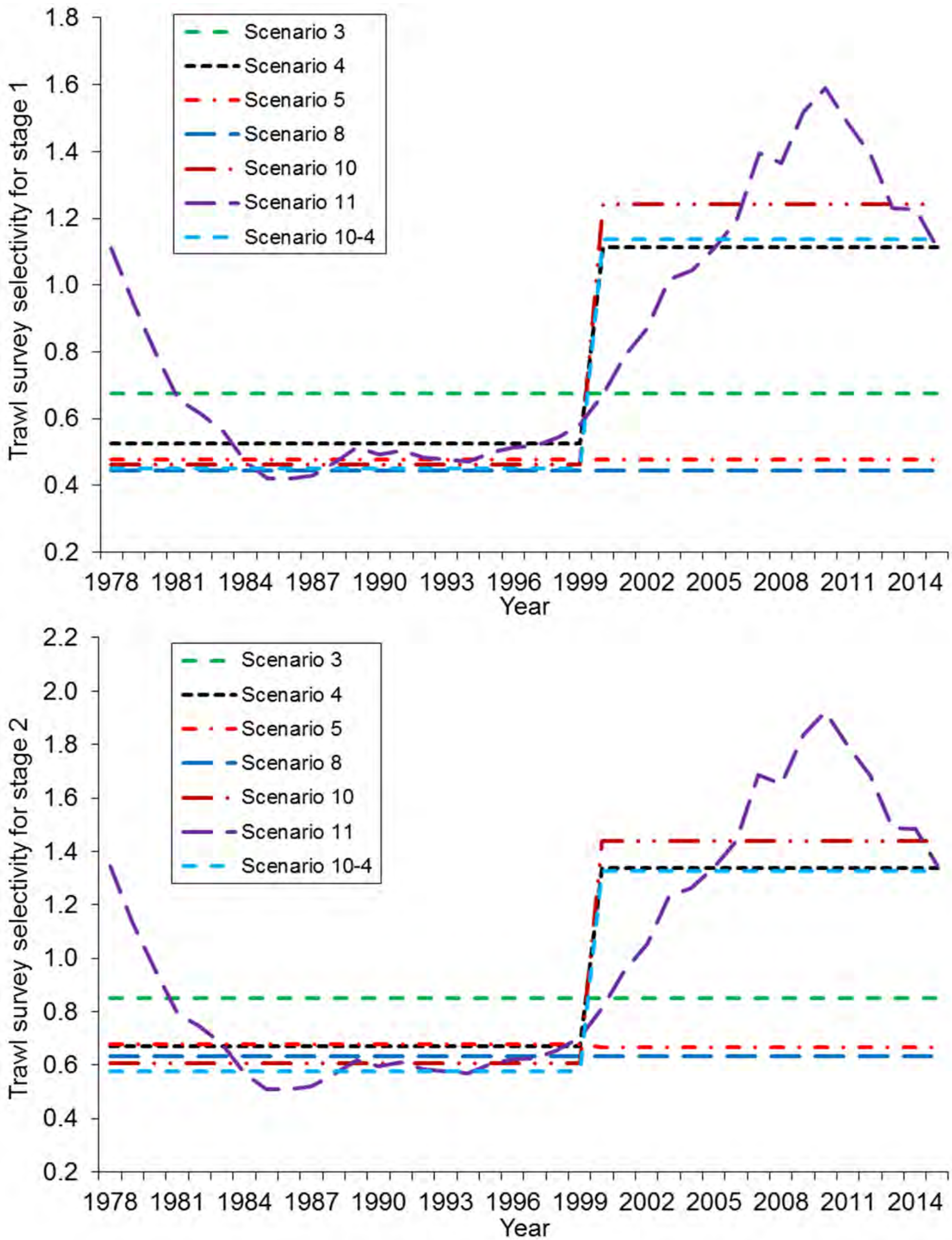


Figure 8. Estimated stage-1 (upper panel) and stage-2 (lower panel) trawl-survey selectivities for different scenarios.

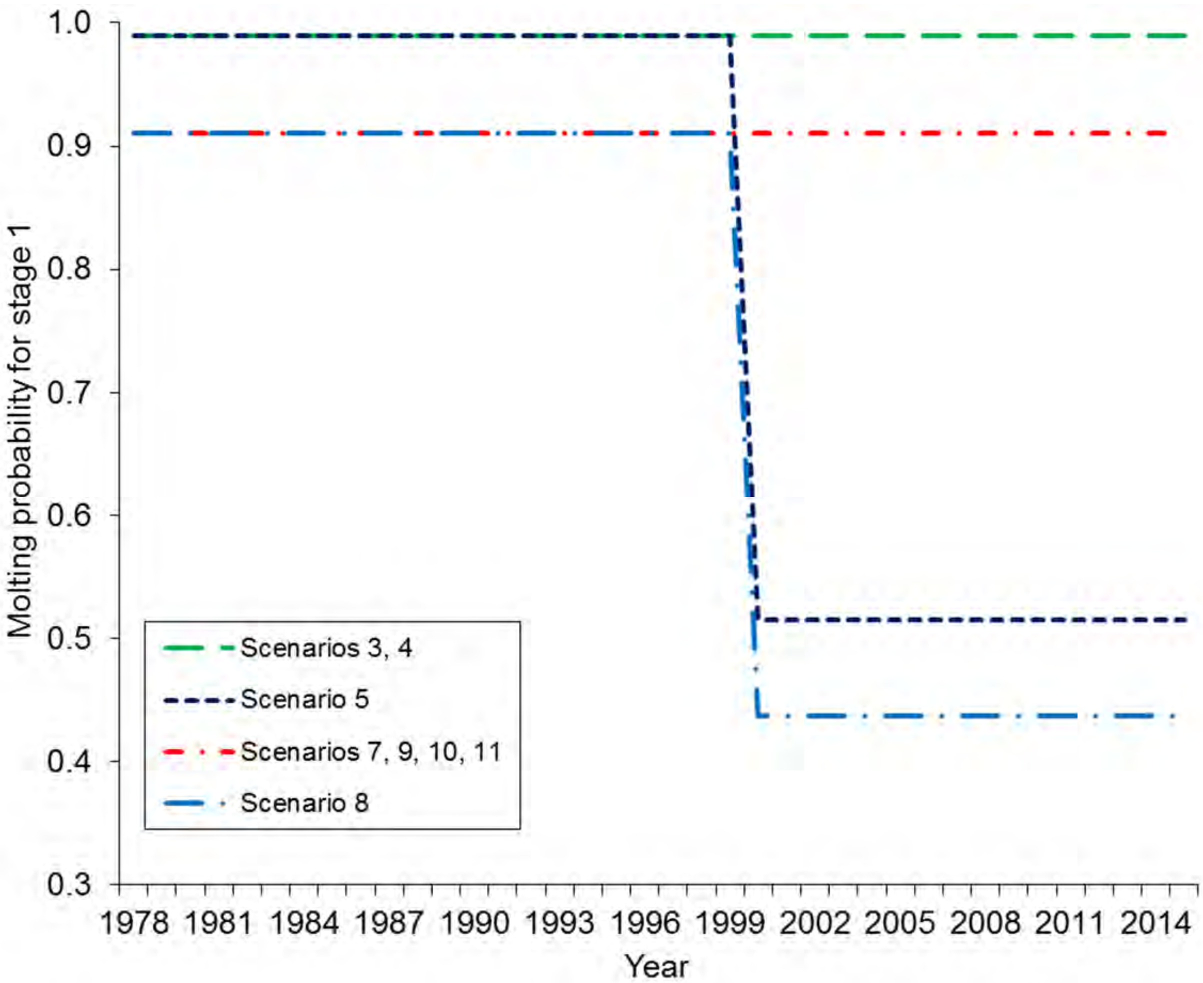


Figure 9. Estimated molting probabilities for stage-1 crab for different scenarios.

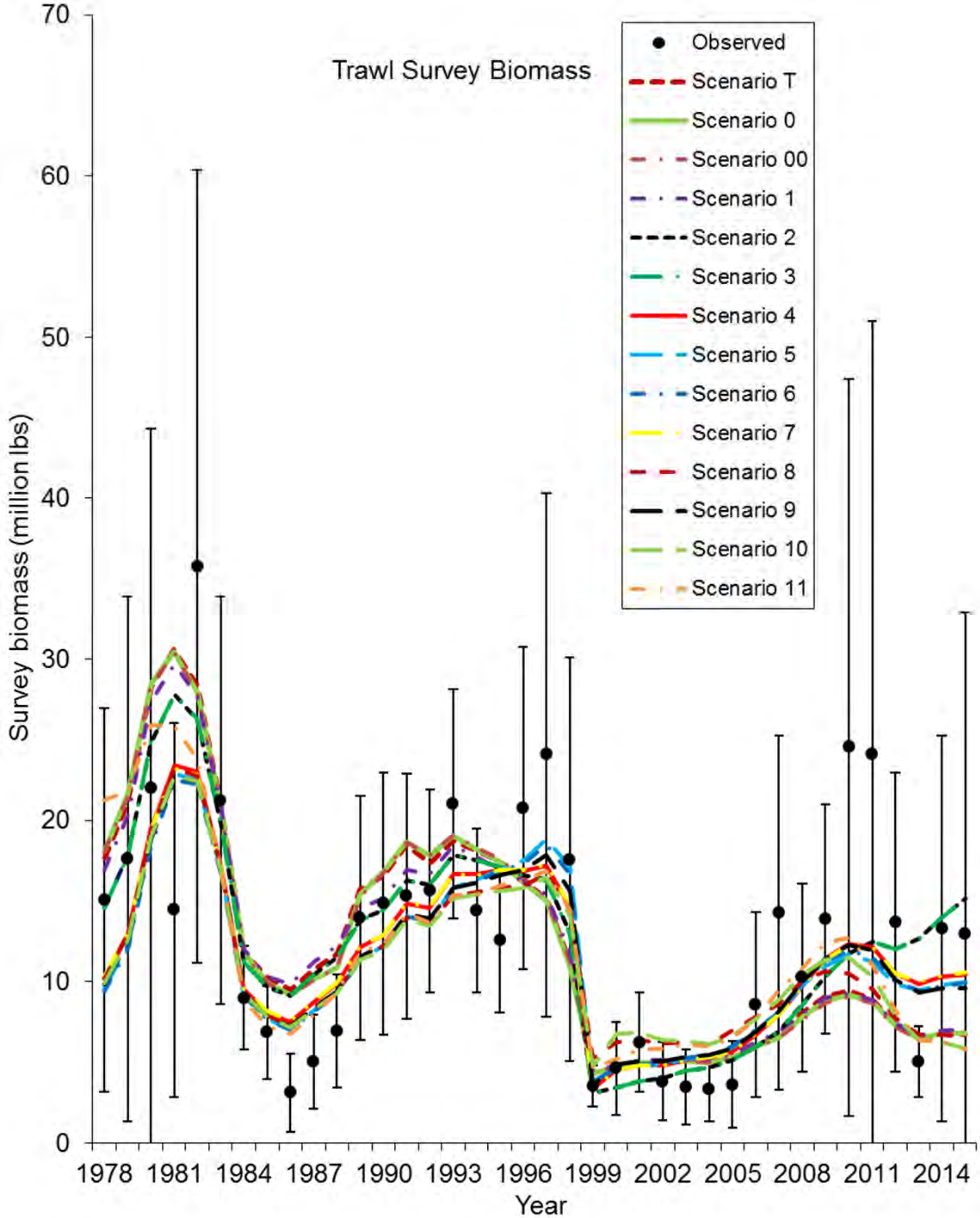


Figure 10. Comparisons of area-swept estimates of total male survey biomasses and model predictions for 2015 model estimates under 18 scenarios. The error bars are plus and minus 2 standard deviations.

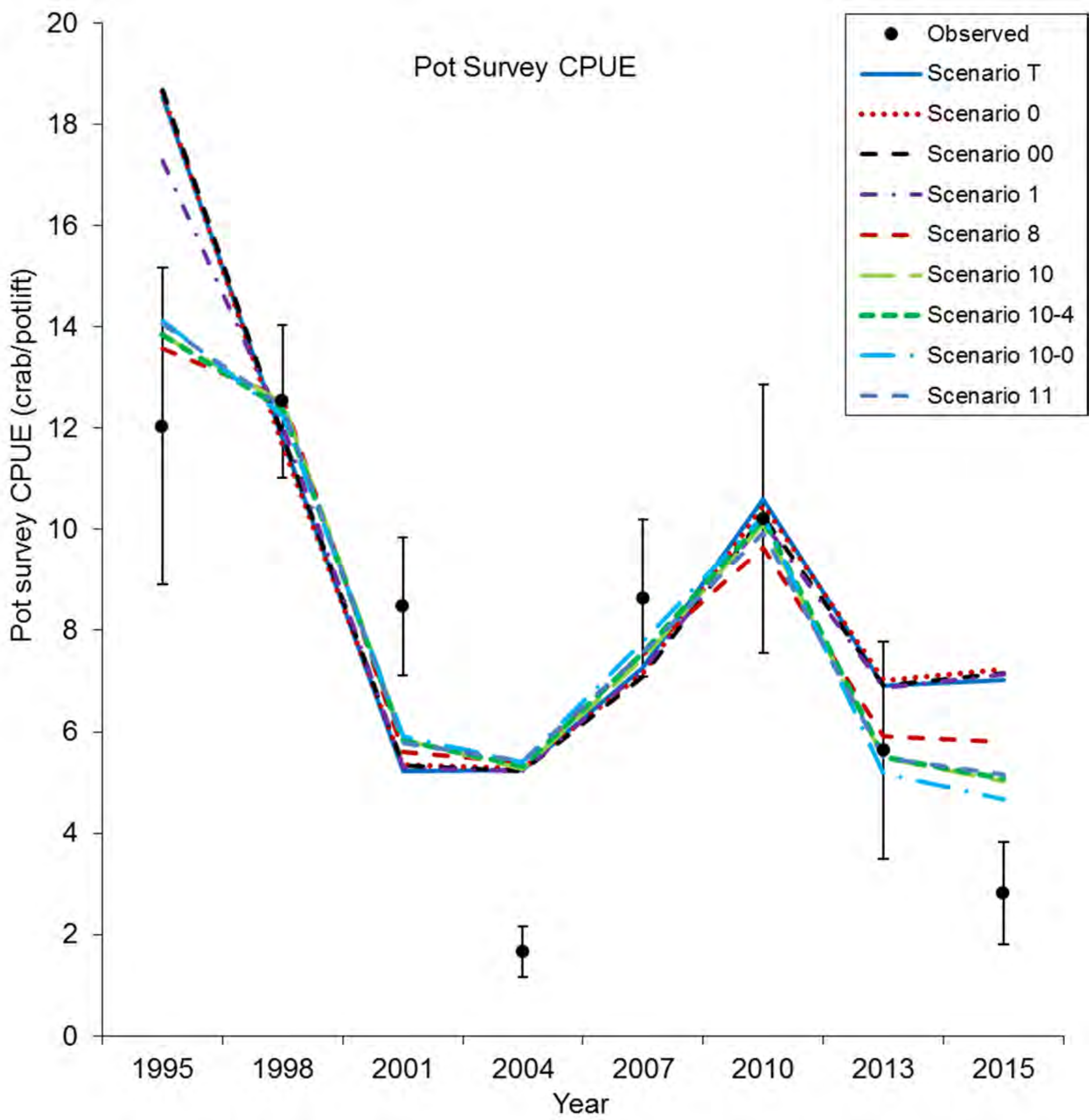


Figure 11a. Comparisons of total male pot survey CPUEs and model predictions for 2015 model estimates under 9 scenarios without additional CV for the pot survey CPUE. The error bars are plus and minus 2 standard deviations of scenario 10.

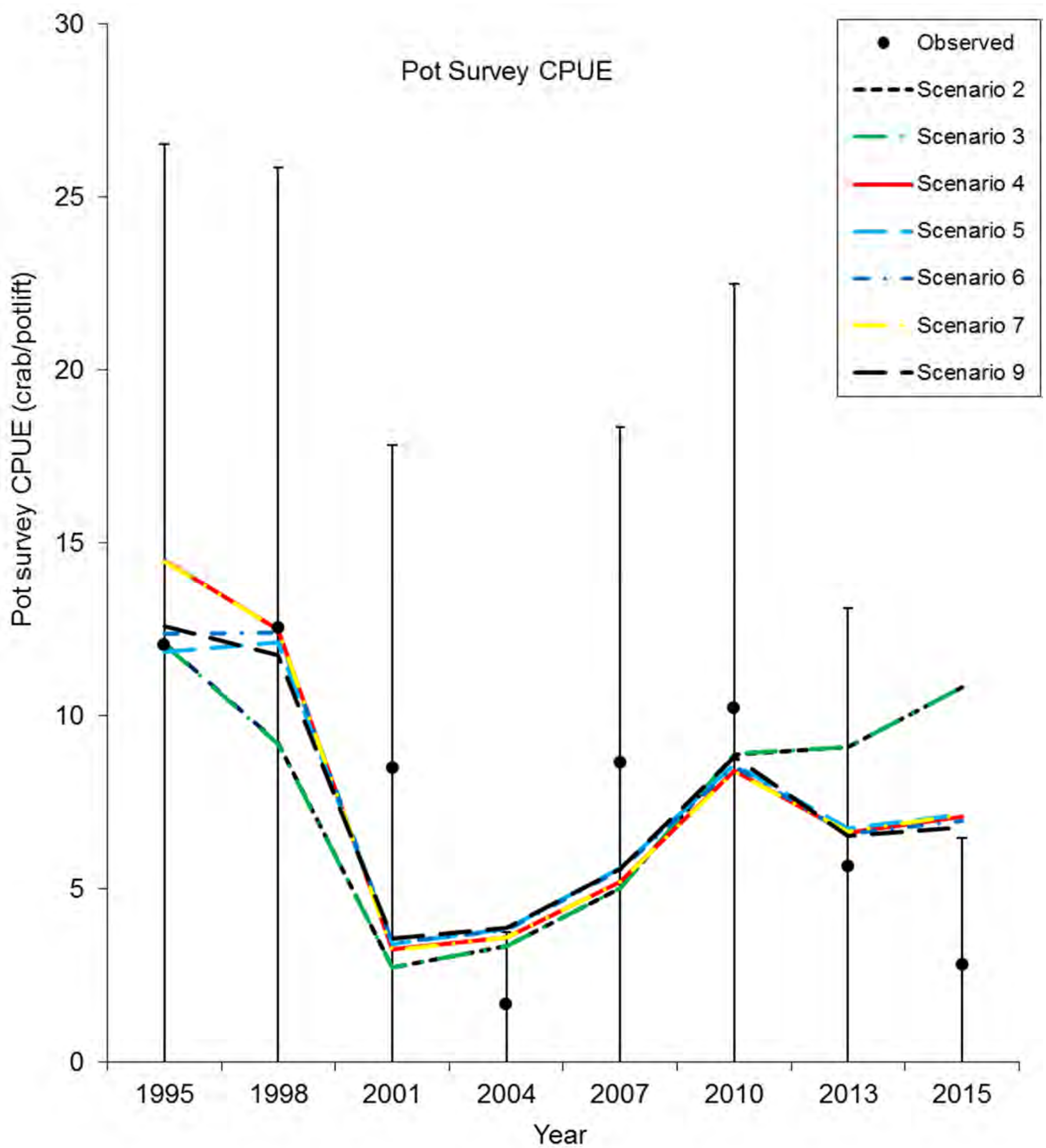


Figure 11b. Comparisons of total male pot survey CPUEs and model predictions for 2015 model estimates under 7 scenarios with additional CV for the pot survey CPUE. The error bars are plus and minus 2 standard deviations of scenario 9.

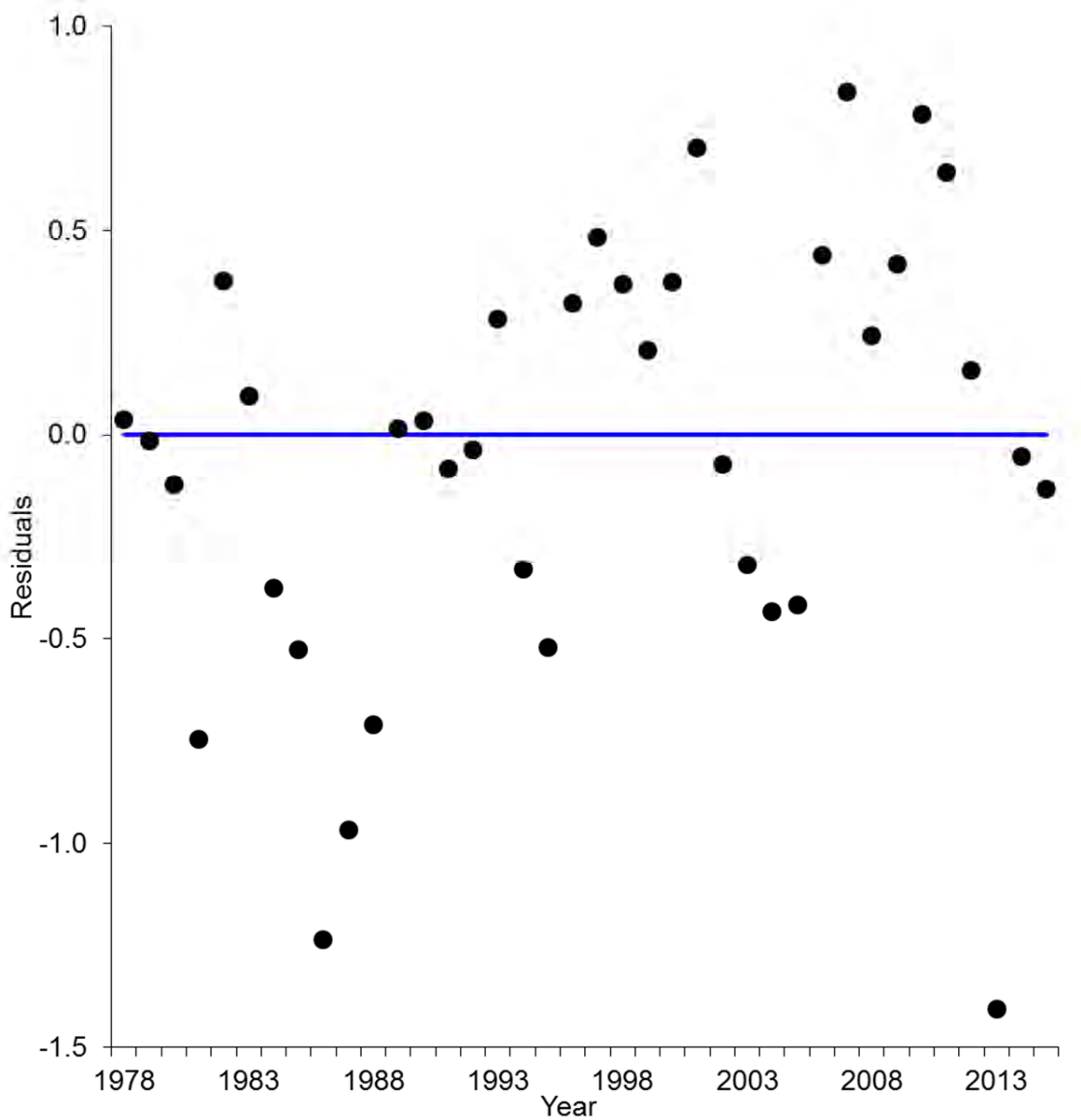


Figure 12(3). Standardized residuals for total trawl survey biomass for scenario 3.

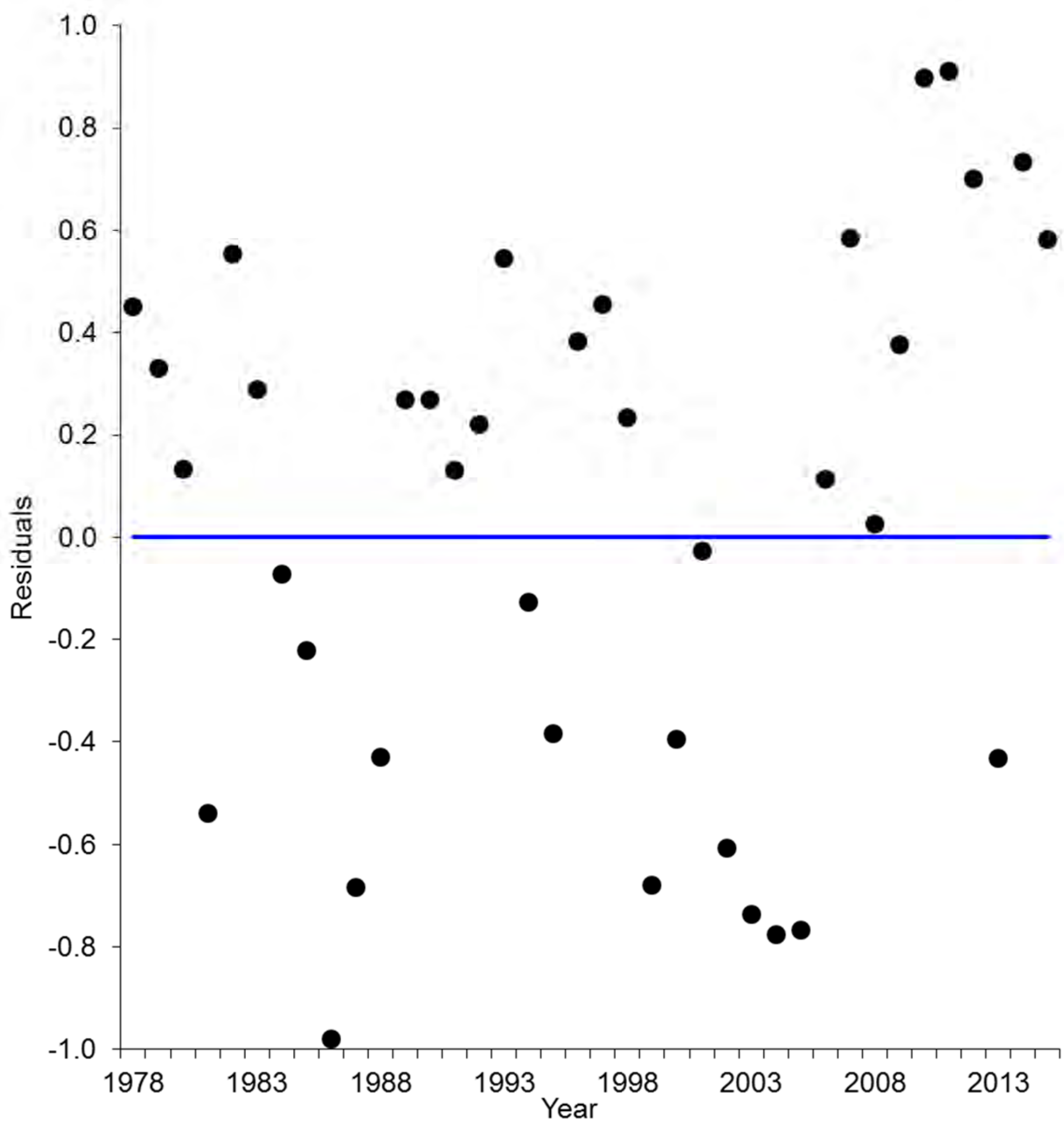


Figure 12(8). Standardized residuals for total trawl survey biomass for scenario 8.

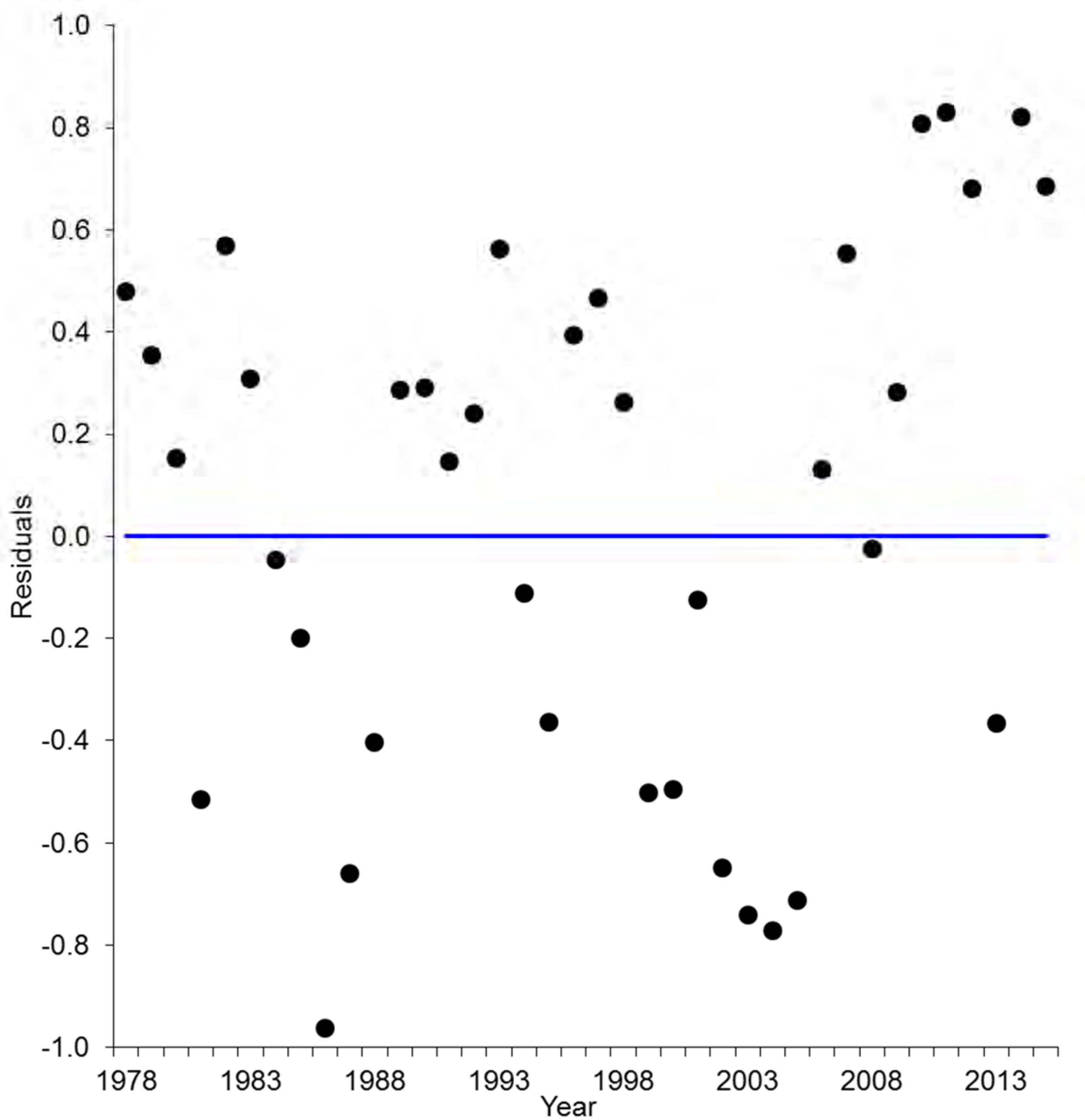


Figure 12(10). Standardized residuals for total trawl survey biomass for scenario 10.

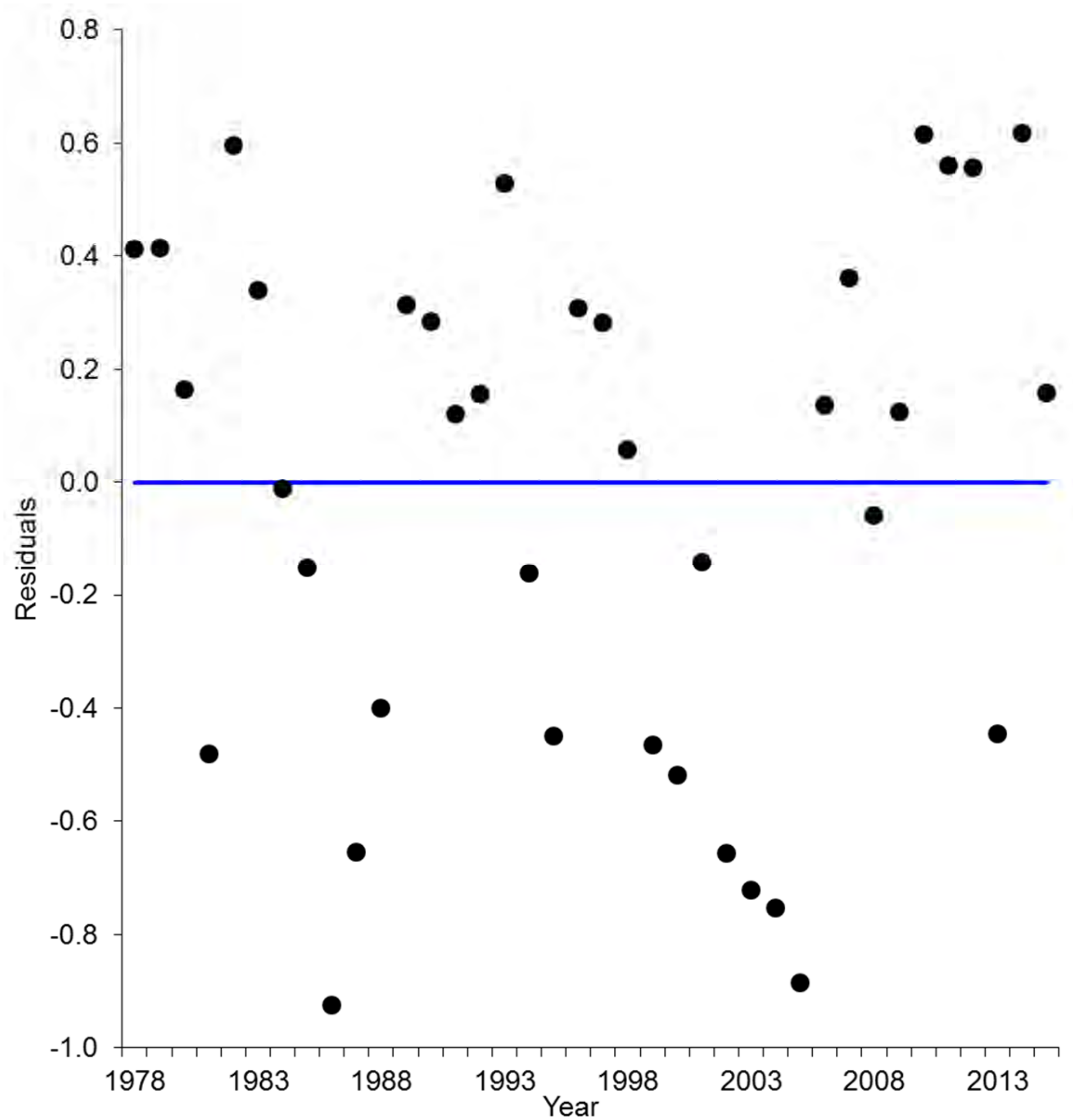


Figure 12(10-4). Standardized residuals for total trawl survey biomass for scenario 10-4.

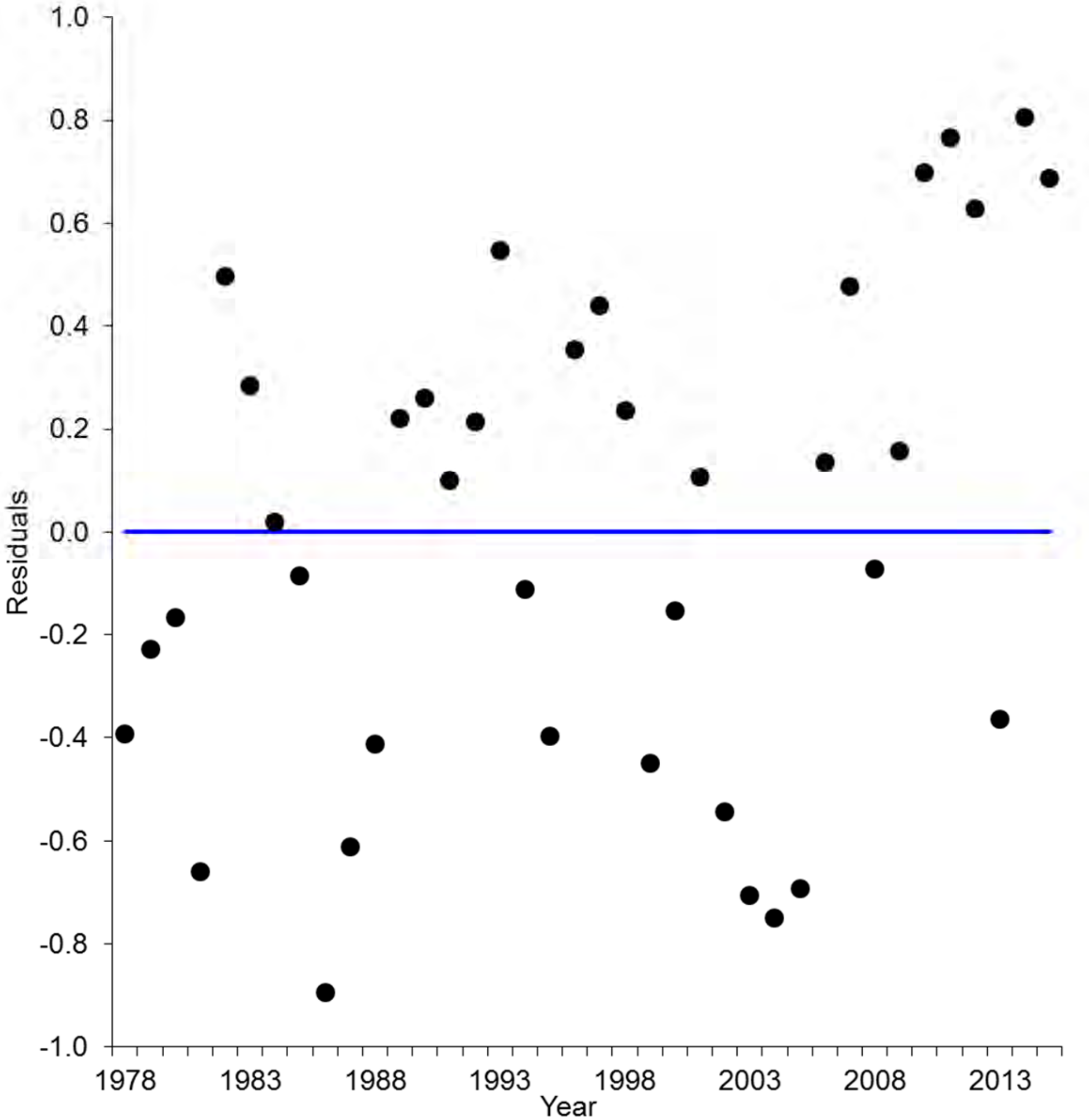


Figure 12(11). Standardized residuals for total trawl survey biomass for scenario 11.

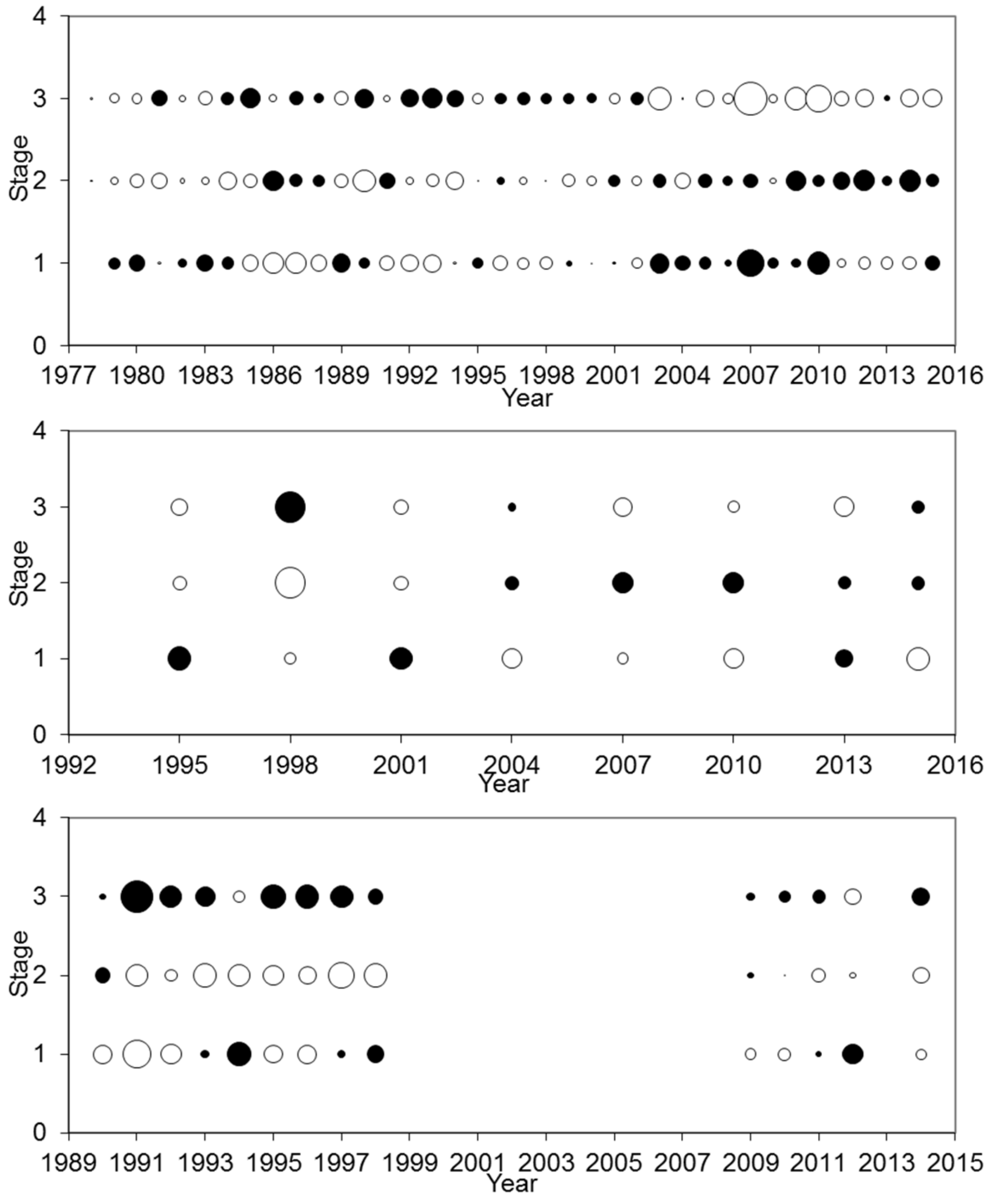


Figure 13(3). Bubble plots of residuals of stage compositions for scenario 3 for St. Mathew Island blue king crab. Empty circles indicate negative residuals, filled circles indicate positive residuals, and differences in bubble size indicate relative differences in the magnitude of residuals. Upper, middle, and lower plots are trawl survey, pot survey, and observer data.

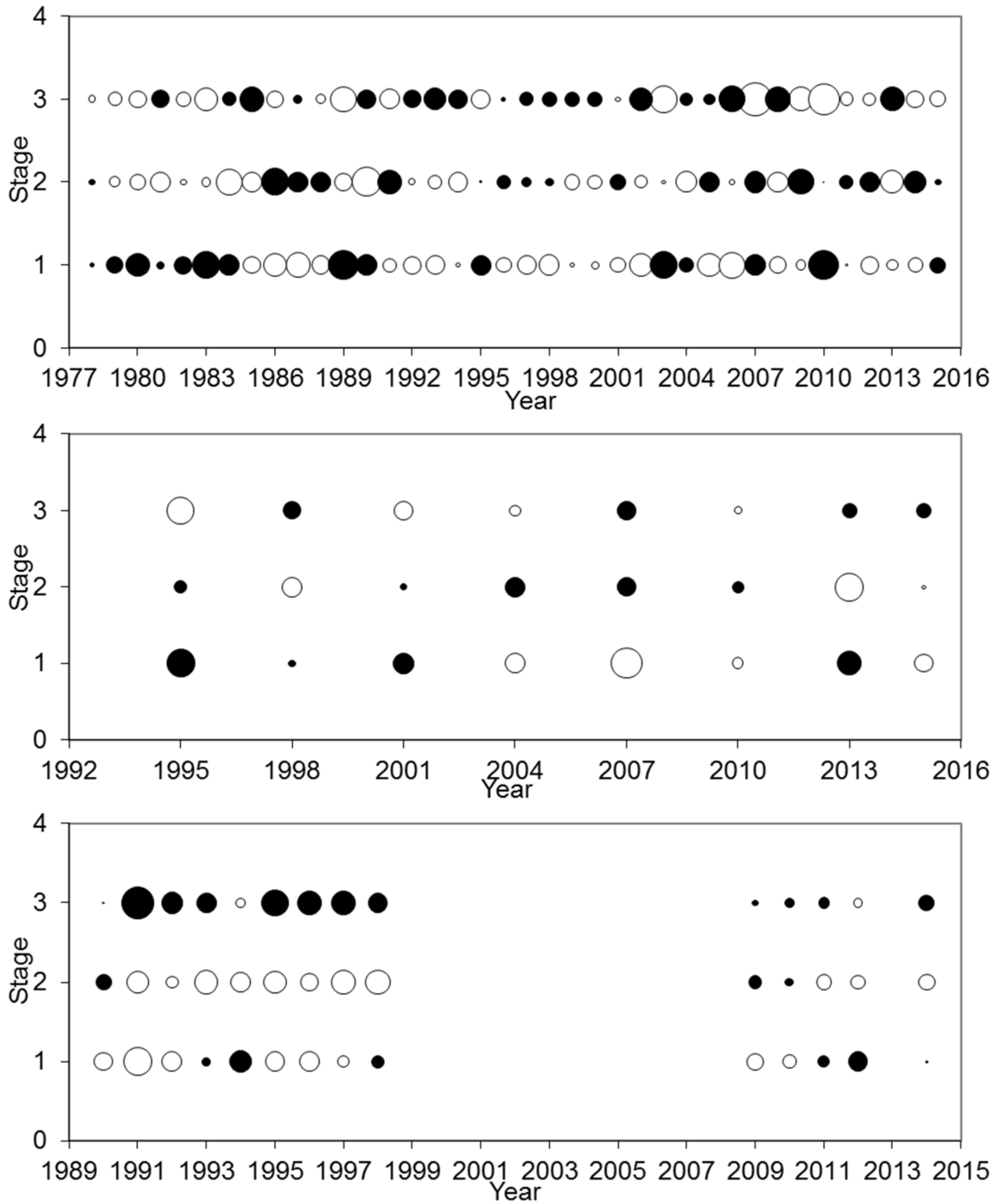


Figure 13(8). Bubble plots of residuals of stage compositions for scenario 8 for St. Mathew Island blue king crab. Empty circles indicate negative residuals, filled circles indicate positive residuals, and differences in bubble size indicate relative differences in the magnitude of residuals. Upper, middle, and lower plots are trawl survey, pot survey, and observer data.

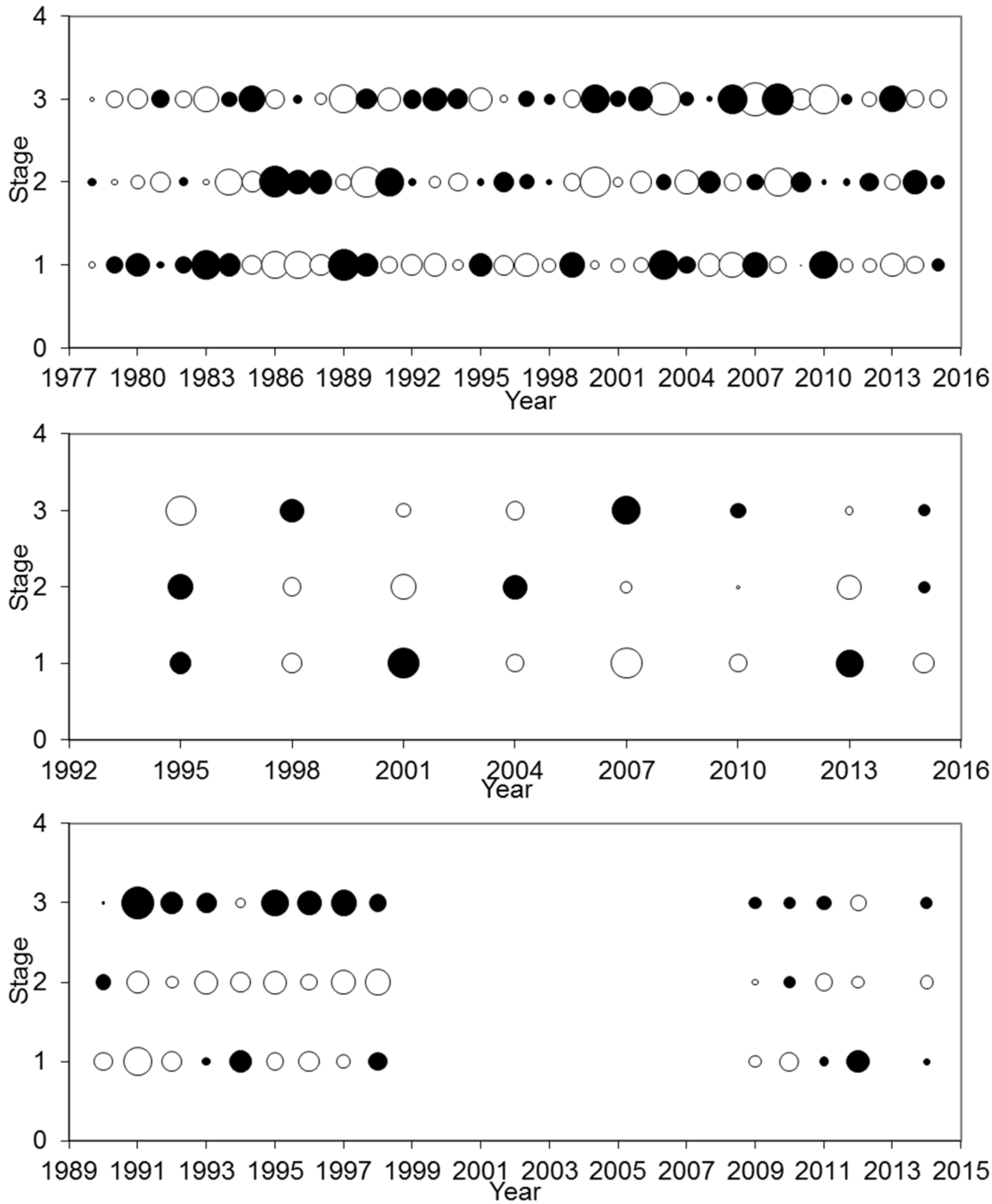


Figure 13(10). Bubble plots of residuals of stage compositions for scenario 10 for St. Mathew Island blue king crab. Empty circles indicate negative residuals, filled circles indicate positive residuals, and differences in bubble size indicate relative differences in the magnitude of residuals. Upper, middle, and lower plots are trawl survey, pot survey, and observer data.

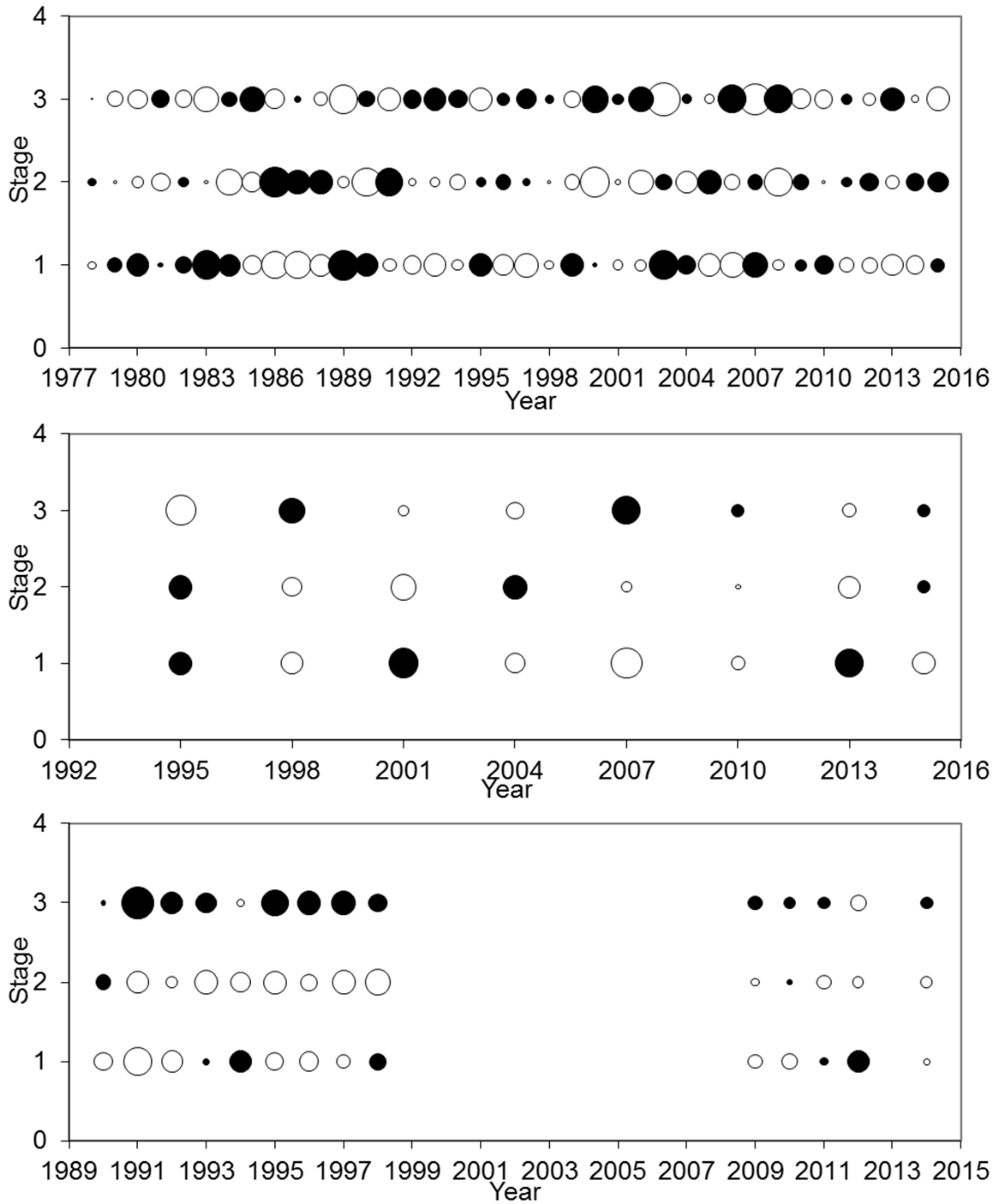


Figure 13(10-4). Bubble plots of residuals of stage compositions for scenario 10-4 for St. Mathew Island blue king crab. Empty circles indicate negative residuals, filled circles indicate positive residuals, and differences in bubble size indicate relative differences in the magnitude of residuals. Upper, middle, and lower plots are trawl survey, pot survey, and observer data.

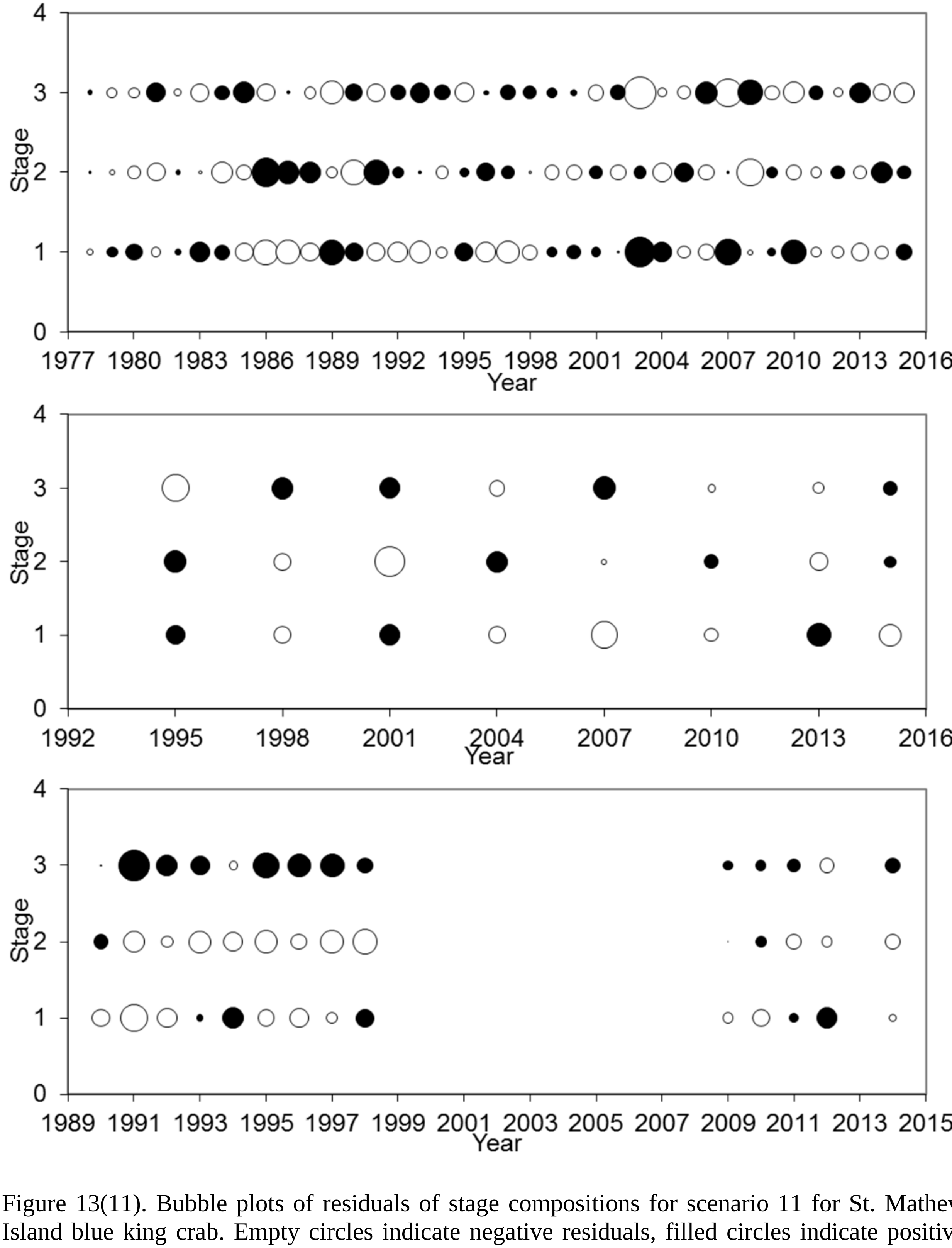


Figure 13(11). Bubble plots of residuals of stage compositions for scenario 11 for St. Mathew Island blue king crab. Empty circles indicate negative residuals, filled circles indicate positive residuals, and differences in bubble size indicate relative differences in the magnitude of residuals. Upper, middle, and lower plots are trawl survey, pot survey, and observer data.

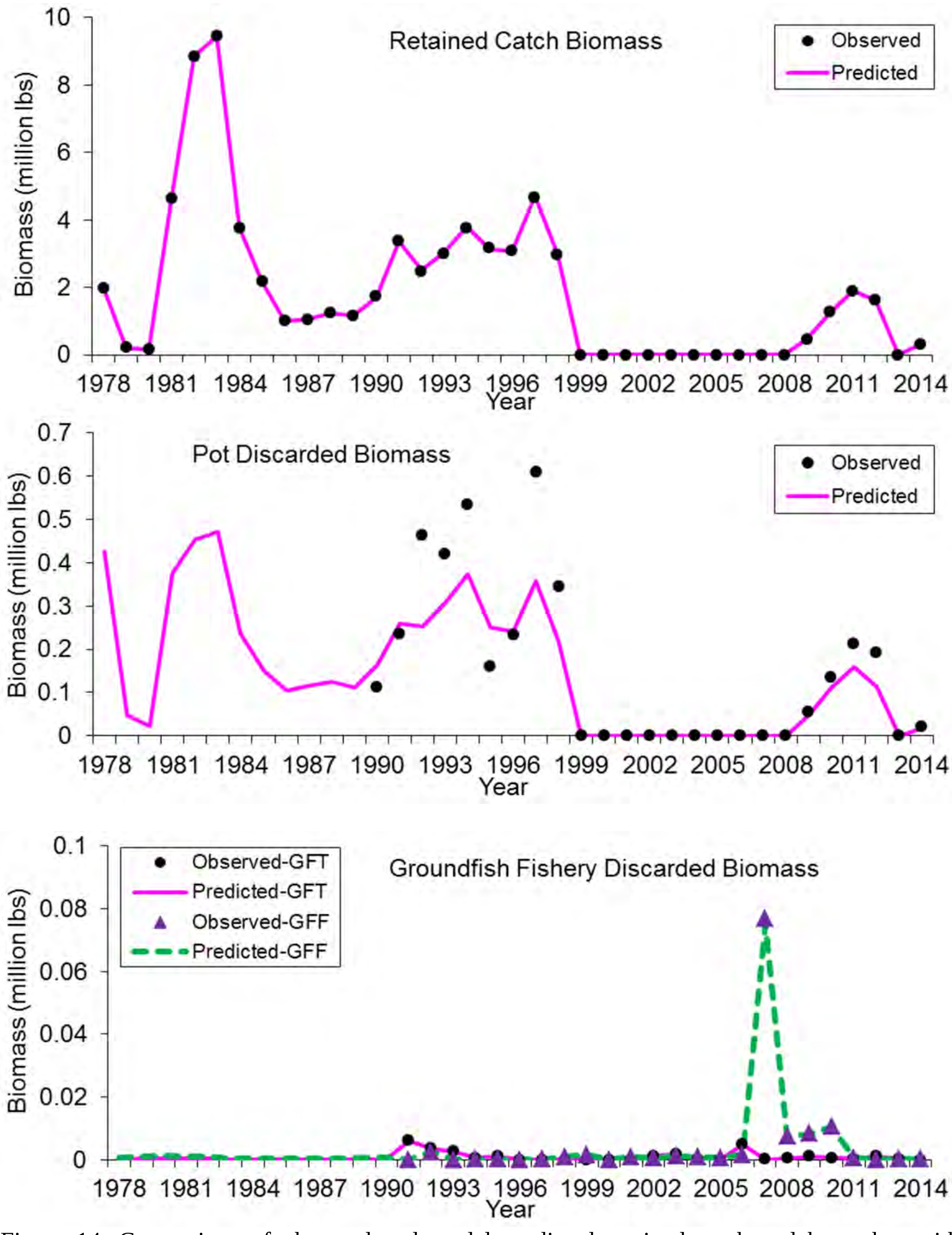


Figure 14. Comparison of observed and model predicted retained catch and bycatches with scenario 10.

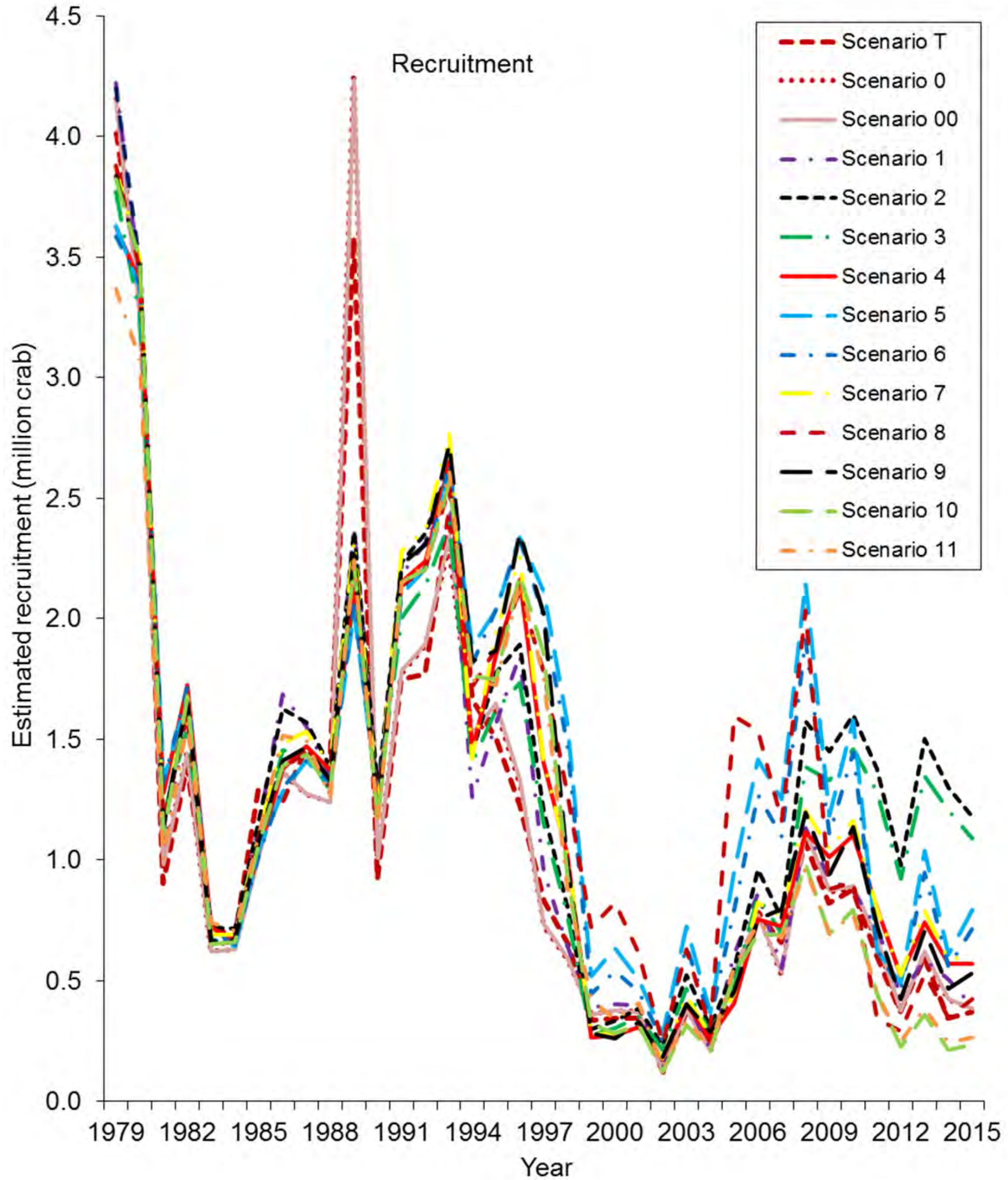


Figure 15. Estimated recruitment time series during 1979-2015 with 18 scenarios.

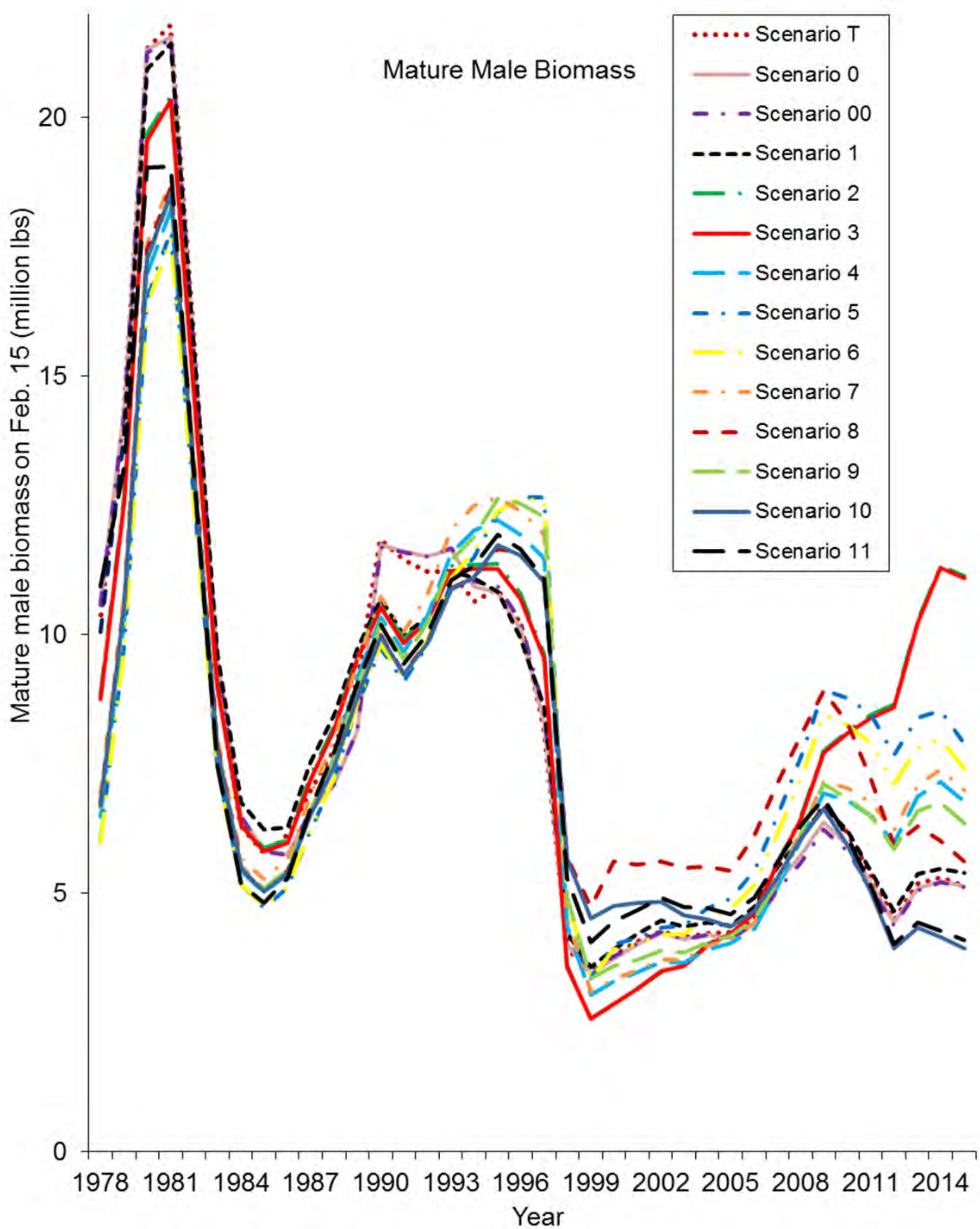


Figure 16. Estimated mature male biomass time series on Feb. 15 during 1978-2015 with 18 scenarios.

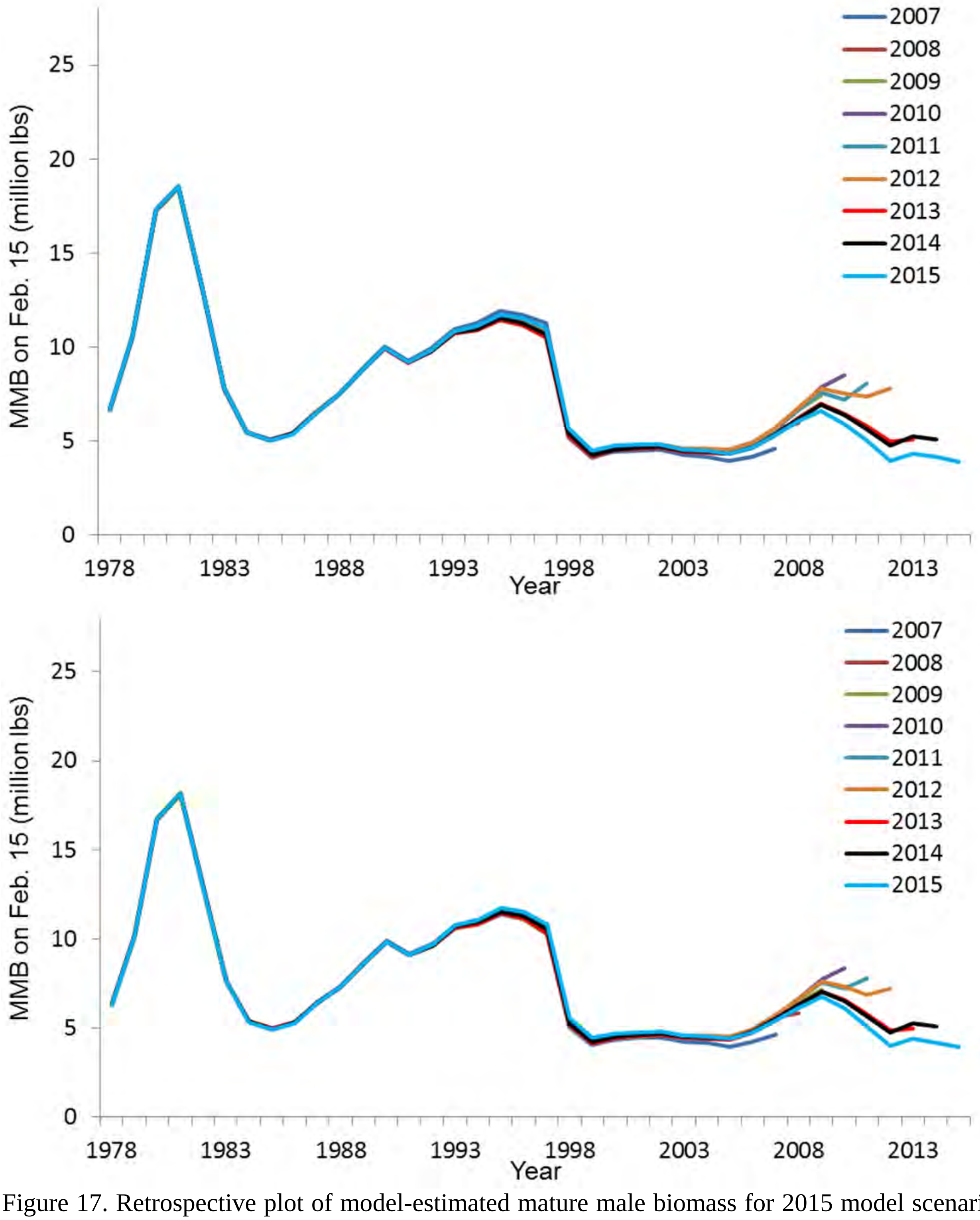


Figure 17. Retrospective plot of model-estimated mature male biomass for 2015 model scenario 10 (top panel) on Feb. 15 and scenario 10-4 (bottom panel) at time of survey with terminal years 2007-2015. Estimates are based on all available data up to and including terminal-year trawl and pot surveys.

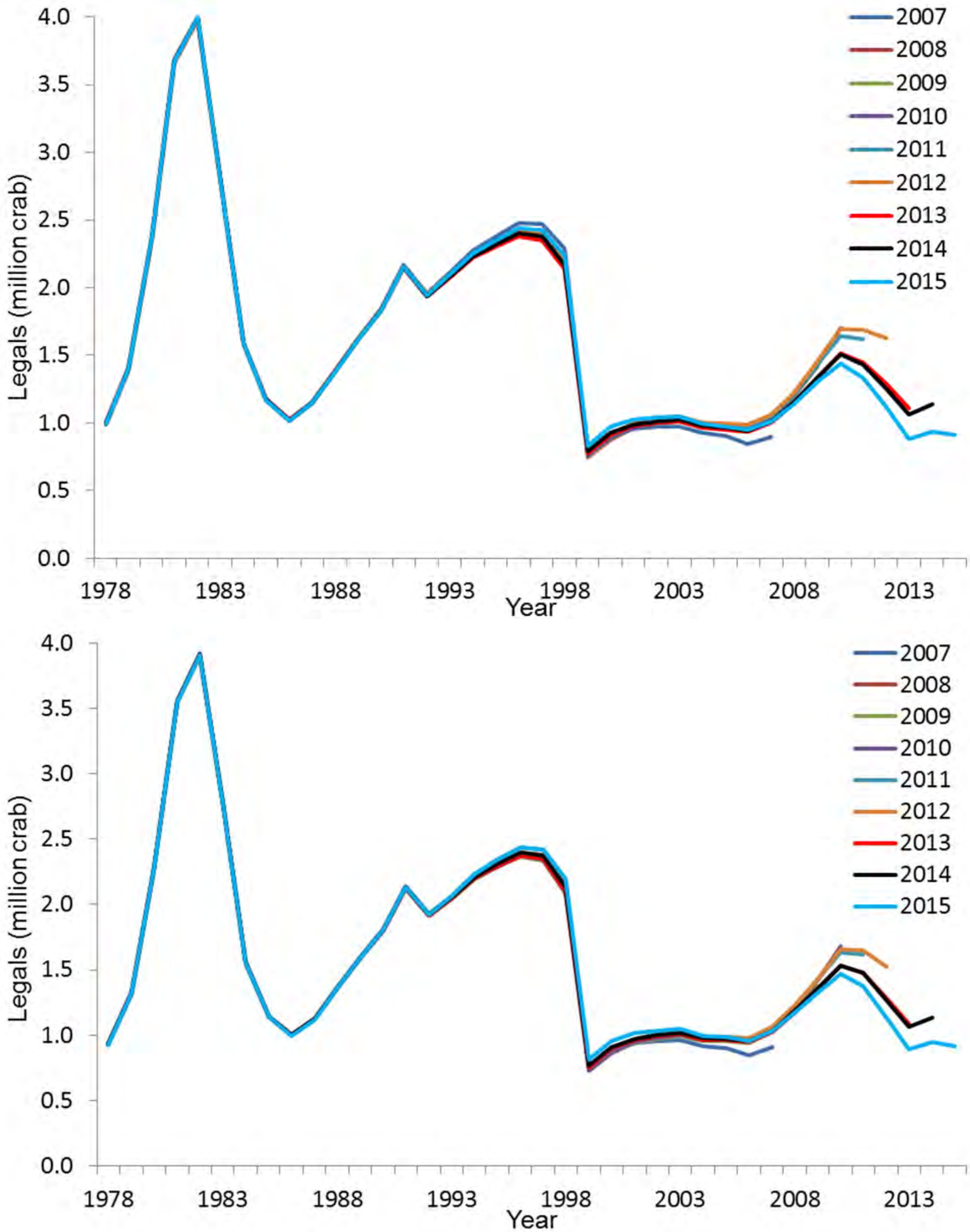


Figure 18. Retrospective plot of model-estimated legal male abundance at time of survey for 2015 model scenario 10 (top panel) and scenario 10-4 (bottom panel) with terminal years 2007-2015. Estimates are based on all available data up to and including terminal-year trawl and pot surveys.

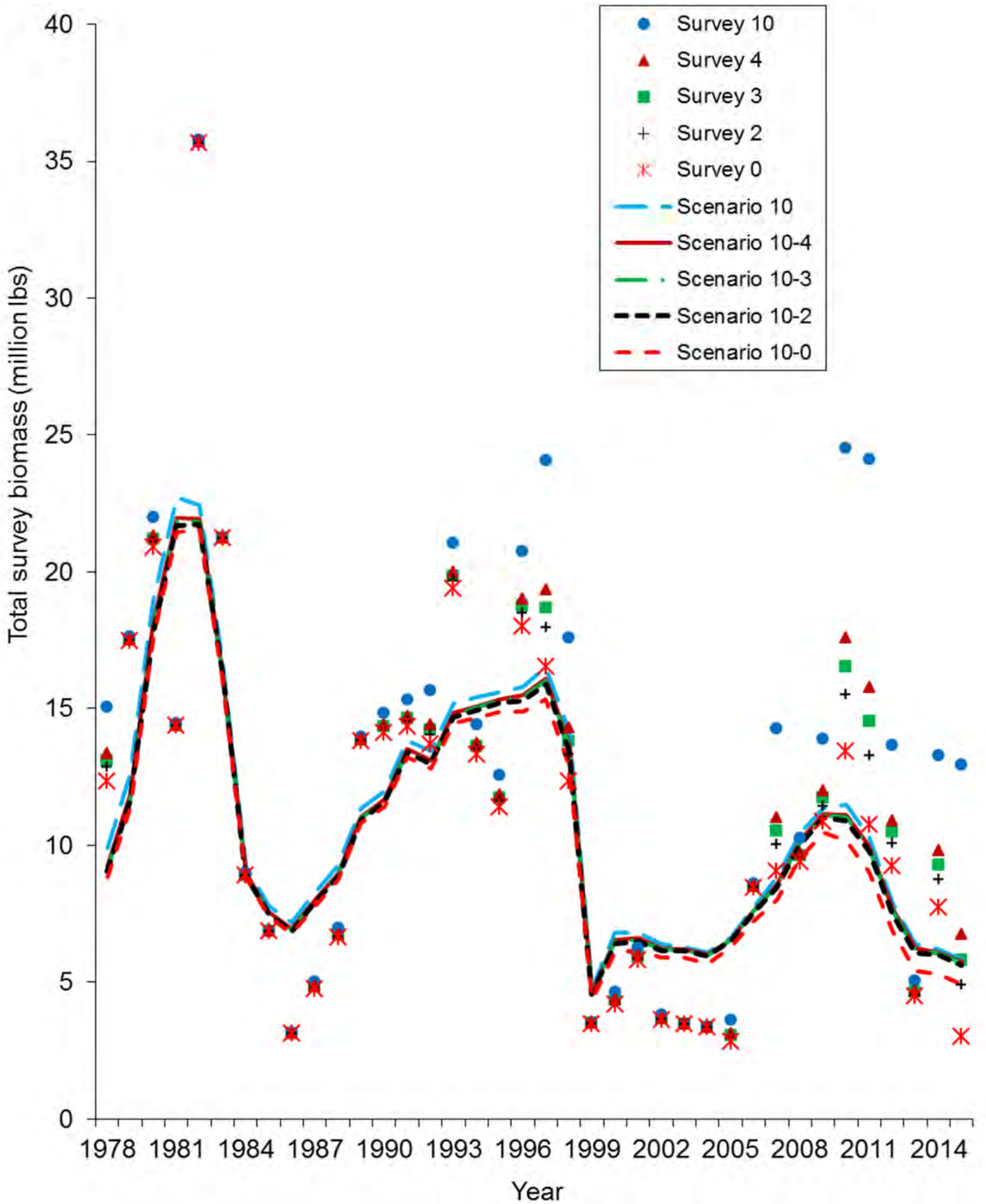


Figure 19. Comparisons of area-swept estimates of total male survey biomasses and model predictions for 2015 model estimates under scenarios 10, 10-4, 10-3, 10-2, and 10-0. "Survey 10, 4, 3, 2 and 0 denote area-swept estimates with 100%, 37.51%, 28.13%, 18.75%, and 0% of trawl survey station R-24 catch.

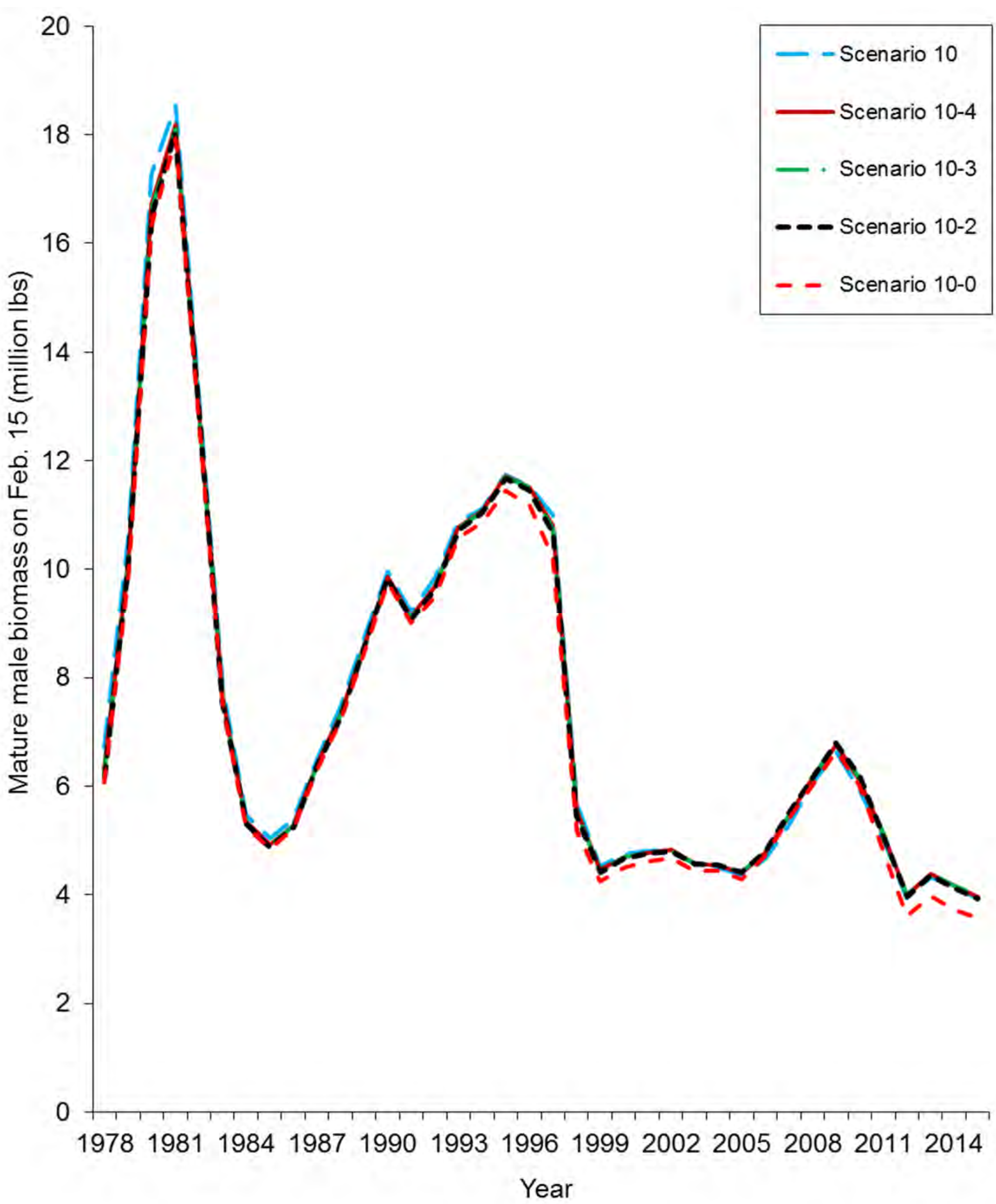


Figure 20. Estimated mature male biomass time series on Feb. 15 during 1978-2015 with scenarios 10, 10-4, 10-3, 10-2, and 10-0.

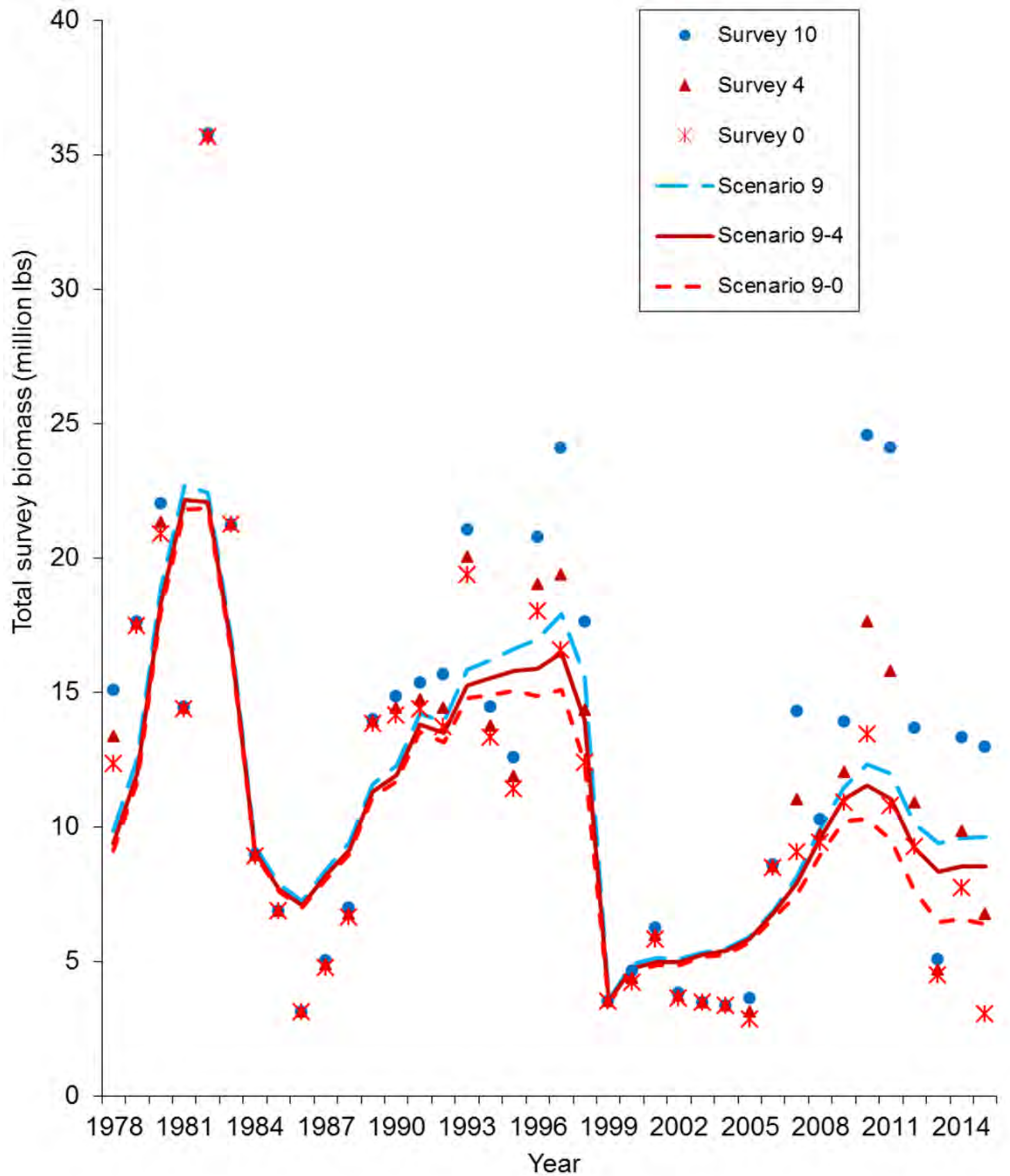


Figure 21. Comparisons of area-swept estimates of total male survey biomasses and model predictions for 2015 model estimates under scenarios 9, 9-4 and 9-0. "Survey 10, 4 and 0 denote area-swept estimates with 100%, 37.51% and 0% of trawl survey station R-24 catch.

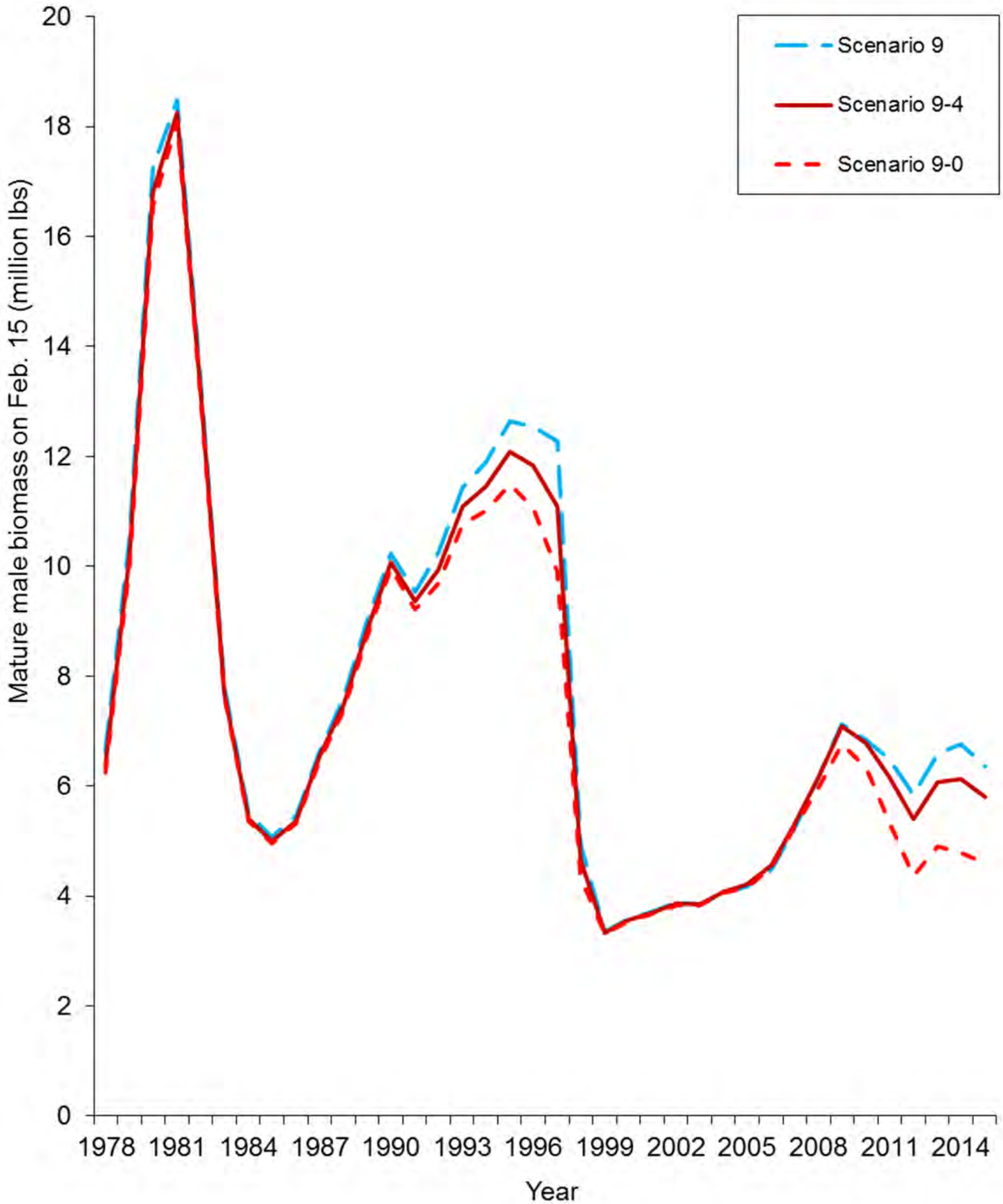


Figure 22. Estimated mature male biomass time series on Feb. 15 during 1978-2015 with scenarios 9, 9-4 and 9-0.

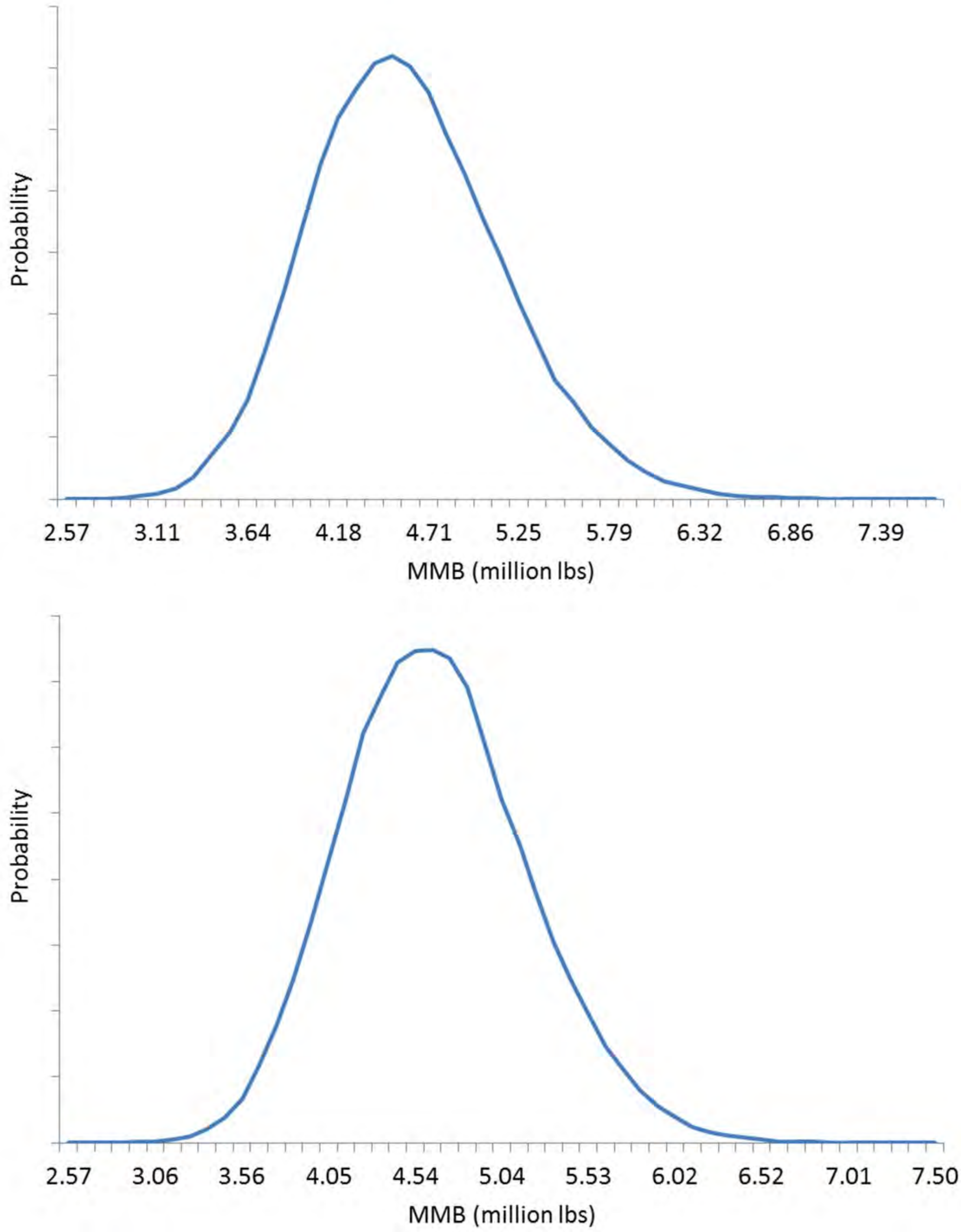


Figure 23. Probability distributions of estimated mature male biomass on Feb. 15, 2015 with Tier 4 control rule under scenarios 10 (top panel) and 10-4 (bottom panel) with the mcmc approach.

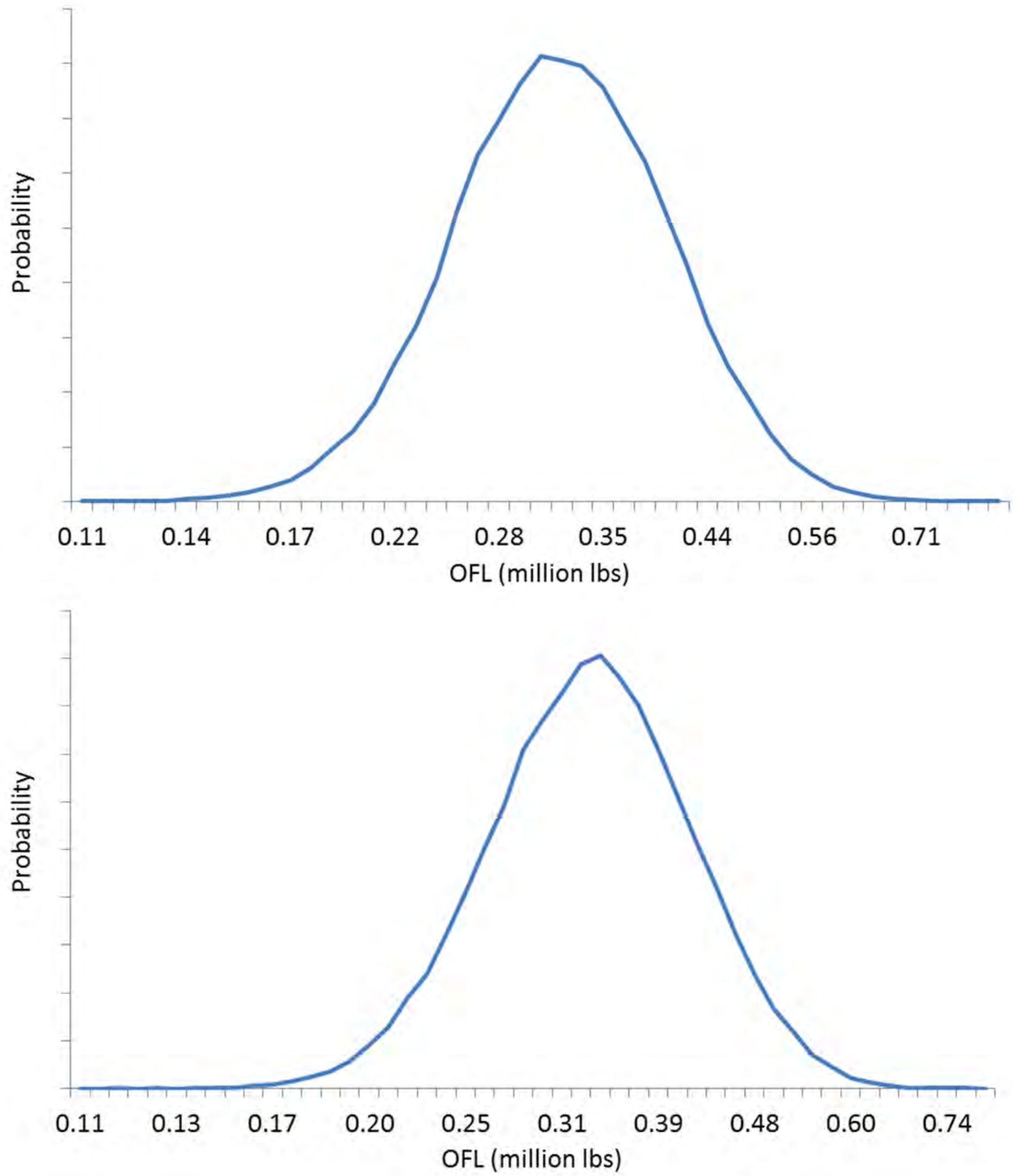


Figure 24. Probability distributions of the 2015 estimated OFL with scenarios 10 (top panel) and 10-4 (bottom panel) with the mcmc approach.

Appendix A: SMBKC Model Description

1. Introduction

The model accounts only for male crab at least 90 mm in carapace length (CL). These are partitioned into three stages (male 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 in carapace width (CW), whereas 105 mm CL is the management proxy for mature-male size (5 AAC 34.917 (d)). Accordingly, within the model only stage-3 crab are retained in the directed fishery, and stage-2 and stage-3 crab together comprise the collection of mature males. Some justification for the 105 mm value is presented in Pengilly and Schmidt (1995), who used it in developing the current regulatory SMBKC harvest strategy. The term "recruit" here designates recruits to the model, i.e., annual new stage-1 crab, rather than recruits to the fishery. The following description of model structure reflects the base-model configuration.

2. Model Population Dynamics

Within the model framework, the beginning of the crab year is assumed contemporaneous with the NMFS trawl survey, nominally assigned a date of July 1. With boldface letters indicating vector quantities, let $\boldsymbol{N}_t = [\ N_{1,t},\ N_{2,t},\ N_{3,t}\ ]^{\mathrm{T}}$ designate the vector of stage abundances at the start of year t. Then the basic population dynamics underlying model construction are described by the linear equation

$$\boldsymbol{N}_{t+1} = \boldsymbol{G}e^{-M_t}\boldsymbol{N}_t + \boldsymbol{N}^{new}{}_{t+1}, \qquad \text{[A1]}$$

where the scalar factor e^{-M_t} accounts for the effect of year-t natural mortality M_t and the hypothesized transition matrix $\boldsymbol{G}$ has the simple structure

$$\boldsymbol{G} = \begin{bmatrix} 1-\pi_{12} & \pi_{12} & 0 \\ 0 & 1-\pi_{23} & \pi_{23} \\ 0 & 0 & 1 \end{bmatrix}, \qquad \text{[A2]}$$

with π_{jk} equal to the proportion of stage-j crab that molt and grow into stage k from any one year to the next. The vector $\boldsymbol{N}^{new}{}_{t+1} = [\ N^{new}{}_{1,t+1},\ 0\ ,0\ ]^{\mathrm{T}}$ registers the number $N^{new}{}_{1,\,t+1}$ of new crab, or "recruits," entering the model at the start of year $t + 1$, all of which are assumed to go into stage 1. Aside from natural mortality and molting and growth, only the directed fishery and some limited bycatch mortality in the groundfish fisheries are assumed to affect the stock. Nontrivial bycatch mortality with another fishery, as occurred in 2012/13, is assumed to be accounted for in the model in the estimate of groundfish bycatch mortality.) The directed fishery is modeled as a mid-season pulse occurring at time τ_t with full-selection fishing mortality F_t^{df} relative to stage-3 crab. Year-t directed-fishery removals from the stock are computed as

$$\boldsymbol{R}_t^{df} = \boldsymbol{H}^{df}\boldsymbol{S}^{df}(1 - e^{-F_t^{df}})e^{-\tau_t M}\boldsymbol{N}_t, \qquad \text{[A3]}$$

where the diagonal matrices $\boldsymbol{S}^{df} = \begin{bmatrix} s_1^{df} & 0 & 0 \\ 0 & s_2^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix}$ and $\boldsymbol{H}^{df} = \begin{bmatrix} h^{df} & 0 & 0 \\ 0 & h^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix}$ account for stage selectivities s_1^{df} and s_2^{df} and discard handling mortality h^{df} in the directed fishery, both assumed constant over time. Yearly stage removals resulting from bycatch mortality in the groundfish trawl and fixed-gear fisheries are calculated as Feb 15 (0.63 yr) pulse effects in terms of the respective fishing mortalities F_t^{gt} and F_t^{gf} by

$$\boldsymbol{R}_t^{gt} = \frac{F_t^{gt}}{F_t^{gt}+F_t^{gf}} e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})(1-e^{-(F^{gt}+F^{gf})})h^{gt} \quad \text{[A4]}$$

$$\boldsymbol{R}_t^{gf} = \frac{F_t^{gf}}{F_t^{gt}+F_t^{gf}} e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})(1-e^{-(F^{gt}+F^{gf})})h^{gf}. \quad \text{[A5]}$$

These last two computations assume that the groundfish fisheries affect all stages proportionally, i.e. that all stage selectivities equal one, and that handling mortalities h^{gt} and h^{gf} are constant across both stages and years. The author believes that the available composition data from these fisheries are of such dubious quality as to preclude meaningful use in estimation. Moreover, evidently with the exception of 2007/08, which in the author's view is suspiciously anomalous, the impact of these fisheries on the stock has typically been small. These considerations suggest that more elaborate efforts to model that impact are unwarranted. Model population dynamics are thus completely determined by the equation

$$\boldsymbol{N}_{t+1} = \boldsymbol{G}e^{-0.37M_t}(e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df}) - (\boldsymbol{R}_t^{gt} + \boldsymbol{R}_t^{gf})) + \boldsymbol{N}^{new}{}_{t+1}, \quad \text{[A6]}$$

for $t \geq 1$ and initial stage abundances $\boldsymbol{N}_1$.

Necessary biomass computations, such as required for management purposes or for integration of groundfish bycatch biomass data into the model, are based on application of the SMBKC length-to-weight relationship from NMFS to the stage-1 and stage-2 CL interval midpoints and use fishery reported average retained weights for stage-3 ("legal") crab. In years with no fishery, including the current assessment year, the time average value over years with a fishery is used. The author believes this approach to be an appropriate simplification given the data limitations associated with the stock.

3. Model Data

Data inputs used in model estimation are listed in Table 1. All quantities relate to male SMBKC ≥ 90mm CL.

Table 1. Data inputs used in model estimation.

Data Quantity	Years	Source
Directed pot-fishery retained-catch number	1978/79-1998/99 2009/10-2014/15	Fish tickets (fishery closed 1999/00-2008/09)
NMFS trawl-survey biomass index (area-swept estimate) and CV	1978-2015	NMFS EBS trawl survey
ADFG pot-survey abundance index (CPUE) and CV	Triennial 1995-2015	ADF&G SMBKC pot survey
NMFS trawl-survey stage proportions and total number of measured crab	1978-2015	NMFS EBS trawl survey
ADFG pot-survey stage proportions and total number of measured crab	Triennial 1995-2015	ADF&G SMBKC pot survey
Directed pot-fishery stage proportions and total number of measured crab	1990/91-1998/99 2009/10-2014/15	ADF&G crab observer program (fishery closed 1999/00-2008/09)
Groundfish trawl bycatch biomass	1992/93-2014/15	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93-2014/15	NMFS groundfish observer program

Model-predicted retained-catch number C_t is calculated assuming catch consists precisely of those stage-three crab captured in the directed fishery so that

$$C_t = e^{-\tau_t M_t} N_{3,t}(1 - e^{-F^{df}}), \qquad \text{[A7]}$$

which is just the third component of [3]. In fact, in the actual pot fishery a small number of captured stage-3 males are discarded, whereas some captured stage-2 males are legally retained, but data from onboard observers and dockside samplers suggest that [7] here provides a serviceable approximation (ADF&G Crab Observer Database). Model analogs of trawl-survey biomass and pot-survey abundance indices are given by

$$B_t^{ts} = Q^{ts}(s_1^{ts} N_{1,t} w_1 + s_2^{ts} N_{2,t} w_2 + N_{3,t} w_{3,t}) \qquad \text{[A8]}$$

$$A_t^{ps} = Q^{ps}(s_1^{ps} N_{1,t} + s_2^{ps} N_{2,t} + N_{3,t}), \qquad \text{[A9]}$$

these being year-*t* trawl-survey area-swept biomass and year-*t* pot-survey CPUE, respectively, both with respect to 90 mm+ CL males. In these expressions, Q^{ts} and Q^{ps} denote model proportionality constants, assumed independent of year and with $Q^{ts} = 1.0$ under all scenarios considered for this assessment, and s_j^{ts} and s_j^{ps} denote corresponding stage-*j* survey selectivities, also assumed independent of year. Model trawl-survey, pot-survey, and directed-fishery stage proportions $\boldsymbol{P}_t^{ts}$, $\boldsymbol{P}_t^{ps}$, and $\boldsymbol{P}_t^{df}$ are then determined by

$$\boldsymbol{P}_t^{ts} = \frac{Q^{ts}}{A_t^{ts}} \begin{bmatrix} s_1^{ts} & 0 & 0 \\ 0 & s_2^{ts} & 0 \\ 0 & 0 & 1 \end{bmatrix} \boldsymbol{N}_t \qquad \text{[A10]}$$

$$\boldsymbol{P}_t^{ps} = \frac{Q^{ps}}{A_t^{ps}} \begin{bmatrix} s_1^{ps} & 0 & 0 \\ 0 & s_2^{ps} & 0 \\ 0 & 0 & 1 \end{bmatrix} \boldsymbol{N}_t \qquad \text{[A11]}$$

$$\boldsymbol{P}_t^{df} = \frac{1}{\langle (\boldsymbol{H}^{df})^{-1} \boldsymbol{R}_t^{df},\ \boldsymbol{1} \rangle} (\boldsymbol{H}^{df})^{-1} \boldsymbol{R}_t^{df}. \qquad \text{[A12]}$$

Letting $\boldsymbol{w}_t = [w_1, w_2, w_{3,t}]^T$ be an estimate of stage mean weights in year *t* as described above, model predicted groundfish bycatch mortality biomasses in the trawl and fixed-gear fisheries are given by

$$B_t^{gt} = \boldsymbol{w}_t{}^T \boldsymbol{R}_t^{gt} \text{ and } B_t^{gf} = \boldsymbol{w}_t{}^T \boldsymbol{R}_t^{gf}. \qquad \text{[A13]}$$

Recall that stage-1 and stage-2 mean weights do not depend on year, being based on the NMFS length-to-weight relationship, whereas stage-3 mean weight is set equal to year-*t* fishery reported average retained weight or its time average for years with no fishery.

4. Model Parameters

Estimated parameters with scenarios 8 and 10 are listed in Table 2 and include an estimated parameter for natural mortality in 1998/99 on the assumption of an anomalous mortality event in that year, as hypothesized by Zheng and Kruse (2002), with natural mortality otherwise fixed at 0.18 yr^{-1}. In any year with no directed fishery, and hence zero retained catch, F_t^{df} is set to zero rather than model estimated. Similarly, for years in which no groundfish bycatch data are available, F_t^{gf} and F_t^{gt} are imputed to be the geometric means of the estimates from years for which there are data. Table 3 lists additional externally determined parameters used in model computations.

For scenarios 0 and 1, stage-transition matrix $\begin{bmatrix} 0.2 & 0.7 & 0.1 \\ 0 & 0.4 & 0.6 \\ 0 & 0 & 1 \end{bmatrix}$, which includes molting probabilities. For scenarios 3-11, the growth matrix with molting crab is $\begin{bmatrix} 0.11 & 0.83 & 0.06 \\ 0 & 0.11 & 0.89 \\ 0 & 0 & 1 \end{bmatrix}$. The combination of the growth matrix and molting probabilities results in the stage-transition matrix for scenarios 3-11. Molting probability for stage 1 for scenarios 8, 9, 10, 11 during 1978-2000 is assumed to be 0.91 estimated from the tagging data and ratio of molting probabilities of stages 2 to stage 1 is fixed as 0.69231 from the tagging data as well.

Both surveys are assigned a nominal date of July 1, the start of the crab year. The directed fishery is treated as a season midpoint pulse. Groundfish bycatch is likewise modeled as a pulse effect, occurring at the nominal time of mating, Feb 15, which is also the reference date for calculation of federal management biomass quantities.

Table 2. Model estimated parameters for scenarios 0 and 4.

	Scenario 8	Scenario 10
Parameter	Number	Number
Log initial stage abundances	3	3
1998/99 natural mortality	1	1
Pot-survey “catchability”	1	1
Stage 1 and 2 Trawl-survey selectivities	2	4
Stage 1 and 2 Pot-survey selectivities	2	4
Stage 1 and 2 Directed-fishery selectivities	4	4
Molting probabilities	1	0
Additional CV for pot survey	0	0
Mean log recruit abundance	1	1
Log recruit abundance deviations	37[a]	37[a]
Mean log directed-fishery mortality	1	1
Log directed-fishery mortality deviations	26[a]	26[a]
Mean log groundfish trawl fishery mortality	1	1
Log groundfish trawl fishery mortality deviations	24[a]	24[a]
Mean log groundfish fixed-gear fishery mortality	1	1
Log groundfish fixed-gear fishery mortality deviations	24[a]	24[a]
Total	129	132

[a] Subject to zero-sum constraint.

Table 3. Fixed parameters for all scenarios except for T.

Parameter	Value	Source/Rationale
Trawl-survey "catchability", i.e. abundance-index proportionality constant	1.0	Default
Natural mortality (except 1998/99)	0.18 yr^{-1}	NPFMC (2007)
Stage 1 and 2 transition probabilities	1.0, 1.0	Default
Stage-1 and 2 mean weights	1.65, 2.57 lbs.	Length-weight equation (B. Foy, NMFS) applied to stage size-interval midpoints.
Stage-3 mean weight	depends on year	Fishery-reported average retained weight from fish tickets, or its average, and mean weights of legal males.
Directed-fishery handling mortality	0.20	2010 Crab SAFE
Groundfish trawl handling mortality	0.80	2010 Crab SAFE
Groundfish fixed-gear handling mortality	0.50	2010 Crab SAFE

5. Model Objective Function and Weighting Scheme

The objective function consists of a sum of eight "negative loglikelihood" terms characterizing the hypothesized error structure of the principal data inputs with respect to their true, i.e., model-predicted, values and four "penalty" terms associated with year-to-year variation in model recruit abundance and fishing mortality in the directed fishery and groundfish trawl and fixed-gear fisheries. See Table 4, where upper and lower case letters designate model-predicted and data-computed quantities, respectively, and boldface letters again indicate vector quantities. Sample sizes n_t (observed number of male SMBKC ≥ 90 mm CL) and estimated coefficients of variation $\widehat{cv}_t$ were used to develop appropriate variances for stage-proportion and abundance-index components. The weights λ_j appearing in the objective function component expressions in Table 4 play the role of "tuning" parameters in the modeling procedure.

Table 4. Loglikelihood and penalty components of base-model objective function. The λ_k are weights, described in text; the $neff_t$ are effective sample sizes, also described in text. All summations are with respect to years over each data series.

Component		Form
Legal retained-catch biomass	Lognormal	$-0.5\sum[\ln(c_t/C_t)^2/\ln(1+cv_c^2\ )]$
Dis. Pot bycatch biomass	Lognormal	$-0.5\sum[\ln(d_t/D_t)^2/\ln(1+cv_{d,t}^2)]$
Trawl-survey biomass index	Lognormal	$-0.5\sum[\frac{\ln(b_t^{ts}\ )-\ln(B_t^{ts})}{sqrt(\ln\left(1+\widehat{cv_t^{ts}}^2\right))}]^2$
Pot-survey abundance index	Lognormal	$-0.5\sum[\frac{\ln\left(a_t^{ps}\right)-\ln\left(A_t^{ps}\right)}{\mathrm{sqrt}(\ln\left(1+\widehat{cv_t^{ps}}^2\right))}]^2$

Trawl-survey stage proportions (scen.0)	Multinomial	$\lambda_4 \sum neff_t^{ts} (\boldsymbol{p}_t^{ts})^T \ln(\boldsymbol{P}_t^{ts} + 0.01)$
Pot-survey stage proportions (scen.0)	Multinomial	$\lambda_5 \sum neff_t^{ps} (\boldsymbol{p}_t^{ps})^T \ln(\boldsymbol{P}_t^{ps} + 0.01)$
Directed-fishery stage proport. (scen.0)	Multinomial	$\lambda_6 \sum neff_t^{df} (\boldsymbol{p}_t^{df})^T \ln(\boldsymbol{P}_t^{df} + 0.01)$
Groundfish trawl mortality biomass	Lognormal	$-0.5 \sum [\ln(b_t^{gt}/B_t^{gt})^2 / \ln(1 + cv_g{}^2)]$
Groundfish fixed-gear mortality biomass	Lognormal	$-0.5 \sum [\ln(b_t^{gf}/B_t^{gf})^2 / \ln(1 + cv_g{}^2)]$
$\ln(N_{1,t}^{new})$ deviations	Quadratic/Normal	$\lambda_9 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{df})$ deviations	Quadratic/Normal	$\lambda_{10} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{gft})$ deviations	Quadratic/Normal	$\lambda_{11} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{gff})$ deviations	Quadratic/Normal	$\lambda_{12} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$

For scenarios 0-11, stage compositions ($p_{l,t,k}$) likelihood functions are :

$$Rf = \prod_{l=1}^{L} \prod_{t=1}^{T} \prod_{k=1}^{3} \frac{\left\{ \exp\left[-\frac{(p_{l,t,k} - \hat{p}_{l,t,k})^2}{2\sigma^2} \right] + 0.01 \right\}}{\sqrt{2\pi\sigma^2}},$$

$$\sigma^2 = \left[p_{l,t,k}(1 - p_{l,t,k}) + 0.1/L \right] / neff_{t,k},$$

where

L is the number of stages,

T is the number of years,

k stands for trawl survey, pot survey, and observer fishery data, and

$neff_{t,k}$ is the effective sample size, which was estimated for trawl and pot surveys and observer stage composition data from the directed pot fishery. See Model Scenarios Section for effective sample size determinations.

The log-likelihood for the pot survey abundance index in Table 4 is for scenario T. For all other scenarios, the log-likelihood is

$$-\sum [\ln(\ln(CV_t^2 + 1))^{0.5} + \ln(a_t^{ps} / A_t^{ps})^2 / (2\ln(CV_t^2 + 1))].$$

Determination of the weighting scheme involved a great deal of trial and error with respect to graphical and other diagnostic tools; however, the author’s basic strategy was to begin with a baseline weighting scheme that was either unity or otherwise defensible in terms of plausible variances and then proceed in the spirit of Francis (2011). The CPT noted in May 2012 that survey weights should generally not exceed unity, and the author has complied with that advice for this assessment.

Table 5 shows the weighting scheme used for the model scenarios. A CV of 0.03 is applied to the lognormal fishery catch-biomass component corresponds. The weights λ_2 and λ_3 on the lognormal trawl-survey and pot-survey abundance components are set at 1.0, allowing the yearly conventional survey-based CV estimates to govern the terms contributed by these two series. The default CV of 1.31 on the lognormal groundfish bycatch mortality biomass components is probably appropriate given the nature of the data. The weight of 1.25 applied to the quadratic/normal recruit-deviation penalty (λ_9) is approximately the inverse of the sample variance of trawl-survey time-series estimates of 90-104 mm male crab (“recruit”) abundance. With λ_4, λ_5, and λ_6 equal to 1.0, the factors denoted by $neff_t$ appearing in the multinomial loglikelihood expressions or robust normal approximation of the objective function represent effective sample sizes describing observed survey and fishery stage-proportion error structure with respect to model predicted values. Each set is determined by a single set-specific parameter N_{max} such that the effective sample size in any given year $neff_t$ is equal to the observed number of crab n_t if $n_t < N_{max}$ and otherwise equal to N_{max} for scenario 0. For scenario T configuration, N_{max} was assigned a value of 50 for trawl-survey composition data and 100 for both pot-survey and fishery observer composition data. Graphical displays of the standardized residuals, including normal Q-Q plots, provided some guidance in making this choice, although model fit to the composition data tends to be rather poor under all scenarios.

Table 5. Model objective-function weighting scheme.

Objective-Function Component	Weight λ_j
Legal retained-catch biomass cv	0.03
Dis. Pot bycatch biomass (1978-1998)	0.6
Dis. Pot bycatch biomass (2009-2014)	0.2
Trawl-survey abundance index	1.0
Pot-survey abundance index	1.0
Trawl-survey stage proportions	1.0
Pot-survey stage proportions	1.0
Directed-fishery stage proportions	1.0
Groundfish trawl mortality biomass cv	1.31
Groundfish fixed-gear mortality biomass cv	1.31
Log model recruit-abundance deviations	1.25
Log directed fishing mortality deviations	0.001
Log groundfish trawl fishing mortality deviations	0.01
Log groundfish fixed-gear fishing mortality deviations	0.01
Deviations from random walk approach for molting prob.	2.0

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. Temporal Changes in Bottom Temperatures and Crab Distributions

There are eight NMFS survey stations (R-23, R-24, R-25, Q-23, Q-25, P-23, P-24, and P-25) around St. Matthew Island (Figure B1). If three (O-23, O-24 and O-25), or another six more stations (N-23, N-24 and N-25), are added, there are either 11 stations or 14 stations (Figure 1). Mean bottom temperatures for these 8, 11 and 14 stations have nearly uniform temporal trends (Figure B2). The mean temperatures from the 14 stations are used as the temperature index in this report.

Distribution centers for three stage crab and mature males (stage 2 plus stage 3) are illustrated in Figure B3. In general, crab in stage 3 (legal crab) occur in more southern area, and crab in stage 1 more northern area, but the differences are very small. Associations between latitudes and longitudes of distribution centers of three stages of crab and bottom temperatures are positive, with crab occurring more northeastern areas in warm temperatures (Figures B4-6); however, the relationships are generally weak.

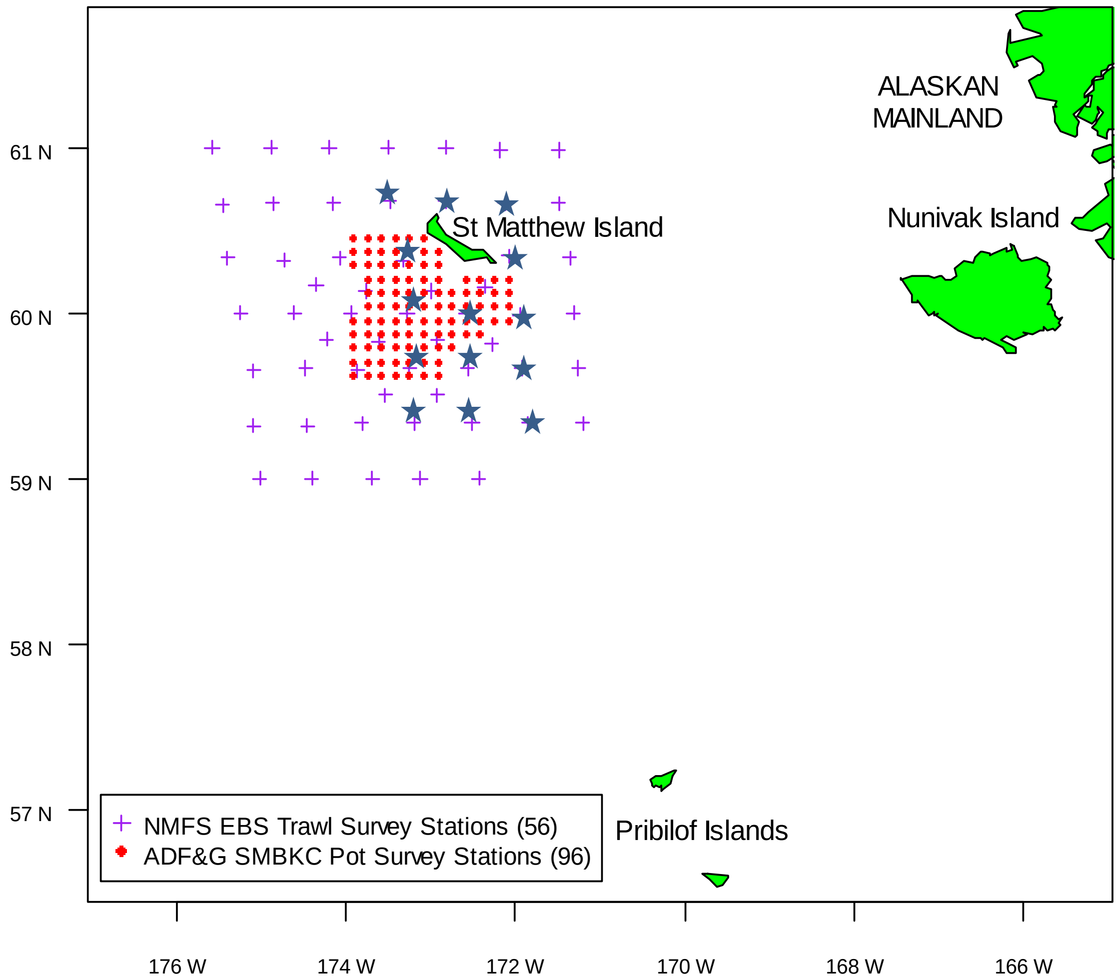


Figure B1. Trawl and pot-survey stations used in the St. Mathew Island blue king crab stock assessment. The stations with ★ are used for bottom temperature indices.

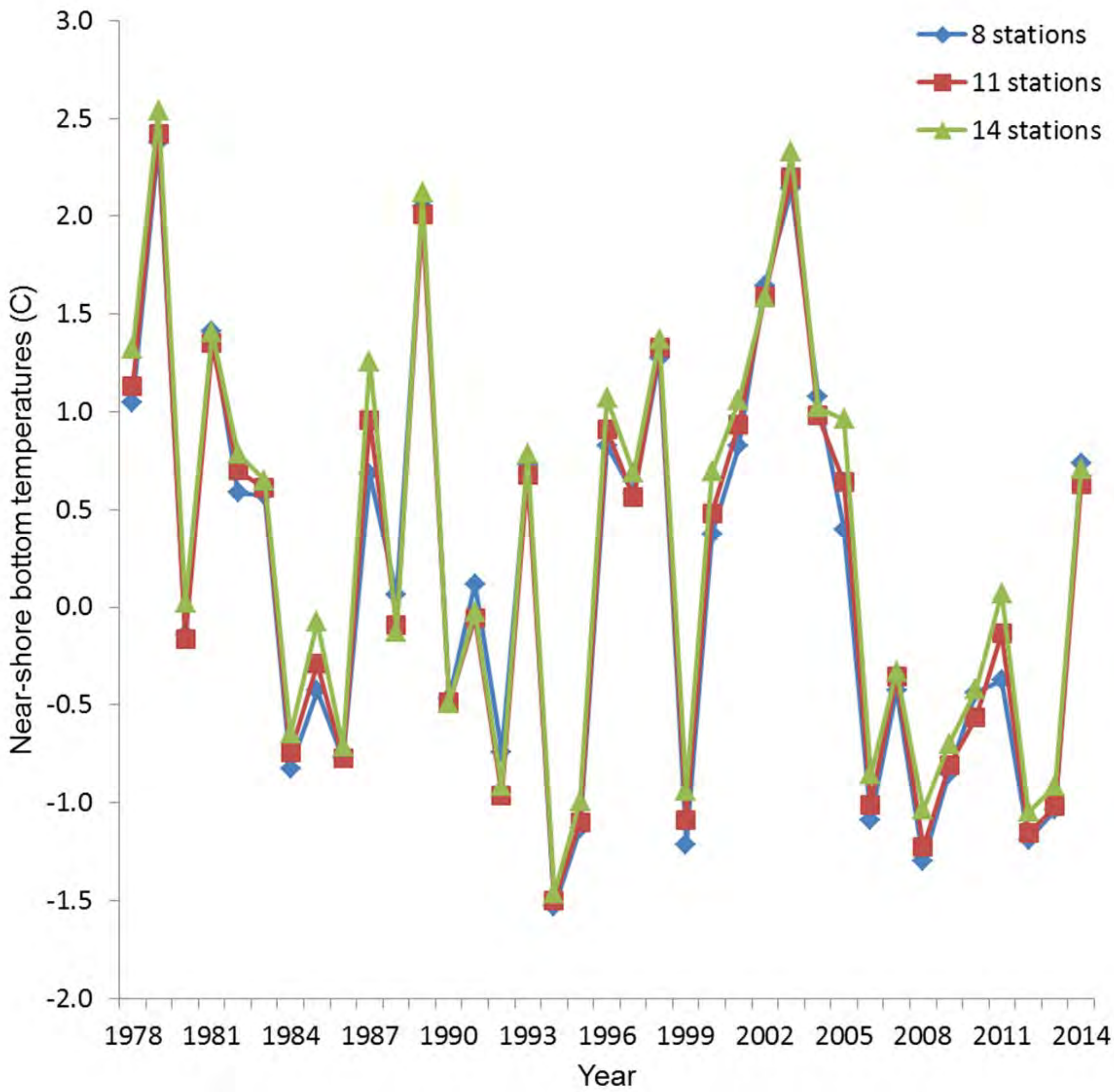


Figure B2. Mean near-shore bottom temperatures within 8, 11, and 14 NMFS survey stations around St. Matthew Island.

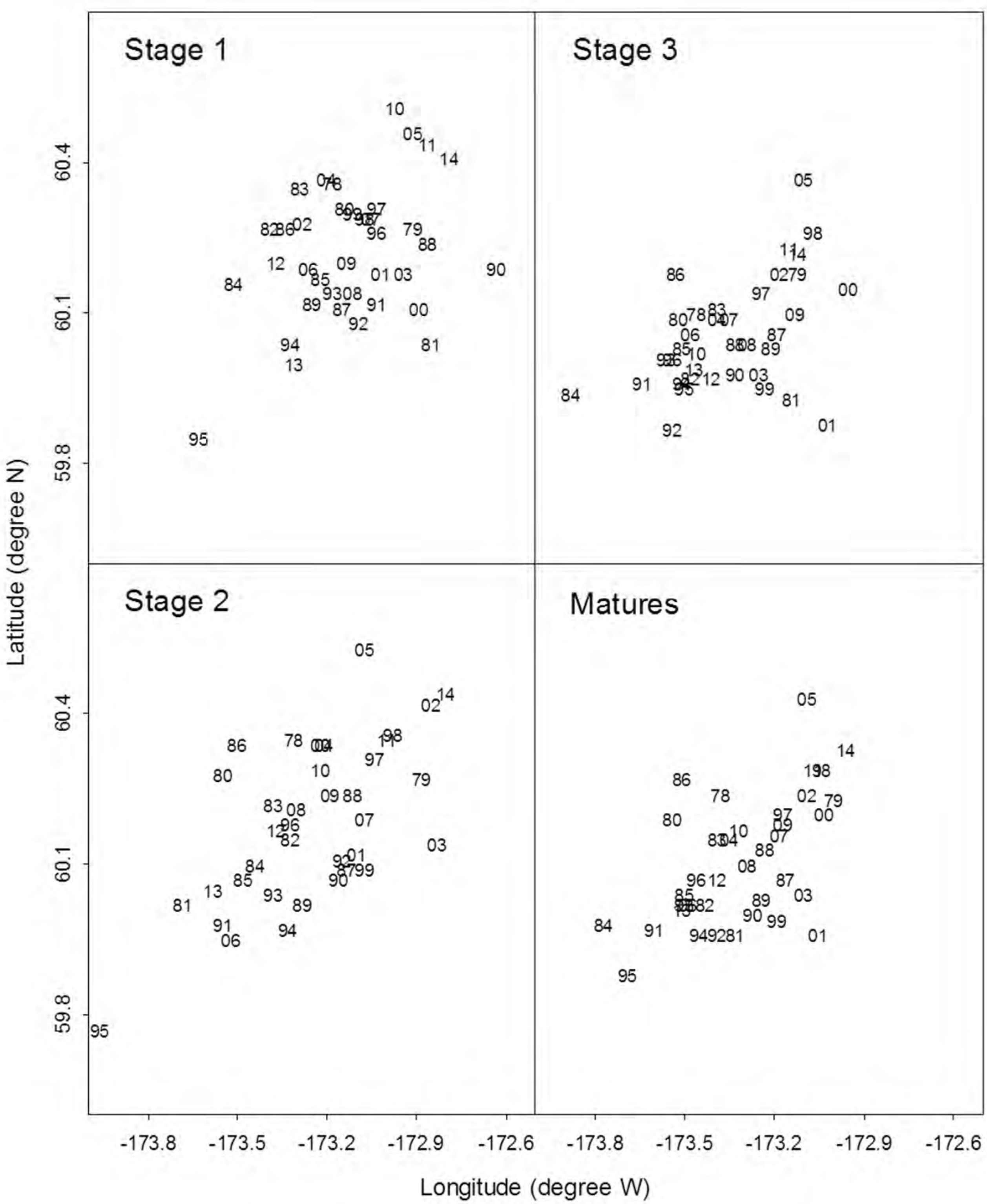
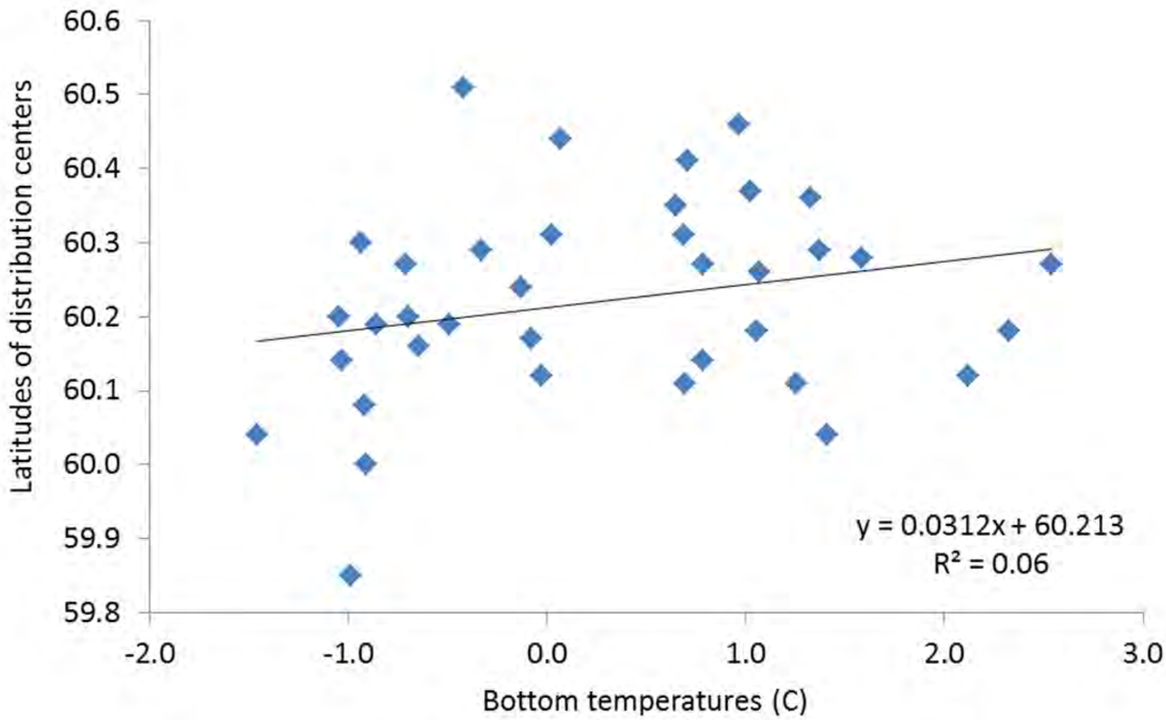


Figure B3. Distribution centers by stage defined by carapace length (CL) (1. 90-104 mm CL, 2. 105-119 mm CL, 3. ≥120 mm CL) for male St. Matthew blue king crab from NMFS summer trawl surveys. Mature males are a combination of stages 2 and 3.



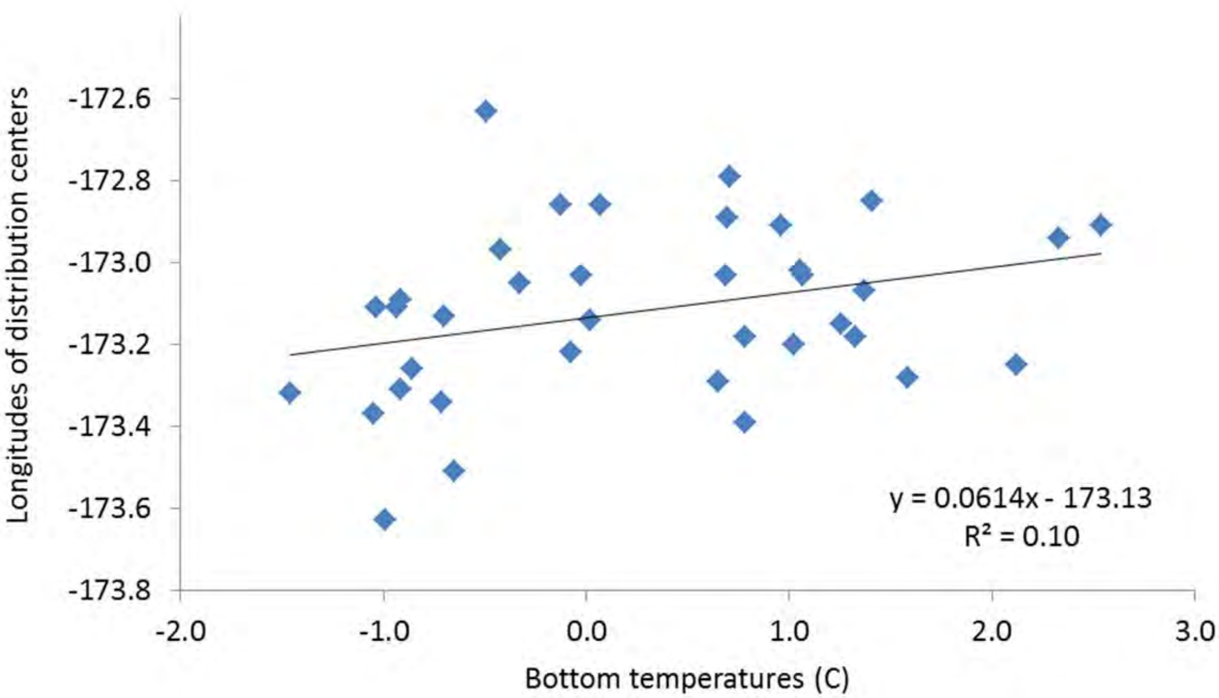
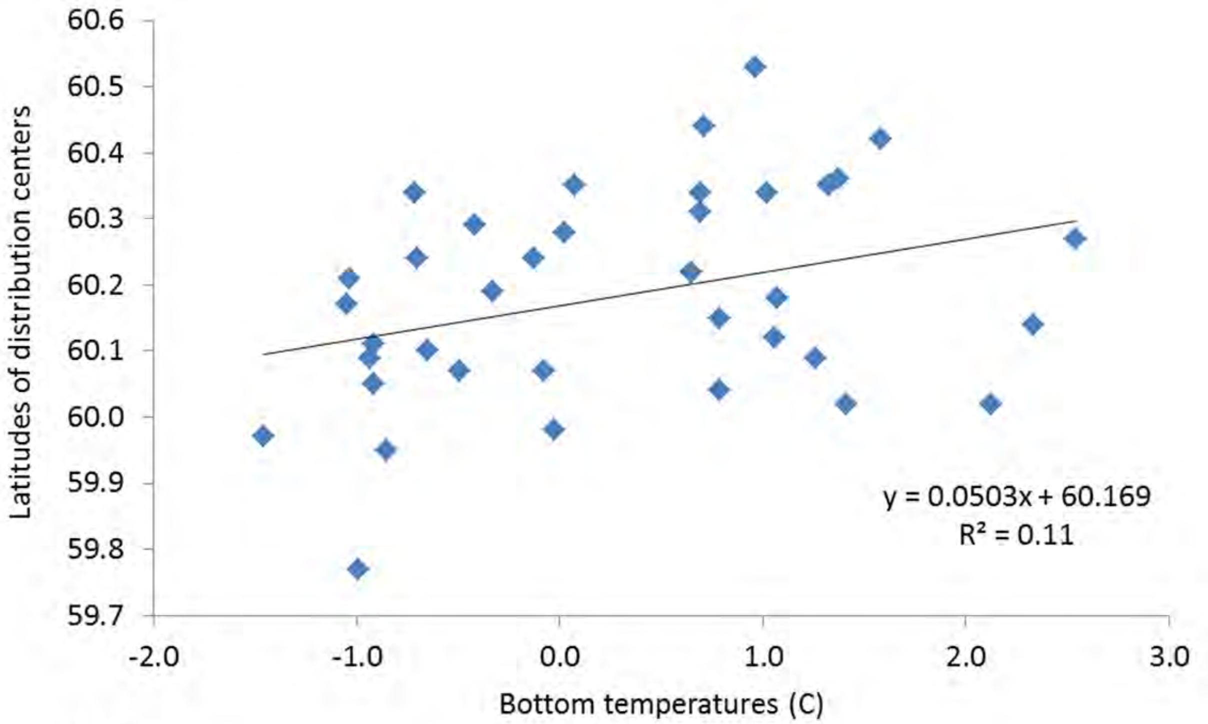


Figure B4. Relationships between annual latitudes and longitudes of stage 1 (90-104 mm carapace length) distribution centers and bottom temperatures for St. Matthew Island blue king crab.



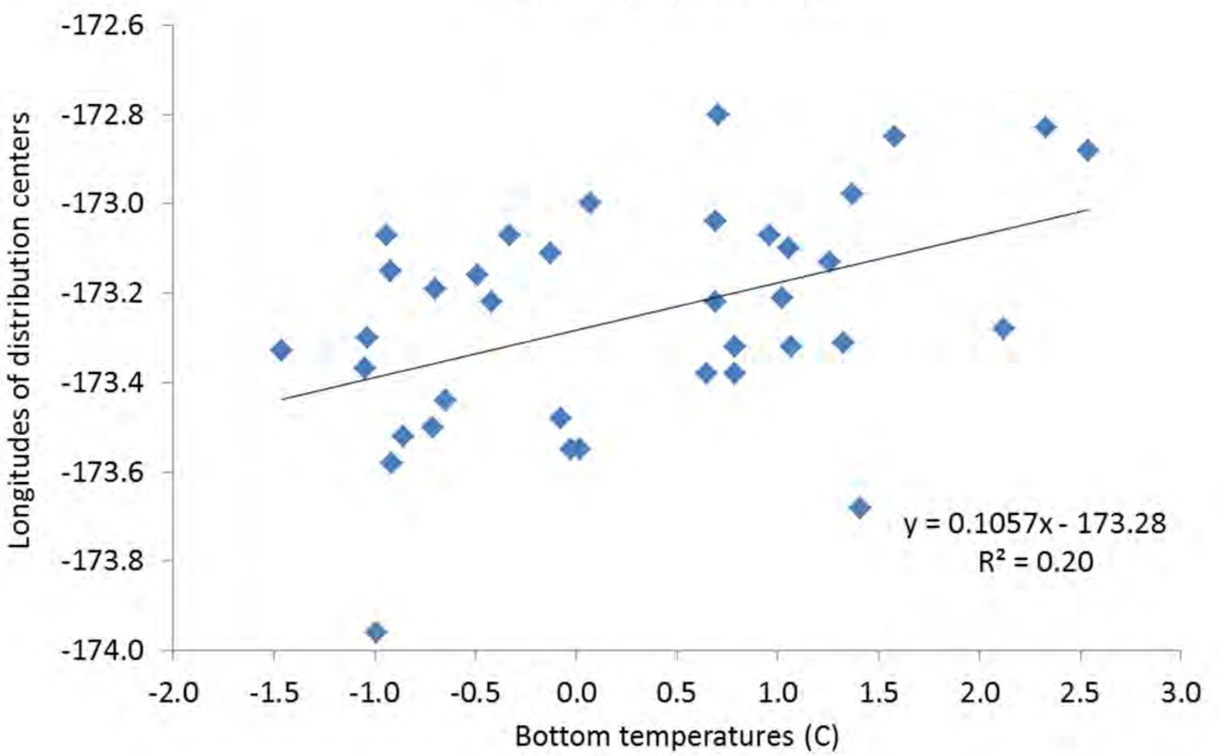


Figure B5. Relationships between annual latitudes and longitudes of stage 2 (105-119 mm carapace length) distribution centers and bottom temperatures for St. Matthew Island blue king crab.

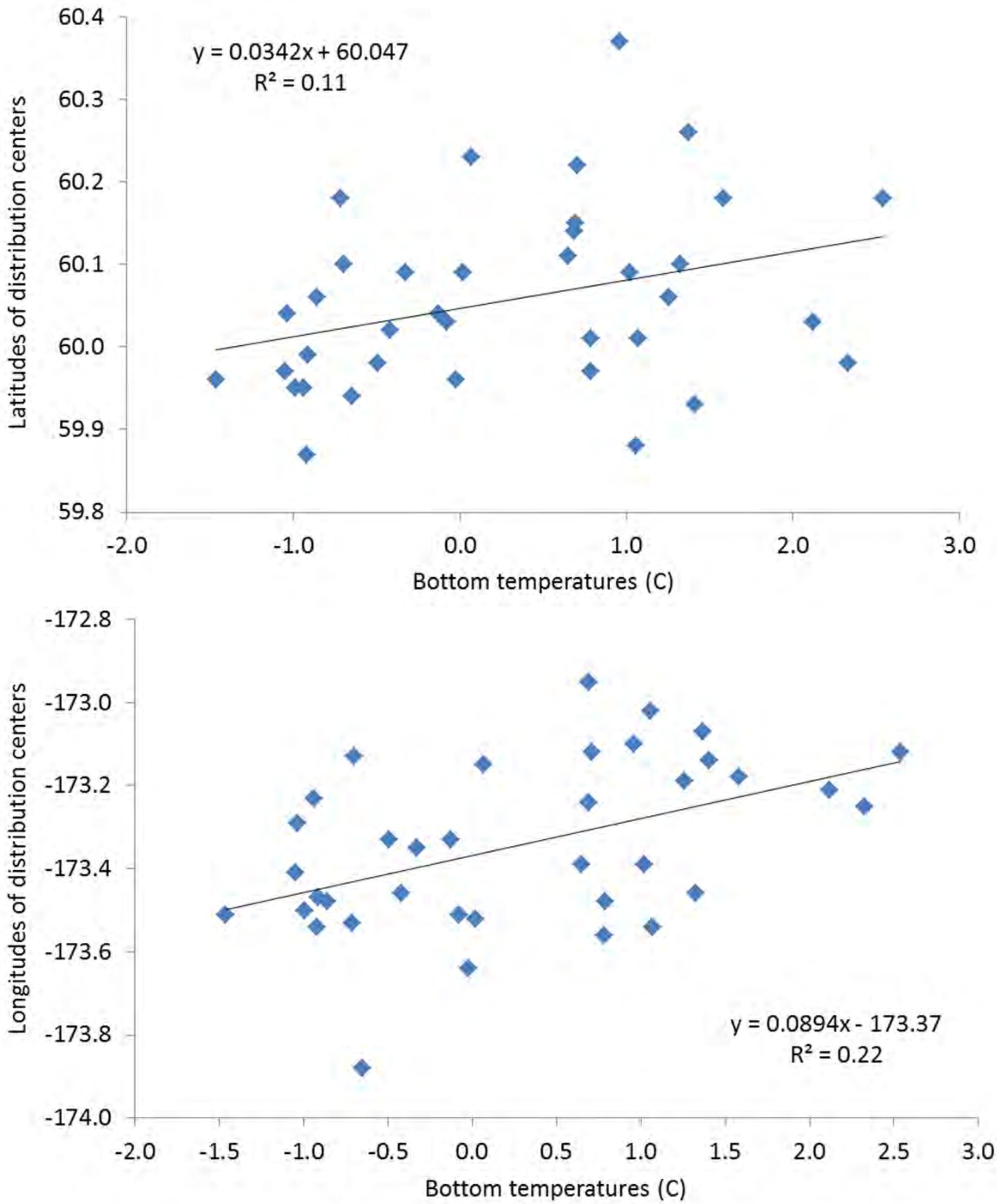


Figure B6. Relationships between annual latitudes and longitudes of stage 3 (≥120 mm carapace length) distribution centers and bottom temperatures for St. Matthew Island blue king crab.

Norton Sound Red King Crab Stock Assessment for the fishing year 2015

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Executive Summary

1. Stock. Red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska.

2. Catches. This stock supports three main fisheries: summer commercial, winter commercial, and winter subsistence fisheries. Of those, the summer commercial fishery accounts for more than 90% of total harvest. The summer commercial fishery started in 1977, and its catch reached a peak 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. Coincident with increasing estimated abundance, retained catches in recent years have increased to about 0.4 million pounds.

3. Stock Biomass. Following a peak in 1977, abundance or the stock collapsed to a historic low in 1982. Estimated mature male biomass (MMB) has shown an increasing trend since 1997. However, uncertainty in historical biomass is high due in part to infrequent trawl surveys (every 3 to 5 years) and limited winter pot surveys.

4. Recruitment. Model estimated recruitment was weak during the late 1970s and high during the early 1980s, with a slight downward trend from 1983 to 1993. Estimated recruitment has been highly variable but on an increasing trend in recent years.

5. Management performance.

Status and catch specifications (million lb.)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2011/12	1.25[A]	4.70	0.36	0.40	0.43	0.66[A]	0.59
2012/13	1.76[B]	4.59	0.47	0.47	0.47	0.53[B]	0.48
2013/14	2.06[C]	5.00	0.50	0.35	0.35	0.58[C]	0.52
2014/15	2.11[D]	3.71	0.38	0.39	0.39	0.46[D]	0.42
2015	2.41[E]	5.13	TBD	TBD	TBD	0.72[E]	0.58

Status and catch specifications (1000t)

Year	MSST	Biomass (MMB)	GHL	Retained Catch	Total Catch	OFL	ABC
2011/12	0.57[A]	2.13	0.16	0.18	0.20	0.30[A]	0.27
2012/13	0.80[B]	2.08	0.21	0.21	0.21	0.24[B]	0.22
2013/14	0.93[C]	2.27	0.23	0.16	0.16	0.26[C]	0.24
2014/15	0.96[D]	1.68	0.17	0.18	0.18	0.21[D]	0.19
2015	1.09[E]	2.33	TBD	TBD	TBD	0.33 [E]	0.26

Notes:
MSST was calculated as $B_{MSY}/2$
A-Calculated from the assessment reviewed by the Crab Plan Team in May 2011
B-Calculated from the assessment reviewed by the Crab Plan Team in May 2012
C-Calculated from the assessment reviewed by the Crab Plan Team in May 2013
D-Calculated from the assessment reviewed by the Crab Plan Team in May 2014
E-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2015
Conversion to Metric ton: 1 Metric ton = 2.2046× 1000 lb

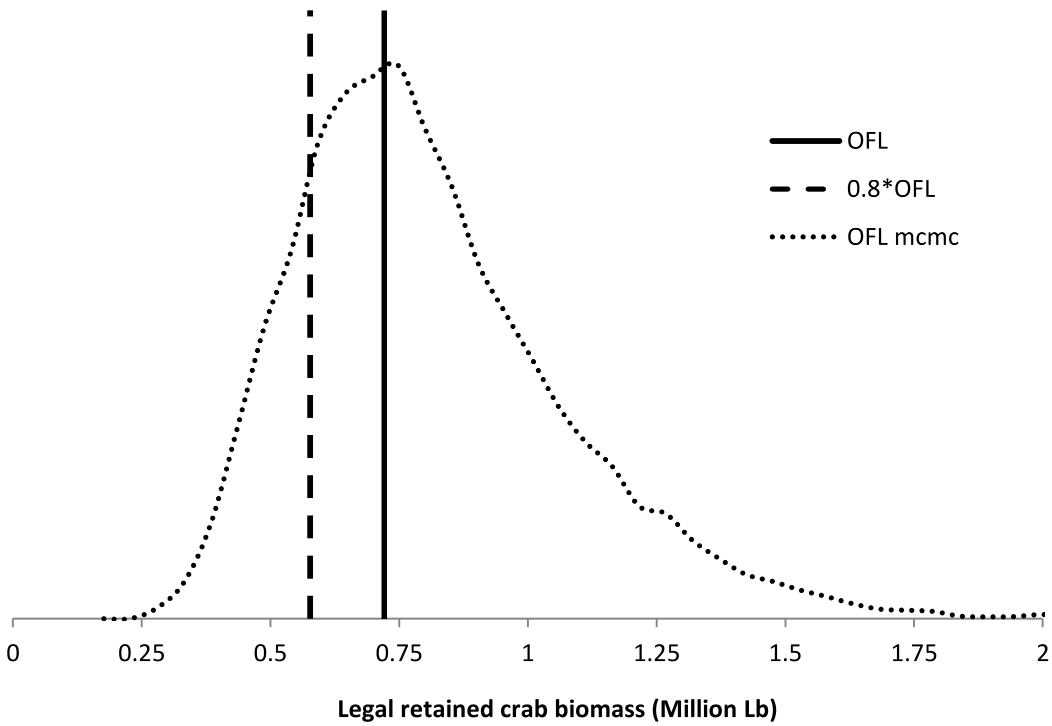
Biomass in millions of pounds

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	ABC
2011/12	4a	2.97	4.70	1.6	0.18	1983-2011	0.18	0.9	0.59
2012/13	4a	3.51	4.59	1.2	0.18	1980-2012	0.18	0.9	0.48
2013/14	4b	4.12	5.00	1.2	0.18	1980-2013	0.18	0.9	0.52
2014/15	4b	4.19	3.71	0.9	0.16	1980-2014	0.18	0.9	0.42
2015	4a	4.81	5.13	1.1	0.18	1980-2015	0.18	0.8	0.58

Biomass in 1000t

Year	Tier	B_{MSY}	Current MMB	B/B_{MSY} (MMB)	F_{OFL}	Years to define B_{MSY}	M	1-Buffer	ABC
2011/12	4a	1.35	2.13	1.6	0.18	1983-2011	0.18	0.9	0.27
2012/13	4a	1.59	2.08	1.2	0.18	1980-2012	0.18	0.9	0.22
2013/14	4a	1.87	2.27	1.2	0.18	1980-2013	0.18	0.9	0.24
2014/15	4b	1.68	1.68	0.9	0.16	1980-2014	0.18	0.9	0.21
2015	4a	2.18	2.33	1.1	0.18	1980-2015	0.18	0.8	0.26

6. Probability Density Function of the OFL



OFL profile. 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 since 2011. In 2015, CPT increased the buffer to 20% (ABC = 80% OFL) being consistent with other tier 4 stocks.

8. A summary of the results of any rebuilding analyses.
   N/A

A. Summary of Major Changes in 2015

1. Changes to the management of the fishery**:**

   None.

2. Changes to the input data
    a. Data update: 2014 summer commercial fishery (total catch, catch length comp, discards length comp), 2013/2014 winter commercial and subsistence catch
    b. Data update: 1977-2014 standardized commercial catch CPUE and CV. No changes in standardization methodology (SAFE 2013).

3. Changes to the assessment methodology:
    a. Changed modeling schedule from July 01 - June 30 to Feb 01 - Jan 30

4. Changes to the assessment results.
    a. OFL determination is based on Feb 01 mature male biomass (MMB)
    b. Calculation of retained OFL and ABC are for both winter (subsistence + commercial) and summer commercial catches. (See section F for details)

B. Response to SSC and CPT Comments

CPT Sept 15-18 2014

- Evaluate a reduction in the weighting of the winter pot survey data.

  Authors' reply:
  This requests came from the fact that profile likelihood analyses of *M* showed higher *M* for winter pot survey length data, and thus reduction of its weight was suggested (CPT 2014 September). However, profile likelihood of a revised model (Appendix B2) showed winter pot survey likelihood minimized at *M* = 0.2. Hence, we did not pursue this issue further.

- Continue to examine models with a single *M* for all size-classes, and a separate *M* for the largest size class using likelihood profiles, but evaluate whether use of a descending logistic curve for the winter pot selectivity changes the likelihood profile.

  Authors' reply:
  Similar to previous likelihood analyses, negative log likelihood was minimized at *M* = 0.3 – 0.4 (Appendix B2). For winter pot selectivity, it was minimized at *M* = 0.2.

- Explore a separate estimated selectivity for the smallest size class.

  Author's reply:

We implemented reverse-logistic with separate selectivity for the smallest size class for winter pot survey. This reduced negative log likelihood, and is thus the author's preferred alternative model.

SSC Oct 6-8 2014

- The SSC concurs with these (CPT's) recommendations. It also recommends comparing the standard deviation of residuals to the input standard deviation to develop a more objective weighting of the various likelihood components in the model.

  Author's reply:
  We calculated RMSE for trawl abundance and standardized CPUE and compared them with those of observed CV. They were close.

C. Introduction

1. Species: red king crab (*Paralithodes camtschaticus*) in Norton Sound, Alaska.

2. General Distribution: Norton Sound red king crab is one of the northernmost red king crab populations that can support a commercial fishery (Powell et al. 1983). It is distributed throughout Norton Sound with a westward limit of 167-168^{o} W. longitude, depths less than 30 m, and summer bottom temperatures above 4^{o}C. The Norton Sound red king crab management area consists of two units: Norton Sound Section (Q3) and Kotzebue Section (Q4) (Menard et al. 2011). The Norton Sound Section (Q3) consists of all waters in Registration Area Q north of the latitude of Cape Romanzof, east of the International Dateline, and south of 66°N latitude (Figure 1). The Kotzebue Section (Q4) lies immediately north of the Norton Sound Section and includes Kotzebue Sound. Commercial fisheries have not occurred regularly in the Kotzebue Section. This report deals with the Norton Sound Section of the Norton Sound red king crab management area.

3. Evidence of stock structure: Thus far, no studies have been made on possible stock separation within the putative stock known as Norton Sound red king crab.

4. Life history characteristics relevant to management: One of the unique life-history traits of Norton Sound red king crab is that they spend their entire lives in shallow water since Norton Sound is generally less than 40 m in depth. Distribution and migration patterns of Norton Sound red king crab have not been well studied. Based on the 1976-2006 trawl surveys, red king crab in Norton Sound are found in areas with a mean depth range of 19 ± 6 (SD) m and bottom temperatures of 7.4 ± 2.5 (SD) ^{o}C during summer. Norton Sound red king crab are consistently abundant offshore of Nome.

   Norton Sound red king crab migrate between deeper offshore and inshore shallow waters. . Timing of the inshore mating migration is unknown, but is assumed to be during late fall to winter (Powell et al. 1983). Offshore migration occurs in late May - July (Jennifer Bell, ADF&G, personal communication). The results from a study funded by North Pacific Research Board (NPRB) during 2012-2014 suggest that older/large crab (> 104mm CL) stay offshore in winter, based on findings that large crab are not found nearshore during spring offshore migration periods (Jennifer Bell, ADF&G, personal communication). Timing of molting is unknown but is considered to occur in late August – September, based on increase catches of fresh-molted crab later in the fishing season (August- September) (Joyce Soong, ADF&G personal communication); however, blood hormonal studies suggests April-May molting season (Jennifer Bell, ADF&G, personal communication), which is consistent with Powell et al. (1983). Recent observations indicate biennial mating (Robert Foy, NOAA, personal communication). Trawl surveys show that crab distribution is dynamic. Recent surveys show high abundance on the southeast side of the sound, offshore of Stebbins and Saint Michael.

5. Brief management history: Norton Sound red king crab fisheries consist of commercial and subsistence fisheries. The commercial red king crab fishery started in 1977 and occurs in summer (June – August) and in winter (December – May). The majority of red king crab is harvested by the summer commercial fisheries in offshore, whereas the majority of subsistence fisheries occur in winter in nearshore.

<u>Summer Commercial Fishery</u>

The summer commercial crab fishery started in 1977 (Table 1). A large-vessel summer commercial crab fishery existed in the Norton Sound Section from 1977 through 1990. No summer commercial fishery occurred in 1991 because there was no staff to manage the fishery. In March 1993, the Alaska Board of Fisheries (BOF) limited participation in the fishery to small boats. Then on June 27, 1994, a super-exclusive designation went into effect for the fishery. This designation stated that a vessel registered for the Norton Sound crab fishery may not be used to take king crabs in any other registration areas during that registration year. A vessel moratorium was put into place before the 1996 season. This was intended to precede a license limitation program. In 1998, Community Development Quota (CDQ) groups were allocated a portion of the summer harvest; however, no CDQ harvest occurred until the 2000 season. On January 1, 2000 the North Pacific License Limitation Program (LLP) went into effect for the Norton Sound crab fishery. The program dictates that a vessel which exceeds 32 feet in length overall must hold a valid crab license issued under the LLP by the National Marine Fisheries Service. Regulation changes and location of buyers resulted in harvest distribution moving eastward in Norton Sound in the mid-1990s. . In the Norton Sound, a legal crab is defined as ≥ 4-3/4 inch carapace width (CW, Menard et al. 2011; equivalent to ≥ 124 mm carapace length [CL]). Since 2005, commercial buyers started accepting only legal crab of ≥ 5 inch CL.

Not all Norton Sound area is open for commercial fisheries. Since the beginning of the commercial fisheries in 1977, inland waters near Nome area have been closed for the summer commercial crab fishery to protect crab nursery grounds (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 they make their first delivery. Fishers operate under authority of the CDQ group and each CDQ group decides how their crab quota is to be harvested. During the March 2002 BOF meeting, new regulations were adopted that affected the CDQ crab fishery and relaxed closed-water boundaries in eastern Norton Sound and waters west of Sledge Island. At its March 2008, the BOF changed the start date of the Norton Sound open-access portion of the fishery to be opened by emergency order and as early as June 15. The CDQ fishery may open at any time (as soon as ice is out), by emergency order.

Winter Commercial Fishery

The winter commercial crab fishery is a small fishery using hand lines and pots through the nearshore ice. On average 10 permit holders harvested 2,500 crab during 1978-2009. During the 2006-2013 periods the winter commercial catch increased to 3,000 – 23,000 (Table 2). Causes for this increase are unclear. The winter commercial fishery catch is influenced not only by crab abundance, but also by changes in near shore crab distribution, ice conditions, the number of participants, and market condition.

Subsistence Fishery

While the subsistence fishery has a long history, harvest information is available only since1977/78. The majority of the subsistence crab fishery harvest occurs during winter using hand lines and pots through nearshore ice. Average annual winter subsistence harvest was 5,400 crab (1977-2010). Subsistence harvesters need to obtain a permit before fishing and record daily effort and catch. There is no size limit in the subsistence fishery. 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 average harvest of 712 crab per year. Since this harvest is very small, the summer subsistence fishery was not included in the assessment model.

6. Brief description of the annual ADF&G harvest strategy

Since 1997 Norton Sound red king crab have been managed based on a guideline harvest limit (GHL). Detailed historical methods of GHL determination are unknown. From 1999 to 2011 GHL is 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 became in effect: (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 when estimated legal biomass >3.0 million lb.

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. Participation limited to small boats. The majority of commercial fishery subsequently shifted to east of 164^{o}W line.
1998	Community Development Quota (CDQ) allocation went into effect
1999	Guideline Harvest Limit (GHL) went into effect
2000	North Pacific License Limitation Program (LLP) went into effect.
2002	Change in closed water boundaries (Figure 2)
2005	Commercially accepted legal crab size changed from ≥ 4-3/4 inch CW to ≥ 5 inch CW
2006	The Statistical area Q3 section expanded (Figure 1)
2008	Start date of the open access fishery changed from July1 to after June 15 by emergency order. Pot configuration requirement: at least 4 escape rings (>4½ inch diameter) per pot located within one mesh of the bottom of the pot, or at least ½ of the vertical surface of a square pot or sloping side-wall surface of a conical or pyramid pot with mesh size > 6½ inches.
2012	The Board of Fisheries adopted a revised harvest strategy.

7. Summary of the history of the B_{MSY}.

NSRKC is a Tier4 crab stock. Direct estimation of the B_{MSY} is not possible. The B_{MSY} proxy is calculated as mean model estimated mature male biomass (MMB) from 1980 to present. . Choice of this period was based on a hypothesized shift in stock productivity a due to a climatic regime shift indexed by the Pacific Decadal Oscillation (PDO) in 1976-77. Stock status of the NSRKC was Tier 4a. In 2014 the stock fell to Tier 4b.

D. Data

1. Summary of new information:

Trawl survey:

The triennial Norton Sound trawl survey was completed in August of 2014. Due to poor weather of the total number of stations trawled (47) was 28% lower than 2011 (65 stations). The total number of stations with red king crab in Norton Sound (34) was the same as 2011. Estimated total male crab (> 73mm) abundance 5.4816 million crab (CV 48.6%) (Table 3). This was double that of 2011 (2.7017, CV 13%), and was the highest abundance ever recorded (the previous highest record was 1976: 4.2475). However, this estimate is largely due to high crab catch at one survey station, which accounted for 50 % of total abundance.

Summer commercial fishery:

The summer commercial fishery opened June 25 and the last delivery was completed on August 15. A total of 129,956 crab were harvested (Table 1). Standardized CPUE was 1.23, 70% higher than 2013 (0.72), but lower than the 2004-2013 average of 1.27 (Table 4). The catch length compositions were similar to 2013 (Table 5).

2. Available survey, catch, and tagging data

	Years	Data Types	Tables
Summer trawl survey	76,79,82,85,88,91,96, 99, 02,06,08,10,11, 14	Abundance Length proportion	3 5, Figure 3
Winter pot survey	81-87, 89-91,93,95-00,02-12	Length proportion	6, Figure 3
Summer commercial fishery	76-90,92-14	Retained catch Standardized CPUE, Length proportion	1 1 4, Figure 3
Summer commercial Discards	87-90,92,94, 2012-2014	Length proportion (sublegal only)	7, Figure 3
Winter subsistence fishery	76-14	Total catch Retained catch	2 2
Winter commercial fishery	78-14	Retained catch	2
Tag recovery	80-14	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	Not reliable due to ice conditions
Preseason Spring pot survey	2011-14	CPUE, Length proportion	Years of data too short
Postseason Fall pot survey	2013-14	CPUE	Years of data too short

Length proportion

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 ground pot	Does not exist	NA
Bycatch in ground fish trawl	Does not exist	NA
Bycatch in the scallop fishery	Does not exist	NA

3. Other miscellaneous data:

Data aggregated

Proportion of legal size crab, estimated from trawl survey and observer data. (Table 11)

Data estimated outside the model

Summer commercial catch standardized CPUE (Table 1)

E. Analytic Approach

1. History of the modeling approach.

The Norton Sound red king crab stock was assessed using a length-based synthesis model (Zheng et al. 1998).

Since adoption of the model, the major challenge was to resolve conflicts among data sources. Due to very low summer trawl survey abundances of large males in 2002, 2006, 2008 and 2010, which contradicted with the expectation from other data sources The model overestimated the abundance/proportion of large length classes, which resulted in overestimation of the projected biomass. This problem has been dealt with by the following approaches: (1) by increasing M of the last length class, (2) by reducing effective sample size of length composition data, and (3) by increasing M for all length classes (Appendix B2). Although all the 3 approaches improve model fits and projections reasonably well, none are without major criticisms. Approach (1) has been criticized for having little biological support or data. Approach (3) is biologically simpler and a reasonable approach; however, it greatly increases OFL and ABC, without any supportive evidence that the population can withstand higher exploitation rates. Attempts to estimate *M* directly from the model itself have failed. When *M* was set as a free parameter, its estimate stayed at the initial starting value.

At the 2013-2014 crab modeling workshop, extensive examination of the model was conducted, including revision of historical survey abundance data, inclusion and exclusion of data (e.g., exclusion of summer pot survey data, inclusion/exclusion of winter pot survey cpue), reducing the number of parameters (e.g., molting probability, selectivity), and reevaluation of the growth transition matrix.

Historical Model configuration progression

2011 (SAFE 2011)

1. M =0.18
2. M of the last length class = 0.288
3. Include summer commercial discards mortality = 0.2
4. Weight of fishing effort = 20,
5. The maximum effective sample size for commercial catch and winter surveys = 100,

2012 (SAFE 2012)

1. M of the last length class = 3.6×M
2. The maximum effective sample size for commercial catch and winter surveys = 50,
3. Weight of fishing effort = 50.

2013 (SAFE 2013)

1. Standardize commercial catch cpue and replace likelihood of commercial catch efforts to standardized commercial catch cpue with weight = 1.0
2. Eliminate summer pot survey data from likelihood
3. Estimate survey q of 1976-1991 NMFS survey with maximum of 1.0
4. The maximum effective sample size for commercial catch and winter surveys = 20.

2014 (SAFE 2014)

1. Modify functional form of selectivity and molting probability to improve parameter estimates (2 parameters 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.

2. Model Description

a. Description of overall modeling approach:

The model is a male-only size structured model that combines multiple sources of survey, catch, and mark-recovery data using a maximum likelihood approach to estimate abundance, recruitment, catchability of the commercial pot gear, and parameters for selectivity and molting probabilities (See Appendix A for full model description).

b-f. See Appendix A.

g. Critical assumptions of the model:

i. Male crab mature at CL length 94mm.

Bases for this assumption have not been located. No formal study has been conducted to test this assumption.

ii. Molting events in fall after the fishery

This is based on more frequent observations of post-molt crab in September. Recent hormonal study seems to support this. More study is needed to confirm the molting timing.

iii. Instantaneous natural mortality M is 0.18 for all length classes, except for the last length group (> 123mm) where M is 3.6 times higher (0.648). M is constant over time.

This mortality is based on Bristol Bay red king crab, estimated with a maximum age 25 and the 1% rule (Zheng 2005), and was adopted for NSRKC by the CPT. The assumption of the higher M for the last length group is not based on biological data. It is a working hypothesis attempting to explain the lower than model predicted proportion of this group in summer commercial fisheries (Figures 10, 13). It is possible, that the last length group moved into areas inaccessible to commercial fisheries (the CPT review 2010). However, this does not explain the low proportion observed in the summer trawl survey, when all of the Norton Sound Area was surveyed. In addition, lowering the catch selectivity did not result in lower log likelihood than increasing the mortality (CPT 2010).

iv. Trawl survey selectivity is a logistic function with 1.0 for length classes 5-6. . Selectivity is constant over time.

This assumption was not based on biological/mechanistic data and reasoning, but rather an attempt to improve model fit.

v. Winter pot survey selectivity is a dome shaped function: logistic function for length classes 1-4, 1.0 for length class 5, and model estimate for the last length group. Selectivity is constant over time.

This assumption is based on the fact that large crab are not caught in near shore area where the winter surveys occur. Causes of this have been argued: (1) large crab do not migrate into near shore in winter, or (2) large crab are fished out by winter fisheries where the survey occurs (i.e., local depletion). Recent studies suggest that the former was more likely the cause (Jennifer Bell, ADFG, personal communication).

In this assessment, we also examined an alternative selectivity model (Alternative models 5 and 6): inverse logistic with the highest selectivity at the smallest crab, and the smallest crab selectivity estimated separately.

vi. Summer commercial fisheries selectivity is an asymptotic logistic function of 1.0 at the length class 5 and 6. It has two selectivity curves: 1977-1992, and 1993-present, reflecting changes in fishing vessel composition and pot configuration. .

Since 2005 commercial buyers accept only legal crab of CW ≥ 5.0 inch and unknown numbers of legal crab with CW < 5.0 are discarded. Further, since 2008, commercial pots are required to install escapement rings for sublegal crab. Hence one can argue that the catch selectivity changed in 2005. However, the model was not able to accurately estimate selectivity parameters for 2005-2013. Consequently, the selectivities for both 1993-2004 and 2005-2013 were combined.

In this assessment, we also examined one selectivity for all years (Alternative model 6).

vii. 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 also used for subsistence harvest, and hence both fisheries have the same selectivity.

viii. Growth increments are a function of length and are constant over time, estimated from tag recovery data.

ix. Molting probability is an inverse logistic function of length for males.

x. A summer fishing season for the directed fishery is short. All summer commercial harvests occur July 1st.

xi. Discards handling mortality for all fisheries is 20%.
No empirical estimate is available.

xii. Annual retained catch is measured without error.

xiii. All legal size crab (≥ 4-3/4 inch CW) are retained.

Since 2005, buyers announced that only legal crab with ≥ 5 inch CW are acceptable for purchase. Since samples are taken at a commercial dock, it was anticipated that this change would lower the proportion of legal crab for length class 4. However, model was not sensitive to this change (SAFE 2013).

xiv. All sublegal size crab or commercially unacceptable size crab (< 5 inch CW, since 2005) are discarded.

xv. Length compositions have a multinomial error structure, and abundance has a log-normal error structure.

h. Changes of assumptions since last assessment:

Winter pot selectivity: Dome shape inverse logistic function (Alternative models 5,6)

Summer commercial pot selectivity: Same for all years (Alternative model 6)

Triennial trawl survey net selectivity: Same for both NMFS and ADF&G (Alternative model 6)

i. Code validation

The model code was reviewed at the CPT modeling workshop in 2013 and 2014. It is available from the authors.

3. Model Selection and Evaluation

a. Description of alternative model configurations.

Following recommendations at the 2014 crab workshop the following alternative model configurations were examined:

1. May 2014 crab assessment model converted to Feb 01 starting dates (Appendix C1)
2. Reduce Weight of tag-recovery: W = 0.5 (Appendix C2)
3. Winter pot survey selectivity is reverse logistic (Appendix C3)
4. Winter pot survey selectivity is an inverse logistic, estimating selectivity of the smallest length group independently. (Appendix C4)
5. Model 4 + 2 (Appendix C5)
6. Model 5 with parsimony: (Assume one trawl survey selectivity and one commercial pot selectivity) (Appendix C6)

Rationales of the alternative models

Alternative model 2: Tag recovery weight reduction (Appendix C2)

Weight of tag recovery likelihood was reduced from 1.0 default to 0.05 (Appendix B1). Among each component, largest changes were observed in trawl length composition, winter pot length composition, and summer commercial length composition. While trawl and winter pot length compositions were minimized at W = 0.05, summer commercial length composition was minimized at W = 1.0. Among parameters, the influence of weight changes was more apparent for NOAA trawl survey selectivity, and 93-2014 summer commercial pot selectivity. However, this does not affect projection of MMB. Considering those, **we chose W = 0.5 as a compromise**.

Alternative model 3: Winter pot selectivity is inverse logistic. (Appendix C3)

This directly responds to CPT and SSC's recommendation. . In 2014 assessment, the model was not able to estimate shape of the winter pot selectivity. Base selectivity model is a logistic curve with peak at length class 5, and separate estimate for the last length class (class 6) (Appendix A, equation 16). This alternative model changes the selectivity form to reverse logistic with peak at length class 1, which is the same form as molting probability (Appendix A, equation 15).

Alternative model 4: Winter pot selectivity is an inverse logistic with the first length class estimated independently. (Appendix C4)

This is the same as the alternative model 3, with length class 1 estimated separately. This will provide possibility of the selectivity dome shape.

Alternative model 5: Winter pot selectivity is an inverse logistic with the first length class estimated independently, and reduce tagging data weights. (Appendix C5)

This is a combination of model 4 and model 2.

Alternative model 6: Model 5 + model parsimony. (Appendix C6)

This alternative assumes trawl net selectivity the same for both NOAA and ADFG and commercial pot selectivity for 77-92 and 93-14 periods. This is based on SSC's recommendation for model parsimony.
This reduces the number of parameters estimated by 2.

b. Evaluation of alternative models results

Summary of negative log-likelihood : comparable (scenario: 1,3,4; 2,5,6)

Scenario	1	2	3	4	5	6
Parameters	60	60	59	60	60	58
Total NLL	312.8	269.7	312.1	305.1	262.4	262.5
TBA	9.7	9.6	9.7	9.7	9.7	9.7
CCPUE	-25.5	-25.6	-25.6	-25.6	-25.7	-25.7
TLP (N)	-21.2	-21	-19.2	-20	-18.6	-19.2
TLP (O)	123.2	120.2	121.0	122.0	118.4	119

WLP (N)	12.9	13.3	5.7	1.2	2.3	2.4
WLP (O)	31.1	29.2	37.1	35.4	33.4	33.4
CLP (N)	62.4	67.5	63.0	63.6	68.8	68.8
CLP (O)	-0.5	-3.4	-1.3	-1.0	-3.9	-3.9
OBS (N)	3.1	3.7	3.8	2.4	2.7	2.8
OBS (O)	20.9	20.3	21.3	20.7	20.2	20.3
REC	11.8	11.9	12.1	12	11.9	11.8
TAG	85.1	43.8	84.4	84.6	43.3	43.1
RMSE (Trawl)	0.36	0.36	0.37	0.36	0.36	0.36
RMSE (CPUE)	0.5	0.5	0.5	0.5	0.5	0.5
MMB (2015)	5.10	5.10	5.13	5.15	5.27	5.13

TBA: Trawl survey abundance
CCPUE: Summer commercial catch standardized cpue
TLP: Trawl survey length composition: (N: for newshell, O: for oldshell)
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

c. Search for balance:

Overall, there was little difference in model performance among alternative models. Excluding tagging data, largest change in likelihood was observed in the fits of winter pot length composition (WLP). Even though both models assumes dome shape selectivity, changing selectivity from a logistic with the last length class estimated (Model 1) to inverse logistic with the first length class estimated (Model 5) improved the model fit.
Comparing Model 5 and Model 6, reduced the number of free parameters by assuming one selectivity for trawl survey (NOAA and ADF&G) and one selectivity for commercial catch (1976-1992, and 1993-2014) did not result in change of likelihood.

Considering the above, we recommend Alternative model 6 for the base model, based on advantages of (1) better model fit and (2) model parsimony.

4. Results

1. List of effective sample sizes and weighting factors (Figure 4)

   Effective sample sizes were calculated as

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

Where $P_{y,l}$ and $\hat{P}_{y,l}$ are observed and estimated length compositions in year y and length group l, respectively. Estimated effective sample sizes vary greatly over time.

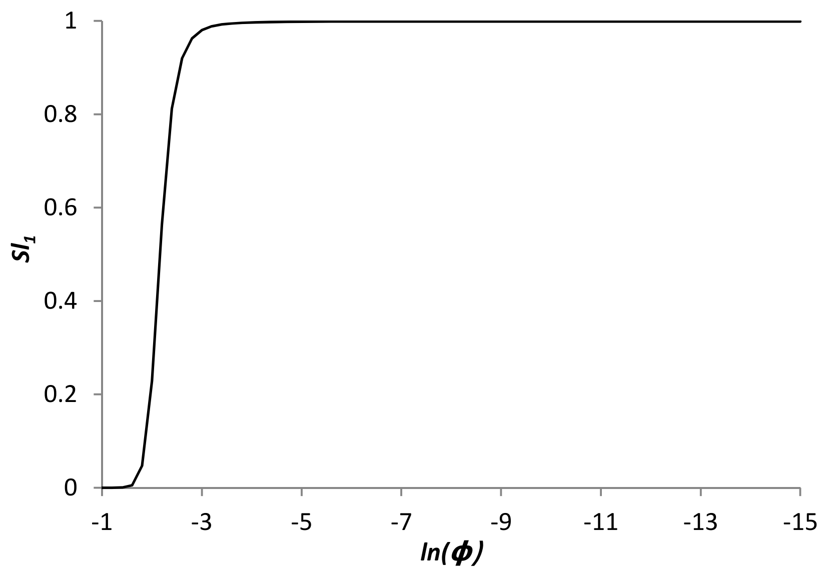
Maximum sample size for length proportion:

Survey data	Sample size
Summer commercial, winter pot, and summer observer	minimum of 0.1× actual sample size or 10
Summer trawl and pot survey	minimum of 0.5× actual sample size or 20

2. Tables of estimates.

a. Model parameter estimates (Tables 10, 11, 12, 13).

Of the 58 parameters estimated, trawl survey selectivity (log_ϕ_{st1}) showed high SD. This is because due to the fact that estimated selectivity 1.0 for all length classes. Any log_ϕ_{st1} less than -3 can reach selectivity close to 1.0.



b. Abundance and biomass time series (Table 14)

c. Recruitment time series (Table 14).

d. Time series of catch/biomass (Table 15)

3. Graphs of estimates.

a. Molting probability and trawl/pot selectivities (Figure 5)

b. Trawl survey and model estimated trawl survey abundance (Figure 6)

c. Estimated male abundances (recruits, legal, and total) (Figure 7)

d. Estimated mature male biomass (Figure 8)

e. Time series of standardized cpue for the summer commercial fishery (Figure 9).

f. Time series of catch and estimated harvest rate (Figure 10).

4. Evaluation of the fit to the data.

a. Fits to observed and model predicted catches.
Not applicable. Catch is assumed to be measured without error; however fits of cpue are available (Figures 9, 11).

b. Model fits to survey numbers (Figures 6, 11).

All model estimated abundances of total crab were within the 95% confidence interval of the survey observed abundance, except for 1976 and 1979, where model estimates were higher than the observed abundances.

c. Fits of catch proportions by lengths (Figures 12, 13).

d. Model fits to catch and survey proportions by length (Figures 12, 14, 15, 16).

e. Marginal distribution for the fits to the composition data

f. Plots of implied versus input effective sample sizes and time-series of implied effective sample size (Figure 4).

g. Tables of RMSEs for the indices:
Trawl survey: 0.36
This is larger than observed survey CV (Table 3).
Summer commercial standardized cpue: 0.5.
This is larger than observed model CV (Table 1), and thus was corrected by including additional variance.

h. QQ plots and histograms of residuals (Figure 11).

5. Retrospective and prospective analyses (Figure 18,19).

6. Uncertainty and sensitivity analyses.

See Sections 2 and 5.

F. Calculation of the OFL

1. Specification of the Tier level and stock status.

The Norton Sound red king crab stock is placed in Tier 4. It is not possible to estimate the spawner-recruit relationship, but some abundance and harvest estimates are available to build a computer simulation model that captures the essential population dynamics. Tier 4 stocks are assumed to have reliable estimates of current survey biomass and instantaneous M; however, the estimates for the Norton Sound red king crab stock are uncertain. Survey biomass is based on triennial trawl surveys with CVs ranging from 15-42% (Table 4).

Tire 4 level and the OFL are determined by the F_{MSY} proxy, B_{MSY} proxy, and estimated legal male abundance and biomass:

level	Criteria	F_{OFL}
a	$B/B_{MSY^{prox}} > 1$	$F_{OFL} = \gamma M$
b	$\beta < B/B_{MSY^{prox}} \le 1$	$F_{OFL} = \gamma M \ (B/B_{MSY^{prox}} - \alpha)/(1-\alpha)$
c	$B/B_{MSY^{prox}} \le \beta$	$F_{OFL} = bycatch\ \ mortality\ \ \&\ directed\ \ \ fishery\ \ F = 0$

where B is a mature male biomass (MMB), B_{MSY} proxy is average mature male biomass over a specified time period, M = 0.18, γ = 1, α = 0.1, and β = 0.25

For Norton Sound red king crab, MMB is defined as CL > 94 mm **on February 01, which is changed from July 01** (Appendix A)**.** B_{MSY} proxy is

B_{MSY} proxy = average model estimated MMB from 1980-2015

Predicted mature male biomass in 2015 is:

Mature male biomass: 5.13 (SD 0.87) million lb.

Estimated B_{MSY} proxy is:

4.81 million lb.

Since projected MMB (5.18) is greater than B_{MSY} proxy (4.81), **Norton Sound red king crab stock status is Tire 4 a.**

2. Calculation of OFL.

The OFL was calculated for retained, unretained, and total male catch, in which OFL is calculated by applying F_{OFL} control rule to crab abundance estimates.

$$OFL = (1 - \exp(-F_{OFL}))B$$

The Norton Sound red king crab fishery consists of small (1-17% of total catch biomass) winter subsistence and commercial fishery from February to May and summer commercial fishery (83-99% of total catch biomass) from mid-June to September.

The two fisheries use not only different fishing gears and thus have different catch selectivity (Figure 5, Table 11), but also target crab population of different abundances. In the assessment model, crab population subject to the summer commercial fishery is calculated as: (Feb 1st abundance – winter fishery harvests – winter fishery discards × handling mortality) × natural mortality from Feb 1st to June 30th (Appendix A: equation 3).

It is ideal that separate OFLs are set for winter and summer fisheries; however, a dependency of summer crab abundance and OFL on catches of winter fishery make it necessary for further discussions.

Under the direction of the CPT (September 15-18, 2014) and the SSC (October 6-7, 2014), the crab abundance used for calculation of the OFL for winter and summer fishery combined is based on legal crab biomass catchable to summer commercial pot fisheries (*Legal_B*) calculated as: Projected legal abundance (Feb 1st) × Commercial pot selectivity × Proportion of legal crab per length class × Average lb per length class. Previous OFL calculation was based on July 1st legal biomass that was calculated as (Feb 1st legal abundance – (Winter harvests)) × Natural mortality from Feb to July. Because Feb 1st legal crab abundance is higher than July 1st legal crab abundance. **OFL calculated this assessment is higher than previous OFLs based on July 1st legal crab biomass.**

$$Legal\_B = \sum_l (N_{w,l,} + O_{w,l,})S_{s,l} L_l wm_l$$

$$OFL_r = (1 - \exp(-F_{OFL}))Legal\_B$$

The unretained OFL is a sub-legal crab biomass catchable to summer commercial pot fisheries calculated as: Projected legal abundance (Feb 1st) × Commercial pot selectivity × Proportion of sub-legal crab per length class × Average lb per length class × handling mortality.

$$OFL_{nr} = (1 - \exp(-F_{OFL})) \sum_{l} (N_{s,l,} + O_{s,l,}) S_{s,l} (1 - L_l) wm_l \; hm$$

where $N_{s,l}$ and $O_{s,l}$ are summer abundances of newshell and oldshell crab in length class *l* in the terminal year, L_l is the proportion of legal males in length class *l*, $S_{s,l}$ is summer commercial catch selectivity, wm_l is average weight in length class *l* and *hm* is handling mortality rate. .

The total male OFL is

$$OFL_T = OFL_r + OFL_{nr}$$

For calculation of the OFL 2015

Legal male biomass: 4.38 (SD 0.71) million lb
OFL_r = 0.721 million lb.
OFL_{nr} = 0.099 million lb.
OFL_T = 0.820 million lb.

G. Calculation of the ABC

1. Specification of the probability distribution of the OFL.

Probability distribution of the OFL was determined based on the CPT recommendation in January 2015 of 20% buffer:

Retained ABC for legal male crab is 80% of OFL

ABC = 0.721 × 0.8 = 0.577 million lb.

H. Rebuilding Analyses

Not applicable

I. Data Gaps and Research Priorities

The major data gap is uncertainties regarding biomass of Norton Sound red king crab. In addition, life-history of the Norton Sound red king crab stock is poorly understood. This includes size at maturity, natural mortality rate, timing and locations of reproduction, molt timing, migration patterns, and the location(s) of females during summer.

Acknowledgments

We thank all CPT modeling workshop attendants for critical review of the assessment model and suggestions for improvements and diagnoses and Joel Webb for ADF&G internal review.

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Table 1. Historical summer commercial red king crab fishery economic performance, Norton Sound Section, eastern Bering Sea, 1977-2014. Bold type shows data that are used for the assessment model.

	Guideline Harvest Level	Commercial Harvest (lb) [a, b]			Total Number (Open Access)			Total Pots		**ST CPUE**		Season Length		**Mid-day from July 1**
Year	(lb) [b]	Open Access	CDQ	**Harvest**	Vessels	Permits	Landings	Registered	Pulls	**CPUE**	**SD**	Days	Dates	
1977	[c]	0.52		**195,877**	7	7	13		5,457	**3.44**	**0.34**	60	[c]	**0.03**
1978	3.00	2.09		**660,829**	8	8	54		10,817	**2.82**	**0.23**	60	6/07-8/15	**0.03**
1979	3.00	2.93		**970,962**	34	34	76		34,773	**2.60**	**0.17**	16	7/15-7/31	**0.063**
1980	1.00	1.19		**329,778**	9	9	50		11,199	**2.43**	**0.25**	16	7/15-7/31	**0.063**
1981	2.50	1.38		**376,313**	36	36	108		33,745	**0.74**	**0.17**	38	7/15-8/22	**0.093**
1982	0.50	0.23		**63,949**	11	11	33		11,230	**0.13**	**0.25**	23	8/09-9/01	**0.14**
1983	0.30	0.37		**132,205**	23	23	26	3,583	11,195	**0.90**	**0.22**	3.8	8/01-8/05	**0.093**
1984	0.40	0.39		**139,759**	8	8	21	1,245	9,706	**1.09**	**0.23**	13.6	8/01-8/15	**0.107**
1985	0.45	0.43		**146,669**	6	6	72	1,116	13,209	**0.37**	**0.21**	21.7	8/01-8/23	**0.132**
1986	0.42	0.48		**162,438**	3	3		578	4,284	**1.00**	**0.43**	13	8/01-8/25	**0.153**
1987	0.40	0.33		**103,338**	9	9		1,430	10,258	**0.63**	**0.32**	11	8/01-8/12	**0.118**
1988	0.20	0.24		**76,148**	2	2		360	2,350	**1.51**	**0.70**	9.9	8/01-8/11	**0.115**
1989	0.20	0.25		**79,116**	10	10		2,555	5,149	**1.61**	**0.33**	3	8/01-8/04	**0.096**
1990	0.20	0.19		**59,132**	4	4		1,388	3,172	**1.18**	**0.42**	4	8/01-8/05	**0.099**
1991	0.34			**0**	No Summer Fishery									
1992	0.34	0.07		**24,902**	27	27		2,635	5,746	**0.26**	**0.31**	2	8/01-8/03	**0.093**
1993	0.34	0.33		**115,913**	14	20	208	560	7,063	**0.91**	**0.08**	52	7/01-8/28	**0.09**
1994	0.34	0.32		**108,824**	34	52	407	1,360	11,729	**0.81**	**0.05**	31	7/01-7/31	**0.044**
1995	0.34	0.32		**105,967**	48	81	665	1,900	18,782	**0.48**	**0.04**	67	7/01-9/05	**0.066**
1996	0.34	0.22		**74,752**	41	50	264	1,640	10,453	**0.45**	**0.06**	57	7/01-9/03	**0.096**
1997	0.08	0.09		**32,606**	13	15	100	520	2,982	**0.86**	**0.08**	44	7/01-8/13	**0.101**
1998	0.08	0.03	0.00	**10,661**	8	11	50	360	1,639	**0.75**	**0.12**	65	7/01-9/03	**0.088**
1999	0.08	0.02	0.00	**8,734**	10	9	53	360	1,630	**0.78**	**0.12**	66	7/01-9/04	**0.101**
2000	0.33	0.29	0.01	**111,728**	15	22	201	560	6,345	**1.28**	**0.06**	91	7/01- 9/29	**0.11**
2001	0.30	0.28	0.00	**98,321**	30	37	319	1,200	11,918	**0.71**	**0.05**	97	7/01- 9/09	**0.085**
2002	0.24	0.24	0.01	**86,666**	32	49	201	1,120	6,491	**1.23**	**0.06**	77	6/15-9/03	**0.074**
2003	0.25	0.25	0.01	**93,638**	25	43	236	960	8,494	**0.91**	**0.05**	68	6/15-8/24	**0.079**
2004	0.35	0.31	0.03	**120,289**	26	39	227	1,120	8,066	**1.40**	**0.05**	51	6/15-8/08	**0.063**
2005	0.37	0.37	0.03	**138,926**	31	42	255	1,320	8,867	**1.32**	**0.05**	73	6/15-8/27	**0.071**
2006	0.45	0.42	0.03	**150,358**	28	40	249	1,120	8,867	**1.46**	**0.05**	68	6/15-8/22	**0.09**
2007	0.32	0.29	0.02	**110,344**	38	30	251	1,200	9,118	**1.15**	**0.05**	52	6/15-8/17	**0.063**
2008	0.41	0.36	0.03	**143,337**	23	30	248	920	8,721	**1.50**	**0.05**	73	6/23-9/03	**0.063**
2009	0.38	0.37	0.03	**143,485**	22	27	359	920	11,934	**0.94**	**0.04**	98	6/15-9/20	**0.1**
2010	0.40	0.39	0.03	**149,822**	23	32	286	1,040	9,698	**1.35**	**0.05**	58	6/28-8/24	**0.096**
2011	0.36	0.37	0.03	**141,626**	24	25	173	1,040	6,808	**1.66**	**0.05**	33	6/28-7/30	**0.038**
2012	0.47	0.44	0.03	**161,113**	40	29	312	1,200	10,041	**1.42**	**0.04**	72	6/29-9/08	**0.077**
2013	0.50	0.37	0.02	**130,603**	37	33	460	1,420	15,058	**0.72**	**0.04**	74	7/3-9/14	**0.107**
2014	0.38	0.36	0.03	**129,656**	52	33	309	1,560	10,127	**1.23**	**0.05**	52	6/25-8/15	**0.052**

[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, 1977-2013. Bold typed data are used for the assessment model.

	Commercial			Subsistence					
					Permits			Total Crab	
Model Year	Year[a]	# of Fishers	# of Crab Harvested	Winter[b]	Issued	Returned	Fished	Caught[c]	Retained[d]
1978	1978	37	**9,625**	1977/78	290	206	149	**NA**	**12,506**
1979	1979	1[f]	**221[f]**	1978/79	48	43	38	**NA**	**224**
1980	1980	1[f]	**22[f]**	1979/80	22	14	9	**NA**	**213**
1981	1981	0	**0**	1980/81	51	39	23	**NA**	**360**
1982	1982	1[f]	**17[f]**	1981/82	101	76	54	**NA**	**1,288**
1983	1983	5	**549**	1982/83	172	106	85	**NA**	**10,432**
1984	1984	8	**856**	1983/84	222	183	143	**15,923**	**11,220**
1985	1985	9	**1,168**	1984/85	203	166	132	**10,757**	**8,377**
1986	1985/86	5	**2,168**	1985/86	136	133	107	**10,751**	**7,052**
1987	1986/87	7	**1,040**	1986/87	138	134	98	**7,406**	**5,772**
1988	1987/88	10	**425**	1987/88	71	58	40	**3,573**	**2,724**
1989	1988/89	5	**403**	1988/89	139	115	94	**7,945**	**6,126**
1990	1989/90	13	**3,626**	1989/90	136	118	107	**16,635**	**12,152**
1991	1990/91	11	**3,800**	1990/91	119	104	79	**9,295**	**7,366**
1992	1991/92	13	**7,478**	1991/92	158	105	105	**15,051**	**11,736**
1993	1992/93	8	**1,788**	1992/93	88	79	37	**1,193**	**1,097**
1994	1993/94	25	**5,753**	1993/94	118	95	71	**4,894**	**4,113**
1995	1994/95	42	**7,538**	1994/95	166	131	97	**7,777**	**5,426**
1996	1995/96	9	**1,778**	1995/96	84	44	35	**2,936**	**1,679**
1997	1996/97	2[f]	**83[f]**	1996/97	38	22	13	**1,617**	**745**
1998	1997/98	5	**984**	1997/98	94	73	64	**20,327**	**8,622**
1999	1998/99	5	**2,714**	1998/99	95	80	71	**10,651**	**7,533**
2000	1999/00	10	**3,045**	1999/00	98	64	52	**9,816**	**5,723**
2001	2000/01	3	**1,098**	2000/01	50	27	12	**366**	**256**
2002	2001/02	11	**2,591**	2001/02	114	61	45	**5,119**	**2,177**
2003	2002/03	13	**6,853**	2002/03	107	70	61	**9,052**	**4,140**
2004	2003/04	2[f]	**522[f]**	2003/04[g]	96	77	41	**1,775**	**1,181**
2005	2004/05	4	**2,091**	2004/05	170	98	58	**6,484**	**3,973**
2006	2005/06	1[f]	**75[f]**	2005/06	98	97	67	**2,083**	**1,239**
2007	2006/07	8	**3,313**	2006/07	129	127	116	**21,444**	**10,690**
2008	2007/08	9	**5,796**	2007/08	139	137	108	**18,621**	**9,485**
2009	2008/09	7	**4,951**	2008/09	105	105	70	**6,971**	**4,752**
2010	2009/10	10	**4,834**	2009/10	125	123	85	**9,004**	**7,044**
2011	2010/11	5	**3,365**	2010/11	148	148	95	**9,183**	**6,640**
2012	2011/12	35	**9,157**	2011/12	204	204	138	**11,341**	**7,311**
2013	2012/13	26	**22,639**	2012/13	149	148	104	**21,524**	**7,622**
2014	2013/14	21	**14,986**	2013/14	103	103	75	**5,421**	**3,252**

a Prior to 1985 the winter commercial fishery occurred from January 1 - April 30. As of March 1985, fishing may occur from November 15 - May 15.

b The winter subsistence fishery occurs during months of two calendar years (as early as December, through May).

c The number of crab actually caught; some may have been returned.

d The number of crab Retained is the number of crab caught and kept.

f Confidentiality was waived by the fishers.

h Prior to 2005, permits were only given out of the Nome ADF&G office. Starting with the 2004-5 season, permits were given out in Elim, Golovin, Shaktoolik, and White Mountain.

Table 3. Summary of triennial trawl survey Norton Sound male red king crab abundance estimates. Trawl survey abundance estimate is based on 10×10 nmil^2 grid, except for 2010 (20×20 nmil^2).

				Survey coverage			Abundance ≥74 mm	
Year	Dates	Survey Agency	Survey method	surveyed stations	Stations w/ NSRKC	n mile^2 covered		CV
1976	9/02 - 9/05	NMFS	Trawl	103	62	10260	**4247.5**	**0.31**
1979	7/26 - 8/05	NMFS	Trawl	85	22	8421	**1417.2**	**0.20**
1980	7/04 - 7/14	ADFG	Pots				2092.3	N/A
1981	6/28 - 7/14	ADFG	Pots				2153.4	N/A
1982	7/06 - 7/20	ADFG	Pots				1140.5	N/A
1982	9/05 - 9/11	NMFS	Trawl	58	37	5721	**2791.7**	**0.29**
1985	7/01 - 7/14	ADFG	Pots				2320.4	0.083
1985	9/16 -10/01	NMFS	Trawl	78	49	7688	**2306.3**	**0.25**
1988	8/16 - 8/30	NMFS	Trawl	78	41	7721	**2263.4**	**0.29**
1991	8/22 - 8/30	NMFS	Trawl	52	38	5183	**3132.5**	**0.43**
1996	8/07 - 8/18	ADFG	Trawl	50	30	4938	**1264.7**	**0.317**
1999	7/28 - 8/07	ADFG	Trawl	53	31	5221	**2276.1**	**0.194**
2002	7/27 - 8/06	ADFG	Trawl	57	37	5621	**1747.6**	**0.125**
2006	7/25 - 8/08	ADFG	Trawl	101	45	10008	**2549.7**	**0.288**
2008	7/24 - 8/11	ADFG	Trawl	74	44	7330	**2707.1**	**0.164**
2010[a]	7/27 - 8/09	NMFS	Trawl	35	15	13749	**2041.0**	**0.455**
2011	7/18 - 8/15	ADFG	Trawl	65	34	6447	**2701.7**	**0.133**
2014	7/18 - 7/30	ADFG	Trawl	47	34	4700	**5481.5**	**0.486**

Table 4. Summer commercial catch size/shell compositions. Sizes in this and Tables 5-10 and 12 are mm carapace length. Legal size (4.75 inch carapace width is approximately equal to 124 mm carapace length.

		New Shell						Old Shell					
Year	Sample	74-83	84-93	94-103	104-113	114-123	124+	74-83	84-93	94-103	104-113	114-123	124+
1977	1549	0	0	0.0032	0.4196	0.3422	0.1220	0	0	0	0.0626	0.040	0.0103
1978	389	0	0	0.0103	0.1851	0.473	0.3059	0	0	0	0.0051	0.0103	0.0103
1979	1660	0	0	0.0253	0.2325	0.3831	0.3217	0	0	0	0.0253	0.0006	0.0114
1980	1068	0	0	0.0037	0.0983	0.3062	0.5543	0	0	0	0.0028	0.0112	0.0234
1981	1748	0	0	0.0039	0.0734	0.1541	0.5090	0	0	0	0.0045	0.0504	0.2046
1982	1093	0	0	0.0421	0.1921	0.1647	0.5050	0	0	0.0037	0.0128	0.022	0.0576
1983	802	0	0	0.0387	0.4127	0.3579	0.0973	0	0	0.0037	0.0362	0.010	0.0436
1984	963	0	0	0.0966	0.4195	0.2804	0.0717	0	0	0.0104	0.0654	0.0488	0.0073
1985	2691	0	0.0004	0.0643	0.3122	0.3716	0.1747	0	0	0.0026	0.0334	0.0312	0.0097
1986	1138	0	0	0.029	0.3559	0.3937	0.1353	0	0	0.0018	0.0202	0.0378	0.0264
1987	1542	0	0	0.0166	0.1788	0.2912	0.3798	0	0	0.0025	0.0267	0.0650	0.0393
1988	1522	0.0007	0	0.0237	0.2004	0.3003	0.2181	0	0	0.0059	0.0644	0.0972	0.0894
1989	2595	0	0	0.0127	0.1643	0.3185	0.2148	0	0	0.0042	0.0555	0.1215	0.1084
1990	1289	0	0	0.0147	0.1435	0.3468	0.3251	0	0	0.0008	0.0372	0.0737	0.0582
1991													
1992	2566	0	0	0.0172	0.201	0.2662	0.2244	0	0	0.0027	0.0792	0.1292	0.080
1993	1813	0	0	0.0142	0.2312	0.3939	0.263	0	0	0.0004	0.0173	0.0437	0.0362
1994	404	0	0	0.0248	0.0941	0.0817	0.0891	0	0	0.0248	0.1881	0.25	0.2475
1995	1174	0	0	0.0392	0.2615	0.2853	0.207	0	0	0.0077	0.0486	0.0741	0.0767
1996	787	0	0	0.0318	0.2236	0.2389	0.141	0	0	0.014	0.1194	0.136	0.0953
1997	1198	0	0	0.0292	0.3656	0.3414	0.1244	0	0	0.0033	0.0559	0.0417	0.0384
1998	1055	0	0	0.0284	0.2332	0.2427	0.1071	0	0	0.0218	0.1118	0.1431	0.1118
1999	561	0	0	0.0026	0.2434	0.2698	0.3836	0	0	0	0	0.0423	0.0582
2000	17213	0	0	0.0194	0.2991	0.3917	0.1249	0	0	0.0028	0.0531	0.0654	0.0436
2001	20030	0	0	0.0243	0.2232	0.3691	0.2781	0	0	0.0008	0.0241	0.0497	0.0304
2002	5198	0	0	0.0442	0.2341	0.2814	0.3253	0	0	0.0046	0.0282	0.0419	0.0402
2003	5220	0	0	0.0232	0.3680	0.3197	0.1523	0	0	0.0011	0.0218	0.0465	0.0674
2004	9605	0	0	0.0087	0.3811	0.3880	0.1395	0	0	0.0004	0.0255	0.0347	0.0221
2005	5360	0	0	0.0022	0.2539	0.4709	0.1823	0	0	0	0.0205	0.0451	0.025
2006	6707	0	0	0.0021	0.1822	0.3484	0.199	0	0	0.0003	0.0498	0.1375	0.0807
2007	6125	0	0	0.0111	0.3574	0.3407	0.1714	0	0	0.0008	0.0247	0.0573	0.0366
2008	5766	0	0	0.0047	0.3512	0.3476	0.0668	0	0	0.0014	0.0895	0.0928	0.0461
2009	6026	0	0	0.0105	0.3445	0.3294	0.1339	0	0	0.0012	0.0768	0.0795	0.0242
2010	5902	0	0	0.0053	0.3855	0.3617	0.1095	0	0	0.0019	0.0546	0.0546	0.0271
2011	2552	0	0	0.0043	0.3170	0.3969	0.1387	0	0	0.0020	0.0611	0.0588	0.0212
2012	5056	0	0	0.0026	0.2421	0.4620	0.2067	0	0	0.0002	0.0259	0.0423	0.0182
2013	4203	0	0	0.0044	0.2388	0.3710	0.3020	0	0	0.0003	0.0140	0.0422	0.0272
2014	4682	0	0	0.0085	0.2828	0.2360	0.2565	0	0	0.0002	0.0412	0.0865	0.0882

Table 5. Summer Trawl Survey size/shell compositions.

		New Shell						Old Shell					
Year	Sample	74-83	84-93	94-103	104-113	114-123	124+	74-83	84-93	94-103	104-113	114-123	124+
1976	1311	0.0214	0.1053	0.1915	0.3455	0.1831	0.0290	0.0046	0.0114	0.0252	0.032	0.0366	0.0145
1979	133	0.0151	0.0075	0.0301	0.0752	0.0827	0.0602	0	0.0075	0.0301	0.1203	0.3835	0.188
1982	256	0.0898	0.2031	0.2891	0.2109	0.0352	0.0078	0	0.0156	0.0195	0.043	0.0234	0.0625
1985	311	0.1190	0.2122	0.1865	0.1768	0.0643	0.0193	0	0	0.0193	0.0514	0.0868	0.0643
1988	306	0.2255	0.1405	0.1536	0.1275	0.0686	0.0392	0	0.0065	0.0131	0.0392	0.0882	0.0980
1991	250	0.0967	0.0223	0.0372	0.0743	0.0409	0.0223	0.0706	0.0297	0.0967	0.197	0.1747	0.1375
1996	196	0.2959	0.1786	0.1224	0.0816	0.0051	0.0153	0.0051	0.0357	0.0459	0.0612	0.0612	0.0918
1999	274	0.0109	0.1058	0.2993	0.2701	0.1314	0.0401	0	0.0036	0.0292	0.0511	0.0401	0.0182
2002	230	0.1261	0.1435	0.1565	0.0304	0.0348	0.0348	0.0304	0.0739	0.1087	0.0957	0.0913	0.0739
2006	208	0.3235	0.2614	0.1405	0.0752	0.0458	0.0294	0	0	0.0196	0.0458	0.0458	0.0131
2008	242	0.1743	0.2407	0.1286	0.112	0.0332	0.029	0.0083	0.0498	0.0705	0.0954	0.0125	0.0456
2010	68	0.1202	0.1366	0.2077	0.1257	0.1093	0.0437	0.0109	0.0328	0.082	0.071	0.0383	0.0219
2011	320	0.1282	0.0989	0.1282	0.2051	0.1612	0.0476	0.0037	0.0147	0.0256	0.0989	0.0513	0.0366
2014	361	0.1607	0.2576	0.1939	0.0997	0.0166	0.0233	0	0.0277	0.1053	0.0554	0.0471	0.0139

Table 6. Winter pot survey size/shell compositions.

			New Shell						Old Shell					
Year	CPUE	Sample	74-83	84-93	94-103	104-113	114-123	124+	74-83	84-93	94-103	104-113	114-123	124+
1981/82	NA	243	0.1481	0.3374	0.3169	0.1029	0.0288	0.0247	0	0	0.0041	0.0082	0.0082	0.0206
1982/83	24.2	2520	0.0855	0.2824	0.2854	0.2155	0.0706	0.0085	0	0	0.004	0.0194	0.0097	0.0189
1983/84	24.0	1655	0.1638	0.2626	0.2291	0.1502	0.0601	0.0057	0	0	0.0178	0.065	0.0329	0.0127
1984/85	24.5	773	0.0932	0.2589	0.3618	0.1586	0.057	0.0097	0	0	0.0065	0.0291	0.0239	0.0013
1985/86	19.2	568	0.1276	0.1831	0.2553	0.2025	0.0863	0.0132	0	0	0.015	0.0607	0.044	0.0123
1986/87	5.8	144	0.0556	0.1597	0.1944	0.0694	0.0417	0	0	0	0.0417	0.2986	0.1111	0.0278
1987/88														
1988/89	13.0	492	0.1341	0.1514	0.1352	0.1941	0.1758	0.0346	0	0	0.002	0.0528	0.0854	0.0346
1989/90	21.0	2072	0.0495	0.2075	0.2616	0.1795	0.1221	0.0726	0	0	0.001	0.0263	0.056	0.0239
1990/91	22.9	1281	0.0125	0.0921	0.2857	0.2678	0.096	0.0109	0	0	0.0039	0.0265	0.1163	0.0882
1992/93	5.5	181	0.0055	0.0331	0.0552	0.1271	0.116	0.0276	0	0	0.0166	0.1934	0.2707	0.1547
1993/94														
1994/95	6.2	850	0.0588	0.08	0.0988	0.2576	0.2341	0.0847	0	0	0.0035	0.0329	0.0718	0.0776
1995/96	9.9	776	0.1214	0.1835	0.1733	0.1022	0.0599	0.0265	0	0	0.0181	0.1214	0.1242	0.0695
1996/97	2.9	1582	0.2297	0.2351	0.1189	0.1568	0.1216	0.0676	0	0	0	0.0189	0.027	0.0243
1997/98	10.9	399	0.1395	0.4136	0.2653	0.0544	0.0236	0.0034	0	0	0.0238	0.0317	0.017	0.0272
1998/99	10.7	882	0.0192	0.1168	0.3566	0.3605	0.0838	0.0154	0	0	0.01	0.0223	0.0069	0.0085
1999/00	6.2	1308	0.0885	0.1062	0.1646	0.3345	0.1788	0.0372	0	0	0.0018	0.0513	0.023	0.0142
2000/01	3.1	44												
2001/02	13.0	832	0.3136	0.2763	0.1761	0.0681	0.0668	0.0501	0	0	0.0077	0.0051	0.0154	0.0064
2002/03	9.6	826	0.0994	0.2236	0.2994	0.1801	0.0559	0.0261	0	0	0.0224	0.0273	0.0261	0.0273
2003/04	3.7	286	0.0175	0.1643	0.2622	0.3462	0.1119	0.0105	0	0	0.0175	0.021	0.014	0.0245
2004/05	4.4	406	0.0741	0.1407	0.1827	0.2173	0.1852	0.0765	0	0	0.0025	0.0395	0.0593	0.0173
2005/06	6.0	512	0.1406	0.2266	0.209	0.1563	0.0547	0.0215	0	0	0.0176	0.043	0.0742	0.0352
2006/07	7.3	160	0.1486	0.2095	0.3784	0.1419	0.0473	0	0	0	0.0068	0.0203	0.0405	0
2007/08	25.0	3482	0.1898	0.3219	0.1703	0.1479	0.0672	0.0083	0	0	0.0359	0.0339	0.0155	0.0092
2008/09	21.9	526	0.0706	0.1336	0.3511	0.2023	0.084	0.0134	0	0	0.0019	0.0382	0.0992	0.0057
2009/10	25.3	581	0.047	0.1357	0.2157	0.2452	0.113	0.0191	0	0	0.0591	0.1009	0.0539	0.0104
2010/11	22.1	597	0.0786	0.1368	0.2103	0.1744	0.1333	0.0513	0	0.0120	0.0325	0.1128	0.0462	0.0120
2011/12	29.4	676	0.1155	0.2340	0.1945	0.1246	0.1292	0.0456	0.0030	0.0030	0.0912	0.0532	0.0532	0.0350

Table 7. Summer commercial1987-1994, 2012-2014 observer discards size/shell compositions (Sub legal crab only).

		New Shell						Old Shell					
Year	Sample	74-83	84-93	94-103	104-113	114-123	124+	74-83	84-93	94-103	104-113	114-123	124+
1987	1076	0.2026	0.3625	0.3522	0.0344	0	0	0	0	0.0437	0.0046	0	0
1988	712	0.052	0.184	0.4831	0.139	0	0	0	0	0.0969	0.0449	0	0
1989	911	0.2492	0.3392	0.2371	0.0274	0	0	0	0	0.1196	0.0274	0	0
1990	459	0.2702	0.3203	0.3028	0.0414	0	0	0	0	0.0588	0.0065	0	0
1992	515	0.2175	0.3592	0.332	0.0369	0	0	0	0	0.0447	0.0097	0	0
1994	726	0.1556	0.303	0.1736	0.0262	0	0	0	0	0.2824	0.0592	0	0
2012	738	0.1396	0.2398	0.4106	0.1314	0.0122	0	0.0027	0.0027	0.0298	0.0285	0.0014	0.0014
2013	1457	0.4379	0.2352	0.2520	0.0639	0.0029	0.0012	0.0006	0.0006	0.0035	0.0012	0.0006	0.0006
2014	1675	0.1045	0.2746	0.4322	0.1236	0.0078	0.0024	0.0024	0.0090	0.0230	0.0113	0.0018	0.0006

Table 8 The number of tagged data released and recovered after 1 year (Y1) – 6 year (Y6) by the summer commercial fishery during 1980-1992 and 1993-2014 periods. The two periods were assumed to have different catch selectivities.

Release Length Class	Recap Length Class	1980-1992						1993-2014					
		Y1	Y2	Y3	Y4	Y5	Y6	Y1	Y2	Y3	Y4	Y5	Y6
1	1	0	0	0	0	0	0	0	0	0	0	0	0
1	2	0	0	0	0	0	0	8	0	0	0	0	0
1	3	0	0	0	0	0	0	13	1	0	0	0	0
1	4	0	2	0	0	0	0	3	29	3	0	0	0
1	5	0	0	1	0	2	0	0	2	0	1	0	0
1	6	0	0	0	0	0	0	0	0	0	1	0	0
2	2	0	0	0	0	0	0	0	0	0	0	0	0
2	3	5	0	0	0	0	0	22	2	0	0	0	0
2	4	10	2	0	1	0	0	39	13	3	0	0	0
2	5	0	1	1	1	0	0	3	23	38	2	2	0
2	6	0	0	0	1	1	0	0	1	1	2	1	1
3	3	2	0	0	0	0	0	0	0	0	0	0	0
3	4	32	1	1	0	0	0	77	10	1	0	0	0
3	5	26	3	3	0	0	0	24	3	7	0	0	0
3	6	1	0	2	1	1	0	0	6	2	0	1	0
4	4	15	0	0	0	0	0	8	0	0	0	0	0
4	5	34	14	0	0	0	0	25	0	3	0	1	0
4	6	8	6	3	2	0	0	4	1	1	0	0	1
5	5	15	2	0	0	0	0	19	0	0	0	0	0
5	6	31	10	2	1	0	0	20	1	0	0	0	0
6	6	41	10	3	0	0	0	14	0	0	1	0	0

Length class: 1: 74-83mm, 2:84-93mm, 3:94-103mm, 4:104-113mm, 5:114-123mm, and 6: 124mm+

Table 9. Summary of initial input parameter values and bounds for a length-based population model of Norton Sound red king crab. Parameters with "log_" indicate log scaled parameters.

Parameter	Parameter description	Equation Number in Appendix A	Lower	Upper
log_q_1	Commercial fishery catchability (1977-92)	(20)	-32.5	8.5
log_q_2	Commercial fishery catchability (1993-2014)	(20)	-32.5	10.0
log_N_{76}	Initial abundance	(1)	2.0	15.0
R_0	Mean Recruit	(13)	2.0	12.0
log_σ_R^2	Recruit standard deviation	(13)	-20.0	20.0
a_1	Parameter for intimal length proportion	(2)	-5.0	5.0
a_2	Parameter for intimal length proportion	(2)	-5.0	5.0
a_3	Parameter for intimal length proportion	(2)	-5.0	5.0
a_4	Parameter for intimal length proportion	(2)	-5.0	5.0
a_5	Parameter for intimal length proportion	(2)	-5.0	5.0
r	Proportion of length class 1 for recruit	(14)	0.5	0.9
log_α	Inverse logistic molting parameter	(15)	-5.5	-2.0
log_ϕ_{st1}	Logistic trawl selectivity parameter (NMFS)	(16)	-15.0	-1.0
log_ϕ_{st2}	Logistic trawl selectivity parameter (ADF&G)	(16)	-15.0	-1.0
log_ϕ_w	Logistic winter pot selectivity parameter Or Inverse logistic winter pot selectivity parameter	(15,16)	-10.0	10.0
Sw_6 / Sw_1	Winter pot selectivity of length class 6 (logistic), length class 1 (inverse logistic)	(15,16)	0.1	1.0
log_ϕ_1	Logistic commercial catch selectivity parameter (1977-92)	(16)	-5.0	-1.0
log_ϕ_2	Logistic commercial catch selectivity parameter (1993-2014)	(16)	-5.0	-1.0
w^2_t	Additional varince for standard CPUE	(31)	0.0	6.0
q	Survey q for NMFS trawl 1976-91	(31)	0.1	1.0
σ	Growth transition sigma	(17)	0.0	30.0
β_1	Growth transition mean	(17)	0.0	20.0
β_2	Growth transition increment	(17)	0.0	20.0

Table 10 . Summary of parameter estimates and standard deviations of Norton Sound red king crab.

Name	Estimate	std.dev
log_q_1	-7.1695	0.17949
log_q_2	-7.0052	0.094063
log_N_{76}	9.0903	0.15807
R_0	6.5111	0.069899
$log\_\sigma_R^2$	0.34419	0.4539
log_R_{77}	-0.29935	0.38957
log_R_{78}	-0.74307	0.35276
log_R_{79}	-0.28749	0.37892
log_R_{80}	0.54114	0.27099
log_R_{81}	0.25666	0.28849
log_R_{82}	0.27011	0.32664
log_R_{83}	0.70377	0.26988
log_R_{84}	0.24143	0.30666
log_R_{85}	0.27018	0.30999
log_R_{86}	0.32682	0.268
log_R_{87}	-0.05633	0.2766
log_R_{88}	0.085734	0.26629
log_R_{89}	-0.07167	0.26779
log_R_{90}	-0.55485	0.29819
log_R_{91}	-0.3935	0.27767
log_R_{92}	-0.84682	0.31789
log_R_{93}	-0.61655	0.28252
log_R_{94}	-0.50293	0.27478
log_R_{95}	-0.23298	0.23981
log_R_{96}	0.037987	0.27396
log_R_{97}	0.39147	0.2191
log_R_{98}	-0.67324	0.32479
log_R_{99}	-0.3067	0.30868
log_R_{00}	-0.05292	0.28968
log_R_{01}	0.19657	0.22958
log_R_{02}	0.36501	0.27604
log_R_{03}	-0.2863	0.3422
log_R_{04}	-0.05434	0.29041
log_R_{05}	0.49922	0.20397
log_R_{06}	-0.00669	0.30448
log_R_{07}	0.59322	0.2078
log_R_{08}	0.36102	0.26451
log_R_{09}	-0.00544	0.27545
log_R_{10}	-0.11936	0.2651
log_R_{11}	-0.11415	0.29373
log_R_{12}	0.49332	0.30772
log_R_{13}	0.24683	0.35443
a_1	0.41021	1.8878
a_2	1.873	1.3696
a_3	2.1804	1.3285
a_4	2.4697	1.3048
a_5	1.6508	1.3586
r1	0.62056	0.054306
log_α	-1.7941	0.019085
log_ϕ_{st1}	-14.556	1485
log_ϕ_{st2}		

log_ϕ_w	-1.8158	0.045533
Sw_1	0.42902	0.1003
log_ϕ_1	-1.8039	0.059877
log_ϕ_2		
w^2_t	0.051598	0.017595
q	0.71459	0.1267
σ	4.5222	0.28733
β_1	9.3851	0.79453
β_2	7.8668	0.25217

Table 11. Estimated selectivities, molting probabilities, and proportions of legal crab by length (mm CL) class for Norton Sound male red king crab.

Model 6

			Selectivity			
Length Class	Legal Proportion	Mean weight (lb)	ADFG/ NOAA	Winter Pot	Summer Fishery 77-13	Molting Probability
74 - 83	0.00	0.854	1.00	0.43	0.21	1.00
84 - 93	0.00	1.210	1.00	1.00	0.58	1.00
94 - 103	0.26	1.652	1.00	0.97	0.88	0.97
104 - 113	0.97	2.187	1.00	0.88	0.97	0.87
114 - 123	0.99	2.825	1.00	0.60	0.99	0.56
124+	1.00	3.697	1.00	0.22	1.00	0.20

Table 12: Estimated molting probability incorporated transition matrix.

Model 6: without molting probability

Pre-molt Length Class	Post-molt Length Class					
	74-83	84-93	94-103	104-113	114-123	124+
74-83	0.003	0.306	0.647	0.043	0.000	0.000
84-93	0	0.013	0.477	0.496	0.014	0.000
94-103	0	0	0.039	0.633	0.324	0.004
104-113	0	0	0	0.098	0.723	0.179
114-123	0	0	0	0	0.223	0.777
124+	0	0	0	0	0	1

Model 6: with molting probability

Pre-molt Length Class	Post-molt Length Class					
	74-83	84-93	94-103	104-113	114-123	124+
74-83	0.002	0.225	0.720	0.053	0.000	0.000
84-93	0	0.011	0.452	0.522	0.016	0.000
94-103	0	0	0.058	0.616	0.322	0.004
104-113	0	0	0	0.213	0.631	0.156
114-123	0	0	0	0	0.562	0.438
124+	0	0	0	0	0	1

Table 13. Annual abundance estimates (million crab) and mature male biomass (MMB, million lb) for Norton Sound red king crab estimated by a length-based analysis from 1976 to 2014 Model 6.

	Abundance			Legal (≥ 104 mm)				MMB	
Year	Recruits	Total (≥ 74 mm)	Mature (≥ 94 mm)	Abundance	S.D	Biomass	S.D	Biomass	S.D.
1976	0.949	8.868	6.831	5.086	1.129	12.019	2.852	14.966	3.138
1977	0.499	8.066	6.994	6.176	1.007	16.359	2.786	17.781	2.880
1978	0.320	6.509	5.851	5.380	0.777	15.549	2.339	16.378	2.333
1979	0.505	4.489	4.084	3.808	0.545	11.498	1.723	11.986	1.743
1980	1.155	2.866	2.308	2.143	0.383	6.5815	1.226	6.870	1.251
1981	0.869	2.916	1.676	1.464	0.278	4.431	0.879	4.793	0.924
1982	0.881	2.728	1.668	1.218	0.262	3.314	0.751	4.067	0.877
1983	1.360	2.956	1.927	1.519	0.296	4.019	0.806	4.709	0.908
1984	0.856	3.546	2.038	1.643	0.307	4.413	0.845	5.083	0.947
1985	0.881	3.511	2.428	1.861	0.337	4.952	0.916	5.905	1.063
1986	0.933	3.487	2.460	2.036	0.369	5.504	1.011	6.226	1.114
1987	0.636	3.486	2.405	2.006	0.359	5.554	1.014	6.232	1.107
1988	0.733	3.224	2.431	2.014	0.343	5.612	0.978	6.320	1.064
1989	0.626	3.119	2.278	1.963	0.318	5.552	0.916	6.091	0.978
1990	0.386	2.913	2.164	1.837	0.282	5.241	0.821	5.797	0.880
1991	0.454	2.517	2.025	1.732	0.250	4.952	0.729	5.452	0.776
1992	0.288	2.310	1.791	1.590	0.212	4.618	0.624	4.963	0.651
1993	0.363	1.963	1.600	1.395	0.170	4.094	0.512	4.442	0.534
1994	0.407	1.700	1.288	1.143	0.140	3.360	0.418	3.610	0.436
1995	0.533	1.558	1.090	0.932	0.117	2.715	0.345	2.984	0.369
1996	0.699	1.597	0.996	0.818	0.106	2.316	0.305	2.616	0.334
1997	0.995	1.855	1.067	0.840	0.108	2.298	0.298	2.680	0.338
1998	0.343	2.418	1.305	1.007	0.125	2.688	0.329	3.190	0.396
1999	0.495	2.240	1.729	1.310	0.146	3.440	0.386	4.147	0.440
2000	0.638	2.226	1.671	1.458	0.152	4.000	0.416	4.365	0.441
2001	0.819	2.236	1.515	1.299	0.136	3.692	0.389	4.062	0.422
2002	0.969	2.435	1.510	1.236	0.130	3.474	0.365	3.937	0.404
2003	0.505	2.765	1.658	1.308	0.128	3.574	0.353	4.164	0.384
2004	0.637	2.568	1.900	1.482	0.145	3.966	0.380	4.672	0.472
2005	1.108	2.517	1.793	1.53	0.179	4.180	0.472	4.636	0.514
2006	0.668	2.914	1.700	1.420	0.170	3.969	0.475	4.443	0.516
2007	1.217	2.795	1.942	1.489	0.169	4.028	0.468	4.790	0.525
2008	0.965	3.273	1.941	1.608	0.173	4.363	0.476	4.930	0.523
2009	0.669	3.380	2.211	1.712	0.170	4.605	0.469	5.447	0.520
2010	0.597	3.171	2.339	1.889	0.176	5.084	0.480	5.846	0.540
2011	0.600	2.906	2.196	1.866	0.181	5.160	0.497	5.723	0.534
2012	1.102	2.679	1.978	1.699	0.161	4.807	0.461	5.285	0.485
2013	0.861	2.973	1.771	1.500	0.156	4.265	0.433	4.725	0.489
2014	0.766	3.006	1.962	1.515	0.198	4.147	0.505	4.900	0.645

Table 14. Summary of catch and estimated discards (million lb) for Norton Sound red king crab. Assumed average crab weight is 2.5 lb for the winter commercial catch, 2.0 lb for the subsistence catch, and 1.0 lb for Winter subsistence discards. Summer and winter commercial discards were estimated from the model.

Year	Summer Com	Winter Com	Winter Sub	Discards Summer	Discards Winter Sub	Discards Winter com	Total	Catch/ MMB
1977	0.52	0.000	0.000	0.011	0.000	0.000	0.531	0.03
1978	2.09	0.024	0.025	0.027	0.008	0.000	2.174	0.13
1979	2.93	0.001	0.000	0.034	0.000	0.000	2.965	0.25
1980	1.19	0.000	0.000	0.016	0.000	0.000	1.206	0.18
1981	1.38	0.000	0.001	0.045	0.000	0.000	1.426	0.30
1982	0.23	0.000	0.003	0.012	0.001	0.000	0.246	0.06
1983	0.37	0.001	0.021	0.019	0.006	0.000	0.417	0.09
1984	0.39	0.002	0.022	0.021	0.005	0.000	0.44	0.09
1985	0.43	0.003	0.017	0.022	0.002	0.000	0.474	0.08
1986	0.48	0.005	0.014	0.018	0.004	0.000	0.521	0.08
1987	0.33	0.003	0.012	0.011	0.002	0.000	0.358	0.06
1988	0.24	0.001	0.005	0.008	0.001	0.000	0.255	0.04
1989	0.25	0.001	0.012	0.007	0.002	0.000	0.272	0.04
1990	0.19	0.009	0.024	0.006	0.004	0.000	0.233	0.04
1991	0	0.010	0.015	0.000	0.002	0.000	0.027	0.00
1992	0.07	0.019	0.023	0.002	0.003	0.001	0.118	0.02
1993	0.33	0.004	0.002	0.008	0.000	0.000	0.344	0.08
1994	0.32	0.014	0.008	0.008	0.001	0.000	0.351	0.10
1995	0.32	0.019	0.011	0.011	0.002	0.001	0.364	0.12
1996	0.22	0.004	0.003	0.010	0.001	0.000	0.238	0.09
1997	0.09	0.000	0.001	0.005	0.001	0.000	0.097	0.04
1998	0.03	0.002	0.017	0.002	0.012	0.000	0.063	0.02
1999	0.02	0.007	0.015	0.001	0.003	0.000	0.046	0.01
2000	0.3	0.008	0.011	0.009	0.004	0.000	0.332	0.08
2001	0.28	0.003	0.001	0.010	0.000	0.000	0.294	0.07
2002	0.25	0.006	0.004	0.012	0.003	0.000	0.275	0.07
2003	0.26	0.017	0.008	0.015	0.005	0.001	0.306	0.07
2004	0.34	0.001	0.002	0.016	0.001	0.000	0.36	0.08
2005	0.4	0.005	0.008	0.013	0.003	0.000	0.429	0.09
2006	0.45	0.000	0.002	0.020	0.001	0.000	0.473	0.11
2007	0.31	0.008	0.021	0.016	0.011	0.000	0.366	0.08
2008	0.39	0.014	0.019	0.019	0.009	0.001	0.452	0.09
2009	0.4	0.012	0.010	0.022	0.002	0.001	0.447	0.08
2010	0.42	0.012	0.014	0.017	0.002	0.001	0.466	0.08
2011	0.4	0.008	0.013	0.013	0.003	0.000	0.437	0.08
2012	0.47	0.023	0.015	0.014	0.004	0.001	0.527	0.10
2013	0.35	0.057	0.015	0.017	0.014	0.003	0.456	0.10
2014	0.39	0.037	0.007	0.020	0.002	0.002	0.458	0.09

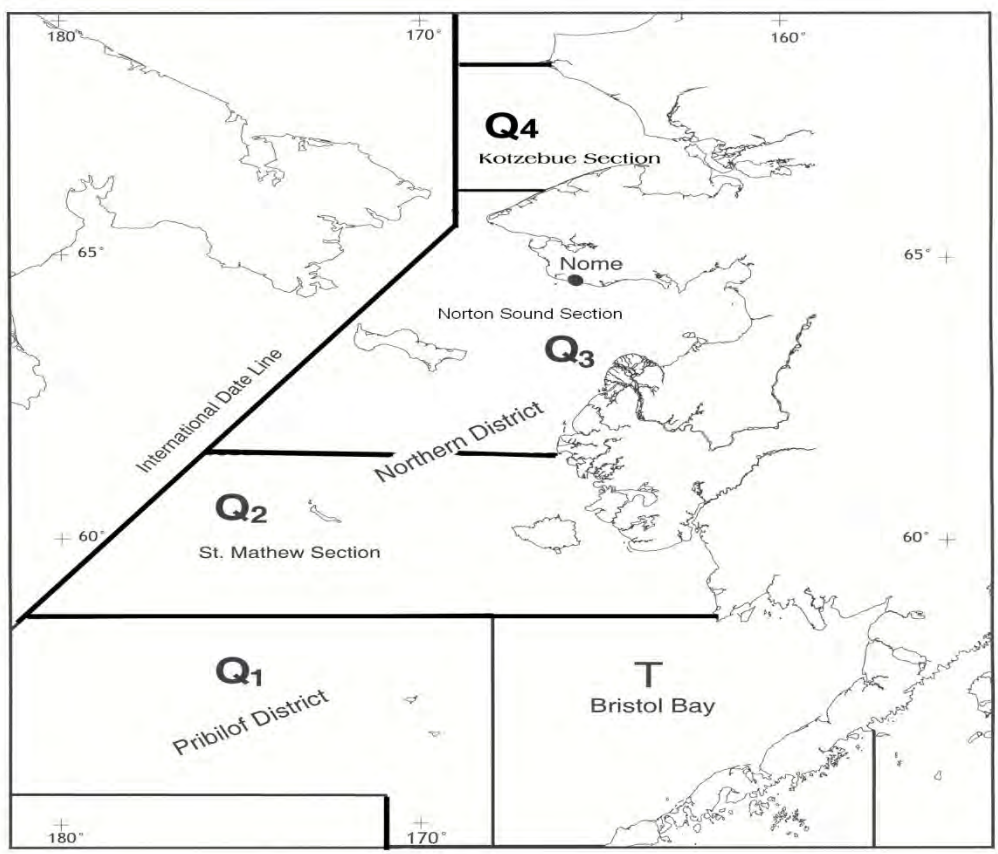


Figure 1. King crab fishing districts and sections of Statistical Area Q.

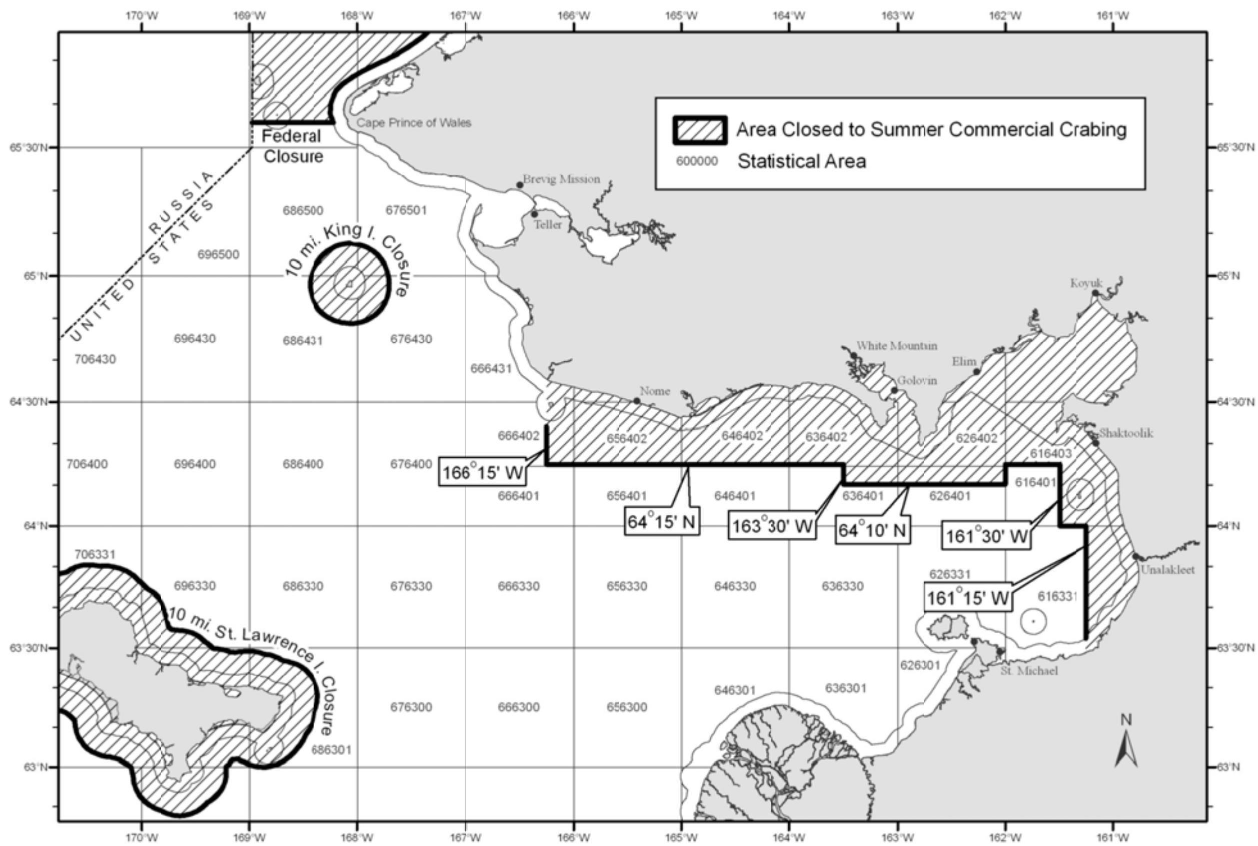
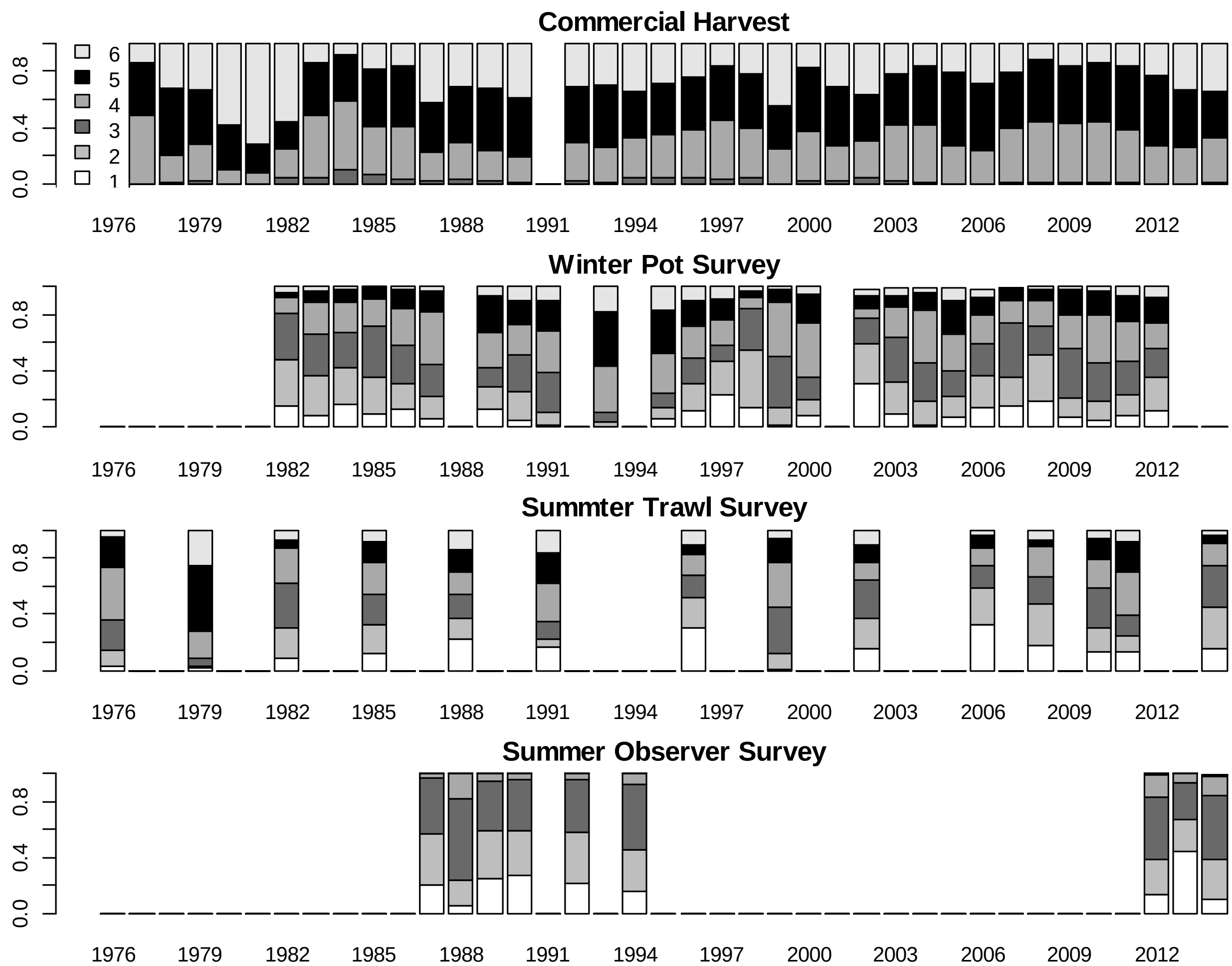


Figure 2. Closed water regulations in effect for the Norton Sound commercial crab fishery.



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure 3. Observed length compositions 1976-2014.

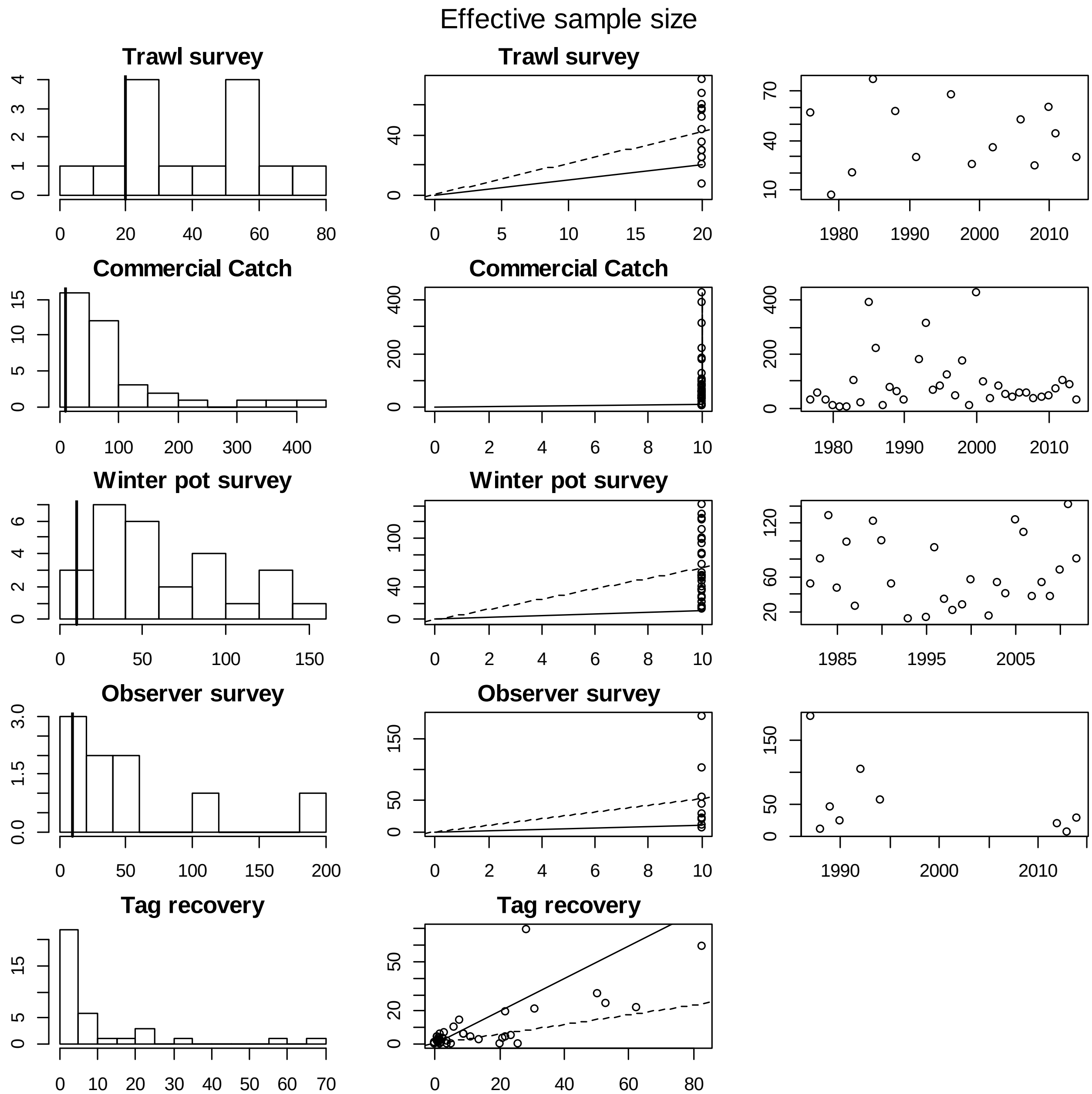


Figure 4. Effective sample size vs. implied sample size. Figures in the first column show effective sample size (x-axis) vs. frequency (y-axis). Vertical solid line is the implied sample size. Figures in the second column show implied sample size (x-axis) vs. effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. Figures in the third column show year (x-axis) vs. effective sample size (y-axis).

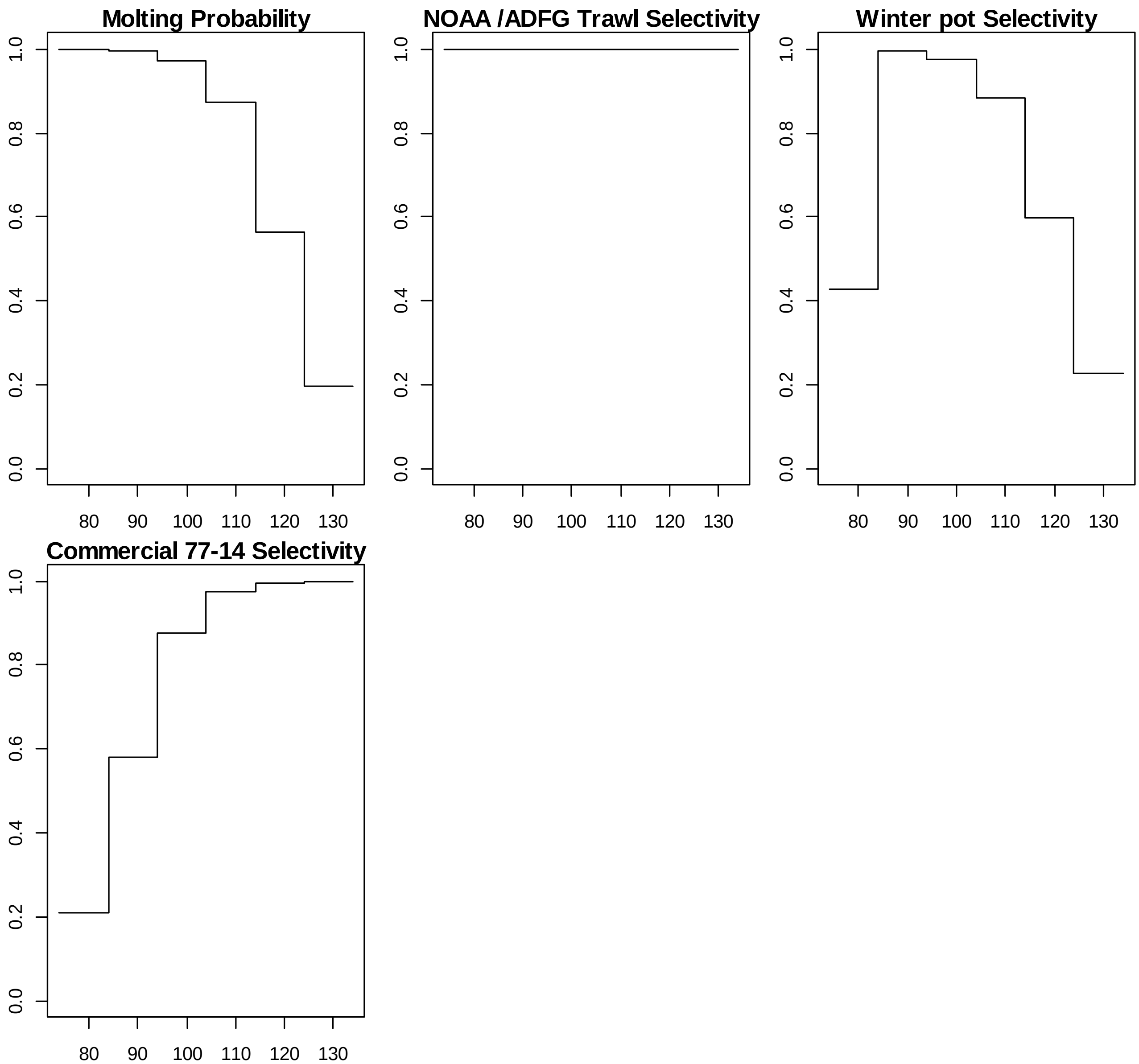


Figure 5. Molting probability and trawl/pot selectivities.

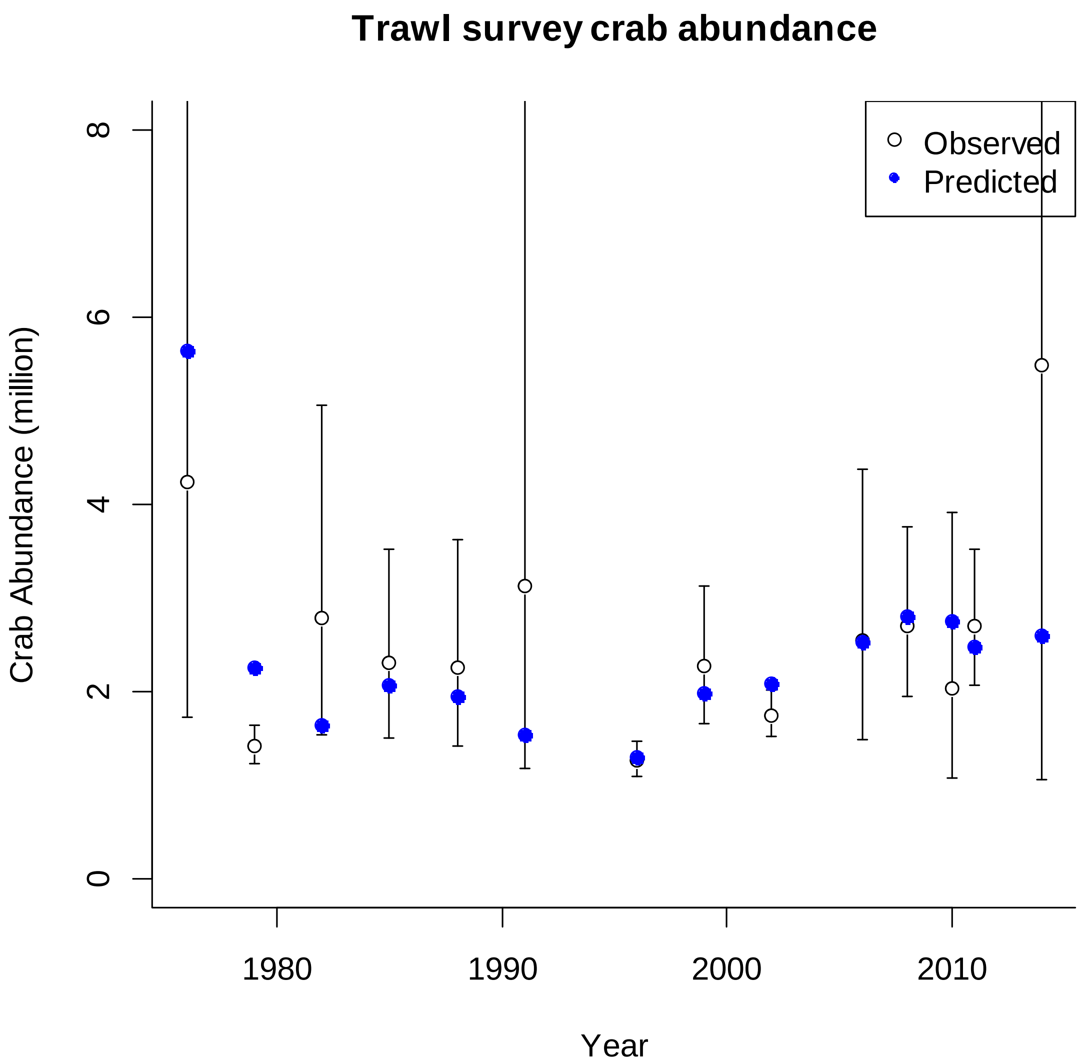


Figure 6. Estimated trawl survey male abundance (crab ≥ 74 mm CL).

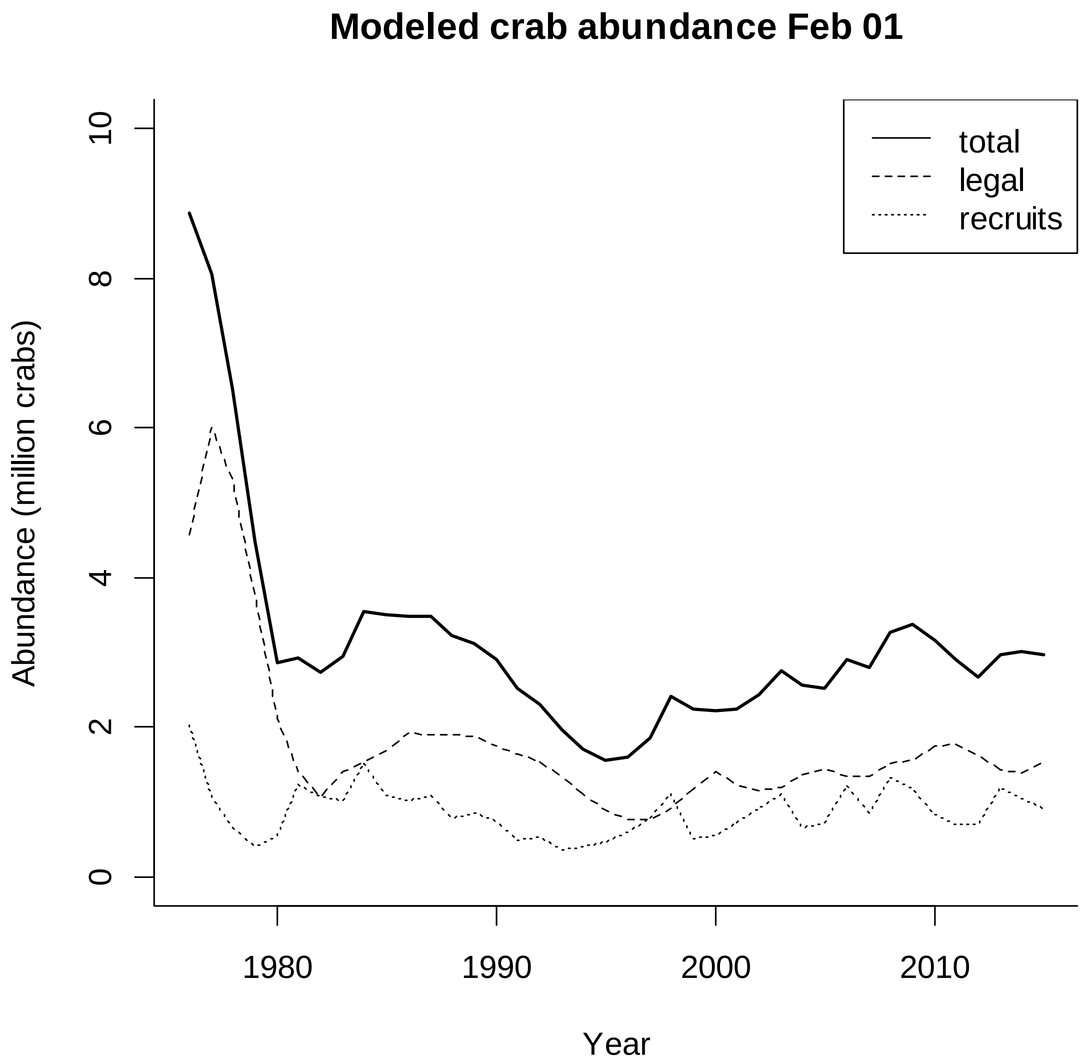


Figure 7. Estimated abundances of legal and recruits males from 1976-2014.

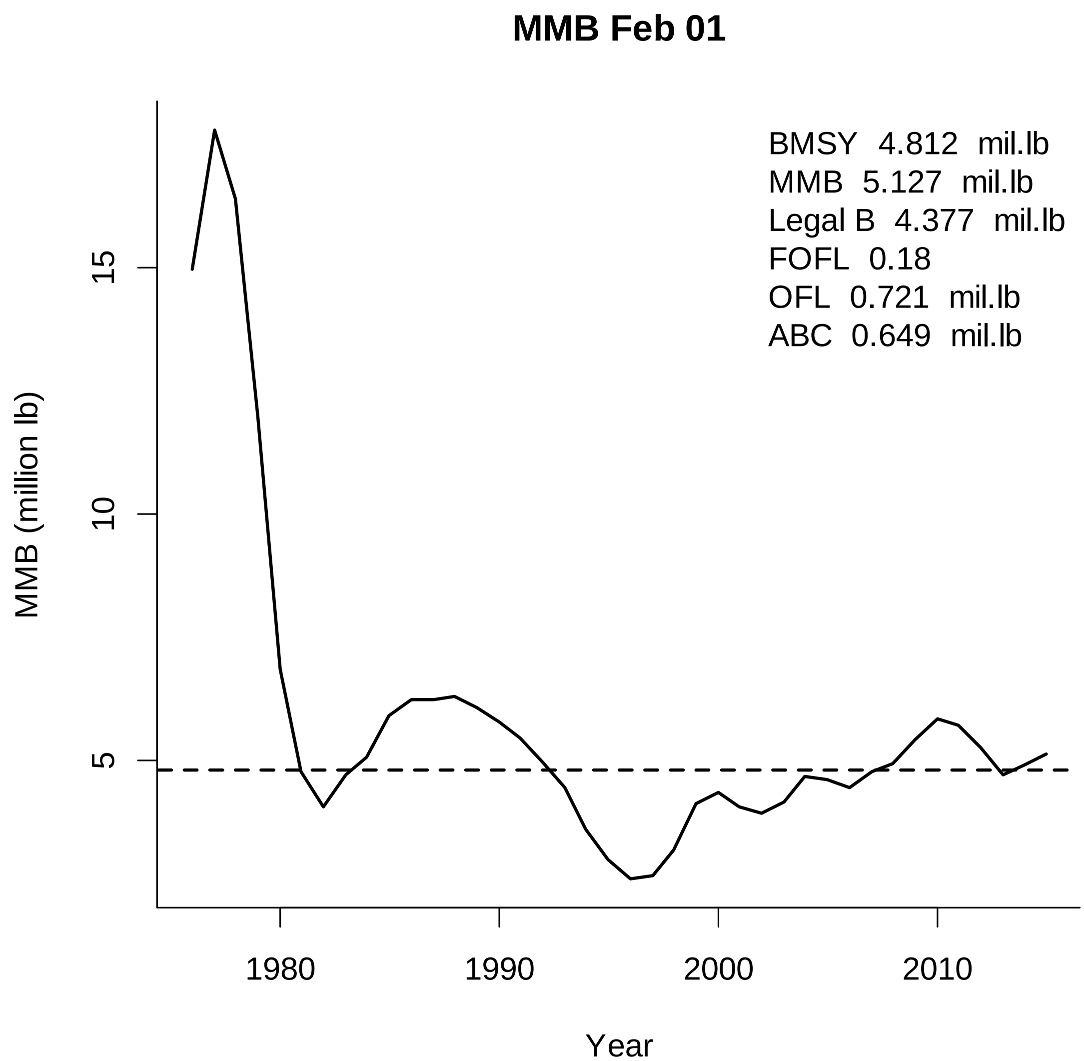


Figure 8. Estimated MMB from 1976-2015. Dash line shows Bmsy (Average MMB of 1980-2015).

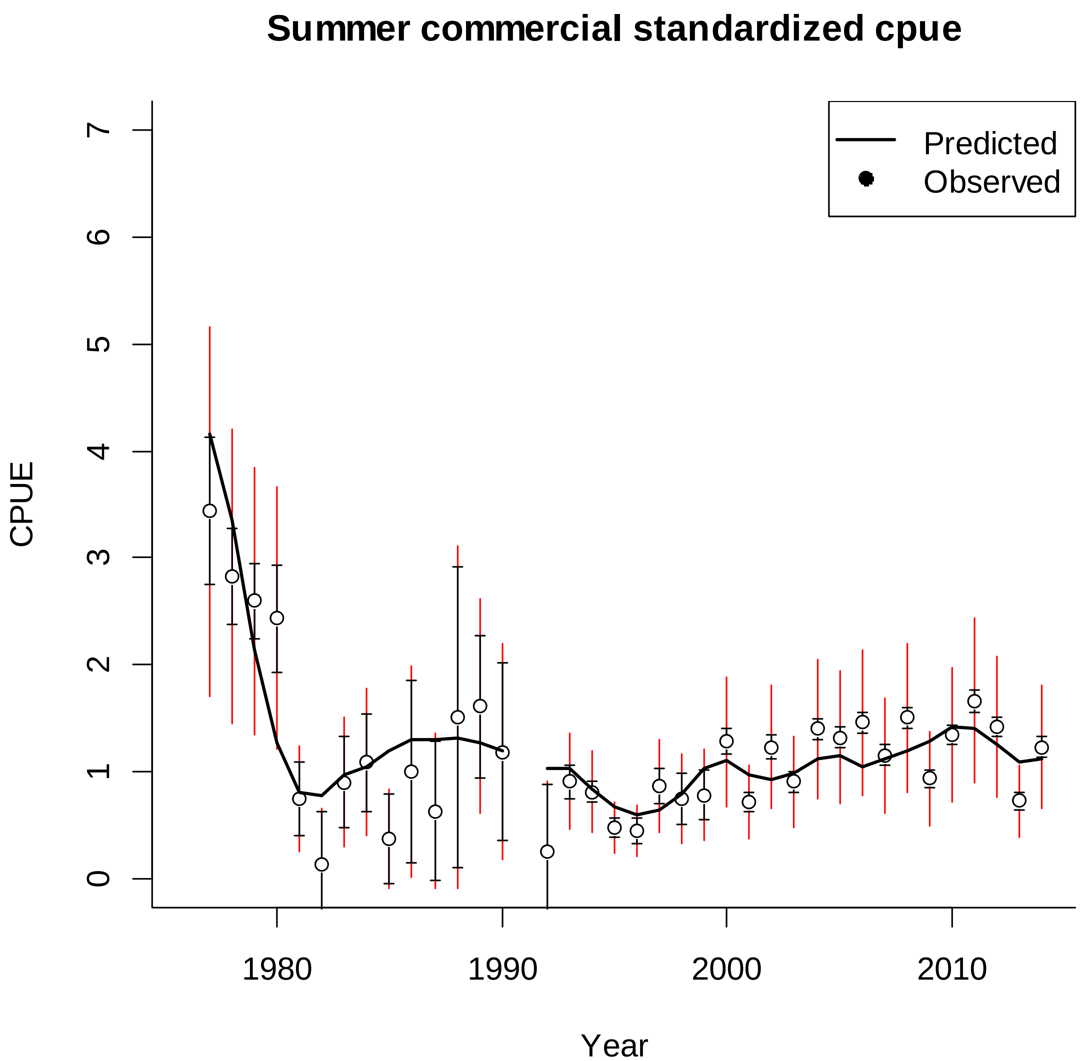


Figure 9. Summer commercial standardized cpue. Black line is input SD and red line is input and estimated additional SD.

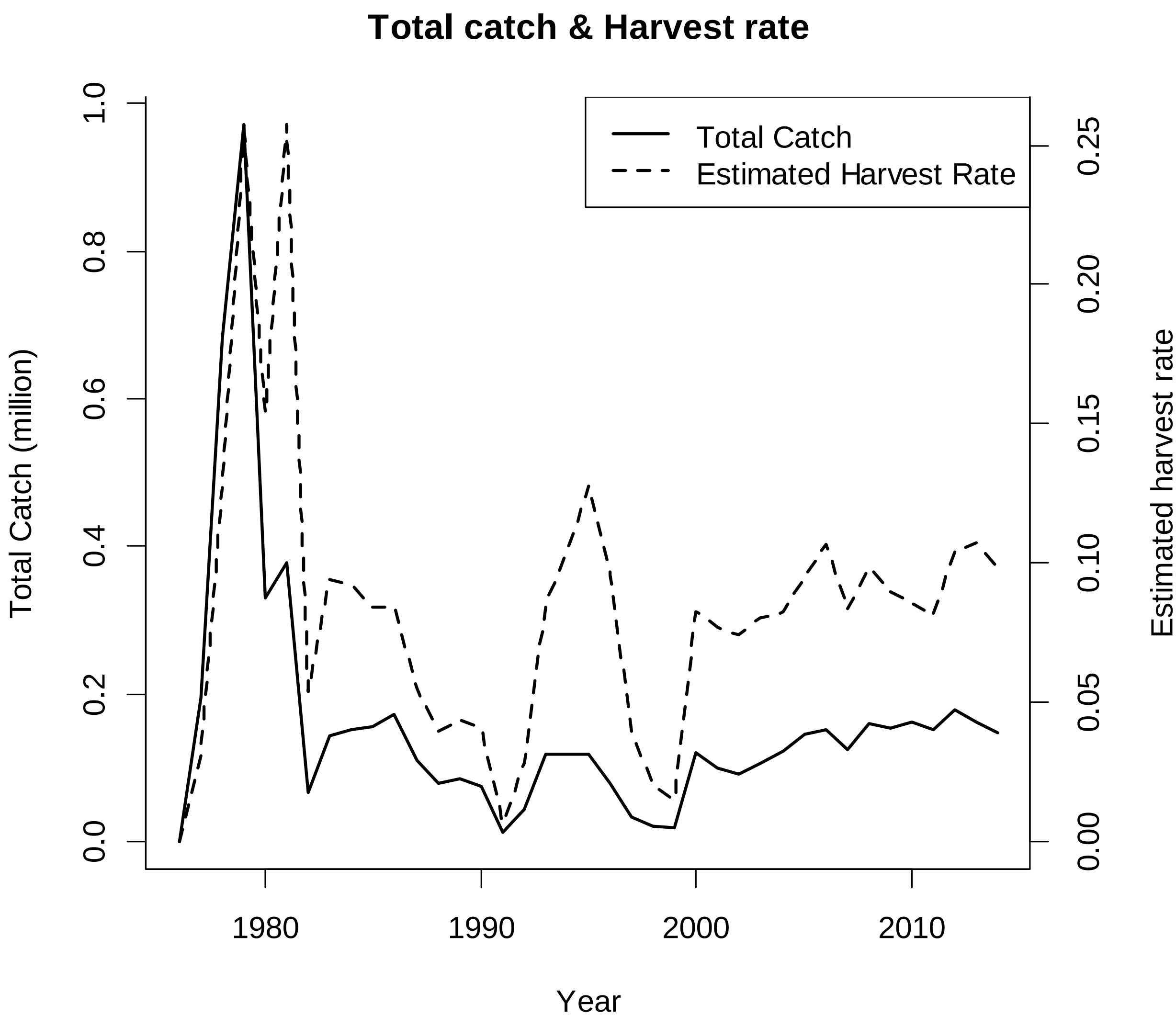


Figure 10. Commercial Catch and estimated harvest rate of legal male.

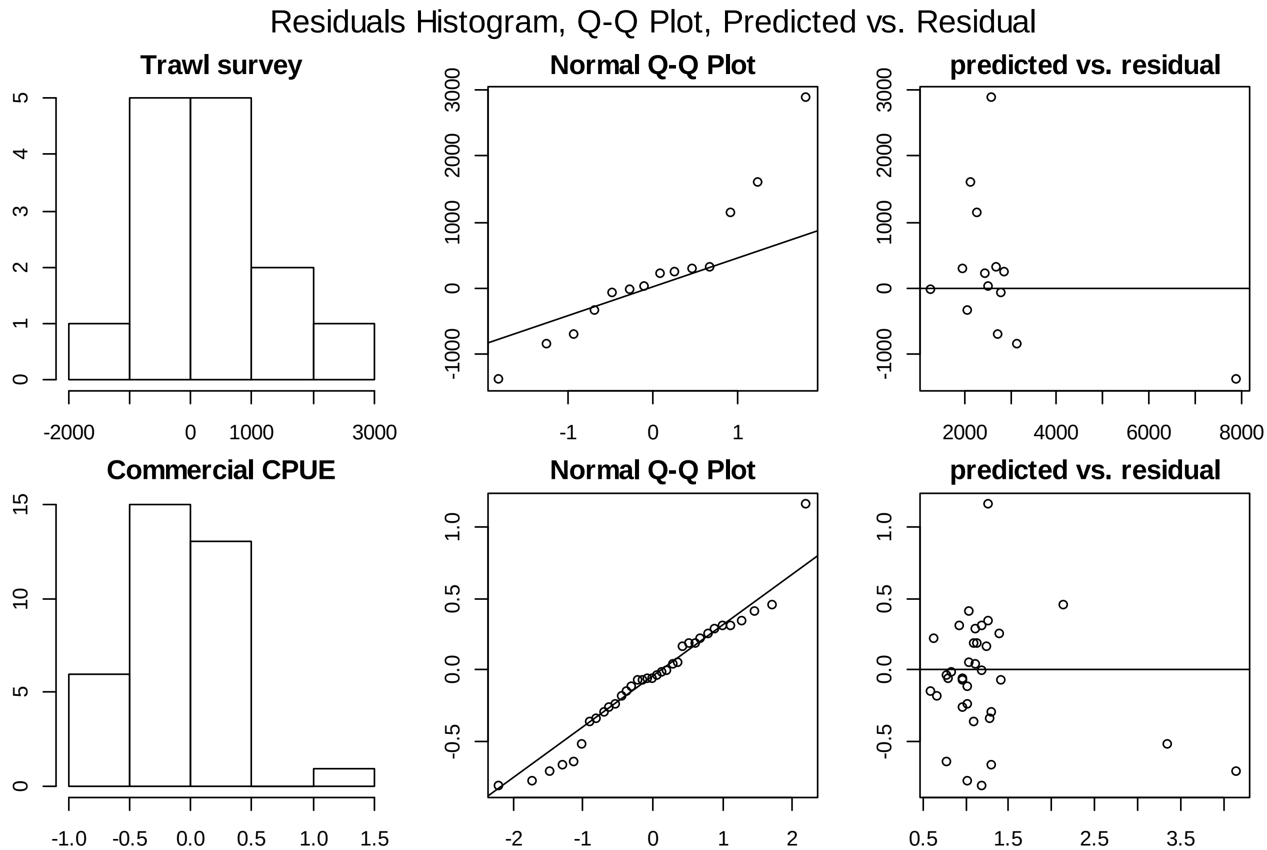
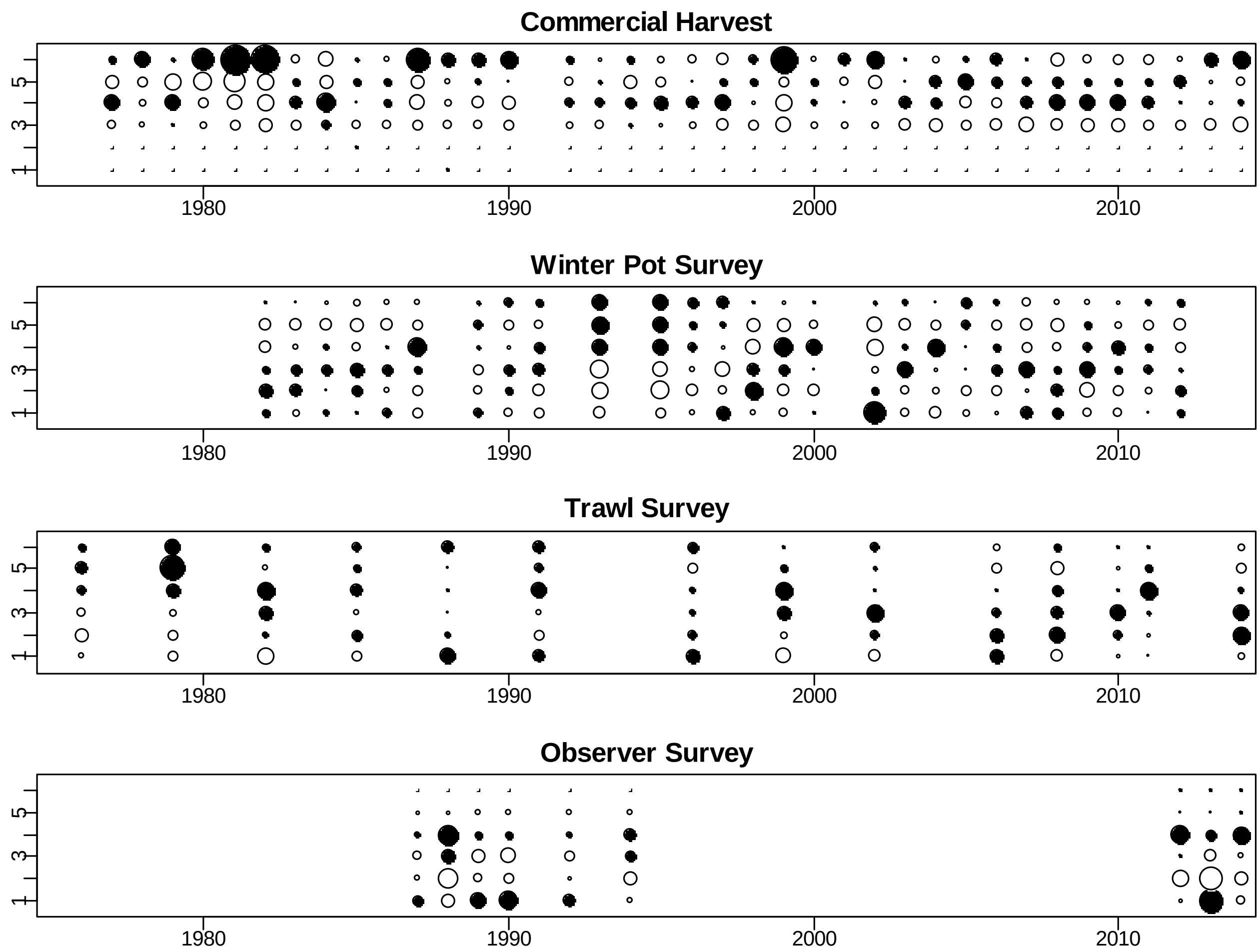


Figure 11. Residual and QQ plot.



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure 12. Bubble plot of predicted and observed length proportion (Alternative model 0). Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicate degree of deviance (larger circle = larger deviance).

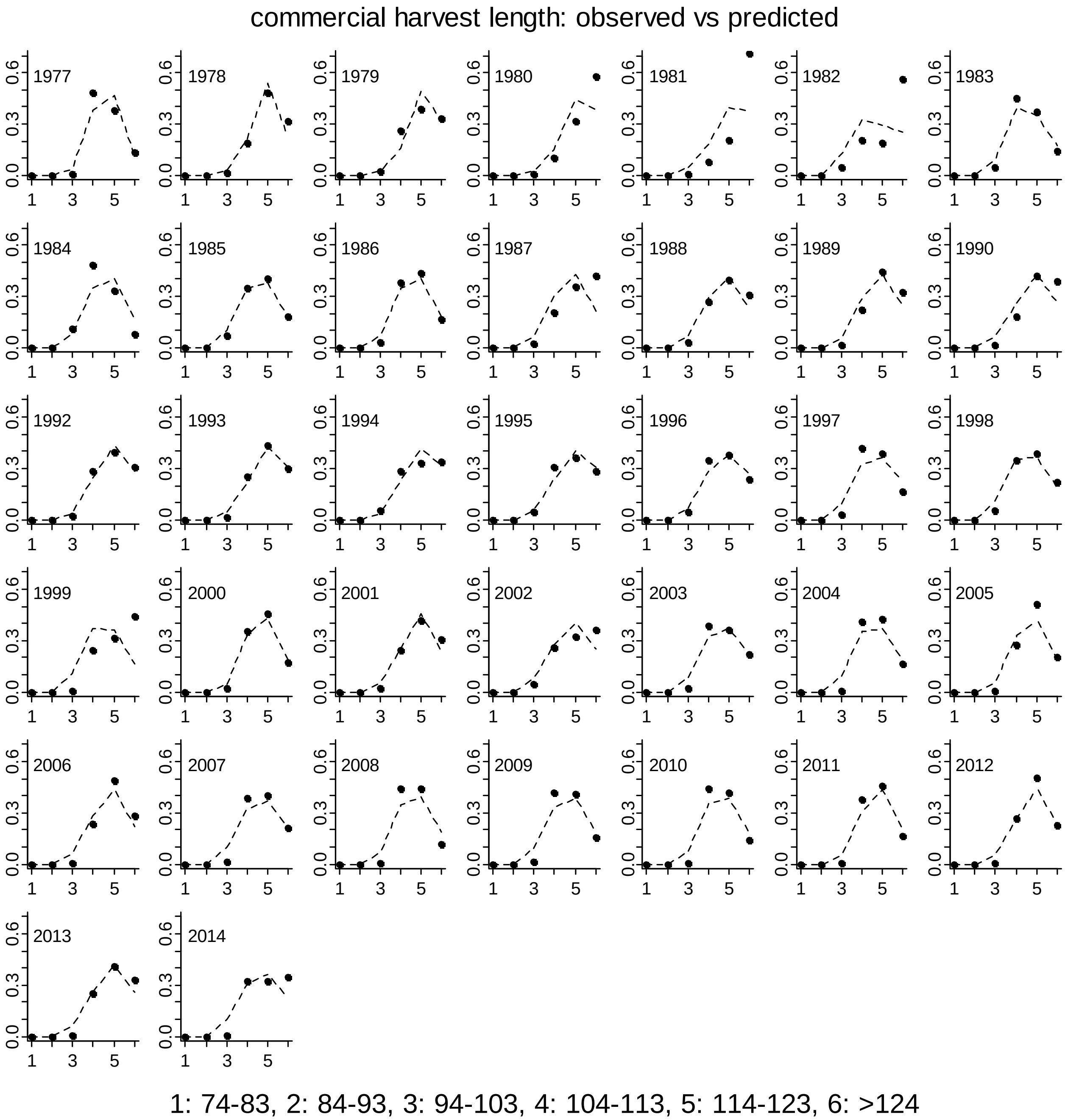
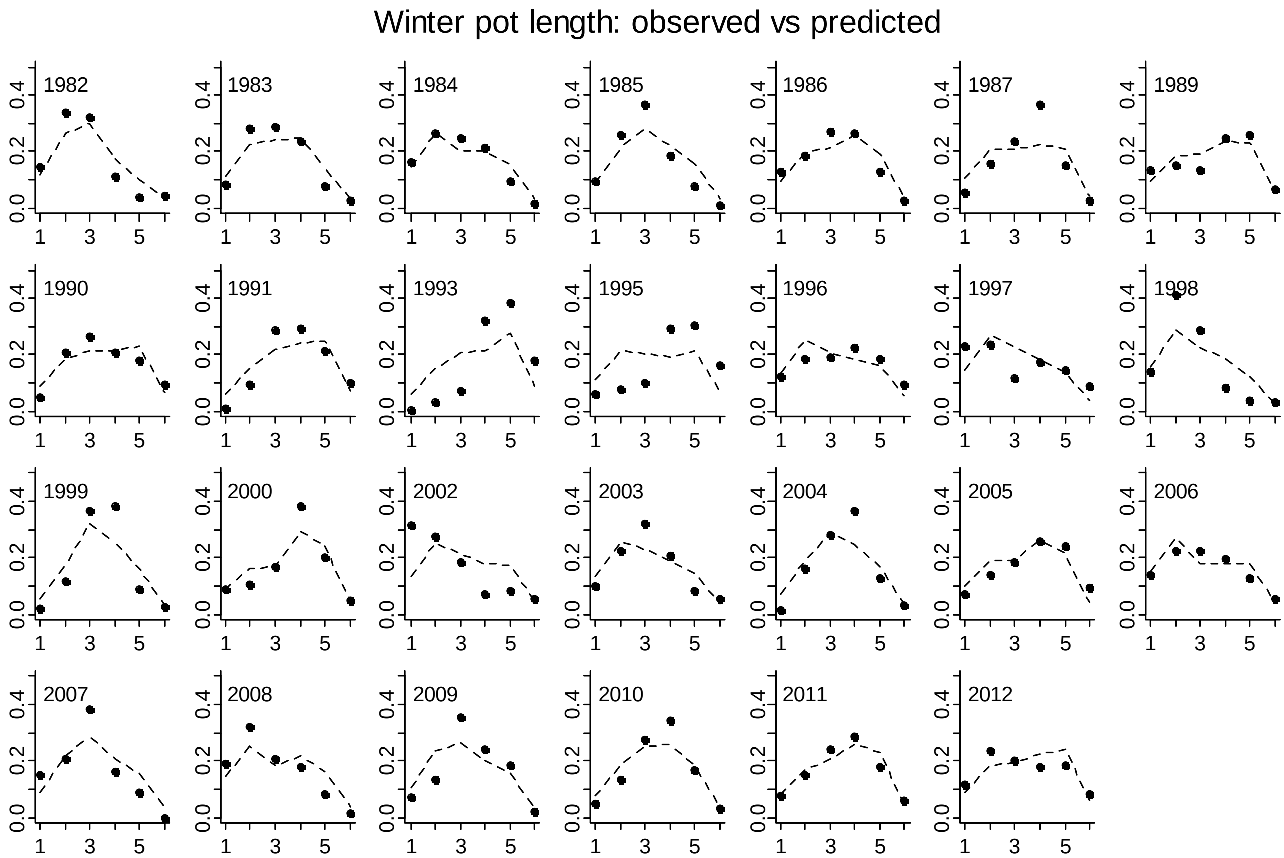
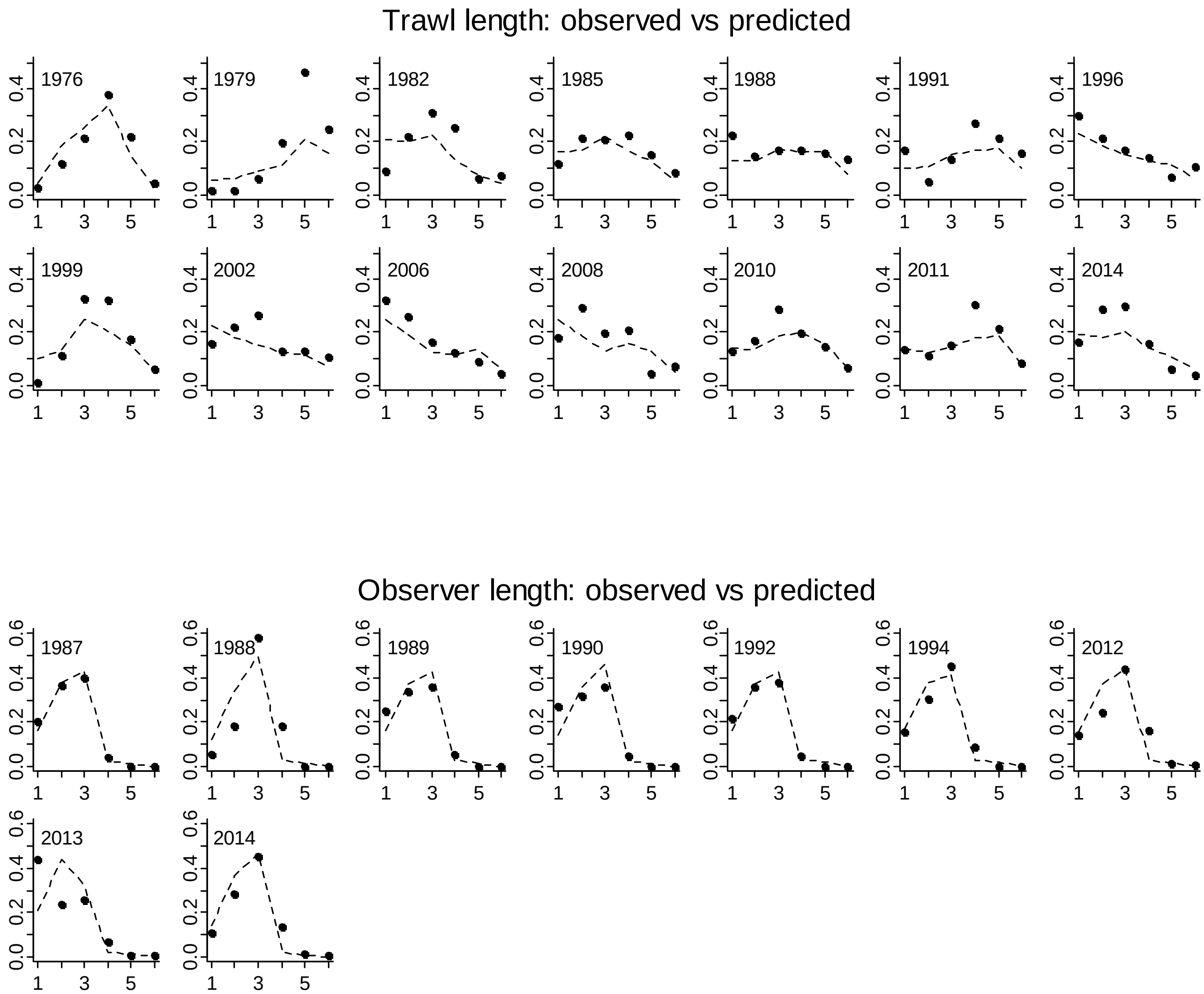


Figure 13. Predicted (dashed line) vs. observed (black dots) length class proportion for the summer commercial catch.



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure 14. Predicted vs. observed length class proportion for winter pot survey.



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure 15. Predicted vs. observed length class proportion for trawl survey and commercial observer.

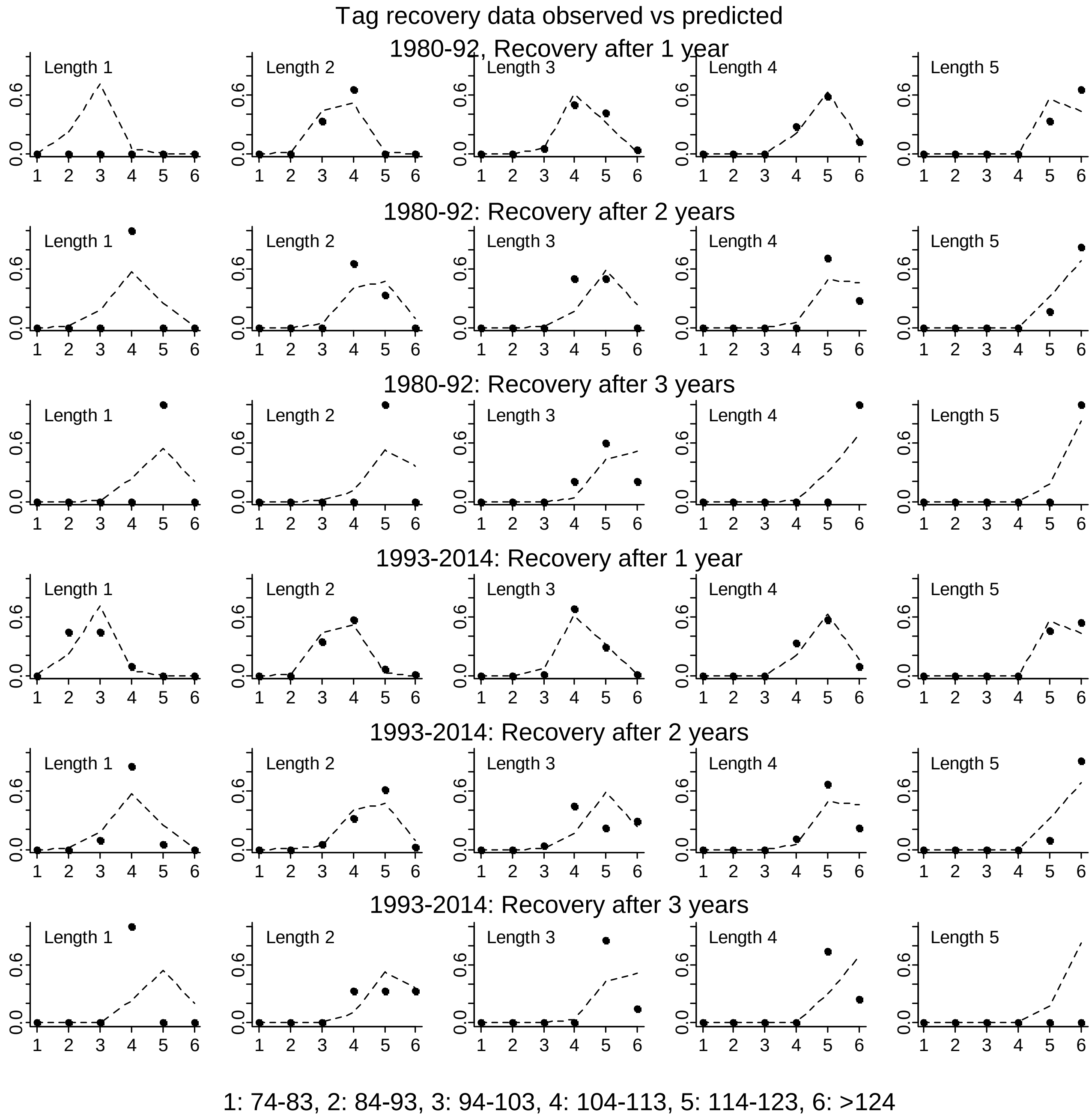


Figure 16. Predicted vs. observed length class proportion for tag recovery data 1980-1992, and 1993-2014.

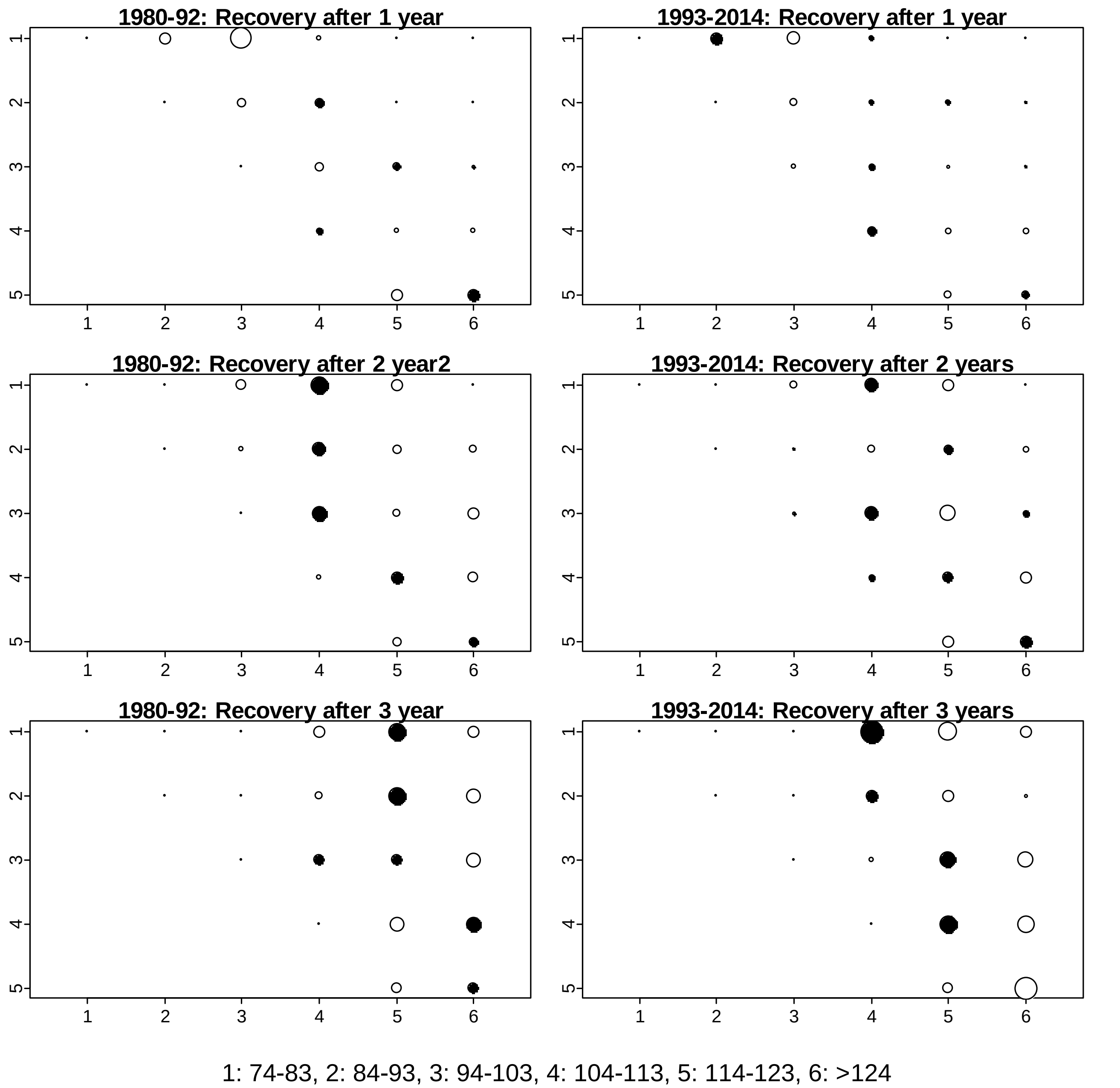


Figure 17. Bubble plot of predicted vs. observed length class proportion for tag recovery data 1980-1992, and 1993-2014.

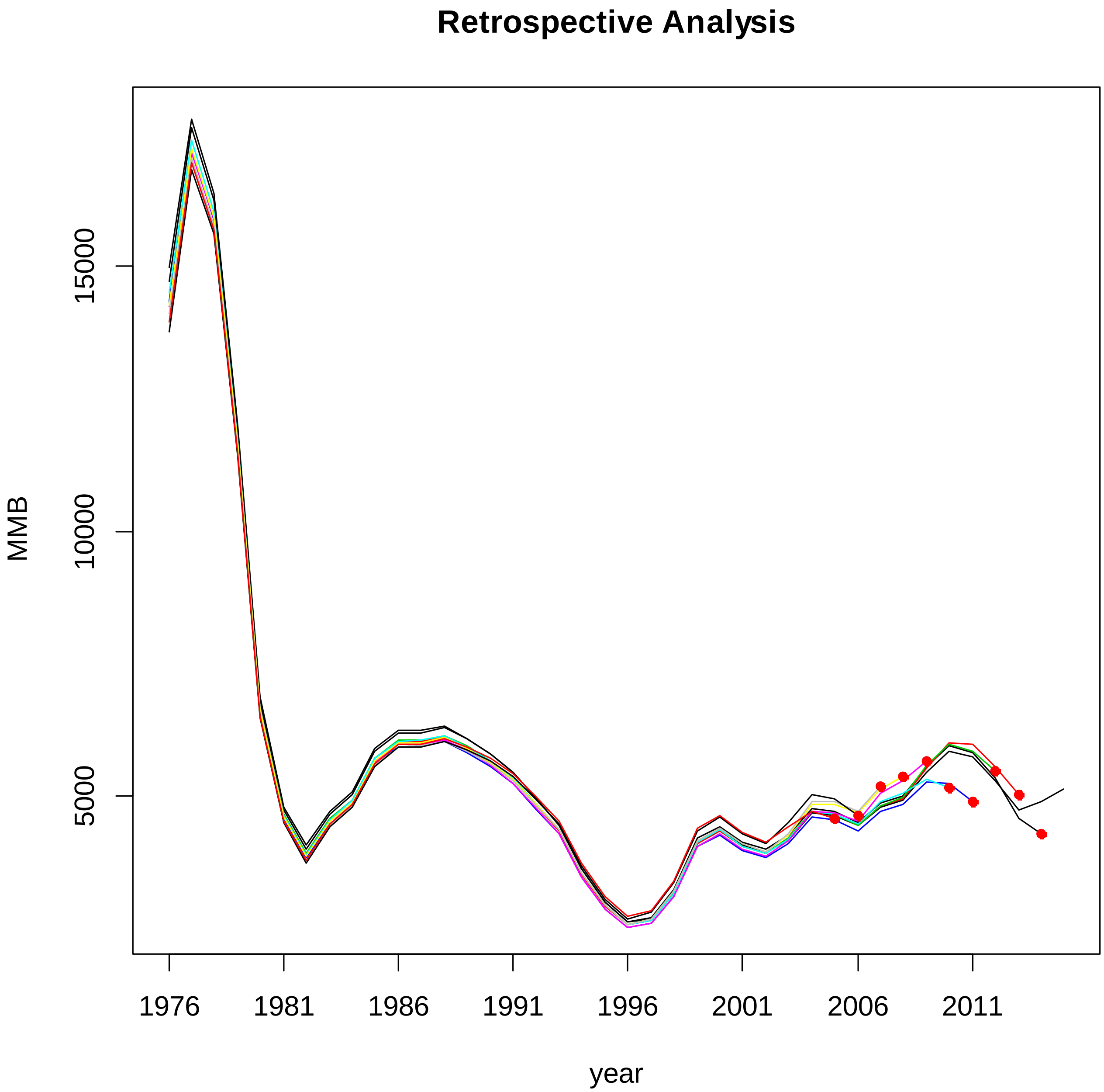


Figure 18. Retrospective analyses. The bold red dot shows retrospectively predicted MMB, and each line shows retrospective MMB.

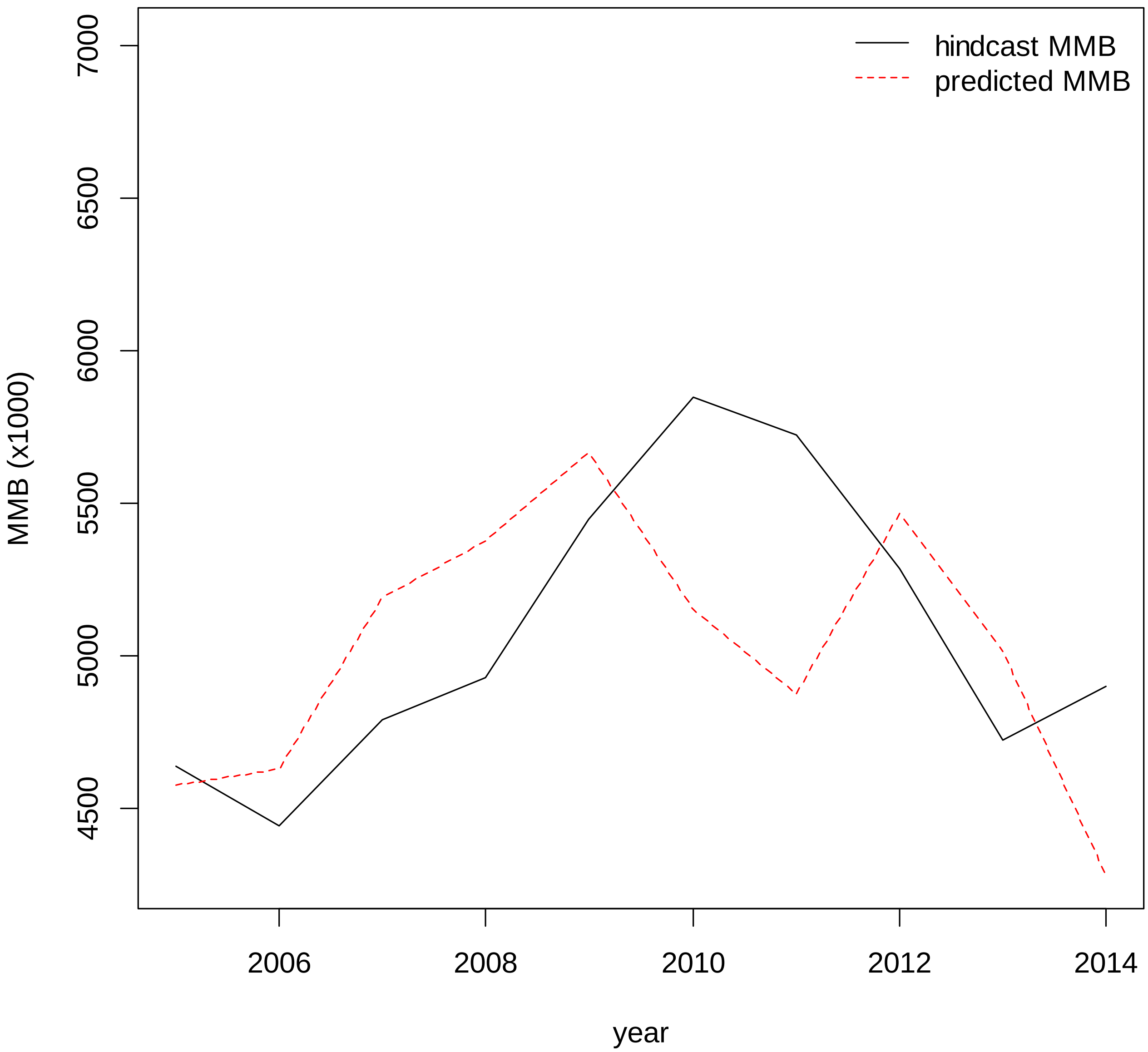
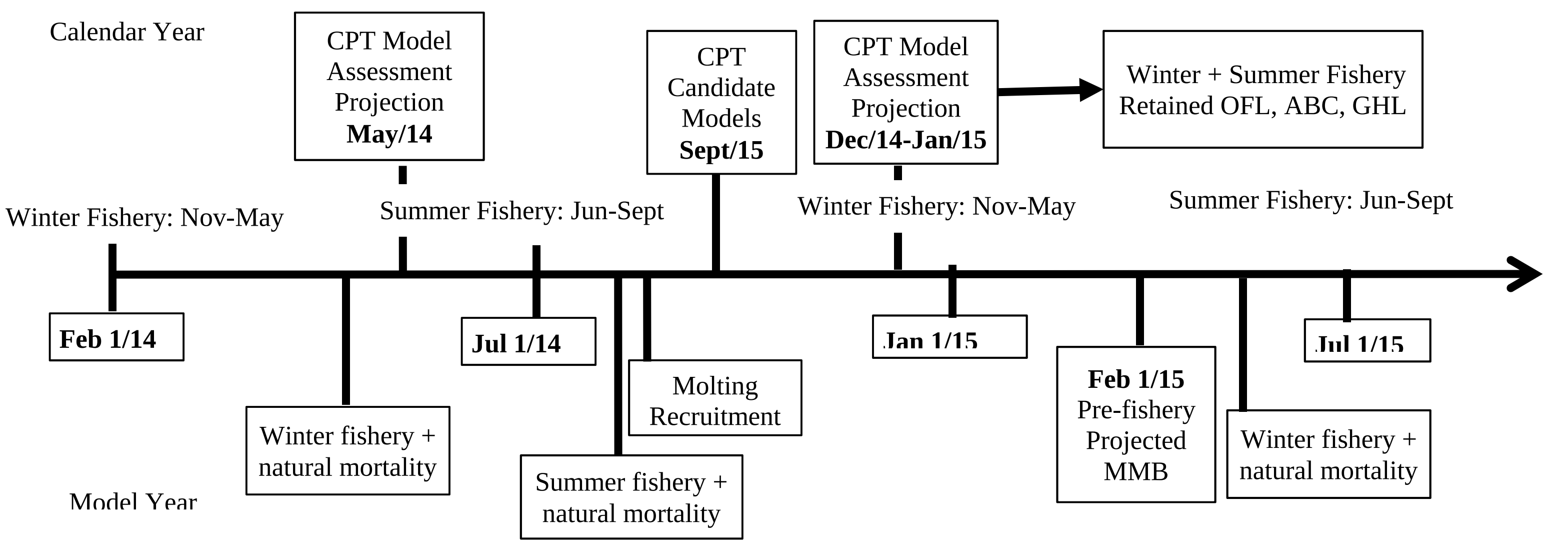


Figure 19. Retrospective analyses 2005-2014. The black line shows retrospective MMB using all (1976-2014) data, and red dash line shows retrospective predicted MMB.

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 6 male length classes with model parameters estimated by the maximum likelihood method. The model estimates abundances of crab with CL ≥74 mm and with 10-mm length intervals (6 length classes) because few crab measuring less than 74 mm CL were caught during surveys or fisheries and there were relatively small sample sizes for trawl and winter pot surveys. The model treats newshell and oldshell male crab separately but assumes they have the same molting probability and natural mortality.



Timeline of calendar events and crab modeling events.

- **Model year starts February 1st to January 31st of the following year.**
- **All winter fishery harvest occurs on February 1st**
- **Molting and recruitment occur on July 1st**
- **Initial Population Date: February 1st 1976**

Initial pre-fishery summer crab abundance on February 1st 1976

Abundance of the initial pre-fishery population was assumed consist of newshell crab to reduce the number of parameters, and estimated as

$$N_{l,1} = p_l e^{\log\_N_{76}} \tag{1}$$

where, length proportion of the first year (p_l)was calculated as

$$p_l = \frac{\exp(a_l)}{1+\sum_{l=1}^{n-1}\exp(a_l)} \text{ for } l = 1,..,n\text{-}1$$
$$p_n = 1 - \frac{\sum_{l=1}^{n-1}\exp(a_l)}{1+\sum_{l=1}^{n-1}\exp(a_l)} \tag{2}$$

for model estimated parameters a_l.

Crab abundance on July 1st

Summer (01 July) crab abundance of new and oldshells consists of survivors of winter commercial and subsistence crab fisheries and natural mortality from 01Feb to 01July:

$$\begin{aligned} N_{s,l,t} &= (\,N_{w,l,t-1} - C_{w,t-1}P_{w,n,l,t-1} - C_{p,t}\,P_{p,n,l,t-1} - D_{w,n,l,t-1} - D_{p,n,l,t-1}\,)e^{-0.42M_l} \\ O_{s,l,t} &= (\,O_{w,l,t-1} - C_{w,t-1}P_{w,o,l,t-1} - C_{p,t}\,P_{p,o,l,t-1} - D_{w,o,l,t-1} - D_{p,o,l,t-1}\,)e^{-0.42M_l} \end{aligned} \tag{3}$$

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:

$$P_{w,n,l,t} = N_{w,l,t} S_{w,l} L_l / \sum_{l=1}[(N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l]$$
$$P_{w,o,l,t} = O_{w,l,t} S_{w,l} L_l / \sum_{l=1}[(N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l] \qquad (4)$$

where
L_l : the proportion of legal males in length class l ,
$S_{w,l}$: Selectivity of winter fishery pot.

The 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

$$P_{p,n,l,t} = N_{w,l,t} S_{w,l} / \sum_{l=3}[(N_{w,l,t} + O_{w,l,t}) S_{w,l}]$$
$$P_{p,o,l,t} = O_{w,l,t} S_{w,l} / \sum_{l=3}[(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \qquad (5)$$

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 ($R_{l,t}$) .

$$N_{w,l,t} = \sum_{l'=1}^{l'=l} G_{l',l}[(N_{s,l',t-1} + O_{s,l',t-1})e^{-y_c M_l} - C_{s,t}(P_{s,n,l',t-1} + P_{s,o,l',t-1}) - D_{l',t-1}] m_{l'} e^{-(0.58-y_c)M_l} + R_{l,t} \qquad (6)$$

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:

$$O_{w,l,t} = [(N_{s,l,t-1} + O_{s,l,t-1})e^{-y_c M_l} - C_{s,t}(P_{s,n,l,t-1} + P_{s,o,l,t-1}) - D_{l,t-1}](1 - m_l) e^{-(0.58-y_c)M_l} \qquad (7)$$

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 Catchx(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

$$D_{l,t} = C_{s,t} \frac{(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - L_l)}{\sum_l (N_{s,l,t} + O_{s,l,t}) S_{s,l} L_l} hm_s \tag{8}$$

$$D_{w,n,l,t} = C_{w,t} \frac{N_{w,l,t} S_{w,l} (1 - L_l)}{\sum_l (N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l} hm_w \tag{9}$$

$$D_{w,o,l,t} = C_{w,t} \frac{O_{w,l,t} S_{w,l} (1 - L_l)}{\sum_l (N_{w,l,t} + O_{w,l,t}) S_{w,l} L_l} hm_w \tag{10}$$

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,

Winter subsistence Discards

Discards of winter subsistence fishery is reported in a permit survey ($C_{d,t}$), though its catch 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 come from only length classes 1 and 2 so that

$$\begin{aligned} R_{1,t} &= r R_t \\ R_{2,t} &= (1-r) R_t \end{aligned} \tag{14}$$

where r is a positive parameter with a value less than or equal to 1. $R_{l,t} = 0$ when $l \geq 3$.

Molting Probability

Molting probability for length class l, m_l, was fitted as a decreasing logistic function of length-class mid carapace length and constrained to equal 0.99 for the smallest length-class (L_1):

$$m_l = \frac{1}{1 + e^{(\alpha(L_1 - L) + \ln(1/0.01 - 1))}} \tag{15}$$

Trawl net and pot selectivity

For efficiency of estimating model parameters, the above equation was modified, so that selectivity reaches 0.999 at the mid-length of the largest lengths class (L_6)

$$S_l = \frac{1}{1 + e^{(\phi(L_6 - L) + \ln(1/0.999 - 1))}} \tag{16}$$

For summer trawl survey, two selectivity curves with parameters (ϕ_{st1}, ϕ_{st2}) were estimated: 1) during NMFS survey 1976-1991, and 2) during ADF&G survey since 1996. Similarly, two selectivity curves with parameters (ϕ_1, ϕ_2) were estimated for the summer commercial fishery: 1) before 1993, and 2) 1933 to present reflecting changes in fisheries, and crab pot configurations.

For winter pot survey and winter harvest parameter (ϕ_w), selectivity ($S_{w,l}$) was assumed to be dome shaped, with $S_{w,5}$ =0.999, and $S_{w,6}$ was directly estimated from the model.

Growth transition matrix

The growth matrix $G_{l',l}$ (the expected proportion of crab molting from length class l' to length class l) was

Growth matrix was assumed to be normally distributed

$$G_{l',l} = \begin{cases} \dfrac{\int_{lm_l-h}^{lm_l+h} N(L \mid \mu_{l'}, \sigma^2)\,dL}{\sum_{l=1}^{n} \int_{lm_l-h}^{lm_l+h} N(L \mid \mu_{l'}, \sigma^2)\,dL} & \text{when } l \geq l' \\ 0 & \text{when } l < l' \end{cases} \tag{17}$$

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 *t-th* year ($B_{st,t}$) is July 1st abundance subtracted by summer commercial fishery harvest occurring from the July 1st to the mid-point of summer trawl survey, multiplied by natural mortality occurring between 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.

$$\hat{B}_{st,t} = \sum_{l}[(N_{s,l,t} + O_{s,l,t})e^{-y_c M_l} - C_{s,t} P_{c,t}(P_{s,n,l,t} + P_{s,o,l,t})]e^{-(y_{st} - y_c)M_l} S_{st,l} \tag{18}$$

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),
$P_{c,t}$: proportion of summer commercial crab harvested before the mid-point of trawl survey date.

Winter pot survey CPUE

Winter pot survey cpue (f_{wt}) was calculated with catchability coefficient q and exploitable abundance

$$\hat{f}_{wt} = q_w \sum_{l}[(N_{w,l,t} + O_{w,l,t})S_{w,l}] \tag{19}$$

Summer commercial CPUE

Summer commercial fishing CPUE (f_t) was calculated as a product of catchability coefficient q and mean exploitable abundance minus one half of summer catch, A_t.

$$\hat{f}_t = q_i(A_t - 0.5C_t) \tag{20}$$

Because fishing fleet and pot limit configuration changed in 1993, q_1 is for fishing efforts before 1993, q_2 is from 1994 to present.

Where A_t is exploitable legal abundance in year t, estimated as

$$A_t = \sum_{l}[(N_{s,l,t} + O_{s,l,t})S_{s,l} L_l] \tag{21}$$

Summer pot survey abundance (Removed from likelihood components)
Abundance of t-th year pot survey was estimated as

$$\hat{B}_{p,t} = \sum_{l}[(N_{s,l,t} + O_{s,l,t})e^{-y_p M_l}]S_{p,l} \tag{22}$$

Where
y_p : the time in year from July 1 to the mid-point of the summer pot survey.
Length composition

Summer commercial catch

Length compositions of the summer commercial catch for new and old shell crabs $P_{s,n,l,t}$ and $P_{s,o,l,t}$, were modeled based on the summer population, selectivity, and legal abundance:

$$\begin{aligned}\hat{P}_{s,n,l,t} &= N_{s,l,t} S_{s,l} L_l / A_t \\ \hat{P}_{s,o,l,t} &= O_{s,l,t} S_{s,l} L_l / A_t\end{aligned} \tag{23}$$

Summer commercial fishery discards

Length/shell compositions of observer discards were modeled as

$$\begin{aligned}\hat{P}_{b,n,l,t} &= N_{s,l,t} S_{s,l} (1 - L_l) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - L_l)] \\ \hat{P}_{b,o,l,t} &= O_{s,l,t} S_{s,l} (1 - L_l) / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l} (1 - L_l)]\end{aligned} \tag{24}$$

Summer trawl survey

Proportions of newshell and oldshell crab, $P_{st,n,l,t}$ and $P_{st,o,l,t}$ were given by

$$\begin{aligned}\hat{P}_{st,n,l,t} &= \frac{[N_{s,l,t}\, e^{-y_c M_l} - C_{s,t}\, P_{c,t}\, \hat{P}_{s,n,l',t}] e^{-(y_{st} - y_c) M_l} S_{st,l}}{\sum_l [(N_{s,l,t} + O_{s,l,t}) e^{-y_c M_l} - C_{s,t} P_{c,t} (\hat{P}_{s,n,l',t} + \hat{P}_{s,o,l',t})] e^{-(y_{st} - y_c) M_l} S_{st,l}} \\ \hat{P}_{st,o,l,t} &= \frac{[O_{s,l,t}\, e^{-y_c M_l} - C_{s,t}\, \hat{P}_{s,o,l',t}\, P_{c,t}] e^{-(y_{st} - y_c) M_l} S_{st,l}}{\sum_l [(N_{s,l,t} + O_{s,l,t}) e^{-y_c M_l} - C_{s,t} P_{c,t} (\hat{P}_{s,n,l,t} + \hat{P}_{s,o,l,t})] e^{-(y_{st} - y_c) M_l} S_{st,l}}\end{aligned} \tag{25}$$

Winter pot survey

Winter pot survey length compositions for newshell and oldshell crab, $P_{sw,n,l,t}$ and $P_{sw,o,l,t}$ ($l \geq 1$) were calculated as

$$\begin{aligned}\hat{P}_{sw,n,l,t} &= N_{w,l,t} S_{w,l} / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}] \\ \hat{P}_{sw,o,l,t} &= O_{w,l,t} S_{w,l} / \sum_l [(N_{w,l,t} + O_{w,l,t}) S_{w,l}]\end{aligned} \tag{26}$$

Summer pre-season survey (1976) (Removed from likelihood due to only 1 year of survey)

The same selectivity for the summer commercial fishery was applied to the summer pre-season survey, resulting in estimated length compositions for both newshell and oldshell crab as:

$$\hat{P}_{sf,n,l,t} = N_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}]$$
$$\hat{P}_{sf,o,l,t} = O_{s,l,t} S_{s,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{s,l}] \quad (27)$$

This was not incorporated into likelihood calculation because of one year data.

Summer pot survey (1980-82, 85) (Removed from likelihood with failure to locate original data)

The length/shell condition compositions of summer pot survey were estimated as

$$\hat{P}_{sp,n,l,t} = N_{s,l,t} S_{sp,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{sp,l}]$$
$$\hat{P}_{sp,o,l,t} = O_{s,l,t} S_{sp,l} / \sum_l [(N_{s,l,t} + O_{s,l,t}) S_{sp,l}] \quad (28)$$

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 proportional to the growth matrix, catch selectivity, and molting probability (m_l) as

$$\hat{P}_{l',l,t,s} = \frac{S_l \cdot [X^t]_{l',l}}{\sum_{l=1}^{n} S_l \cdot [X^t]_{l',l}} \quad (29)$$

where X is a molting probability adjusted growth matrix with each component consisting of

$$X_{l',l} = \begin{cases} m_{l'} \cdot G_{l',l} & \text{when } l' \neq l \\ m_l \cdot G_{l',l} + (1\text{-}m_i) & \text{when } l' = l \end{cases} \quad (30)$$

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:

$$\sum_{i=1}^{i=4}\sum_{t=1}^{t=n_i}K_{i,t}\left[\sum_{l=1}^{l=6}P_{i,l,t}\ln(\hat{p}_{i,l,t}+\kappa)-\sum_{l=1}^{l=6}P_{i,l,t}\ln(P_{i,l,t}+\kappa)\right]$$
$$-\sum_{t=1}^{t=n_i}\frac{[\ln(q\cdot\hat{B}_{i,t}+\kappa)-\ln(B_{i,t}+\kappa)]^2}{2\cdot ln(CV_{i,t}^2+1)}$$
$$-\sum_{t=1}^{t=n_i}\left[\frac{\ln\left[\ln(CV_t^2+1)+w_t\right]}{2}+\frac{[\ln(\hat{f}_t+\kappa)-\ln(f_t+\kappa)]^2}{2\cdot\left[\ln(CV_t^2+1)+w_t\right]}\right] \tag{31}$$
$$-\sum_{t=1}\frac{\tau_t^2}{2\cdot SDR^2}$$
$$+W\sum_{s=1}^{s=2}\sum_{t=1}^{t=3}\sum_{l'=1}^{l'=6}K_{l',t,s}\left[\sum_{l=1}^{l=6}P_{l',l,t}\ln(\hat{P}_{l',l,t,s}+\kappa)-\sum_{l=1}^{l=6}P_{l',l,t}\ln(P_{l',l,t,s}+\kappa)\right]$$

where
i: length/shell compositions of :
  1 triennial summer trawl survey,
  2 annual winter pot survey,
  3 summer commercial fishery,
  4 observer discards during the summer fishery.
n_i: the number of years in which data set *i* is available,
$K_{i,t}$: 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*.
In this, while observation and estimation were made for oldshell and newshell separately, both were combined for likelihood calculations.
κ : a constant equal to 0.001,
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_w : Standard deviation of winter survey CPUE = 0.3,
SDR : Standard deviation of recruitment = 0.5,
$K_{l',t}$: the effective sample size of length class *l'* released and recovered after *t-th* in year,
$K_{l',t}$: the effective 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*,
s: fishery selectivity (1) 1976-1992, (2) 1993- present,
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.

e. 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

f. 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 of 3 to 6

$$MMB = \sum_{l=3}(N_{s,l,} + O_{s,l,})wm_l$$

wm_l: mean weight of each length class (Table 11).

ii. Projected legal male biomass for winter and summer fishery OFL was calculated as

$$Legal\_B = \sum_{l}(N_{s,l,} + O_{s,l,})S_{s,l}L_l wm_l$$

iii. Recruitment: the number of males of the length classes 1 and 2.

Appendix B1. Likelihood profile for weights: Using model 0

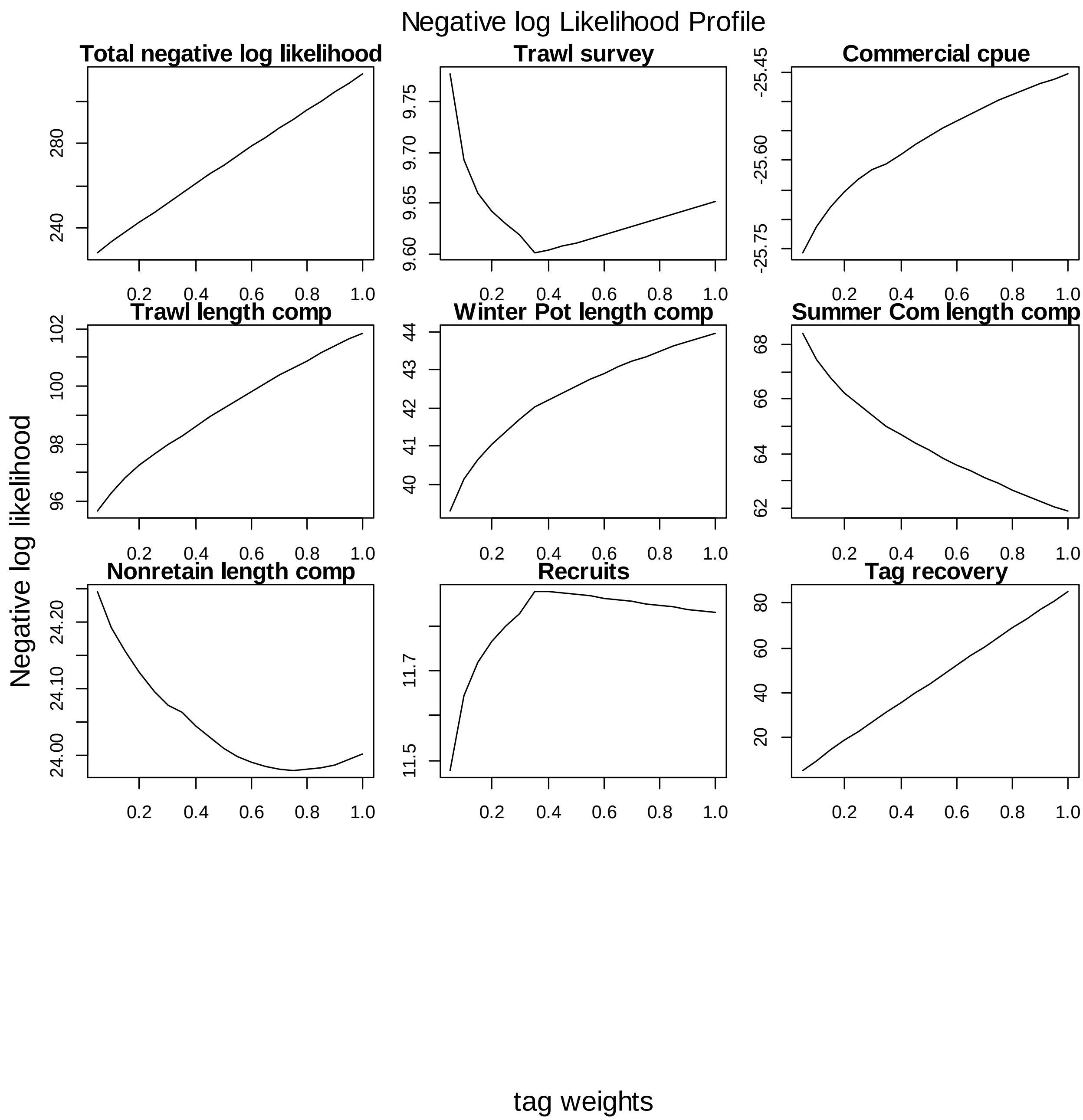


Figure B1-1. Negative log-likelihood.

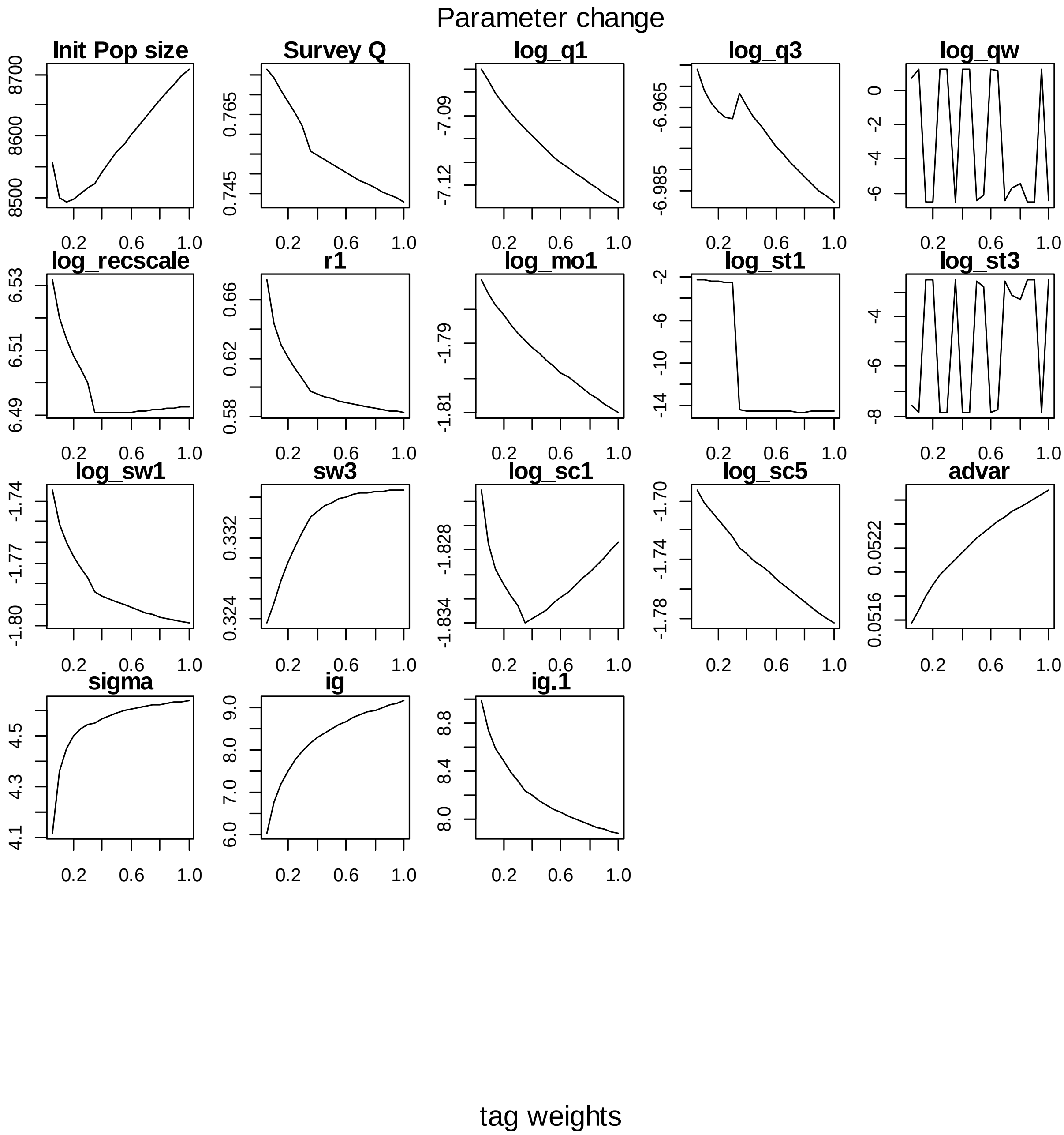


Figure B1-2. Changes in Parameter value.

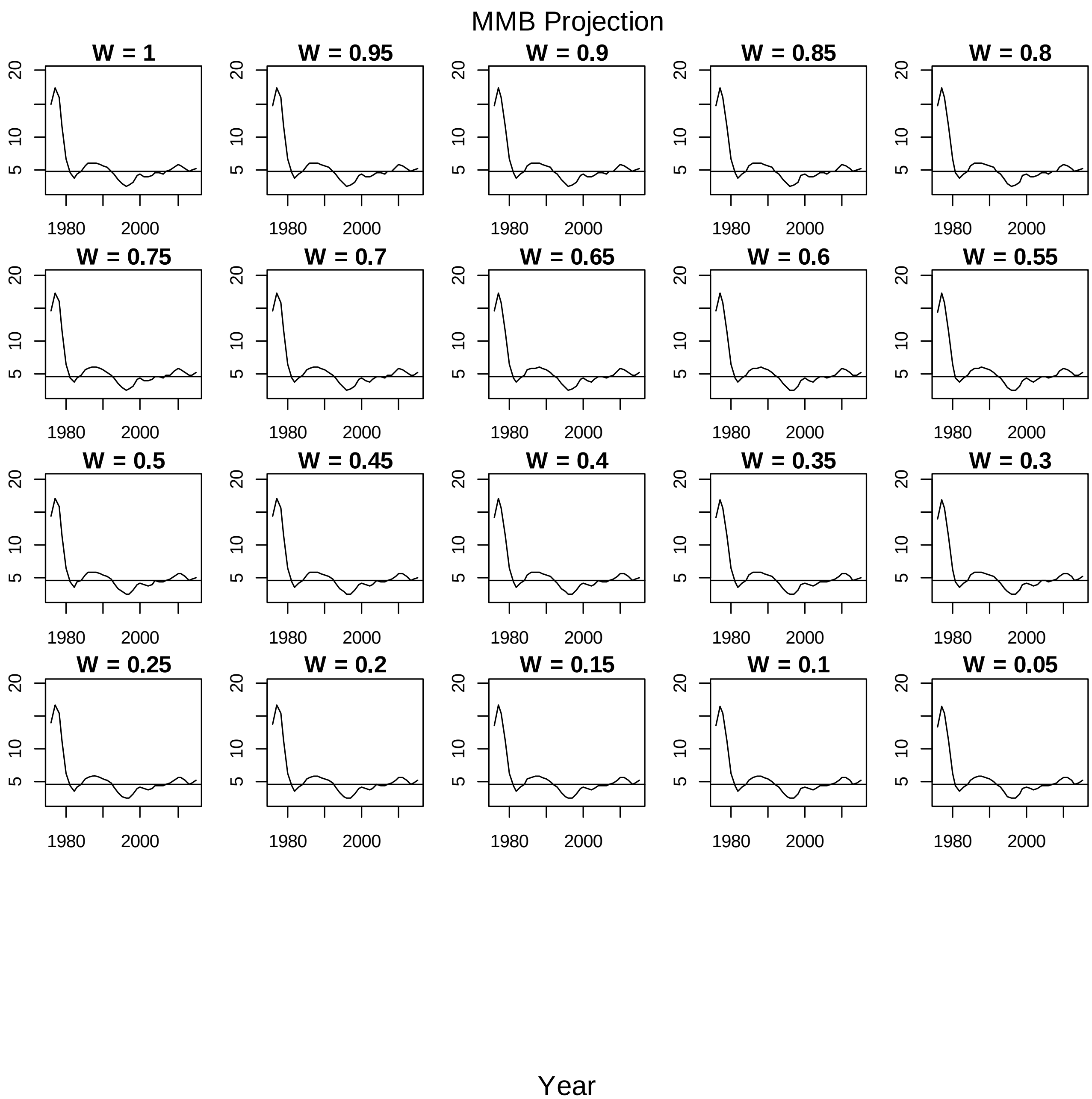


Figure B1-3. MMB projection changes.

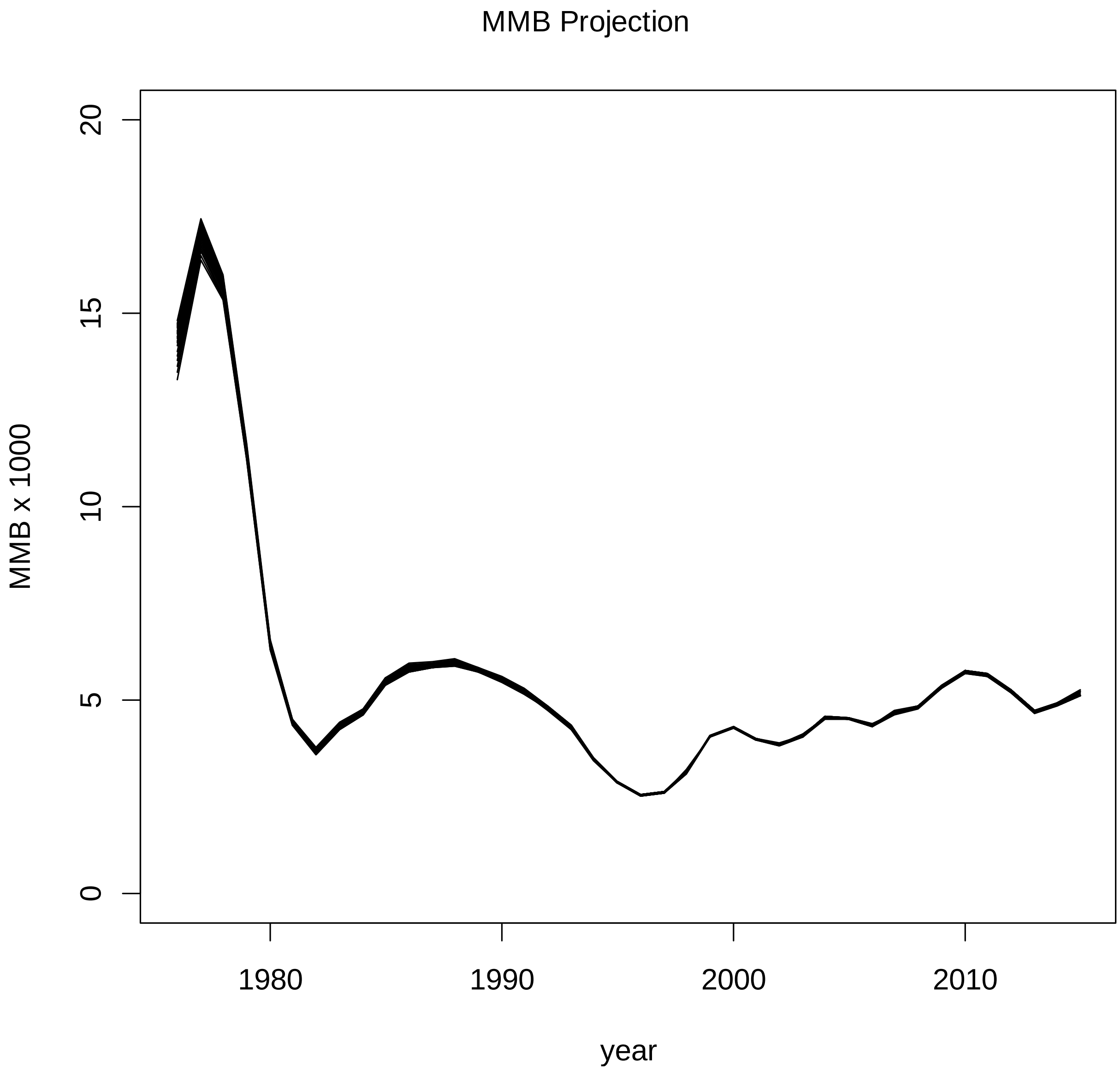


Figure B1-4. MMB projection.

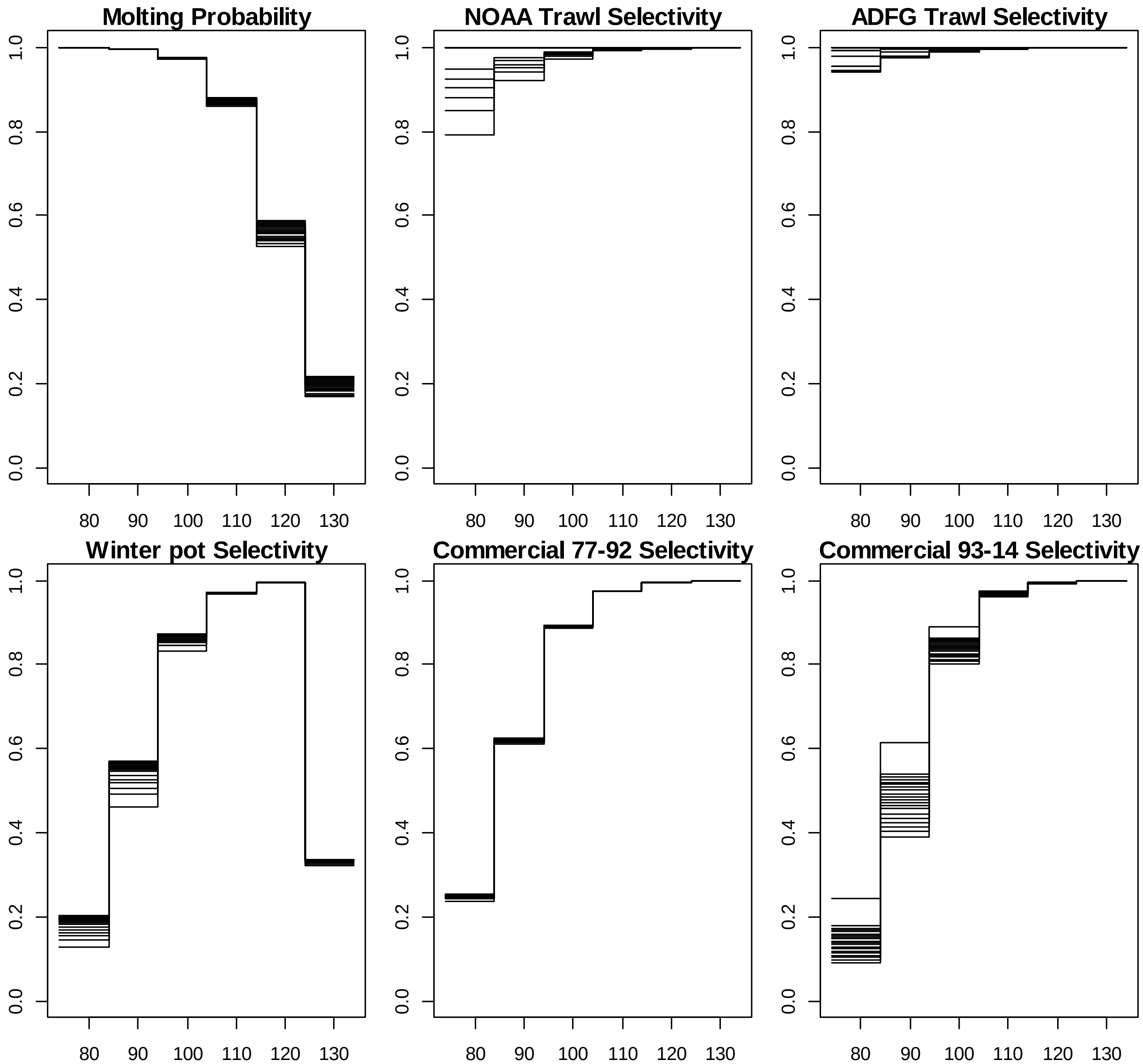


Figure B1-5. Changes of selectivities and molting probability combined.

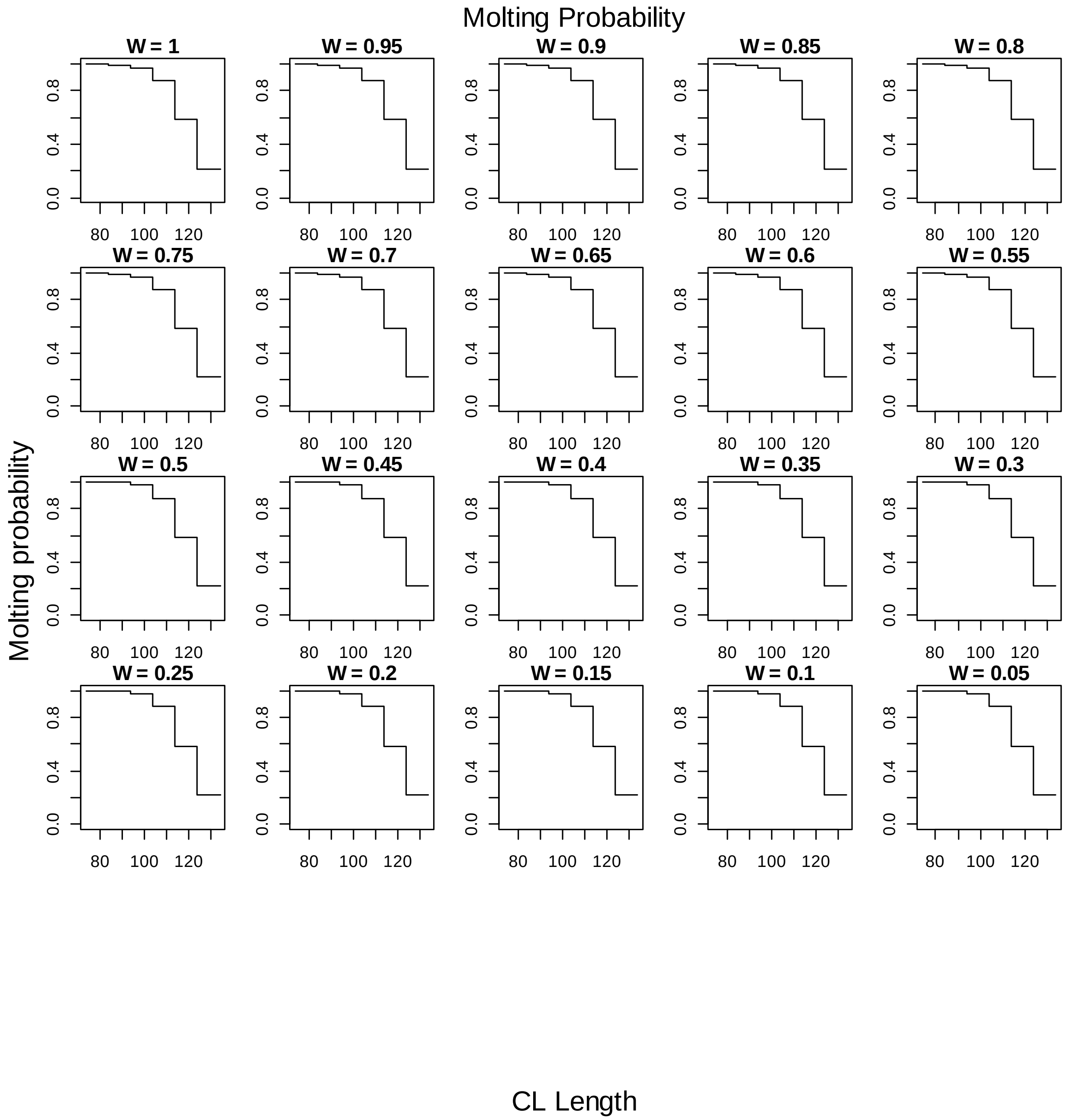


Figure B1-6. Changes of molting probability by different weights

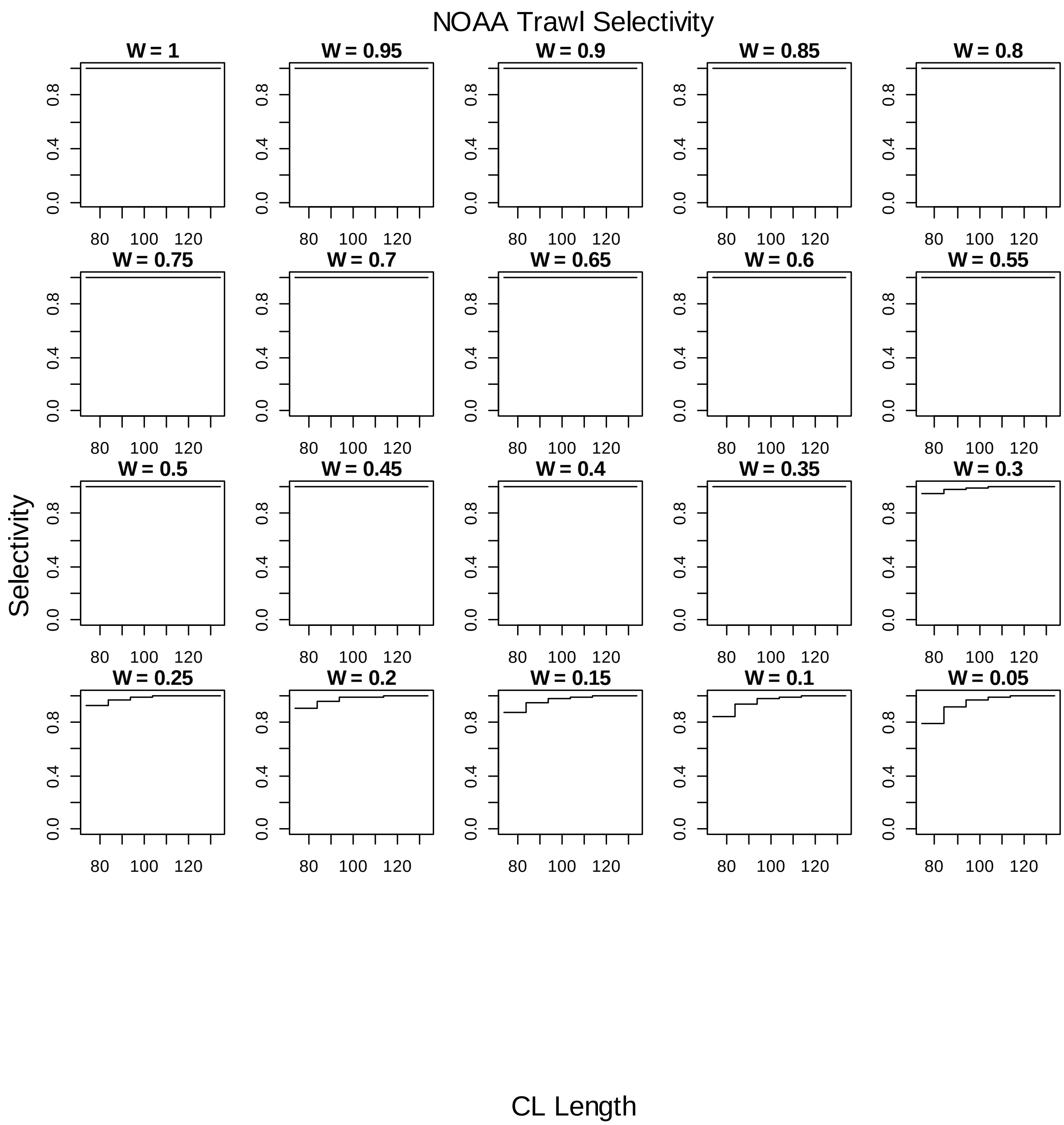


Figure B1-7. Changes of NMFS trawl selectivity by different weights

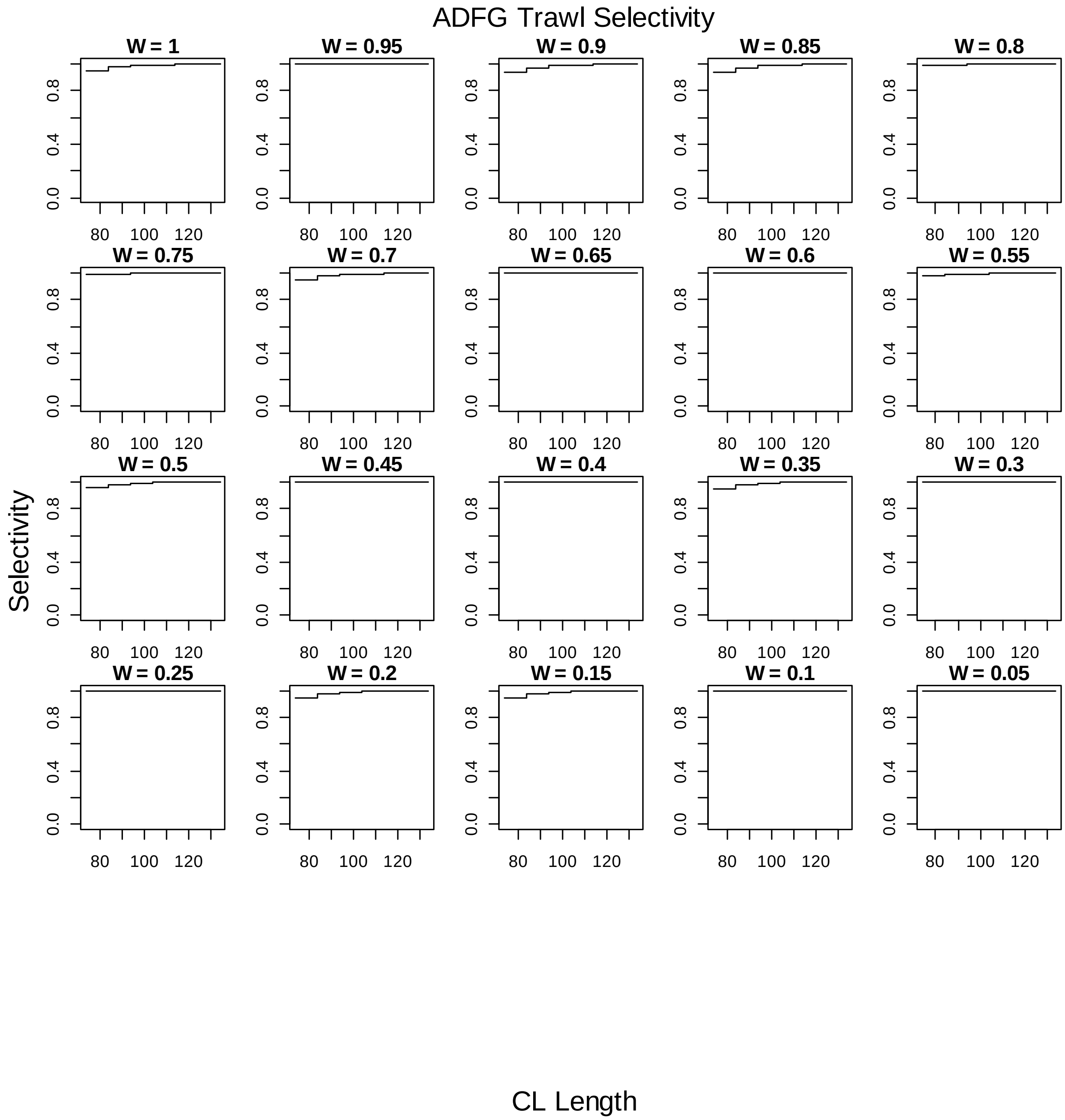


Figure B1-8: Changes of ADF&G Trawl selectivity by different weights

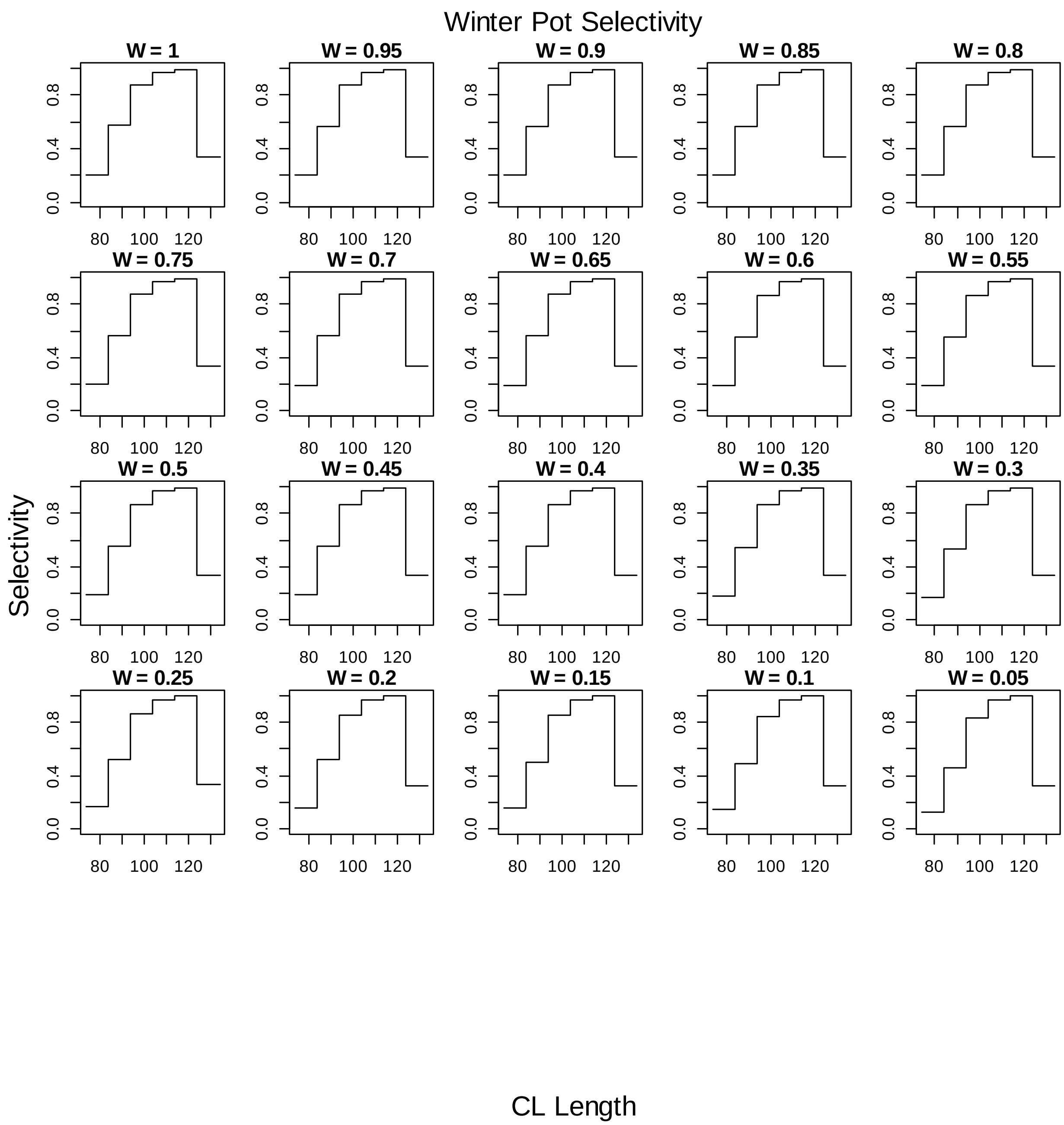


Figure B1-9. Changes of Winter pot selectivity by different weights

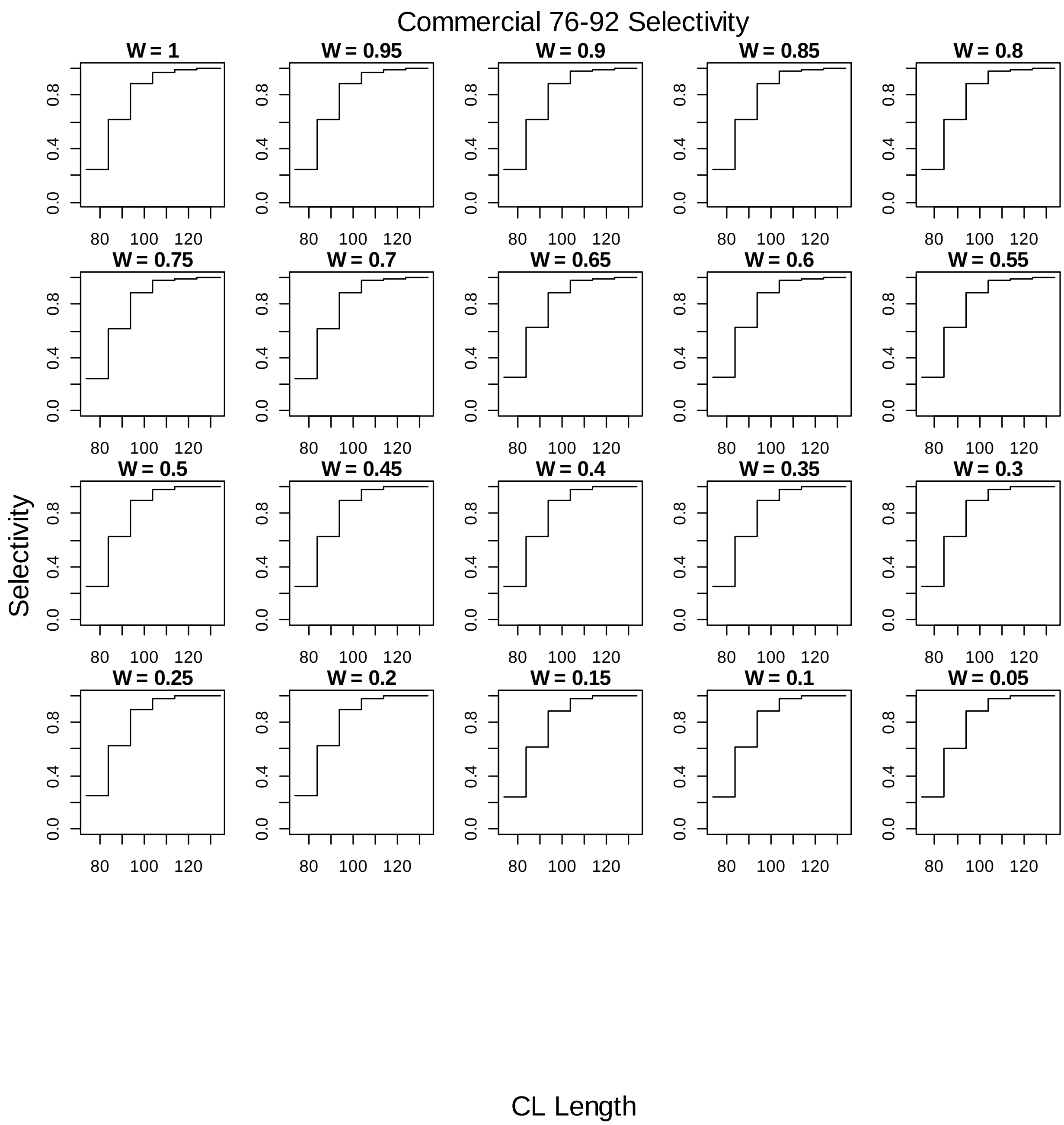


Figure B1-10. Changes of 1976-1992 Commercial Catch selectivity by different weights

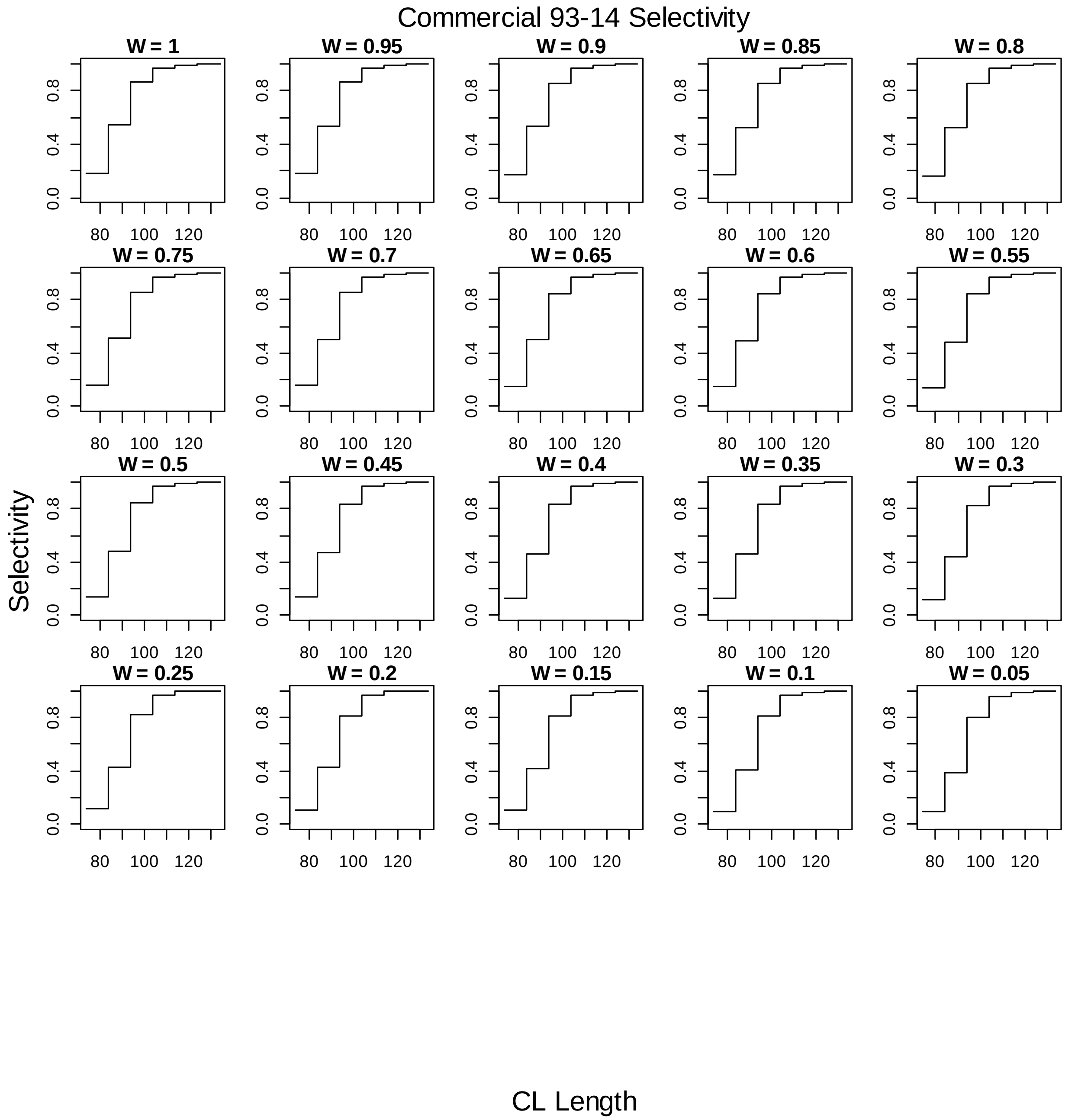


Figure B1-11. Changes of 1993-2014 Commercial Catch selectivity by different weights

Appendix B2: Likelihood profile for M: using model 4

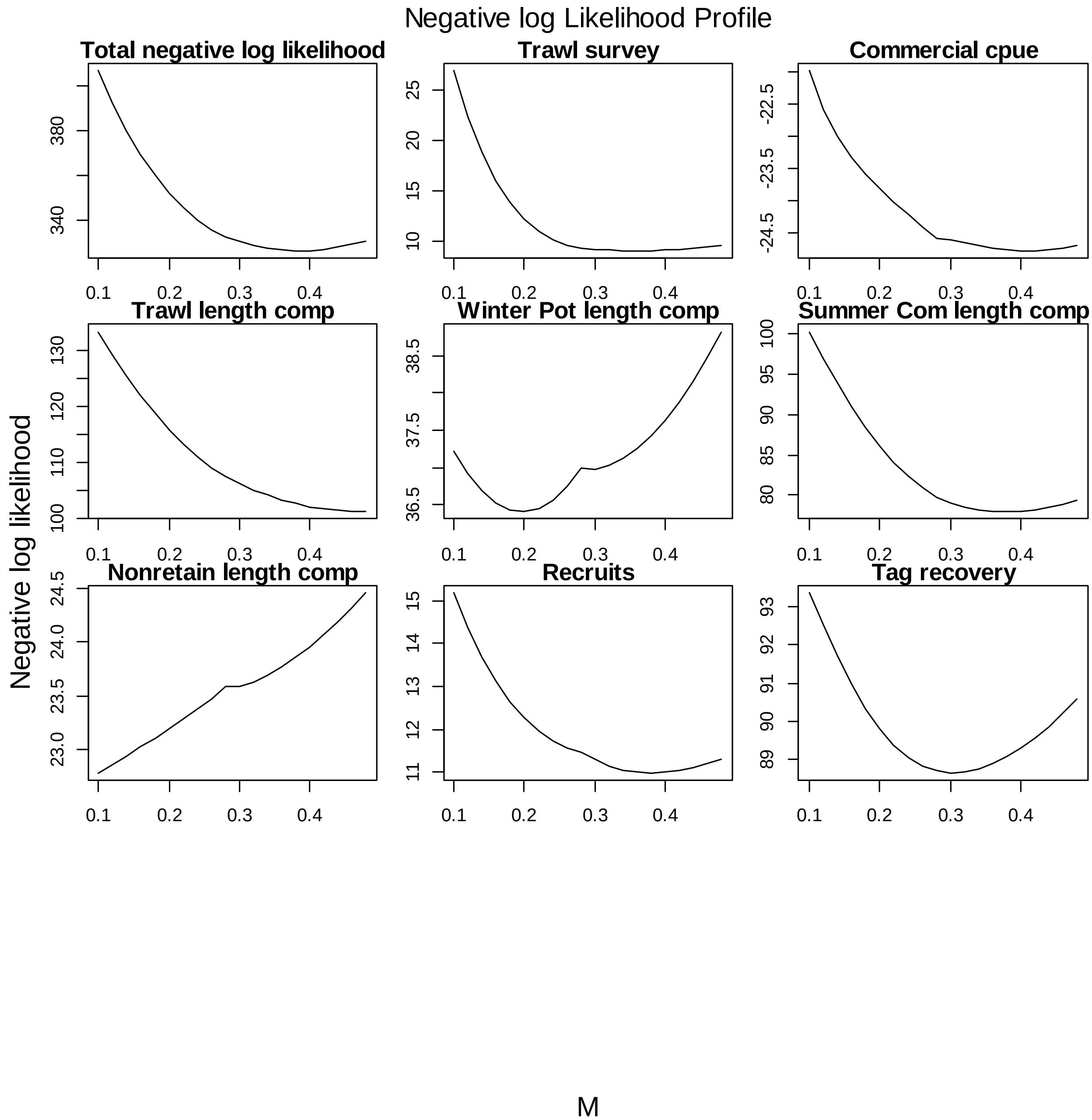


Figure B2-1: Negative log-likelihood

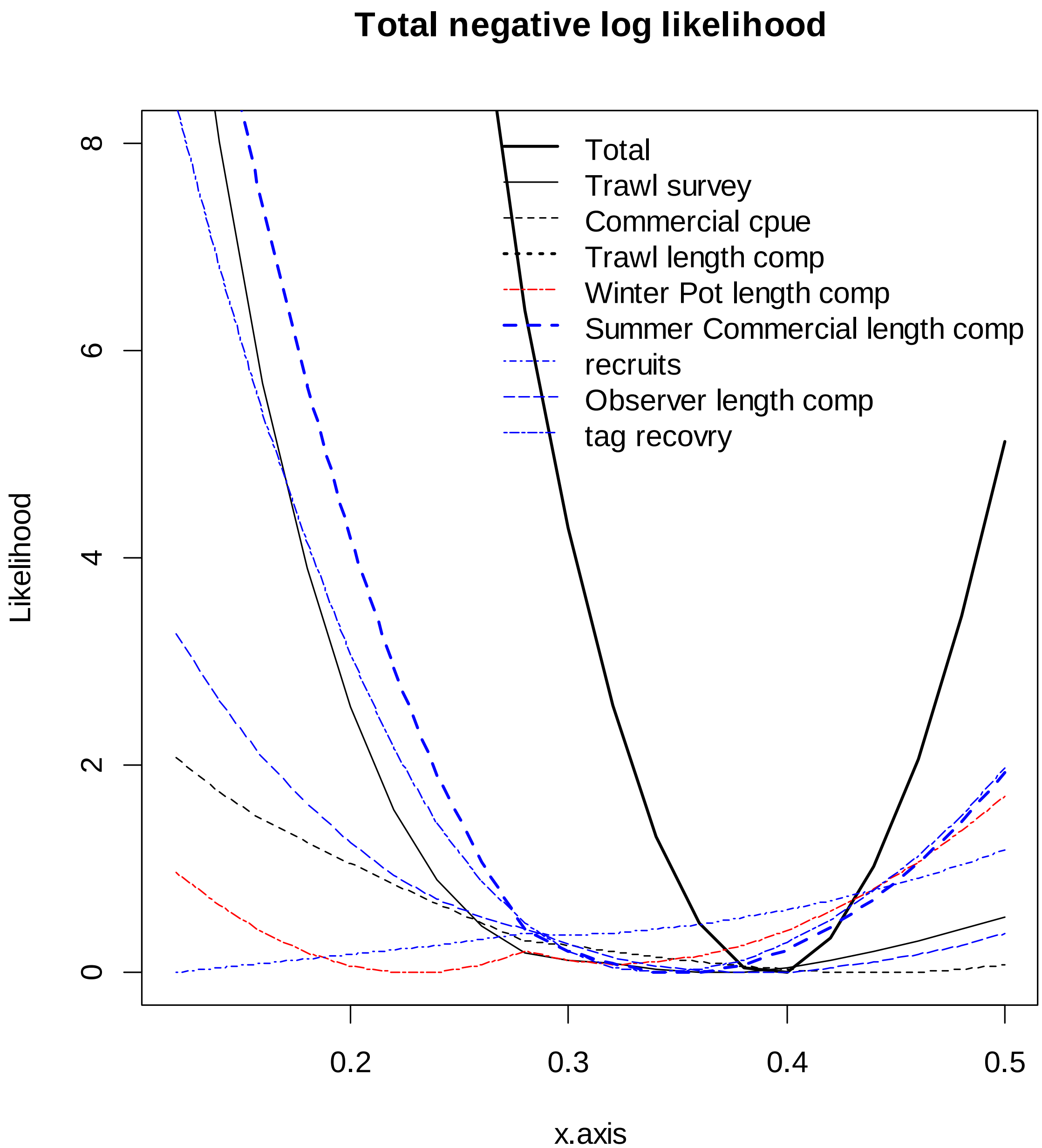


Figure B2-1.1: Negative log-likelihood profile combined

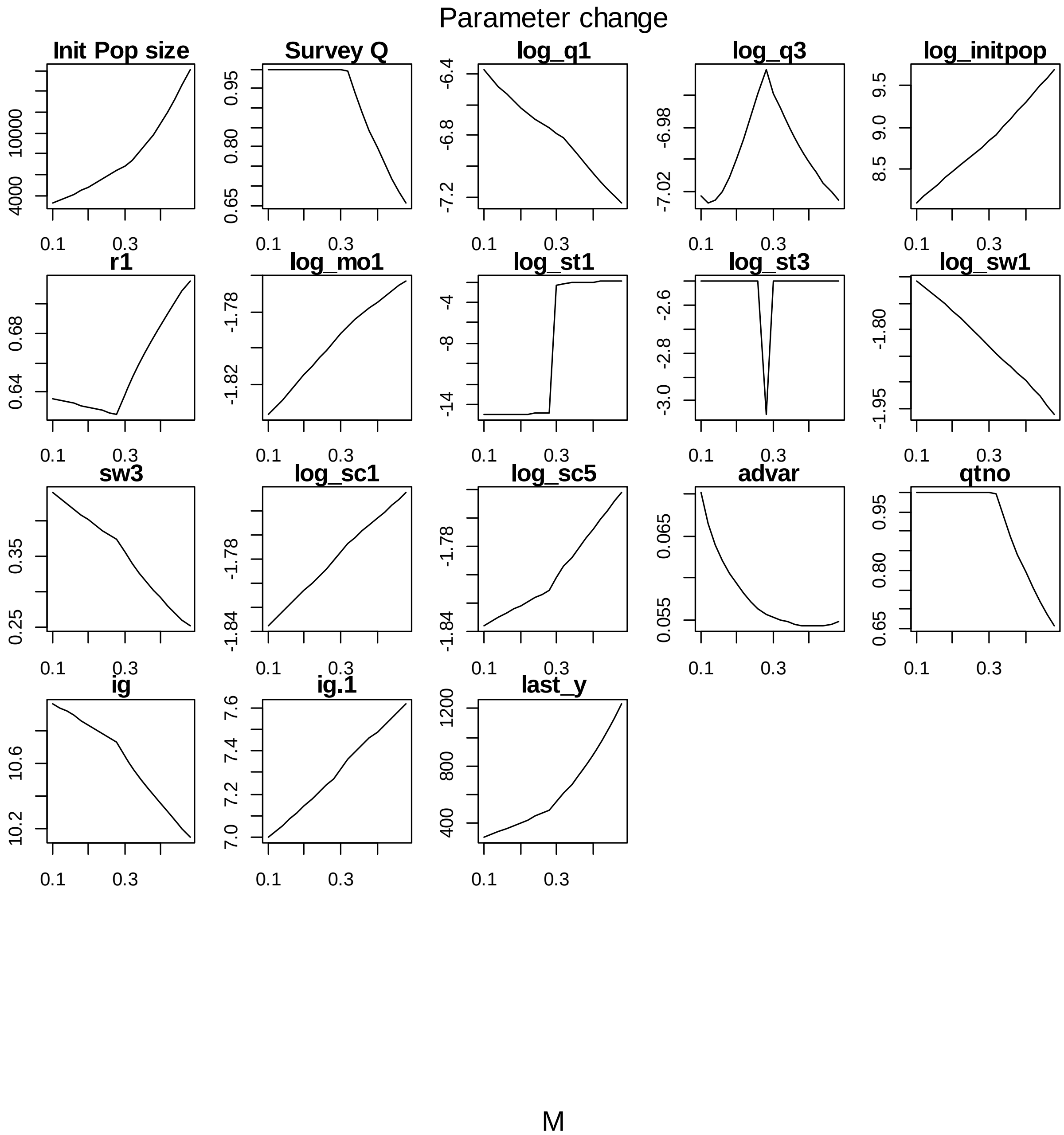


Figure B2-2. Change in Parameter value in different *M*

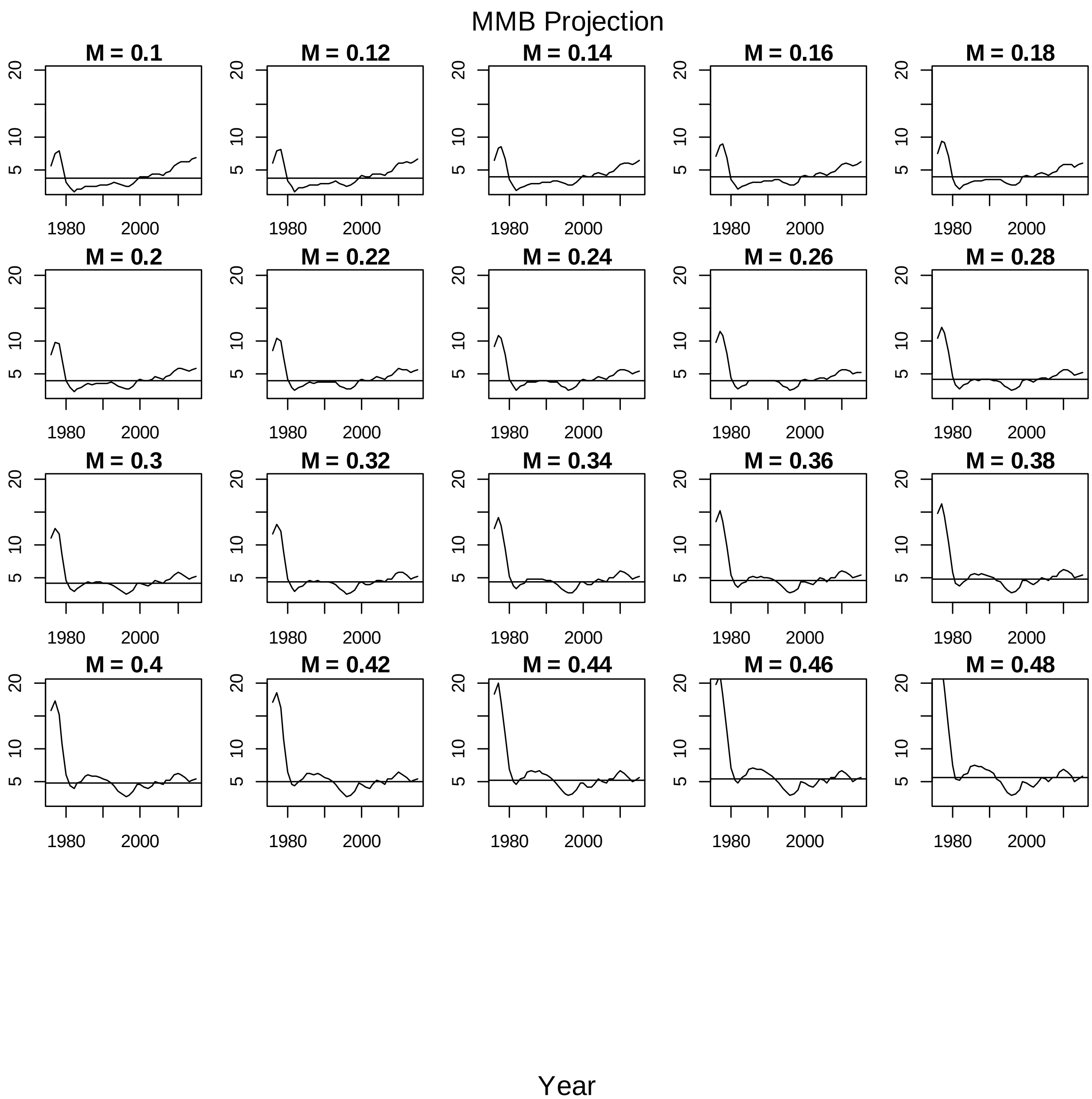


Figure B2-3. Change of MMB projection in different *M*

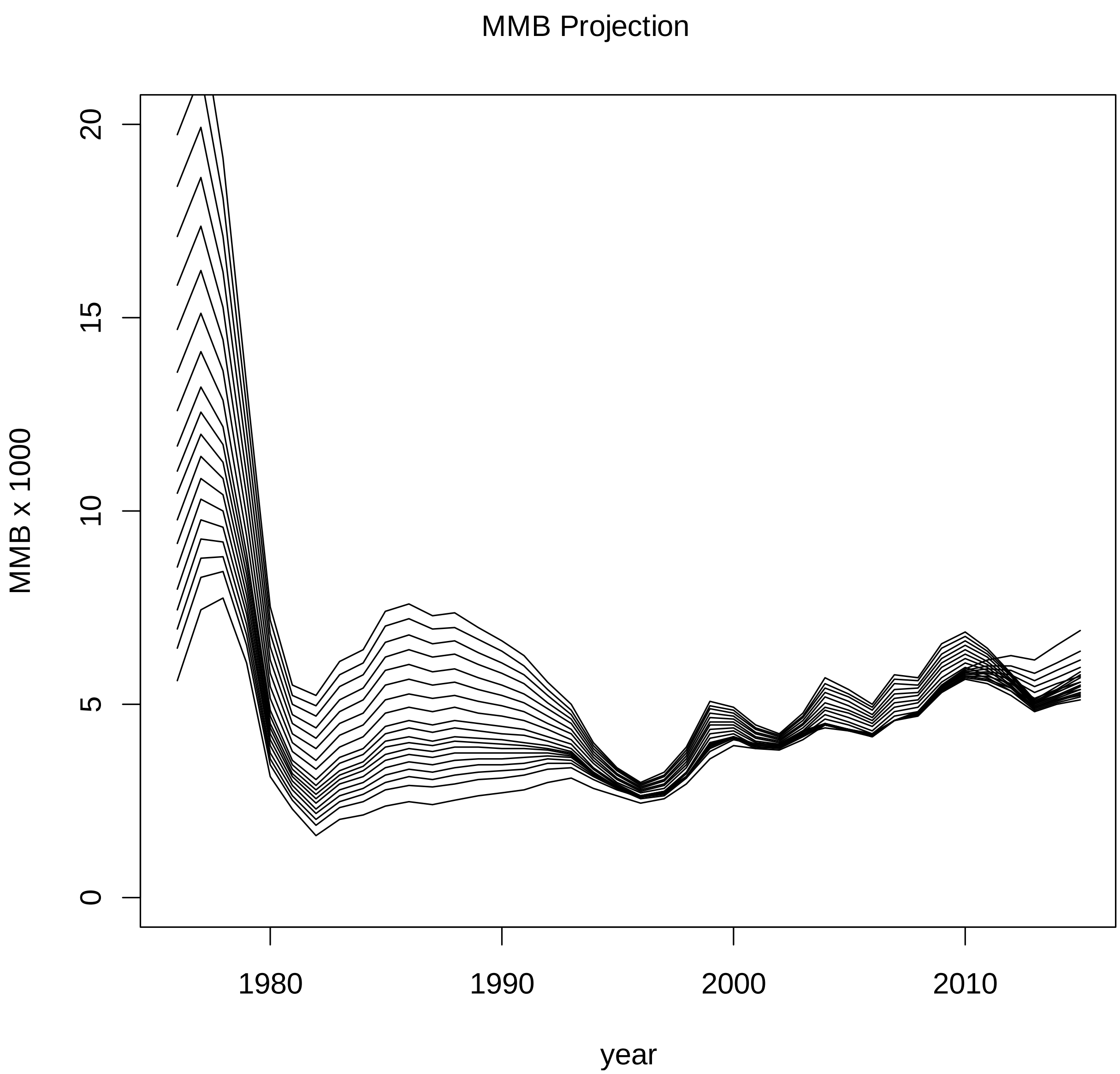


Figure B2-4. Change of MMB projection in different *M* combined

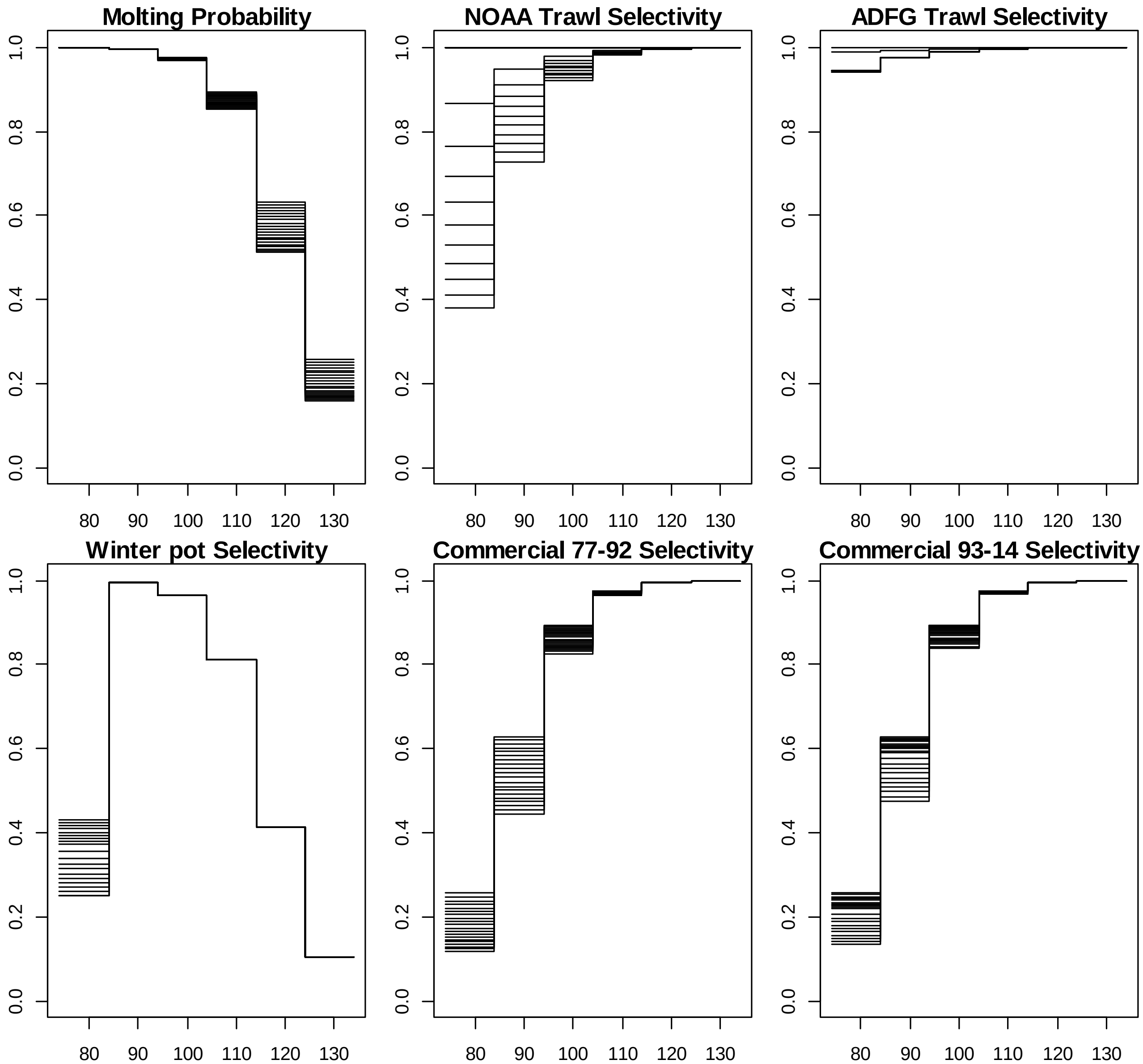


Figure B2-5. Change of selectivities and molting probability in different *M* (combined)

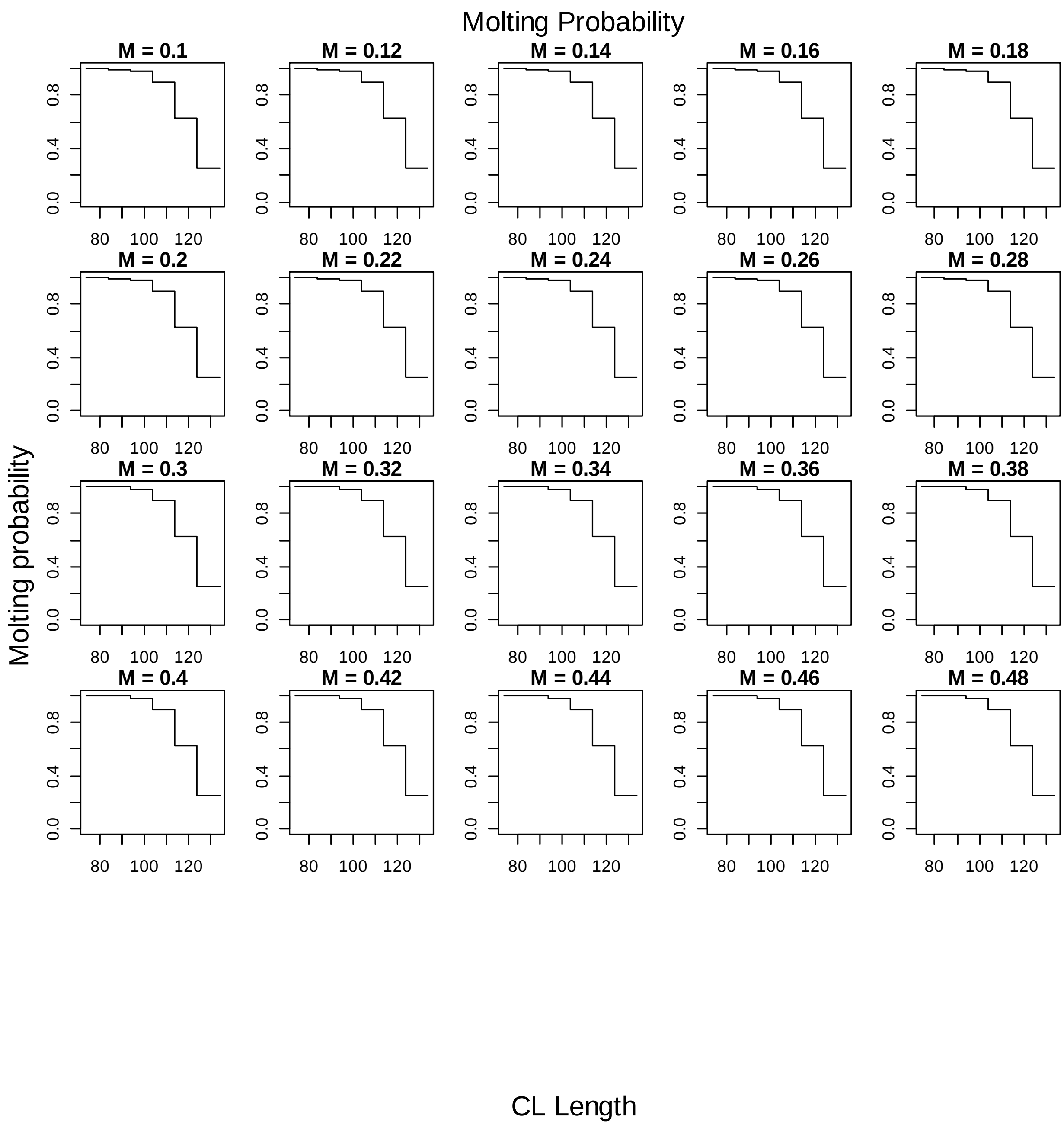


Figure B2-6. Change of molting probability in different *M*

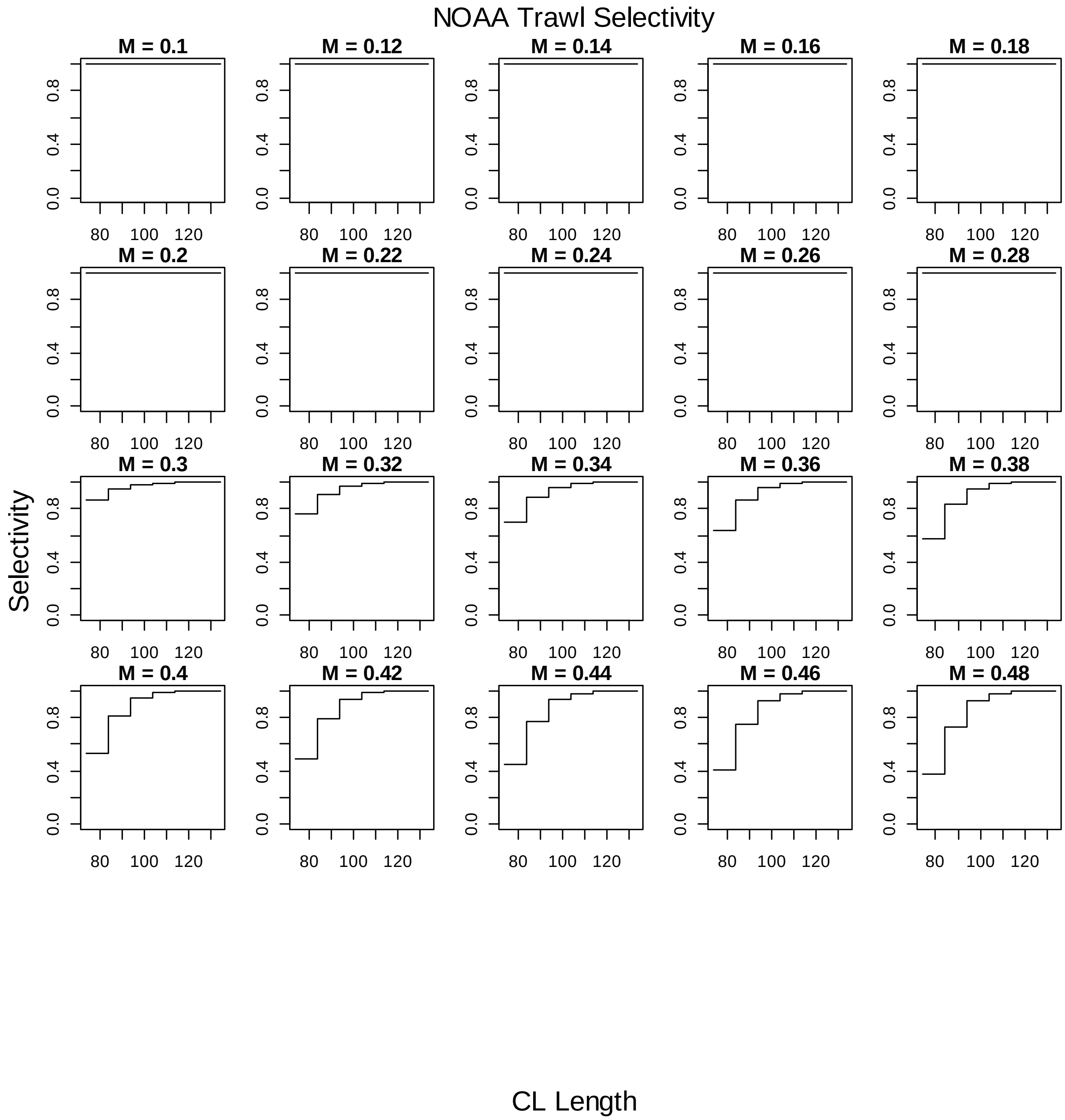


Figure B2-7. Change of NMFS trawl survey selectivity in different *M*

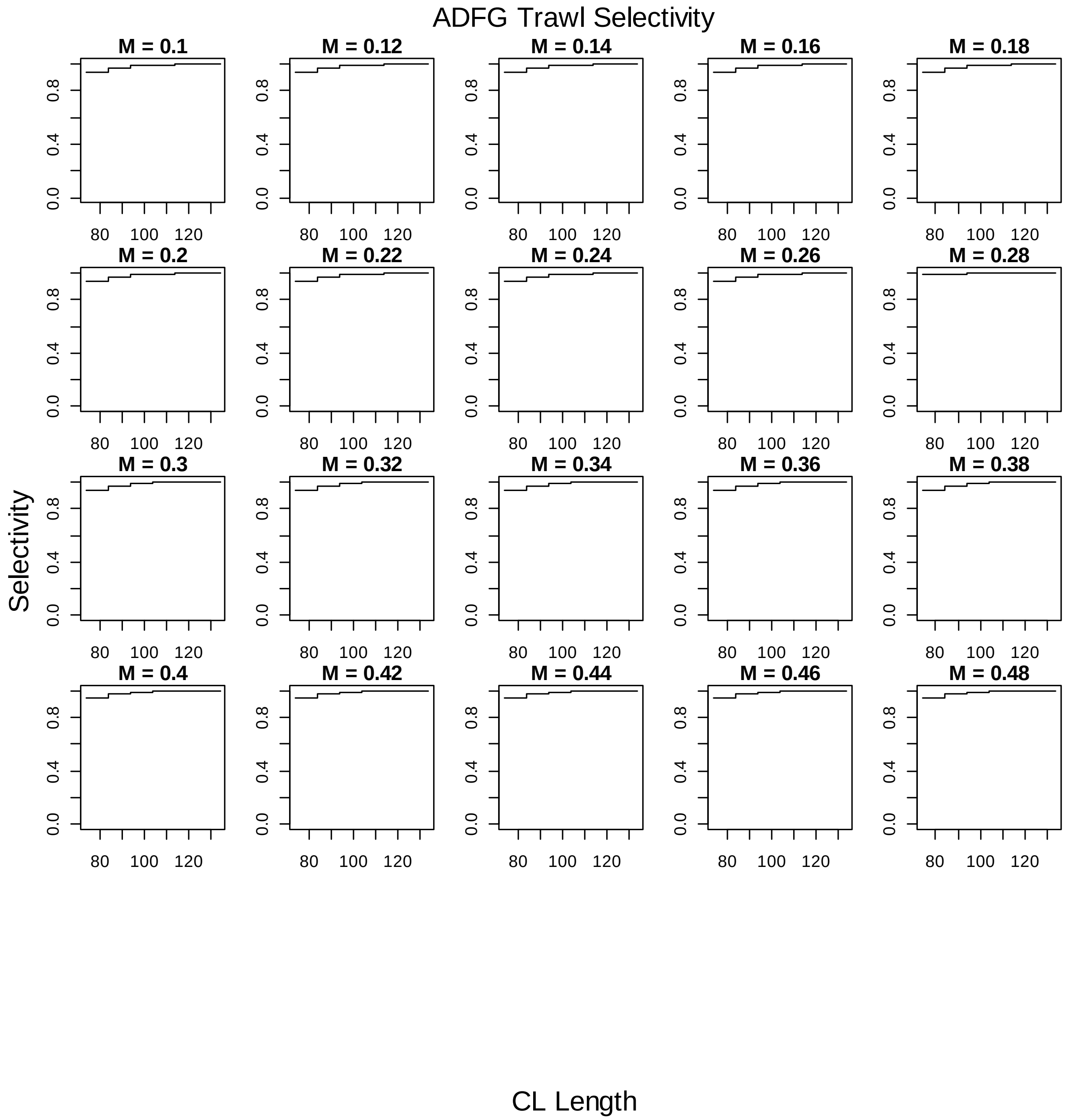


Figure B2-8: Change of ADF&G trawl survey selectivity in different *M*

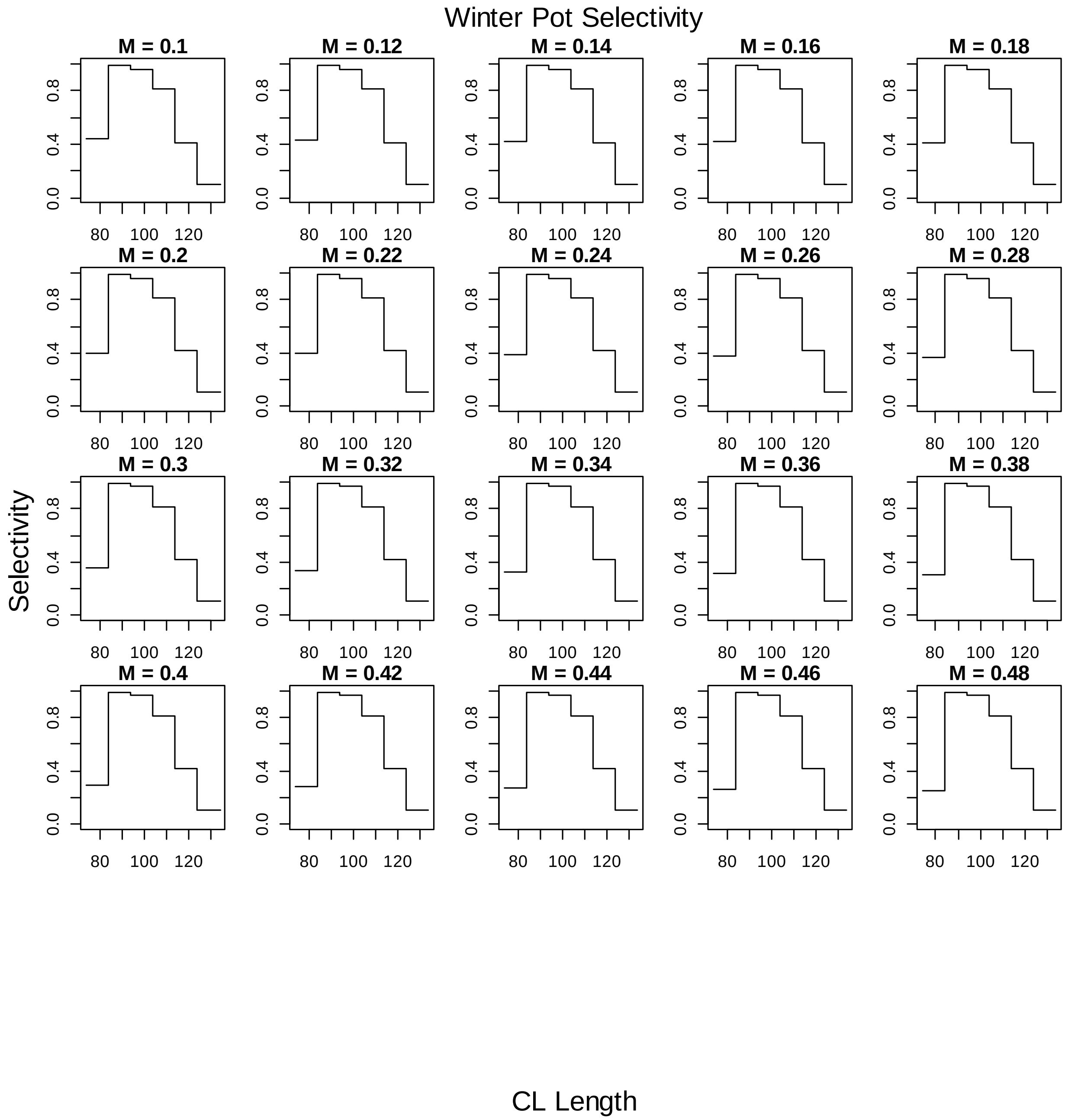


Figure B2-9: Change of Winter pot survey selectivity in different *M*

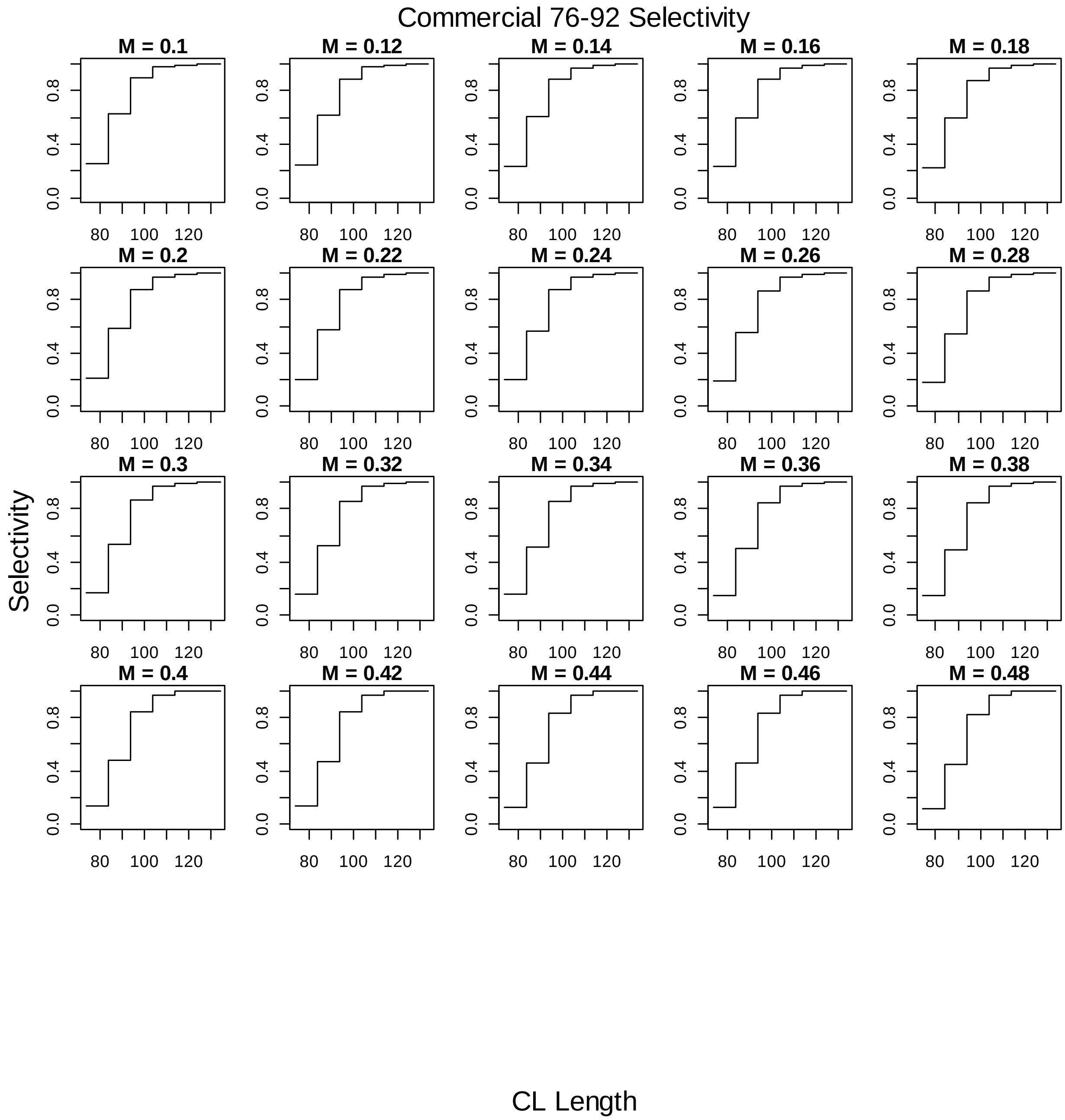


Figure B2-10: Change of 1977-92 commercial catch selectivity in different *M*

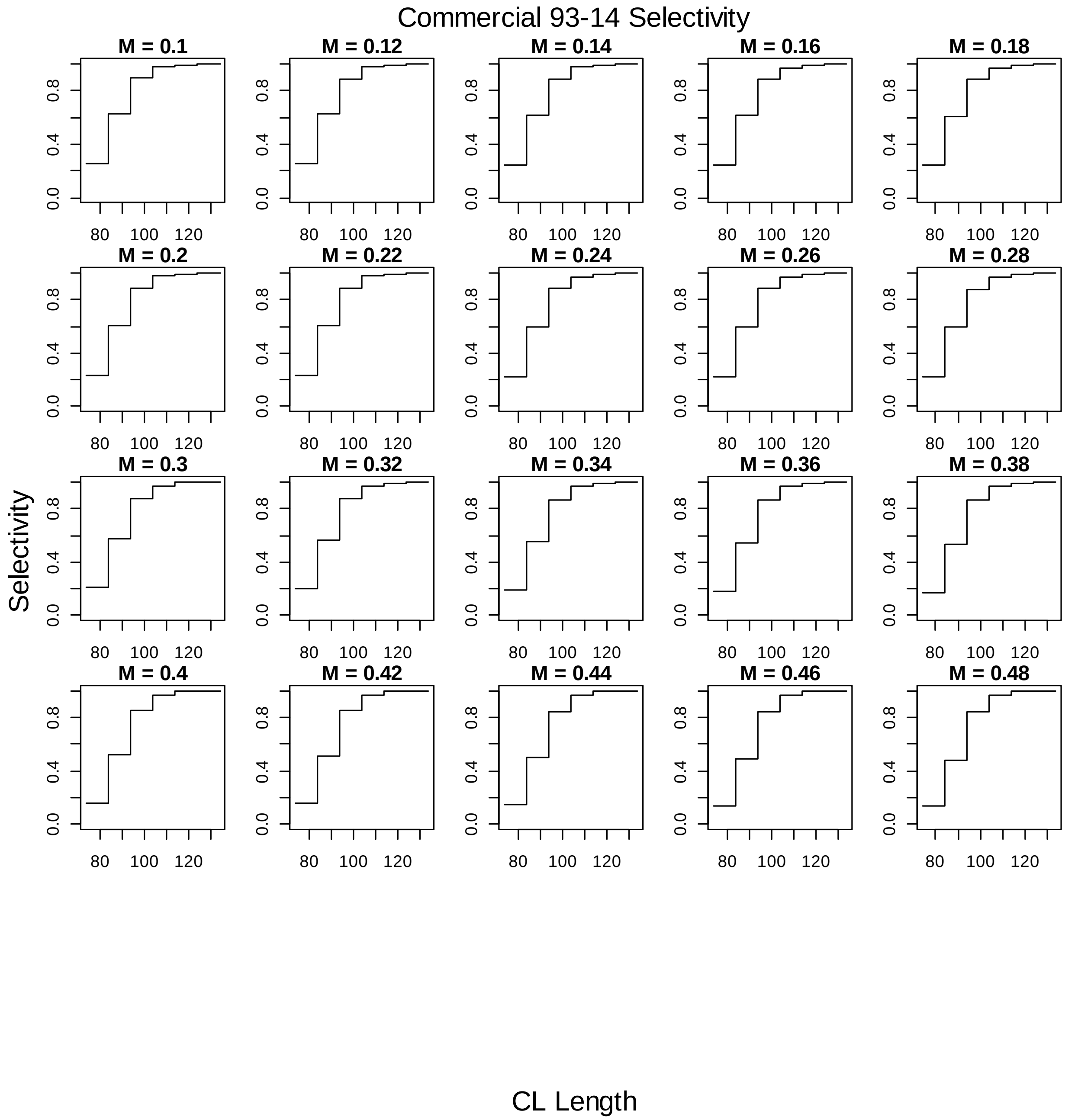


Figure B2-11: Change of 1993-2014 commercial catch selectivity in different *M*

Appendix C1: Results Model 1

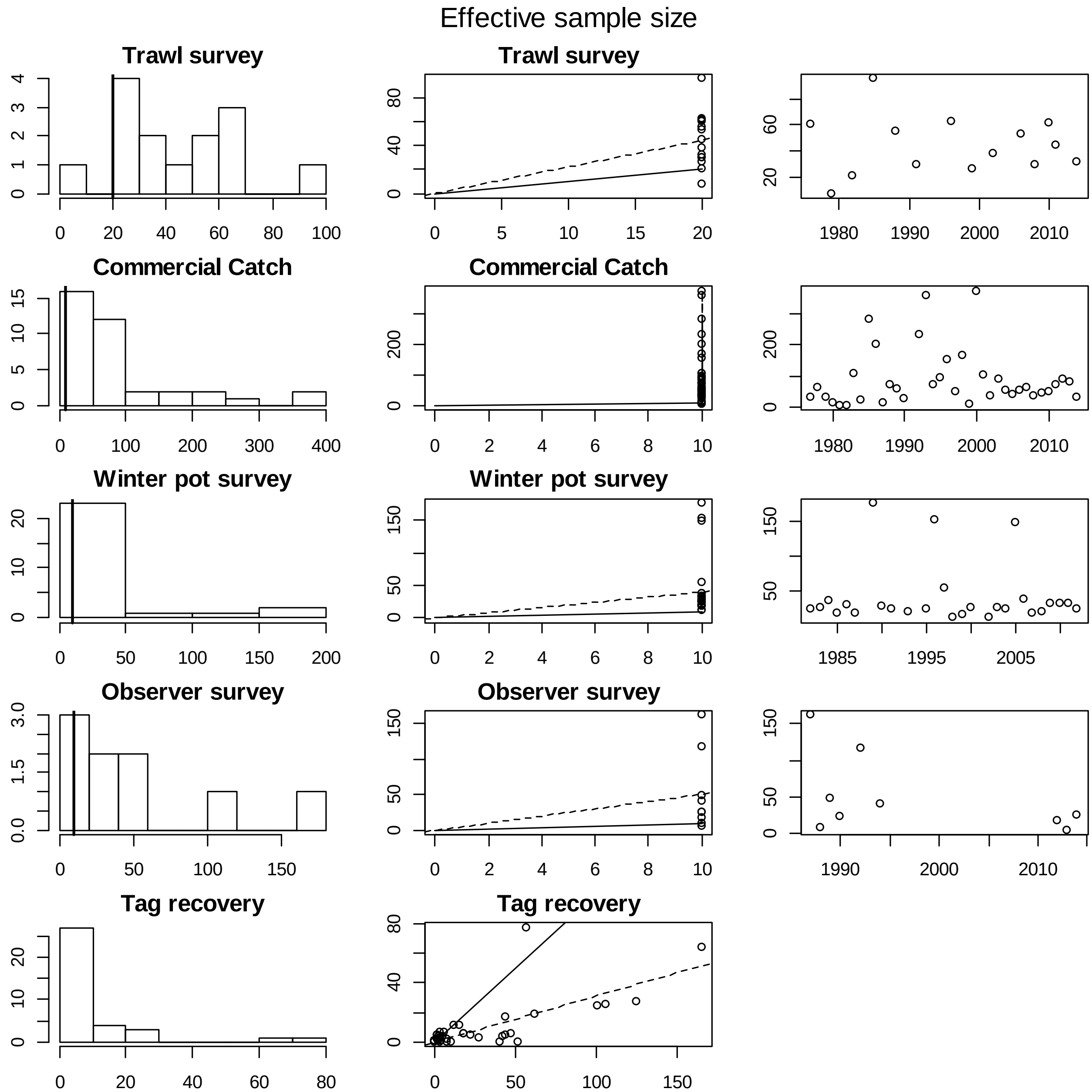


Figure C1-1: Effective sample size vs. implied sample size. Figures in the first column show effective sample size (x-axis) vs. frequency (y-axis). Vertical solid line is the implied sample size. Figures in the second column show implied sample size (x-axis) vs. effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. Figures in the third column show year (x-axis) vs. effective sample size (y-axis).

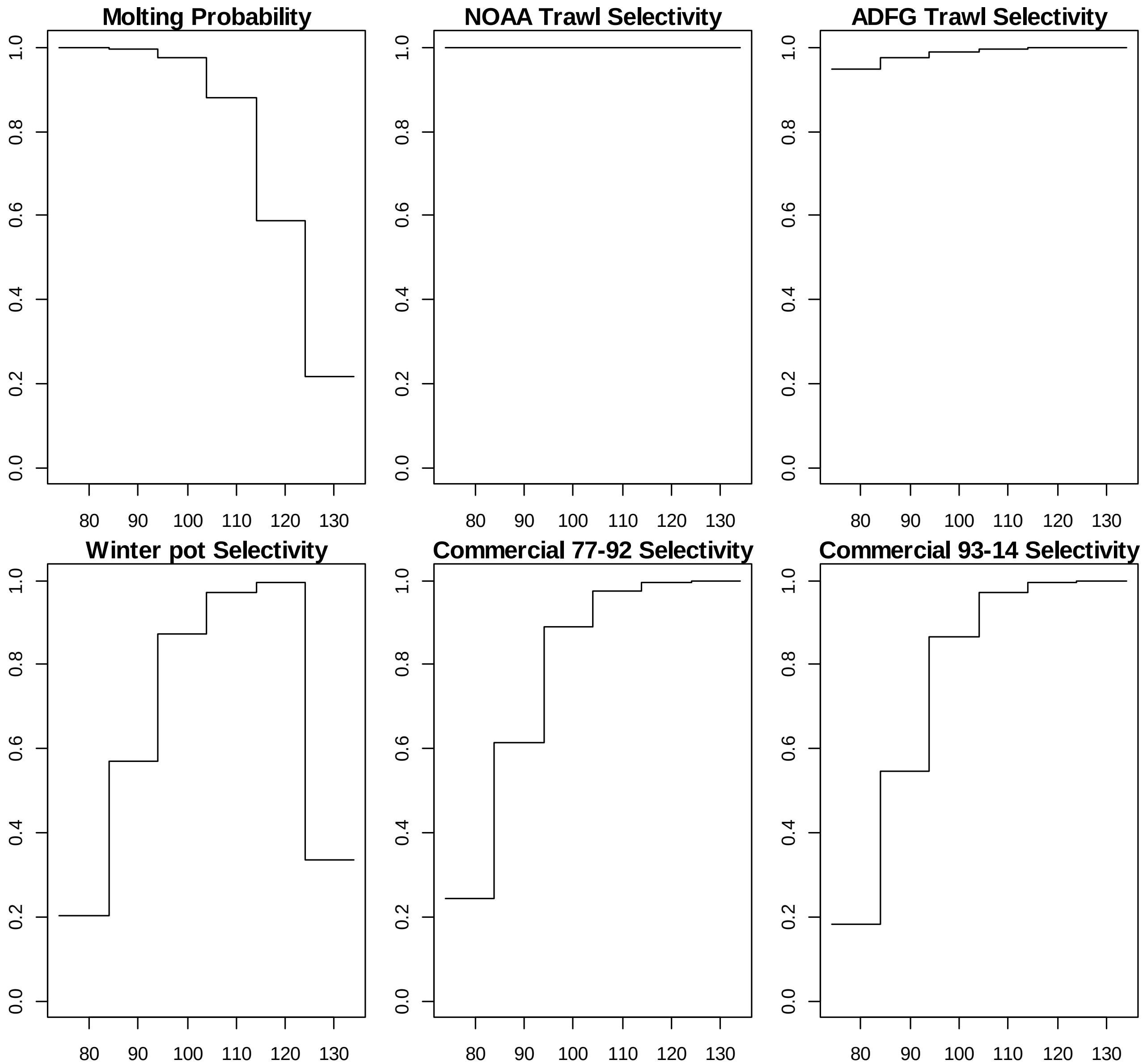


Figure C1-2. Molting probability and trawl/pot selectivities. X-axis is carapace length.

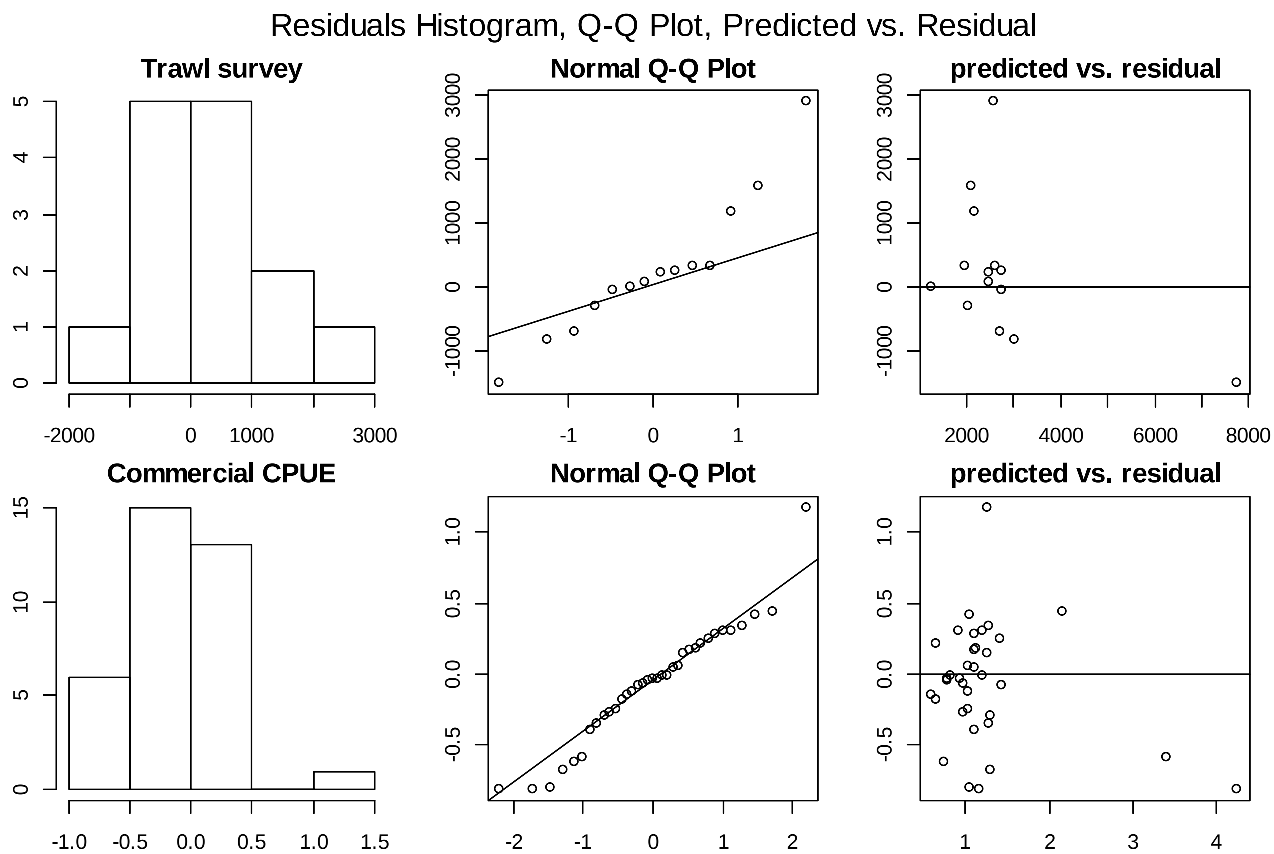


Figure C1-3. QQ Plot of Trawl survey and Commercial CPUE.

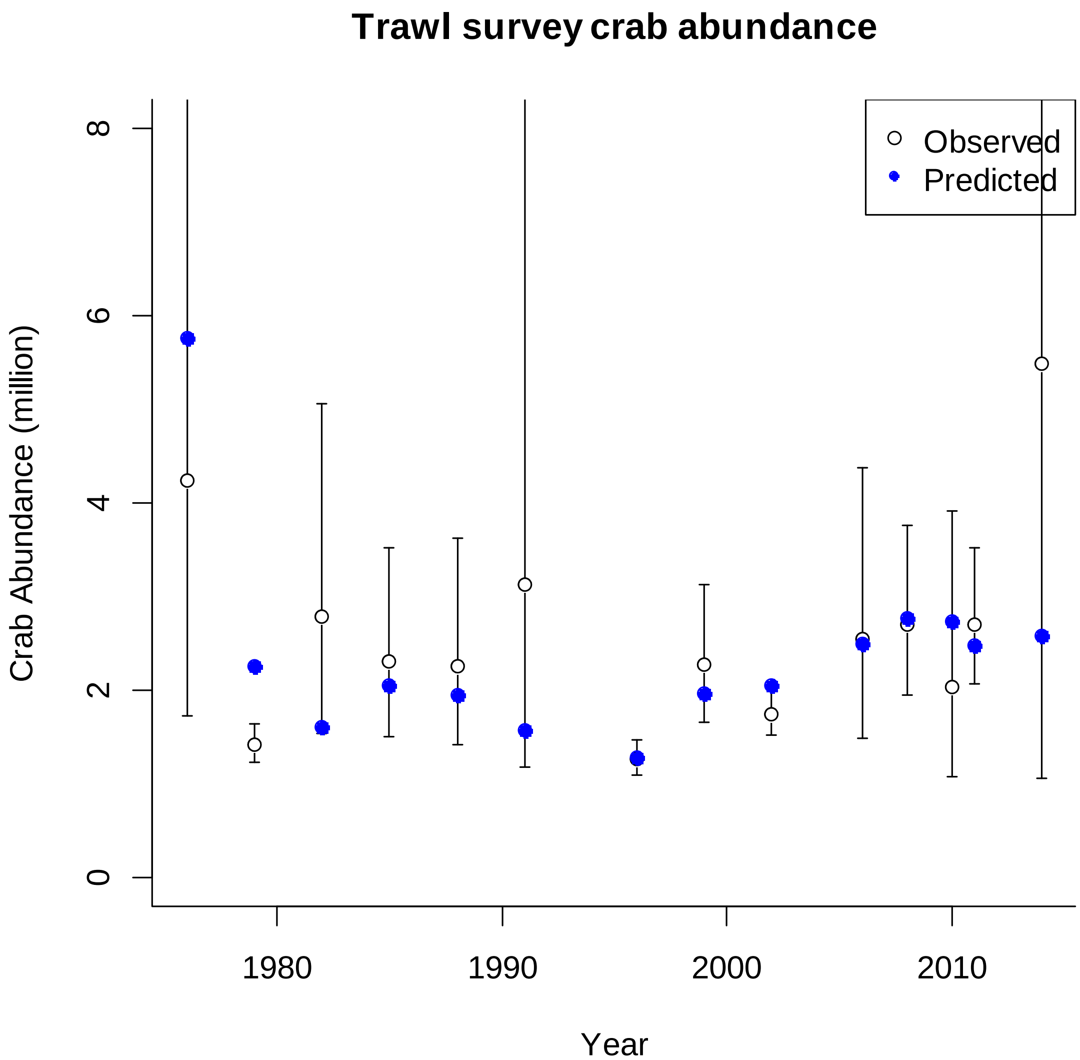


Figure C1-4. Estimated trawl survey male abundance (crab ≥ 74 mm CL).

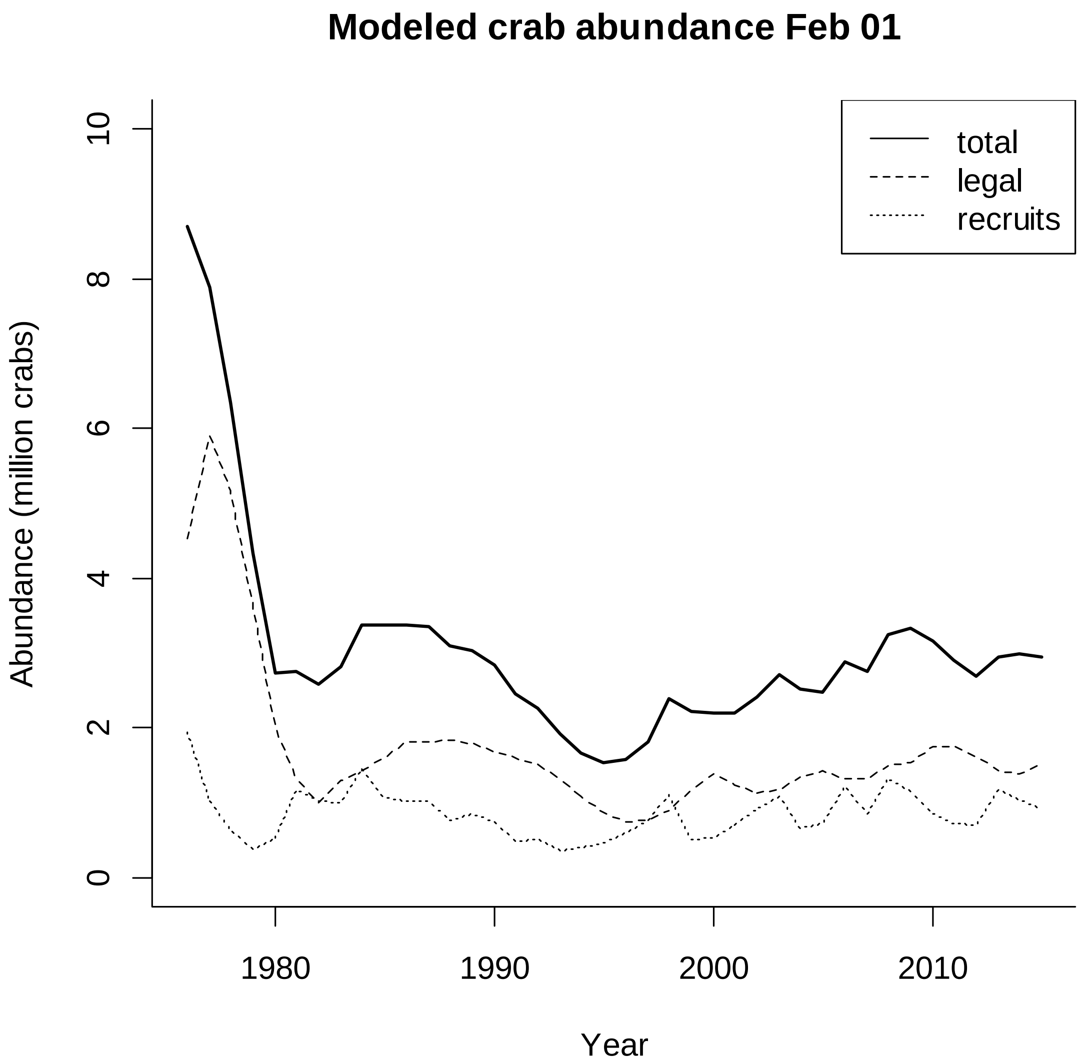


Figure C1-5. Estimated abundance of legal males from 1976-2014.

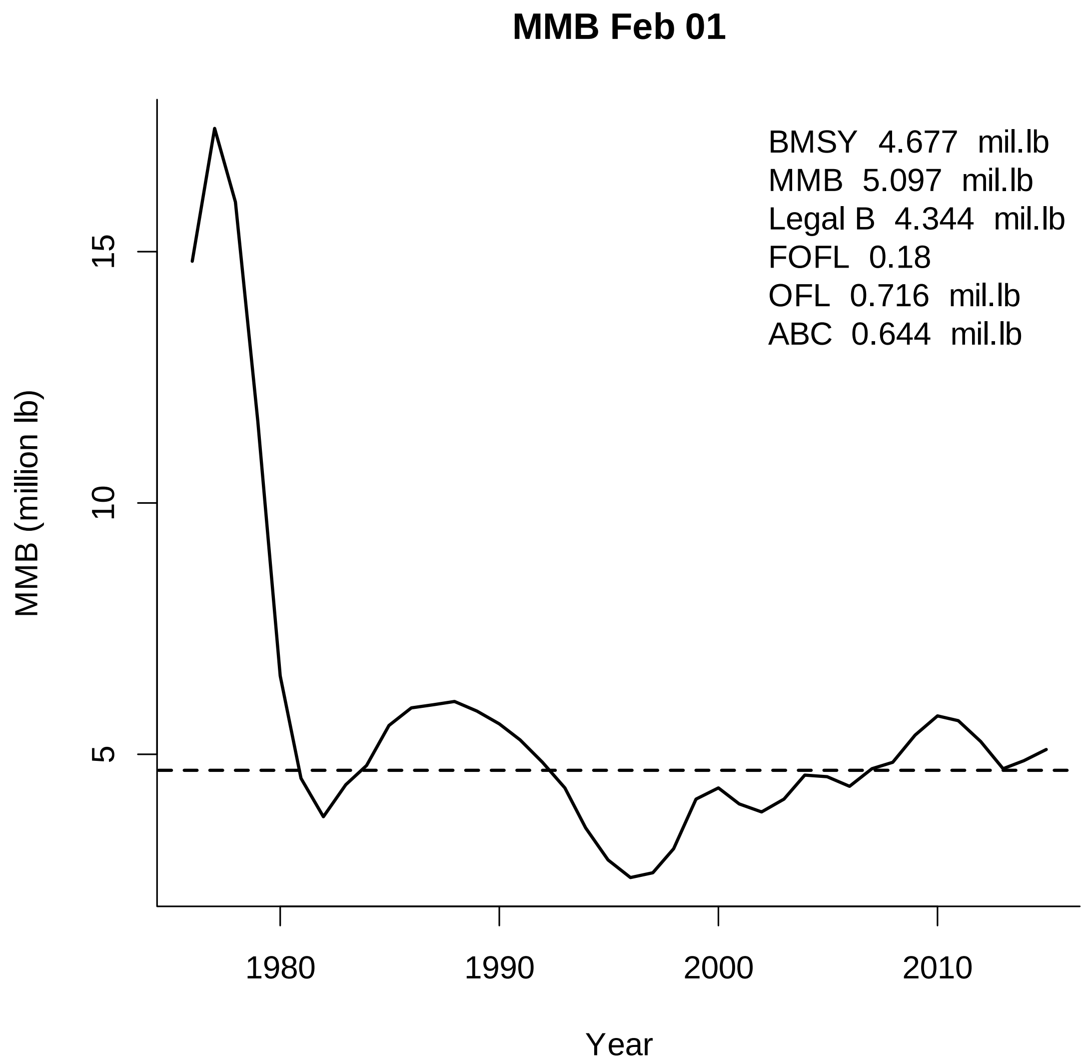


Figure C1-6. Estimated abundance of leg recruits from 1976-2015. Dash line shows Bmsy (Average MMB of 1980-2015).

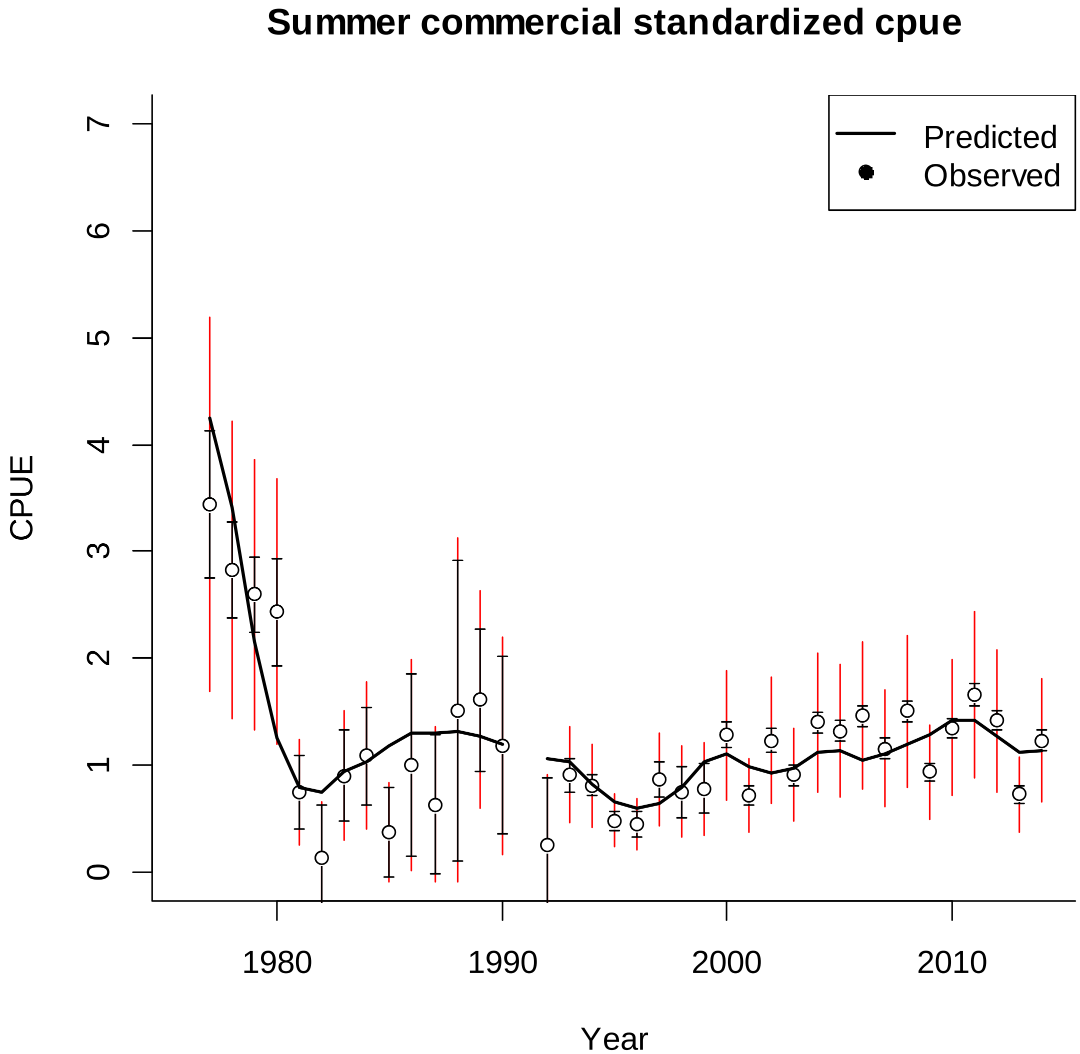


Figure C1-7. Summer commercial standardized cpue (1977-2014).

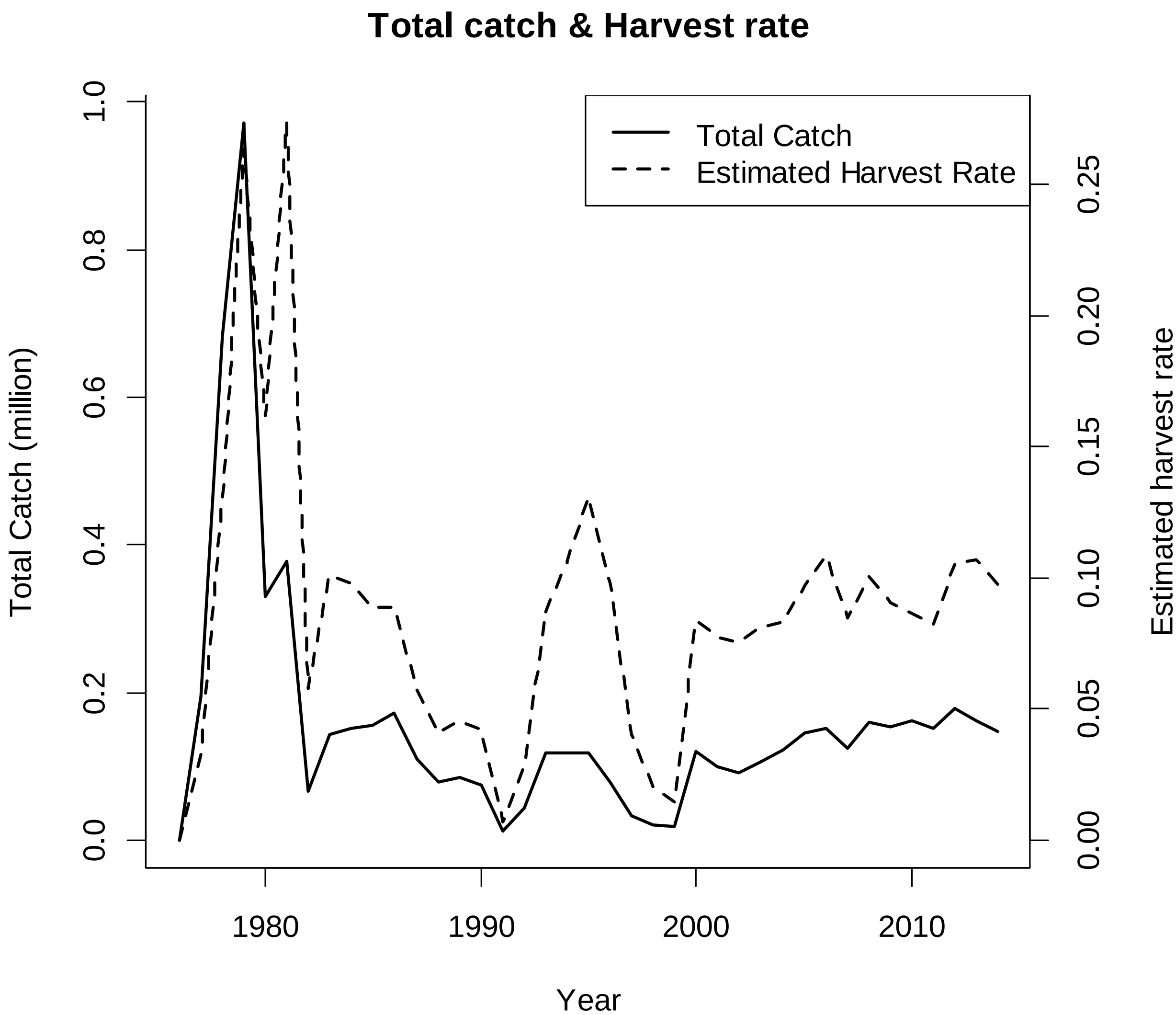


Figure C1-8. Total catch and estimated harvest rate 1976-2014.

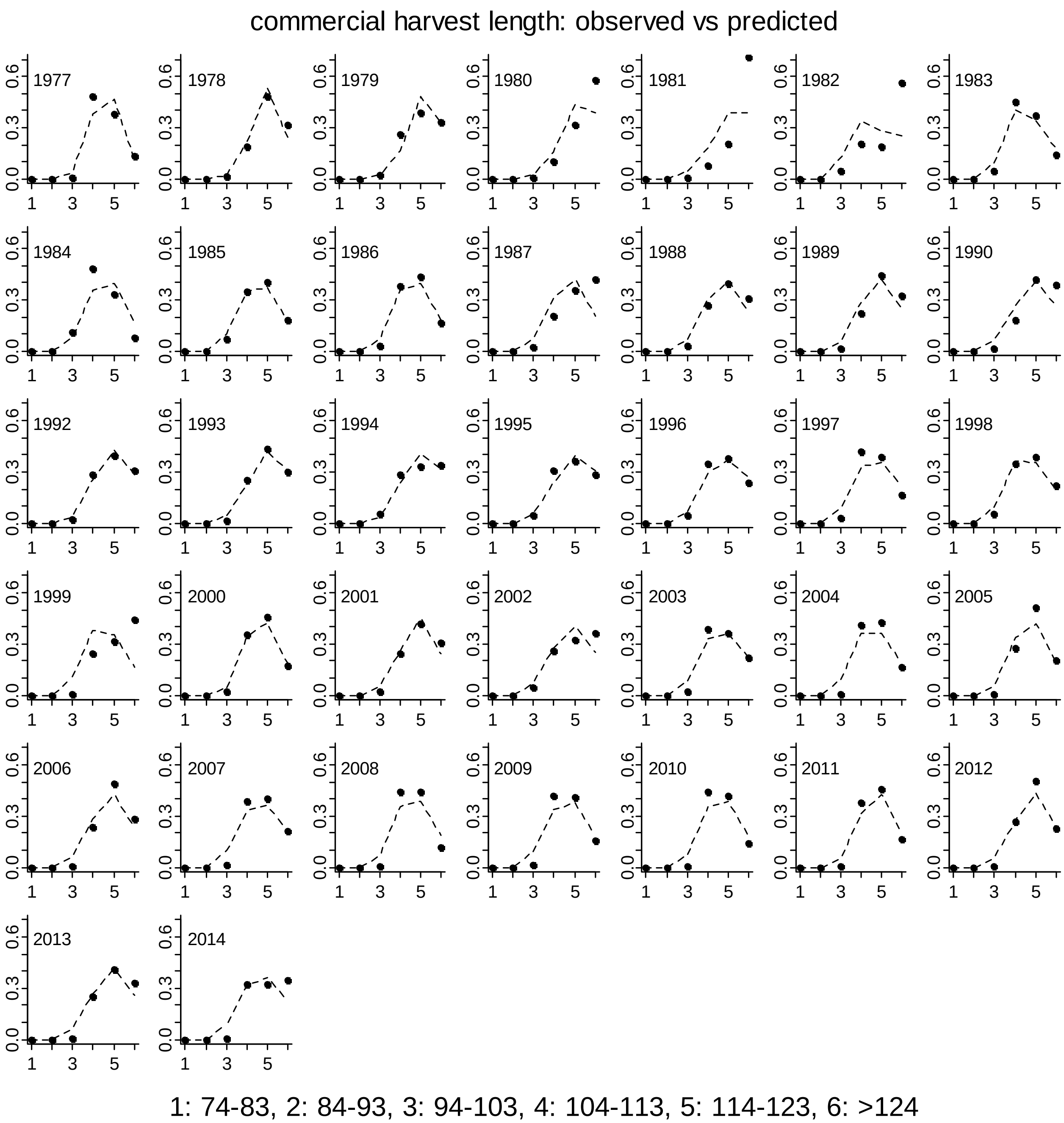
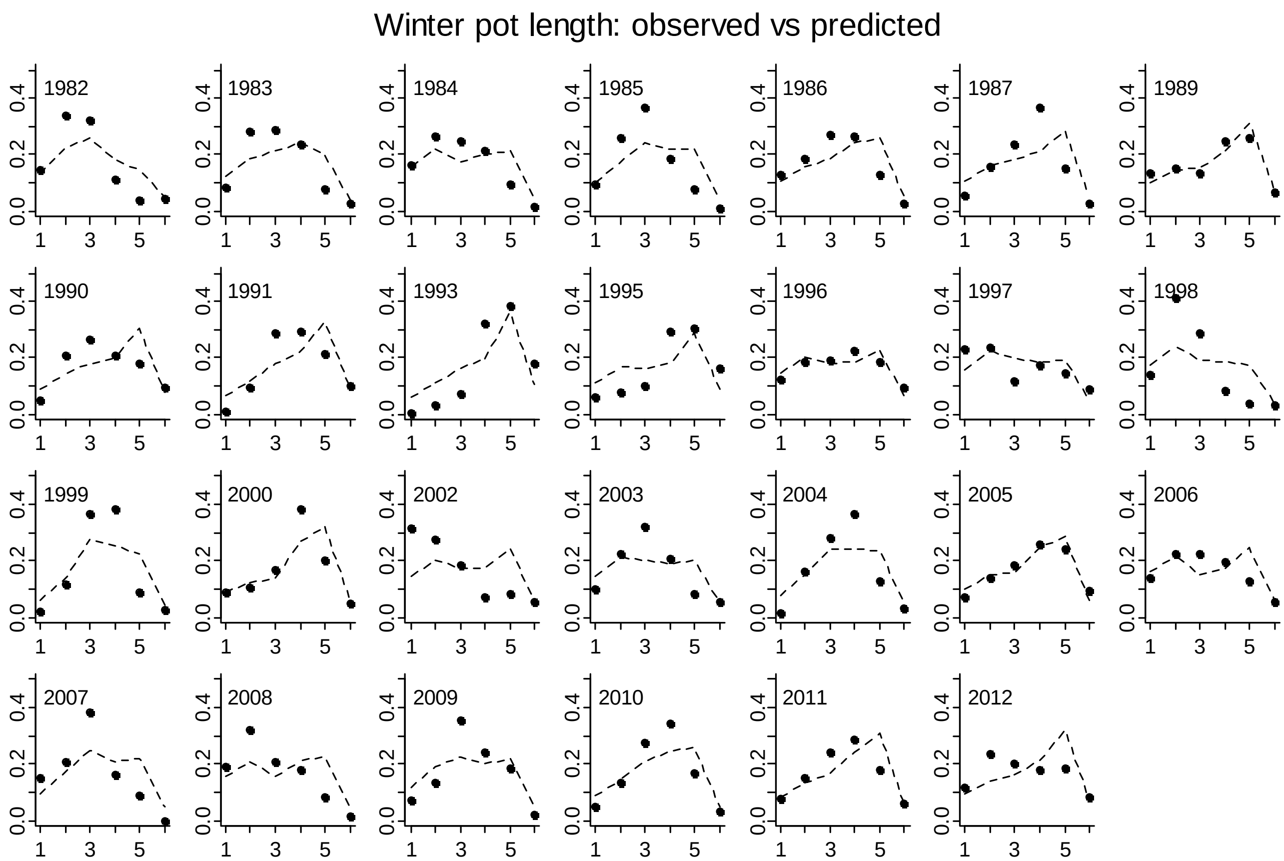
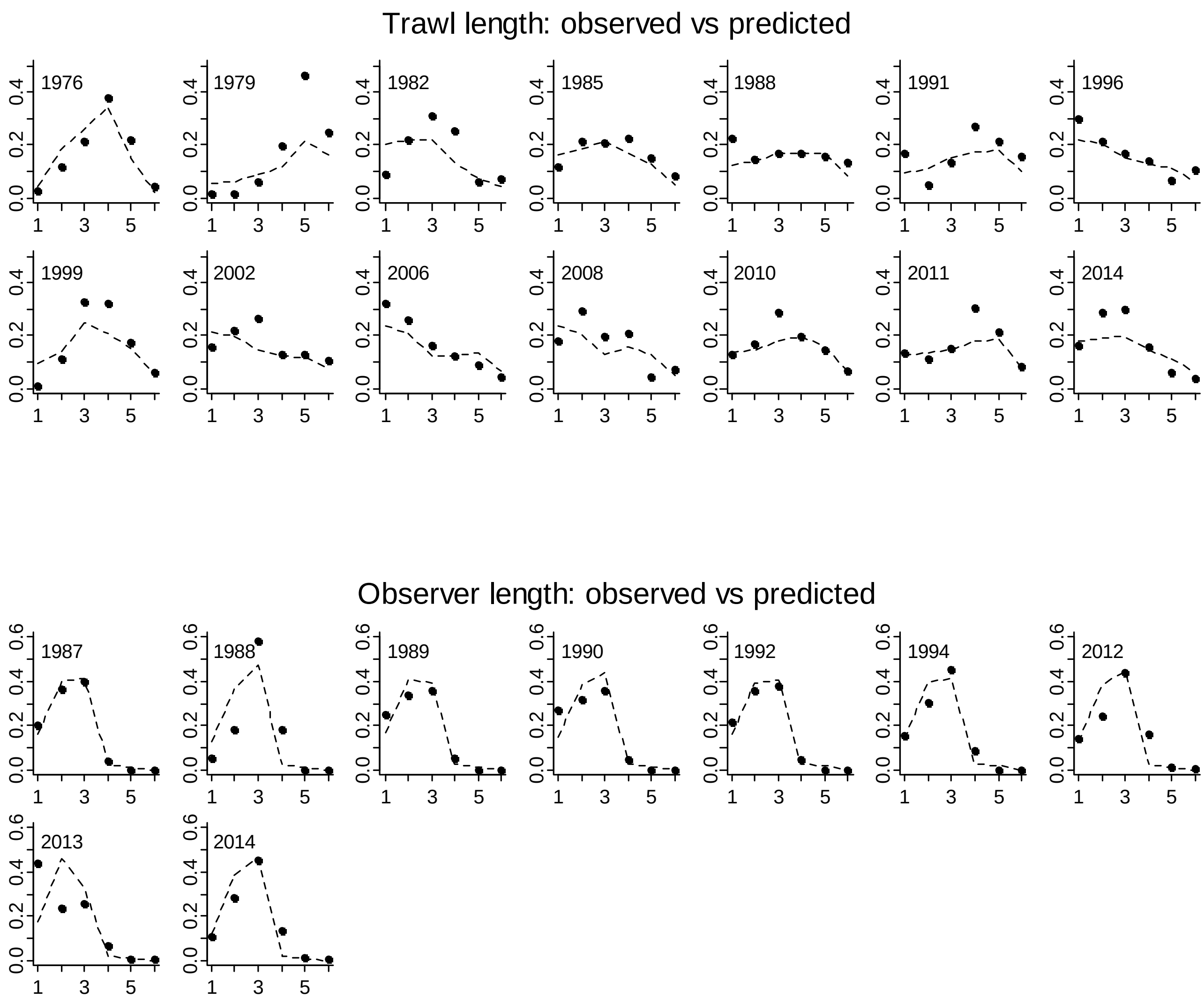


Figure C1-9. Predicted (dashed line) vs. observed (black dots) length class proportions for commercial catch.



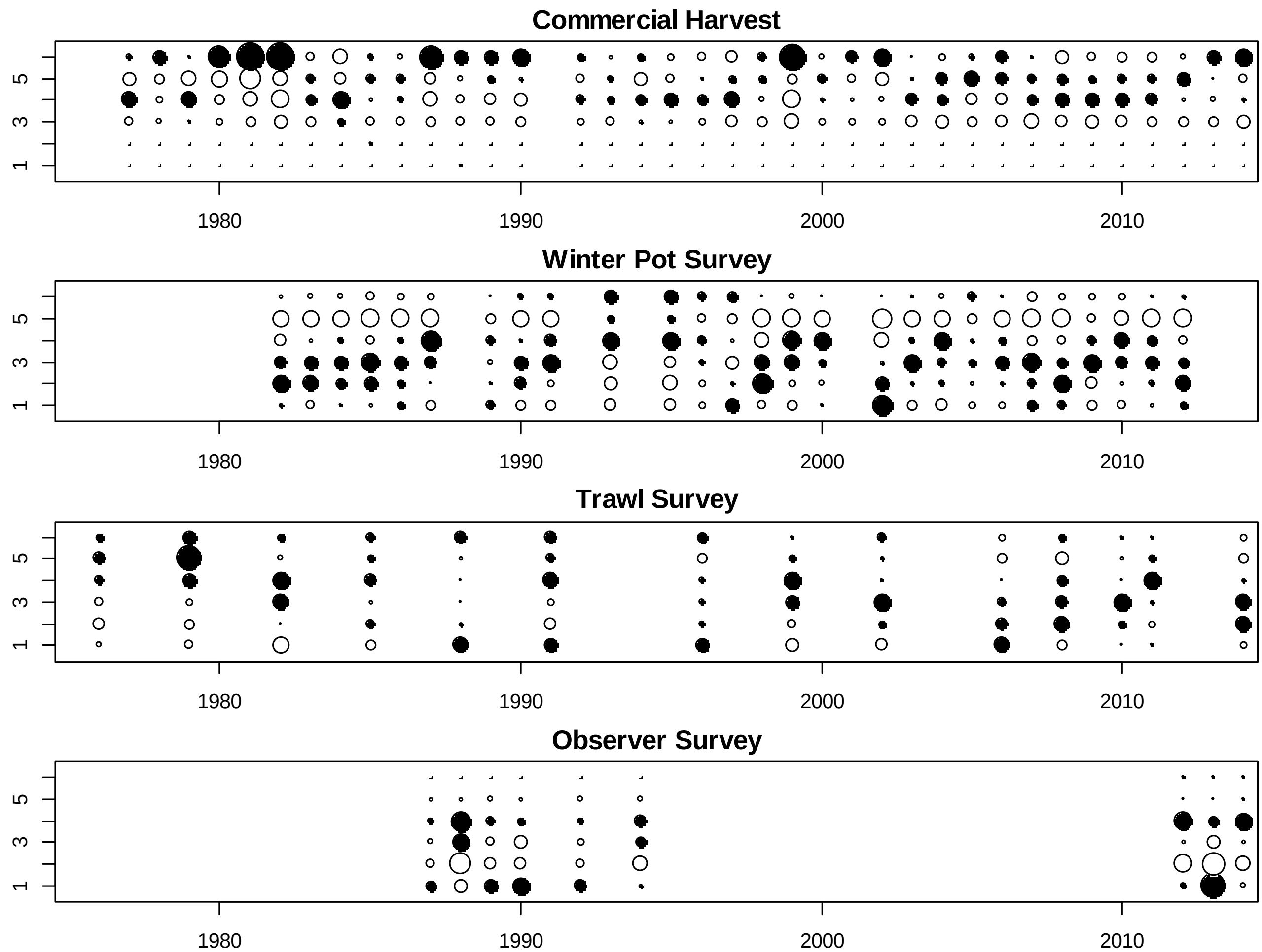
1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C1-10. Predicted (dashed line) vs. observed (black dots) length class proportions for the winter pot survey.



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C1-11. Predicted (dashed line) vs. observed (black dots) length class proportions for the trawl survey and observer survey.



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C1-12. 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).

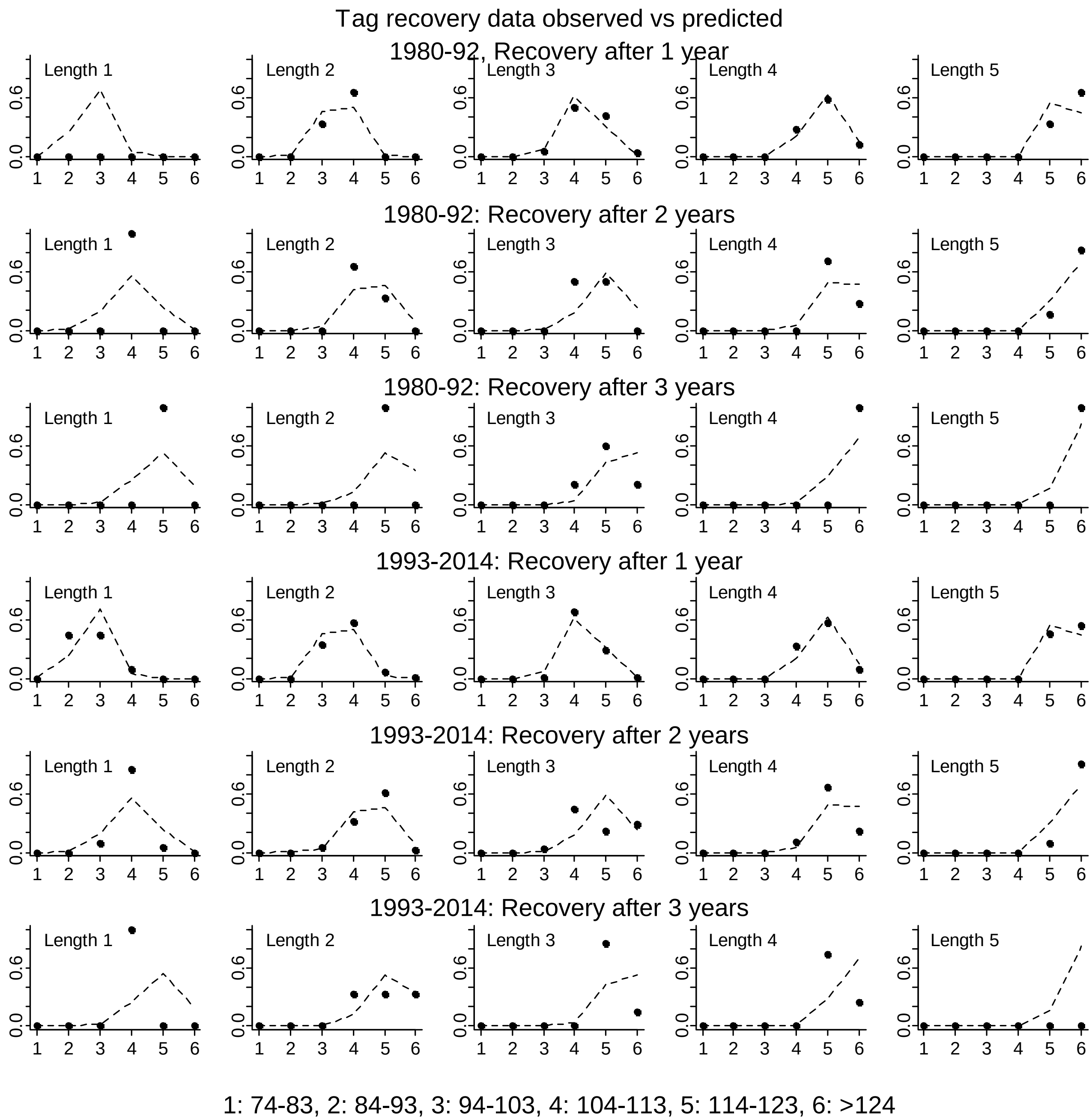
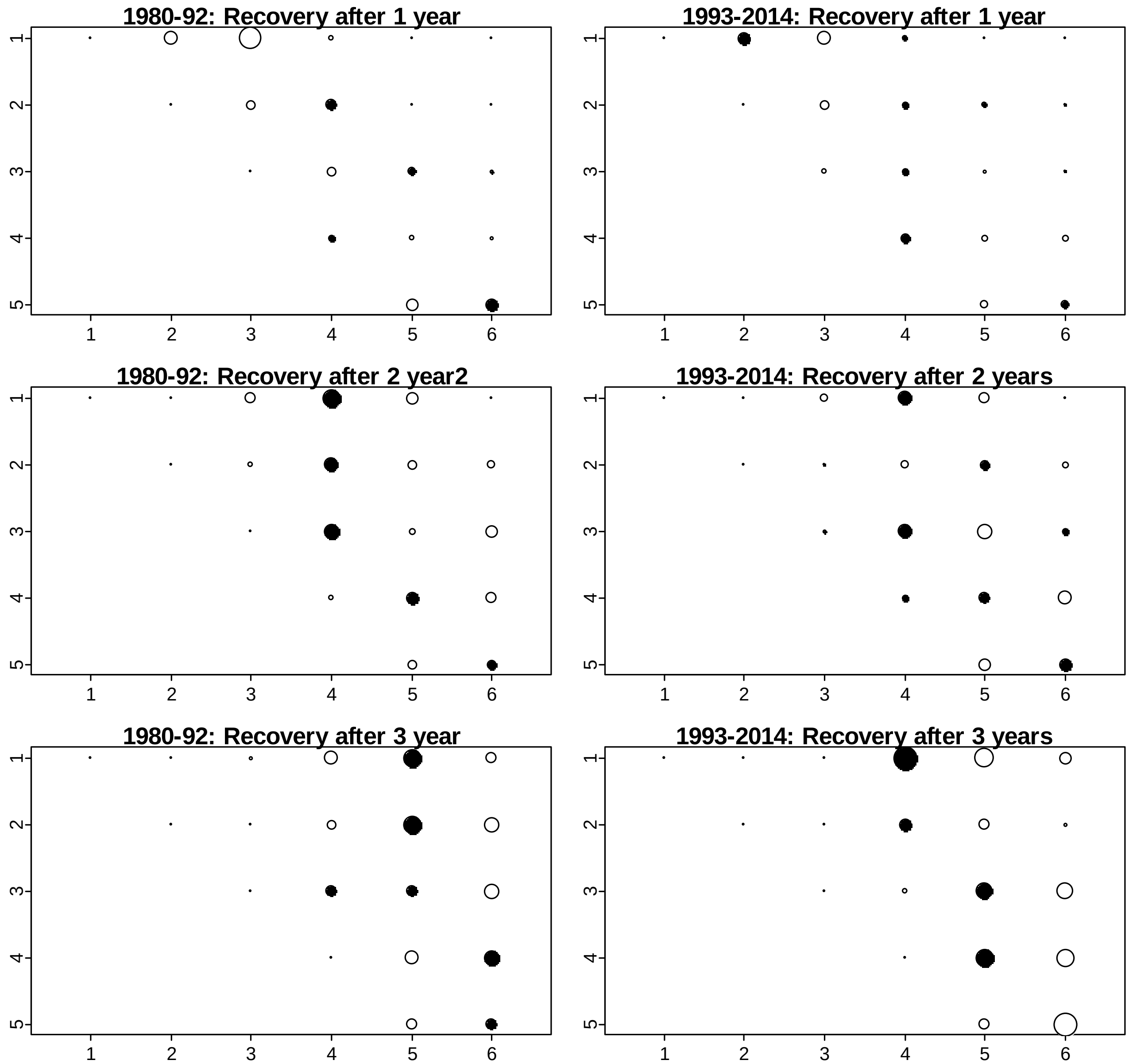


Figure C1-13. Predicted vs. observed length class proportions for tag recovery data 1980-1992, and 1993-2014.



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C1-14. Bubble plots of predicted vs. observed length class proportions for tag recovery data 1980-1992 and 1993-2014.

Table C1-1 . 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	-7.127	0.17656
log_q_2	-6.9878	0.094566
log_N_{76}	9.0721	0.1535
R_0	6.4929	0.069105
log_σ_R^2	0.30948	0.4562
log_R_{77}	-0.31725	0.38802
log_R_{78}	-0.76475	0.35056
log_R_{79}	-0.34097	0.37631
log_R_{80}	0.5063	0.26909
log_R_{81}	0.2481	0.28528
log_R_{82}	0.25407	0.326
log_R_{83}	0.67982	0.27011
log_R_{84}	0.25391	0.30368
log_R_{85}	0.2811	0.31083
log_R_{86}	0.28163	0.27041
log_R_{87}	-0.05958	0.27581
log_R_{88}	0.11129	0.26565
log_R_{89}	-0.06254	0.27019
log_R_{90}	-0.54924	0.29976
log_R_{91}	-0.39701	0.28092
log_R_{92}	-0.87032	0.32178
log_R_{93}	-0.6006	0.28479
log_R_{94}	-0.49694	0.27573
log_R_{95}	-0.21499	0.23842
log_R_{96}	0.030493	0.27535
log_R_{97}	0.41201	0.21789
log_R_{98}	-0.65183	0.3258
log_R_{99}	-0.32476	0.31115
log_R_{00}	-0.06076	0.29164
log_R_{01}	0.21447	0.22834
log_R_{02}	0.36023	0.27723
log_R_{03}	-0.27403	0.34387
log_R_{04}	-0.05466	0.29202
log_R_{05}	0.51508	0.20307
log_R_{06}	-0.01012	0.30701
log_R_{07}	0.60996	0.20771
log_R_{08}	0.36358	0.26953
log_R_{09}	0.029118	0.27672
log_R_{10}	-0.07926	0.26879
log_R_{11}	-0.09526	0.29552
log_R_{12}	0.48873	0.30875
log_R_{13}	0.27551	0.35564
a_1	0.36358	1.8991
a_2	1.8521	1.3711
a_3	2.188	1.3278
a_4	2.481	1.3052
a_5	1.6617	1.3594

r1	0.58293	0.052011
log_α	-1.8099	0.018035
log_ϕ_{st1}	-14.548	1430.8
log_ϕ_{st2}	-2.525	15547
log_ϕ_{W}	-1.7991	0.078231
Sw_6	0.33674	0.09315
log_ϕ_{1}	-1.8274	0.085364
log_ϕ_{2}	-1.7831	0.091305
w^2_t	0.052679	0.017827
q	0.74288	0.12989
σ	4.6363	0.21147
β_1	9.1501	0.67711
β_2	7.8816	0.21291

Appendix C2: Results Model 2

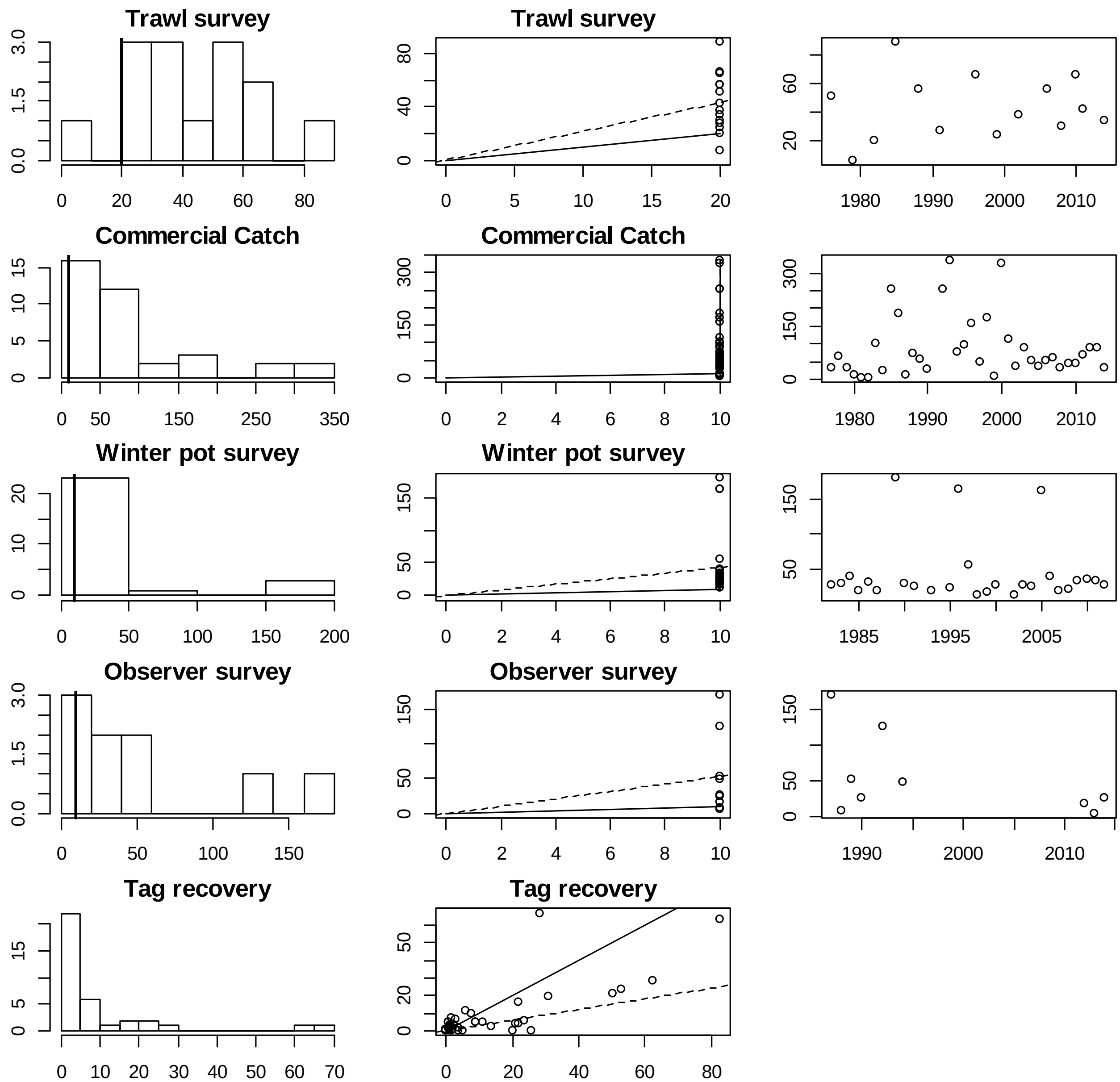


Figure C2-1: Effective sample size vs. implied sample size. Figures in the first column show effective sample size (x-axis) vs. frequency (y-axis). Vertical solid line is the implied sample size. Figures in the second column show implied sample size (x-axis) vs. effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. Figures in the third column show year (x-axis) vs. effective sample size (y-axis).

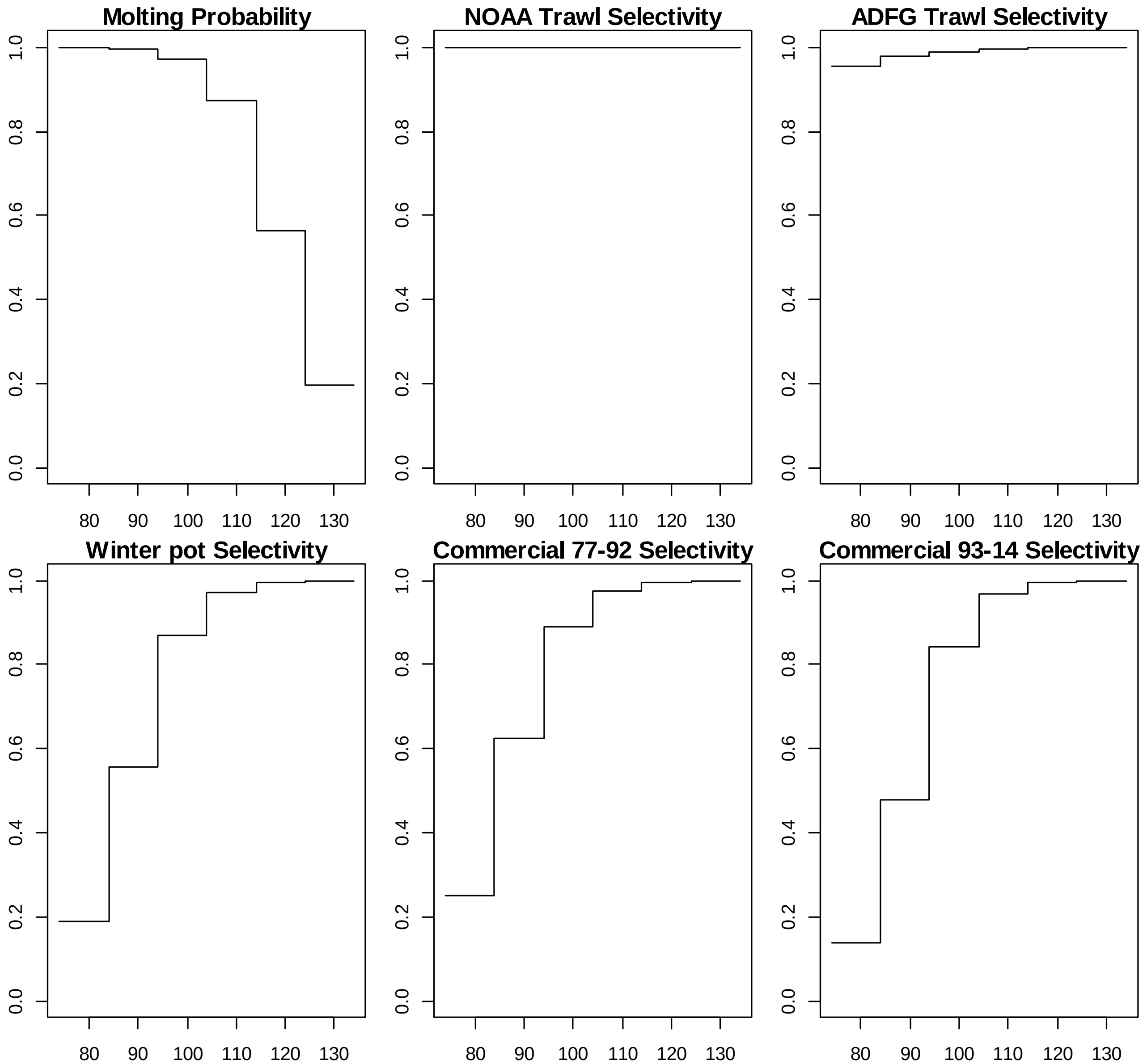


Figure C2-2. Molting probability and trawl/pot selectivities. X-axis is carapace length.

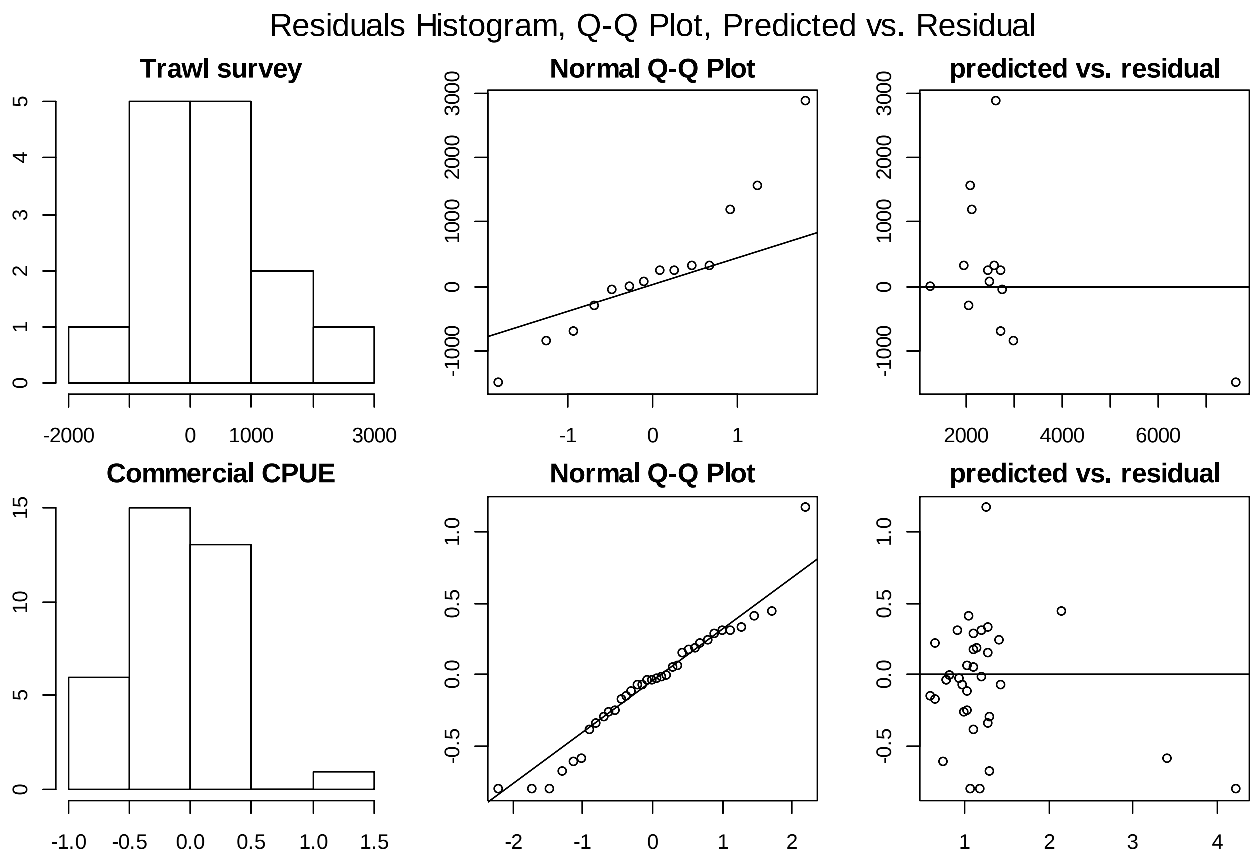


Figure C2-3. QQ Plot of Trawl survey and Commercial CPUE

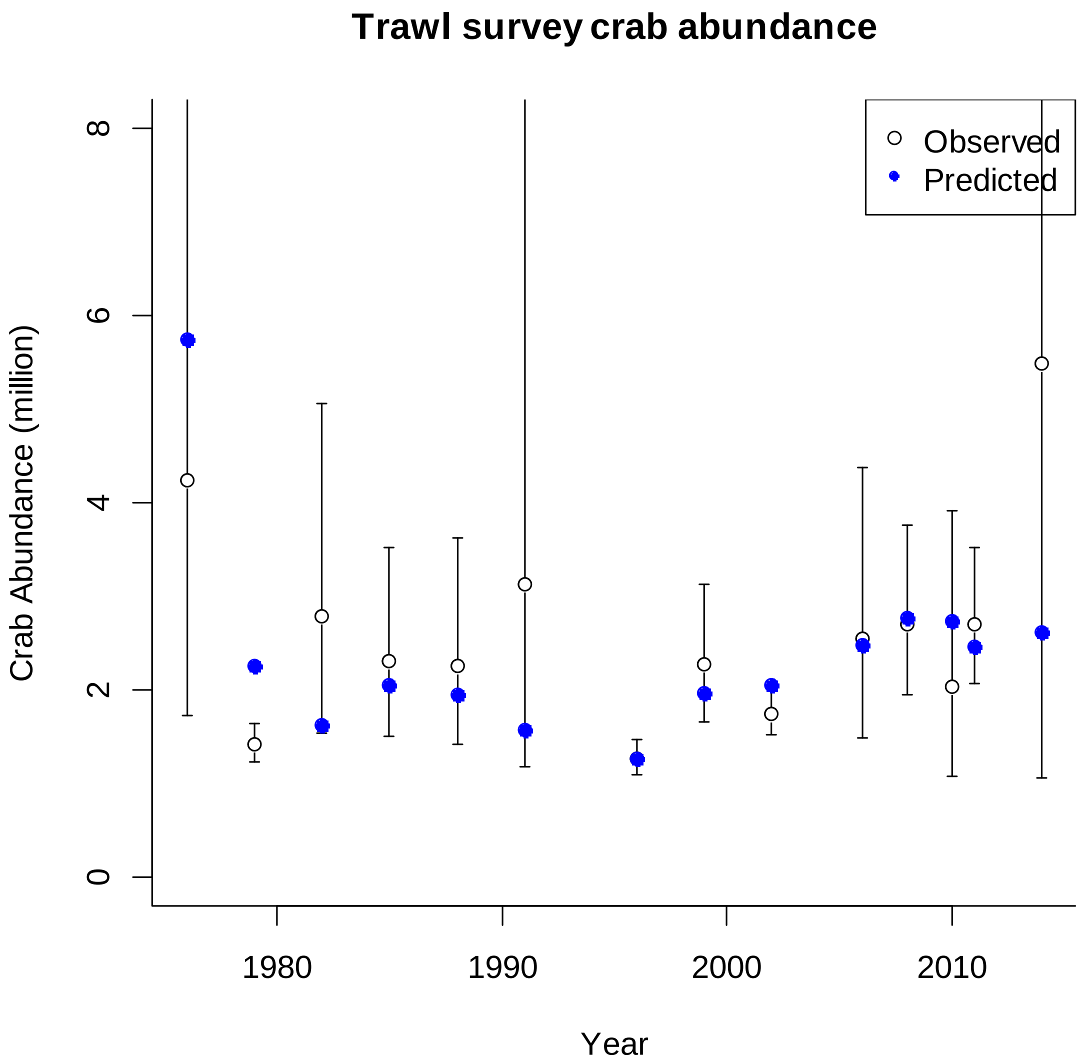


Figure C2-4. Estimated trawl survey abundance (crabs ≥ 74 mm CL) male

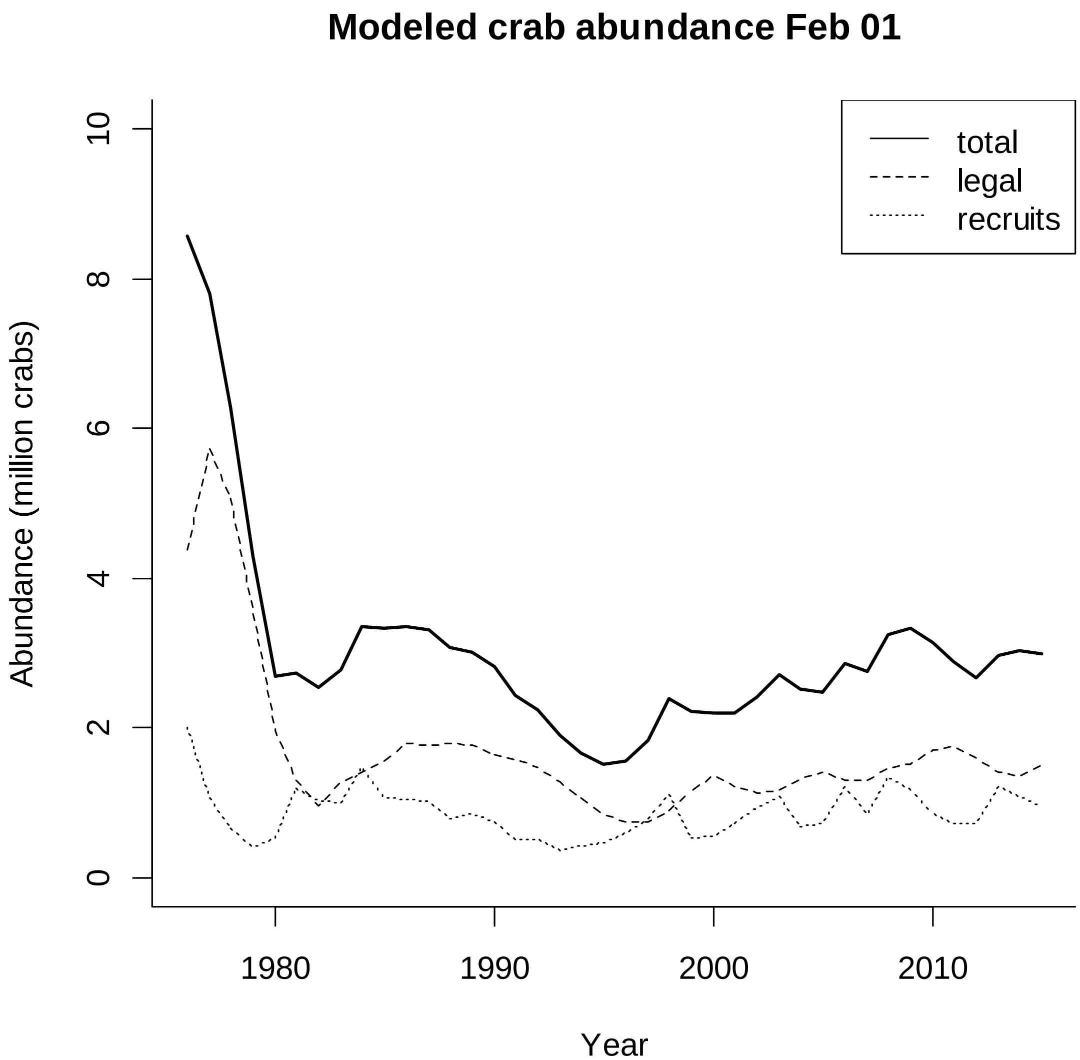


Figure C2-5. Estimated abundance of legal male from 1976-2014

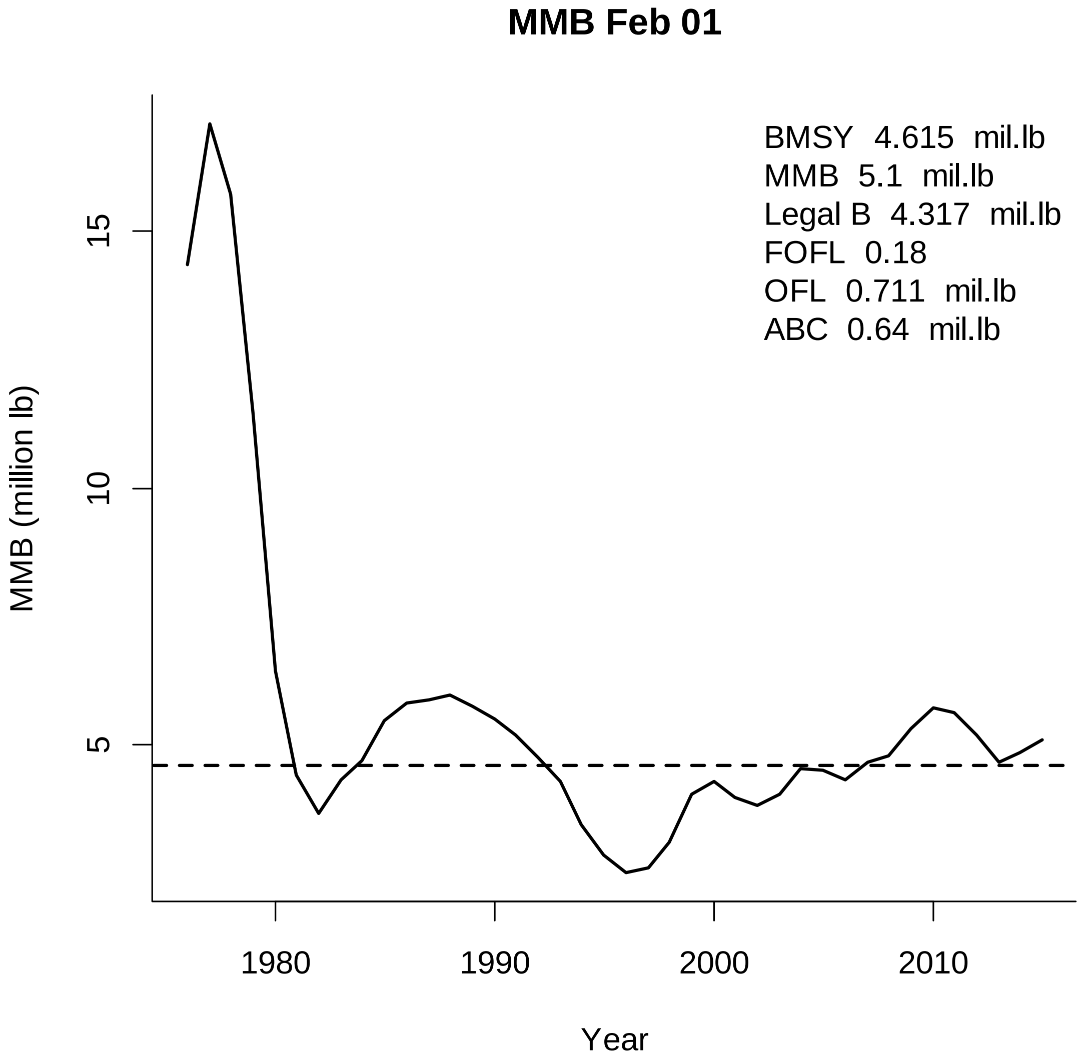


Figure C2-6. Estimated abundance of leg recruits from 1976-2015. Dash line shows Bmsy (Average MMB of 1980-2015)

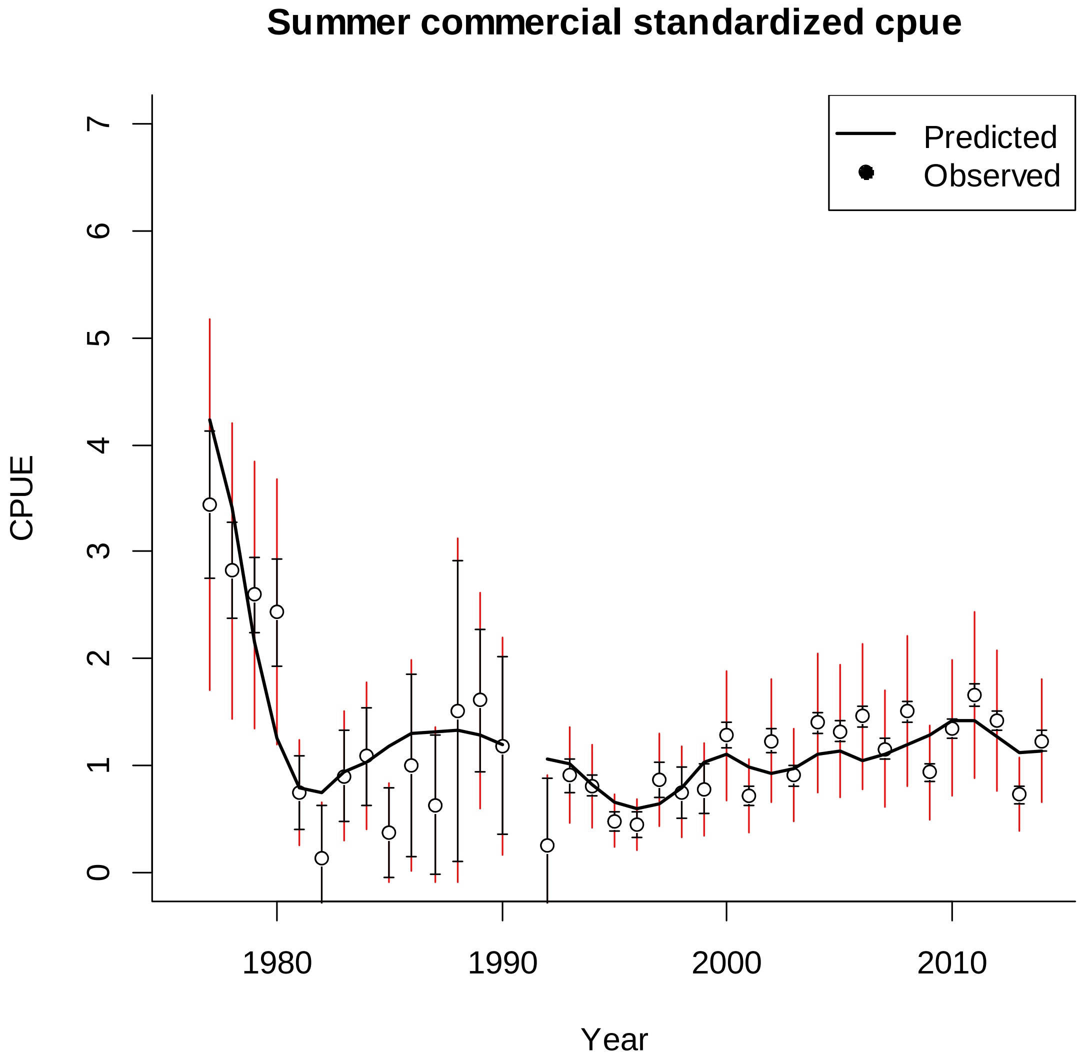


Figure C2-7. Summer commercial standardized cpue (1977-2014)

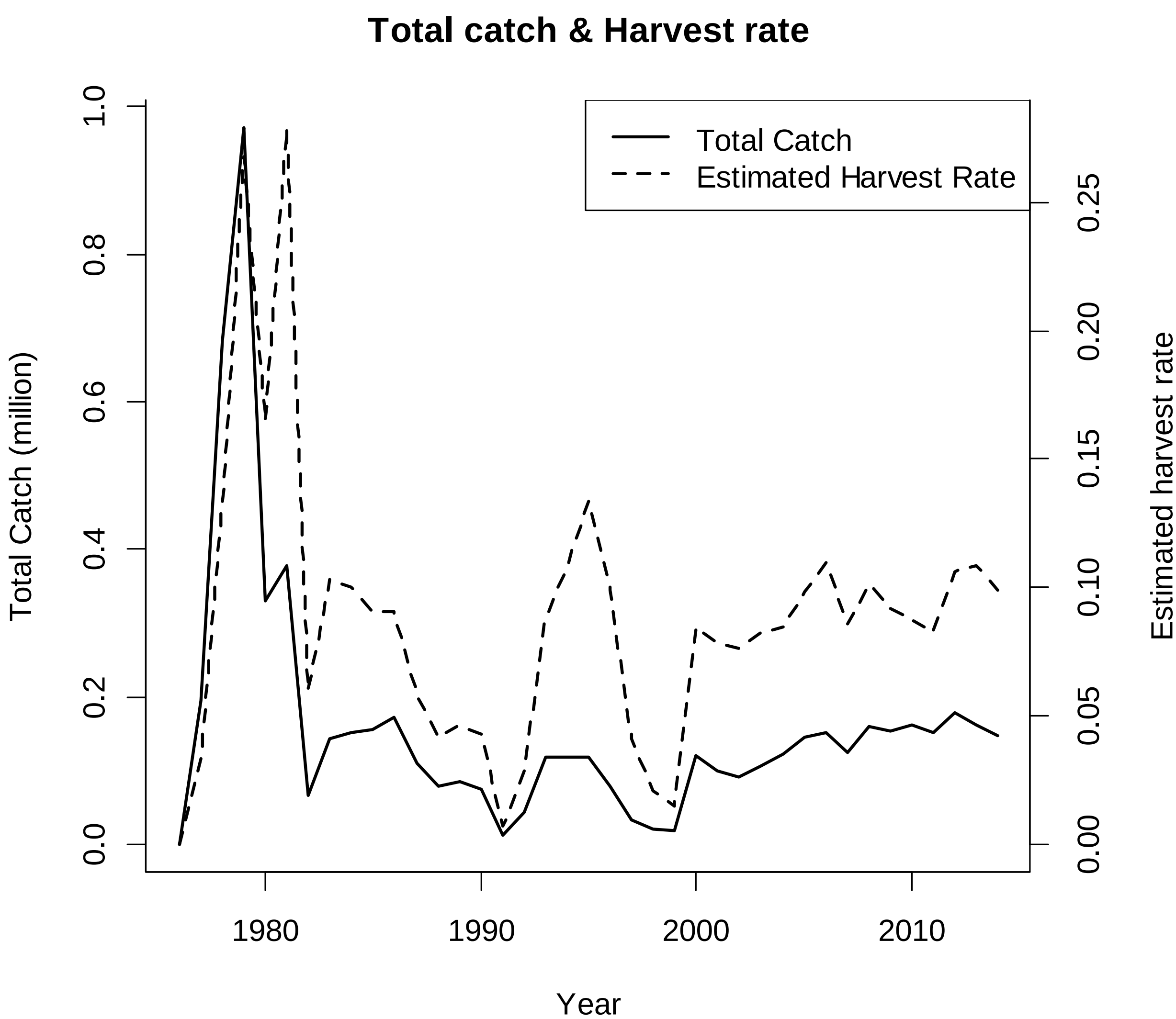
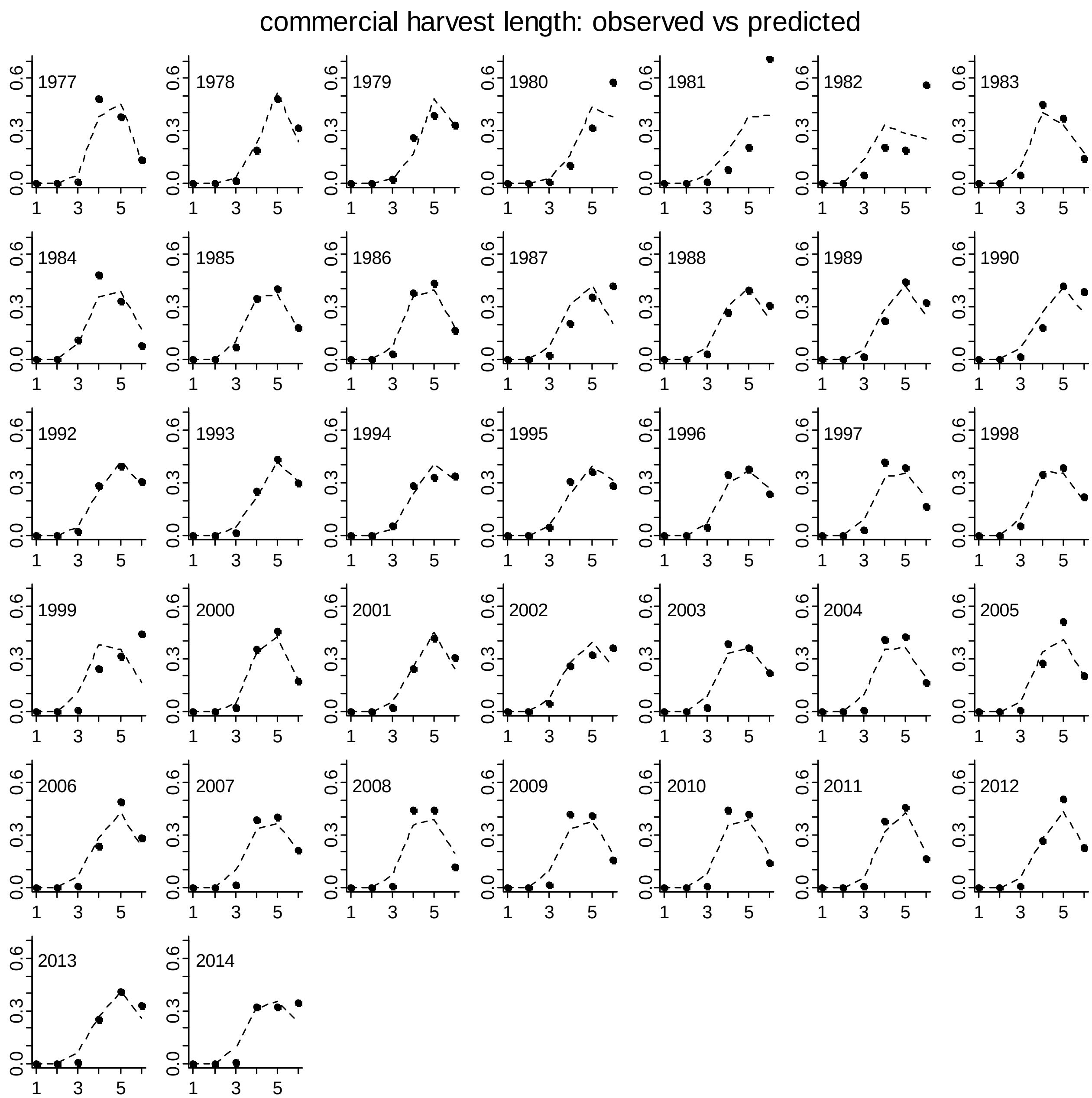


Figure C2-8: Total catch and estimated harvest rate 1976-2014



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C2-9: Predicted (dashed line) vs. observed (black dots) length class proportion for commercial catch:

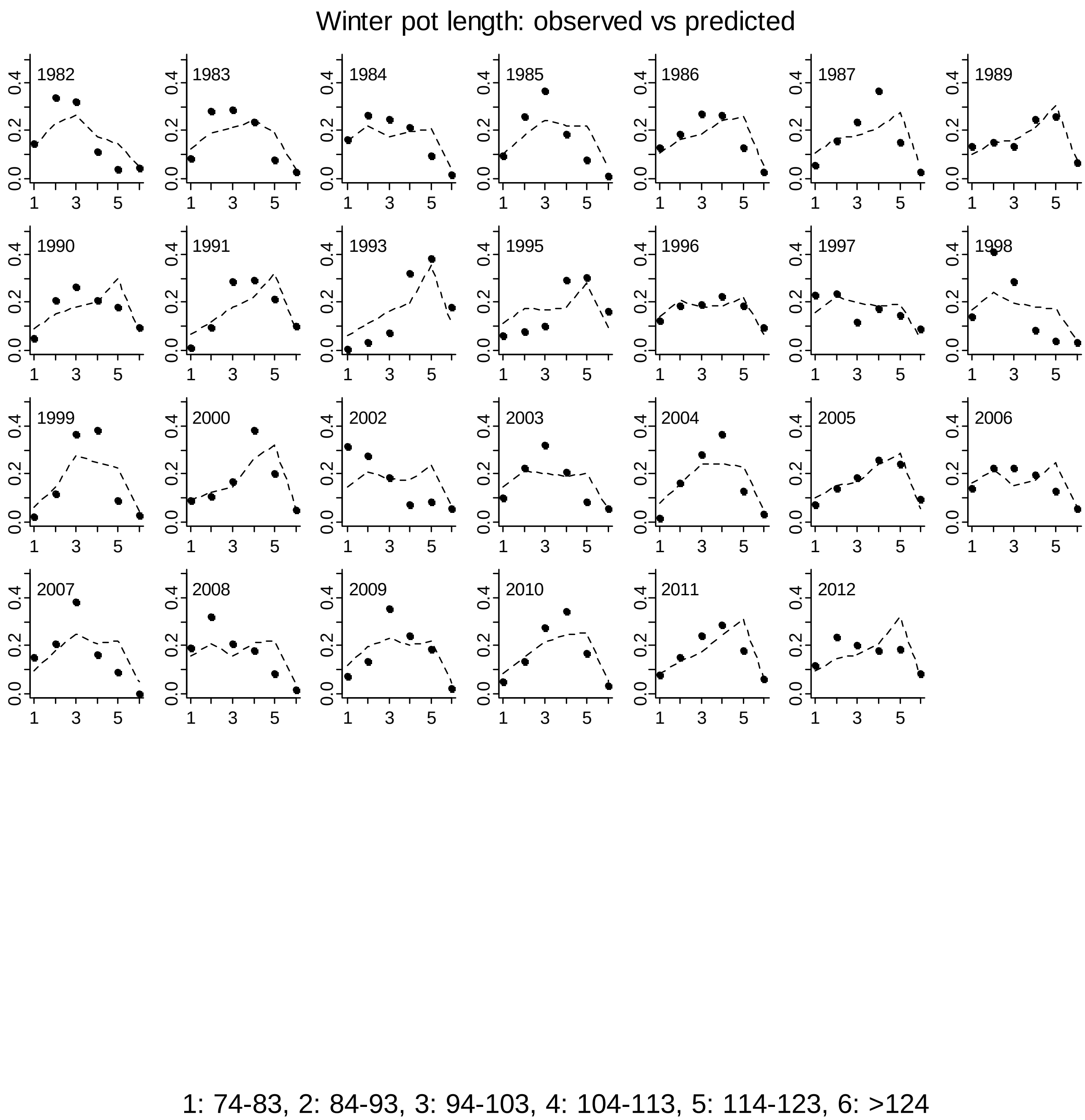
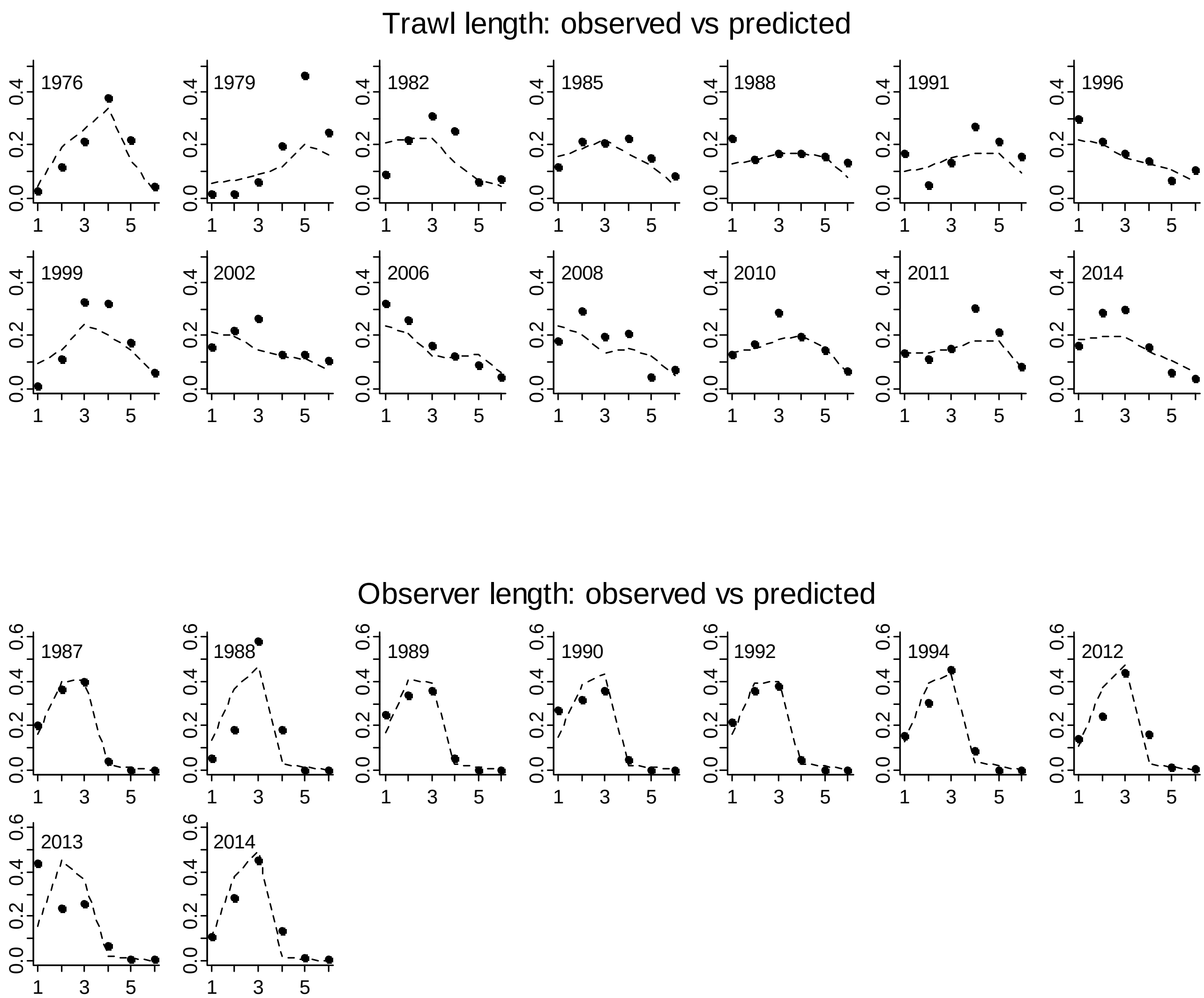
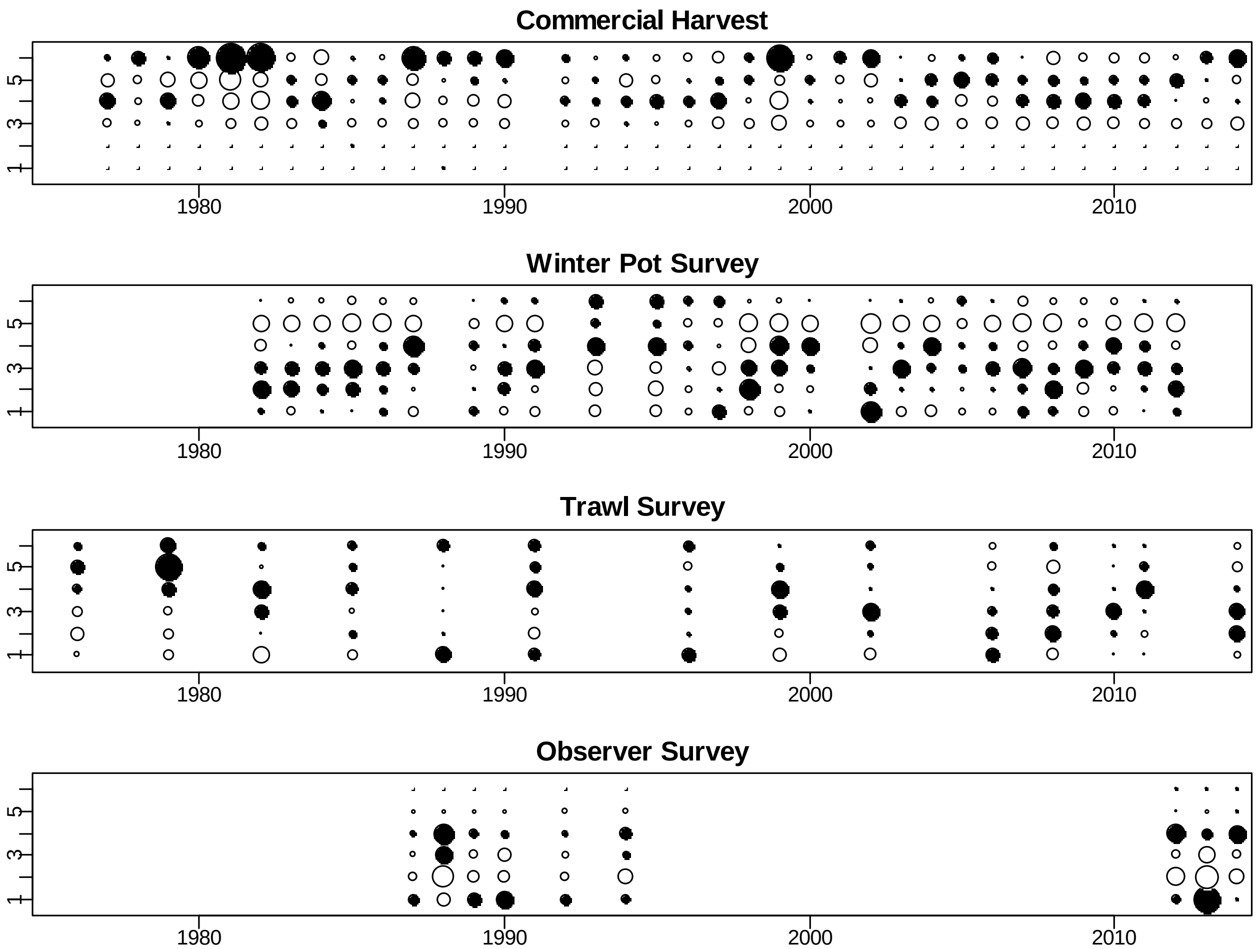


Figure C2-10: Predicted (dashed line) vs. observed (black dots) length class proportion for winter pot survey



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C2-11: Predicted (dashed line) vs. observed (black dots) length class proportion for trawl survey and observer survey



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C2-12: 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 indicate degree of deviance (larger circle = larger deviance).

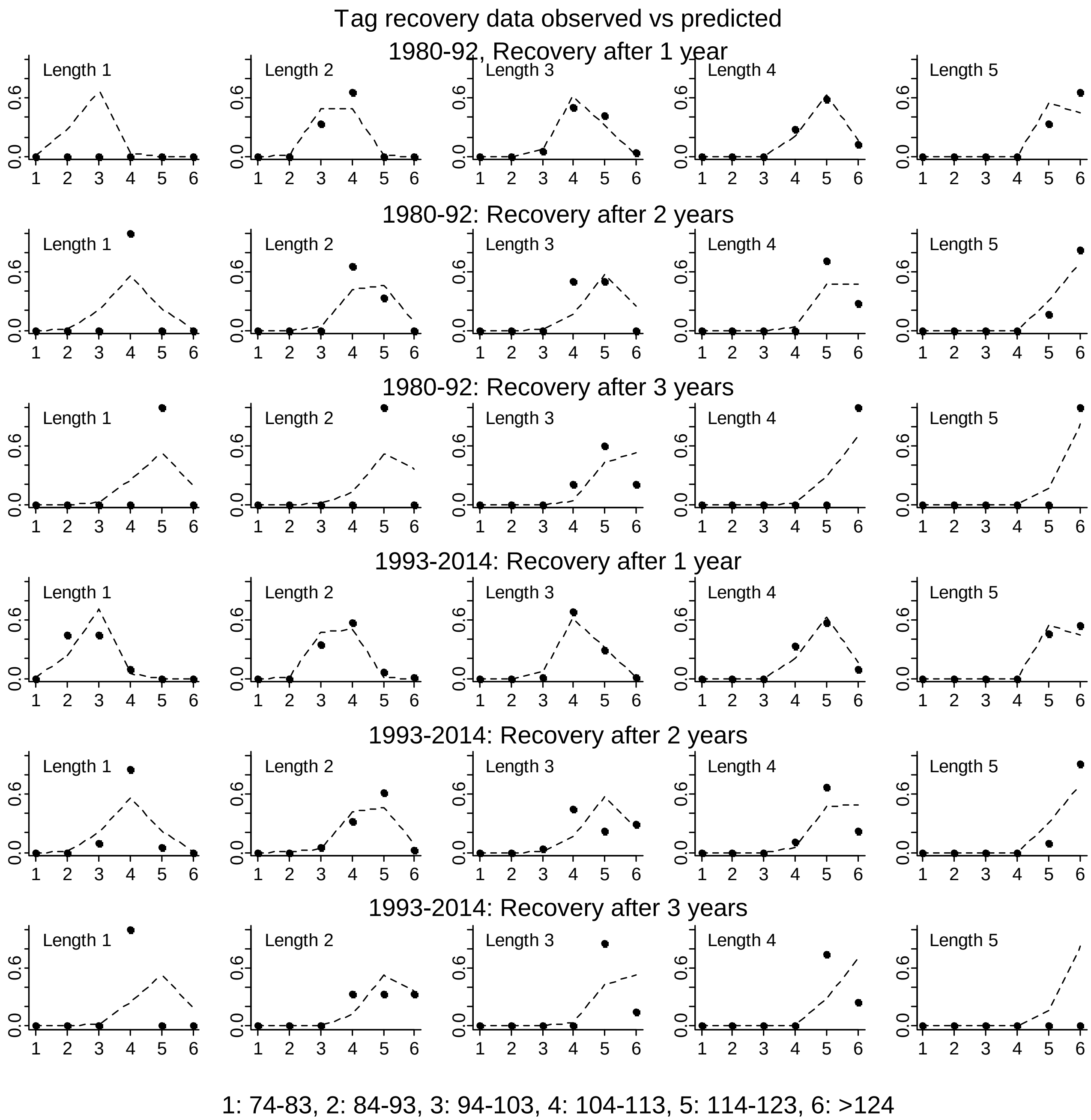
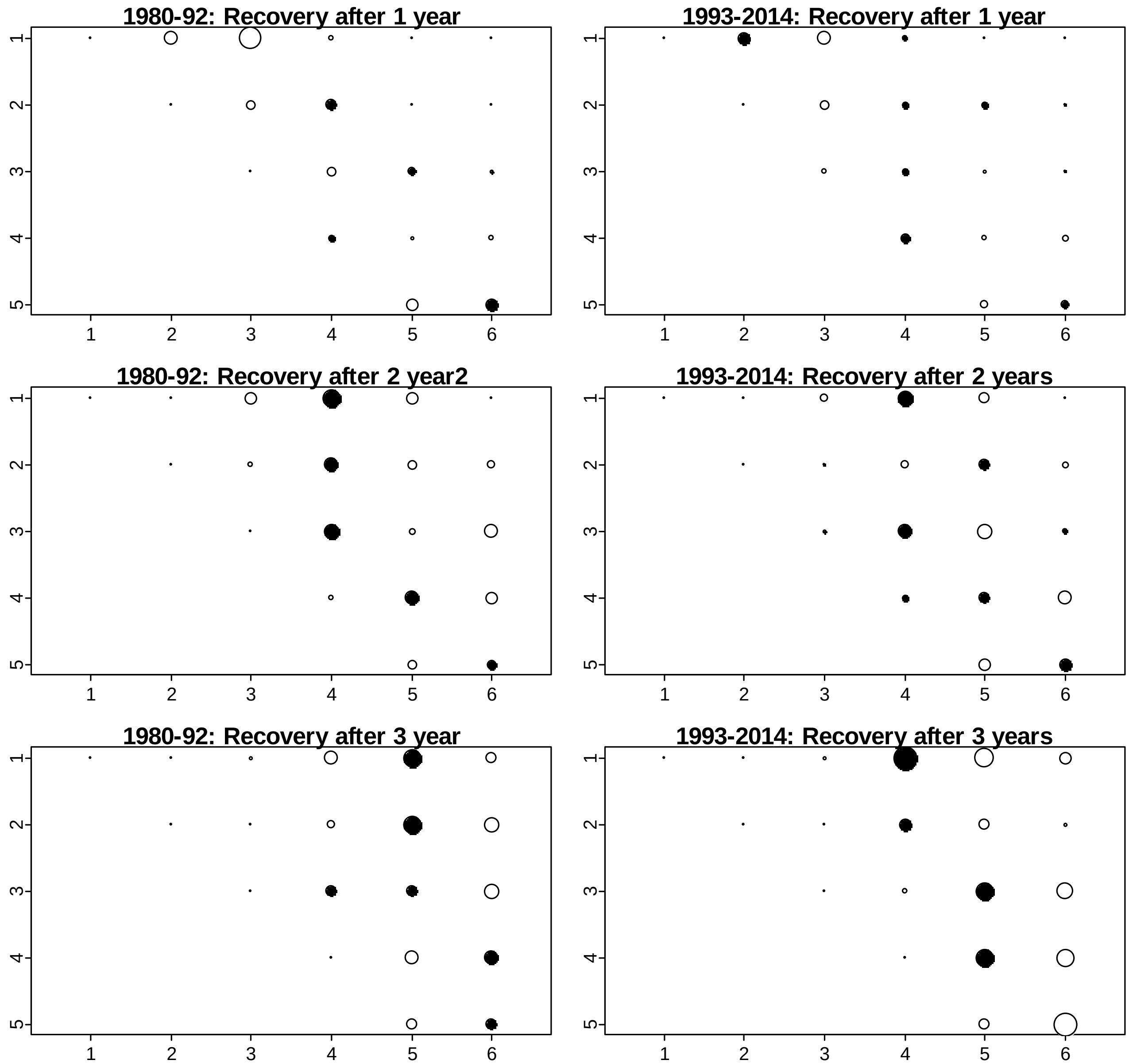


Figure C2-13: Predicted vs. observed length class proportion for tag recovery data 1980-1992, and 1993-2014:



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C2-14: Bubble plot of predicted vs. observed length class proportion for tag recovery data 1980-1992, and 1993-2014:

Table C2-1 . 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	-7.1048	0.17662
log_q_2	-6.97	0.095744
log_N_{76}	9.0563	0.15446
R_0	6.491	0.069347
$log\_\sigma_R{}^2$	0.33714	0.45763
log_R_{77}	-0.3232	0.38865
log_R_{78}	-0.76706	0.3502
log_R_{79}	-0.32615	0.37662
log_R_{80}	0.50643	0.27111
log_R_{81}	0.22724	0.28926
log_R_{82}	0.25405	0.32796
log_R_{83}	0.68092	0.27108
log_R_{84}	0.2244	0.30905
log_R_{85}	0.29406	0.31167
log_R_{86}	0.26992	0.2736
log_R_{87}	-0.06733	0.27727
log_R_{88}	0.10828	0.26692
log_R_{89}	-0.07751	0.2724
log_R_{90}	-0.54716	0.30018
log_R_{91}	-0.41064	0.28191
log_R_{92}	-0.8815	0.32382
log_R_{93}	-0.57371	0.28374
log_R_{94}	-0.49641	0.27707
log_R_{95}	-0.2247	0.24044
log_R_{96}	0.049319	0.27676
log_R_{97}	0.40068	0.22156
log_R_{98}	-0.66152	0.32784
log_R_{99}	-0.31458	0.31108
log_R_{00}	-0.05404	0.29304
log_R_{01}	0.21408	0.23024
log_R_{02}	0.3549	0.27847
log_R_{03}	-0.27601	0.34569
log_R_{04}	-0.04466	0.29359
log_R_{05}	0.50884	0.20501
log_R_{06}	-0.00859	0.30991
log_R_{07}	0.61182	0.20922
log_R_{08}	0.36676	0.27064
log_R_{09}	0.018401	0.28083
log_R_{10}	-0.09418	0.2731
log_R_{11}	-0.08166	0.29694
log_R_{12}	0.51037	0.31218
log_R_{13}	0.293	0.35983
a_1	0.45931	1.8886
a_2	1.913	1.3704
a_3	2.2159	1.3292
a_4	2.4852	1.3068
a_5	1.6554	1.3603

r1	0.59245	0.055077
log_α	-1.7948	0.018979
log_ϕ_{st1}	-14.505	1533.7
log_ϕ_{st2}	-2.569	15686
log_ϕ_w	-1.789	0.07563
Sw_6	0.33555	0.093222
log_ϕ_1	-1.8329	0.085933
log_ϕ_2	-1.7446	0.094652
w^2_t	0.052278	0.017716
q	0.75234	0.13156
σ	4.5884	0.29558
β_1	8.5014	0.87056
β_2	8.121	0.27127

Appendix C3: Results Model 3

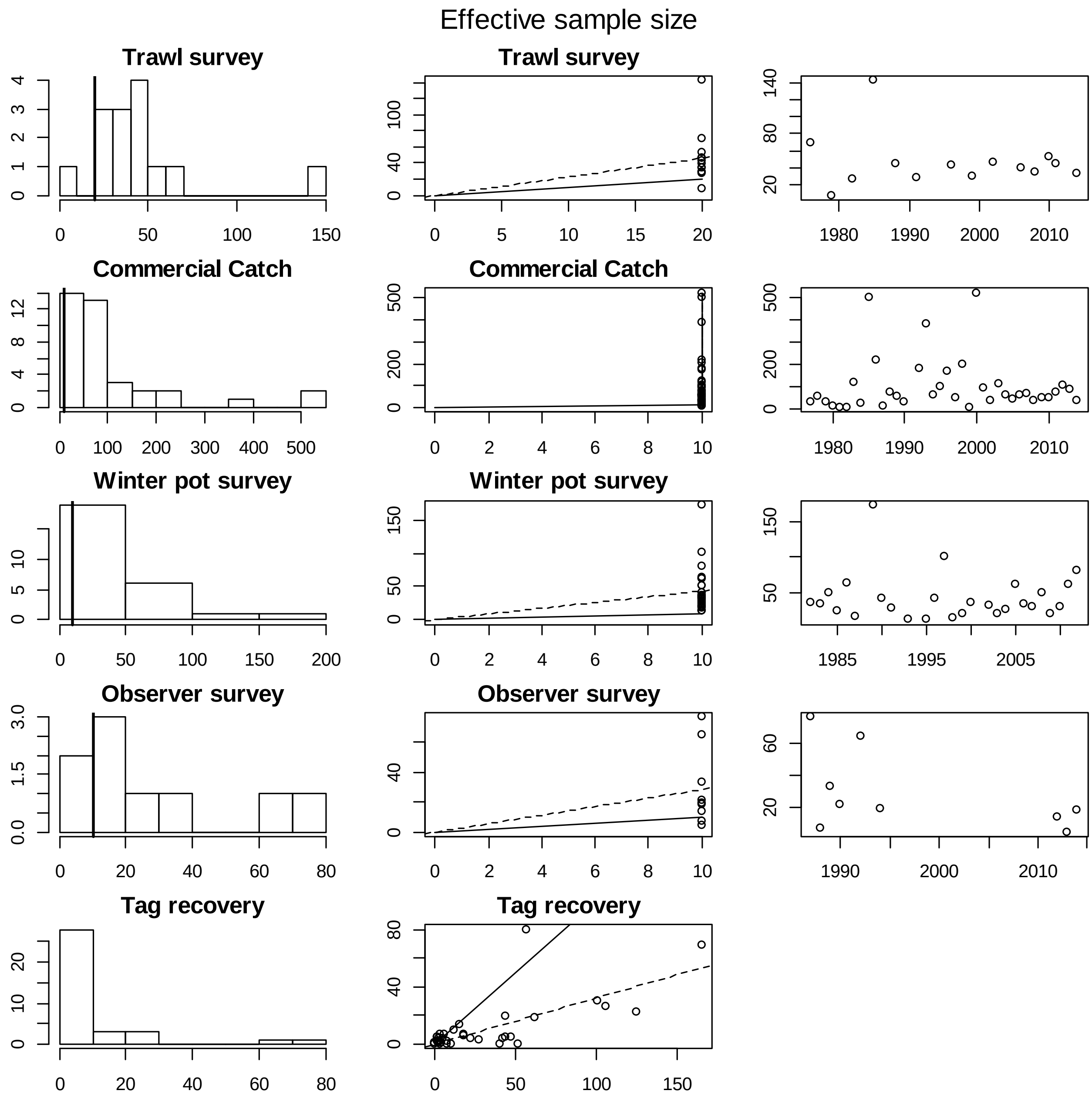


Figure C3-1: Effective sample size vs. implied sample size. Figures in the first column show effective sample size (x-axis) vs. frequency (y-axis). Vertical solid line is the implied sample size. Figures in the second column show implied sample size (x-axis) vs. effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. Figures in the third column show year (x-axis) vs. effective sample size (y-axis).

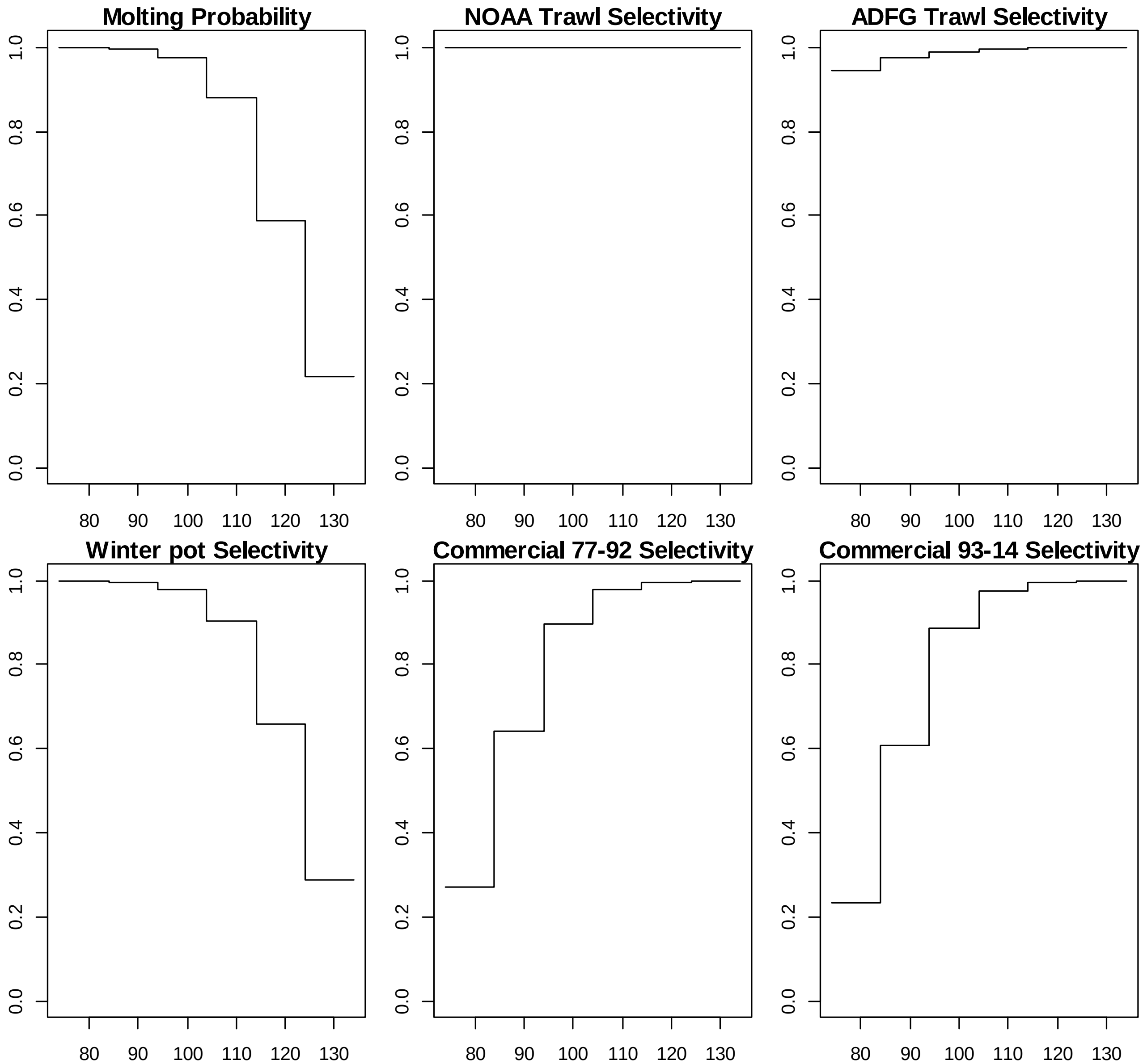


Figure C3-2. Molting probability and trawl/pot selectivities. X-axis is carapace length.

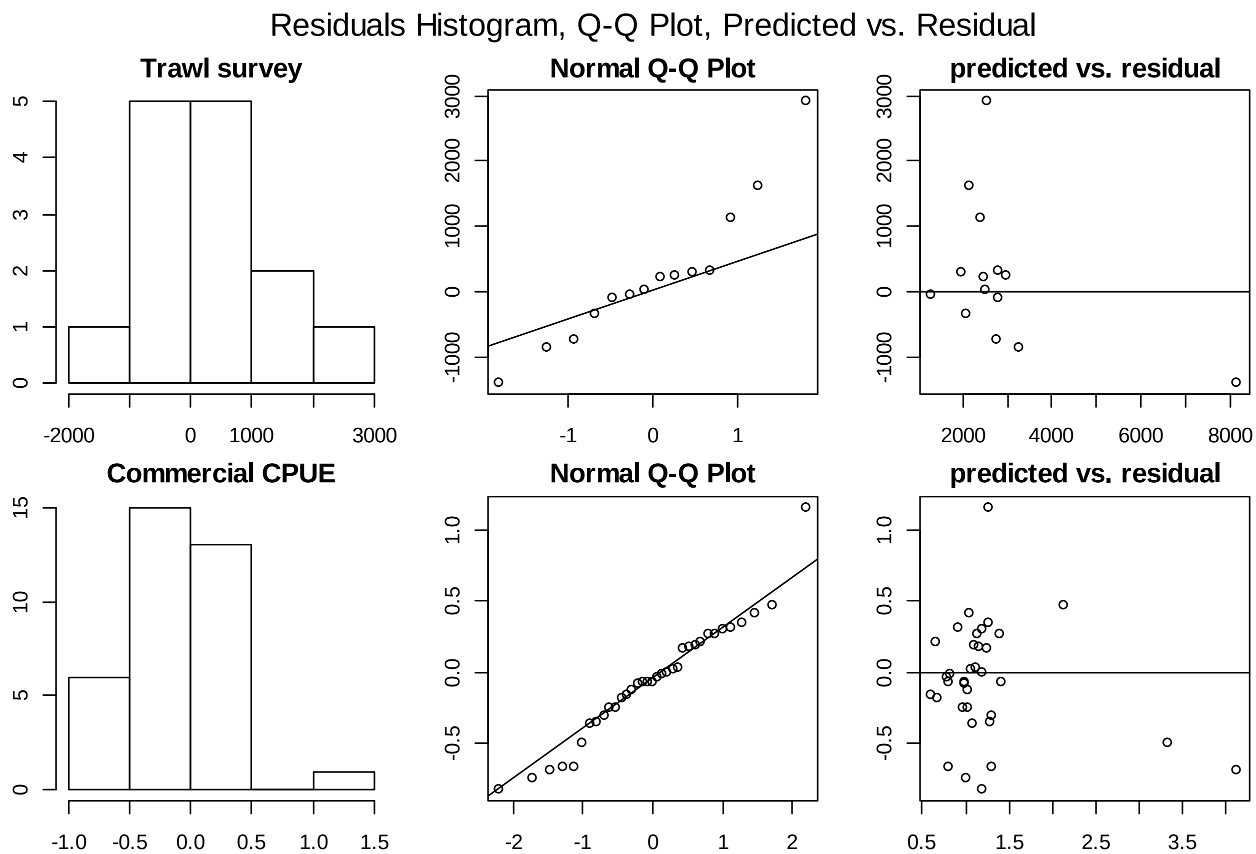


Figure C3-3. QQ Plot of Trawl survey and Commercial CPUE

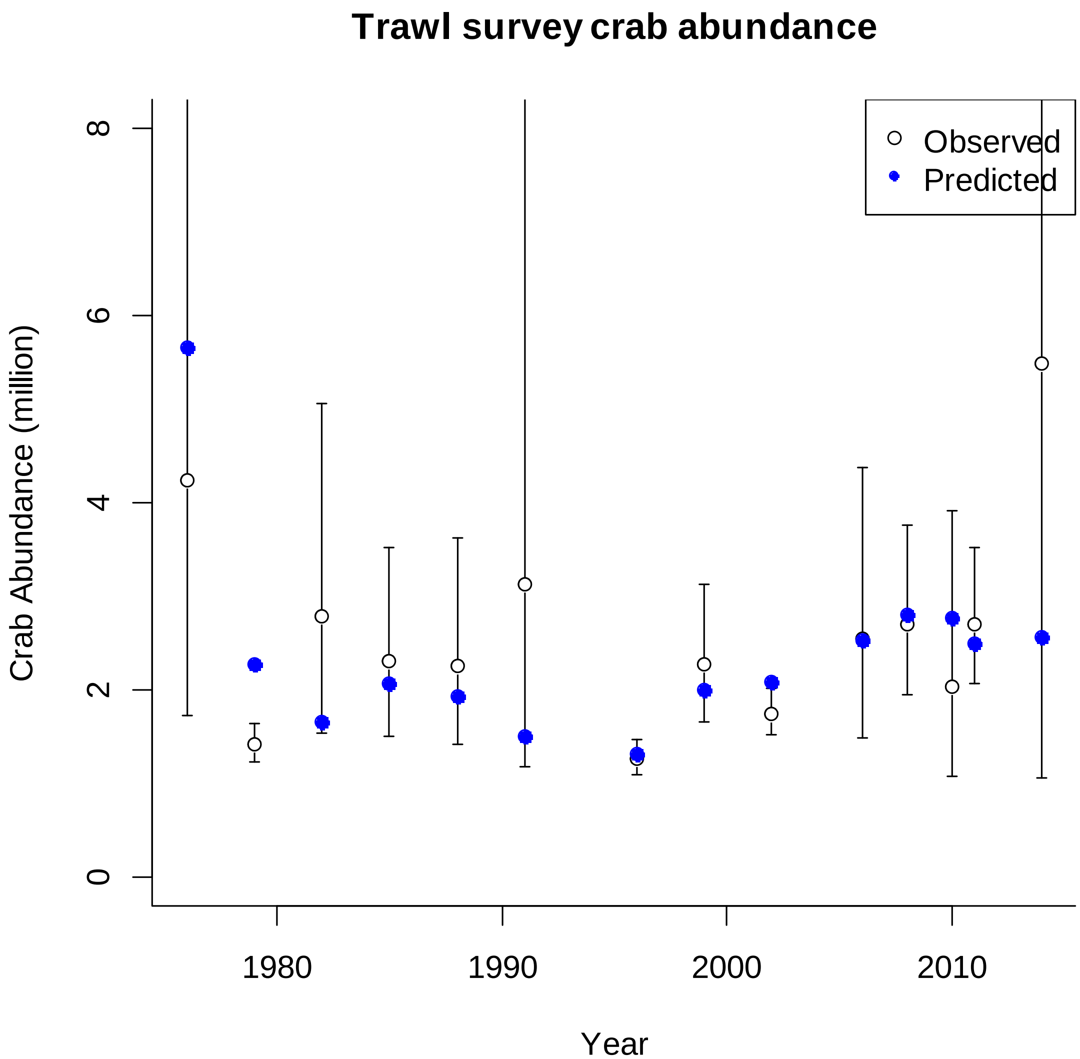


Figure C3-4. Estimated trawl survey abundance (crabs ≥ 74 mm CL) male

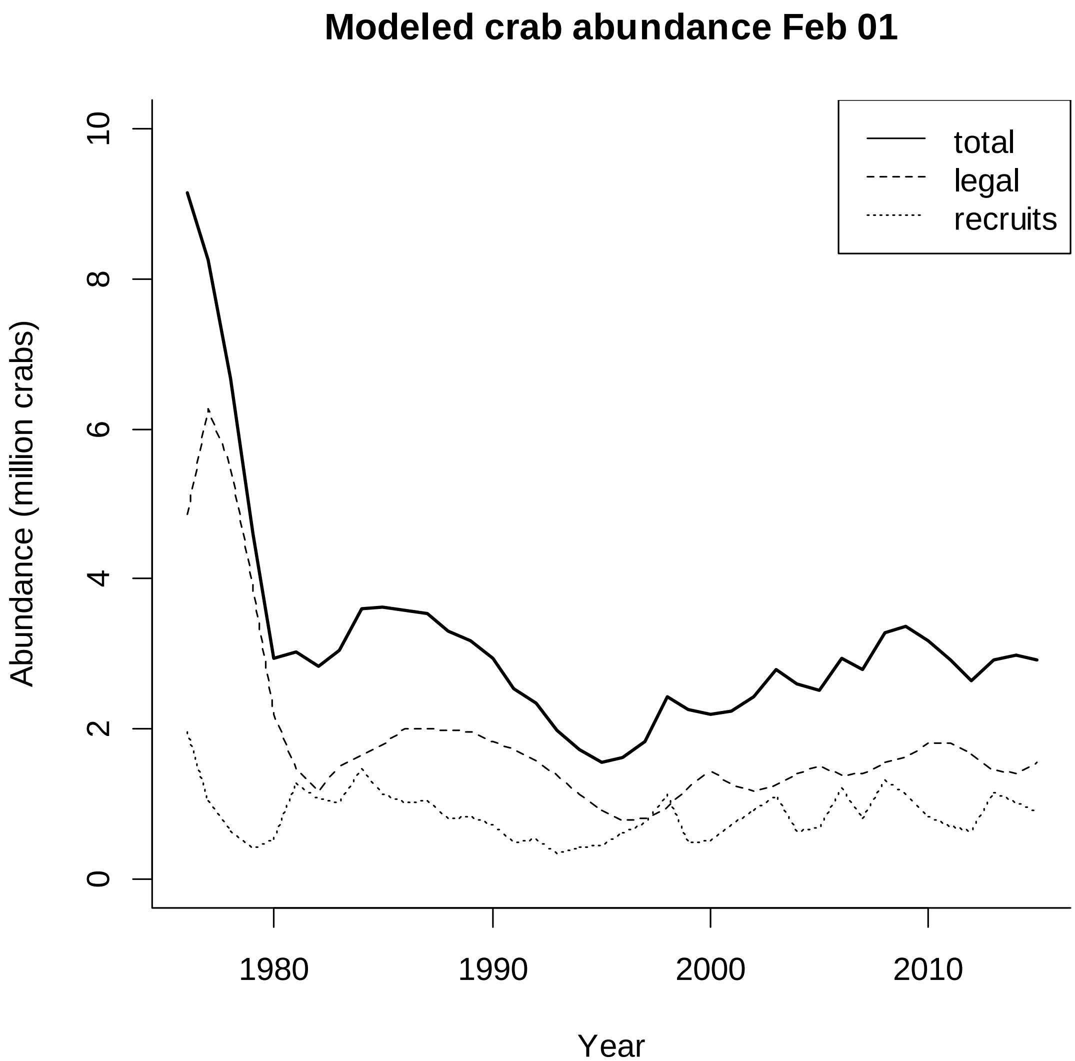


Figure C3-5. Estimated abundance of legal male from 1976-2014

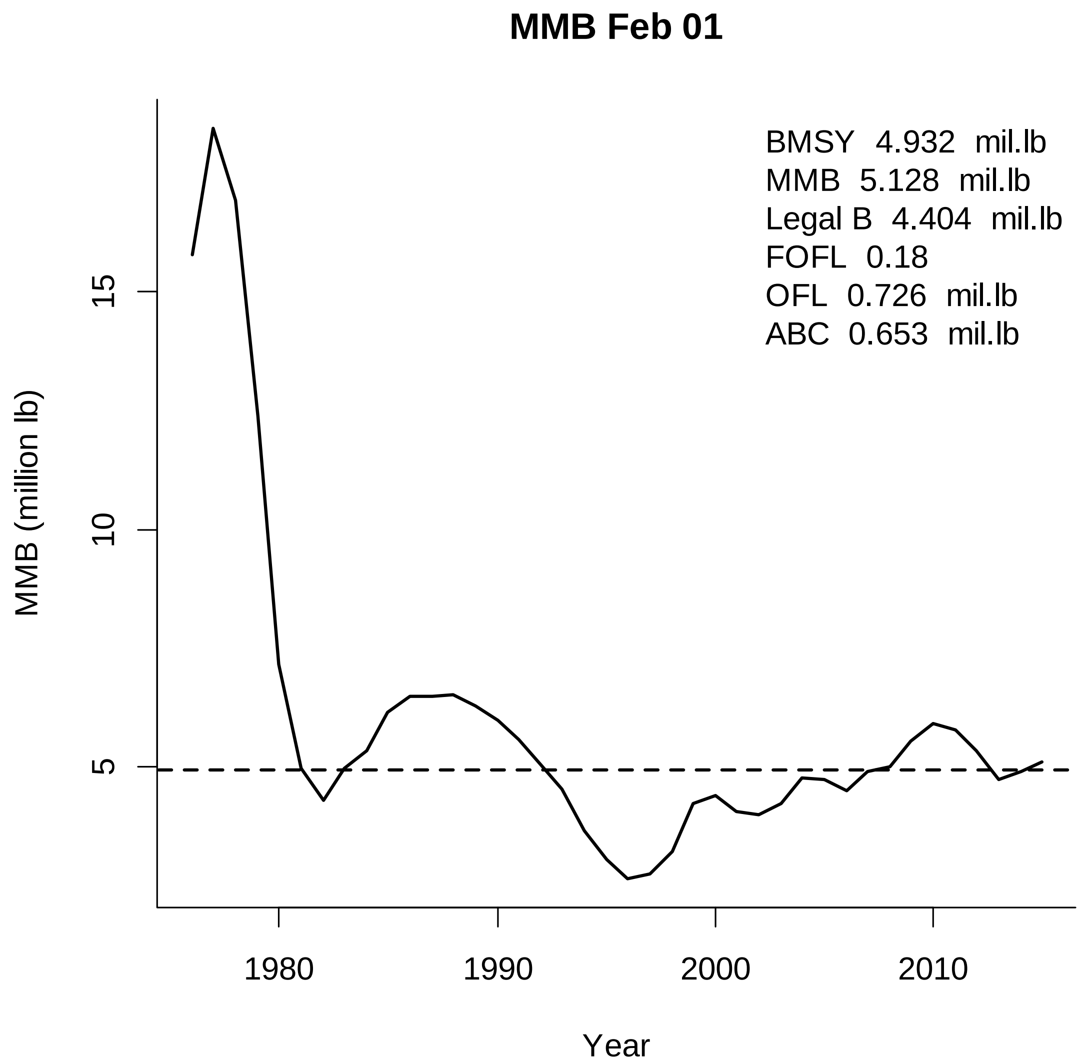


Figure C3-6. Estimated abundance of leg recruits from 1976-2015. Dash line shows Bmsy (Average MMB of 1980-2015)

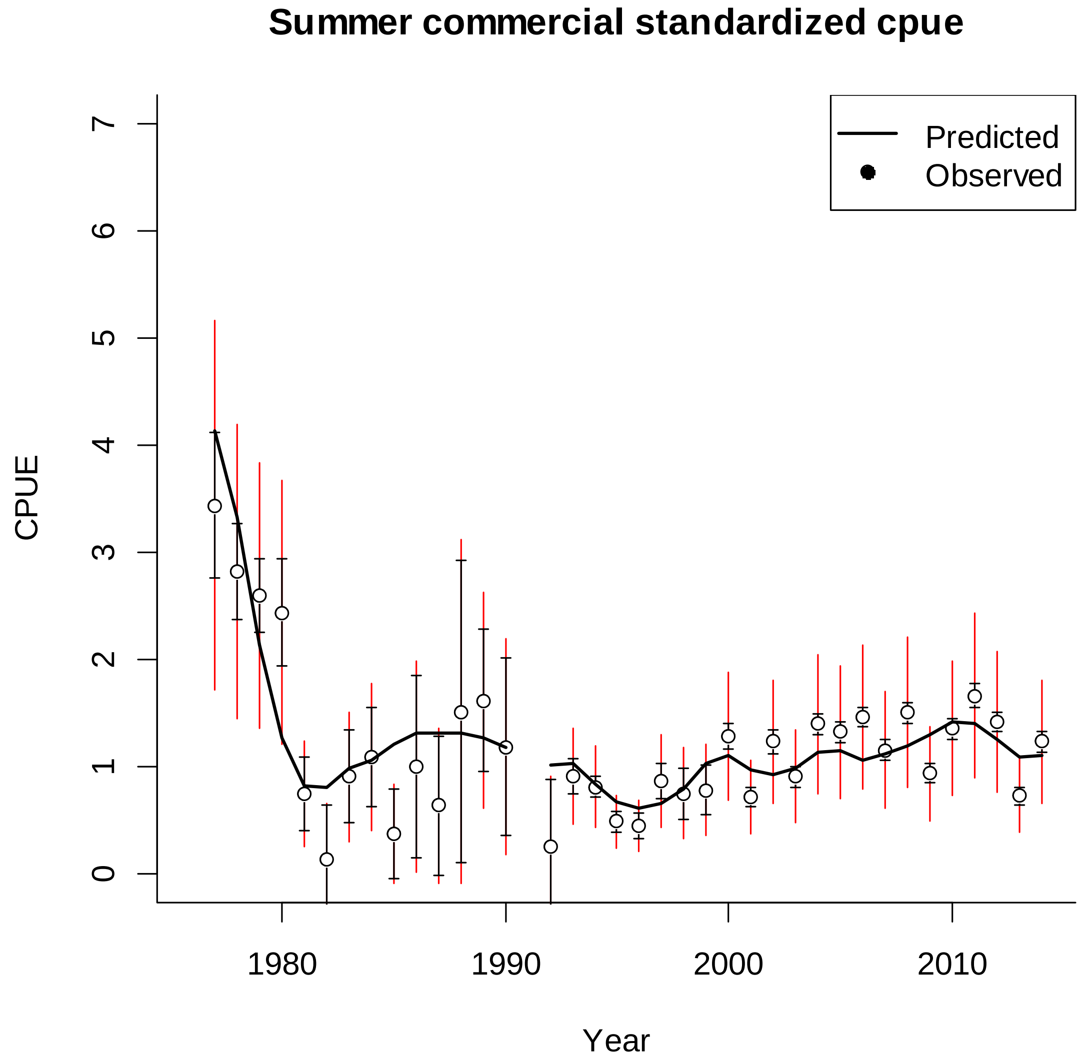


Figure C3-7. Summer commercial standardized cpue (1977-2014)

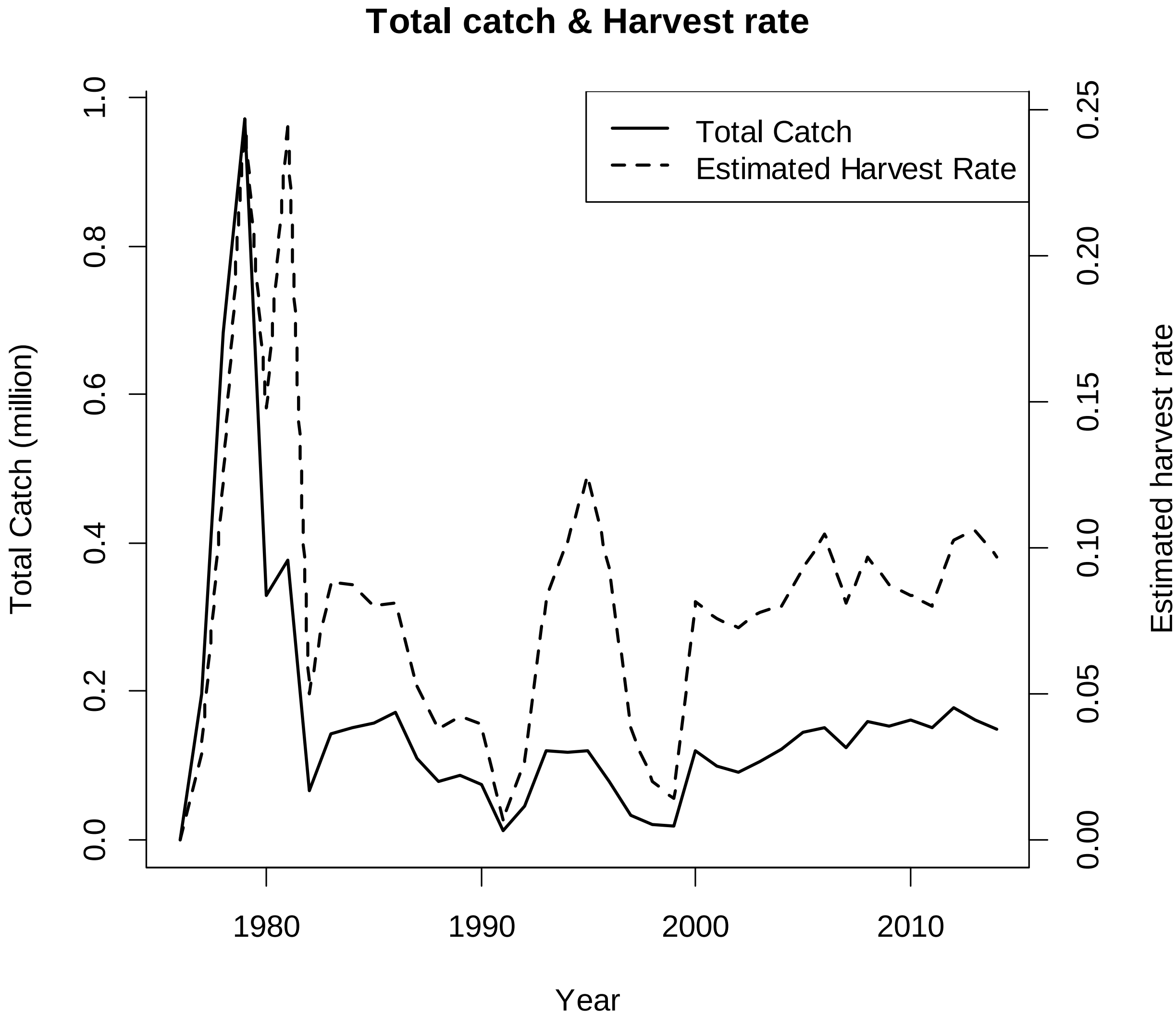
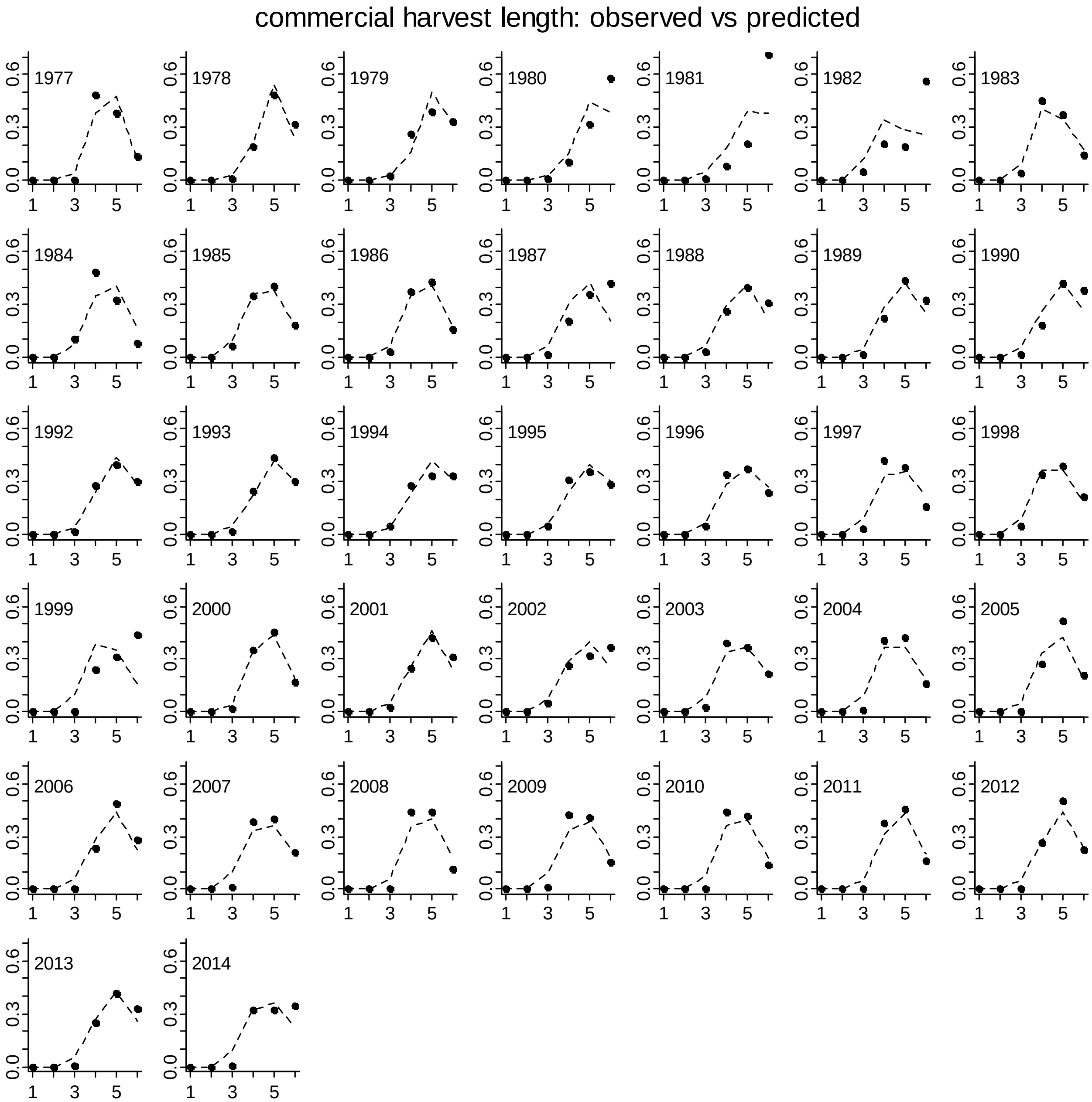
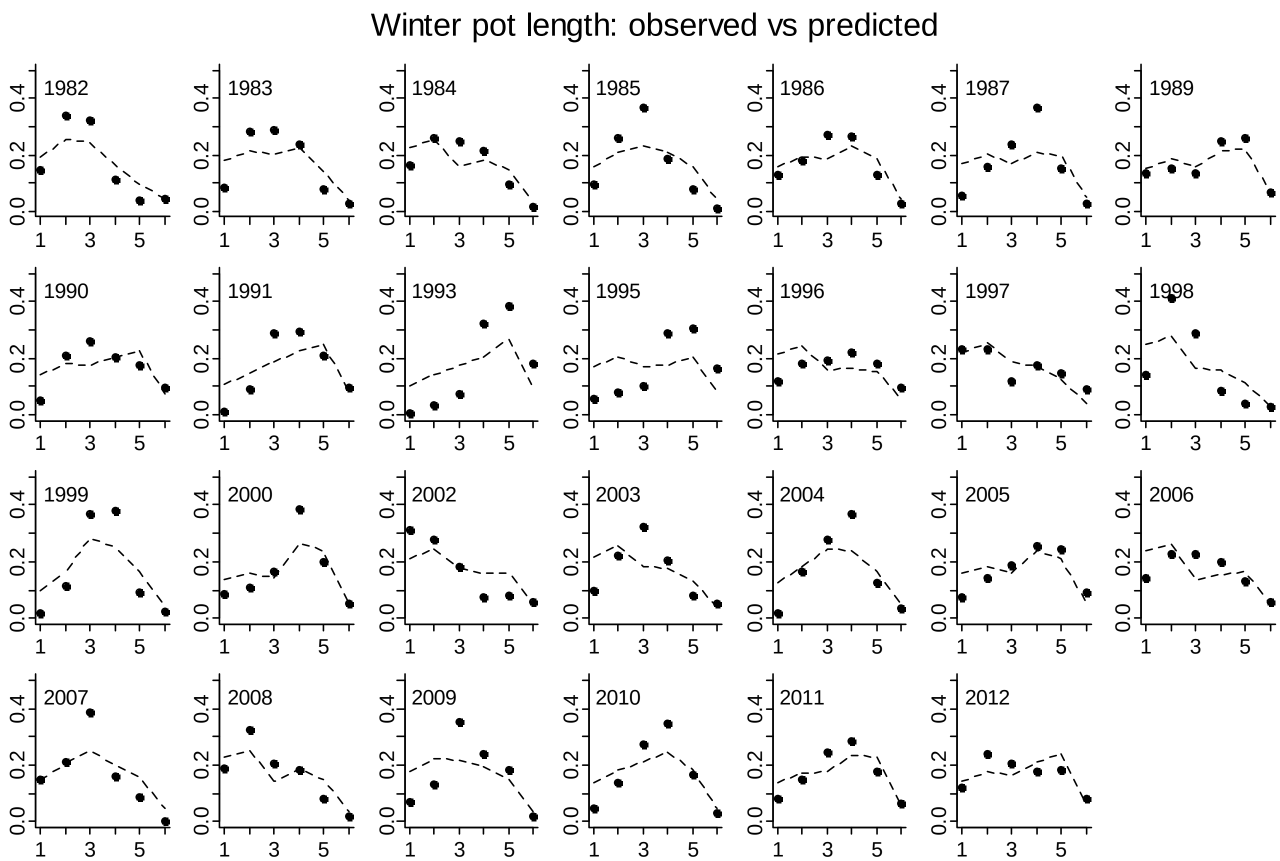


Figure C3-8: Total catch and estimated harvest rate 1976-2014



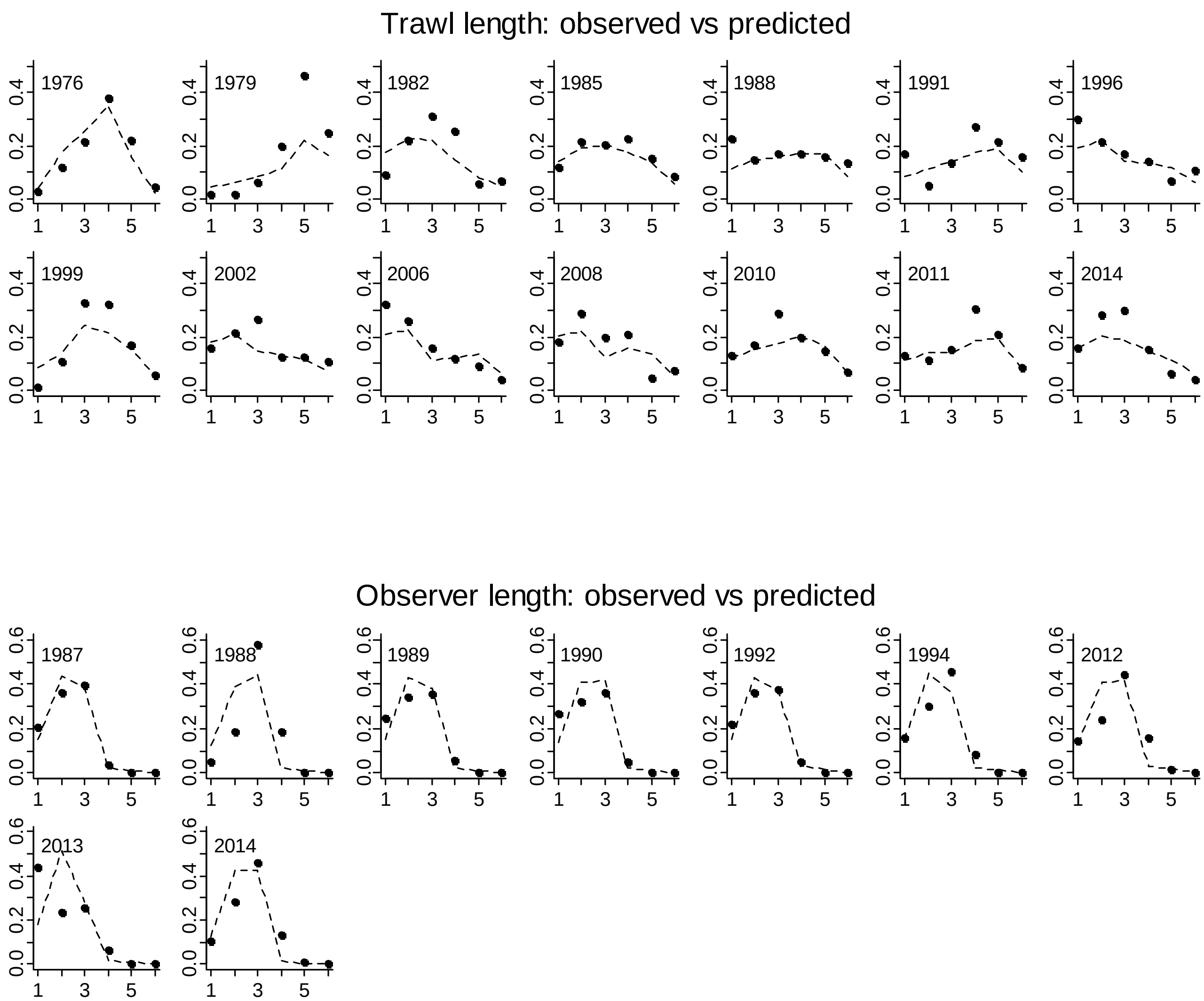
1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C3-9: Predicted (dashed line) vs. observed (black dots) length class proportion for commercial catch:



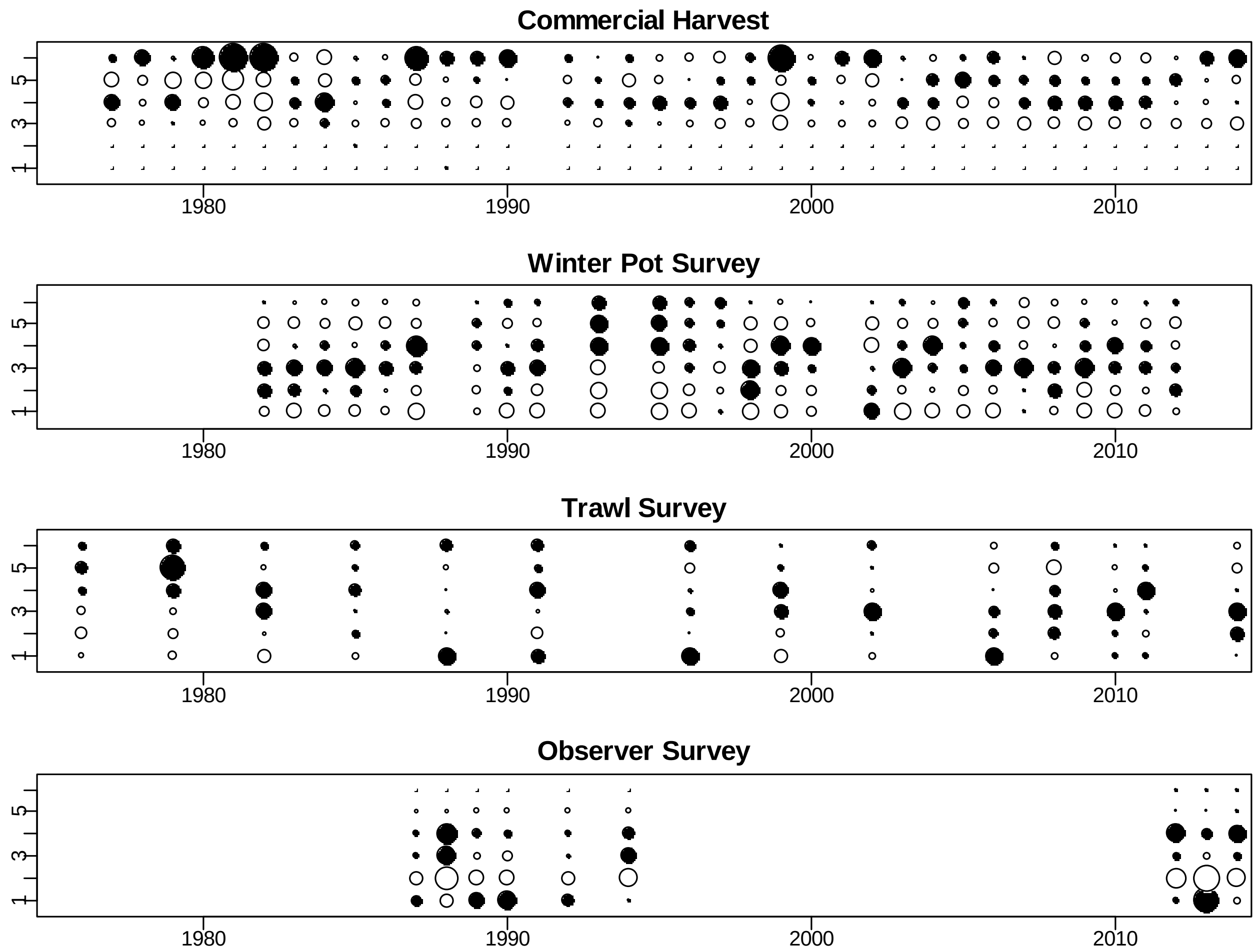
1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C3-10: Predicted (dashed line) vs. observed (black dots) length class proportion for winter pot survey



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C3-11: Predicted (dashed line) vs. observed (black dots) length class proportion for trawl survey and observer survey



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C3-12: Bubble plot of predicted and observed length proportion . Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicate degree of deviance (larger circle = larger deviance).

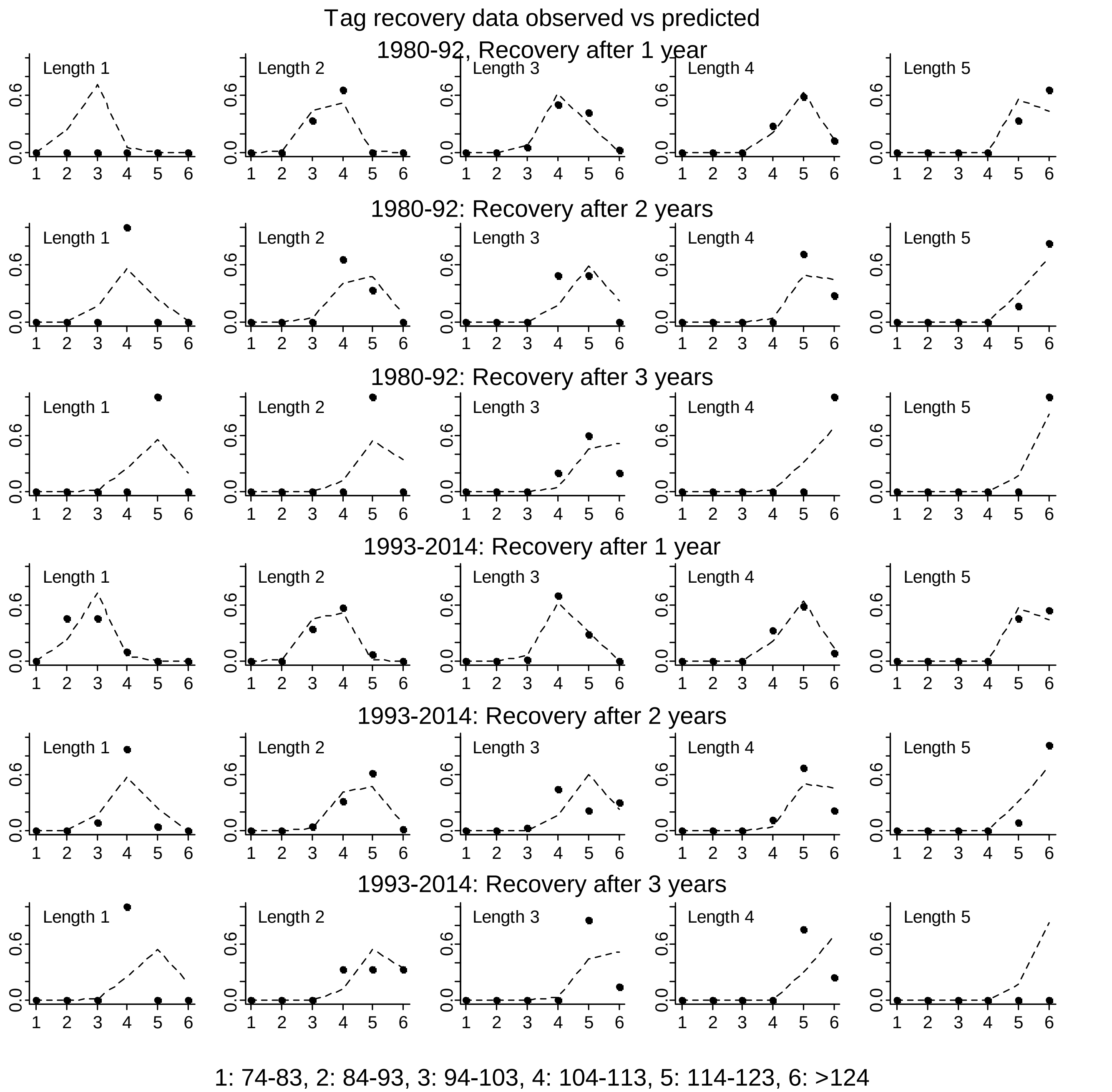
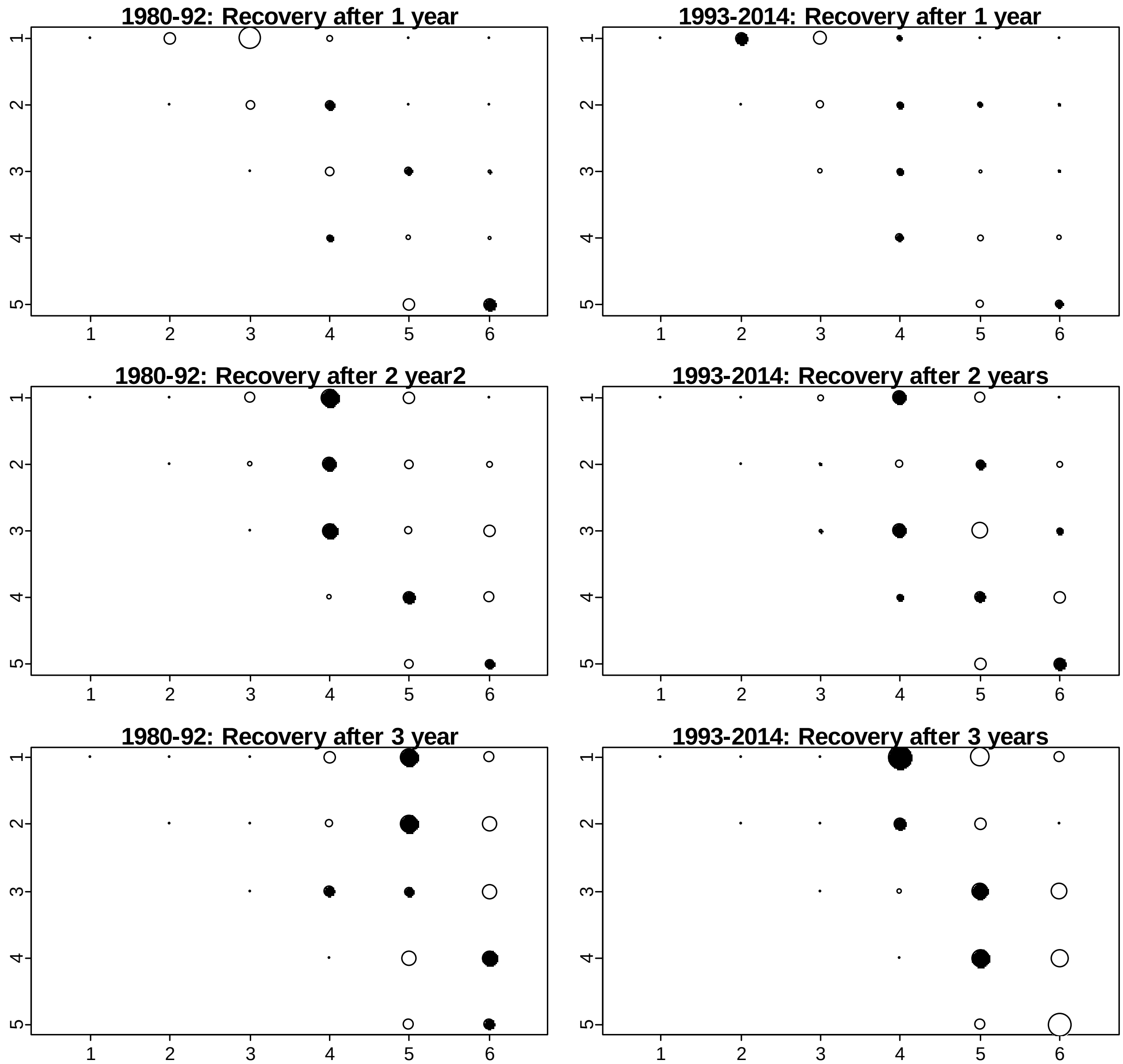


Figure C3-13: Predicted vs. observed length class proportion for tag recovery data 1980-1992, and 1993-2014:



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C3-14: Bubble plot of predicted vs. observed length class proportion for tag recovery data 1980-1992, and 1993-2014:

Table C3-1 . 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	-7.2176	0.1805
log_q_2	-7.0309	0.093333
log_N_{76}	9.1211	0.15957
R_0	6.5171	0.070141
$log\_\sigma_R^2$	0.30409	0.46236
log_R_{77}	-0.26608	0.39184
log_R_{78}	-0.72726	0.35463
log_R_{79}	-0.31435	0.38272
log_R_{80}	0.58792	0.26648
log_R_{81}	0.2934	0.28261
log_R_{82}	0.2703	0.32665
log_R_{83}	0.68811	0.27189
log_R_{84}	0.32209	0.29393
log_R_{85}	0.26882	0.31001
log_R_{86}	0.31723	0.26586
log_R_{87}	0.004382	0.2714
log_R_{88}	0.077068	0.26439
log_R_{89}	-0.08253	0.26903
log_R_{90}	-0.54831	0.29556
log_R_{91}	-0.37248	0.28053
log_R_{92}	-0.88449	0.32019
log_R_{93}	-0.58086	0.28374
log_R_{94}	-0.54005	0.27747
log_R_{95}	-0.20784	0.23538
log_R_{96}	-0.02517	0.27768
log_R_{97}	0.41586	0.21341
log_R_{98}	-0.65499	0.31988
log_R_{99}	-0.37687	0.31366
log_R_{00}	-0.01518	0.28277
log_R_{01}	0.18113	0.22872
log_R_{02}	0.38636	0.27371
log_R_{03}	-0.28422	0.34102
log_R_{04}	-0.10123	0.29073
log_R_{05}	0.51816	0.1996
log_R_{06}	-0.03695	0.30198
log_R_{07}	0.59517	0.20504
log_R_{08}	0.34852	0.2666
log_R_{09}	0.021378	0.2684
log_R_{10}	-0.11698	0.26211
log_R_{11}	-0.18468	0.2909
log_R_{12}	0.45683	0.30116
log_R_{13}	0.26369	0.34828
a_1	0.26973	1.9082
a_2	1.7902	1.3712
a_3	2.1566	1.3255
a_4	2.4659	1.3028
a_5	1.6572	1.3575
r1	0.51166	0.04434
log_α	-1.8095	0.018184
log_ϕ_{st1}	-14.633	1218.6
log_ϕ_{st2}	-2.5079	15493

log_ϕ_w	-1.8572	0.048906
Sw_6		
log_ϕ_1	-1.8451	0.093991
log_ϕ_2	-1.8208	0.098123
w^2_t	0.051556	0.017566
q	0.69375	0.12407
σ	4.567	0.20487
β_1	9.7	0.63122
β_2	7.7074	0.20045

Appendix C4: Results Model 4

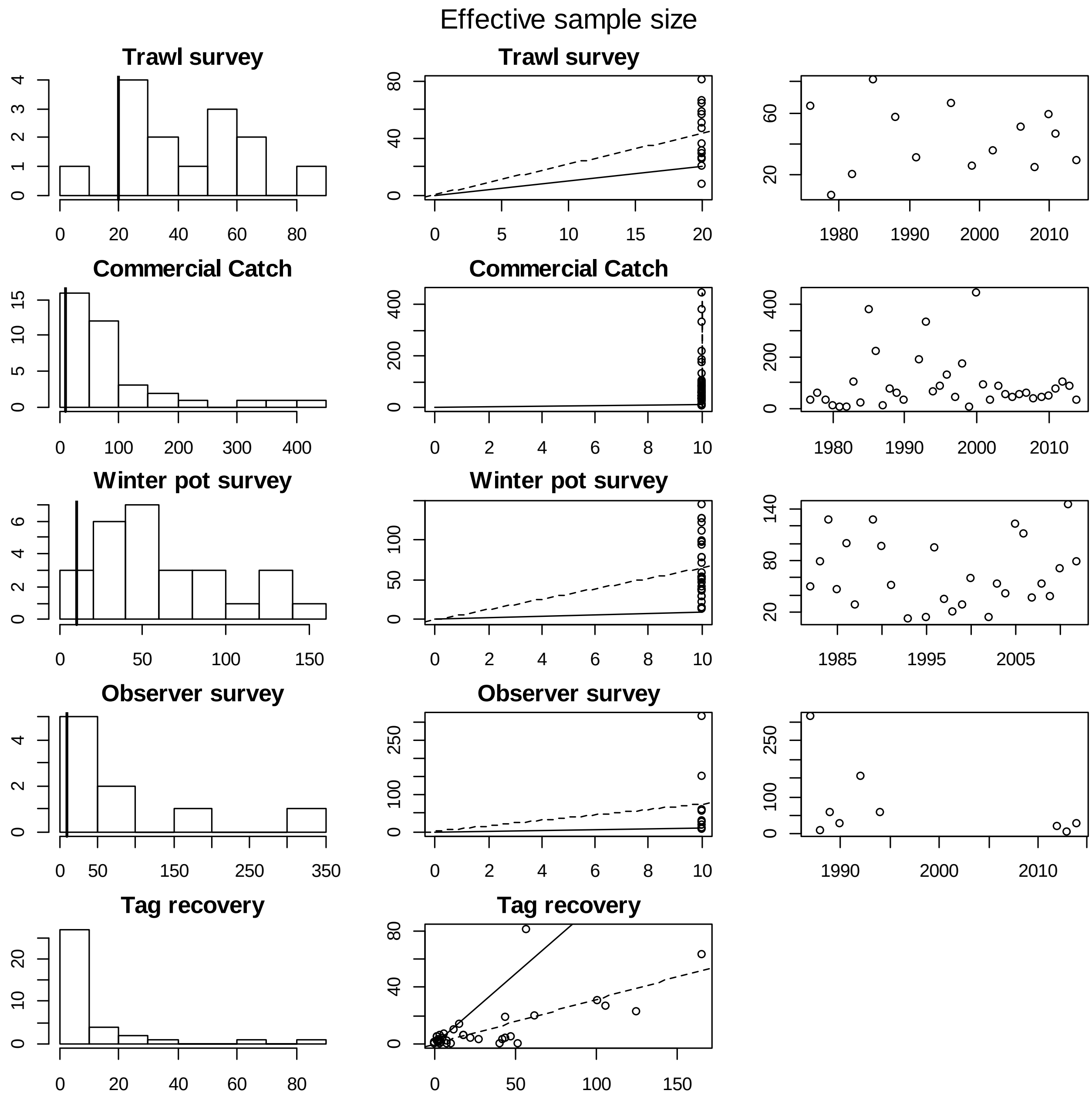


Figure C4-1: Effective sample size vs. implied sample size. Figures in the first column show effective sample size (x-axis) vs. frequency (y-axis). Vertical solid line is the implied sample size. Figures in the second column show implied sample size (x-axis) vs. effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. Figures in the third column show year (x-axis) vs. effective sample size (y-axis).

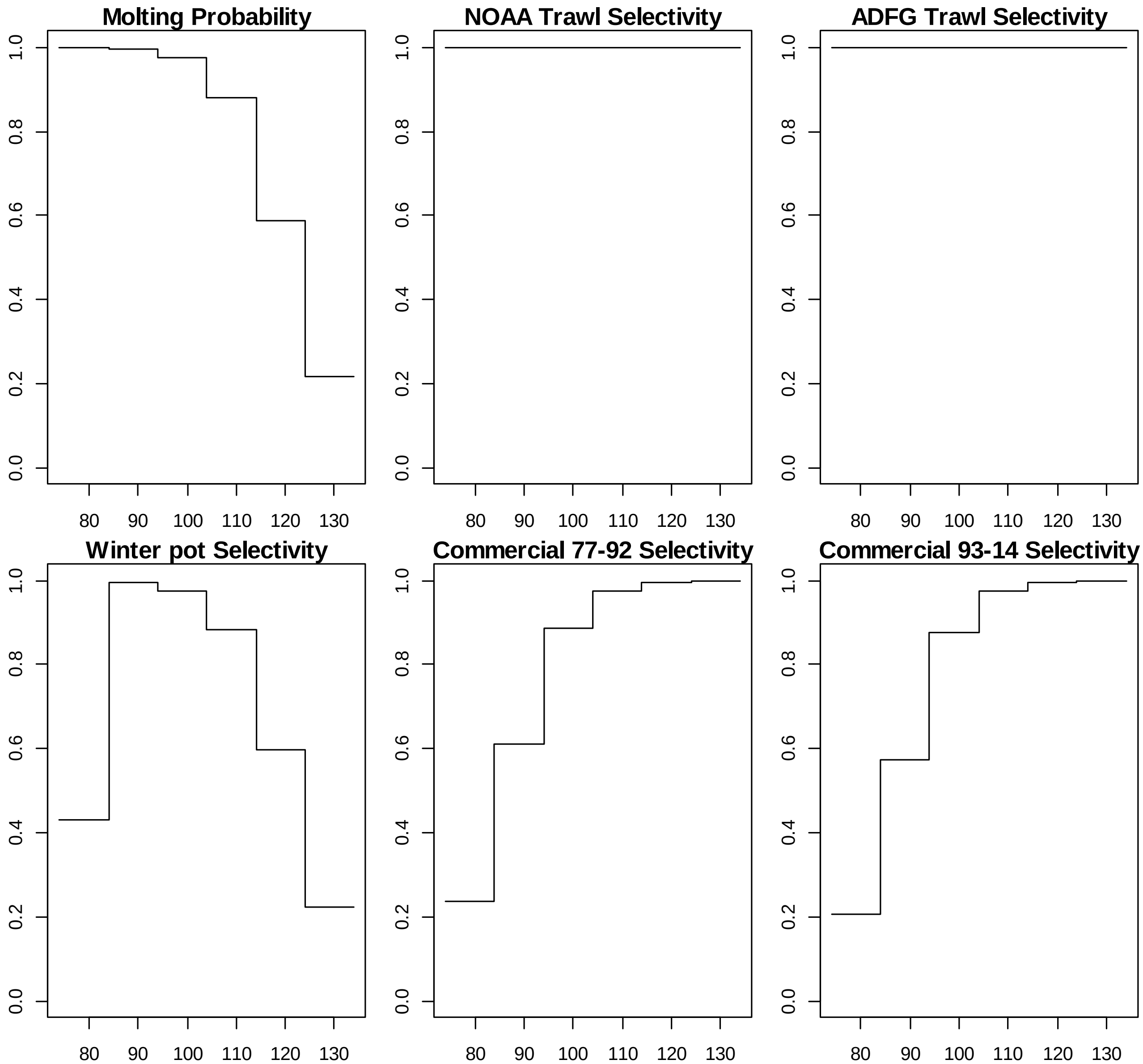


Figure C4-2. Molting probability and trawl/pot selectivities. X-axis is carapace length.

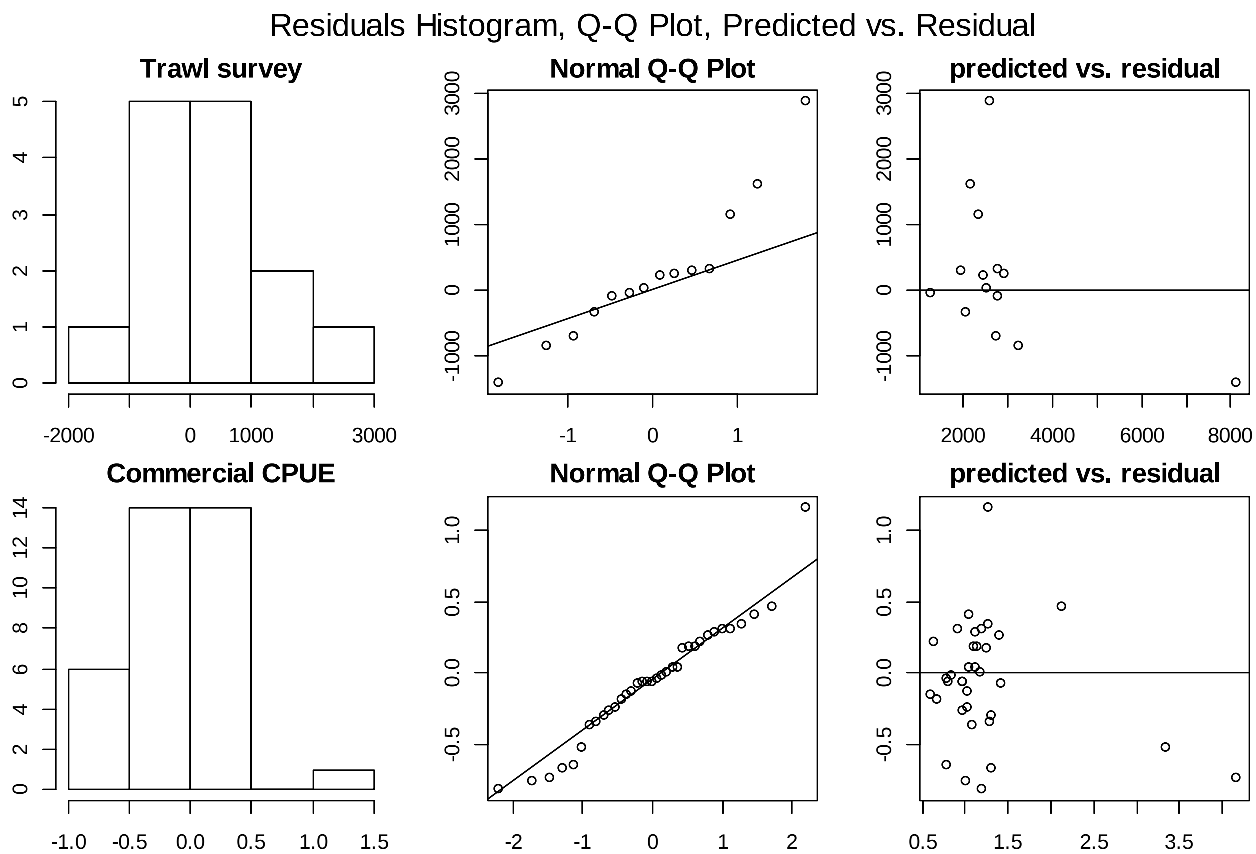


Figure C4-3. QQ Plot of Trawl survey and Commercial CPUE

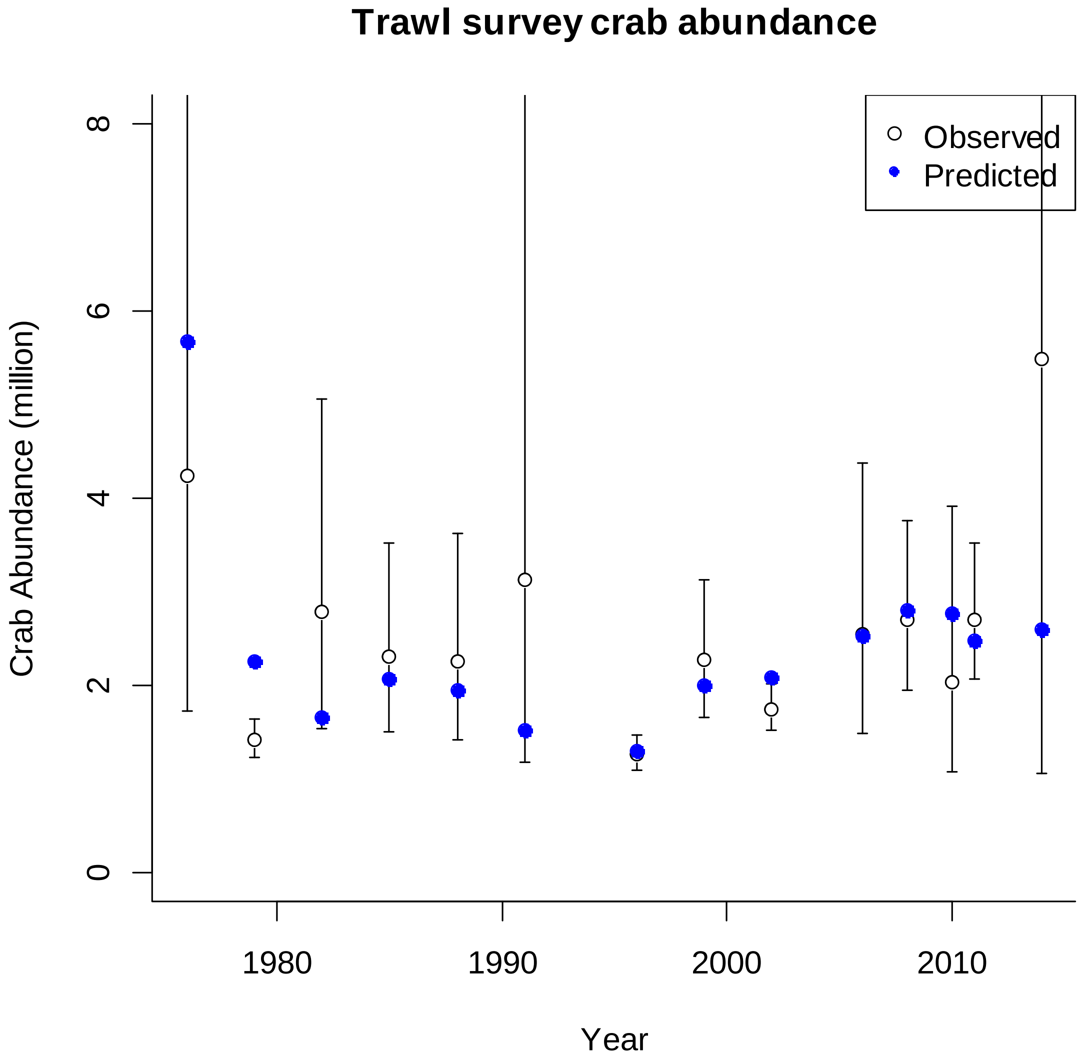


Figure C4-4. Estimated trawl survey abundance (crabs ≥ 74 mm CL) male

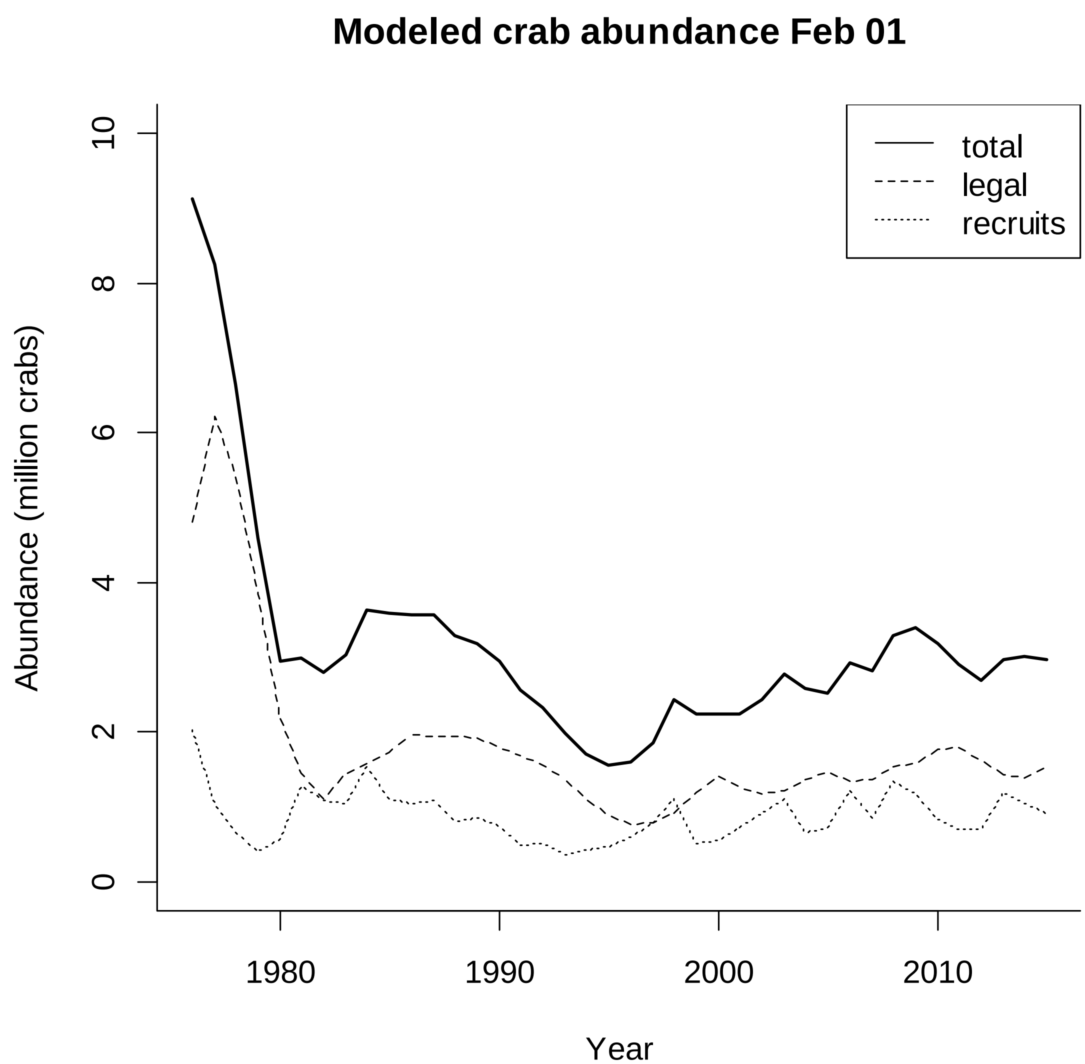


Figure C4-5. Estimated abundance of legal male from 1976-2014

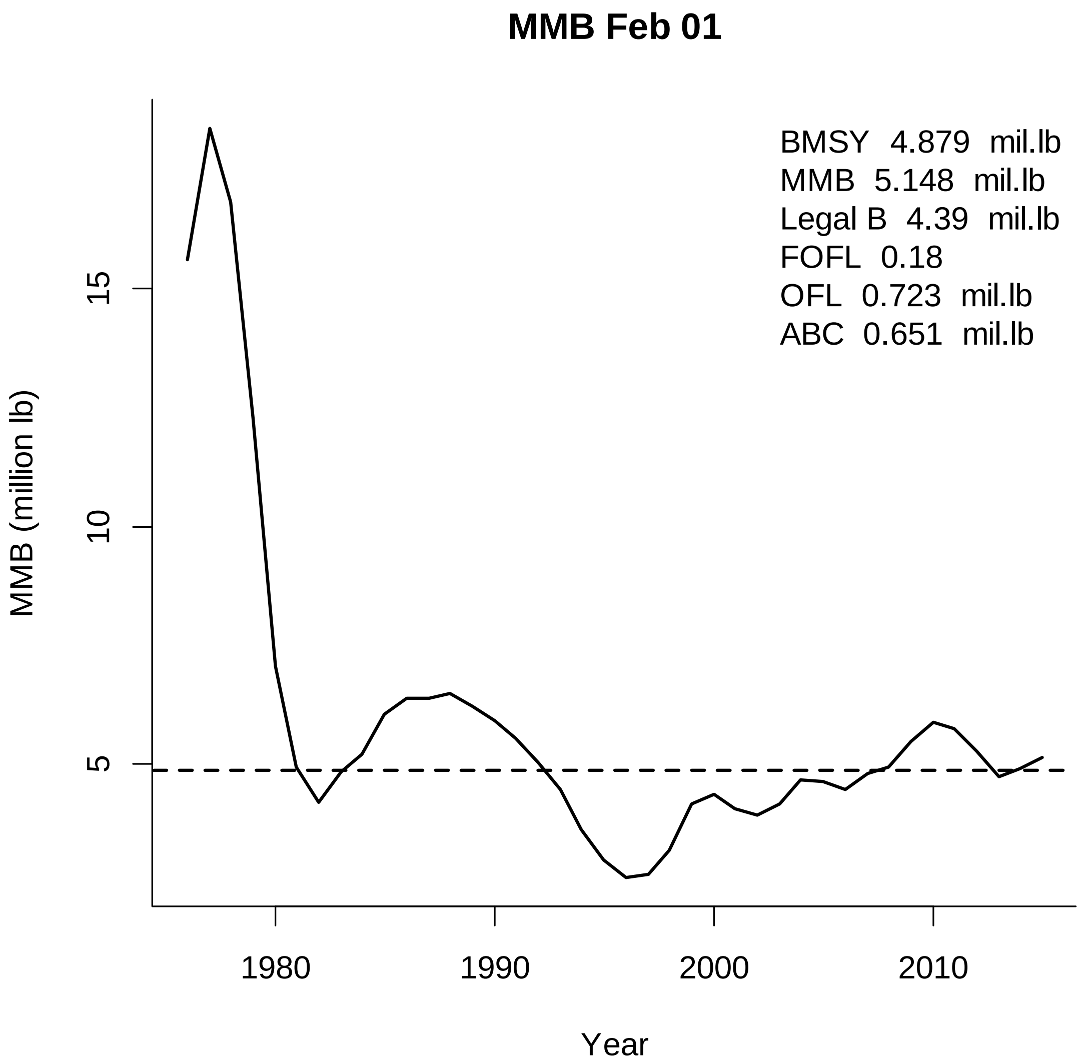


Figure C4-6. Estimated abundance of leg recruits from 1976-2015. Dash line shows Bmsy (Average MMB of 1980-2015)

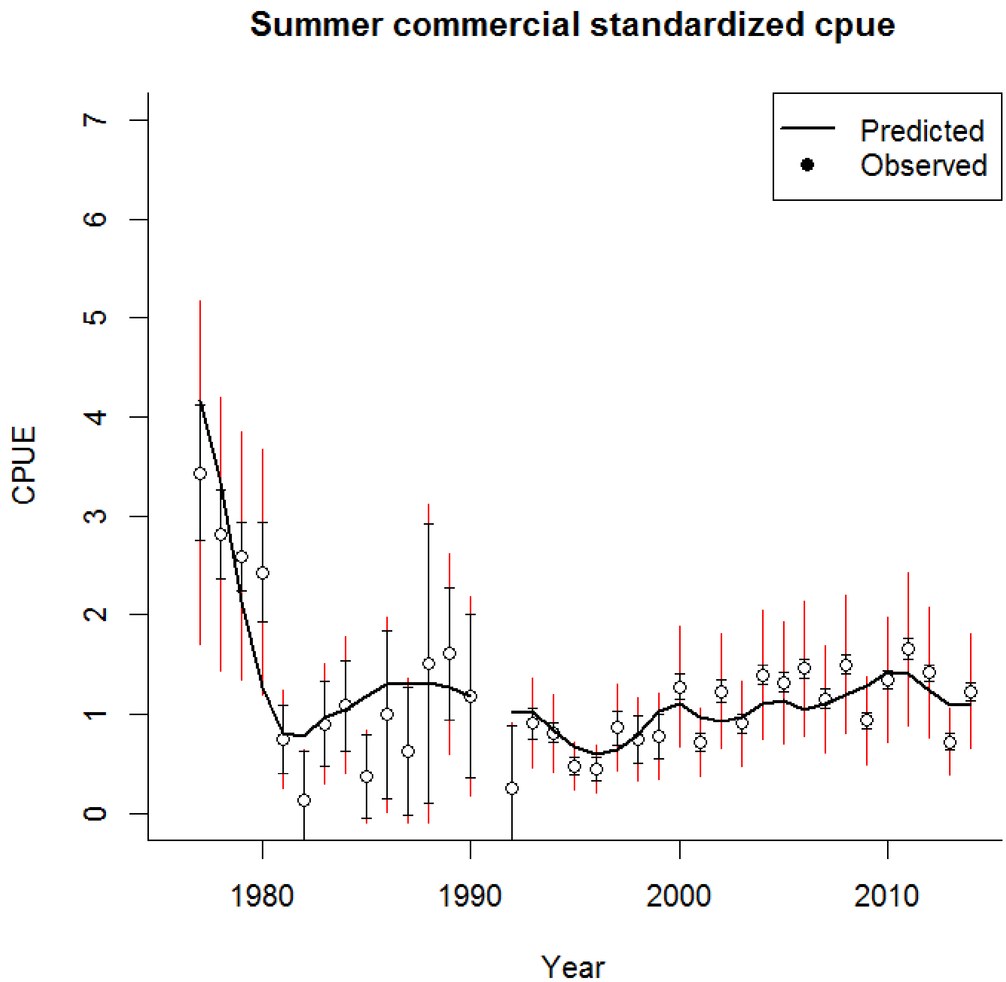


Figure C4-7. Summer commercial standardized cpue (1977-2014)

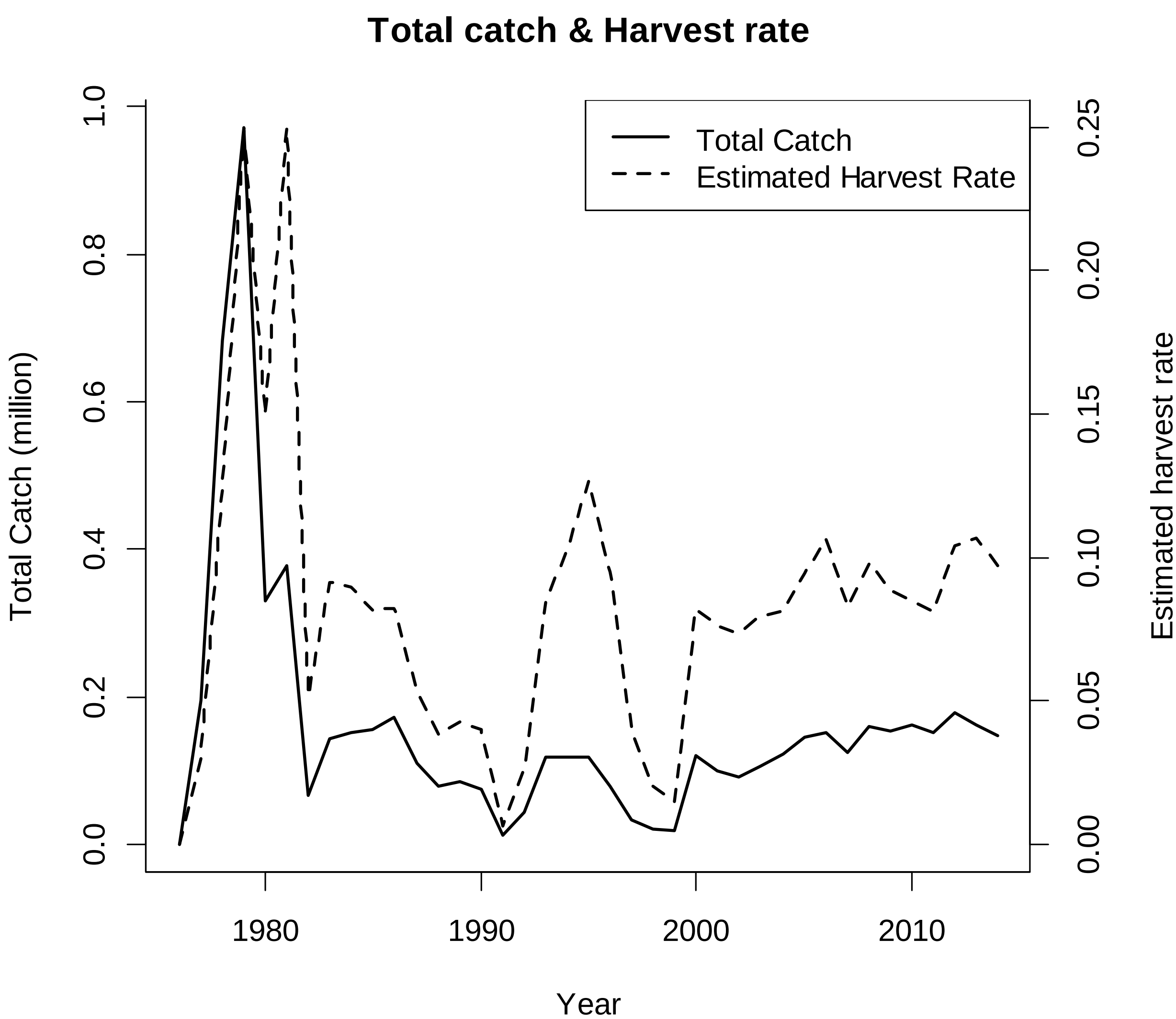
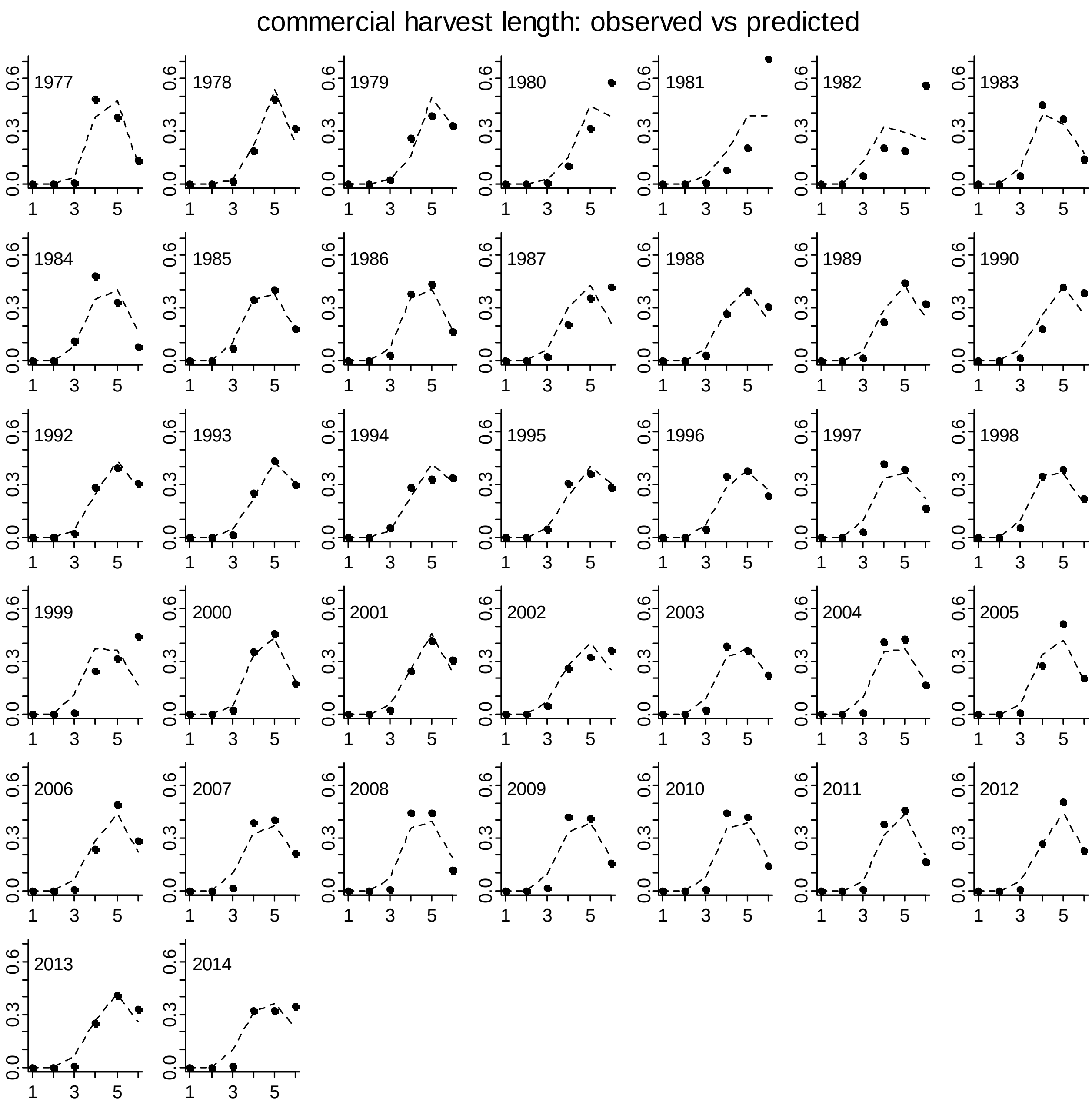
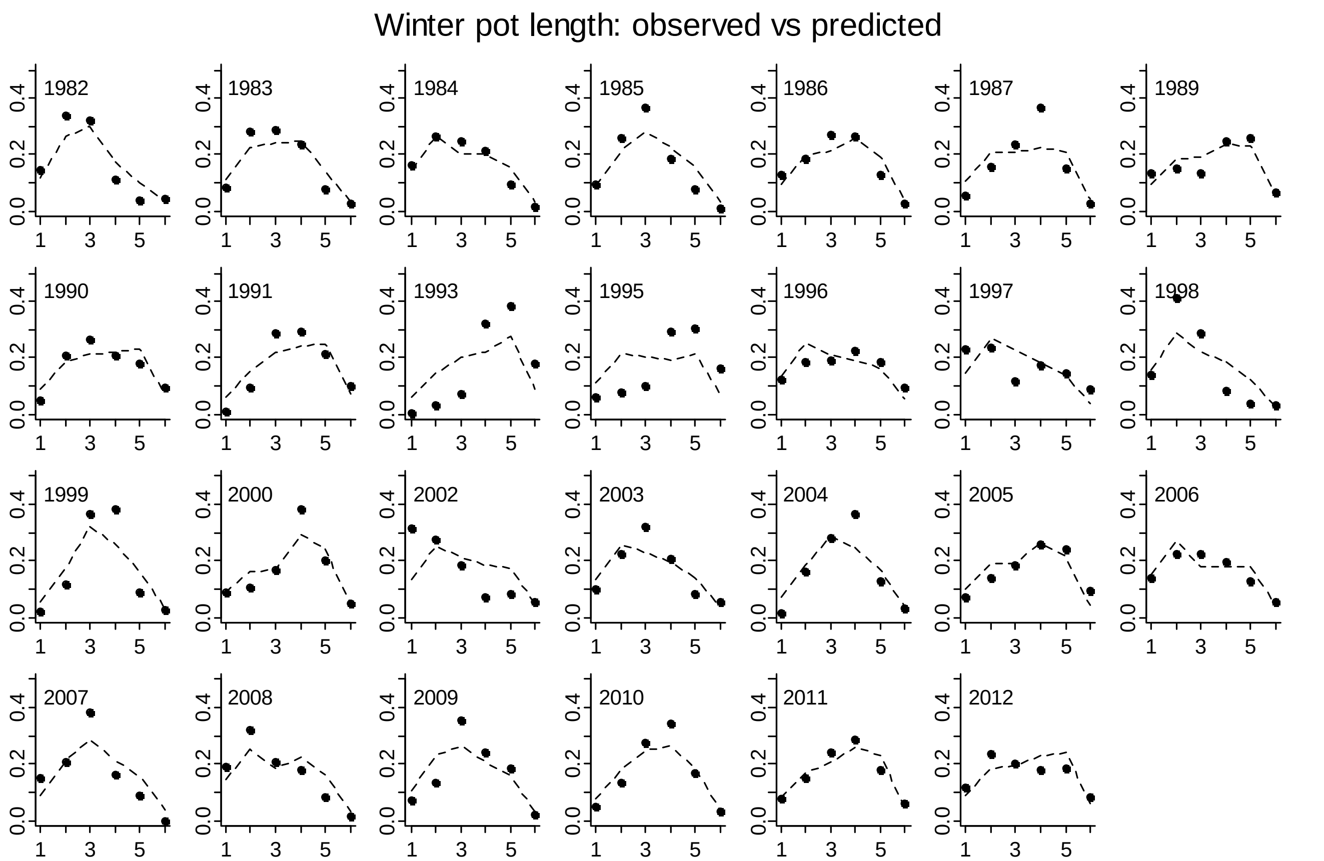


Figure C4-8: Total catch and estimated harvest rate 1976-2014



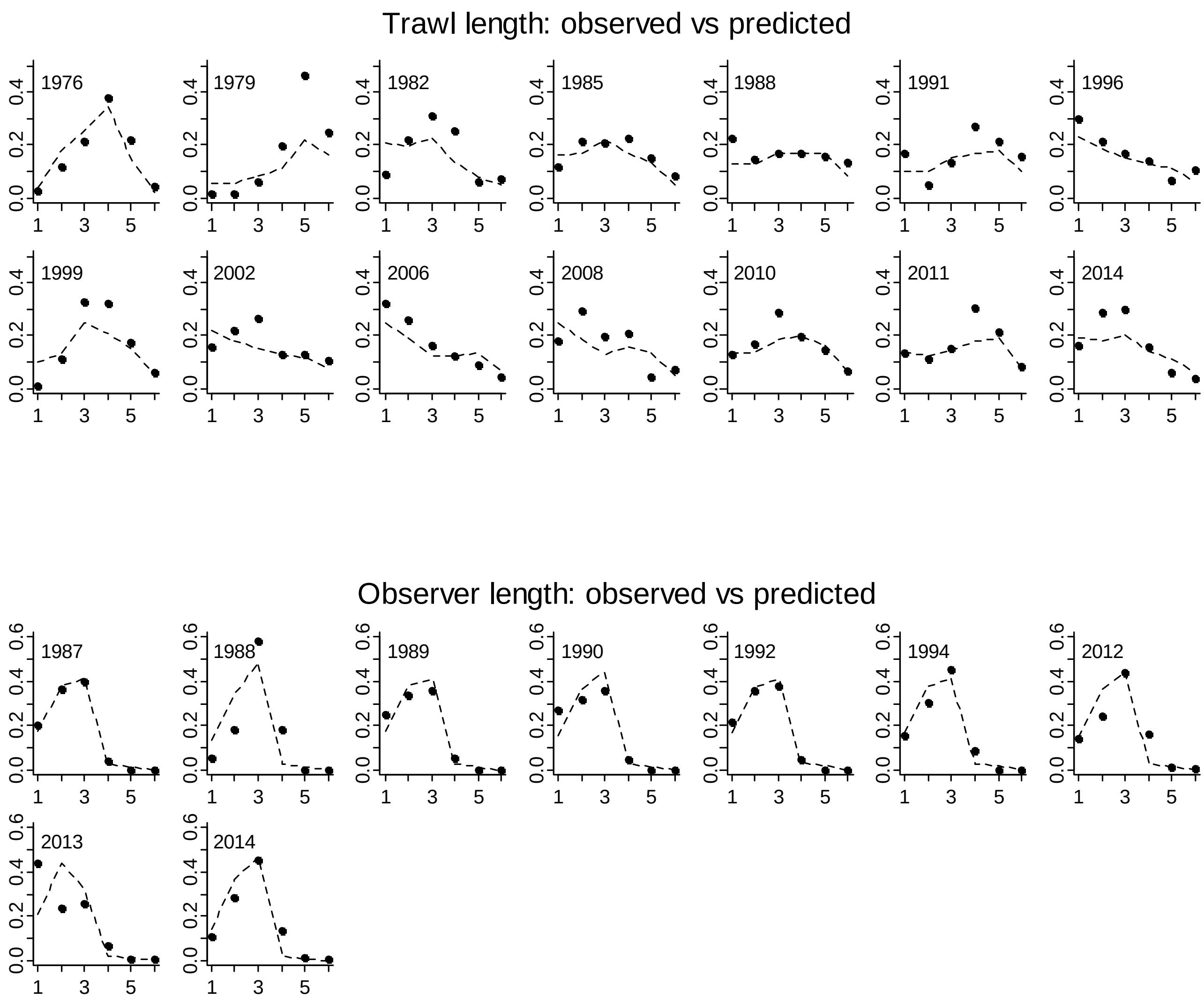
1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C4-9: Predicted (dashed line) vs. observed (black dots) length class proportion for commercial catch:



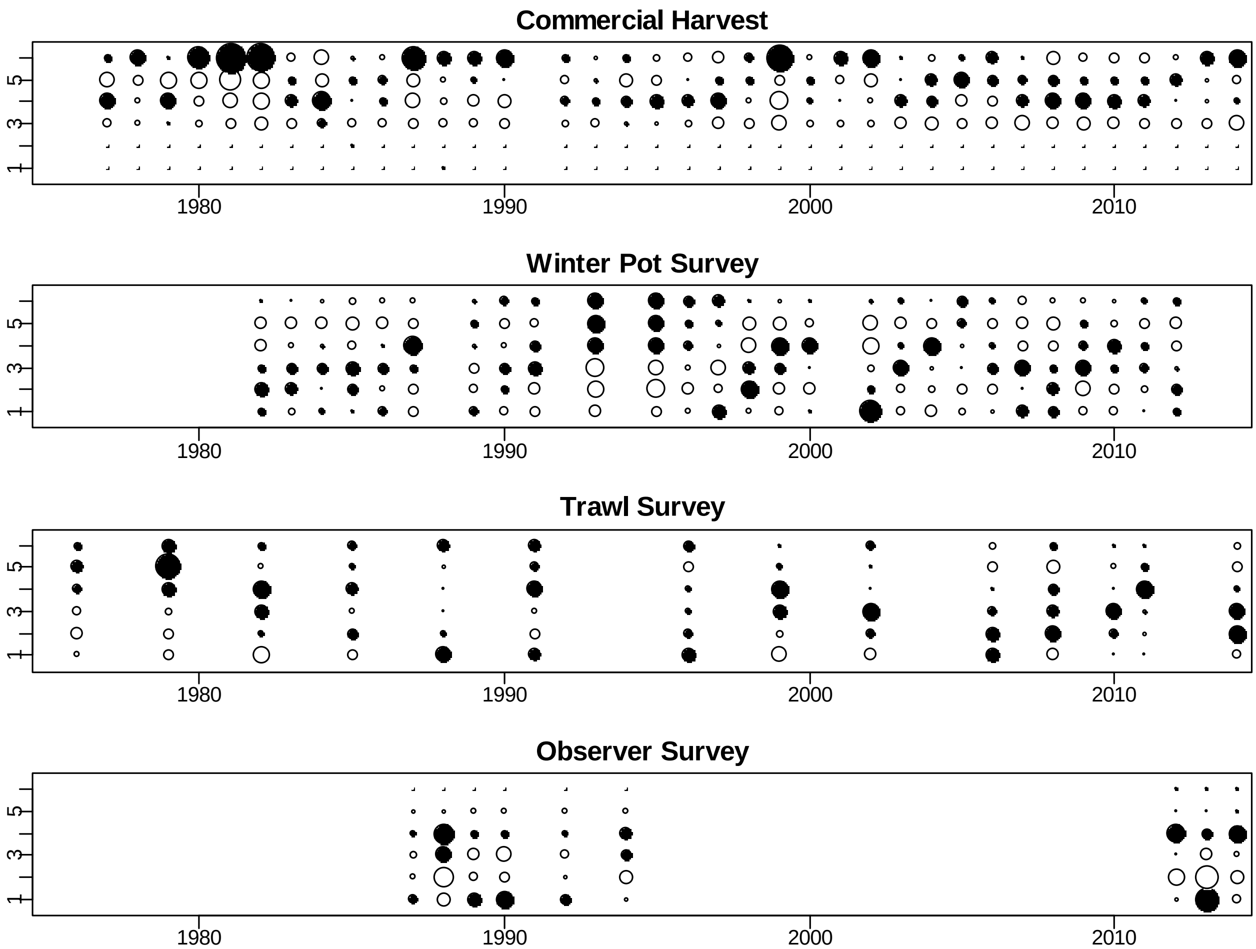
1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C4-10: Predicted (dashed line) vs. observed (black dots) length class proportion for winter pot survey



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C4-11: Predicted (dashed line) vs. observed (black dots) length class proportion for trawl survey and observer survey



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C4-12: Bubble plot of predicted and observed length proportion . Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicate degree of deviance (larger circle = larger deviance).

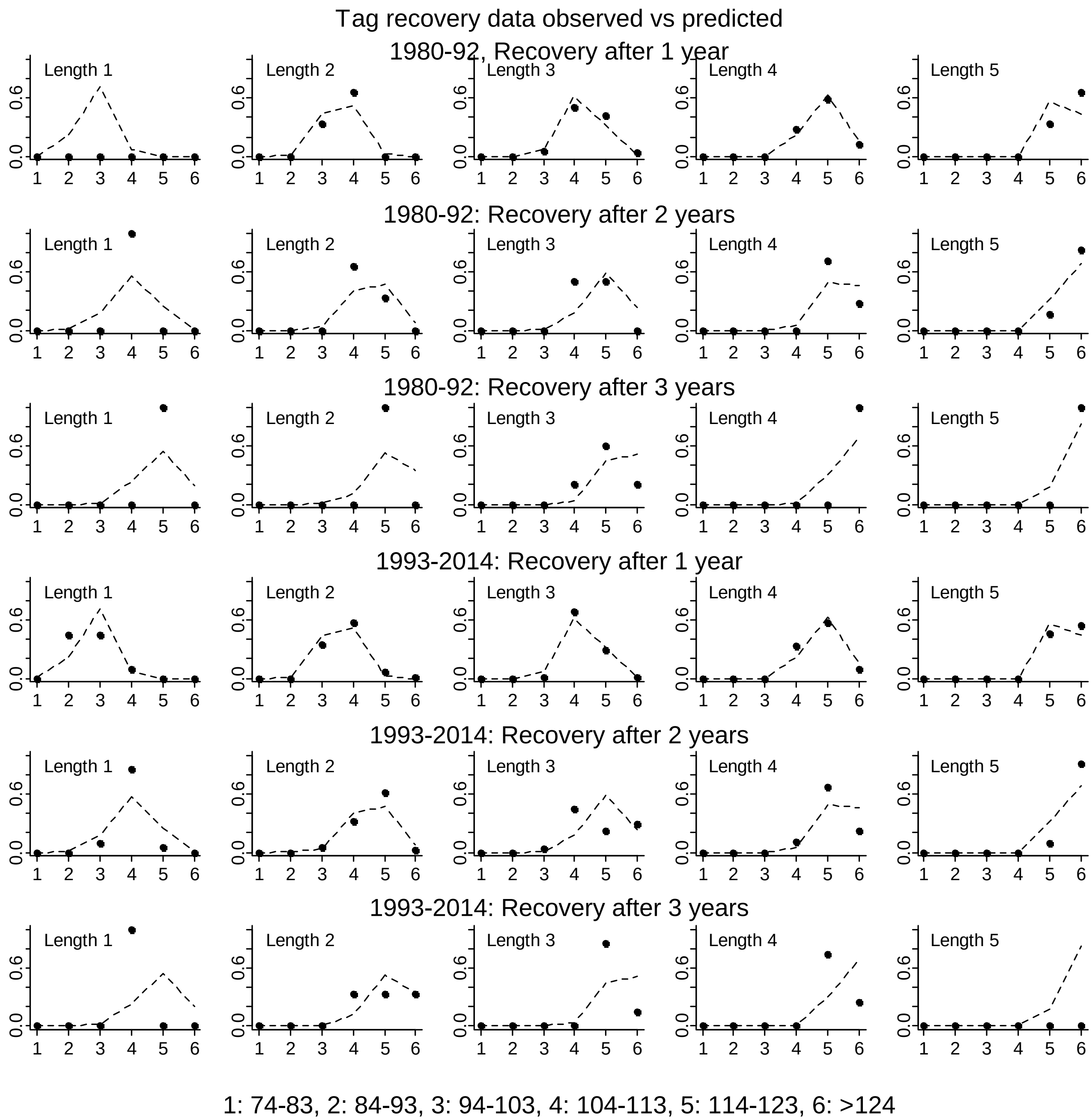
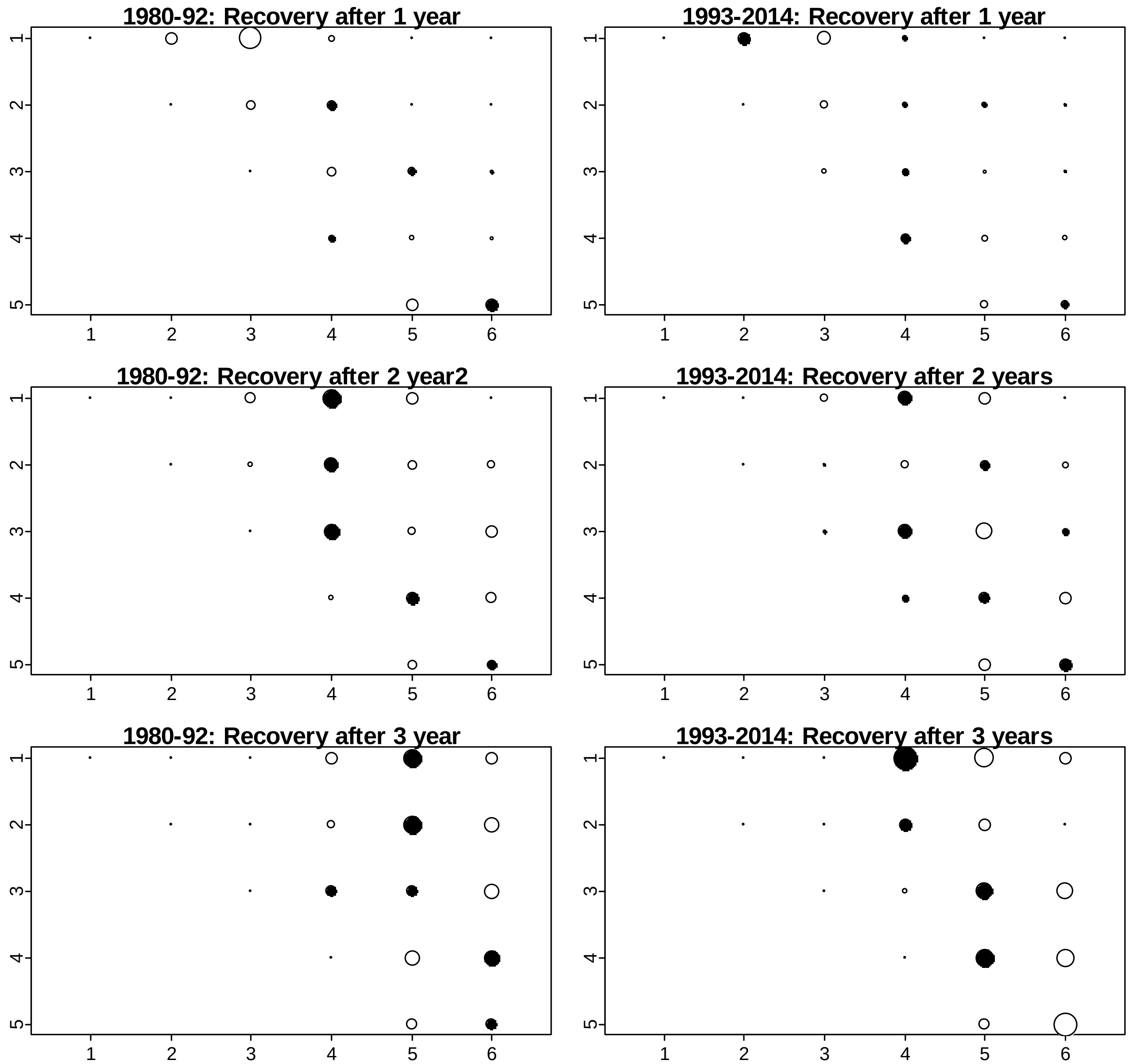


Figure C4-13: Predicted vs. observed length class proportion for tag recovery data 1980-1992, and 1993-2014:



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C4-14: Bubble plot of predicted vs. observed length class proportion for tag recovery data 1980-1992, and 1993-2014:

Table C4-1 . 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	-7.2007	0.17984
log_q_2	-7.012	0.093943
log_N_{76}	9.12	0.15753
R_0	6.5168	0.069861
$log\_\sigma_R{}^2$	0.30721	0.45469
log_R_{77}	-0.30085	0.38974
log_R_{78}	-0.73562	0.35409
log_R_{79}	-0.27985	0.3816
log_R_{80}	0.56302	0.27212
log_R_{81}	0.27521	0.28978
log_R_{82}	0.28151	0.32921
log_R_{83}	0.71707	0.27177
log_R_{84}	0.26055	0.30733
log_R_{85}	0.28923	0.31347
log_R_{86}	0.33146	0.26982
log_R_{87}	-0.04833	0.27741
log_R_{88}	0.088558	0.26734
log_R_{89}	-0.07871	0.27109
log_R_{90}	-0.5462	0.29931
log_R_{91}	-0.40695	0.28289
log_R_{92}	-0.8547	0.32056
log_R_{93}	-0.61636	0.28558
log_R_{94}	-0.50884	0.27609
log_R_{95}	-0.23007	0.24
log_R_{96}	0.034955	0.27414
log_R_{97}	0.38802	0.21982
log_R_{98}	-0.67758	0.32486
log_R_{99}	-0.3138	0.31012
log_R_{00}	-0.05479	0.29043
log_R_{01}	0.19204	0.23028
log_R_{02}	0.36308	0.27723
log_R_{03}	-0.29049	0.34326
log_R_{04}	-0.05957	0.29124
log_R_{05}	0.49961	0.20451
log_R_{06}	-0.00793	0.30527
log_R_{07}	0.59015	0.20861
log_R_{08}	0.3516	0.2665
log_R_{09}	-0.01241	0.27569
log_R_{10}	-0.12878	0.26778
log_R_{11}	-0.12222	0.29413
log_R_{12}	0.48911	0.30812
log_R_{13}	0.25167	0.35643
a_1	0.33834	1.896
a_2	1.825	1.3702
a_3	2.1639	1.3271
a_4	2.4693	1.3038
a_5	1.6571	1.3583
r1	0.61885	0.053389
log_α	-1.8092	0.018122
log_ϕ_{st1}	-14.554	1490.1
log_ϕ_{st2}	-7.0019	22627

log_ϕ_w	-1.8149	0.045224
Sw_6	0.43187	0.10078
log_ϕ_1	-1.8239	0.080854
log_ϕ_2	-1.8009	0.085995
w^2_t	0.051837	0.017658
q	0.697	0.12387
σ	4.6062	0.20796
β_1	9.624	0.65185
β_2	7.741	0.2062

Appendix C5: Results Model 5

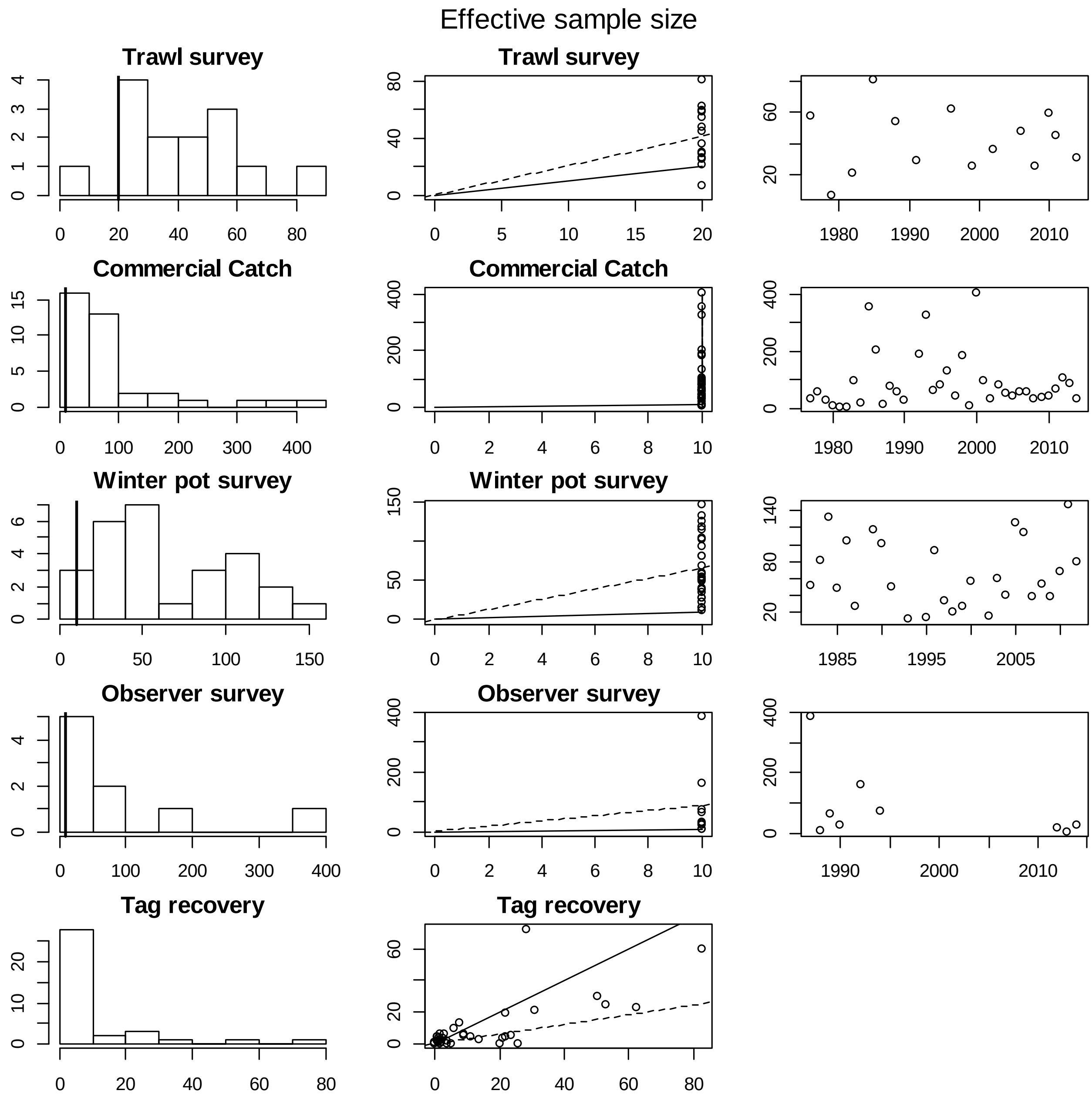


Figure C5-1: Effective sample size vs. implied sample size. Figures in the first column show effective sample size (x-axis) vs. frequency (y-axis). Vertical solid line is the implied sample size. Figures in the second column show implied sample size (x-axis) vs. effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. Figures in the third column show year (x-axis) vs. effective sample size (y-axis).

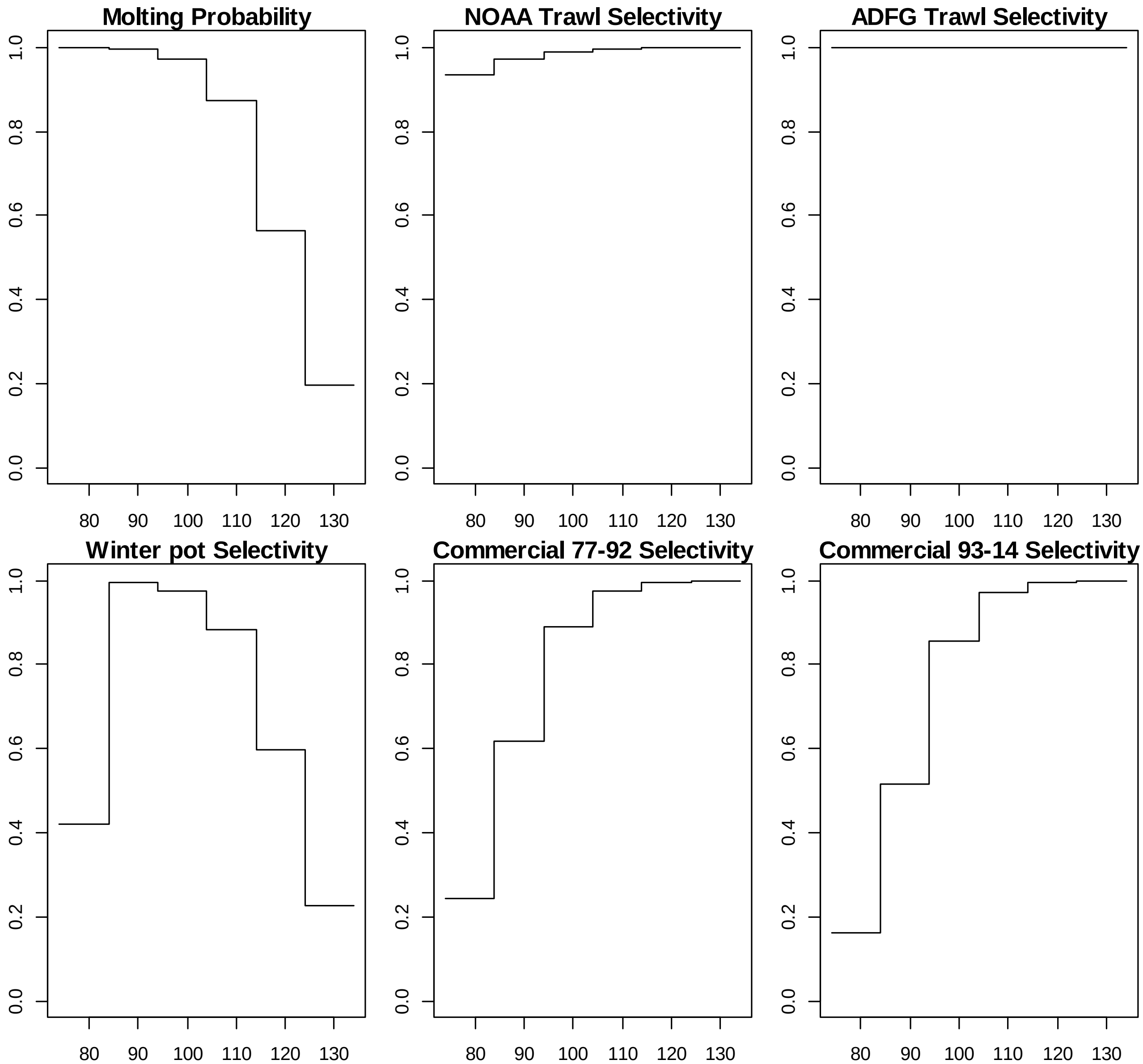


Figure C5-2. Molting probability and trawl/pot selectivities. X-axis is carapace length.

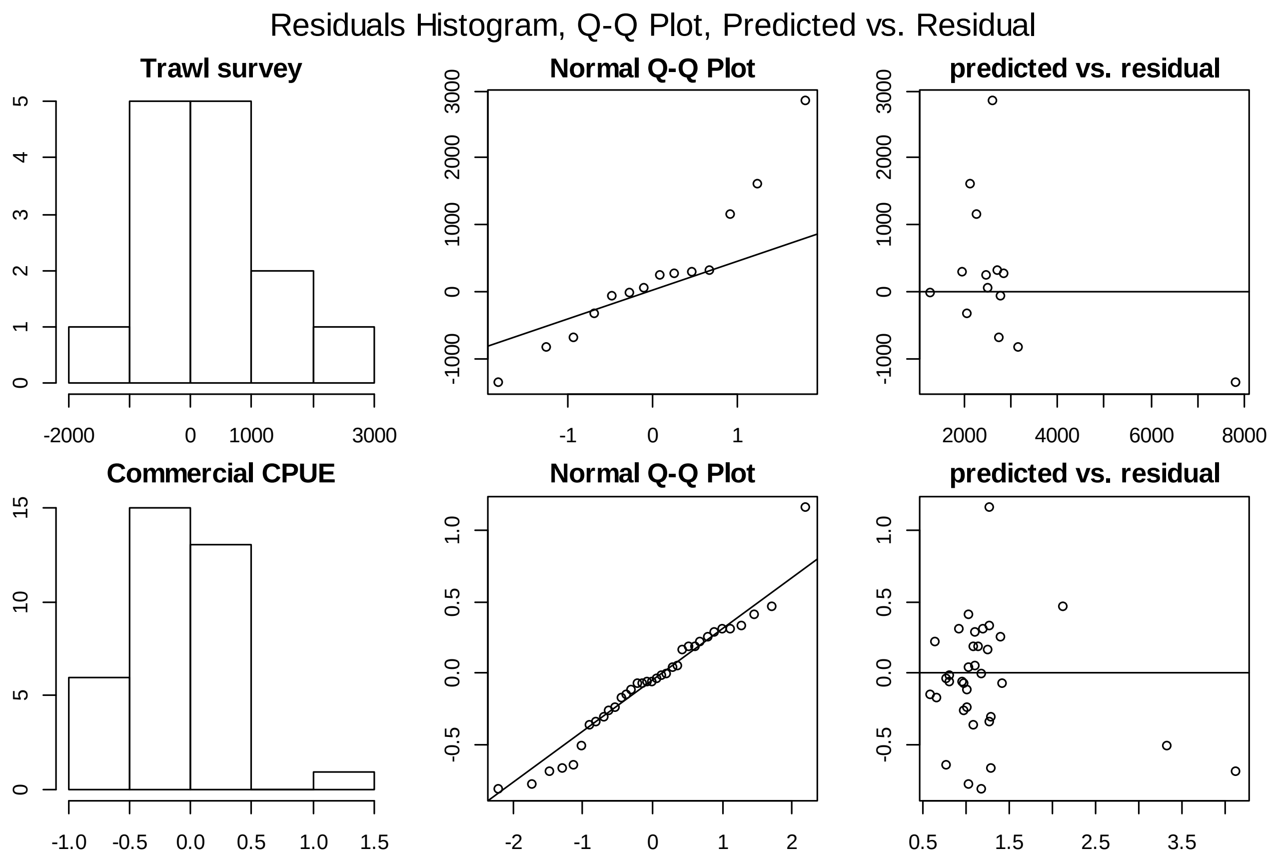


Figure C5-3. QQ Plot of Trawl survey and Commercial CPUE

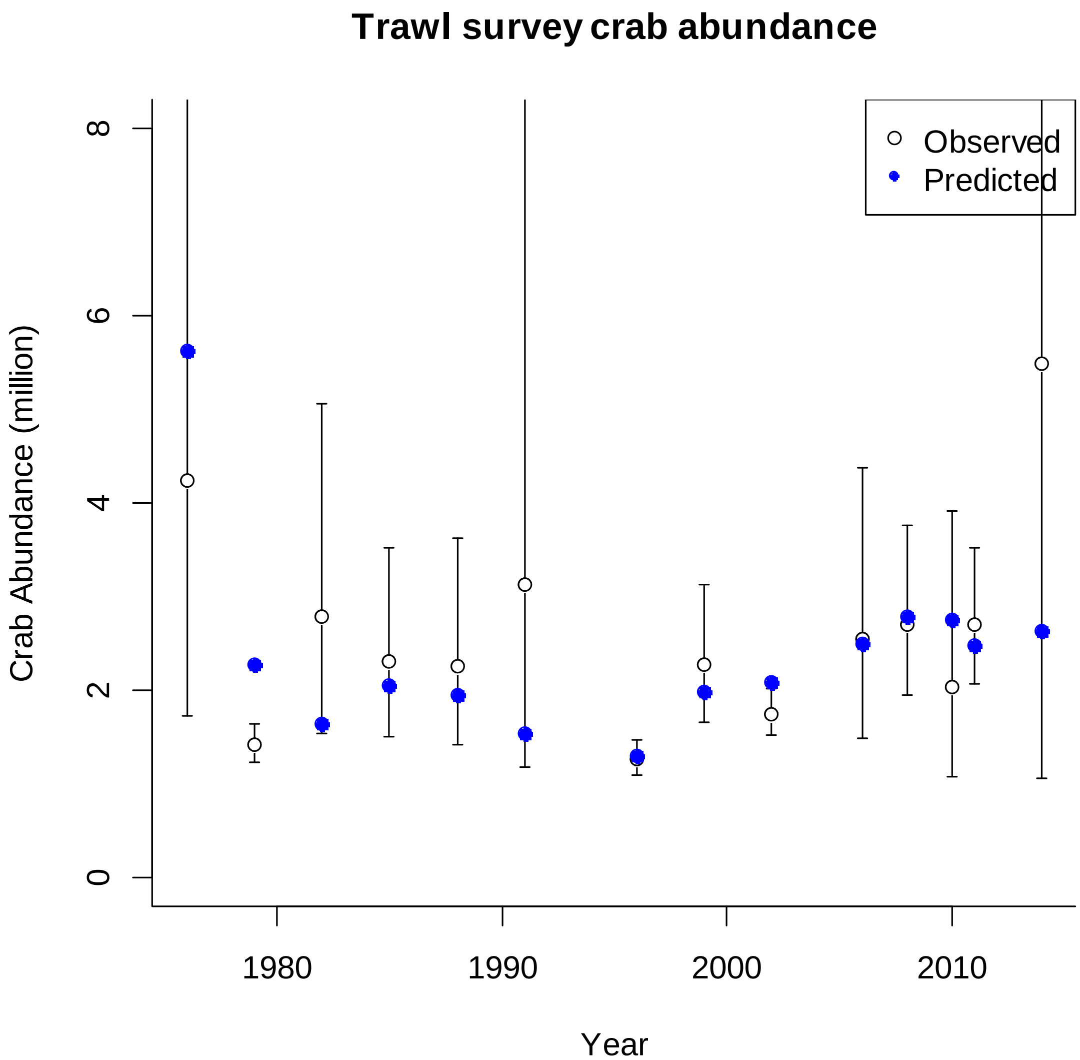


Figure C5-4. Estimated trawl survey abundance (crabs ≥ 74 mm CL) male

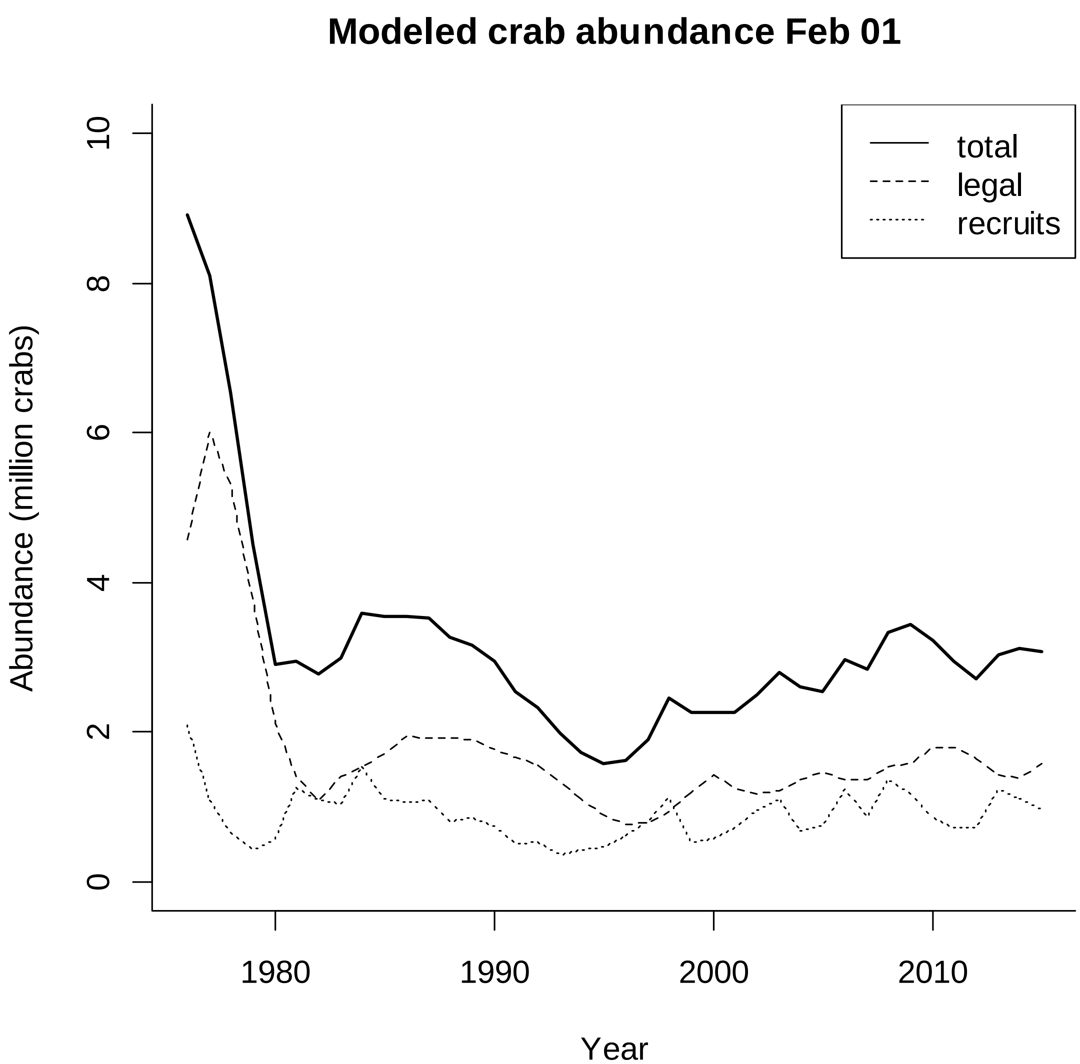


Figure C5-5. Estimated abundance of legal male from 1976-2014

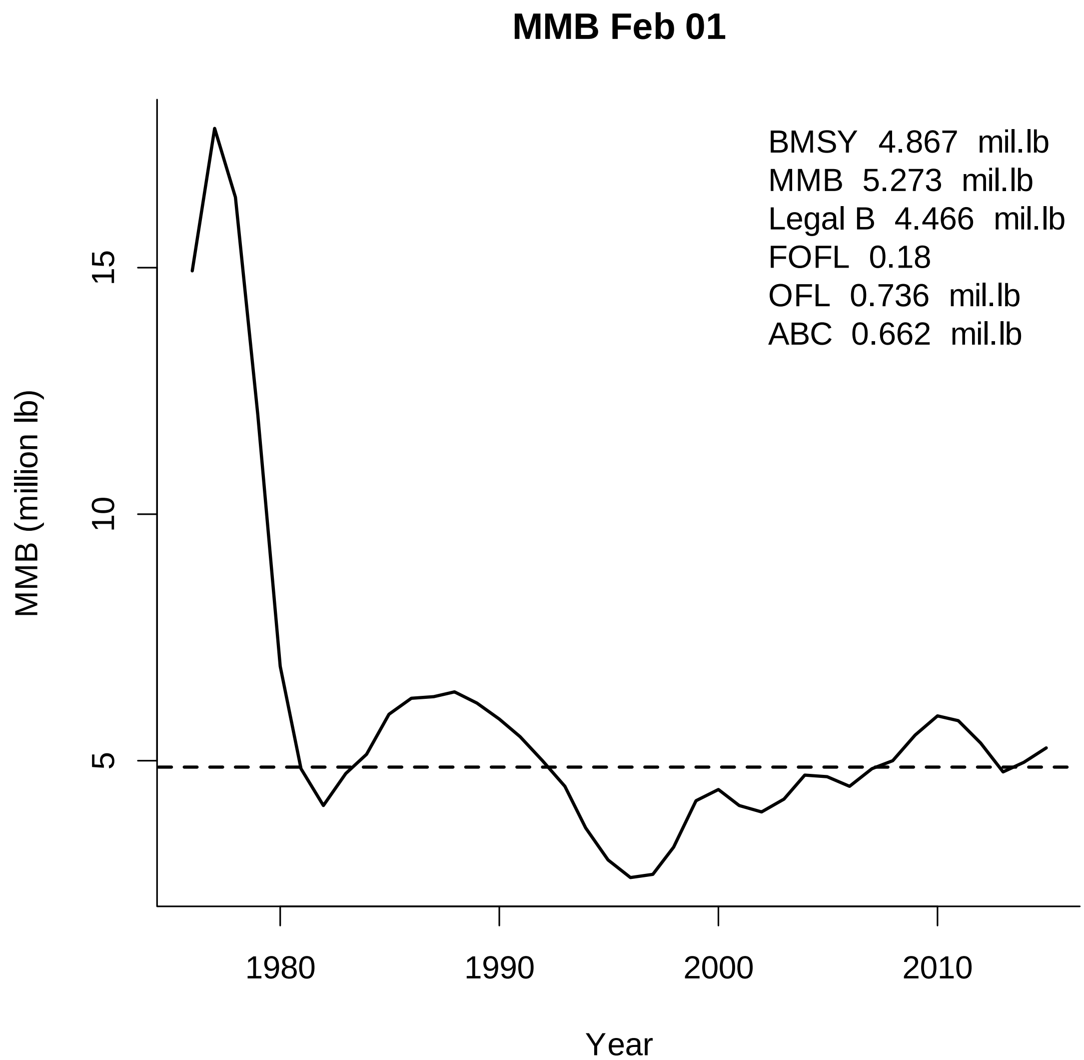


Figure C5-6. Estimated abundance of leg recruits from 1976-2015. Dash line shows Bmsy (Average MMB of 1980-2015)

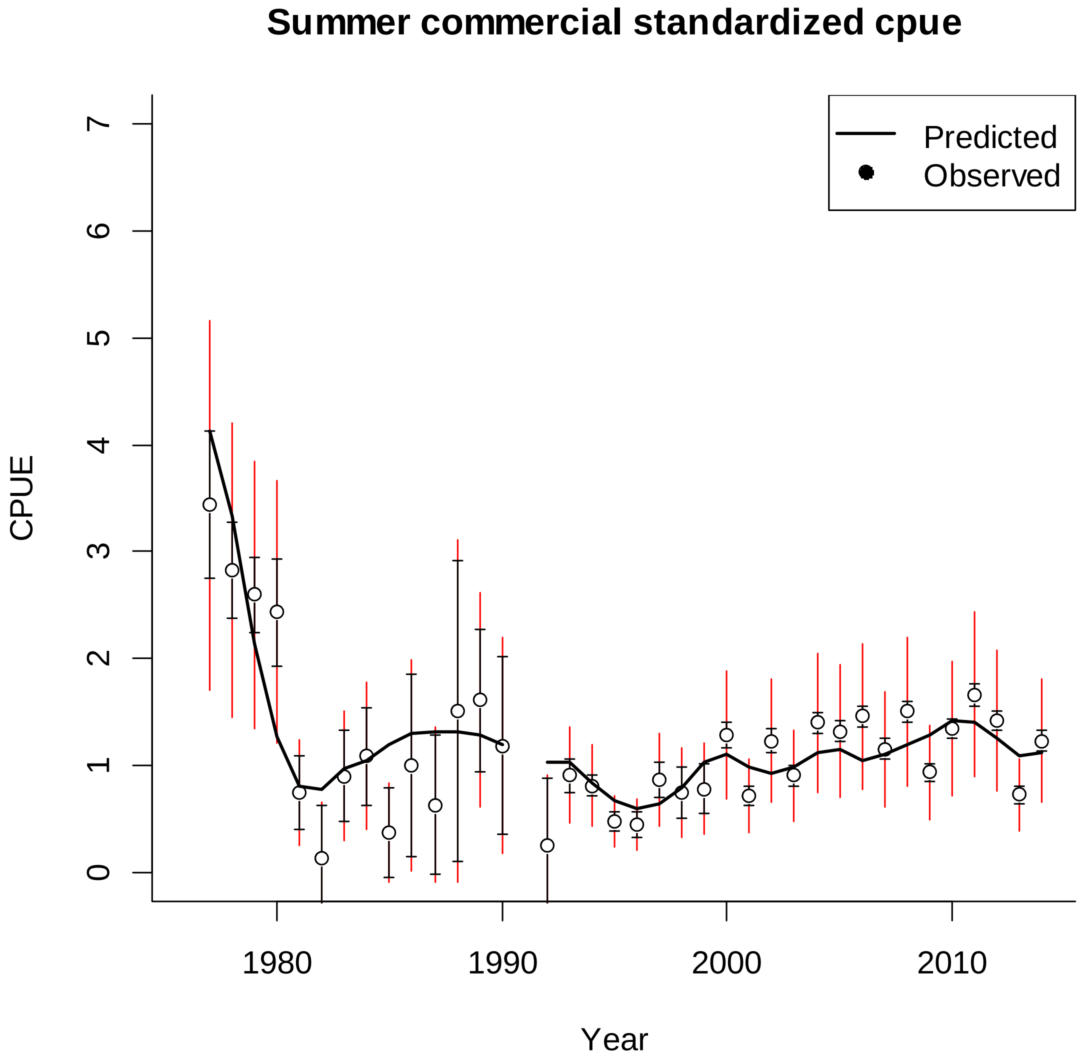


Figure C5-7. Summer commercial standardized cpue (1977-2014)

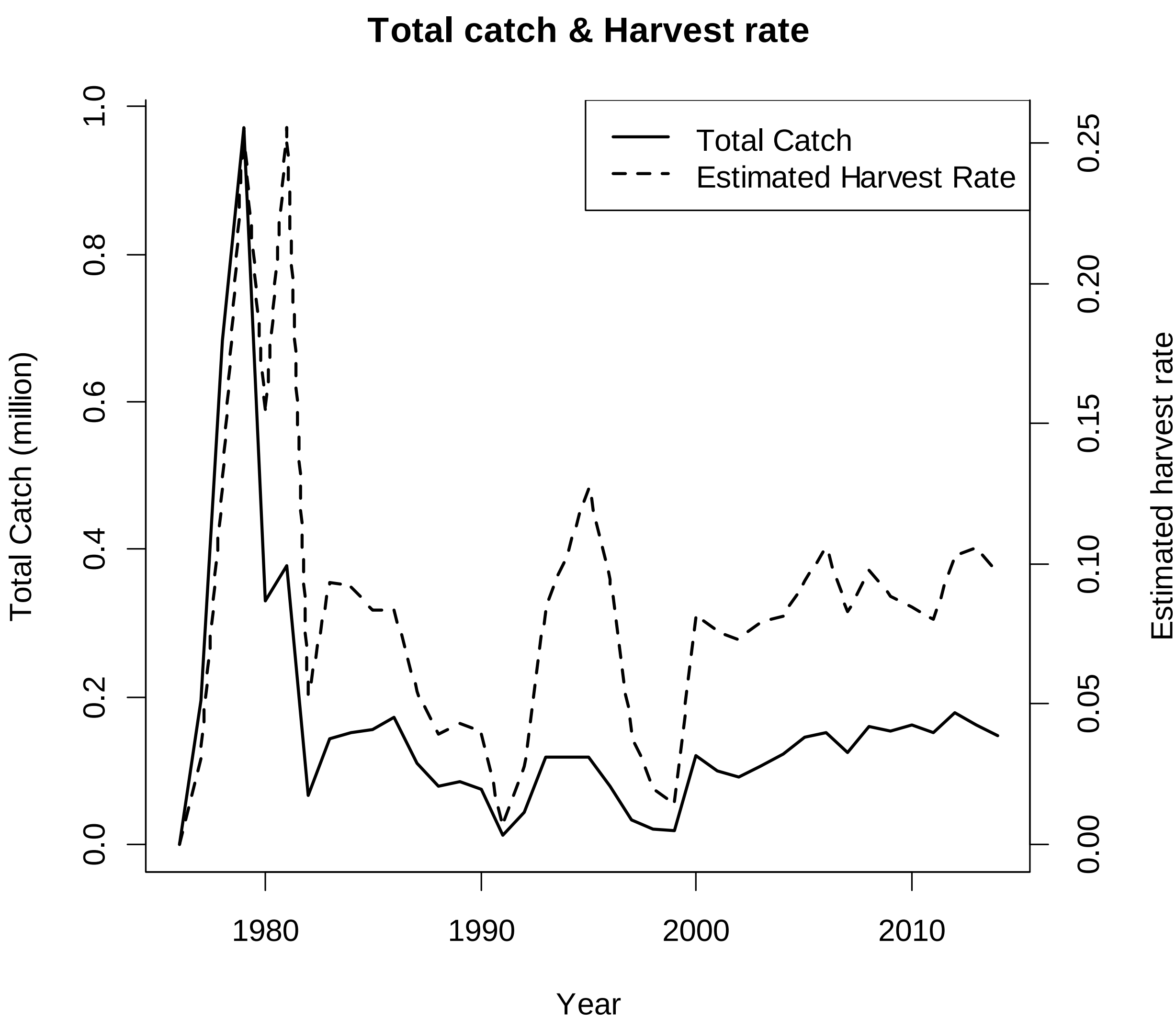


Figure C5-8: Total catch and estimated harvest rate 1976-2014

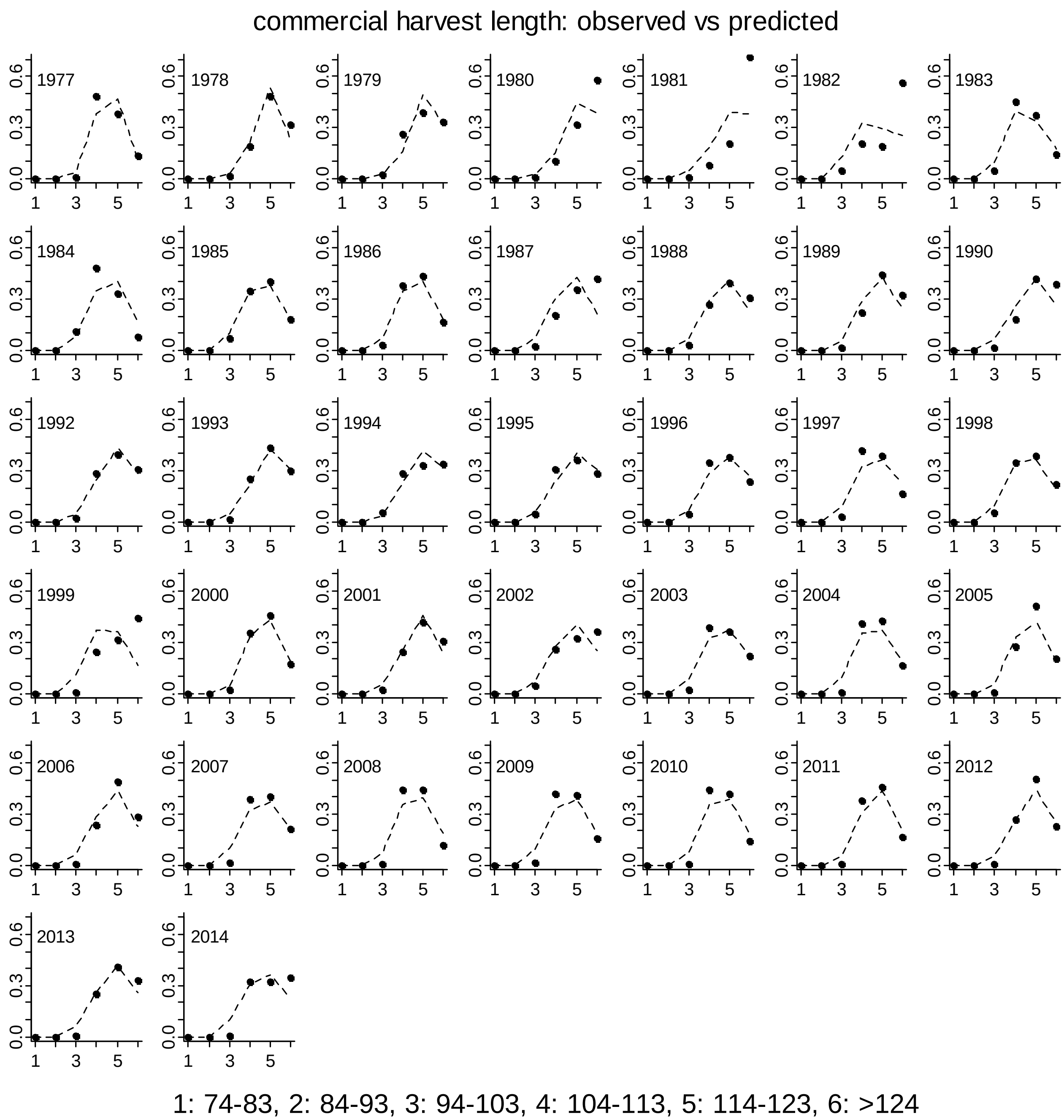
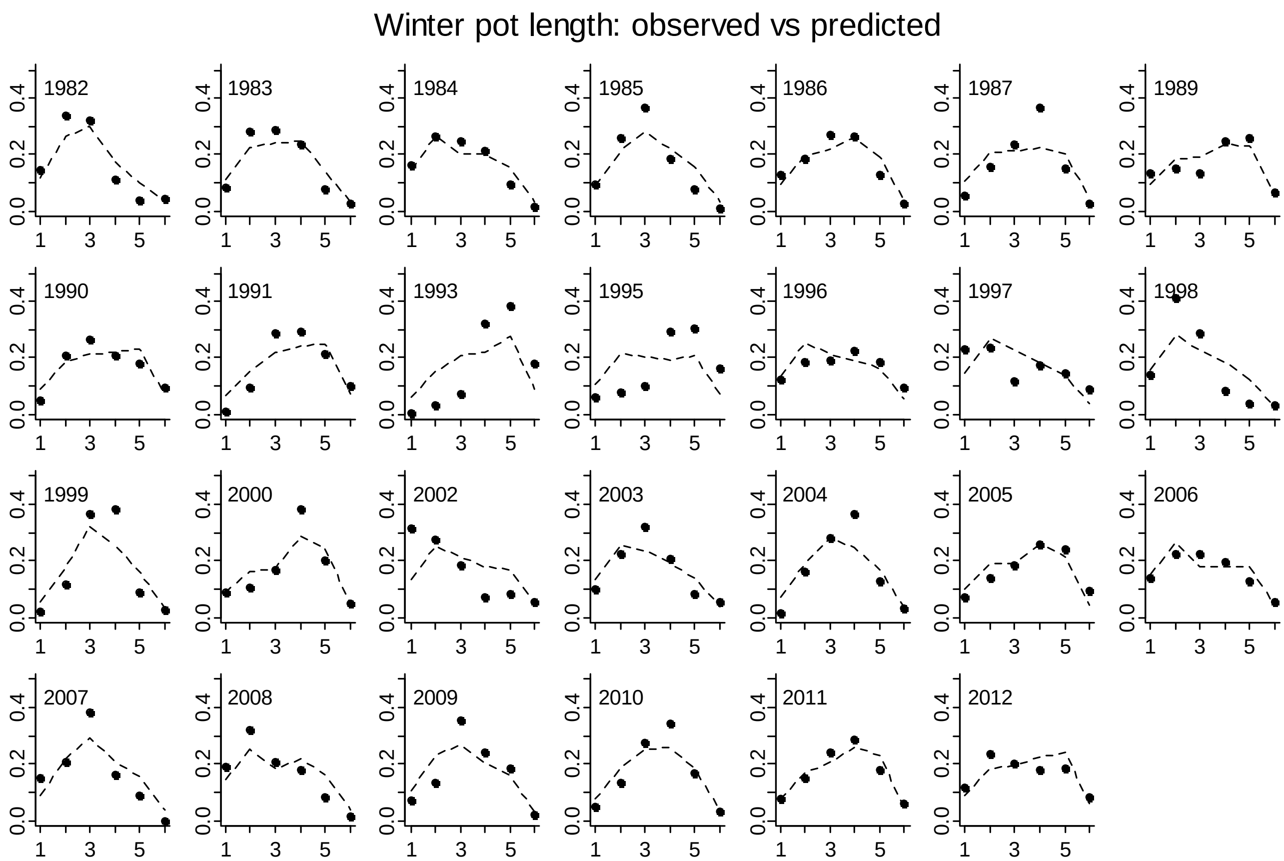
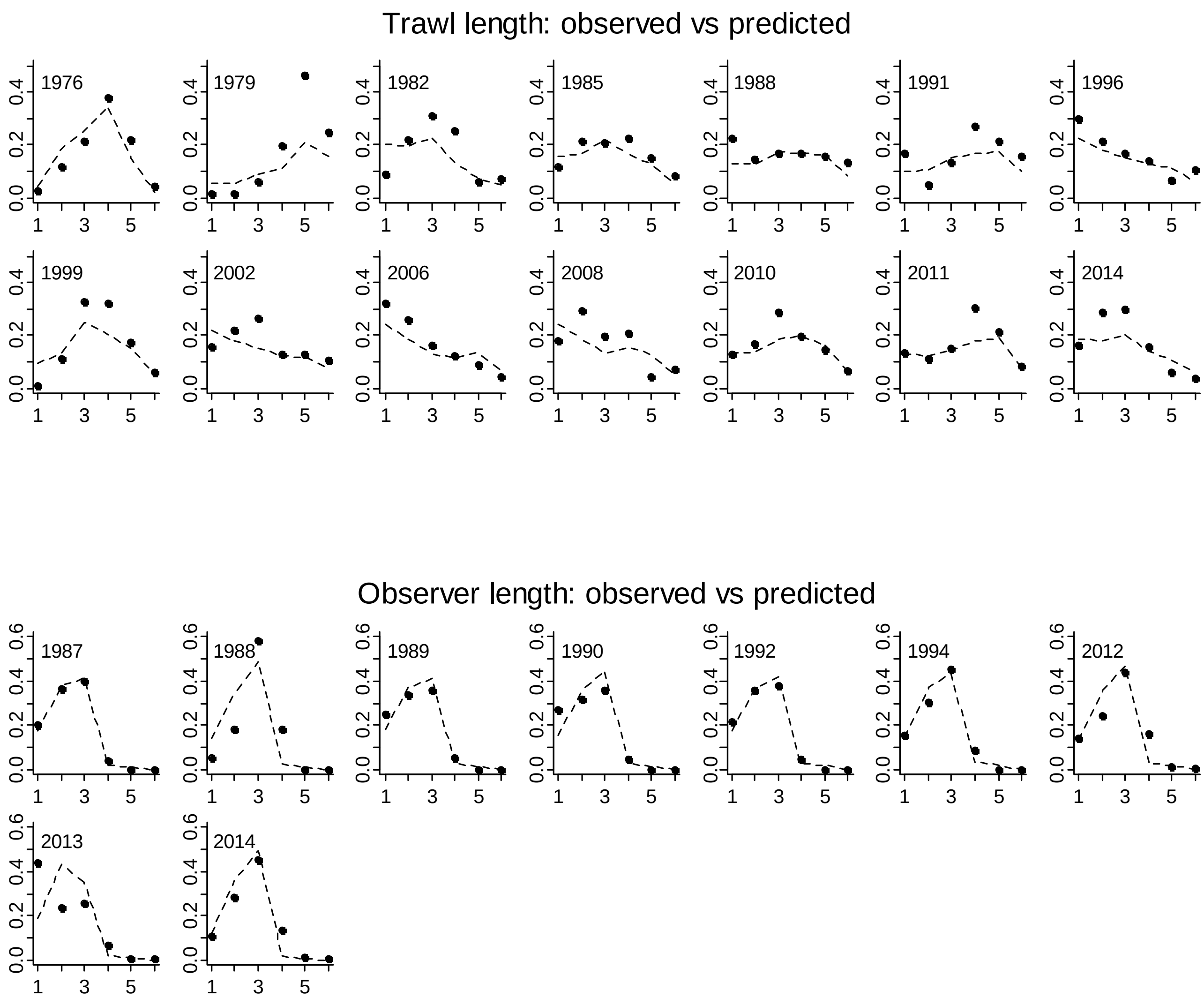


Figure C5-9: Predicted (dashed line) vs. observed (black dots) length class proportion for commercial catch:



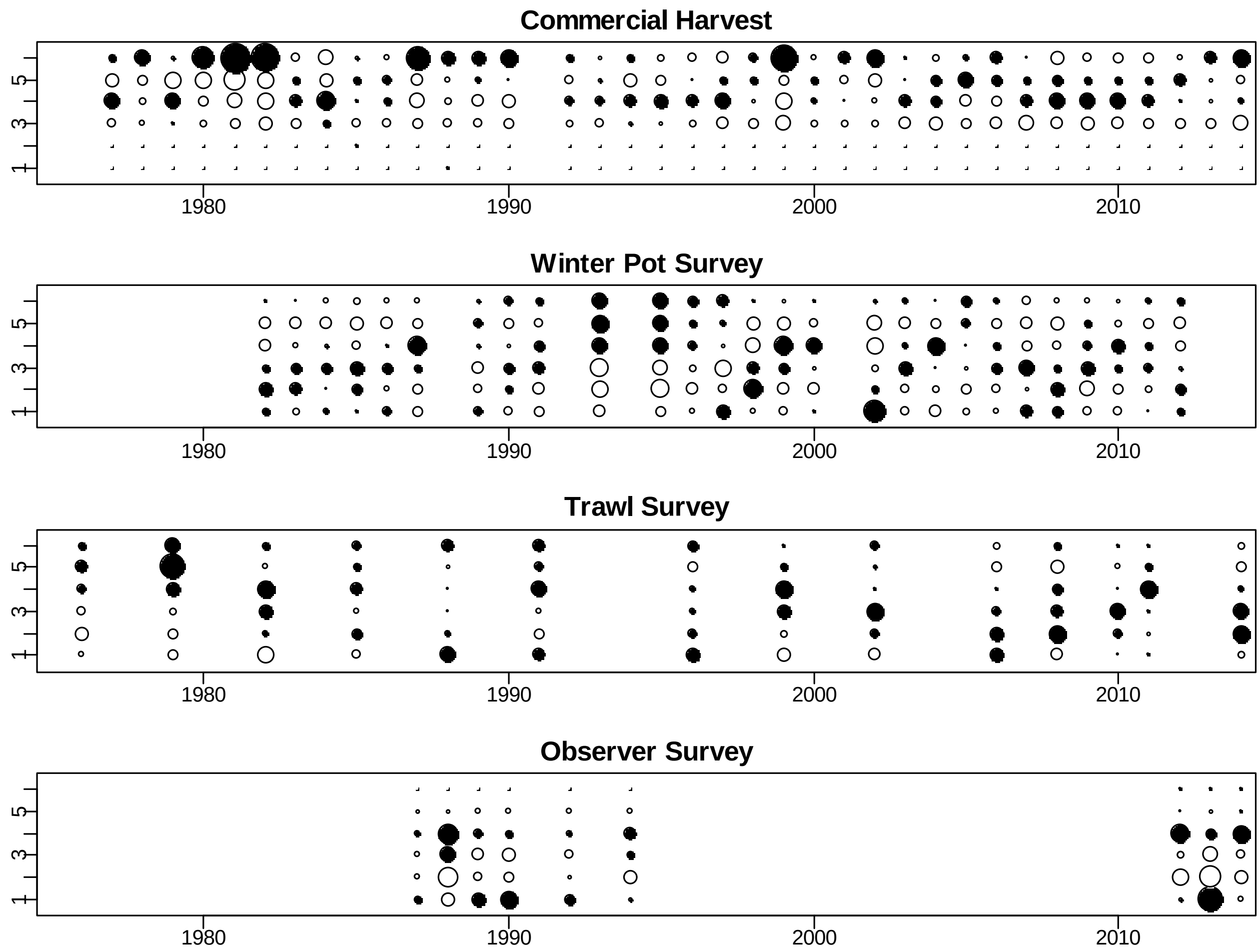
1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C5-10: Predicted (dashed line) vs. observed (black dots) length class proportion for winter pot survey



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C5-11: Predicted (dashed line) vs. observed (black dots) length class proportion for trawl survey and observer survey



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C5-12: Bubble plot of predicted and observed length proportion . Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicate degree of deviance (larger circle = larger deviance).

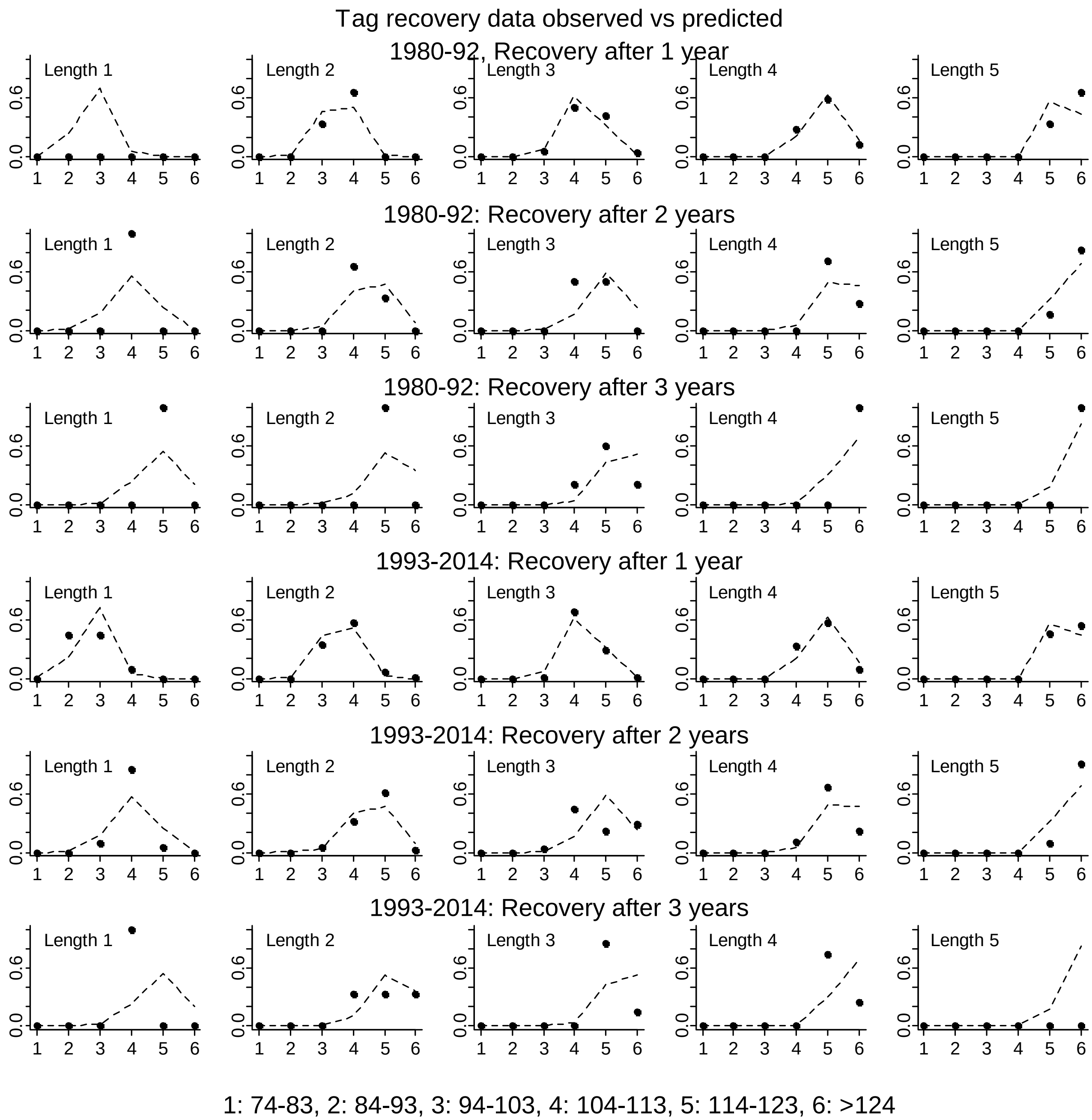
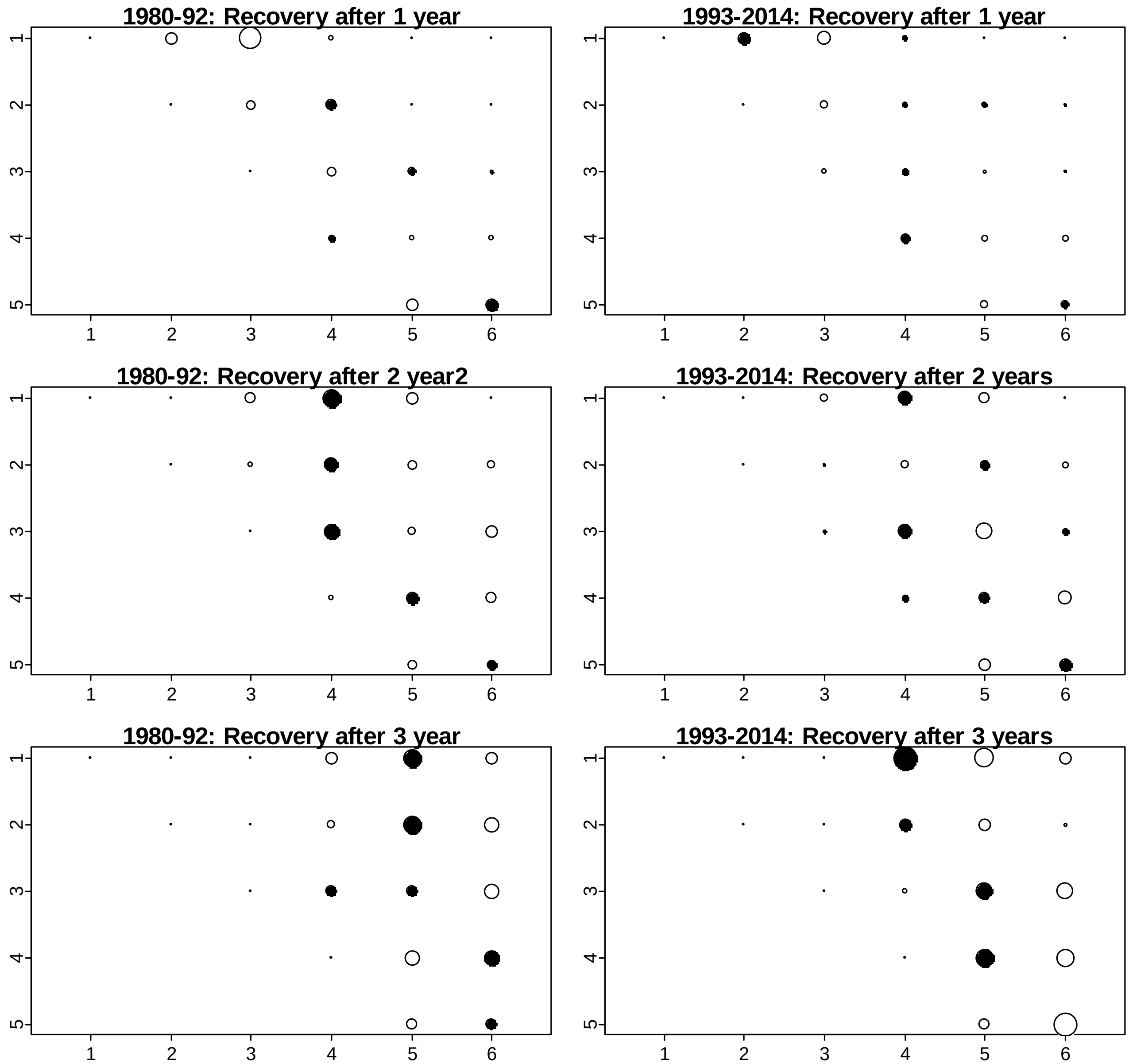


Figure C5-13: Predicted vs. observed length class proportion for tag recovery data 1980-1992, and 1993-2014:



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C5-14: Bubble plot of predicted vs. observed length class proportion for tag recovery data 1980-1992, and 1993-2014:

Table C5-1 . 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	-7.1769	0.18021
log_q_2	-7.0132	0.1077
log_N_{76}	9.0963	0.15818
R_0	6.5239	0.084183
$log\_\sigma_R^2$	0.32119	0.46213
log_R_{77}	-0.30989	0.39151
log_R_{78}	-0.73221	0.35602
log_R_{79}	-0.28266	0.37971
log_R_{80}	0.54195	0.27537
log_R_{81}	0.25807	0.29092
log_R_{82}	0.26419	0.33208
log_R_{83}	0.70234	0.27318
log_R_{84}	0.23998	0.30984
log_R_{85}	0.28344	0.31501
log_R_{86}	0.3154	0.27307
log_R_{87}	-0.0515	0.27872
log_R_{88}	0.081239	0.2679
log_R_{89}	-0.09071	0.27308
log_R_{90}	-0.53588	0.30059
log_R_{91}	-0.41832	0.28358
log_R_{92}	-0.86762	0.32214
log_R_{93}	-0.59476	0.28365
log_R_{94}	-0.50774	0.27655
log_R_{95}	-0.2231	0.24822
log_R_{96}	0.046086	0.27588
log_R_{97}	0.38157	0.2234
log_R_{98}	-0.672	0.32778
log_R_{99}	-0.3073	0.30932
log_R_{00}	-0.0569	0.2924
log_R_{01}	0.21971	0.25843
log_R_{02}	0.34527	0.289
log_R_{03}	-0.29191	0.34332
log_R_{04}	-0.05486	0.29183
log_R_{05}	0.50433	0.20842
log_R_{06}	-0.01536	0.30917
log_R_{07}	0.60502	0.21724
log_R_{08}	0.34547	0.27491
log_R_{09}	-0.00377	0.27913
log_R_{10}	-0.13521	0.27242
log_R_{11}	-0.10872	0.29472
log_R_{12}	0.51081	0.31087
log_R_{13}	0.29438	0.37189
a_1	0.4976	1.9201
a_2	1.8887	1.3711
a_3	2.1849	1.3285
a_4	2.4719	1.3048
a_5	1.6505	1.3585
r1	0.63163	0.069899
log_α	-1.7941	0.019067
log_ϕ_{st1}	-2.459	1.1245
log_ϕ_{st2}	-6.9997	22627

log_ϕ_w	-1.8164	0.045592
Sw_1	0.4214	0.10435
log_ϕ_1	-1.8278	0.080917
log_ϕ_2	-1.765	0.088935
w^2_t	0.051411	0.017522
q	0.71734	0.13061
σ	4.5486	0.29561
β_1	9.2161	0.89774
β_2	7.911	0.27801

Appendix C6: Results Model 6

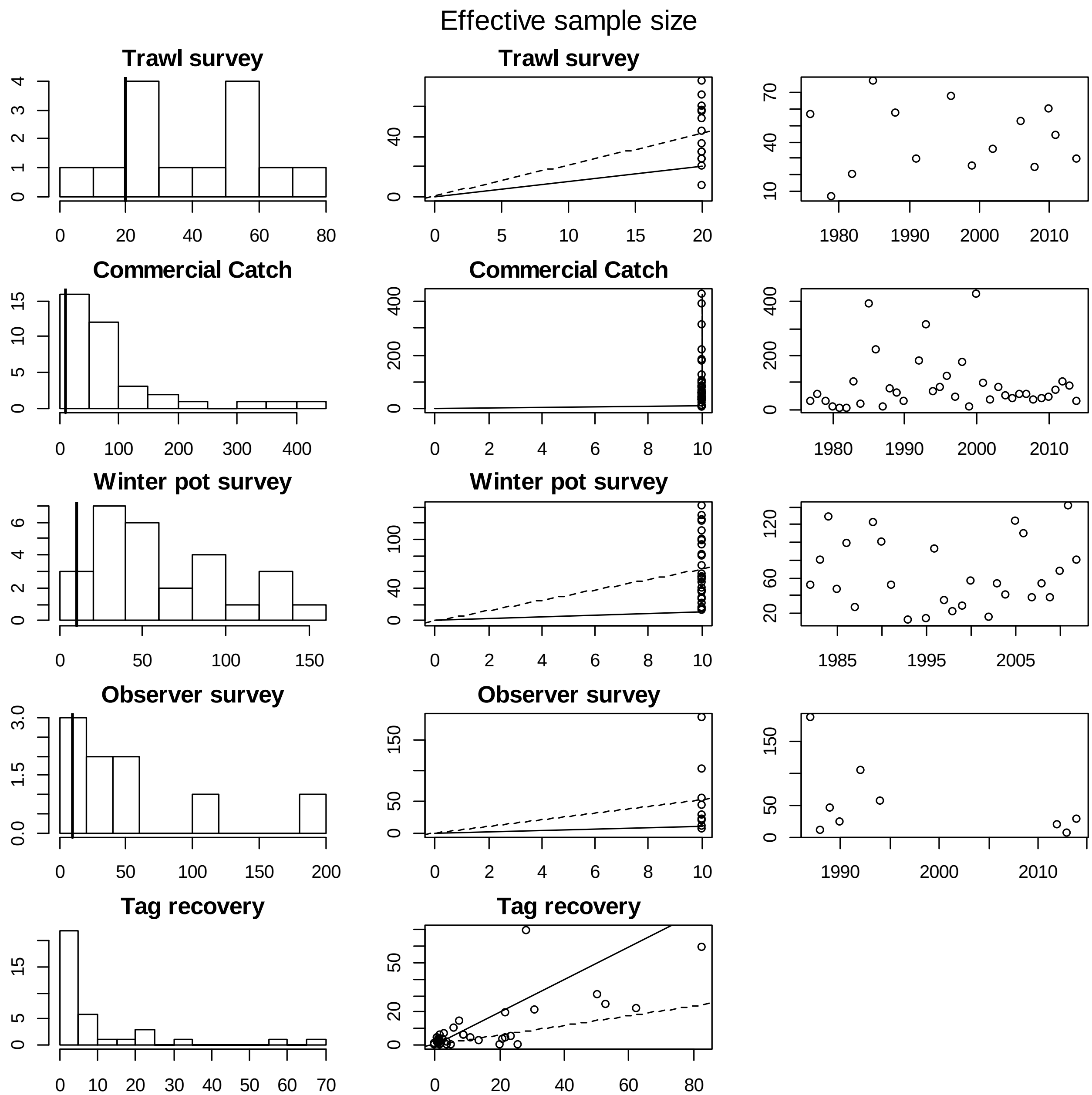


Figure C6-1: Effective sample size vs. implied sample size. Figures in the first column show effective sample size (x-axis) vs. frequency (y-axis). Vertical solid line is the implied sample size. Figures in the second column show implied sample size (x-axis) vs. effective sample size (y-axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. Figures in the third column show year (x-axis) vs. effective sample size (y-axis).

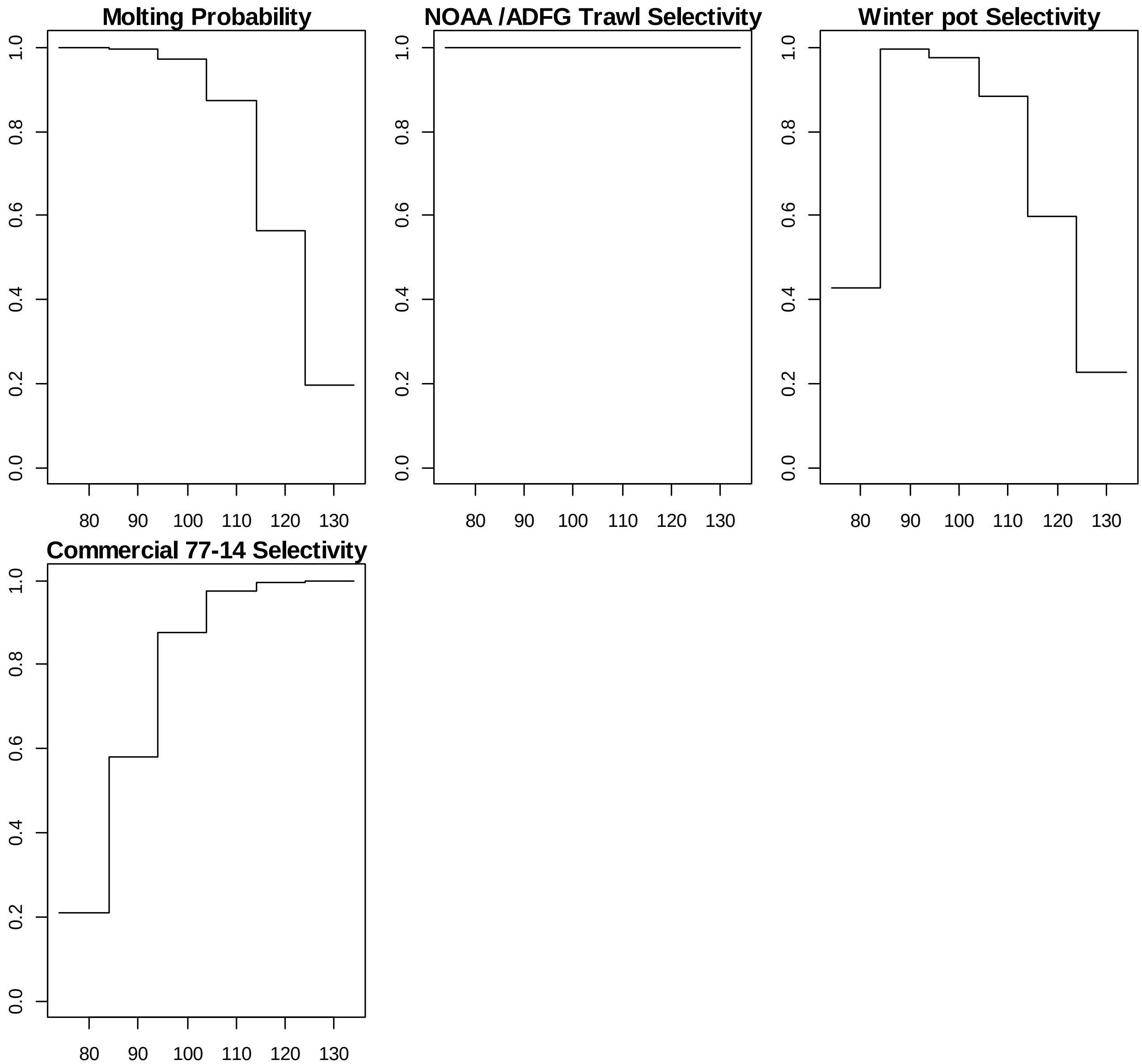


Figure C6-2. Molting probability and trawl/pot selectivities. X-axis is carapace length.

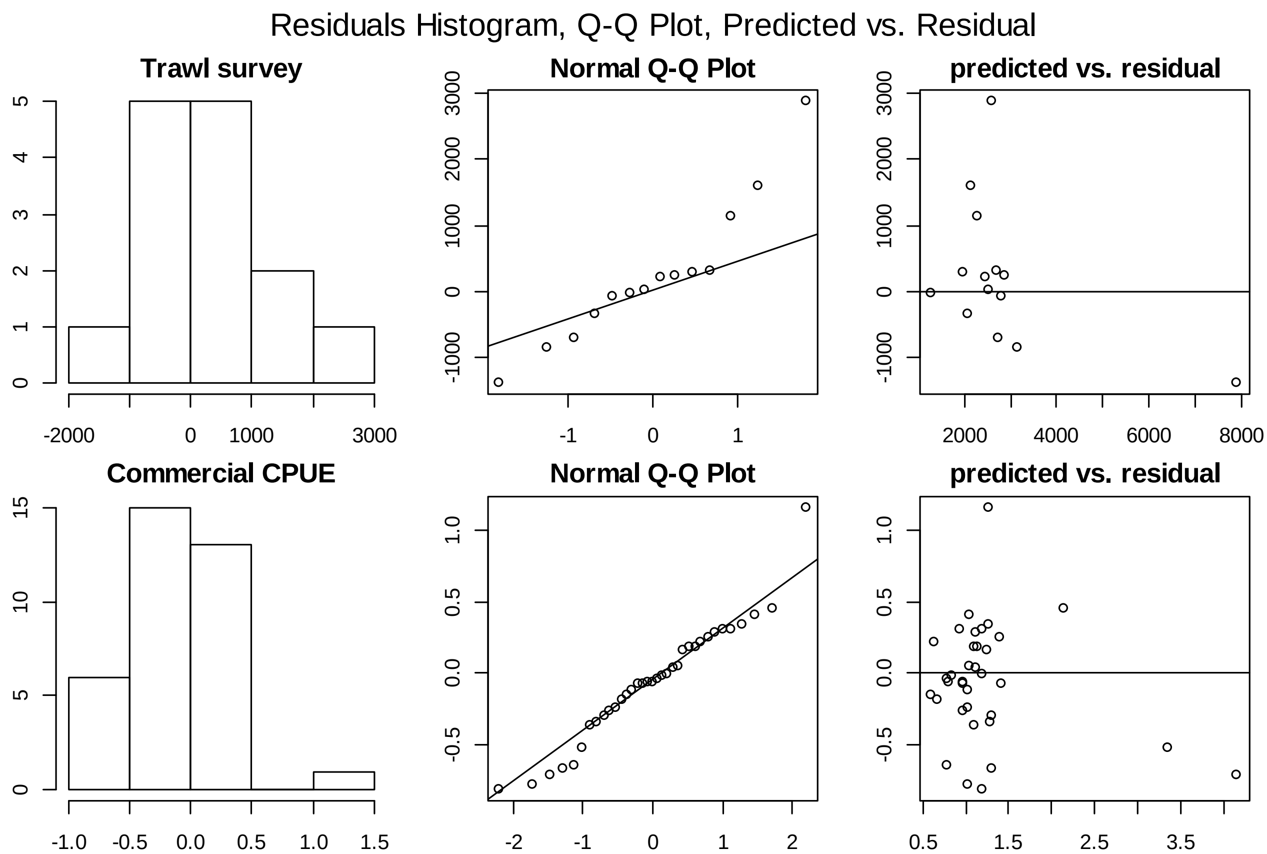


Figure C6-3. QQ Plot of Trawl survey and Commercial CPUE

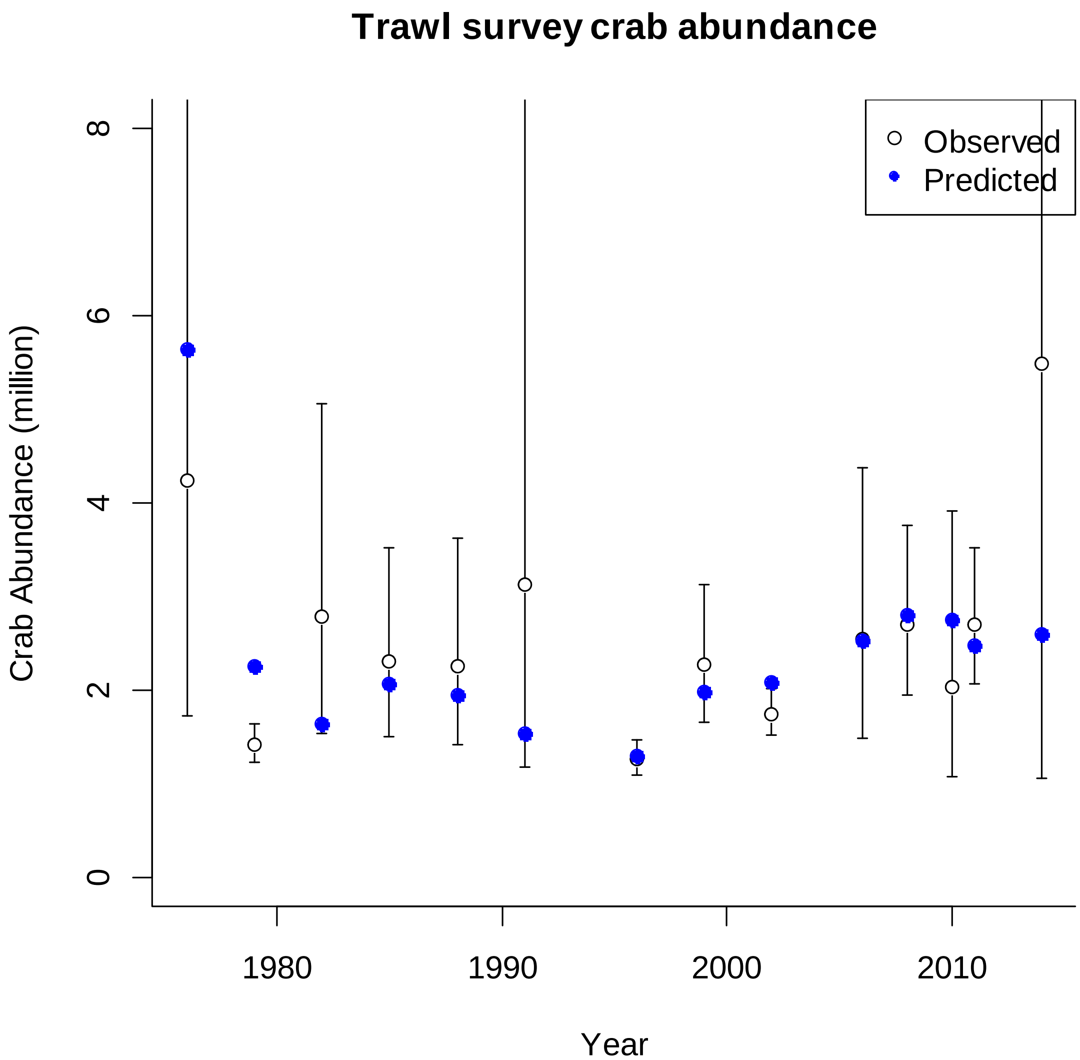


Figure C6-4. Estimated trawl survey abundance (crabs ≥ 74 mm CL) male

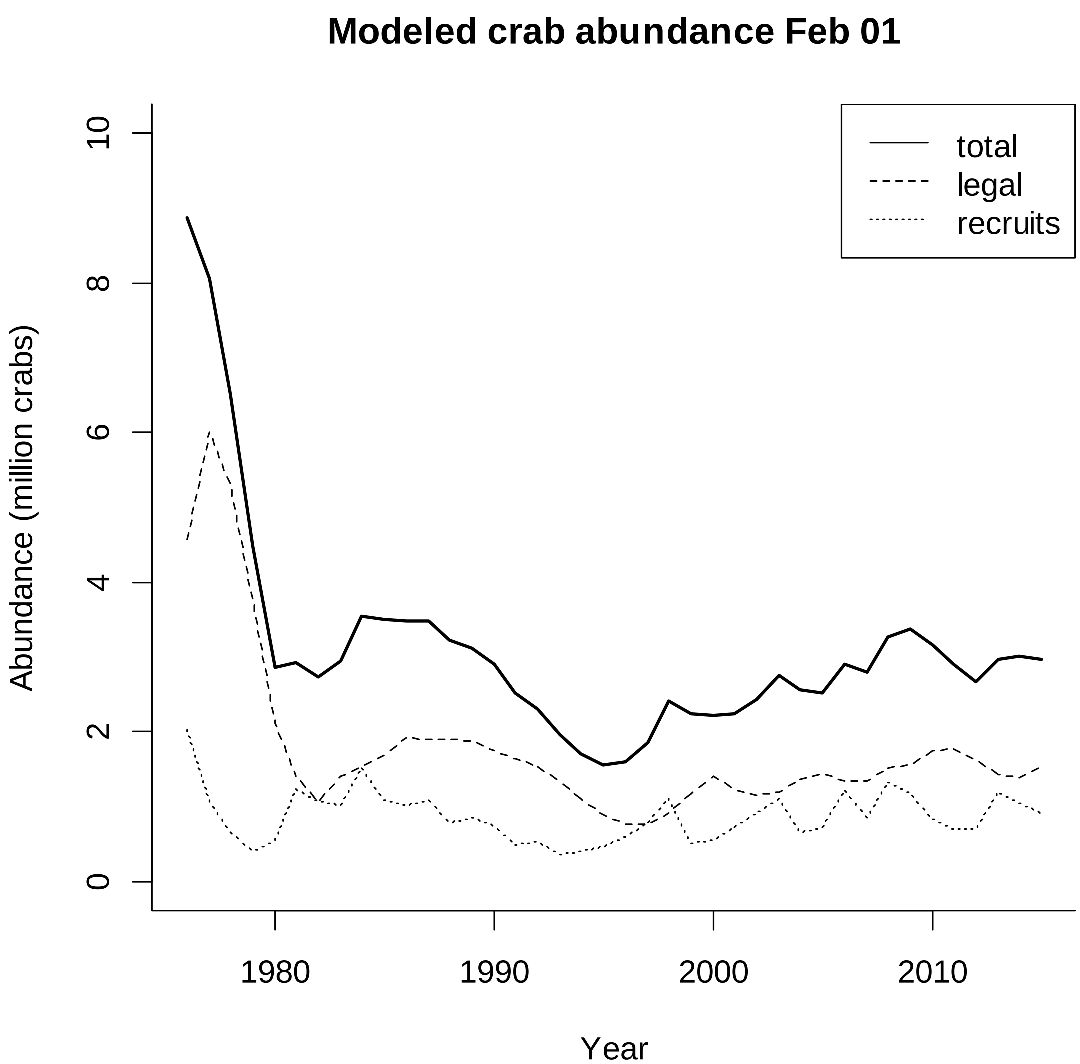


Figure C6-5. Estimated abundance of legal male from 1976-2014

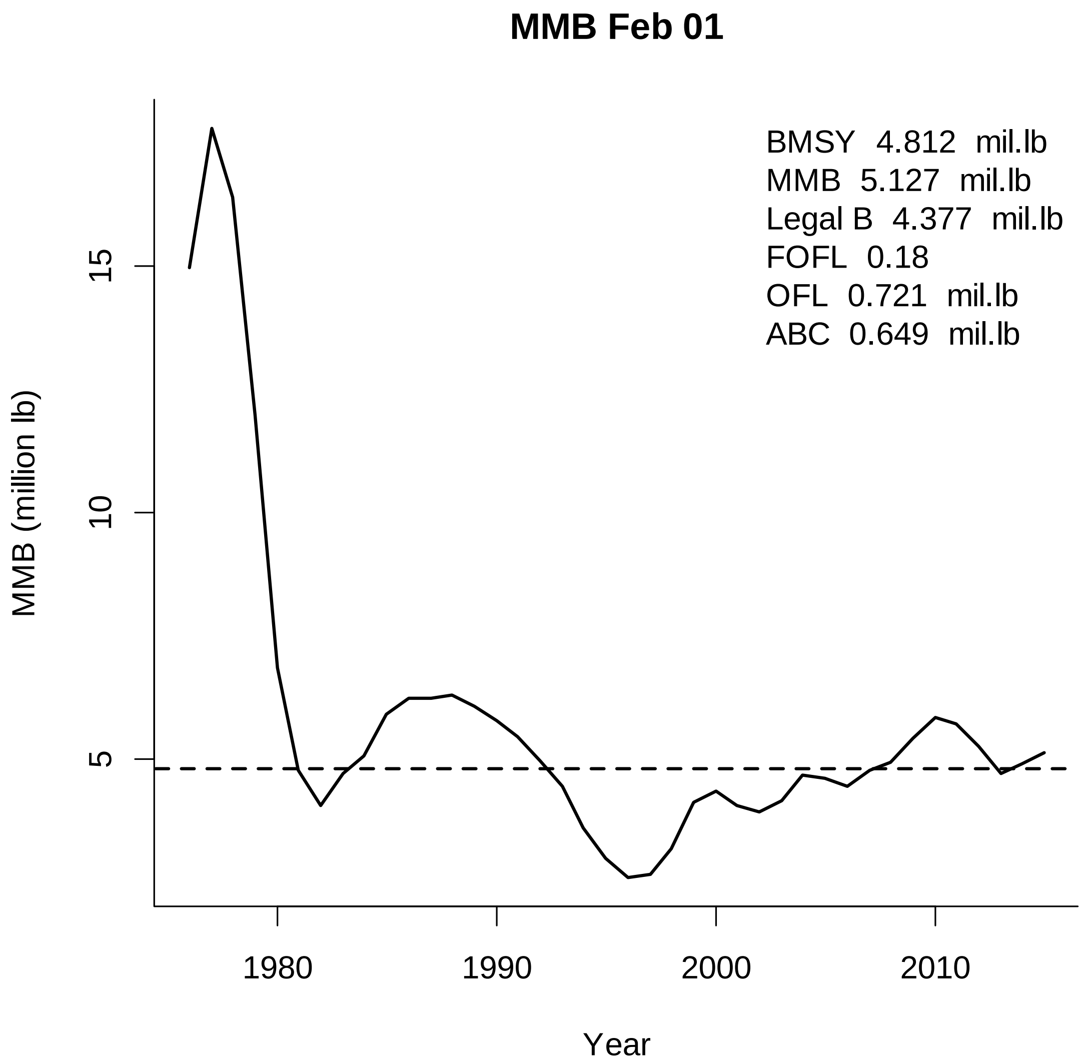


Figure C6-6. Estimated abundance of leg recruits from 1976-2015. Dash line shows Bmsy (Average MMB of 1980-2015)

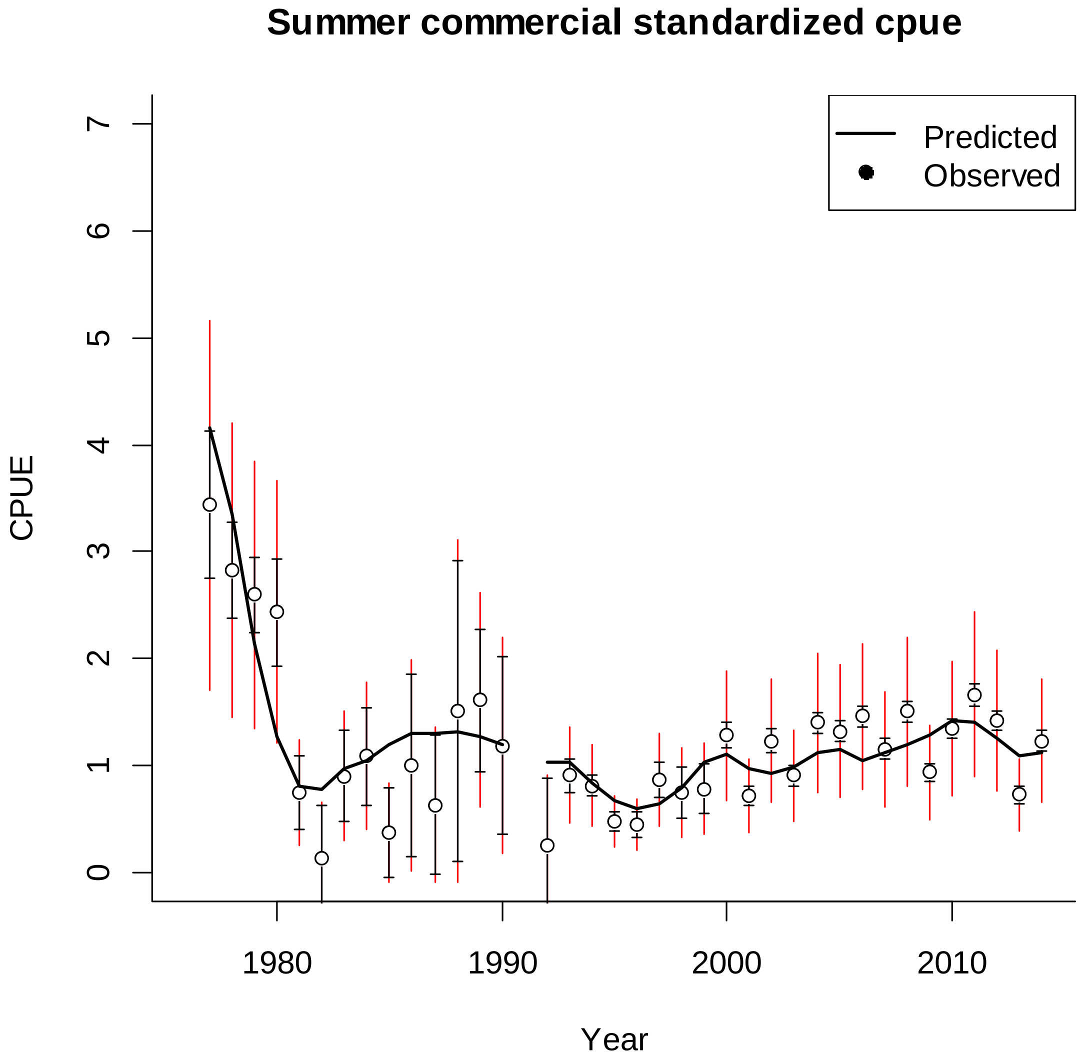


Figure C6-7. Summer commercial standardized cpue (1977-2014)

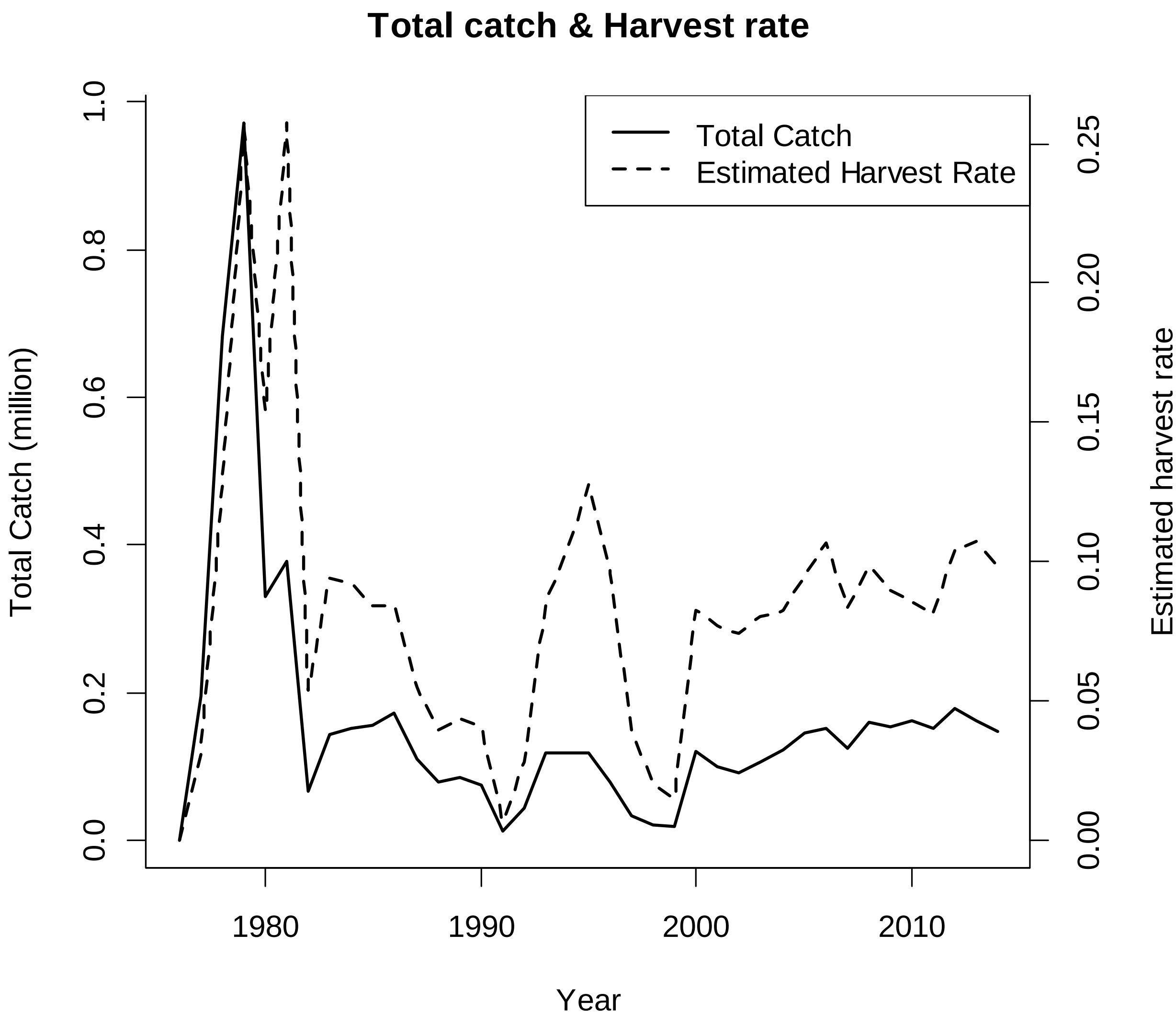
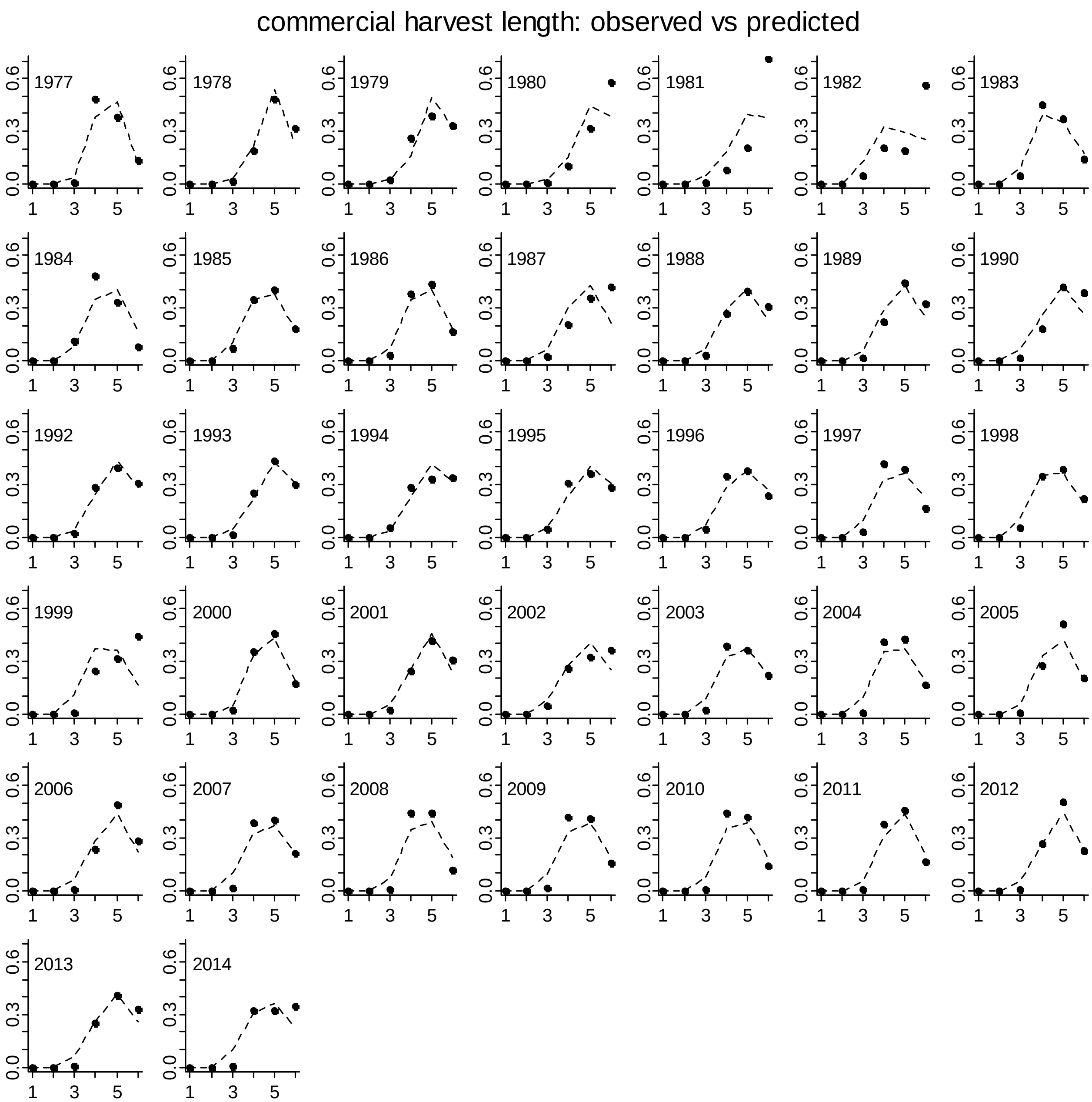


Figure C6-8: Total catch and estimated harvest rate 1976-2014



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C6-9: Predicted (dashed line) vs. observed (black dots) length class proportion for commercial catch:

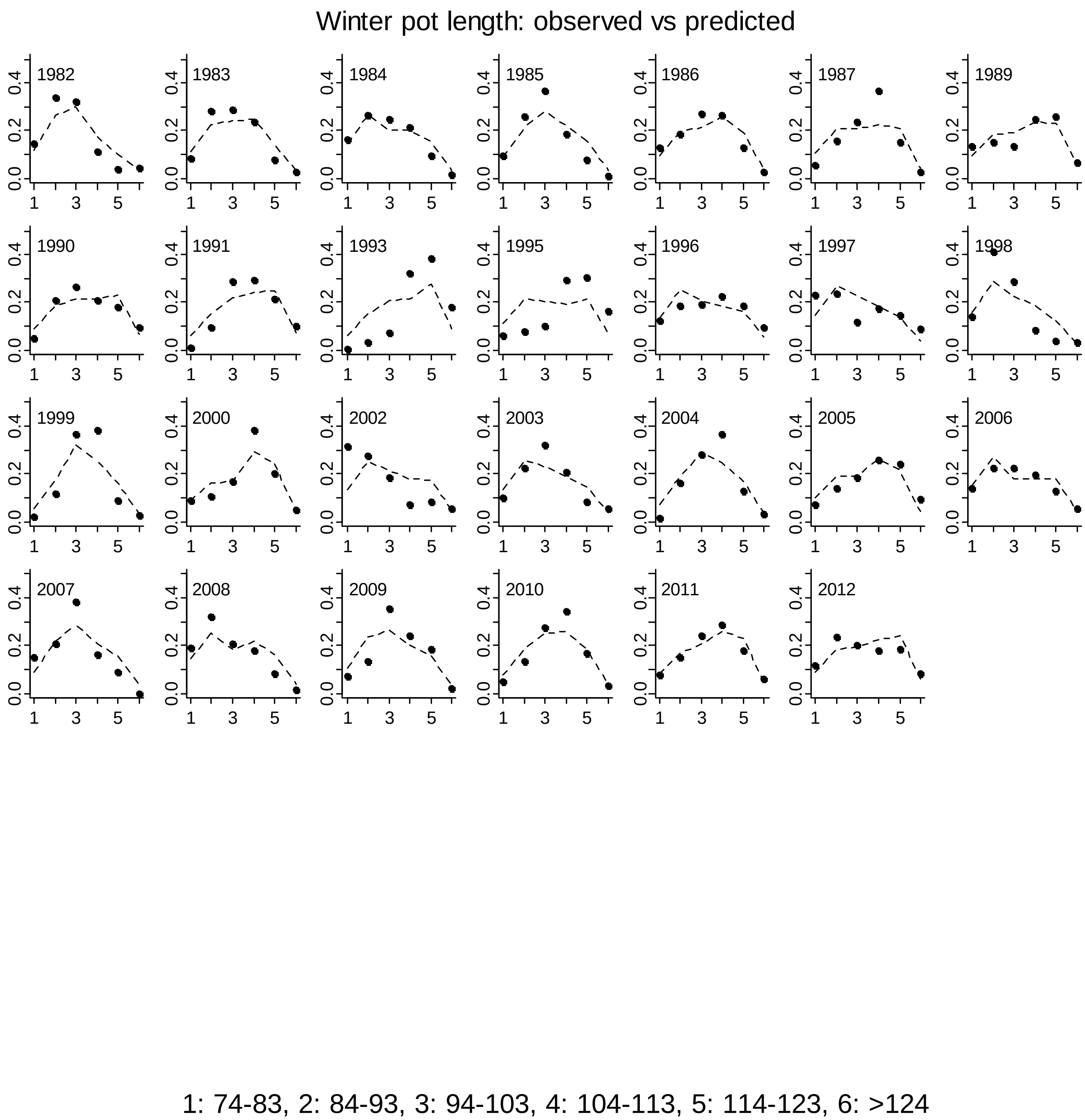
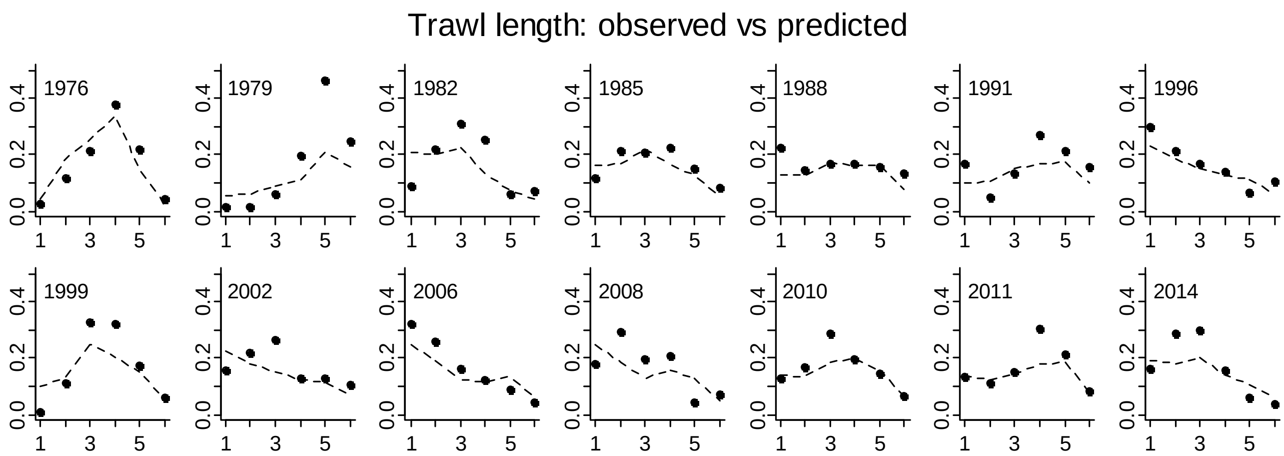
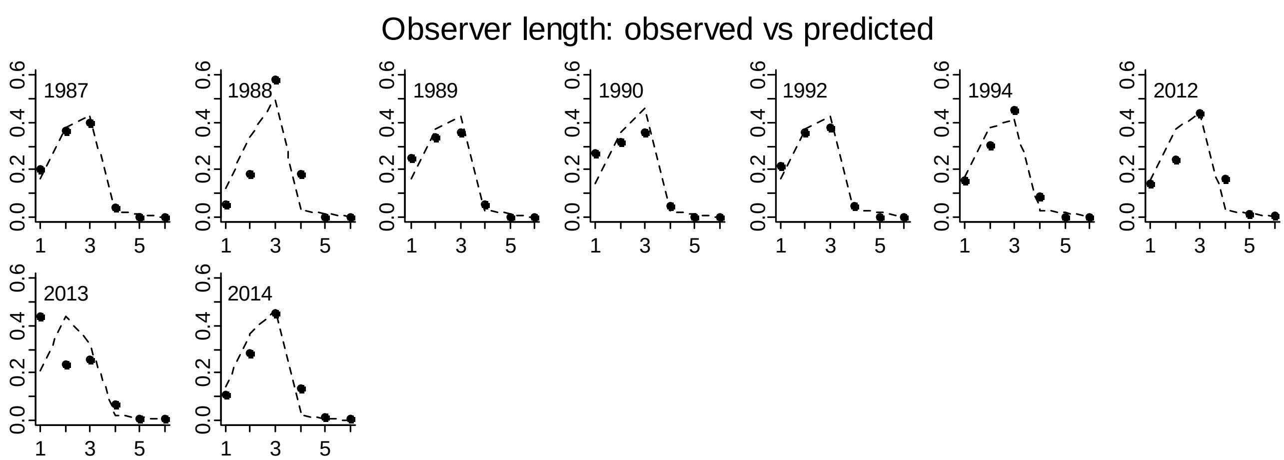


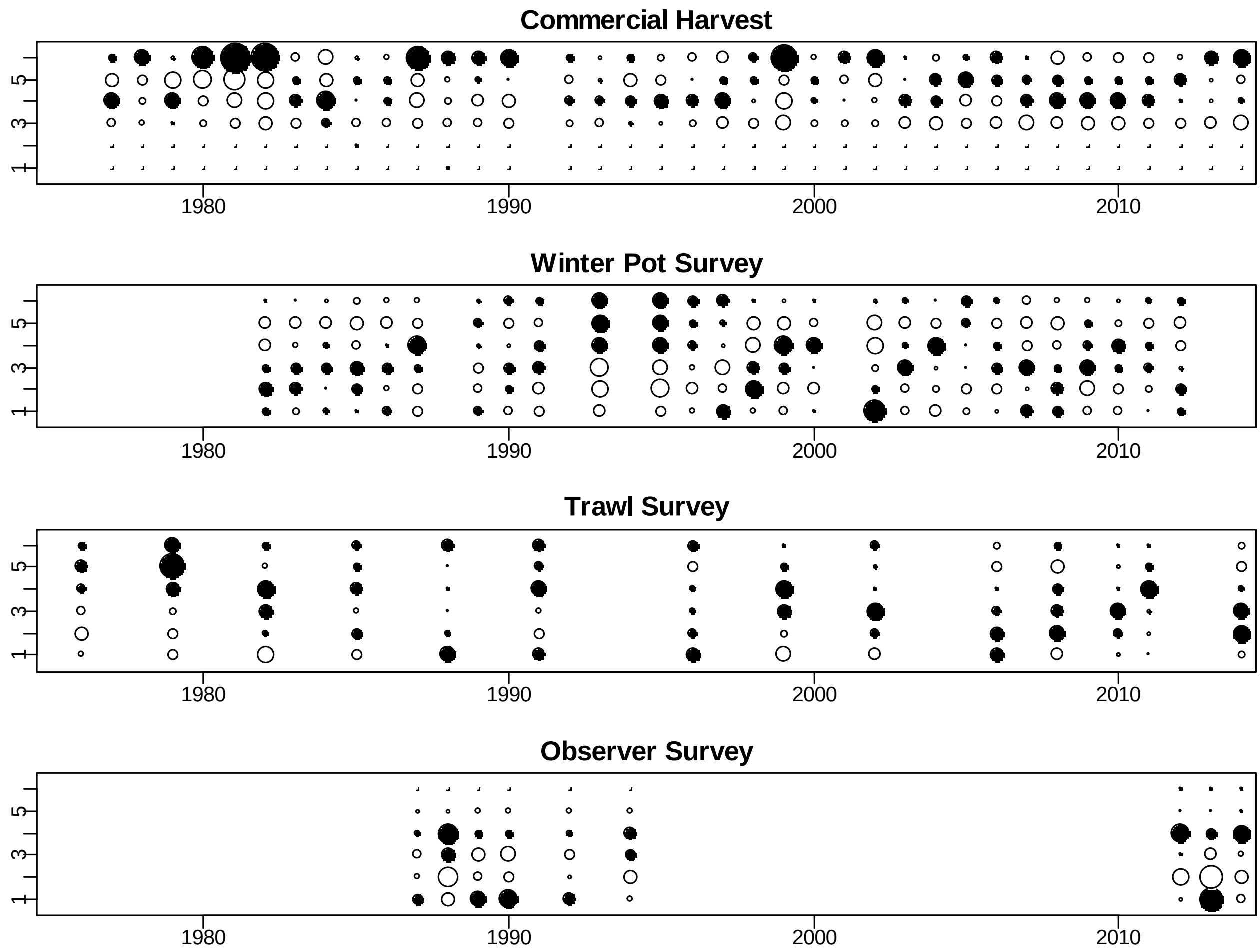
Figure C6-10: Predicted (dashed line) vs. observed (black dots) length class proportion for winter pot survey





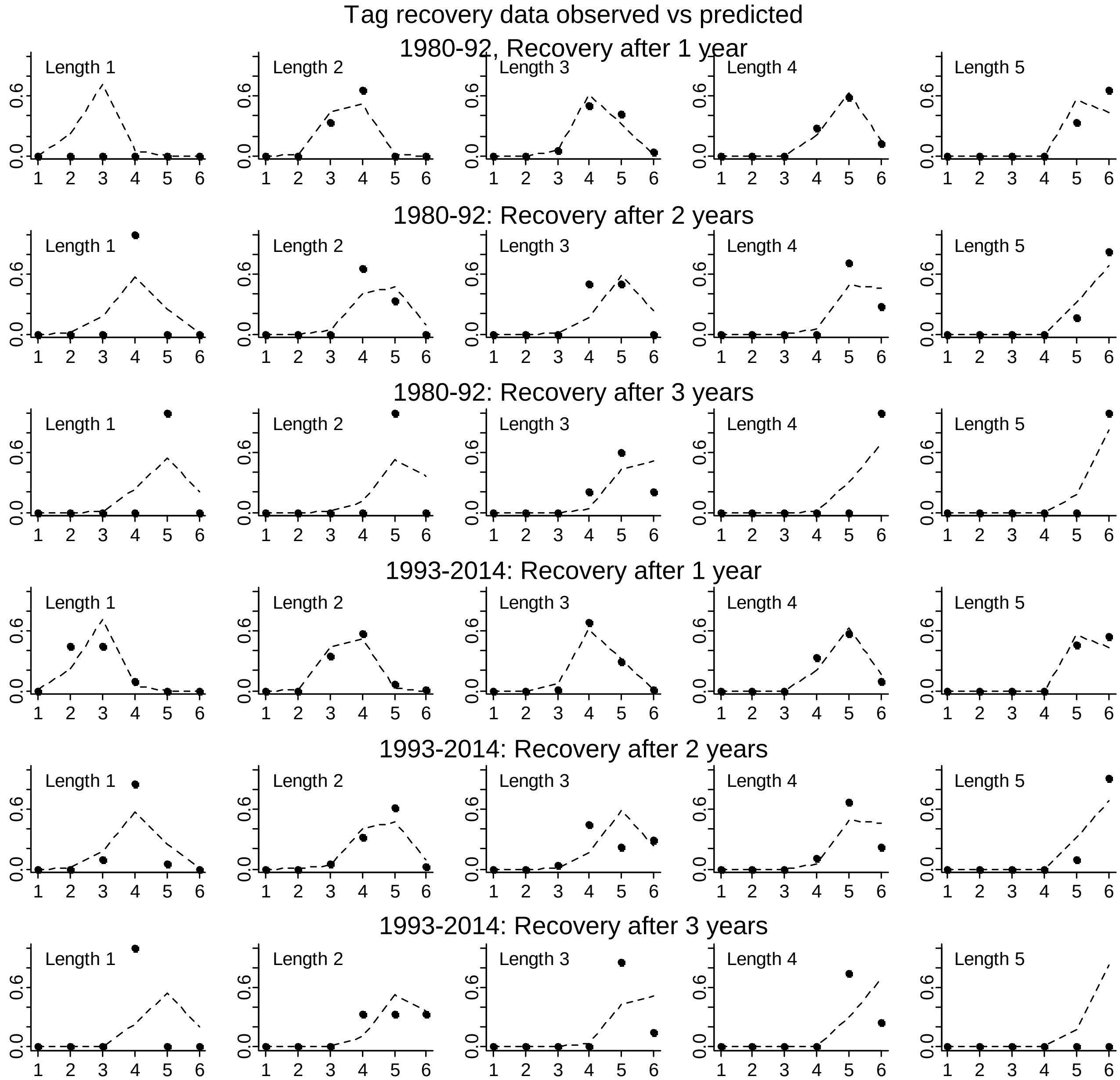
1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C6-11: Predicted (dashed line) vs. observed (black dots) length class proportion for trawl survey and observer survey



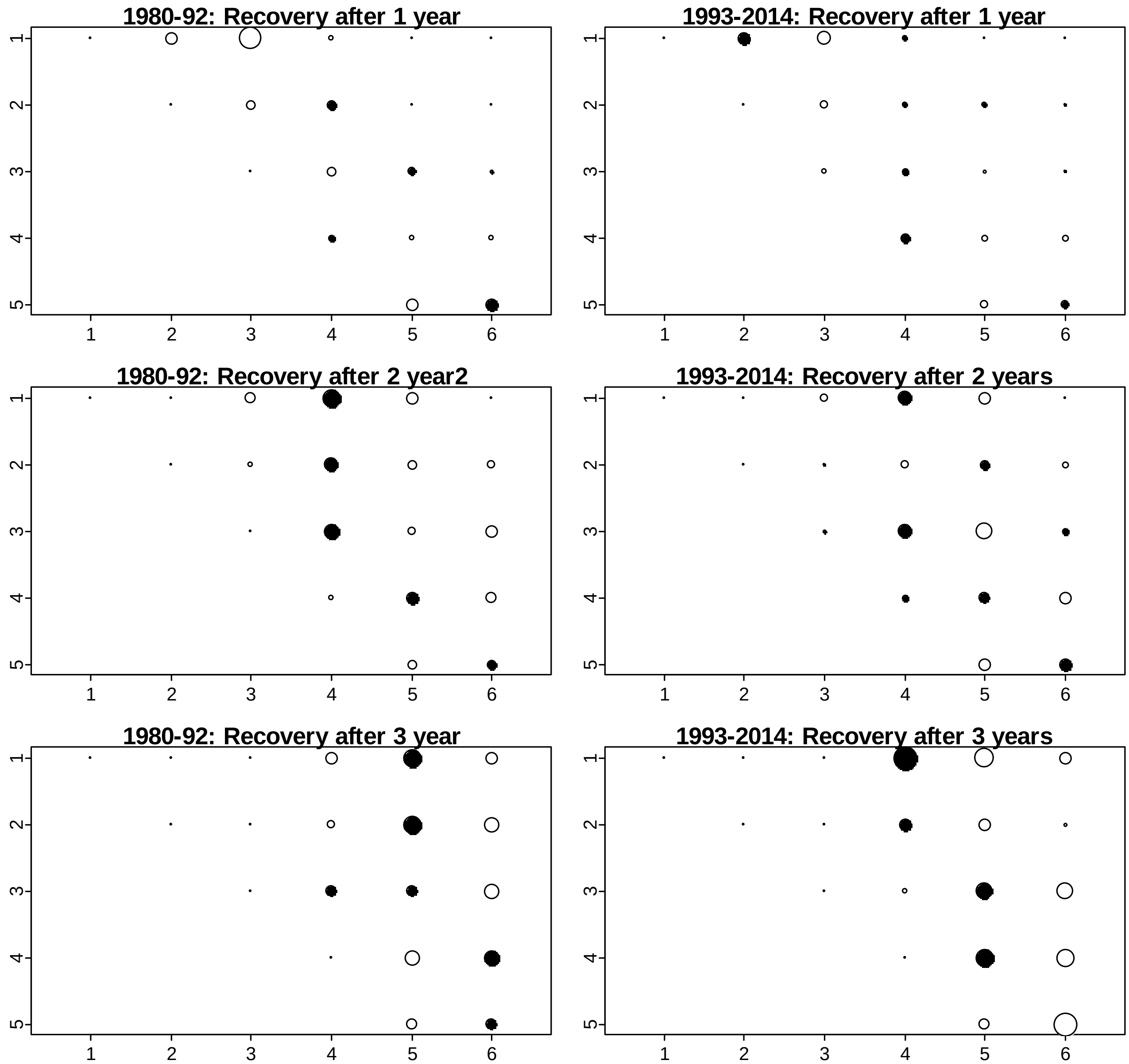
1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C6-12: Bubble plot of predicted and observed length proportion . Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicate degree of deviance (larger circle = larger deviance).



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C6-13: Predicted vs. observed length class proportion for tag recovery data 1980-1992, and 1993-2014:



1: 74-83, 2: 84-93, 3: 94-103, 4: 104-113, 5: 114-123, 6: >124

Figure C6-14: Bubble plot of predicted vs. observed length class proportion for tag recovery data 1980-1992, and 1993-2014:

Table C6-1 . 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	-7.1695	0.17949
log_q_2	-7.0052	0.094063
log_N_{76}	9.0903	0.15807
R_0	6.5111	0.069899
$log\_\sigma_R^2$	0.34419	0.4539
log_R_{77}	-0.29935	0.38957
log_R_{78}	-0.74307	0.35276
log_R_{79}	-0.28749	0.37892
log_R_{80}	0.54114	0.27099
log_R_{81}	0.25666	0.28849
log_R_{82}	0.27011	0.32664
log_R_{83}	0.70377	0.26988
log_R_{84}	0.24143	0.30666
log_R_{85}	0.27018	0.30999
log_R_{86}	0.32682	0.268
log_R_{87}	-0.05633	0.2766
log_R_{88}	0.085734	0.26629
log_R_{89}	-0.07167	0.26779
log_R_{90}	-0.55485	0.29819
log_R_{91}	-0.3935	0.27767
log_R_{92}	-0.84682	0.31789
log_R_{93}	-0.61655	0.28252
log_R_{94}	-0.50293	0.27478
log_R_{95}	-0.23298	0.23981
log_R_{96}	0.037987	0.27396
log_R_{97}	0.39147	0.2191
log_R_{98}	-0.67324	0.32479
log_R_{99}	-0.3067	0.30868
log_R_{00}	-0.05292	0.28968
log_R_{01}	0.19657	0.22958
log_R_{02}	0.36501	0.27604
log_R_{03}	-0.2863	0.3422
log_R_{04}	-0.05434	0.29041
log_R_{05}	0.49922	0.20397
log_R_{06}	-0.00669	0.30448
log_R_{07}	0.59322	0.2078
log_R_{08}	0.36102	0.26451
log_R_{09}	-0.00544	0.27545
log_R_{10}	-0.11936	0.2651
log_R_{11}	-0.11415	0.29373
log_R_{12}	0.49332	0.30772
log_R_{13}	0.24683	0.35443
a_1	0.41021	1.8878
a_2	1.873	1.3696
a_3	2.1804	1.3285
a_4	2.4697	1.3048
a_5	1.6508	1.3586
r1	0.62056	0.054306
log_α	-1.7941	0.019085
log_ϕ_{st1}	-14.556	1485
log_ϕ_{st2}		

log_ϕ_w	-1.8158	0.045533
Sw_1	0.42902	0.1003
log_ϕ_1	-1.8039	0.059877
log_ϕ_2		
w^2_t	0.051598	0.017595
q	0.71459	0.1267
σ	4.5222	0.28733
β_1	9.3851	0.79453
β_2	7.8668	0.25217

Aleutian Islands Golden King Crab – 2015 Tier 5 Assessment

2015 Crab SAFE Report Chapter (May 2015 Draft)

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Executive Summary

1. **Stock:** Aleutian Islands golden king crab *Lithodes aequispinus*

2. **Catches:**

The fishery has been prosecuted as a directed fishery since the 1981/82 season and has been open every season since then. Retained catch peaked during the 1985/86–1989/90 seasons (average annual retained catch = 11.876-million lb, 5,387 t), but the retained catch dropped sharply from the 1989/90 to 1990/91 season and average annual retained catch for the period 1990/91–1995/96 was 6.931-million lb (3,144 t). A guideline harvest level (GHL) was introduced into management for the first time in the 1996/97 season. A GHL of 5.900-million lb (2,676 t) was established in the 1996/97 and subsequently reduced to 5.700-million lb (2,585 t) beginning with the 1998/99 season. The GHL (or, since the 2005/06 season, the total allowable catch, or TAC) remained at 5.700-million lb (2,585 t) through the 2007/08 season, but was increased to 5.985-million lb (2,715 t) for 2008/09–2011/12 seasons and increased to 6.290-million lb (2,853 t) for the 2012/13 and 2013/14 seasons. Average annual retained catch for the period 1996/97–2007/08 was 5.623-million lb (2,550 t). Average annual retained catch in 2008/09–2012/13 was 5.959-million lb (2,703 t). The TAC for the 2012/13 season was 6.290-million lb (2,853 t) and the landed harvest was 6,268-million lb (2,843 t). Catch per pot lift of retained legal males decreased from the 1980s into the mid-1990s, but increased steadily following the 1994/95 season and increased markedly at the initiation of the Crab Rationalization program in the 2005/06 season. Non-retained bycatch occurs mainly during the directed fishery. Although minor levels of bycatch can occur during other crab fisheries, there have been no such fisheries prosecuted since 2004/05, except as surveys for red king crab conducted by industry under a commissioner's permit. Bycatch also occurs during fixed-gear and trawl groundfish fisheries. Although bycatch during groundfish fisheries exceeded 0.100-million lb (45 t) for the first time during 2007/08 and 2008/09, that bycatch was less than 10% of the weight of bycatch during the directed fishery for those seasons. Estimated bycatch in groundfish fisheries during 2009/10–2012/13 was ≤ 0.066-million lb (30 t). Annual non-retained catch (i.e., discarded bycatch) of golden king crab during crab fisheries has decreased relative to the retained catch and in absolute numbers and weight since the 1990s. Annual estimated weight of discarded bycatch during crab fisheries decreased from 13.824-million lb (6,270 t) in 1990/91 (equivalent to 199% of the retained catch during that season), to 9.100-million lb (4,128 t) in 1996/97 (equivalent to 156% of the retained catch for that season), and to 4.321-million lb (1,960 t) in the 2004/05 season (equivalent to 78% of the retained catch for that season). During the nine seasons (2005/06–2013/14) since fishery rationalization, estimated weight of discarded bycatch during crab fisheries has ranged from 2.524-million lb (1,145 t) for the 2005/06 season (equivalent to 46% of the retained catch for that season) to 3.165-million lb (1,436 t) for the 2013/14 season (representing 50% of the retained catch for that season). Estimates of the annual weight of bycatch mortality have correspondingly decreased since 1996/97, both in absolute value and relative to the retained catch weight. Estimated total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) has ranged from 5.816-million lb (2,638 t) to 9.375-million lb (4,252 t) during 1995/96–2013/14; estimated total fishery mortality for 2013/14 was 7.037-million lb (3,192 t). In addition to the catch of 6.273-million lb (2,845 t) that was retained toward the 2013/14 TAC, an additional 0.107-million lb (0.05 t) was retained towards a cost-recovery fishery goal of $300,000 that ADF&G was authorized to receive from the harvest and sale of Aleutian Islands golden king crab during 2013/14.

The 2014/15 season ends by regulation on 15 May 2015 and complete fishery data are not yet available. Currently available data from the 2014/15 season in the area west of 174° W longitude are confidential due to the participation of less than three fishing vessels (M. Westphal, ADF&G, Dutch Harbor, *pers. comm.* 6 April 2015)

3. <u>Stock biomass</u>:
Estimates of stock biomass are not available for this Tier 5 assessment.

4. <u>Recruitment</u>:
Estimates of recruitment trends and current levels relative to virgin or historic levels are not available for this Tier 5 assessment.

5. <u>Management performance</u>:
Overfishing did not occur during 2013/14 because the estimated total catch did not exceed the Tier 5 overfishing limit (OFL) of 12.54-million lb (5.69 kt). The total catch did not exceed the ABC established for 2013/14 (11.28-million lb, or 5.12 kt). The TAC for 2013/14 does not include landings towards a cost-recovery fishing goal of $300,000 to cover costs of observer deployments in the fishery; the catch totals for 2013/14 do include the catch towards the 2013/14 cost-recovery fishery. Fishery catch data from the ongoing 2014/15 are not available at this time. The 2014/15 TAC has not yet been established. The OFL and ABC values for 2015/16 are the author's recommended values.

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

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

Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch[a]	Total Catch[a,b]	OFL[a]	ABC[a]
2011/12	N/A	N/A	2.72	2.71	2.95	5.17	4.66
2012/13	N/A	N/A	2.85	2.84	3.12	5.69	5.12
2013/14	N/A	N/A	2.85	2.89	3.19	5.69	5.12
2014/15	N/A	N/A	2.85			5.69	4.26
2015/16	N/A	N/A				5.69	4.26

a. kt.

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

Basis for the OFL and ABC: See table below; 2015/16 values are the author's recommended values.

Year	Tier	Years to define Average catch (OFL)	Natural Mortality[a]	Buffer
2011/12	5	1985/86–1995/96[b]	0.18	10%
2012/13	5	1985/86–1995/96[b]	0.18	10%
2013/14	5	1985/86–1995/96[b]	0.18	10%
2014/15	5	1985/86–1995/96[b]	0.18	25%
2015/16	5	1985/86–1995/96[b]	0.18	25%

a. Assumed value for FMP king crab in NPFMC (2007b); does not enter into OFL estimation for Tier 5 stock.

b. OFL was for total catch as was computed as the average of the retained catch for these years times an estimated average annual value of (bycatch mortality in crab fisheries)/(retained catch) plus an estimated average annual bycatch mortality in groundfish fisheries.

6. **PDF of the OFL:** Sampling distribution of the recommended (status quo) Tier 5 OFL was estimated by bootstrapping (see section G.1). The standard deviation of the estimated sampling distribution of the recommended OFL is 1.18-million lb (CV = 0.09). Note that generated sampling distribution and computed standard deviation are meaningful as measures in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Sections E.2 and E.4.f).

7. **Basis for the ABC recommendation:** A 25% buffer on the OFL; i.e., ABC = (1.0-0.25)·OFL.

8. **A summary of the results of any rebuilding analyses:** Not applicable; stock is not under a rebuilding plan.

A. Summary of Major Changes

1. **Changes to the management of the fishery:**

- In March 2014 the BOF changed the 9-month season opening date from 15 August to 1 August; that change will become effective in the 2015/16 season.
- In 2014 the SOA legislature increased the allocation that ADF&G may receive annually from the harvest and sale of Aleutian Islands golden king crab from $300,000 to $500,000. Retained catch from that cost-recovery fishing is counted towards attainment of the annually-established TAC.

2. **Changes to the input data:**
   - Fishery data has been updated with the data for 2013/14: retained catch for the directed fishery and bycatch estimates for the directed fishery, non-directed crab fisheries, and groundfish fisheries. Complete data from the ongoing 2014/15 are not available.

3. **Changes to the assessment methodology:** None: the computation of OFL in this assessment follows the methodology recommended by the CPT in May 2012 and the SSC in June 2012.

4. **Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL:**
   - The OFL established for each of 2008/09 and 2009/10 was 9.18-million lb (4.16 kt) of retained catch and was estimated by the average annual retained catch (not including deadloss) for the period 1985/86–1995/96.
   - The OFL for 2010/11 was established as a total-catch OFL of 11.06-million lb (502 t) and, following the recommendation of the SSC in June 2010, was computed as the average of the annual retained catch during 1985/86–1995/96 plus the average of the annual retained catch during 1985/86–1995/96 times the estimated average annual value of (bycatch mortality in crab fisheries)/(retained catch) during 1996/97–2008/09 plus the estimated average annual bycatch mortality in groundfish fisheries during 1996/97–2008/09.
   - The OFL for 2011/12 was established as a total-catch OFL of 11.40-million lb (517 t), with the ABC set at the maximum (i.e., with a 10% buffer below the OFL) of 10.26 million lb (466 t). Methods and results followed the June 2010 CPT, May 2011 CPT and June 2011 SSC recommendations by using 1985/86–1995/96 data for retained catch, incorporating as much data on bycatch as is available, and “freezing” the final year of bycatch data included in the assessment at 2008/09. The recommended total catch OFL was computed as the average of the annual retained catch during 1985/86–1995/96 plus the average of the annual retained catch during 1985/86–1995/96 times the estimated average annual value of (bycatch mortality in crab fisheries)/(retained catch) during 1990/91–2008/09 (excluding 1993/94–1994/95 due to lack of sufficient data) plus the estimated average annual bycatch mortality in groundfish fisheries during 1993/94–2008/09.
   - The OFL and ABC for 2012/13 and 2013/14 was a total-catch OFL of 12.54-million lb (569 t), with the ABC set at the maximum (i.e., with a 10% buffer below the OFL) of 11.28 million lb (512 t). The methods to compute the OFL were the same as for the 2011/12 OFL, except that a different time period was used to estimate the average annual value of (bycatch mortality in crab fisheries)/(retained catch) in the directed fishery (1990/91–1995/96 as opposed to 1990/91–2008/09).

- The OFL and ABC for 2014/15 were a total-catch OFL of 12.53-million lb (5.69 kt) and an ABC of 9.40-million lb (4.26 kt) that was set using a 25% buffer (i.e., set at 75% of the OFL). The 2014/15 OFL was the status quo value whereas the 2014/15 ABC was a departure from the maximum-value ABC (i.e., set with a 10% buffer below the OFL) that was established for 2013/14.
- The OFL and ABC recommended for 2015/16 are the status quo from 2014/15: a total-catch OFL of 12.53-million lb (5.69 kt) and an ABC of 9.40-million lb (4.26 kt) that was set using a 25% buffer.

B. Responses to SSC and CPT Comments

1. **Responses to the most recent two sets of SSC and CPT comments on assessments in general (and relevant to this assessment):**
    - CPT, May 2014: *None pertaining to a Tier 5 assessment*.
    - SSC, June 2014: *Recommended that the Scallop and Crab Plan Teams conduct a workshop to address procedures for data-poor stocks with participants from all Plan Teams that are dealing with Tier 5 assessments and with the desired outcome of clearly articulating "the procedures and minimum requirements for establishing 10%, 20%,..., X% buffers such that they can be applied consistently across a range of species and different stocks*."
        - Response: Activities in response dependent upon scheduling of workshop; results would be incorporated into May 2016 assessment.
    - CPT, September 2014 (via September 2014 SAFE Introduction chapter): *None pertaining to a Tier 5 assessment*.
    - SSC, October 2014: *Recommended that an uncertainty workshop be held in the fall of 2015 to address ABCs*.
        - Response: Results would be incorporated into the May 2016 assessment.

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

- CPT, May 2014 (May 2014 CPT minutes):
    - *"The CPT agreed that there is more uncertainty in Aleutian Islands golden king crab assessment than is consistent with a 10% buffer. However, the CPT could not agree on an appropriate approach to determine a buffer for between the OFL and ABC."*
        - Response: The author's recommends a 25% buffer between OFL and ABC for 2015/16, as was recommended for 2014/15 by the SSC in June 2014.
- SSC, June 2014 (June 2014 SSC minutes):
    - *"The SSC recommends that a 25% buffer suggested by the author be adopted for setting the ABC for this stock."*
        - Response: The author's recommended ABC for 2015/16 is based on the 25% buffer recommended by the SSC.
- CPT, September 2014 (via Sept 2014 SAFE): *None.*
- SSC, October 2014: *None*.

C. Introduction

1. **Scientific name:** *Lithodes aequispinus* J. E. Benedict, 1895

2. **Description of general distribution:**

General distribution of golden king crab is summarized by NMFS (2004):

> Golden king crab, also called brown king crab, range from Japan to British Columbia. In the BSAI [Bering Sea and Aleutian Islands], golden king crab are found at depths from 200 m to 1,000 m, generally in high-relief habitat such as inter-island passes (Chapter 3, pages 34–35).
>
> Golden, or brown, king crab occur from the Japan Sea to the northern Bering Sea (ca. 61° N latitude), around the Aleutian Islands, on various sea mounts, and as far south as northern British Columbia (Alice Arm) (Jewett et al. 1985). They are typically found on the continental slope at depths of 300–1,000 m on extremely rough bottom. They are frequently found on coral bottom (Chapter 3, page 44).

The Aleutian Islands king crab stock boundary is defined by the boundaries of the Aleutian Islands king crab Registration Area O (Figure 1). Baechler and Cook (2014, page 7) define those boundaries:

> The Aleutian Islands king crab Registration Area O has as its eastern boundary the longitude of Scotch Cap Light (164° 44' W long.), its northern boundary a line from Cape Sarichef (54° 36' N latitude) to 171° W long., north to 55° 30' N lat., and as its western boundary the Maritime Boundary Agreement Line as that line is described in the text of and depicted in the annex to the Maritime Boundary Agreement between the United States and the Union of Soviet Socialist Republics signed in Washington, June 1, 1990. Area O encompasses both the waters of the Territorial Sea (0–3 nautical miles) and waters of the Exclusive Economic Zone (3–200 nautical miles).

During the 1984/85–1995/96 seasons, the Aleutian Islands king crab populations had been managed using the Adak and Dutch Harbor Registration Areas, which were divided at 171° W longitude (Figure 2), but from the 1996/97 season to present the fishery has been managed using a division at 174° W longitude (Figure 1; Baechler and Cook 2014). In March 1996 the Alaska Board of Fisheries (BOF) replaced the Adak and Dutch Harbor areas with the newly created Aleutian Islands Registration Area O and directed 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 the 1996/97 season (Figure 3). The longitudinal pattern in fishery production since 1996/97 is similar to that observed prior to the change in management (Figure 4). In this chapter, “Aleutian Islands Area” means the area described by the current definition of Aleutian Islands king crab Registration Area O.

Commercial fishing for golden king crab in the Aleutian Islands Area typically occurs at depths of 100–275 fathoms (183–503 m). During the 2012/13 season the pots sampled by at-sea observers 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. Effort and catch data by statistical area are available since 1982 and locations of over 70,000 fished pots sampled by observers since the 1996/97 season indicate that habitat for legal-sized males may be continuous throughout the waters adjacent to the Aleutian Islands. However, regions of low fishery catch suggest that availability of suitable habitat, in which golden king crab are present at only low densities, may vary longitudinally. Catch has been low in the fishery in the area between 174° W longitude and 176° W longitude (the Adak Island area, Figures 3 and 4) in comparison to adjacent areas, a pattern that is consistent with low CPUE for golden king crab in between 174° W longitude and 176° W longitude (Figure 5) during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys (von Szalay et al. 2011). In addition to longitudinal variation in density, there is also a gap in fishery catch and effort between the Petrel Bank-Petrel Spur area and the Bowers Bank area; both of those areas, which are separated by Bowers Canyon, have reported effort and catch. Recoveries during commercial fisheries of golden king crab tagged during ADF&G surveys (Blau and Pengilly 1994; Blau et al. 1998; Watson and Gish 2002; Watson 2004, 2007) provided no evidence of substantial movements by crab in the size classes that were tagged (males and females ≥90-mm carapace length [CL]). Maximum straight-line distance between release and recovery location of 90 golden king crab released prior to the 1991/92 season and recovered through the 1992/93 season was 33.1 nm (61.2 km; Blau and Pengilly 1994). Of the 4,053 recoveries reported through 14 March 2008 for the golden king crab tagged and released between 170.5° W longitude and 171.5° W longitude during the 1997, 2000, 2003, and 2006 triennial ADF&G Aleutian Island golden king pot surveys, none were recovered west of 174° W longitude and only four were recovered west of 172° W longitude (V. Vanek, ADF&G, Kodiak, personnel communication).

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 their observations on embryo development in golden king crab, Otto and Cummiskey (1985) suggested that time between successive ovipositions was roughly twice that of embryo development and that spawning and molting of mature females occurs approximately every two years. Sloan (1985) also suggested a reproductive cycle >1 year with a protracted barren phase for female golden king crab. Data from tagging studies on female golden king crab in the Aleutian Islands are generally consistent with a molt period for mature females of 2 years or less and that females carry embryos for less than two years with a prolonged period in which they remain in barren condition (Watson et al 2002). From laboratory studies of golden king crab collected from Prince William Sound, Paul and Paul (2001) estimated a 20-month reproductive cycle with a 12-month clutch brooding period.

Numerous observations on clutch and embryo condition of mature female golden king crab captured during surveys have been consistent with asynchronous, aseasonal reproduction (Otto and Cummiskey 1985; Hiramoto 1985; Sloan 1985; Somerton and Otto 1986, Blau and Pengilly 1994, Blau et al. 1998, Watson et al. 2002). Based on data from Japan (Hiramoto and Sato 1970), McBride et al. (1982) suggested that spawning of golden king crab in the Bering Sea and Aleutian Islands occurs predominately during the summer and fall.

The success of asynchronous and aseasonal spawning of golden king crab may be facilitated by fully lecithotrophic larval development (i.e., the larvae can develop successfully to juvenile crab without eating; Shirley and Zhou 1997). Current knowledge of reproductive biology and maturity of male and female golden king crab is also reviewed by Webb (2014).

Note that asynchronous, aseasonal molting and the prolonged intermolt period (>1 year) of mature female and the larger male golden king crab likely makes precise scoring of shell conditions very difficult. This pattern would obscure potential relationships between shell condition and time-elapsed since molting and pose problems for inclusion of shell condition data into assessment models.

5. Brief summary of management history:

A complete summary of the management history through the 2011/12 season is provided in Baechler and Cook (2014, pages 13–19). The first commercial landing of golden king crab in the Aleutian Islands was in 1975/76, but directed fishing did not occur until 1981/82. Peak harvest occurred during 1986/87 when 14.739-million lb (6,686 t) were harvested. Between 1981/82 and 1995/96 the fishery was managed as two separate fisheries in two separate registration areas, the Adak and Dutch Harbor areas, with the two areas divided at 172° W longitude through 1983/84 and at 171° W longitude after 1983/84. Prior to the 1996/97 season no formal preseason harvest target or limit was established for the fishery and average annual retained catch during 1981/82 – 1995/96 was 8.456-million lb (3,836 t).

The Aleutian Islands golden king crab fishery was restructured beginning with the 1996/97 season 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. The 1996/97–1997/98 seasons were managed under a 5.900-million lb (2,676 t) guideline harvest level (GHL), with 3.200-million lb (1,452 t) apportioned to the area east of 174° W longitude and 2.700-million lb (1,225 t) apportioned to the area west of 174° W longitude. The 1998/99–2004/05 seasons were managed under a 5.700-million lb (2,585 t) GHL, with 3.000-million lb (1,361 t) apportioned to the area east of 174° W longitude and 2.700-million lb (1,225 t) apportioned to the area west of 174° W longitude. The 2005/06–2007/08 seasons were managed under a 5.700-million lb (2,585 t) total allowable catch (TAC), with 3.000-million lb (1,361 t) apportioned to the area east of 174° W longitude and 2.700-million lb (1,225 t) apportioned to the area west of 174° W longitude. By state regulation (5 AAC 34.612), the TAC for retained catch for the Aleutian Islands golden king crab fishery for each of the 2008/09–2011/12 seasons was 5.985-million lb (2,715 t), apportioned as 3.150-million lb (1,429 t) for the area east of 174° W longitude and 2.835-million lb (1,286 t) for the area west of 174° W longitude. In March 2012 the BOF changed **5 AAC 34.612** so that the TAC beginning with the 2012/13 season would be 6.290-million lb (2,853 t), apportioned as 3.310-million lb (1,501 t) for the area east of 174° W longitude and 2.980-million lb (1,352 t) for the area west of 174° W longitude. Additionally, the BOF added a provision to **5 AAC 34.612** that allows ADF&G to lower the TAC below the specified level if conservation concerns arise. Over the period 1996/97–2013/14 the total of the annual retained catch during commercial fishing (including ADF&G cost-recovery fishing that occurred during the 2013/14 season) has averaged 2% below the total of the annual GHL/TACs. During 1996/97–2013/14 the retained catch has been as much as 13% below (the 1998/99 season) and as much as 6% above (the 2000/01 season) the GHL/TAC. The retained catch for the 2013/14 season was 1% above the 6.290-million lb (2,853 t) TAC. The TAC for the ongoing 2014/15 season was established at 6.290-million lb (2,853 t); in addition to the retained catch that is counted towards the 2014/15 TAC, legal crab sufficient to provide $300,000 in receipts to ADF&G were also retained during a cost-recovery fishery.

A summary of other relevant SOA fishery regulations and management actions pertaining to the Aleutian Islands golden king crab fishery is provided below.

The 2005/06 season was the first Aleutian Islands golden king crab fishery prosecuted under the Crab Rationalization Program. Accompanying the implementation of the Crab Rationalization program was implementation of a community development quota (CDQ) fishery for golden king crab in the eastern Aleutians (i.e., east of 174° W longitude) and the Adak Community Allocation (ACA) fishery for golden king crab in the western Aleutians (i.e., west of 174° W longitude; Hartill 2012). The CDQ fishery in the eastern Aleutians is allocated 10% of the golden king crab TAC for the area east of 174° W longitude and the ACA fishery in the western Aleutians is allocated 10% of the golden king crab TAC for the area west of 174° W longitude. The CDQ fishery and the ACA fishery are prosecuted concurrently with the IFQ fishery and are managed by ADF&G.

Only males of a minimum size may be retained by the commercial golden king crab fishery in the Aleutian Islands Area. By SOA regulation (**5 AAC 34.620 (b)**), the minimum legal size limit is 6.0-inches (152 mm) carapace width (CW), including spines. A carapace length (CL) ≥136 mm is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007b). Note that size limit for golden king crab has been 6-inches (165 mm) CW for the entire Aleutian Islands Area only since the 1985/86 season. Prior to the 1985/86 season the legal size limit was 6.5-inches for at least one of the now-defunct Adak or Dutch Harbor Registration Areas.

Golden king crab may be commercially fished only with king crab pots (defined in **5 AAC 34.050**). Pots used to fish for golden king crab in the Aleutian Islands Area must be operated from a shellfish longline and, since 1996, must have at least four escape rings of five and one-half inches minimum inside diameter installed on the vertical plane or at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized golden king crab (**5 AAC 34.625 (b)**). Prior to the regulation requiring an escape mechanism on pots, some participants in the Aleutian Islands golden king crab fishery voluntarily sewed escape rings (typically 139-mm or 5.5 inches) into their gear or, more rarely, included panels with escape mesh (Beers 1992). With regard to the gear used by fishers since the establishment of **5 AAC 34.625 (b)** in 1996, Linda Kozak, a representative of the industry, reported in a 19 September 2008 email to the Crab Plan Team that, "… the golden king crab fleet has modified their gear to allow for small crab sorting," and provided a written statement from Lance Nylander, of Dungeness Gear Works in Seattle, who "believes he makes all the gear for the golden king crab harvesting fleet," saying that, "Since 1999, DGW has installed 9[-inch] escape web on the door of over 95% of Golden Crab pot orders we manufactured." A study to estimate the contact-selection curve for male golden king crab that was conducted aboard one vessel commercial fishing for golden king crab during the 2012/13 season showed that gear and fishing practices used by that vessel was highly effective in reducing bycatch of sublegal-sized males and females (Vanek et al. 2013). In March 2011 (effective for the 2011/12 season), 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** (Escape Mechanism for Shellfish and Bottomfish Pots) 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 15 August through 15 May. The BOF in March 2014 voted to change regulation (**5 AAC 34.610 (b)**) to set the commercial fishing season for golden king crab in the Aleutian Islands Area as 1 August through 30 April; that change will become effective in the 2015/16 season.

Current regulations stipulate that onboard observers are required during the harvest of 50% of the total golden king crab weight harvested by each catcher vessel and 100% of the fishing activity of each catcher-processor during each of the three trimesters as outlined in **5 AAC 39.645 (d)(4)(A)**.

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.: 3.31 million pounds; and
> > (2) west of 174° W long.: 2.98 million pounds;
>
> (b) The department may reduce the harvest levels based on the best scientific information available and considering the reliability of estimates and performance measures, sources of uncertainty as necessary to avoid overfishing, and any other factors necessary to be consistent with sustained yield principles.

In addition to the retained catch that is limited by the TAC established by ADF&G under **5 AAC 34.612**, ADF&G also has authority to annually receive receipts of $500,000 through cost-recovery fishing on Aleutian Islands golden king crab. The retained catch from that cost-recovery fishing is not counted against attainment of the annually-established TAC.

7. **Summary of the history of B_{MSY}:** Not applicable for this Tier 5 stock.

D. Data

1. **Summary of new information:**
   - Fishery data on retained catch and non-retained bycatch during 2013/14 crab fisheries have been added.
   - Data on bycatch during groundfish fisheries in reporting areas 541, 542, and 543 have been updated with data grouped by “fixed” (hook-and-line and pot) and “trawl” (non-pelagic trawl) for 2013/14 have been added.
   - Estimates of total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) during 2013/14 have been added.

2. **Data presented as time series:**

a. Total catch and b. Information on bycatch and discards:
   - Fish ticket data on retained catch numbers, retained catch weight, pot lifts, CPUE, and average weight of retained catch for the 1981/82–2013/14 seasons are presented (Table 1).
   - Statistics from all available data on bycatch of Aleutian Islands golden king crab obtained from pot lifts sampled by at-sea observers during the directed and non-directed crab fisheries are presented for 1990/91–1992/93 and 1995/96–2013/14 (Table 2). Some observer data exists for the 1988/89–1989/90 seasons, but those data are not considered reliable. Although bycatch can occur in the red king crab, scarlet king crab, grooved

Tanner crab, and triangle Tanner crab fisheries of the Aleutian Islands, such bycatch accounts for ≤2% of the estimated total weight in the crab fisheries annually when those fisheries are prosecuted. Only one vessel was observed during the directed fishery throughout the 1993/94 season and only two vessels were observed throughout the 1994/95 season (an additional catcher vessel carried an observer for one trip during the 1993/94 season and an additional three catcher vessels carried an observer for one trip during the 1994/95 season, but observed effort was small relative to the total season effort for those vessels and the author does not consider the data from those vessels reliable). Hence data on bycatch during the 1993/94 and 1994/95 directed fishery seasons are confidential and not presented here. Observer data on size distributions and estimated catch numbers of non-retained catch were used to estimate the weight of non-retained catch of red king crab by applying a weight-at-length estimator (see below); data on the size distribution of non-retained legal males was not recorded prior to 1998/99 and weights of retained legal males are used to estimate the weights of non-retained legal males during those years. Data on bycatch of golden king crab obtained by at-sea observers during groundfish fisheries in reporting areas 541, 542, and 543 (Figure 6) for crab fishery years 1993/94–2013/14 are presented (estimates for 1991/92–1992/93 are also presented, but they appear to be suspect; Table 3).

- Estimates of bycatch mortality during 1990/91–1992/93 and 1995/96–2013/14 directed and non-directed crab fisheries and 1993/94–2013/14 groundfish fisheries are presented in Table 4. Estimates of total fishery mortality (retained catch plus estimated bycatch mortality during crab and groundfish fisheries) during 1995/96–2013/14 are presented (Table 4). Following Siddeek et al. (2014), the bycatch mortality rate of king crab captured and discarded during Aleutian Islands king crab fisheries was assumed to be 0.2; that value was also applied as the bycatch mortality during other crab fisheries. Following Foy (2012a, 2012b), the bycatch mortality of king crab captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crab captured by trawls during groundfish fisheries was assumed to be 0.8.

c. ***Catch-at-length:*** Not used in a Tier 5 assessment; none are presented.

d. ***Survey biomass estimates:*** Not used in a Tier 5 assessment; none are presented.

e. ***Survey catch at length:*** Not used in a Tier 5 assessment; none are presented (see section D.4).

f. ***Other data time series:*** See section D.4 on other time-series data that are available, but not presented here.

3. Data which may be aggregated over time:

a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):

Growth per molt and probability of molt estimates are not used in a Tier 5 assessment. However, growth per molt and probability of molt have been estimated for Aleutian Islands golden king crab by Watson et al. (2002) based on information received from recoveries during the 1997/98–2000/01 commercial fisheries in the area east of 174° W longitude of male and female golden king crab tagged and released during July–August 1997 in the area east of 174° W longitude (see Tables 24–28 *in* Pengilly 2009).

Watson et al. (2002) used logistic regression to estimate the probability as a function of carapace length (CL, mm) at release that a male tagged and released in new-shell condition would molt within 12–15 months after release:

$$P(\text{molt}) = \exp(17.930 - 0.129*CL)/[1 + \exp(17.930 - 0.129*CL)].$$

Based on the above logistic regression, Watson et al. (2002) estimated that the size at which 50% of new-shell males would be expected to molt within 12–15 months is 139-mm CL (S.E. = 0.81-mm CL).

Watson et al. (2002) used logistic regression to estimate the probability as a function of carapace length (CL, mm) at release that a male tagged and released as a sublegal ≥ 90-mm CL in new-shell condition would molt to legal size within 12–15 months after release:

$$P(\text{molt to legal size}) = 1 - \exp(15.541 - 0.127*CL)/[1 + \exp(15.541 - 0.127*CL)].$$

Based on the above logistic regression, Watson et al. (2002) estimated that the size at which 50% of sublegal ≥90-mm CL, new-shell males would be expected to molt to legal size within 12–15 months is 123-mm CL (S.E. = 1.54-mm CL).

See section C.4 for discussion of evidence that mature female and the larger male golden king crab exhibit asynchronous, aseasonal molting and a prolonged intermolt period (>1 year).

b. Weight-at length or weight-at-age (by sex):

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female golden king crab according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007b) are: A = 0.0002988 and B = 3.135 for males and A = 0.001424 and B = 2.781 for females. Although the parameters A and B were derived from 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:

The default natural mortality rate assumed for king crab species by NPFMC (2007b) is M=0.18. However, that natural mortality assumption was not used in this Tier 5 stock 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 east of 174° W longitude (between 170° 21’ and 171° 33’ W longitude) that were performed during 1997 (Blau et al. 1998), 2000 (Watson and Gish 2002), 2003 (Watson 2004), and 2006 (Watson 2007) are available, but were not used in this Tier 5 assessment.

E. Analytic Approach

1. <u>History of modeling approaches for this stock</u>: This is a Tier 5 stock.

2. <u>Model Description</u>: *Subsections a–i are not applicable to a Tier 5 stock.*
It was recommended by NPFMC (2007b) that the Aleutian Islands golden king crab stock be managed as a Tier 5 stock until an assessment model is accepted for use in management. In 2014 the SSC recommended that this stock continue to be managed under Tier 5 for 2014/15 (June 2012 SSC minutes). An Aleutian Islands golden king crab assessment model (Siddeek et al. 2014) will be reviewed for use in Tier 4 or Tier 3 management of this stock by the Crab Plan Team in May 2015.

For Tier 5 stocks only an OFL is estimated, because it is not possible to estimate MSST without an estimate of biomass, and "the OFL represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007b). Additionally, NPFMC (2007b) states that for estimating the OFL of Tier 5 stocks, "The time period selected for computing the average catch, hence the OFL, should be based on the best scientific information available and provide the required risk aversion for stock conservation and utilization goals." Although NPFMC (2007b) defined the OFL in terms of the retained catch, total-catch OFLs may be considered for Tier 5 stocks for which nontarget fishery removal data are available (Federal Register/Vol. 73, No. 116, 33926). The CPT (in May 2010) and the SSC (in June 2010) endorsed the use of a total-catch OFL to establish the 2010/11 and subsequent OFLs for this stock. This assessment recommends – and only considers – use of a total-catch Tier 5 OFL for 2014/15.

For estimating the OFL of Tier 5 stocks, NPFMC (2007b) states, "The time period selected for computing the average catch, hence the OFL, should be based on the best scientific information available and provide the required risk aversion for stock conservation and utilization goals." Prior to 2008, two time periods were considered for computing the average retained catch for Aleutian Islands golden king crab: 1985–2005 (NPFMC 2007a) and 1985–1999 (NPFMC 2007b). The average retained catch over the years 1985 to 1999 was recommended by NPFMC (2007b) for the estimated OFL for Aleutian Islands golden king crab. Years post-1984 were chosen based on an assumed 8-year lag between hatching during the 1976/77 "regime shift" and growth to legal size. With regard to excluding data from years after 1999, NPFMC (2007b) states, "Years from 2000 to 2005 were excluded for Aleutian Islands golden king crab when the TAC was set below the previous average catch." Note, however, that there was no TAC or GHL established for the entire Aleutian Islands Area prior to the 1996/97 season (see above) and the GHL for the Aleutian Islands Area was reduced from 5.9-million lb (2,676 t) for the 1996/97 and 1997/98 seasons to 5.7-million lb (2,585 t) for the 1998/1999 season; the GHL or TAC has remained at 5.7-million lb (2,585 t) for all subsequent seasons until it was increased to 5.985-million lb (2,715 t) for the 2008/09 season. Pengilly (2008) discussed nine periods, spanning periods as long as 26 seasons (1981/82–2006/07) to as short as six seasons (1990/91–1995/96), for computing average annual retained catch and estimating the OFL for the 2008/09 season. Only periods beginning no earlier than 1985/86 were recommended for consideration, however, due to the size limit change that occurred prior to the 1985/86 season (Table 1, footnotes d–f). The Crab Plan Team in May 2008 recommended using the period 1990/91–1995/96 for computing the 2008/09 OFL. The CPT recommended the period 1990/91–1995/96 due to concerns raised by a decline in retained catch and CPUE that occurred from 1985/86 into the mid-1990s, the seasons of unconstrained catch under the current size limit. The SSC recommended using the period 1985/86–1995/96 for computing the 2008/09 OFL, however, because the period 1985/86–1995/96 is the longest possible period of unconstrained catch under the current size limit ("Earlier years were not recommended for inclusion because of a difference in the size limit regulations prior to 1985/86." Minutes of the NPFMC SSC meeting, 2–4 June 2008)**.** Pengilly (2009) discussed only three time periods to consider for setting the 2009/10 OFL: 1985/86–1995/96 (the period recommended by the SSC for the 2008/09 OFL); 1990/91–1995/96; (the period recommended by the CPT for the 2008/09 OFL); and 1987/88–1995/96. The period 1987/88–1995/96 was offered for consideration on the basis of having the longest period of unconstrained catch under the current size limit, while excluding the two seasons with the highest retained catch in the history of the fishery (the 1985/86–1986/87 seasons). Trends of declining catch, declining CPUE, and declining average weight of landed crab that occurred from 1985/86 into the mid-1990s could be interpreted as resulting from a fishery that relied increasingly on annual recruitment to legal size while harvesting a declining stock of legal-size males. Hence the catches during the full period of unconstrained catch under the current size limit, 1985/86–1995/96, could be viewed as unsustainable. Removal of the two highest-catch seasons, 1985/86–1986/87, at the beginning of that time period was offered as a compromise between the desire for the longest period possible for averaging catch and the desire for a period reflecting long-term production potential of the stock. Of those, the Crab Plan Team at the May 2009 again recommended using the period 1990/91–1995/96 for computing the 2009/10 OFL, whereas the SSC again recommended 1985/86–1995/96, noting that "the management system was relatively constant from 1985 onward" and that a "longer time period likely provides a more robust estimate than a shorter time period." (Minutes of the NPFMC SSC meeting, 1–3 June 2009).

Three alternatives were considered for setting a total-catch OFL for 2010/11 (see the Executive Summary of the May Draft of the 2010 Crab SAFE), none of which could be chosen with consensus by the CPT in May 2010 and all of which were rejected by the SSC in June 2010. In June 2010 the SSC recommended an approach to computing a total-catch OFL for this stock for 2010/11 as follows (Minutes of the NPFMC SSC meeting, 7–9 June 2010):

$$OFL_{2010/11} = (1+R_{96/97\text{-}08/09})\bullet RET_{85/86\text{-}95/96} + BM_{GF,96/97\text{-}08/09} = 11.0 \text{ million lbs.},$$

where

- $R_{96/97\text{-}08/09}$ is the average of the estimated annual ratios of lb of bycatch mortality due to crab fisheries to lb of retained catch in the directed fishery during the period 1996/97-2008/09,
- $RET_{85/86\text{-}95/96}$ is the average annual retained catch in the directed crab fishery during the period 1985/86-1995/96, and
- $BM_{GF,\ 96/97\text{-}08/09}$ is the average of the annual estimates of bycatch mortality due to groundfish fisheries over the period 1996/97-2008/09.

Additionally, the SSC in June 2010 recommended that "...this time period be frozen to stabilize the control rule."

Data on bycatch during crab fisheries prior to 1996/97 were presented to the CPT in May 2011 and the CPT recommended the following OFL for the 2011/12 season, which was also recommended by the SSC in June 2011:

$$OFL_{2011/12} = (1+R_{90/91\text{-}08/09})\bullet RET_{85/86\text{-}95/96} + BM_{GF,93/94\text{-}08/09} ,$$

where,

- $R_{90/91\text{-}08/09}$ is the average of the estimated annual ratios of lb of bycatch mortality due to crab fisheries to lb of retained catch in the directed fishery during the period 1990/91-2008/09 (excluding 1993/94–1994/95, due to data confidentialities and insufficiencies)
- $RET_{85/86\text{-}95/96}$ is the same as defined for $OFL_{2010/11}$, above (i.e., the average annual retained catch in the directed crab fishery during the period 1985/86-1995/96), and
- $BM_{GF,93/94\text{-}08/09}$ is the same as defined for $OFL_{2010/11}$, above (i.e., the average of the annual estimates of bycatch mortality due to groundfish fisheries over the period 1993/94-2008/09).

Trends in the estimated annual ratios of lb of bycatch mortality due to crab fisheries to lb of retained catch in the directed fishery during the period 1990/91-2008/09 were presented to the CPT in May 2012 and SSC in June 2012. The SSC found that the estimated annual ratios of lb of bycatch mortality due to crab fisheries to lb of retained catch in the directed fishery prior to the 1996/97 season were a better reflection of bycatch mortality during the 1985/86–1995/96 seasons than the estimates from the 1996/97–2008/09 seasons. Accordingly, the SSC (June 2012 SSC minutes) recommended that the OFL for the 2012/13 season be computed as:

$$OFL_{2012/13} = (1+R_{90/91\text{-}95/96})\bullet RET_{85/86\text{-}95/96} + BM_{GF,93/94\text{-}08/09},$$

where,

- $R_{90/91\text{-}95/96}$ is the average of the estimated annual ratios of lb of bycatch mortality due to crab fisheries to lb of retained catch in the directed fishery during the period 1990/91–1995/96 (excluding 1993/94–1994/95, due to data confidentialities and insufficiencies),
- $RET_{85/86\text{-}95/96}$ is the same as defined for Alternative 1, above (i.e., the average annual retained catch in the directed crab fishery during the period 1985/86-1995/96), and
- $BM_{GF,93/94\text{-}08/09}$ is the same as defined for Alternative 1, above (i.e., the average of the annual estimates of bycatch mortality due to groundfish fisheries over the period 1993/94-2008/09).

The OFLs for 2013/14–2014/15 were determined following the same procedure as for 2012/13.

3. <u>Model Selection and Evaluation</u>:

a. ***<u>Description of alternative model configurations</u>***

The SSC has recommended that the "time period be frozen to stabilize the control rule" in determination of a Tier 5 OFL (see section 2, above). With regard to the Tier 5 OFL for the Aleutian Islands golden king crab stock, the SSC has recommended that computation of the OFL computation should use: 1) the period 1985/86–1995/96 to compute the average retained catch (June 2008, and 2009 SSC minutes); 2) the "time period [to compute the Tier 5 OFL] be frozen to stabilize the control rule" at 1985/86–2008/09 (June 2010 SSC minutes); and 3) that bycatch data from crab fisheries from the period prior to 1996/97 be used to compute the Tier 5 OFL. Given those recommendations from the SSC and the lack of any additional fishery data from the period 1985/86–2008/09 that were not already available and presented during 2012–2014, only one alternative is presented, the author's recommended alternative, which is the status quo (i.e., the same as the Tier 5 OFL for 2012/13–2014/15 that was established in 2012):

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

where,

- $R_{90/91\text{-}95/96}$ is the average of the estimated annual ratios of lb of bycatch mortality due to crab fisheries to lb of retained catch in the directed fishery during the period 1990/91–1995/96 (excluding 1993/94–1994/95, due to data confidentialities and insufficiencies),
- $RET_{85/86\text{-}95/96}$ is the average annual retained catch in the directed crab fishery during the period 1985/86-1995/96, and
- $BM_{GF,93/94\text{-}08/09}$ is the average of the annual estimates of bycatch mortality due to groundfish fisheries over the period 1993/94-2008/09.

Statistics on the data and estimates used to calculate, $RET_{(85/86\text{-}95/96}$, $R_{90/91\text{-}95/96}$, and $BM_{GF,93/94\text{-}08/09}$ are provided in Table 5; the column averages in Table 5 are the calculated values of $RET_{(85/86\text{-}95/96}$, $R_{90/91\text{-}95/96}$, and $BM_{GF,93/94\text{-}08/09}$. Using those calculated values of $RET_{(85/86\text{-}95/96}$, $R_{90/91\text{-}95/96}$, and $BM_{GF,93/94\text{-}08/09}$, $OFL_{2015/16}$ is computed as,

$$OFL_{2015/16} = (1+0.363)\bullet(9{,}178{,}438) + 23{,}359 = 12{,}533{,}570 \text{ lb (12.53-million lb; 5.69 kt).}$$

Note that although the OFL for 2015/16 is computed using the same procedure and values as were used to compute the OFL for 2012/13–2014/15, the resulting computed value expressed in lb for $OFL_{2015/16}$ (12,533,569 lb) is inexplicably different from the value reported for $OFL_{2012/13}$ and $OFL_{2013/14}$ (12,537,757 lb) in the 2012 and 2013 SAFEs.

b. ***Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed:*** See the section A.4.

c. ***Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models:*** 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?:***
The 1985/86–2008/09 time period and the time periods for fishery mortality subcomponents within 1985/86–2008/09 used for determining the OFL were established by the SSC during 2008–2012. The values for retained catch and estimated bycatch mortality used in the OFL computation are in Table 5. Temporal trends during 1985/86–2013/14 in retained catch and

in the available estimates of bycatch mortality due to crab fisheries and groundfish fisheries are shown in Figure 7. Trends in the ratio of the estimated bycatch mortality due to crab fisheries to the retained catch are shown in Figures 8 and 9 for the years that data and estimates are available during 1985/86–2013/14. Retained catch data come from fish tickets and annual retained catch is assumed to be known. Estimates of catch from crab fishery observer data are generally considered credible (e.g., Byrne and Pengilly 1998; Gaeuman 2014). Estimates of bycatch mortality were derived as estimates of bycatch times an assumed bycatch mortality rate. The assumed bycatch mortality rates (i.e., 0.2 for crab fisheries, 0.5 for fixed-gear groundfish fisheries, and 0.8 for trawl groundfish fisheries) have not been estimated from data.

g. ***Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty:*** See section E.3.c, above.

h. ***Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach):*** Not applicable.

i. ***Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented:*** The model for computing the single recommended OFL follows the SSC recommendations to freeze the time period to stabilize the control role by using only 1985/86–1995/96 to estimate the average annual retained catch component of the OFL (June 2008 and June 2009 SSC minutes), to not include bycatch data after 2008/09 (June 2010 SSC minutes), and to use only the bycatch mortality estimates from the crab fisheries that are available from 1990/91–1995/96 (June 2012 SSC minutes). The author and the SSC (June 2012 SSC minutes) agree that the bycatch data from crab fisheries during 1990/91–1995/96 are the most representative data available of the conditions that existed during 1985/86–1995/96: those years fall within the period 1985/86–1995/96; regulations stipulating escape mechanisms in pots became effective after 1995/96 (see section **C.5-Brief summary of management history**); and there is a clear decreasing trend in the estimated ratio of lb of bycatch mortality due to crab fisheries to lb of retained crab in the directed fishery since 1996/97 (Figures 8 and 9).

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 5–6.

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 stocks.

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 stocks.

f. ***Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.):*** For a Tier 5 assessment, the major uncertainties are:

- Whether the chosen time period is "representative of the production potential of the stock" and if it serves to "provide the required risk aversion for stock conservation and utilization goals" or whether any such time period exists.
  - The Tier 5 OFL for this stock is highly sensitive to the choice of years used to compute the average annual catch. The table on page 19 of Pengilly (2008) addressed the justifications for alternative choices of time periods that could be used to compute the retained-catch portion of the OFL. Interested readers are directed to that document; briefly, however, the average retained-catch of the OFL for the nine alternative time periods presented ranged from 5.633 million lb (2,555 t; for 1996/97–2006/07) to 9.178 million lb (4,163 t; for 1985/86–1995/96, the time period selected and "frozen" by the SSC). The CPT in 2008 and 2009 recommended that the years 1990/91–1995/96 be used to compute the retained-catch OFL (resulting in a retained-catch OFL of 6.931-million lb; 3,144 t). In both 2008 and 2009, the SSC overrode the CPT's recommendation and selected the years 1985/86–1995/96 to compute the retained-catch OFL at 9.178-million lb (4,163 t). The SSC recommended that the time period for computing the retained-catch portion of the OFL "be frozen" at 1985/86–1995/96 "to stabilize the control rule."
  - The Tier 5 OFL is also sensitive to the choice of years used to estimate the average annual ratio of lb of bycatch mortality to lb of retained crab in the crab fisheries. The SSC recommended that the time period for computing the bycatch-mortality portion of the OFL be frozen to end at 2008/09. The estimates of annual bycatch biomass (not discounted for bycatch mortality) to retained catch are generally highest during 1990/91–1995/96 and show a decreasing trend during 1996/97–2008/09: that ratio during 1990/91–1995/96 ranges from 1.5:1 to 2.1:1, during 1996/97–2004/05 ranges from 0.8:1 to 1.7:1, and during 2005/06–2008/09 ranges from 0.5:1 to 0.6:1 (see Figures 8 and 9 for the trend in ratios after a default bycatch mortality rate is applied to the bycatch biomass estimates). Hence including the later years to compute the average annual ratio decreases the OFL estimate, whereas restricting the period to 1990/91–1995/96 increases the OFL estimate.
  - The Tier 5 OFL has only a slight sensitivity to the choice of years used to compute the bycatch due to groundfish fisheries. This assessment only considers the period 1993/94–2008/09 for bycatch in the groundfish fisheries. Estimates of annual bycatch mortality due to groundfish fisheries during 1993/94–2008/09 range from <0.001-million lb (<1 t) to 0.130-million lb (59 t). Because the estimate of bycatch biomass due to groundfish fisheries is small relative to the

biomass of retained catch (≥4.819-million lb [2,186 t] annually since 1985/86), the effect of choice of years here is negligibly small.

- The bycatch mortality rates used in estimation of total fishery mortality are assumed values. Bycatch mortality is unknown and no data that could be used to estimate the bycatch mortality of this stock is known to the author. After discussion on information presented on the apparent "hardiness" of golden king relative to red king crab at the May 2013 meeting, the CPT conclude that the handling mortality rate used in golden king crab assessments remain at the status quo, 0.2, until data for estimating handling mortality are presented (May 2013 CPT minutes). Hence only the values that are assumed for other BSAI king crab stock assessments are considered in this assessment. Due to the difference in scale between the estimated bycatch in crab fisheries and the groundfish fisheries (see bullet above), the estimated OFL is most sensitive to the assumed bycatch mortality in crab fisheries and less sensitive to the assumed bycatch in groundfish fisheries. Given a fixed period of years to compute the average of annual bycatch biomass estimates for the crab fisheries, the estimated OFL is inversely related to the bycatch mortality rate assumed for the crab fisheries. If the assumed bycatch mortality rate is doubled from 0.2 to 0.4, the OFL estimate increases by a factor of 1.17 (1.4/1.2); if halved from 0.2 to 0.1, the assumed bycatch mortality rate, and the OFL estimate decreases by a factor of 0.92 (1.1/1.2).
- There has been no program to survey this stock in its entirety and a program to survey a portion of this stock on a triennial basis ended after 2006 due to the costs of survey implementation. The CPT in September 2013 strongly recommended that, *"A survey is needed to provide a better index of abundance and information on recruitment for stock assessment"* and encouraged ADF&G, NMFS, and industry to discuss how to make such a survey happen. Such discussions occurred at meetings amongst ADF&G, NMFS, and the Aleutian King Crab Research Foundation (AKCRF) in January and March 2014 and follow-up meetings between ADF&G and AKCRF to develop plans for a survey designed to be implemented with cooperating commercial fishing vessels (see May 2014 CPT minutes for more details on the survey design that was developed). An 11-day "pilot survey" to test implementation of the survey design that developed from those meetings was performed during September 2014 in the Aleutian Islands east of 174° W longitude through a cooperative effort between ADF&G and the AKCRF from aboard the commercial crab-fishing vessel *F/V Patricia Lee* (M. Westphal, ADF&G, Dutch Harbor, *pers. comm.*).

F. Calculation of the OFL

1. <u>Specification of the Tier level and stock status level for computing the OFL:</u>

- Recommended as Tier 5, total-catch OFL computed as the estimated average annual total catch over a specified period.
- Recommended time period for computing retained-catch portion of the OFL: 1985/86–1995/96.
- Recommended time period for computing bycatch mortality due to crab fisheries: 1990/91–1995/96.
- Recommended time period for computing bycatch due to groundfish fisheries: 1993/94–2008/09.

- Recommended bycatch mortality rates: 0.2 for crab fisheries; 0.5 for fixed-gear groundfish fisheries; 0.8 for trawl groundfish fisheries.

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 stocks.

3. **Specification of the OFL:**

a. Provide the equations (from Amendment 24) on which the OFL is to be based:

From **Federal Register** / Vol. 73, No. 116, page 33926, "For stocks in Tier 5, the overfishing level is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information." Additionally, "For stocks where nontarget fishery removal data are available, catch includes all fishery removals, including retained catch and discard losses. Discard losses will be determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the overfishing level is set for and compared to the retained catch" (FR/Vol. 73, No. 116, 33926). That compares with the specification of NPFMC (2007b) that the OFL "represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock."

b. Basis for projecting MMB to the time of mating: Not applicable for Tier 5 stocks.

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 tables below. The OFL and ABC values for 2015/16 in the table below are the recommended values. The 2015/16 TAC has not yet been established. The TAC for 2013/14 and 2014/15 in the table below does not include landings towards a cost-recovery fishing goal to cover costs of observer deployments in the fishery.

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

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

Year	MSST	Biomass (MMB)	TAC[a]	Retained Catch[a]	Total Catch[a,b]	OFL[a]	ABC[a]
2011/12	N/A	N/A	2.72	2.71	2.95	5.17	4.66
2012/13	N/A	N/A	2.85	2.84	3.12	5.69	5.12
2013/14	N/A	N/A	2.85	2.89	3.19	5.69	5.12
2014/15	N/A	N/A	2.85			5.69	4.26
2015/16	N/A	N/A				5.69	4.26

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

4. Specification of the retained-catch portion of the total-catch OFL:
a. Equation for recommended retained-portion of total-catch OFL:

Retained-catch portion = average retained catch during 1985/86–1995/96
= 9,178,438 lb (9.18-million lb; 4,163 t).

5. Recommended F_{OFL}, OFL total catch and the retained portion for the coming year:
See sections ***F.3*** and ***F.4***, above; no F_{OFL} is recommended for a Tier 5 stock.

G. Calculation of ABC

1. PDF of OFL. Bootstrap estimate of the sampling distribution (assuming no error in estimation of bycatch) of the recommended OFL is shown in Figure 10 (1,000 samples drawn with replacement independently from each of the three columns of values in Table 5 to calculate $R_{90/91\text{-}95/96}$, $RET_{85/86\text{-}95/96}$, $BM_{GF,93/94\text{-}08/09}$ and $OFL_{Alt\text{-}2,2010/11}$). Table 6 provides statistics on the generated distributions. Note that generated sampling distribution and computed standard deviation are meaningful as measures in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Sections E.2 and E.4.f).

2. List of variables related to scientific uncertainty.

- The time period to compute the average catch relative to an assumption that this represents “a time period determined to be representative of the production potential of the stock.”
- Bycatch mortality rate in each fishery that bycatch occurs. Note that for Tier 5 stocks, an increase in an assumed bycatch rate will increase the total-catch OFL (and hence the ABC), but has no effect on the retained-catch portion of the OFL or the retained-catch portion of the ABC.
- Estimated bycatch and bycatch mortality for each fishery that bycatch occurred in during 1985/86–1995/96.
- See **E.4.*f*** for details.

3. List of additional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

5. Author recommended ABC.

(1.0-0.25)·12,533,570 lb = 9,400,177 lb (9.40-million lb; 4,264 t).

The recommended ABC for 2015/16 was computed according to the status quo buffer of 0.25 recommended by the Crab Plan Team and SSC for 2014/15. The 2014 SAFE, May 2014 CPT minutes, and June 2014 SSC minutes provide the reasoning for use of a buffer of 0.25, rather than a buffer of 0.1 as was used to compute the ABCs for 2011/12 – 2013/14.

H. Rebuilding Analyses

Not applicable; this stock has not been declared overfished.

I. Data Gaps and Research Priorities

Currently, there are no biomass estimates for this stock and no program for providing fishery-independent data on the stock. The CPT in September 2013 identified development of a survey to provide better data than fishery CPUE and other fishery-dependent data to index stock abundance and recruitment. To address that priority need, ADF&G, NMFS, and industry began discussions in January 2014 to develop such a survey and a "pilot survey" using a cooperating commercial fishing vessel was performed during September 2014 in the Aleutian Islands east of 174° W longitude.

Bycatch mortality rate in directed fishery is unknown.

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Table 1. Harvest history for the Aleutian Islands golden king crab fishery (GHL/TAC, lb and number of retained crabs, pot lifts, fishery catch per unit effort, and average weight of landed crab) by fishery season from the 1981/82 season through the 2013/14 season, including the Community Development Quota (CDQ) and Adak Community Allocation (ACA) fisheries for the 2005/06–2013/14, and cost-recovery fishery for 2013/14 (from 2014 Crab SAFE, updated for 2013/14).

Season	GHL/TAC Millions of Lb	Harvest Lb[a]	Harvest Number[a]	Pot lifts	CPUE[b]	Average Weight[c]
1981/82	-	1,319,666	242,407	28,263	8.4	5.4[d]
1982/83	-	9,236,942	1,746,206	179,888	9.4	5.3[d]
1983/84	-	10,495,045	1,964,772	267,519	7.2	5.3[d]
1984/85	-	4,819,347	995,453	90,066	10.7	4.8[e]
1985/86	-	12,734,212	2,811,195	236,281	11.9	4.5[f]
1986/87	-	14,738,744	3,340,627	433,020	7.7	4.4[f]
1987/88	-	9,257,005	2,174,576	306,730	7.1	4.2[f]
1988/89	-	10,627,042	2,488,433	321,927	7.6	4.3[f]
1989/90	-	12,022,052	2,902,913	357,803	8.0	4.1[f]
1990/91	-	6,950,362	1,703,251	214,814	7.7	4.1[f]
1991/92	-	7,702,141	1,847,398	234,857	7.7	4.2[f]
1992/93	-	6,291,197	1,528,328	203,221	7.4	4.1[f]
1993/94	-	5,551,143	1,397,530	234,654	5.8	4.0[f]
1994/95	-	8,128,511	1,924,271	386,593	4.8	4.2[f]
1995/96	-	6,960,406	1,582,333	293,021	5.2	4.4[f]
1996/97	5.900	5,815,772	1,334,877	212,727	6.0	4.4[f]
1997/98	5.900	5,945,683	1,350,160	193,214	6.8	4.4[f]
1998/99	5.700	4,941,893	1,150,029	119,353	9.4	4.3[f]
1999/00	5.700	5,838,788	1,385,890	186,169	7.2	4.2[f]
2000/01	5.700	6,018,761	1,410,315	172,790	8.0	4.3[f]
2001/02	5.700	5,918,706	1,416,768	168,151	8.3	4.2[f]
2002/03	5.700	5,462,455	1,308,709	131,021	9.8	4.2[f]
2003/04	5.700	5,665,828	1,319,707	125,119	10.3	4.3[f]
2004/05	5.700	5,575,051	1,323,001	91,694	14.2	4.2[f]
2005/06	5.700	5,520,318	1,263,339	54,685	22.9	4.4[f]
2006/07	5.700	5,262,342	1,178,321	53,065	22.0	4.5[f]
2007/08	5.700	5,508,100	1,233,848	52,609	23.5	4.5[f]
2008/09	5.985	5,680,084	1,254,607	50,666	24.8	4.5[f]
2009/10	5.985	5,912,287	1,308,218	52,787	24.8	4.5[f]
2010/11	5.985	5,968,849	1,297,229	55,795	23.2	4.6[f]
2011/12	5.985	5,964,416	1,284,946	44,241	29.0	4.6[f]
2012/13	6.290	6,267,759	1,360,582	53,543	25.4	4.6[f]
2013/14[g]	6.290	6,379,553	1,407,103	63,223	22.3	4.5[f]

a. Includes deadloss.
b. Catch (number of crab) per pot lift.
c. Average weight (lb) of landed crab, including deadloss.
d. Managed with 6.5" CW minimum size limit.
e. Managed with 6.5" CW minimum size limit west of 171° W longitude and 6.0" minimum size limit east of 171° W longitude.
f. Managed with 6.0" minimum size limit.
g. Catch and effort data includes cost-recovery fishery.

Table 2. Retained catch (thousands of lb) of Aleutian Islands golden king crab, with the estimated non-retained catch (thousands of lb; not discounted for an assumed bycatch mortality rate) and components of non-retained catch (non-retained legal males, non-retained sublegal males, non-retained females) during commercial crab fisheries by season,1990/91–2013/14 (from 2014 Crab SAFE, updated for 2013/14).

	Retained	Non-retained	Components of non-retained catch:		
Season	Catch	Catch	Legal males	Sublegal males	Females
1990/91	6,950	13,824	12	6,407	7,405
1991/92	7,702	11,257	214	5,533	5,510
1992/93	6,291	13,082	62	5,875	7,145
1993/94	5,551	—	—	—	—
1994/95	8,129	—	—	—	—
1995/96	6,960	12,050	64	6,054	5,932
1996/97	5,816	9,100	25	4,222	4,854
1997/98	5,946	8,733	40	4,199	4,494
1998/99	4,942	7,388	41	4,303	3,044
1999/00	5,839	7,552	64	3,930	3,557
2000/01	6,019	8,902	35	4,782	4,084
2001/02	5,919	6,888	27	3,787	3,075
2002/03	5,462	5,671	42	3,113	2,516
2003/04	5,666	4,973	39	2,664	2,271
2004/05	5,575	4,321	76	2,512	1,733
2005/06	5,520	2,524	140	1,479	905
2006/07	5,262	2,573	120	1,263	1,190
2007/08	5,508	3,035	128	1,505	1,402
2008/09	5,680	2,764	175	1,365	1,223
2009/10	5,912	2,787	164	1,364	1,260
2010/11	5,969	2,726	223	1,249	1,255
2011/12	5,964	2,540	269	1,181	1,089
2012/13	6,268	2,900	342	1,235	1,323
2013/14	6,380	3,165	369	1,489	1,307

Table 3. Estimated annual weight (lb) of discarded bycatch of golden king crab (all sizes, males and females) and bycatch mortality (lb) during federal groundfish fisheries by gear type (fixed or trawl), 1991/92–2013/14 (assumes bycatch mortality rate of 0.5 for fixed-gear fisheries and 0.8 for trawl fisheries (from 2014 Crab SAFE, updated for 2013/14).

	Bycatch		Bycatch Mortality		
Year	Fixed Gear	Trawl Gear	Fixed Gear	Trawl Gear	Total
1991/92	0	0	0	0	0
1992/93	5	3	3	2	5
1993/94	3,960	8,164	1,980	6,531	8,511
1994/95	1,346	2,674	673	2,139	2,812
1995/96	367	5,165	184	4,132	4,316
1996/97	26	13,862	13	11,090	11,103
1997/98	539	1,071	270	857	1,126
1998/99	3,901	1,381	1,951	1,105	3,055
1999/00	10,572	1,422	5,286	1,138	6,424
2000/01	7,166	669	3,583	535	4,118
2001/02	1,387	417	694	334	1,027
2002/03	75,952	871	37,976	697	38,673
2003/04	86,186	1,498	43,093	1,198	44,291
2004/05	2,450	2,452	1,225	1,962	3,187
2005/06	1,246	4,151	623	3,321	3,944
2006/07	72,306	3,077	36,153	2,462	38,615
2007/08	254,225	3,641	127,113	2,913	130,025
2008/09	108,683	22,712	54,342	18,170	72,511
2009/10	44,226	18,061	22,113	14,449	36,562
2010/11	31,456	34,801	15,728	27,841	43,569
2011/12	36,236	20,038	18,118	16,030	34,148
2012/13	1,191	24,593	596	19,674	20,270
2013/14	3,480	27,382	1,740	21,906	23,645

Table 4. Estimated annual weight (thousands of lb) of total fishery mortality to Aleutian Islands golden king crab, 1990/91–2013/14, partitioned by source of mortality: retained catch, bycatch mortality during crab fisheries, and bycatch mortality during groundfish fisheries (from 2014 Crab SAFE, updated for 2013/14).

		Bycatch Mortality by Fishery Type		Total
Season	Retained Catch	Crab	Groundfish	Fishery Mortality
1990/91	6,950	2,765	—	—
1991/92	7,702	2,251	—	—
1992/93	6,291	2,616	—	—
1993/94	5,551	—	9	—
1994/95	8,129	—	3	—
1995/96	6,960	2,410	4	9,375
1996/97	5,816	1,815	11	7,642
1997/98	5,946	1,739	1	7,685
1998/99	4,942	1,478	3	6,423
1999/00	5,839	1,510	6	7,356
2000/01	6,019	1,780	4	7,803
2001/02	5,919	1,378	1	7,297
2002/03	5,462	1,134	39	6,635
2003/04	5,666	995	44	6,705
2004/05	5,575	864	3	6,442
2005/06	5,520	505	4	6,029
2006/07	5,262	515	39	5,816
2007/08	5,508	607	130	6,245
2008/09	5,680	553	73	6,305
2009/10	5,912	557	37	6,506
2010/11	5,969	545	44	6,558
2011/12	5,964	508	34	6,506
2012/13	6,268	580	20	6,868
2013/14	6,380	633	24	7,037

Table 5. Data for calculation of $RET_{85/86\text{-}95/96}$ and estimates used in calculation of $R_{90/91\text{-}95/96}$ and $BM_{GF,93/94\text{-}08/09}$ for calculation of the recommended (status quo) Aleutian Islands golden king crab Tier 5 2015/16 OFL (lb); values under $RET_{85/86\text{-}95/96}$ are from Table 1, values under $R_{90/91\text{-}95/96}$ were computed from the retained catch data and the crab bycatch mortality estimates in Table 4; values under $BM_{GF,93/94\text{-}08/09}$ are from Table 4.

Season	$RET_{85/86\text{-}95/96}$ [a]	$R_{90/91\text{-}95/96}$ [b]	$BM_{GF,93/94\text{-}08/09}$ [c]
1985/86	12,734,212		
1986/87	14,738,744		
1987/88	9,257,005		
1988/89	10,627,042		
1989/90	12,022,052		
1990/91	6,950,362	0.398	
1991/92	7,702,141	0.292	
1992/93	6,291,197	0.416	
1993/94	5,551,143	—	8,511
1994/95	8,128,511	—	2,812
1995/96	6,960,406	0.346	4,315
1996/97			11,102
1997/98			1,126
1998/99			3,055
1999/00			6,424
2000/01			4,119
2001/02			1,027
2002/03			38,673
2003/04			44,291
2004/05			3,187
2005/06			3,944
2006/07			38,614
2007/08			130,026
2008/09			72,511
N	11	4	16
Average	9,178,438	0.363	23,359
S.E.M.	896,511	0.028	8,827
CV	0.10	0.08	0.38

a. $RET_{85/86\text{-}95/96}$ is the average annual retained catch (lb) in the directed crab fishery during the period 1985/86–1995/96; data from Table 1.

b. $R_{90/91\text{-}95/96}$ is the average of the estimated annual ratios of lb of bycatch mortality due to crab fisheries to lb of retained catch in the directed fishery during the period 1990/91–1995/96 (excluding 1993/94–1994/95, due to data confidentialities and insufficiencies); data from Table 4.

c. $BM_{GF,93/94\text{-}08/09}$ is the average of the annual estimates of bycatch mortality (lb) due to groundfish fisheries over the period 1993/94–2008/09; data from Table 4.

Table 6. Statistics for 1,000 bootstrap OFLs (lb) calculated according to the author recommended (status quo) approach for 2015/16 OFL calculation, with the computed OFL for comparison (from 2013 Crab SAFE).

	Recommend – status quo approach
Computed OFL (lb)	12,537,757
Mean of 1,000 bootstrapped OFLs (lb)	12,510,742
Std. dev. of 1,000 bootstrapped OFLs	1,184,511
CV = (std. dev.)/(Mean)	0.09

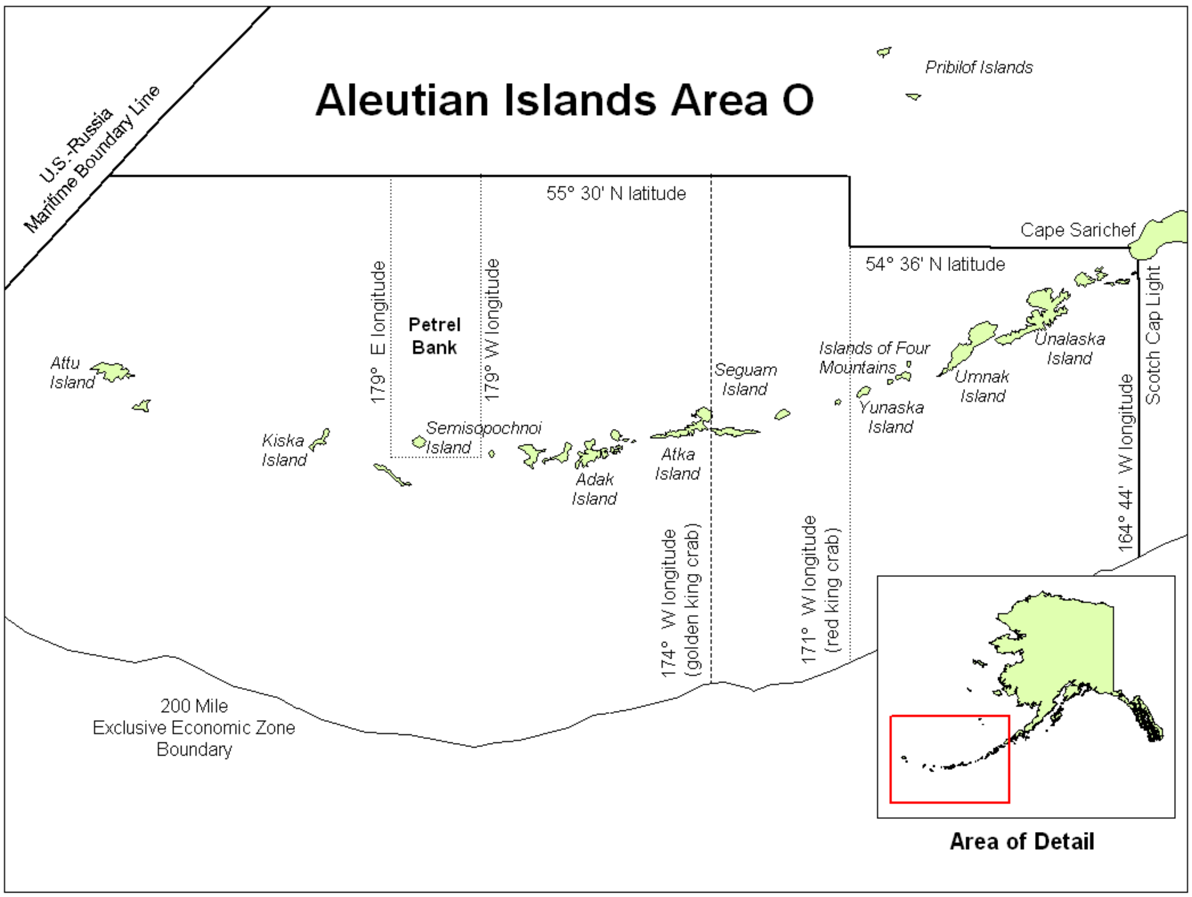

Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Baechler and Cook 2014).

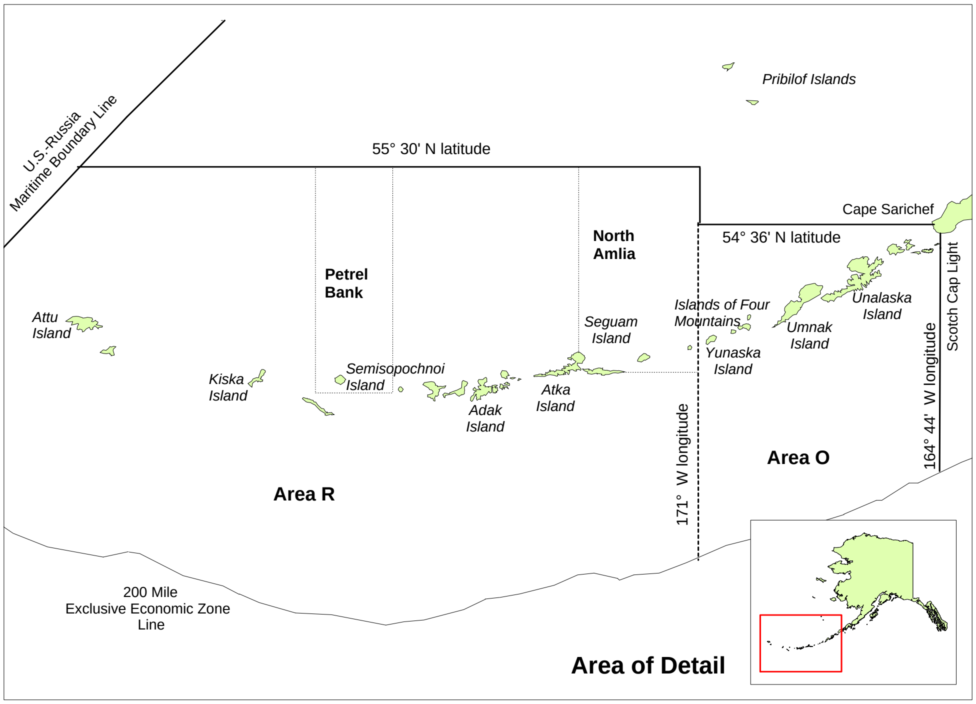

Figure 2. Adak (Area R) and Dutch Harbor (Area O) king crab Registration Areas and Districts, 1984/85–1995/96 seasons (from Baechler 2012).

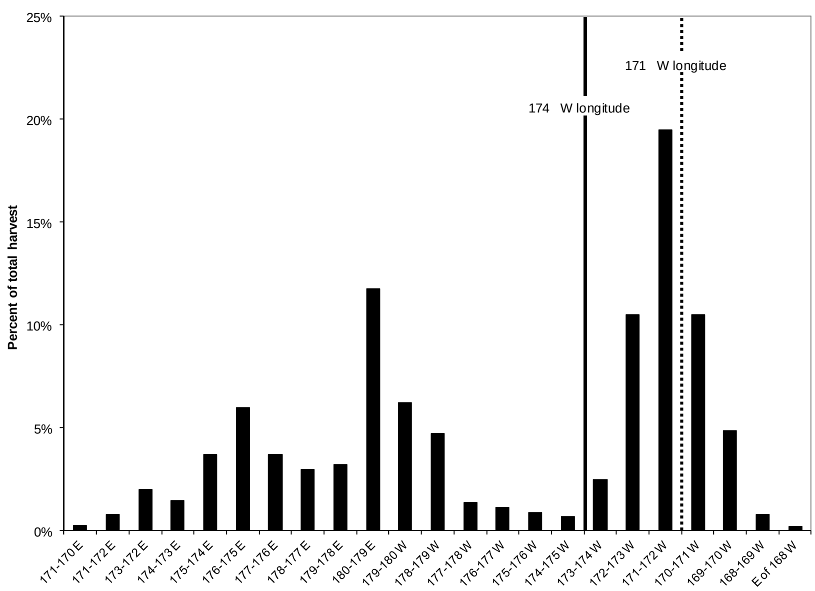

Figure 3. Percent of total 1981/82–1995/96 golden king crab harvest from one-degree longitude intervals in the Aleutian Islands, with dotted line denoting the border at 171° W longitude used during the 1984/85–1995/96 seasons to divide fishery management between the Dutch Harbor Area (east of 171° W longitude) and the Adak Area (west of 171° W longitude) and solid line denoting the border at 174° W longitude used since the 1996/97 season to manage crab east and west of 174° W longitude (adapted from Figure 4-2 *in* Morrison et al. 1998).

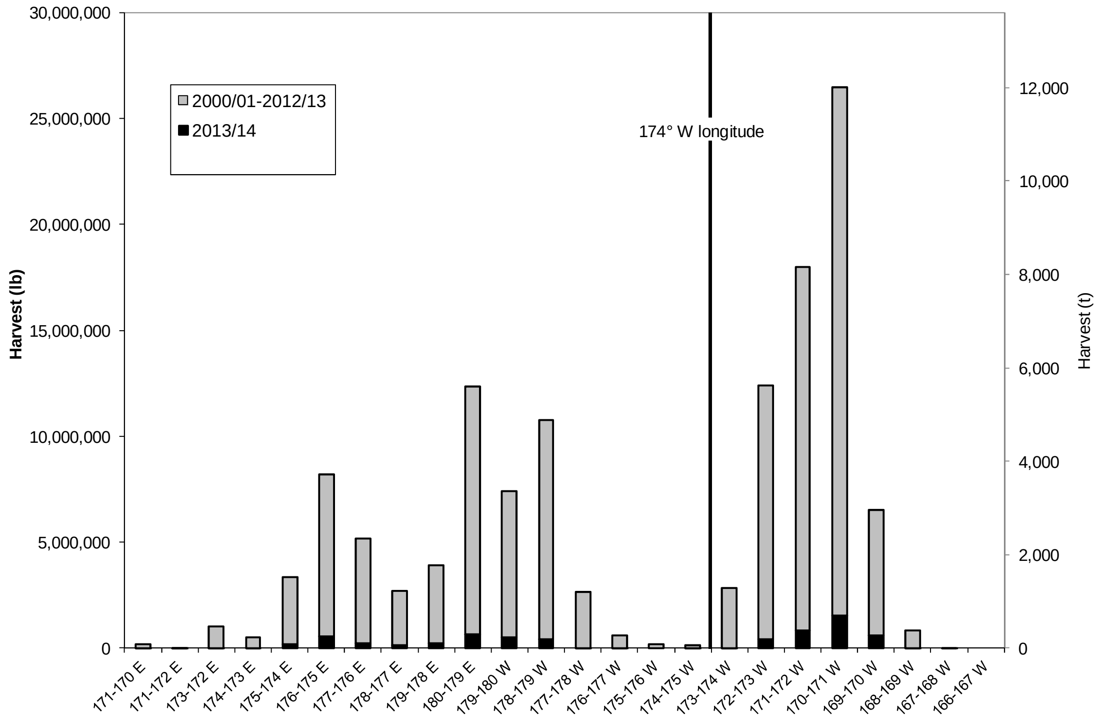

Figure 4. Harvest (lb on left axis and t on right axis) of golden king crab from one-degree longitude intervals in the Aleutian Islands during the 2000/01 through 2013/14 commercial fishery seasons; solid line denotes the border at 174° W longitude that has been used since the 1996/97 season to manage Aleutian Island golden king crab as separate stocks east and west of 174° W longitude (from 2014 Crab SAFE, updated for 2013/14).

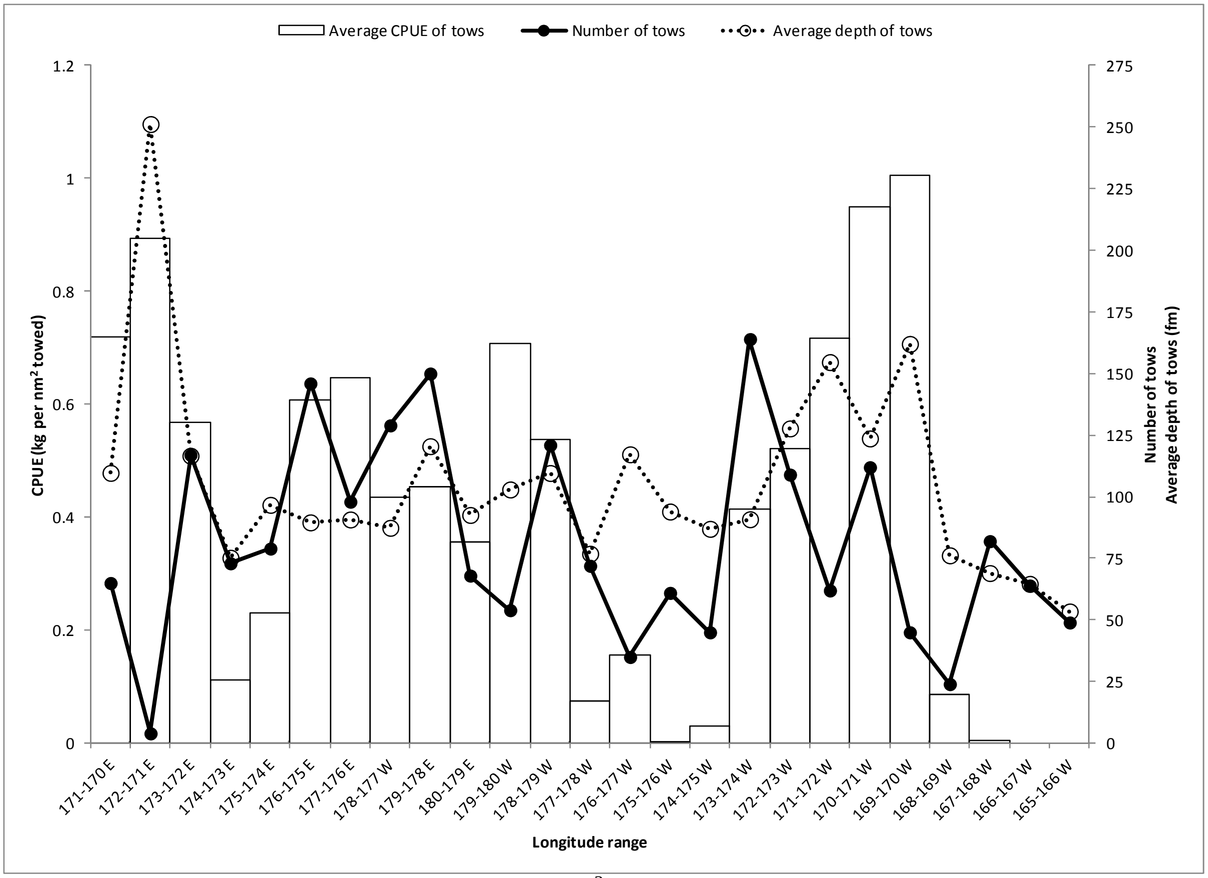

Figure 5. Average golden king crab CPUE (kg/nm^2) for tows, number of tows, and average depth of tows from one-degree longitude intervals during the 2002, 2004, 2006, 2010, and 2012 NMFS Aleutian Islands bottom trawl surveys; preliminary summary of data obtained on 1 April 2013 from http://www.afsc.noaa.gov/RACE/groundfish/survey_data/default.htm.

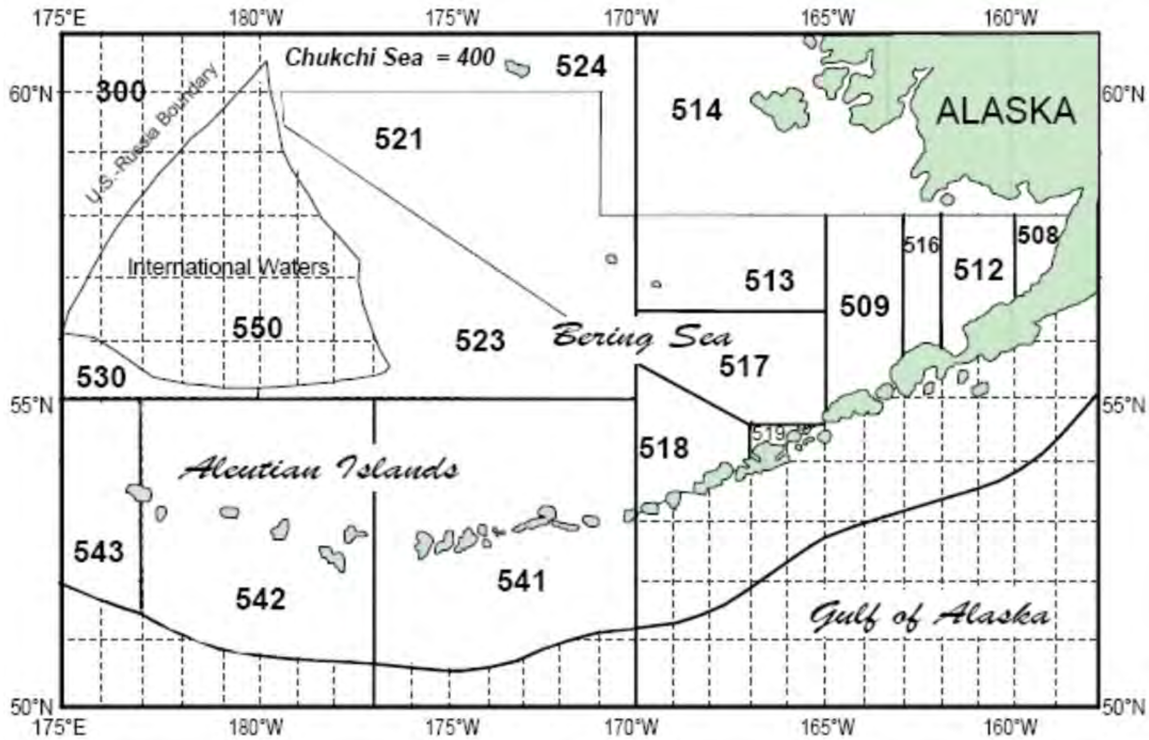

Figure 6. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands showing reporting areas 541, 542, and 543 that are used to summarize groundfish fisheries bycatch data for Aleutian Islands golden king crab (from http://www.alaskafisheries.noaa.gov/rr/figures/fig1.pdf).

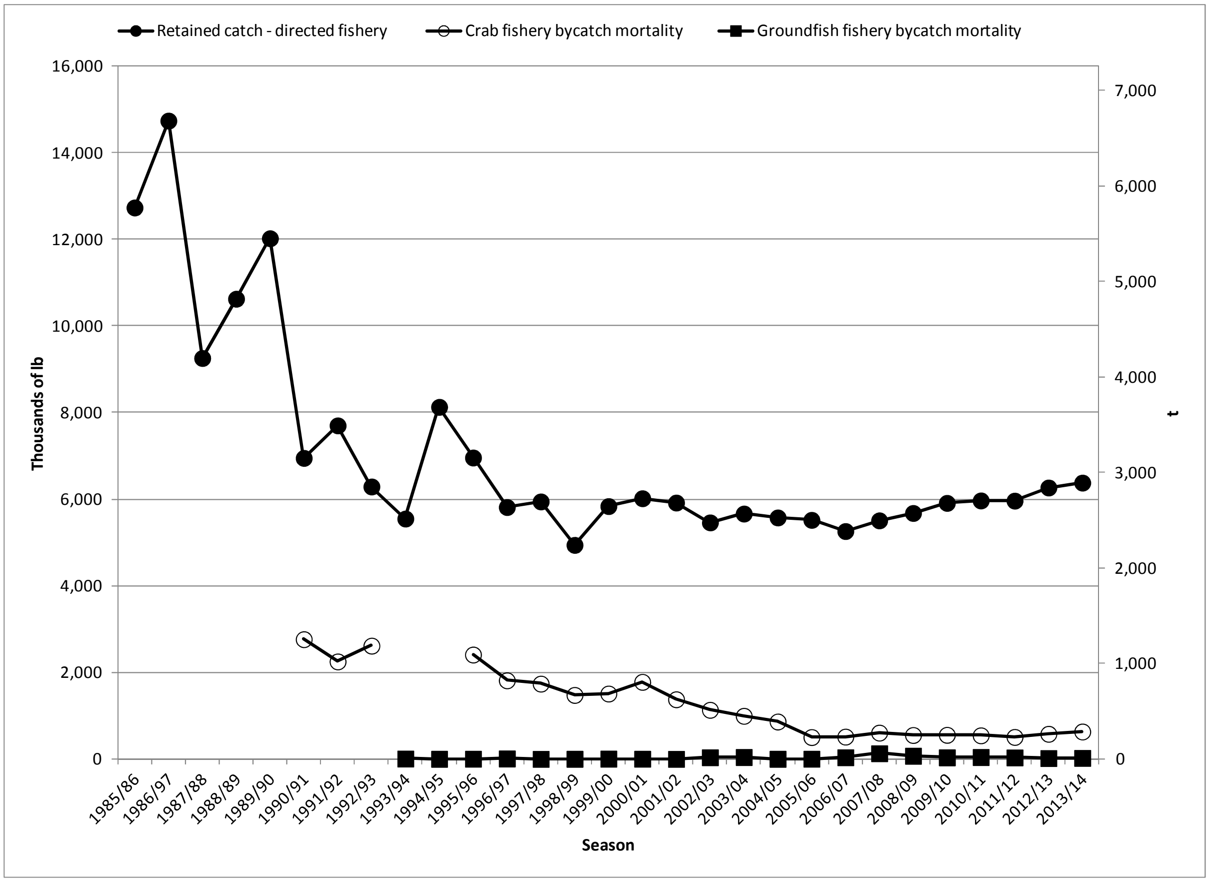

Figure 7. Retained catch during the Aleutian Islands golden king crab (AIGKC) fishery, estimated bycatch mortality of AIGKC (when available) during all crab fisheries, and estimated bycatch mortality of AIGKC (when available) for all groundfish fisheries, 1985/86–2013/14 (thousands of lb on left axis and t on right axis; from Table 4).

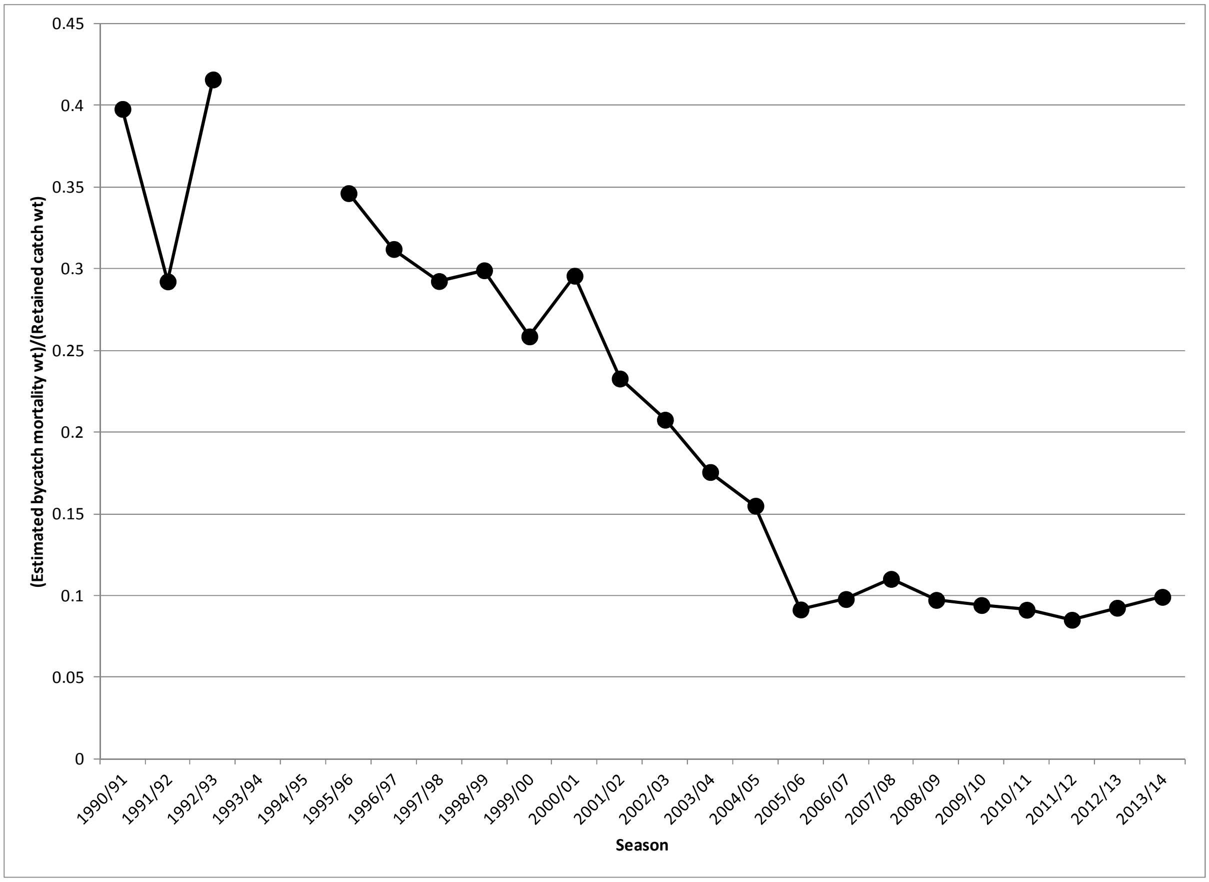

Figure 8. Ratio of estimated weight of bycatch mortality in directed and non-directed crab fisheries to weight of retained catch for Aleutian Islands golden king crab, 1990/91–2013/14 (ratios for 1993/94–1994/95 not available due to data confidentialities and insufficiencies).

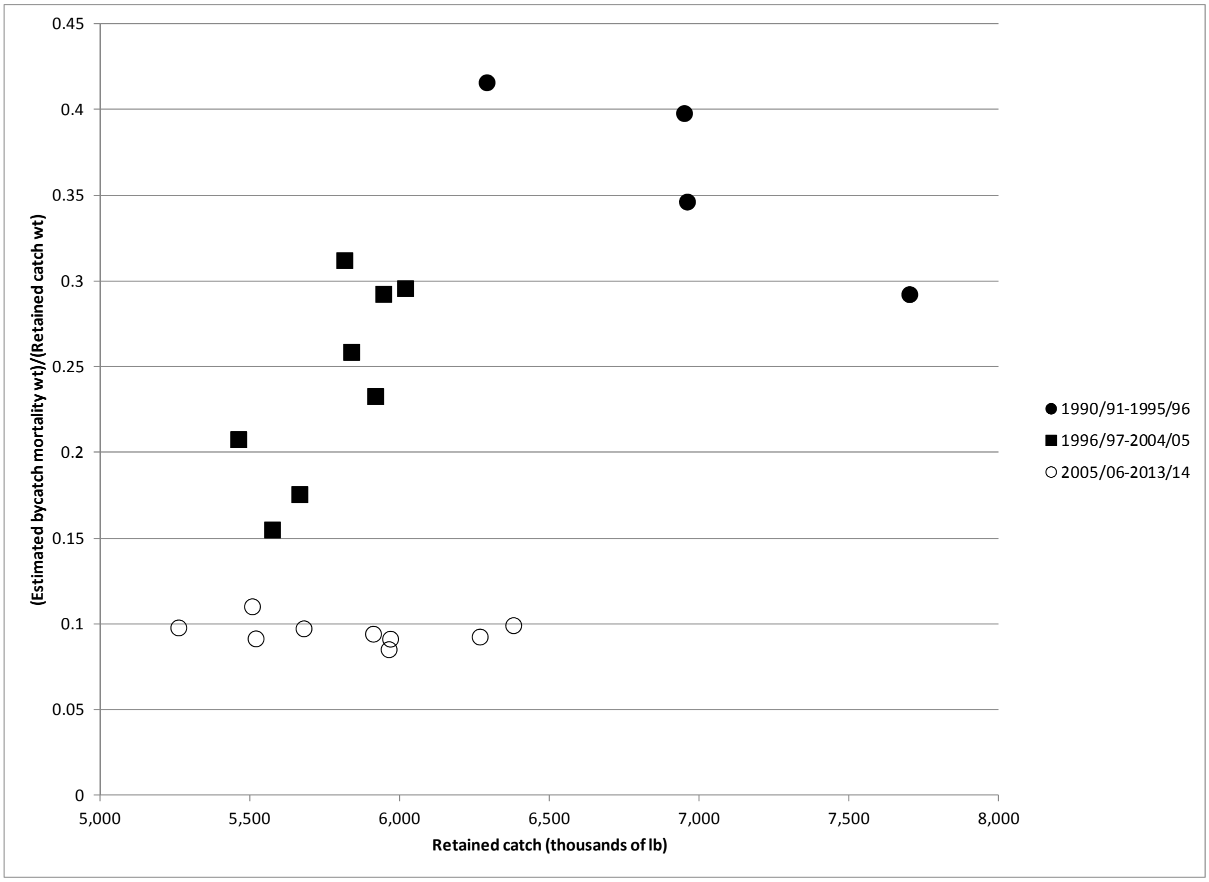

Figure 9. Ratio of estimated weight of bycatch mortality in directed and non-directed crab fisheries to weight of retained catch for Aleutian Islands golden king crab plotted against weight of retained catch, 1990/91–2013/14 (ratios for 1993/94–1994/95 not available due to data confidentialities and insufficiencies).

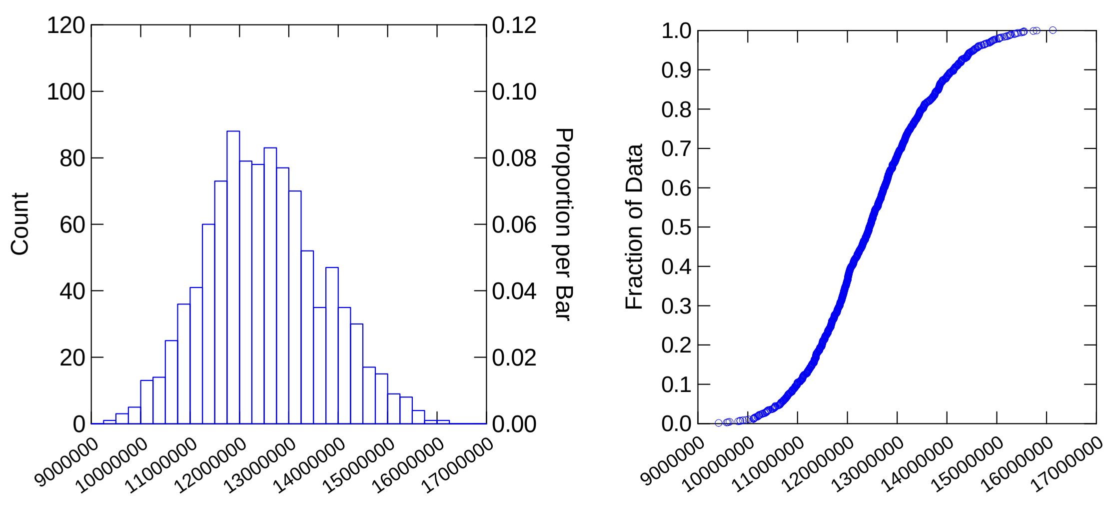

Figure 10. Bootstrapped estimates of the sampling distribution of the recommended 2015/2016 Tier 5 OFL (lb of total-catch) for the Aleutian Islands golden king crab stock; histograms in left column, cumulative distribution in right column (from 2013 Crab SAFE).

Pribilof Islands Golden King Crab

– 2015 Tier 5 Assessment

2015 Crab SAFE Report Chapter (May 2015)

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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 the 1982/83 season, although some limited fishing occurred at least as early as 1981/82. Peak harvest occurred in the 1983/84 season with a retained catch of 0.856-million lb (388 t) by 50 vessels. The fishing season for this stock has been defined as a calendar year (as opposed to 1-July-to-30-June "crab fishery year") following the close of the 1983/84 season and, since then, participation in the fishery has been sporadic and annually retained catch has been variable, from 0 lb in the nine years that no vessels participated (1984, 1986, 1990–1992, 2006–2009) up to a maximum of 0.342-million lb (155 t) 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 0.200-million lb (91 t) and has been managed with a GHL of 0.150-million lb (68 t) since 2000. No vessels participated in the directed fishery and no landings were made during 2006–2009. One vessel landed catch in 2010, two vessels landed catch in 2011, and one vessel landed catch in each of 2012, 2013, and 2014; hence catch and other fishery data from the directed fishery during the previous five years cannot be reported here under the confidentiality requirements of State of Alaska (SOA) statute Sec. 16.05.815. Non-retained bycatch occurs in the directed golden king crab fishery and can occur in the eastern Bering Sea snow crab fishery, the Bering Sea grooved Tanner crab fishery, and Bering Sea groundfish fisheries. Estimated annual weight of non-retained bycatch in directed and non-directed crab fisheries during calendar years 2001–2013 ranges from 0 lb to 0.049-million lb (22 t); complete data on bycatch during all crab fisheries in 2014 are not presently available. Estimates of annual total fishery mortality during calendar years 2001–2013 due to crab fisheries range from 0 to 0.160-million lb (73 t), with an average of 0.072-million lb (33 t); complete data on bycatch during all crab fisheries in 2014 are not presently available. Estimates of annually discarded bycatch during Bering Sea groundfish fisheries are reported for crab fishery years. Those estimates range from <0.001-million (<1 t) to 0.027-million lb (12 t) annually during the 1991/92–2013/14 crab fishery years. Estimates of annual fishery mortality during 1991/92–2013/14 due to groundfish fisheries range from <0.001-million lb (<1 t) to 0.019-million lb (9 t), with an average of 0.005-million lb (2 t).

3. Stock biomass:

Stock biomass (all sizes, both sexes) of golden king crab have been estimated for the Pribilof Canyon area using the area-swept technique applied to data obtained from the erstwhile biennial eastern Bering Sea upper continental slope trawl survey performed by NMFS-AFSC in 2002 (Hoff and Britt 2003), 2004 (Hoff and Britt 2005), 2008 (Hoff and Britt 2009), 2010 (Hoff and Britt 2011), and 2012 (Hoff 2013). Hoff (2013) estimated total stock biomass for the entire slope survey area in 2012 to be 4.475-million lb (2.030 t) and for the Pribilof Canyon area to be 1.716-million lb (778 t).

Complete data on size-sex composition of survey catch are available only from the 2008–2012 biennial surveys (C. Armistead, NMFS-AFSC, Kodiak). Biomass estimates by sex and size class from the 2008, 2010, and 2012 surveys were presented in a May 2013 (Gaeuman 2013b) report to the Crab Plan Team and biomass estimates of mature males from the 2008–2012 biennial surveys were presented in a September 2013 (Gaeuman 2013a) report to the Crab Plan Team. Using the size-sex composition data from the 2012 NMFS-AFSC eastern Bering Sea upper continental slope survey, Gaeuman (2013b) estimated total biomass for 2012 to be 4.244-million lb (1,925 t) for the entire survey area and 1.567-million lb (711 t) in the Pribilof Canyon area and Gaeuman (2013a) estimated mature male biomass for 2012 to be 1.790-million lb (812 t) for the entire survey area and 0.565-million lb (256 t) in the Pribilof Canyon area.

Sadly, the survey scheduled for 2014 was cancelled[1].

4. Recruitment:

Biomass of golden king crab (all sizes and both sexes) as estimated from data collected during the 2002–2012 biennial NMFS-AFSC eastern Bering Sea upper continental slope surveys increased in the entire slope survey area from 2.227-million lb (1,010 t) in 2002 (Hoff and Britt 2003) to 5.071-million lb (2,300 t) in 2010 (Hoff and Britt 2011); estimated biomass in the Pribilof Canyon area increased from 1.504-million lb (682 t) in 2002 to 3.560-million lb (1,615 t) in 2010. The estimate of total biomass for the entire survey area in 2012 is 88% of the 2010 estimate, however, and the estimate of total biomass for the Pribilof Canyon area in 2012 is 48% of the 2010 estimate (see **3. Stock biomass**, above).

Using the size-sex composition data from the surveys, Gaeuman (2013a) estimated mature male biomass in the entire survey area to have increased slightly from 1.692-million lb (767 t) in 2010 to 1.790-million lb (812 t) in 2012. However, estimated mature male biomass in the Pribilof canyon area was estimated to have decreased markedly from 0.970-million lb (440 t) in 2010 to 0.565-million lb (256 t) in 2012.

5. Management performance:

No overfished determination (i.e., MSST) has been made for this stock, although approaches to using data from the biennial NMFS-AFSC eastern Bering Sea upper continental slope surveys has been presented to and considered by the Crab Plan Team Gaeuman (2013a, 2013b). Retained

[1] https://www.fbo.gov/index?s=opportunity&mode=form&id=b3bb5ad289a0d04224c234acb57fe5aa&tab=core&_cview=1

catch and total-catch mortality in 2014 directed fishery are confidential under the requirements of Sec. 16.05.815 (SOA statute) and complete data on bycatch during all crab fisheries in 2014 are not presently available. Because complete data from all crab fisheries in 2014 are not presently available, total catch in 2014 cannot be estimated for comparison with the 2014 OFL and ABC at this time. The GHL for the 2015 season has yet to be established (H. Fitch, ADF&G, Dutch Harbor, *pers. comm.*, 21 April 2015). The 2016 OFL and ABC in the table below are the author's recommendations.

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c]	ABC[c]
2011	N/A	N/A	0.150	Conf.[e]	Conf.[e]	0.18	N/A
2012	N/A	N/A	0.150	Conf.[e]	Conf.[e]	0.20	0.18
2013	N/A	N/A	0.150	Conf.[e]	Conf.[e]	0.20	0.18
2014	N/A	N/A	0.150	Conf.[e]	Conf.[e]	0.20	0.18
2015	N/A	N/A				0.20	0.15
2016	N/A	N/A				0.20	0.15

a. Season is based on a calendar year.
b. Guideline harvest level expressed in millions of lb.
c. Millions of lb.
d. Total retained catch plus estimated bycatch mortality during crab fisheries only. Bycatch mortality due to groundfish fisheries is not included here because available data are summarized by "crab fishery year" rather than calendar year; estimates of annual bycatch mortality during 1991/92–2012/13 groundfish fisheries are ≤0.019-million lb, with an average of 0.005-million lb.
e. Catch statistics are confidential under Sec. 16.05.815 (SOA statute): ≤2 vessels participated in each season.

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c]	ABC[c]
2012	N/A	N/A	68	Conf. [e]	Conf. [e]	91	82
2013	N/A	N/A	68	Conf. [e]	Conf. [e]	91	82
2014	N/A	N/A	68	Conf. [e]	Conf. [e]	91	82
2015	N/A	N/A				91	68
2016	N/A	N/A				91	68

a. Season is based on a calendar year.
b. Guideline harvest level expressed in t.
c. Metric tons.
d. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries only. Bycatch mortality due to groundfish fisheries is not included here because available data are summarized by "crab fishery year" rather than calendar year; estimates of annual bycatch mortality during 1991/92–2012/13 groundfish fisheries are ≤9 t, with an average of 2 t.
e. Catch statistics are confidential under Sec. 16.05.815 (SOA statute): ≤2 vessels participated in each season.

6. <u>Basis for the OFL and ABC</u>: The values for 2016 are the author's recommendation.

Year[a]	Tier	Years to define Average catch (OFL)	Natural Mortality[d]	Buffer
2012	5	1993–1998[c]	0.18 yr^{-1}	10%
2013	5	1993–1998[c]	0.18 yr^{-1}	10%
2014	5	1993–1998[c]	0.18 yr^{-1}	10%
2015	5	1993–1998[c]	0.18 yr^{-1}	25%
2016	5	1993–1998[c]	0.18 yr^{-1}	25%

a. Season is based on a calendar year.
b. OFL was for total catch and was determined by the average of the annual retained catch for these years times a factor of 1.05 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.
c. OFL was for total catch and was determined by the average of the annual retained catch for these years times 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.
d. 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 Tier 5 OFL was estimated by bootstrapping. The standard deviation of the estimated sampling distribution of the recommended OFL (Alternative 1) is 0.510-million lb (CV = 0.25). See 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:** None. Fishery continued into 2014 to be managed under authority of an ADF&G commissioner's permit and with a guideline harvest level (GHL) of 0.150-million lb (68 t). As of this writing, no vessels have fished in the 2015 season (H. Fitch, ADF&G, Dutch Harbor, *pers. comm.*, 22 April 2015).

2. **Changes to the input data:**
   - Retained catch and bycatch data have been updated with the results for the 2014 directed fishery, during which only one vessel participated in the fishery, rendering the catch data confidential under the requirements of Sec. 16.05.815 (SOA statute); complete data on bycatch during all crab fisheries in 2014 are not presently available.
   - Bycatch estimates from groundfish fisheries have been updated with estimates for 2013/14.

3. **Changes to the assessment methodology:** None. 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 OFLs for 2009 and 2010 were both established as retained-catch OFLs of 0.17-million lb. The 2009 OFL was estimated by the average annual retained catch for the

period 1993–1999, whereas the 2010 OFL was estimated by the average annual retained catch for the period 1993–1998; in 2009 the CPT and SSC recommended removing 1999 from the period for computing retained catch because 1999 was the first year that a GHL was established for the fishery.

- The OFL for 2011 was established as a total-catch OFL of 0.18-million lb and was estimated as the average retained catch (including deadloss) for the period 1993–1998 times 1.05 plus 0.006-million lb; i.e.,

$$OFL_{tot,2011} = 1.05 * OFL_{ret,1993\text{-}1998} + 0.006\text{-million lb.}$$

  $OFL_{ret,1993\text{-}1998}$ is the average annual retained catch in the directed fishery during 1993–1998. The factor of 1.05 was used to account for the crab bycatch mortality in the directed crab fishery and 0.006-million lb was used to account for the "background level" of bycatch mortality occurring in the groundfish and non-directed crab fisheries, estimated by the average annual bycatch mortality using data available; 2001–2005 for crab fisheries and 1991/92–2008/09 for groundfish fisheries.

- The OFLs for 2012–2015 were each a total-catch OFL of 0.20-million lb and were estimated using 1993–1998 to compute average annual retained catch, an estimate of lb of bycatch mortality per pound of retained catch during the directed fishery, an estimate of the average annual bycatch mortality due to non-directed crab fisheries during 1994–1998 and an estimate of average annual bycatch mortality due to groundfish fisheries during 1992/93–1998/99; i.e.,

$$OFL_{2012\text{–}2015} = (1+R_{2001\text{–}2010}) * RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,1992/93\text{–}1998/99},$$

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

- The recommended Tier 5 OFL for 2016 is a total-catch OFL of 0.20-million lb, estimated by the calculations given for the 2012–2015 OFLs.

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 2014: *None*.
  - SSC, June 2014: "*The SSC recommends conducting a workshop to address procedures for assigning buffers for data-poor stocks.*" … "*The outcome of such a workshop should clearly articulate the procedures and minimum requirements for establishing 10%,*

20%,…, X% buffers such that they can be consistently applied across a range of species and different stocks."

- Response: The 25% buffer on the OFL that the author recommends using for setting the ABC is consistent with the buffer on OFL that the SSC recommended in June 2014 for the other unsurveyed golden king crab stock managed under the BSAI Crab FMP (i.e., Aleutian Islands golden king crab).

- CPT, September 2014 (via September 2014 SAFE Introduction chapter): *None pertaining to a Tier 5 assessment*.
- SSC, October 2014: *Recommended that an uncertainty workshop be held in the fall of 2015 to address ABCs*.
  - Response: Results would be incorporated into the May 2016 assessment.

- **Responses to the most recent two sets of SSC and CPT comments specific to the assessment:**
  - CPT, May 2014: *None*.
  - SSC, June 2014: *None*.
  - CPT, September 2014: *None*.
  - SSC, October 2014:
    - *Concurred with author-recommended 2015 OFL and application of a 25% buffer to determine the 2015 ABC.*
      - Response: The author recommends the same Tier 5 OFL for 2016 as the SSC recommended for 2015 and the same 25% buffer to determine the ABC for 2016.
    - *Recommended revisiting alternative Tier 4 calculations, as was suggested by the SSC and CPT in 2013, but acknowledged that that recommendation "is moot until a survey can be completed."*
      - Response: No comment.

C. Introduction

1. **Scientific name:** *Lithodes aequispinus* J. E. Benedict, 1895

2. **Description of general distribution:**

General distribution of golden king crab is summarized by NMFS (2004):

> Golden king crab, also called brown king crab, range from Japan to British Columbia. In the BSAI, golden king crab are found at depths from 200 m to 1,000 m, generally in high-relief habitat such as inter-island passes (pages 3–34).
>
> Golden, or brown, king crab occur from the Japan Sea to the northern Bering Sea (ca. 61° N latitude), around the Aleutian Islands, on various sea mounts, and as far south as northern British Columbia (Alice Arm) (Jewett et al. 1985). They are typically found on the continental slope at depths of 300–1,000 m on extremely rough bottom. They are frequently found on coral bottom (pages 3–43).

The Pribilof District is part of king crab Registration Area Q (Figure 1). Fitch et al. (2014, page 8) define those boundaries:

> The Bering Sea king crab Registration Area Q has as its southern boundary a line from 54° 36’ N lat., 168° W long., to 54° 36’ N lat., 171° W long., to 55° 30’ N lat., 171° W. long., to 55° 30’ N lat., 173° 30’ E long., as its northern boundary the latitude of Point Hope (68° 21’ N lat.), as its eastern boundary a line from 54° 36’ N lat., 168° W long., to 58° 39’ N lat., 168° W long., to Cape Newenham (58° 39’ N lat.), and as its western boundary the United States-Russia Maritime Boundary Line of 1991. Area Q is divided into the Pribilof District, which includes waters south of Cape Newenham, and the Northern District, which incorporates all waters north of Cape Newenham.

NMFS-AFSC conducted an eastern Bering Sea continental slope trawl survey on a biennial during 2002–2012 (a survey scheduled for 2014 was cancelled). Results of the 2002–2012 biennial eastern Bering Sea continental slope trawl surveys show that the biomass, number, and density (in number per area and in weight per area) of golden king crab on the eastern Bering Sea continental slope are higher in the southern areas than in the northern areas (Gaeuman 2013a; Haaga et al. 2009; Hoff 2013; Hoff and Britt 2003, 2005, 2009, 2011). Of the six survey subareas (see Figure 1 in Hoff 2013), biomass and abundance of golden king crab were estimated through 2010 to be highest in the Pribilof Canyon area (survey subarea 2). Most of the commercial fishery catch for golden king crab is reported to occur in the Pribilof Canyon area (Fitch et al. 2014; Neufeld and Barnard 2003; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006). However, biomass was estimated to have decreased between 2010 and 2012 in the Pribilof Canyon area and to have increased between 2010 and 2012 in the survey subarea 1 (the southernmost of the survey subareas), so that biomass in 2012 was estimated to be highest in survey subarea 1.

Results of the 2002–2012 biennial NMFS-AFSC eastern Bering Sea continental slope trawl surveys showed that a majority of golden king crab on the eastern Bering Sea continental slope occurred in the 200–400 m and 400–600 m depth ranges (Haaga et al. 2009; Hoff 2013; Hoff and Britt 2003, 2005, 2009, 2011). Commercial fishing for golden king crab in the Bering Sea typically occurs at depths of 100–300 fathoms (183–549 m; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006; Gaeuman 2011, 2013c; Neufeld and Barnard 2003); average depth of pots fished in the Pribilof District golden king crab fishery during the 2002 fishing season (the most recently prosecuted fishery for which fishery observer data are not confidential) was 214 fathoms (391 m).

3. **Evidence of stock structure:**

Although highest densities of golden king crab are found in the deep canyons of the eastern Bering Sea continental slope, golden king crab occur sporadically on the surveyed slope at locations between those canyons in the eastern Bering Sea (Hoff 2013; Hoff and Britt 2003, 2005, 2009, 2011; Gaeuman 2013b). Stock structure within the Pribilof District and the stock relationship of the golden king crab within the Pribilof District with the golden king crab outside of the Pribilof District have 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 their observations on embryo development in golden king crab, Otto and Cummiskey's (1985) suggested that time between successive ovipositions was roughly twice that of embryo development and that spawning and molting of mature females occurs approximately every two years. Sloan (1985) also suggested a reproductive cycle >1 year with a protracted barren phase for female golden king crab. Data from tagging studies on female golden king crab in the Aleutian Islands are generally consistent with a molt period for mature females of 2 years or less and that females carry embryos for less than two years with a prolonged period in which they remain in barren condition (Watson et al 2002). From laboratory studies of golden king crab collected from Prince William Sound, Paul and Paul (2001b) estimated a 20-month reproductive cycle with a 12-month clutch brooding period.
>
> Numerous observations on clutch and embryo condition of mature female golden king crab captured during surveys have been consistent with asynchronous, aseasonal reproduction (Otto and Cummiskey 1985, Hiramoto 1985, Sloan 1985, Somerton and Otto 1986, Blau and Pengilly 1994, Blau et al. 1998, Watson et al. 2002). Based on data from Japan (Hiramoto and Sato 1970), McBride et al. (1982) suggested that spawning of golden king crab in the Bering Sea and Aleutian Islands occurs predominately during the summer and fall.

The success of asynchronous and aseasonal spawning of golden king crab may be facilitated by fully lecithotrophic larval development (i.e., the larvae can develop successfully to juvenile crab without eating; Shirley and Zhou 1997).

Current knowledge of reproductive biology and maturity of male and female golden king crab is also reviewed by Webb (2014).

Note that asynchronous, aseasonal molting and the prolonged intermolt period (>1 year) of mature female and the larger male golden king crab likely makes scoring shell conditions very difficult and especially difficult to relate to "time post-molt," posing problems for inclusion of shell condition data into assessment models.

5. <u>Brief summary of management history</u>:

A complete summary of the management history through 2010 is provided in Fitch et al. (2014, pages 86–87).

The first domestic harvest of golden king crab in the Pribilof District was in 1982 when two vessels fished. Peak harvest and participation occurred in the 1983/84 season with a retained catch of 0.856-million lb landed by 50 vessels. Since 1984 the fishery has been managed with a calendar-year season under authority of a commissioner's permit and landings and participation has been low and sporadic. Retained catch during 1984–2009 has ranged from 0 lb to 0.342-million lb and the number of vessels participating annually has ranged from 0 to 8; no vessels registered for the fishery and there was no retained catch in 2006–2009. One vessel fished in the 2010 season and two vessels fished in the 2011 season; catch statistics for those two seasons are confidential under Sec. 16.05.815 of SOA statutes. The fishery is not rationalized and has been managed inseason to a guideline harvest level (GHL) since 1999. The GHL for 1999 was 0.200-million lb (91 t), whereas the GHL for the 2000–2014 seasons was 0.150-million lb (68 t).

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 fish for golden king crab in the Pribilof Islands must have at least four escape rings of no less than five and one-half inches inside diameter installed on the vertical plane or at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized golden king crab (5 AAC 34.925 (c)) and the sidewall "…must contain an opening equal to or exceeding 18 inches in length... The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread." (5 AAC 39.145(1)). There is a pot limit of 40 pots for vessels ≤125-feet LOA and of 50 pots for vessels >125-feet LOA (5 AAC 34.925 (e)(1)(B)). Golden king crab can be harvested from 1 January through 31 December only under conditions of a permit issued by the commissioner of ADF&G (**5 AAC 34.910 (b)(3)**). Since 2001 those conditions have included the carrying of a fisheries observer.

D. Data

1. <u>Summary of new information</u>:

1. Retained catch and estimated bycatch during the 2014 directed fishery (both of which are confidential) and the estimated of bycatch in groundfish fisheries during the 2013/14 crab fishery year have been added; complete data on bycatch during all crab fisheries in 2014 are not presently available.

2. <u>Data presented as time series</u>:

a. <u>Total catch</u> and b. <u>Information on bycatch and discards</u>:

- The 1981/82–1983/84, 1984–2014 time series of retained catch (number and lb of crab harvested, including deadloss), effort (vessels, landings, 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 Table 1.
- The 1993–2014 time series of weight of retained catch and estimated bycatch and estimated weight of fishery mortality of Pribilof golden king crab during the directed fishery are given in Table 2; complete data on bycatch during all crab fisheries in 2014 are not presently available. Bycatch 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. Because the Bering Sea snow crab fishery is prosecuted mainly or entirely between January and May and the Bering Sea grooved Tanner crab fishery is prosecuted with a calendar year season, bycatch for the crab fisheries can be estimated on a calendar year basis to align with the season for Pribilof District golden king crab. Observer data on size distributions and estimated catch numbers of non-retained catch were used to estimate the weight of non-retained catch of golden king crab by applying a weight-at-length estimator (see below). Observers were first deployed to collect bycatch 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 bycatch data were grouped into crab fishery years, rather than into calendar years. The 1991/92–2013/14 time series of estimated annual weight of bycatch and total fishery mortality of golden king crab during federal groundfish fisheries by gear type (combining pot and hook-and-line gear as a single "fixed gear" category and combining non-pelagic and pelagic trawl gear as a single "trawl" category) is provided in Table 3. Following Foy (2013), the bycatch mortality of king crab captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crab captured by trawls during groundfish fisheries was assumed to be 0.8. Data from 1991/92–2008/09 are from federal reporting areas 513, 517, and 521, whereas the data from 2009/10–2013/14 (received 30 July 2014) are from the State statistical areas falling within the Pribilof district (see various attachments to 30 July 2014 email from R. Foy, NMFS-AFSC-Kodiak).

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 Gaeuman (2013a) for biomass estimates of mature male golden king crab using data from the 2002–2012 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey.

e. ***Survey catch at length:*** Survey catch at length data are not used in a Tier 5 assessment. However, see Gaeuman (2013b) and Hoff (2013) for size data composition by sex of golden king crab during the 2002–2012 Bering Sea upper continental slope trawl surveys.

f. ***Other data time series:*** None.

3. Data which may be aggregated over time:

a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):

The author is not aware of data on growth per molt collected from golden king crab in the Pribilof District. Growth per molt of juvenile golden king crab, 2–35 mm CL, collected from Prince William Sound have been observed in a laboratory setting and equations describing the increase in CL and intermolt period were estimated from those observations (Paul and Paul 2001a); those results are not provided here. Growth per molt has also been estimated from golden king crab with CL ≥90 mm that were tagged in the Aleutian Islands and recovered during subsequent commercial fisheries (Watson et al. 2002); those results are not presented here because growth-per-molt information does not enter into a Tier 5 assessment.

See section **C.4** for discussion of evidence that mature female and the larger male golden king crab exhibit asynchronous, aseasonal molting and a prolonged intermolt period (>1 year).

b. Weight-at length or weight-at-age (by sex):

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female golden king crab according to the equation, Weight = $A*CL^B$ (from Table 3-5, NPFMC 2007) are: A = 0.0002988 and B = 3.135 for males and A = 0.001424 and B = 2.781 for females; 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:

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, and 2012 (Hoff and Britt 2003, 2005, 2009, 2011; Haaga et al. 2009, Gaeuman 2013a, b). Data and analysed results from the 2008–2012 EBS upper continental slope surveys were presented in Gaeuman (2013a, b), but are not presented in this Tier 5 assessment. The eastern Bering Sea upper continental slope bottom trawl survey scheduled for 2014 was cancelled.
- Data on the size and sex composition of retained catch and bycatch 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. <u>History of modeling approaches for this stock</u>:

Gaeuman (2013a, b) 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 2015, as had been recommended by NPFMC (2007) and by the CPT and SSC in 2008−2014.

2. <u>Model Description</u>: *Subsections a–i are not applicable to a Tier 5 sock.*

Only an OFL and ABC is estimated For Tier 5 stocks, where "the OFL represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007). Although NPFMC (2007) defined the OFL in terms of the retained catch, total-catch OFLs may be considered for Tier 5 stocks for which non-target fishery removal data are available (Federal Register/Vol. 73, No. 116, 33926). The CPT (in May 2010) and the SSC (in June 2010) endorsed the use of a total-catch OFL to establish the OFL for this stock. This assessment recommends – and only considers – use of a total-catch OFL for 2016.

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 non-retained 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 Islands 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 setting a retained-catch OFL for 2010, but using the average retained catch during 1993–1998; 1999 was excluded because it was the first year that a preseason GHL was established for the fishery. In May 2010, the CPT established a total-catch OFL computed as a function of the average retained catch during 1993–1998, a ratio-based estimate of the bycatch mortality during the directed fishery of that period, and an estimate of the "background" bycatch mortality due to other fisheries. Other time periods, extending into years post-1999, had been considered for computing the average retained catch in the establishment of the 2009, 2010, 2011 OFLs, but those time periods were rejected by the CPT and the SSC. Hence the period for calculating the retained-catch portion of the Tier 5 total-catch OFL for this stock has been firmly established by the CPT and SSC at 1993–1998 (the CPT said "this freezes the time frame..."). For the 2012 and the 2013 OFLs, the CPT and SSC recommended the period 2001–2010 for calculating the ratio-based estimate of the bycatch mortality during the 1993–1998 directed fishery, the period 1994–1998 for calculating the estimated bycatch mortality due to non-directed crab fisheries during 1993–1998, and the period 1992/93–1998/99 for calculating the estimated bycatch mortality due to groundfish fisheries during 1993–1998.

Two alternative approaches for determination of the 2013 OFL were presented to the CPT and SSC in May–June 2013. Alternative 1 was the status quo approach (i.e., the approach used to establish the 2012 total-catch OFL). Alternative 2 was the same as Alternative 1 except that it used updated bycatch 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 Tier 5 OFL for each of 2014 and 2015 (i.e., the Alternative 1 that was presented in 2013). The 2016 Tier 5 OFL recommended here is the same as for the Tier 5 OFL for 2013–2015.

3. <u>Model Selection and Evaluation</u>:

a. ***<u>Description of alternative model configurations</u>***

The recommended OFL is set as a total-catch OFL using 1993–1998 to compute average annual retained catch, an estimate of lb of bycatch mortality per pound of 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.,

$$OFL_{2016} = (1+R_{2001\text{–}2010})*RET_{1993\text{-}1998} + BM_{NC,1994\text{-}1998} + BM_{GF,92/93\text{–}98/99},$$

where,

- $R_{2001\text{–}2010}$ is the average of the estimated annual ratio of lb of bycatch mortality to lb of retained catch in the directed fishery during 2001–2010
- $RET_{1993\text{-}1998}$ is the average annual retained catch in the directed crab fishery during 1993–1998
- $BM_{NC,1994\text{-}1998}$ is the estimated average annual bycatch mortality in non-directed crab fisheries during 1994–1998
- $BM_{GF,92/93\text{–}98/99}$ is the estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99.

The average of the estimated annual ratio of lb of bycatch mortality to lb of retained 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 bycatch for the directed fishery during 1993–1998, there are such data from the directed fishery during 2001–2010 (excluding 2006–2009, when there was no fishery effort).

The estimated average annual bycatch mortality in non-directed fisheries during 1994–1998 is used to estimate the average annual bycatch mortality in non-directed fisheries during 1993–1998 because there are no bycatch data available for the non-directed fisheries during 1993.

The estimated average annual bycatch mortality in groundfish fisheries during 1992/93–1998/99 is used to estimate the average annual bycatch mortality in groundfish fisheries during 1993–1998 because 1992/93–1998/99 is the shortest time period of crab fishery years that encompasses calendar years 1993–1998.

Statistics on the data and estimates used to calculate $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,93/94\text{-}98/99}$ are provided in Table 4; the column means in Table 4 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 $BM_{GF,93/94\text{-}98/99}$, OFL_{2016} is,

$$OFL_{2016} = (1+0.052)*173{,}722 + 13{,}418 + 8{,}353 = 204{,}611 \text{ lbs (0.20-million lbs).}$$

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 (millions of lb)**
Recommended/status quo	Total-catch	1993–1998	0.20

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. ***<u>Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models</u>:*** See Section E, above.

d. ***<u>Convergence status and convergence criteria for the base-case model (or proposed base-case model)</u>:*** Not applicable.

e. ***<u>Table (or plot) of the sample sizes assumed for the compositional data</u>:*** Not applicable.

f. ***<u>Do parameter estimates for all models make sense, are they credible?</u>:***
The time period used for determining the OFL was established by the SSC in June 2012. Estimates of total retained catch (lb) during a season are from fish tickets landings and are assumed here to be correct. Estimates of bycatch from crab fisheries data are generally considered credible (e.g., Byrne and Pengilly 1998, Gaeuman 2011, 2013c), 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 bycatch times an assumed bycatch mortality rate. Bycatch mortality rates 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 bycatch 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 bycatch to retained catch during the post-2000 seasons can be used to accurately estimate that ratio for the 1993–1998 seasons.

- 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 the 2010–2015 seasons. The time period 1993–1998 provides the longest continuous time period through 2014 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 bycatch mortality 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. Retained in 2014 cannot be presented here due to the confidentiality of data and, because complete data from all crab fisheries in 2014 are not presently available, total catch in 2014 cannot be estimated for comparison with the 2014 OFL and ABC at this time. Values for the 2016 OFL and ABC are the author's recommendations.

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c]	ABC[c]
2012	N/A	N/A	0.150	Conf.[e]	Conf.[e]	0.20	0.18
2013	N/A	N/A	0.150	Conf.[e]	Conf.[e]	0.20	0.18
2014	N/A	N/A	0.150	Conf.[e]	Conf.[e]	0.20	0.18
2015	N/A	N/A				0.20	0.15
2016	N/A	N/A				0.20	0.15

a. Season is based on a calendar year.
b. Guideline harvest level expressed in millions of lb.
c. Millions of lb.
d. Total retained catch plus estimated bycatch mortality during crab fisheries only. Bycatch mortality due to groundfish fisheries is not included here because available data are summarized by "crab fishery year" rather than calendar year; estimates of annual bycatch mortality during 1991/92–2010/11 groundfish fisheries are ≤0.019-million lb, with an average of 0.006-million lb.
e. Catch statistics are confidential under Sec. 16.05.815 (SOA statute): ≤2 vessels participated in each season.

Year[a]	MSST	Biomass (MMB)	GHL[b]	Retained Catch[c]	Total Catch[c,d]	OFL[c]	ABC[c]
2012	N/A	N/A	68	Conf.[e]	Conf.[e]	91	82
2013	N/A	N/A	68	Conf.[e]	Conf.[e]	91	82
2014	N/A	N/A	68	Conf.[e]	Conf.[e]	91	82
2015	N/A	N/A				91	68
2016	N/A	N/A				91	68

a. Season is based on a calendar year.
b. Guideline harvest level expressed in t.
c. Metric tons.
d. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries only. Bycatch mortality due to groundfish fisheries is not included here because available data are summarized by "crab fishery year" rather than calendar year; estimates of annual bycatch mortality during 1991/92–2010/11 groundfish fisheries are ≤9 t, with an average of 3 t.
e. Catch statistics are confidential under Sec. 16.05.815 (SOA statute): ≤2 vessels participated in each season.

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
= 173,722 lb (0.17-million lb; 79 t).

Note that a retained catch of 0.17-million lb (79 t) would exceed the author's recommended ABC for 2016 (0.15-million lb; 68 t); see G.4, below.

5. Recommended F_{OFL}, OFL total catch and the retained portion for the coming year:
See sections ***F.3*** and ***F.4***, above; no F_{OFL} is recommended for a Tier 5 stock.

G. Calculation of ABC

1. PDF of OFL. A bootstrap estimates of the sampling distribution (assuming no error in estimation of bycatch) 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 4 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}). Table 5 provides statistics on the generated distributions.

2. List of variables related to scientific uncertainty.

- Bycatch mortality rate in each fishery that bycatch occurs. Note that for Tier 5 stocks, an increase in an assumed bycatch 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 bycatch and bycatch mortality for each fishery that bycatch 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 2016 is unknown.

3. List of addititional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

4. Author recommended ABC. 25% buffer on OFL; i.e., ABC = (1-0.25)·(204,612 lb) = 0.15-million lb (68 t).

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 shelf trawl surveys have been examined for their utility in determining overfishing levels and stock status by Gaeuman (2103a, b). Cancellation of the survey that was scheduled for 2014 raises uncertainties on the prospects for obtaining fishery-independent survey data on this stock in the future.

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Table 1. Harvest history for the Pribilof District golden king crab fishery from the 1981/82 season through 2014 (from 2014 SAFE, updated with 2014 data provided by H. Fitch, ADF&G, Dutch Harbor via 21 April 2015 email).

	Number of						Average			
Season	Vessels	Landings	Crabs[a]	Pots lifted	GHL[b]	Harvest[a,c]	Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1981/82	2	CF	CF	CF	-	CF	CF	CF	CF	CF
1982/83	10	19	15,330	5,252	-	69,970	4.6	3	151	570
1983/84	50	115	253,162	26,035	-	856,475	3.4	10	127	20,041
1984	0	0	0	0	-	0	0	0	0	0
1985	1	CF	CF	CF	-	CF	CF	CF	CF	CF
1986	0	0	0	0	-	0	0	0	0	0
1987	1	CF	CF	CF	-	CF	CF	CF	CF	CF
1988	2	CF	CF	CF	-	CF	CF	CF	CF	CF
1989	2	CF	CF	CF	-	CF	CF	CF	CF	CF
1990	0	0	0	0	-	0	0	0	0	0
1991	0	0	0	0	-	0	0	0	0	0
1992	0	0	0	0	-	0	0	0	0	0
1993	5	15	17,643	15,395	-	67,458	3.8	1	NA	0
1994	3	5	21,477	1,845	-	88,985	4.1	12	NA	730
1995	7	22	82,489	9,551	-	341,908	4.1	9	NA	716
1996	6	32	91,947	9,952	-	329,009	3.6	9	NA	3,570
1997	7	23	43,305	4,673	-	179,249	4.1	9	NA	5,554
1998	3	9	9,205	1,530	-	35,722	3.9	6	NA	474
1999	3	9	44,098	2,995	200,000	177,108	4.0	15	NA	319
2000	7	19	29,145	5,450	150,000	127,217	4.4	5	NA	4,599
2001	6	14	33,723	4,262	150,000	145,876	4.3	8	143	8,227
2002	8	20	34,860	5,279	150,000	150,434	4.3	6	144	8,984
2003	3	CF	CF	CF	150,000	CF	CF	CF	CF	CF
2004	5	CF	CF	CF	150,000	CF	CF	CF	CF	CF
2005	4	CF	CF	CF	150,000	CF	CF	CF	CF	CF
2006-2009	0	0	0	0	150,000	0	0	0	0	0
2010	1	CF	CF	CF	150,000	CF	CF	CF	CF	CF
2011	2	CF	CF	CF	150,000	CF	CF	CF	CF	CF
2012	1	CF	CF	CF	150,000	CF	CF	CF	CF	CF
2013	1	CF	CF	CF	150,000	CF	CF	CF	CF	CF
2014	1	CF	CF	CF	150,000	CF	CF	CF	CF	CF

Note: CF = confidential, less than three vessels or processors participated in fishery

[a] Deadloss included.

[b] Guideline harvest level (lb).

[c] lb.

[d] Number of legal crab per pot lift.

[e] Carapace length in millimeters.

Table 2. Weight (in lb) of retained catch and estimated non-retained bycatch of Pribilof golden king crab during crab fisheries, 1993–2014, with total fishery mortality estimated by assuming a bycatch mortality rate of 0.2 for the directed fishery and a bycatch mortality rate of 0.5 for non-directed fisheries (from 2014 Crab SAFE, with update for the 2014 retained catch and bycatch in the directed fishery; bycatch data from the Bering Sea snow crab fishery during 15 Oct – 31 Dec 2014 were not available as of 21 April 2014).

		Bycatch in crab fisheries (lb; no mortality rate applied)			
Year	Retained Catch (lb)	Pribilof Islands golden king crab	Bering Sea snow crab	Bering Sea grooved Tanner crab	Total Mortality (lb)
1993	67,458	no data	0	no data	—
1994	88,985	no data	8,387	2,531	—
1995	341,908	no data	1,391	34,492	—
1996	329,009	no data	526	5,151	—
1997	179,249	no data	8,937	no fishing	—
1998	35,722	no data	72,760	no fishing	—
1999	177,108	no data	0	confidential	—
2000	127,217	no data	0	confidential	—
2001	145,876	39,278	0	confidential	confidential
2002	150,434	41,894	2,335	no fishing	159,980
2003	confidential	confidential	329	confidential	159,184
2004	confidential	confidential	0	confidential	147,552
2005	confidential	confidential	0	confidential	65,817
2006	no fishing	no fishing	0	0	0
2007	no fishing	no fishing	0	0	0
2008	no fishing	no fishing	0	no fishing	0
2009	no fishing	no fishing	2,122[a]	no fishing	1,061[a]
2010	confidential	confidential	0	no fishing	confidential
2011	confidential	confidential	591[b]	no fishing	confidential
2012	confidential	confidential	598[c]	no fishing	confidential
2013	confidential	confidential	1,284[d]	no fishing	confidential
2014	confidential	confidential		no fishing	confidential

a. Only 5 golden king crab (1 sublegal male and 4 legal males) were counted in 1,657 pot lifts sampled out of the 163,536 pot lifts performed during the 2008/09 Bering Sea snow crab fishery (including waters north of the Pribilof District; Gaeuman 2010), but none of those were measured to provide an estimate of weight. Bycatch weight was estimated by (4.3)x(5)x(163,536)/(1,657); the assumed average weight per crab (4.3 lb) is the average weight of landed golden king crab during the 2002 Pribilof District golden king crab fishery.

b. Only 2 golden king crab (1 sublegal male and 1 legal male) were counted in 2,142 pot lifts sampled out of the 147,244 pot lifts performed during the 2010/11 Bering Sea snow crab fishery (including waters north of the Pribilof District; Gaeuman 2011), but none of those were measured to provide an estimate of weight. Bycatch weight was estimated by 4.3x(2x147,244)/2,142; the assumed average weight per crab (4.3 lb) is the average weight of landed golden king crab during the 2002 Pribilof District golden king crab fishery.

c. A single 156 mm CL legal male golden king crab occurred in the 2,235 pot lifts sampled out of the 270,602 pot lifts performed during the 2011/12 Bering Sea snow crab fishery (including waters north of the Pribilof District; Gaeuman 2013c). Total bycatch weight was estimated by (4.9)x(270,602)/(2,235), where 4.9 is the average weight (lb) of a 156 mm CL male golden king crab estimated by the weight-at-length estimator (Section D.3.b).

d. Only 2 sublegal and 1 legal male golden king crab of unknown sizes were counted in the 2,348 pot lifts sampled within the Pribilof District and within calendar year 2013 during the 2012/13 Bering Sea snow crab fishery; no golden king crab occurred in pot lifts sampled during the 2013/14 snow crab season prior to 1 Jan 2014. During the 2012/13 snow crab season, 216,580 pot lifts were recorded within the Pribilof District. The author assumed a very generous average weight of 4.64 lb for the 3 captured golden king crab males. You do the math.

Table 3. Estimated annual weight (lb) of discarded bycatch of Pribilof golden king crab (all sizes, males and females) during federal groundfish fisheries by gear type (fixed or trawl), 1991/92–2013/14, with total bycatch mortality (lb) estimated by assuming bycatch mortality rate = 0.5 for fixed-gear fisheries and bycatch mortality rate = 0.8 for trawl fisheries (updated from 2014 SAFE with 2013/14 data provided by R. Foy AFSC, Kodiak Laboratory via 30 July 2014 email).

	Bycatch in groundfish fisheries (lb; no mortality rate applied)			Total
Season	Fixed	Trawl	Total	Mortality (lb)
1991/92	110	13,464	13,574	10,826
1992/93	7,690	19,544	27,234	19,480
1993/94	1,116	21,248	22,364	17,556
1994/95	558	7,103	7,661	5,962
1995/96	895	4,187	5,082	3,797
1996/97	53	1,918	1,971	1,561
1997/98	2,952	1,074	4,026	2,335
1998/99	14,930	395	15,324	7,781
1999/00	10,556	1,426	11,982	6,419
2000/01	3,589	4,134	7,723	5,101
2001/02	3,300	783	4,083	2,276
2002/03	1,219	472	1,691	987
2003/04	503	401	904	572
2004/05	342	860	1,202	859
2005/06	198	126	324	200
2006/07	2,915	254	3,168	1,660
2007/08	18,678	351	19,028	9,619
2008/09	8,799	3,433	12,231	7,145
2009/10	5,299	2,573	7,873	4,708
2010/11	1,431	2,070	3,501	2,372
2011/12	1,614	2,502	4,117	2,809
2012/13	1,549	1,929	3,478	2,318
2013/14	995	5,828	6,824	6,160
Average	3,882	4,177	8,059	5,326

Table 4. Data for calculation of $RET_{1993\text{-}1998}$ and estimates used in calculation of $R_{2001\text{-}2010}$, $BM_{NC,1994\text{-}1998}$, and $BM_{GF,92/93\text{-}98/99}$ for calculation of the Pribilof Islands golden king crab 2016 Tier 5 total-catch OFL; 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 bycatch 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 bycatch estimates in Table 2 (assumed bycatch mortality rate = 0.5) and values under $BM_{GF,92/93\text{-}98/99}$ are from Table 3; from 2014 SAFE.

Season[a]	Season[b]	$RET_{1993\text{-}1998}$	$R_{2001\text{-}2010}$	$BM_{NC,1994\text{-}1998}$	$BM_{GF,92/93\text{-}98/99}$
1993	1992/93	67,458			19,480
1994	1993/94	88,985		5,459	17,556
1995	1994/95	341,908		17,941	5,962
1996	1995/96	329,009		2,839	3,797
1997	1996/97	179,249		4,469	1,561
1998	1997/98	35,722		36,380	2,335
1999	1998/99				7,781
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	173,722	0.052	13,418	8,353
	S.E.M	54,756	0.004	6,337	2,750
	CV	0.32	0.07	0.47	0.33

a. Season convention corresponding with values under $RET_{1993\text{-}1998}$, $R_{2001\text{-}2010}$, and $BM_{NC,1994\text{-}1998}$.
b. Season convention corresponding with values under $BM_{GF,92/93\text{-}98/99}$.

Table 5. Statistics for 1,000 bootstrap 2016 Tier OFL for Pribilof Islands golden king crab stock calculated according to recommended approach with the computed OFL for comparison.

	Alternative 1 OFL
Computed OFL	204,611
Mean of 1,000 bootstrapped OFLs	203,870
Std. dev. of 1,000 bootstrapped OFLs	51,030
CV = (std. dev.)/(Mean)	0.25

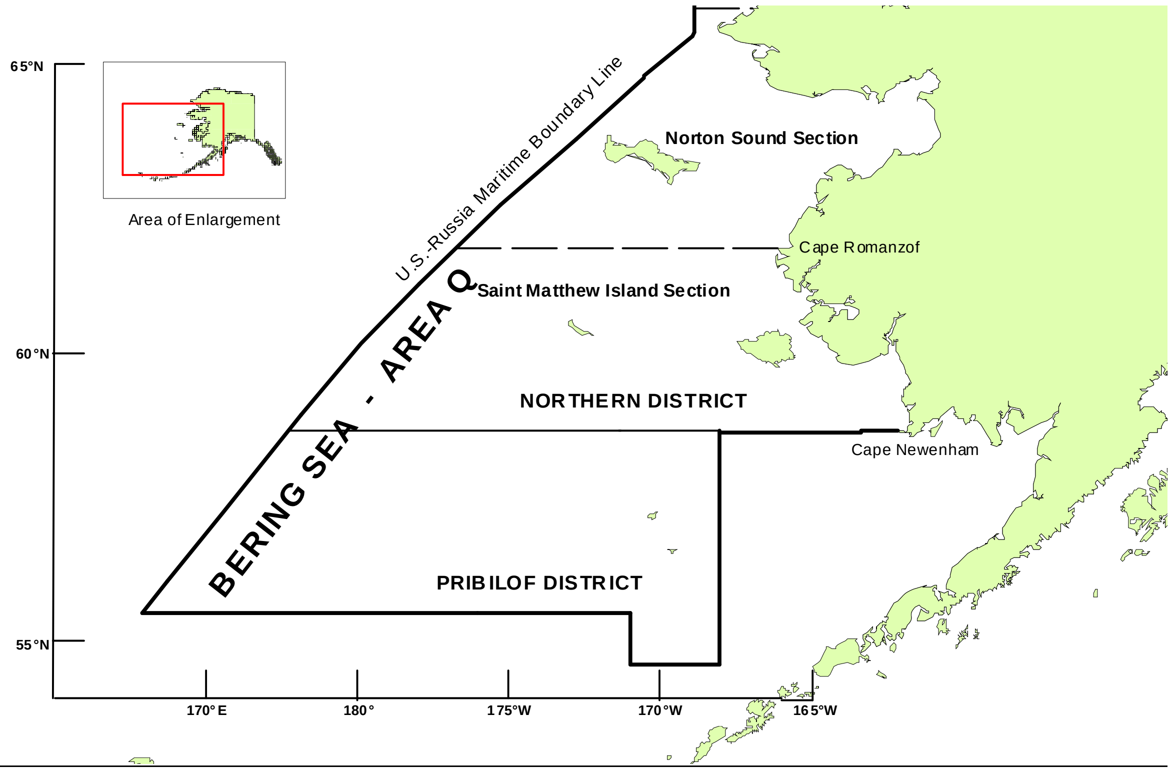

Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District (from Figure 2-4 *in* Fitch et al. 2014).

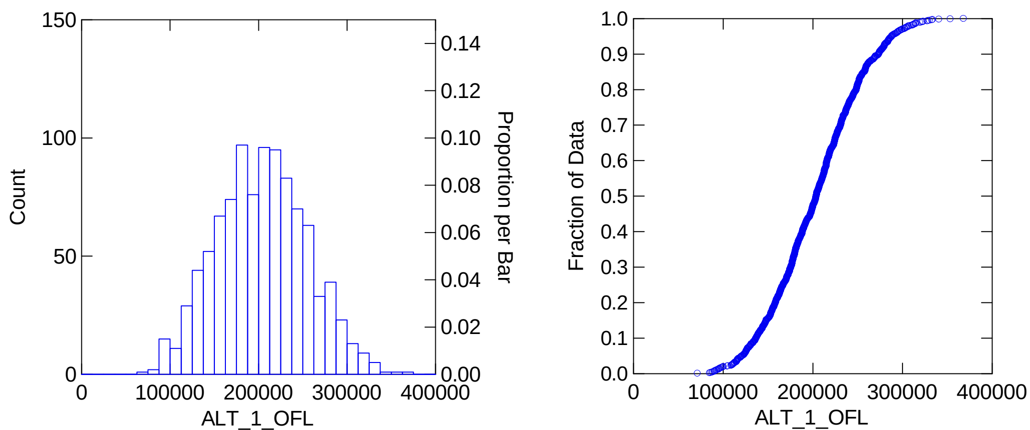

Figure 2. Bootstrapped estimates of the sampling distribution of the 2016 Tier 5 OFL (lb of total catch) for the Pribilof Islands golden king crab stock; histograms in left column, quantile plots in right column.

Western Aleutian Islands Red King Crab

– 2015 Tier 5 Assessment

2015 Crab SAFE Report Chapter (May 2015)

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Executive Summary

1. **Stock:**

Western Aleutian Islands (the Aleutian Islands, west of 171° W longitude) red king crab, *Paralithodes camtschaticus*

The Alaska Board of Fisheries in March 2014 established two districts for management of commercial red king crab fisheries in waters of the Aleutian Islands west of 171º (the Adak District for waters 171º to 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, to avoid confusion with the Adak District, this report will refer to the stock as the "Western Aleutian Islands (WAI) red king crab" stock.

2. **Catches:**

The domestic fishery has been prosecuted since 1960/61 and was opened every season through the 1995/96 season. Peak harvest occurred during the 1964/65 season with a retained catch of 21.193-million lb (9,613 t). 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 0.943-million lb (428 t), but the retained catch during the 1995/96 season was only 0.039-million lb (18 t). The fishery has been opened only occasionally since the 1995/96 season. 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 0.500-million lb (227 t) during the 2002/03 and 2003/04 seasons. 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 seasons (the 2002/03 and 2003/04 seasons) were opened only in the Petrel Bank area. Retained catch in the last two commercial fishery seasons was 0.506-million lb (230 t) in 2002/03 and 0.479-million lb (217 t) in 2003/04. The fishery has been closed every season during 2004/05–2014/15. 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 during the 1995/96–2013/14 seasons averaged 0.002-million lb (1 t) in crab fisheries and 0.018-million lb (0 t) in groundfish fisheries. Estimated weight of annual total fishery mortality during 1995/96–2013/14 averaged 0.087-million lb (39 t); the average annual retained catch during that period was 0.066-million lb (30 t). Estimated total fishery mortality for 2013/14 was <0.001-million lb (<1 t). Data for estimating total fishery mortality for the 2014/15 season are not yet available.

3. <u>Stock biomass</u>:

Estimates of past or present stock biomass are not available. There is no assessment model developed for this stock and standardized stock surveys have been too limited in geographic scope and too infrequent to provide a reliable index of abundance for the entire red king crab population in the Aleutian Islands west of 171° W longitude.

4. <u>Recruitment</u>:

Estimates of recruitment trends and current levels relative to virgin or historic levels are not available. The fishery has been closed since the end of the 2003/04 season due to apparent poor recruitment. A pot survey conducted by ADF&G in the Petrel Bank area (roughly, 179° W longitude to 179° E longitude) in November 2006 provided no evidence of strong recruitment (Gish 2007). The overall survey CPUEs (catch per pot lift) of red king crab in the standard, systematic survey (170 stations with 4 pots per station resulting in 680 pot lifts) of the Petrel Bank area were 1.2 legal males, 0.2 sublegal males, and 0.2 females; 98% of all red king crab were captured at 30 stations within an area of approximately 185 nmi^2 (633 km^2). Additionally, concurrent with the November 2006 ADF&G survey, 165 pots were fished in "string" arrays, similar to the setting of pots during commercial fishing, between standard survey stations in areas with highest CPUE during the standard survey and at locations where strings were fished during the November 2001 ADF&G-Industry survey (see Bowers et al. 2002). The CPUEs of red king crab in those "niche fishing" pots in 2006 were 15.6 legal males, 4.1 sublegal males, and 3.1 females. Ninety-two pots fished in four strings during the November 2006 ADF&G survey at the locations where four strings were fished during the November 2001 ADF&G-Industry yielded CPUEs of 9.8 legal males, 2.5 sublegal males, and 2.1 females; during the November 2001 ADF&G-Industry survey the CPUEs for the 121 pots fished at those locations were 85.5 legal males, 5.5 sublegal males, and 9.7 females. Red king crab captured during the November 2009 pot survey conducted by ADF&G were predominately larger, matured-sized crab and the size distribution of captured males provided no expectations for near-term recruitment of legal males (Gish 2010). Only 117 4-pot stations (468 pot lifts) could be fished in the November 2009 ADF&G survey. The overall CPUEs of red king crab during the November 2009 ADF&G survey was 1.5 legal males, <0.1 sublegal males, and 0.1 females. Limited (18 pot lifts) exploratory catch-and-release fishing for red king crab was also conducted by a commercial fishing vessel during mid-October to mid-December 2009 under provisions of a commissioner's permit at depths ≤ 100 fathoms (183 m) using red king crab pot gear (i.e., fished as single-pots, not long-lined) with escape webbing closed to help retain sublegal and female crab in four areas west of Petrel Bank between 178°00' E longitude and 175°30' E longitude; that limited effort yielded a catch of one legal-sized male red king crab (J. Alas, ADF&G, 7 May 2010 ADF&G Memorandum).

Another ADF&G-Industry survey was conducted as a commissioner's permit fishery in the Adak-Atka-Amlia Islands area in November 2002 (Granath 2003). Although the survey design called for a possible 2,900 pot lifts to be performed, survey participants only completed 1,085 pot lifts before withdrawing from participation. Four legal male red king crabs were captured: three legal males and one sublegal male red king crab were captured around Adak Island; no red king crabs were captured in areas on the north side of Atka Island, but an estimated 520 sublegal males and females were captured in one pot on the north side of Atka Island; one legal male and no sublegal or female red king crabs were captured on the north side of Amlia Island; and no red king crabs were captured on the south side of Atka and Amlia Islands. By comparison, ADF&G conducted a pot survey in the Atka-Amlia Islands area in 1977 and captured 4,035 male and 1,088 female red king crabs in 360 pot lifts (ADF&G 1978), although from those results it was reported at that time that "King crab stocks at Adak still seem to be depressed" (ADF&G 1978, page 167).

5. Management performance:

No overfished determination (i.e., MSST) is possible for this stock given the lack of biomass information. Overfishing did not occur during 2013/14; the estimated total catch did not exceed the Tier 5 OFL of 0.12-million lb (56 t). The total catch did not exceed the ABC established for 2013/14 (0.7-million lb, or 34 t). The OFL and ABC values for 2014/15 in the tables below are the values recommended by the SSC in June 2014. Data for computing total catch relative to the 2014/15 OFL and ABC are not yet available. The OFL and ABC values for 2015/16 in the tables below are the author's recommended values. No determination has yet been made for a fishery opening or harvest level, if opened, for the 2015/16 season.

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

a. Millions of lb.

b. Includes bycatch mortality of discarded bycatch.

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

a. t.

b. Includes bycatch mortality of discarded bycatch.

6. **Basis for the OFL and ABC:** See table, below; values for 2015/16 are the author's recommended values.

Year	Tier	Years to define Average catch (OFL)	Natural Mortality	Buffer
2011/12	5	1995/96-2007/08[a]	0.18[b]	75%
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%

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 Tier 5 OFL was estimated by bootstrapping; see section G.1. Estimated CV (sample standard error of mean divided by sample mean) of the annual total catch estimates for 1995/96–2007/08 is 0.43. 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 is the status quo; i.e., the ABC as was recommended by the CPT and SSC for 2012/13 – 2014/15. The ABC established for 2012/13 – 2014/15 was an increase from the ABC established for 2011/12 (0.027 million lb, 12 t). The 2011/12 ABC was based on the mean bycatch in non-directed crab fisheries and groundfish fisheries during the period 1995/96–2007/08 (June 2011 SSC minutes, page 4). The increase in the ABC for 2012/13 and maintenance of the ABC at the same level through 2014/15 was made to accommodate an Industry request for a small test fishery during 2012/13 or in future years to obtain additional data on the stock (CPT minutes for May 2013 meeting and SSC minutes for June 2013 meeting). No test fishery was performed during 2012/13 – 2014/15. However, Industry is working with ADF&G to perform a "reconnaissance survey" for red king crab in the vicinity of Adak Island during September 2015, which will not be conducted as a test fishery with retention of captured legal red king crab (J. Hilsinger, Aleutian King Crab Research Foundation, *pers. comm.*, 20 April 2015).

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 since March 2014 by the Alaska Board of Fisheries to regulations pertaining to this fishery.

2. **<u>Changes to the input data</u>:**
   - Data on non-retained bycatch and estimates of bycatch mortality in crab and groundfish fisheries during 2013/14 have been added, but are not put into the calculation of the recommended 2015/16 total-catch OFL. Data on retained catch during 2014/15 have been added, but data on bycatch mortality from 2014/15 are not presently available.

3. **<u>Changes to the assessment methodology</u>:** None.

4. **<u>Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL</u>:** None.

B. Responses to SSC and CPT Comments

1. **<u>Responses to the most recent two sets of SSC and CPT comments on assessments in general</u>:**

   - <u>CPT, May 2014</u>: *None pertaining to a Tier 5 assessment*.
   - <u>SSC, June 2014</u>: *Recommended that the Scallop and Crab Plan Teams conduct a workshop to address procedures for data-poor stocks with participants from all Plan Teams that are dealing with Tier 5 assessments and with the desired outcome of clearly articulating "the procedures and minimum requirements for establishing 10%, 20%,..., X% buffers such that they can be applied consistently across a range of species and different stocks*."
     - <u>Response</u>: Activities in response dependent upon scheduling of workshop; results would be incorporated into May 2016 assessment.
   - <u>CPT, September 2014</u> (via September 2014 SAFE Introduction chapter): *None pertaining to a Tier 5 assessment*.
   - <u>SSC, October 2014</u>: *Recommended that an uncertainty workshop be held in the fall of 2015 to address ABCs*.
     - <u>Response</u>: Results would be incorporated into the May 2016 assessment.

2. **<u>Responses to the most recent two sets of SSC and CPT comments specific to the assessment</u>:**
   - <u>CPT, May 2014</u>: *Recommended that the OFL and ABC for 2014/15 be the status quo OFL and ABC that were established in 2012/13.*
     - <u>Response</u>: The author's recommended OFL and ABC for 2015/16 are the same as those established for 2012/13 – 2014/15.
   - <u>SSC, June 2014</u>:
   - *Established the OFL and ABC for 2014/15 to be the status quo OFL and ABC that were established for 2012/13: 56 t (0.124-million lb) and 34 t (0.074-million lb), respectively*.
     - <u>Response</u>: The author's recommended OFL and ABC for 2015/16 are the same as those established for 2014/15. Author notes in this report that a "reconnaissance survey" for red king crab by the Industry and ADF&G in the

Adak Island area is being planned for September 2015 (J. Hilsinger, Aleutian King Crab Research Foundation, *pers. comm.*, 20 April 2015).

- *Encouraged efforts to gather additional data on status of the stock.*
  - Response: Author notes in this report that a "reconnaissance survey" for red king crab by the Industry and ADF&G in the Adak Island area is being planned for September 2015 (J. Hilsinger, Aleutian King Crab Research Foundation, *pers. comm.*, 20 April 2015).
- *Noted that reductions in the ABC may be necessary in the future. Expressed concerns that the reproductive potential of the stock may have been dramatically impacted.*
  - Response: The current ABC buffer of this stock, 40%, was the largest buffer of all FMP crab stocks in 2014/15, but is lower than the 75% buffer that was established for this stock in 2011/12 (see September 2014 CPT Report). Author notes that the ABC buffer of 75% for this stock in 2011/12 was established by the SSC to accommodate the "average needs in groundfish fisheries" (see September 2014 CPT Report) and the SSC reduced that buffer to the present buffer of 40% in 2012/13 to accommodate the catch needs of a test-fishery-based Industry survey of the Adak Island area that was planned, but not executed. In that regard, the author notes that the "reconnaissance survey" for red king crab in the Adak Island area that is being planned for execution in September 2015 by Industry and ADF&G (see above) would not require the retention for sale of any red king crab, because it would be funded by a cost-recovery fishery for Aleutian Islands golden king crab (L. Kozak, Golden King Crab Coalition, *pers. comm.*, 2 April 2015).

- CPT, September 2014 (via Sept 2014 SAFE): *Cites the 2010/11 – 2014/15 OFL as 54 t and the 2012/13 – 2014/15 ABC as 34 t, rather than the 56 t and 34 t, respectively, recommended by the assessment author.*
  - Response: The discrepancy is apparently due to the CPT (or SSC?) rounding values expressed in lb prior to converting to t.
- SSC, October 2014: *None*.

C. Introduction

1. **Scientific name:** *Paralithodes camtschaticus*, Tilesius, 1815

2. **Description of general distribution:**

The general distribution of red king crab is summarized by NMFS (2004):

> "Red king crab are widely distributed throughout the BSAI, GOA, Sea of Okhotsk, and along the Kamchatka shelf up to depths of 250 m. Red king crab are found from eastern Korea around the Pacific rim to northern British Columbia and as far north as Point Barrow (page 3-27).
>
> Most red and blue king crab fisheries occur at depths from 50-200 m, but red king crab fisheries in the Aleutian Islands sometimes extend to 300 m (page 3-41).

> 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 (pages 3-41–42)."

Commercial fishing for WAI red king crab during the last two prosecuted seasons (2002/03 and 2003/04) was opened only in the Petrel Bank area (i.e., between 179° W longitude and 179° E longitude; Baechler and Cook 2014) and effort during those two seasons typically occurred at depths of 60–90 fathoms (110–165 m); average depth of pots fished in the Aleutian Islands area during the 2002/03 season was 68 fathoms (124 m; Barnard and Burt 2004) and during the 2003/04 season was 82 fathoms (151 m; Burt and Barnard 2005). In the 580 pot lifts sampled by observers during the 1996/97–2006/07 Aleutian Islands golden king crab fishery that contained one or more red king crab, depth was recorded for 578 pots (ADF&G observer database, Dutch Harbor, April 2008). Of those, the deepest recorded depth was 266 fathoms (486 m) and 90% of pot lifts had recorded depths of 100–200 fathoms (183–366 m); no red king crab were present in any of the 6,465 pot lifts sampled during the 1996/97–2006/07 Aleutian Islands golden king crab fishery with depths >266 fathoms (486 m).

Although the Adak Registration Area is no longer defined in State regulation, 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 [Figure 1]. 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 the 1984/85 season until the March 1996 Alaska Board of Fisheries meeting, the Aleutian Islands king crab Registration Area O as currently defined had been subdivided at 171° W longitude into the historic Adak Registration Area R and the Dutch Harbor Registration Area O. The geographic boundaries of the WAI red king crab stock are defined here by the boundaries of the historic Adak Registration Area R; i.e., the current Aleutian Islands king crab Registration Area O, west of 171° W longitude. Note that in March 2014 the Alaska Board of Fisheries established two districts for management of commercial fisheries for red king crab in the waters of the Aleutian Islands west of 171° W longitude: 1) the Adak District, 171º to 179º W longitude; and the Petrel District, west of 179º W longitude.

3. Evidence of stock structure:

Seeb and Smith (2005) analyzed microsatellite DNA variability in nearly 1,800 individual red king crab originating from the Sea of Okhotsk to Southeast Alaska, including a sample 75 specimens collected during 2002 from the vicinity of Adak Island in the Aleutian Islands (51° 51' N latitude, 176° 39' W longitude), to evaluate the degree to which the established geographic boundaries between stocks in the BSAI reflect genetic stock divisions. Seeb and Smith (2005) concluded that, "There is significant divergence of the Aleutian Islands population (Adak sample) and the Norton Sound population from the southeastern Bering Sea population (Bristol Bay, Port Moller, and Pribilof Islands samples)." Recent analysis of patterns of genetic diversity among red king crab stocks in the western north Pacific (Asia), eastern North Pacific, and Bering Sea by multiple techniques (SNPs, allozymes, and mtDNA) also showed that red king crab sampled near Adak Island had greater genetic similarity to stocks in Asia rather than other stocks in Alaskan waters including Bristol Bay and the Gulf of Alaska (Grant et al. 2014).

We know of no analyses of genetic relationships among red king crab from different locations within the WAI. However, given the expansiveness of the WAI and the canyons between some islands that are deep (>1,000 m) relative to the depth zone restrictions of red king crab (see above), at least some weak structuring within the WAI red king crab stock would be expected. A summary of total retained catch by 1-degree longitude groupings during 1985/86–1995/96 (seasons for which state statistical area definitions allow for grouping by 1-degree longitude and for which catch distribution was not affected by area closures and openings; see Section C.5) shows that catch and, presumably, distribution of legal-sized male red king crab is not evenly distributed across the Aleutian Islands, with most catch during that period having come from Petrel Bank, followed by the vicinity of Adak, Atka, and Amlia Islands (Figure 2). Note that the 1-degree longitude grouping of catch does not portray the spatial gaps in catch that are apparent in a closer inspection of the 1985/86–1995/96 catch data by state statistical areas. For example, no catch was reported during 1985/86–1995/96 from the two statistical areas (795102 and 795132) that include Amchitka Pass (Amchitka Pass lies between Petrel Bank and the Delarof Is; see Figure 2).

McMullen and Yoshihara (1971) reported the following on male red king crab that were tagged in February 1970 on the Bering Sea and Pacific Ocean sides of Atka Island and recovered in the subsequent fishery season:

> "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. Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology):

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 season timing for the commercial fishery, little data on reproductive condition of WAI red king crab females have been collected by at-sea fishery observers that can be used for evaluating the mating period. For example, of the 3,211 mature females that were examined during the 2002/03 and 2003/04 red king crab seasons in the Petrel Bank area, both of which seasons were restricted to late October, only 10 were scored as "hatching" (ADF&G observer database, Dutch Harbor, April 2008).

Data on mating pairs of red king crab collected from the Kodiak area during March–May of 1968 and 1969 showed that size of the females in the pairs increased from March to May, indicating that females tend to release their larvae and mate later in the mating season with increasing body size (Powell et al. 2002). Size of the males in those mating pairs did not increase with later sampling periods, but did show a decreasing trend in estimated time since last molt. In all the data on mating pairs collected from the Kodiak area during 1960–1984, the proportion of males that were estimated to have not recently molted prior to mating decreased monthly over the mating period (Powell et al. 2002). Those data suggest that males that do not molt early in the mating period have an advantage in mating early in the mating period, when primiparous females and smaller, multiparous females tend to ovulate, and that males that do molt early in the mating period likely participate later in the mating period, likely mating with the larger females.

Current knowledge of red king crab reproductive biology, including male and female maturation, migration, mating dynamics, and potential effects of exploitation on reproductive potential, is summarized by Webb (2014).

5. Brief summary of management history:

A complete summary of the management history through 2011/12 is provided by Baechler and Cook (2014, pages 7–13). The domestic fishery for red king crab in the WAI began with the 1960/61 season. Retained catch of red king crab in the Aleutians west of 172° W longitude averaged 11.595-million lb (5,259 t) during the 1960/61–1975/76 seasons, with a peak harvest of 21.193-million lb (9,613 t) in the 1964/65 season (Table 1, Figure 3). Guideline harvest levels (GHL; sometimes expressed as ranges, with an upper and lower GHL) for the fishery have been established for most seasons since the 1970s. The fishery was closed for the 1976/77 season in the area west of 172º W longitude, but reopened for the 1977/78–1995/96 seasons. Average retained catch during the 1977/78–1995/96 seasons (for the area west of 172º W longitude prior to the 1984/85 season and for the area west of 171º W longitude since the 1984/85 season) was 1.044-million lb (474 t); the peak harvest during that period was 1.982-million lb (899 t) for the 1983/84 season. 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 the 1990/91–1994/95 seasons (Figure 4). The WAI red king crab fishery was closed for the 1996/97 season following the diminishing harvests of the preceding two seasons that did not reach the lower GHL. Due to concerns about low stock levels and poor recruitment, the fishery has been opened only intermittently since 1996/97. The fishery was closed for the 1996/97–1997/98 seasons, closed in the Petrel Bank area for the 1998/99 season, closed for the 1999/2000 season, restricted to the Petrel Bank area for the 2000/01–2003/04 seasons (except for an ADF&G-Industry survey in the Adak, Atka, and Amlia Islands area conducted as a commissioner's permit fishery), and closed for the 2004/05–2014/15 seasons. The peak harvest since the 1996/97 season was 0.506-million lb (229 t), which occurred in the 2002/03 season. A summary of relevant fishery activities and management measures pertaining to the WAI red king crab fishery since the 1996/97 season is provided in Table 2.

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 was closed for the 1996/97–1997/98 seasons. The following area closures and harvest restrictions have been applied to the red king crab fishery, when opened, in the WAI since the 1998/99 season:

- The 1998/99 season for red king crab in the WAI was open east of 179° W longitude with a guideline harvest level (GHL) of 0.005-million lb (2 t) and west of 179° E longitude with a GHL of 0.010-million lb (5 t), but was closed between 179° W longitude and 179° E longitude.
- ADF&G-Industry pot surveys for red king crab were conducted in January—February 2001 (the 2000/01 season) and November 2001 (the 2001/02 season) under the restrictions of a commissioner's permit fishery in the Petrel Bank area (north of 51° 45' N latitude and between 179° W longitude and 179° E longitude; Bowers et al. 2002, Baechler and Cook 2014). The WAI was closed to commercial red king crab fishing outside of the designated survey area.
- The 2002/03 season opened in those waters of king crab Registration Area O between 179° W longitude and 179° E longitude and north of 51° 45' N latitude (the Petrel Bank area; Baechler and Cook 2014) with a GHL of 0.500-million lb (227 t). Additionally, an ADF&G-Industry pot survey for red king crab was conducted in November 2002 under the restrictions of a commissioner's permit fishery in the vicinity of Adak, Atka, and Amlia Islands to assess the WAI red king crab stock in the area between 172° W longitude and 179° W longitude (Granath 2003). The remaining area outside of the Petrel Bank area and the designated survey area in the WAI was closed to commercial red king crab fishing during the 2002/03 season.
- The 2003/04 season opened in those waters of king crab Registration Area O between 179° W longitude and 179° E longitude and north of 51° 45' N latitude (the so-called "Petrel Bank area"; Baechler and Cook 2014). The remaining area in the WAI was closed to commercial red king crab fishing during the 2003/04 season.

The WAI red king crab fishery west of 179° W longitude has been managed since the 2005/06 season 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 showed healthy levels of legal males (CPUE = 28 crab per pot lift), but low catches of females and sublegal males, ADF&G opened the 2002/03 and 2003/04 seasons with a GHL of 0.500-million lb (227 t); 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 for the 2004/05 season due to continued uncertainty on the status of pre-recruit legal males, a reduction in legal male CPUE between the 2002/03 and 2003/04 seasons (18 legal crab per pot in 2002/03 and 10 legal crab per pot in 2003/04), and a strategy adopted by ADF&G to close the fishery before the CPUE of legal crab dropped below 10 per pot.

The harvest strategy for red king crab in the Adak District adopted by the Alaska Board of Fisheries in March 2014 is as follows:

> **5 AAC 34.616. Adak District red king crab harvest strategy.** (a) In the Adak District, based on the best scientific information available, if the department determines that there is a harvestable surplus of
>
> > (1) red king crab available in the waters of Alaska in the Adak District, the commissioner may open, by emergency order, a commercial red king crab fishery only in the waters of Alaska in the Adak District under 5 AAC 34.610(a)(1);
> >
> > (2) at least 250,000 pounds of red king crab in the Adak District, the commissioner may open, by emergency order, a commercial red king crab fishery in the entire Adak District under 5 AAC 34.610(a)(1).

(b) In the Adak District, during a season opened under 5 AAC 34.610(a)(1), the operator of a validly registered king crab fishing vessel shall

(1) report each day to the department

(A) the number of pot lifts;

(B) the number of crab retained for the 24-hour fishing period preceding the report; and

(C) any other information the commissioner determines is necessary for the management and conservation of the fishery, as specified in the vessel registration certificate issued under 5 AAC 34.020; and

(2) complete and submit a logbook as prescribed and provided by the department.

7. **Summary of the history of B_{MSY}:** Not applicable for this Tier 5 stock.

D. Data

1. **Summary of new information:**
   - Retained catch data from the closed 2014/15 directed fishery season has been added; the retained catch was 0 lb.
   - Data on non-retained bycatch in crab and groundfish fisheries has been updated with data from the 2013/14 Aleutian Islands golden king crab fishery and the 2013/14 groundfish fisheries in reporting areas 541, 542, and 543 (Figure 5).

2. **Data presented as time series:**

a. ***Total catch*** ***and b.*** ***Information on bycatch and discards:***

- The 1960/61–2014/15 time series of retained catch (number and lb of crab harvested, including deadloss), effort (vessels, landings, and pot lifts), average weight of landed crab, average carapace length of landed crab, and CPUE (number of landed crab captured per pot lift) is presented in Table 1.
- The 1960/61–2014/15 time series of retained catch (lb of landed crab) is presented graphically in Figure 3.
- The 1995/96–2013/14 times series of weight of retained legal males and estimated weight of non-retained legal male, non-retained sublegal male, and non-retained female red king crab in the WAI during commercial crab fisheries is given in Table 3. Observer data on size distributions and estimated catch numbers of non-retained catch were used to estimate the weight of non-retained catch of red king crab by applying a weight-at-length estimator (see below). Estimates of bycatch prior to the 1995/96 season are not given due to non-existence of data or to limitations on bycatch sampling during the crab fisheries. Prior to 1988/89 there was no fishery observer program for Aleutian Islands crab fisheries and during the 1988/89–1994/95 seasons observers were required only on vessels processing king crab at sea, including catcher-processor vessels. 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 the 1990/91 and 1992/93–1994/95 seasons and golden king crab fishery in the 1993/94 and 1994/95 seasons are confidential due to the limited number of observed vessels. During the 1995/96–2004/05 seasons, 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 the 2005/06 season, 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 harvest 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 as bycatch during the Aleutian Islands golden king crab fishery west of 174° W longitude by a vessel while an observer was on board during the 2001/02–2002/03 and 2004/05–2013/14 seasons were counted and recorded for capture location and biological data.

- The 1993/94–2013/14 time series of estimated weight of bycatch and estimated bycatch mortality of red king crab 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) is provided in 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. Estimated weight of bycatch (not discounted by an assumed mortality rate) during the 1993/94–2013/14 groundfish fisheries by reporting area (541, 542, or 543) is provided in Table 5. Bycatch estimates for 1992/93 are available, but appear to be suspect because they are extremely low.
- The 1995/96–2013/14 time series of estimated weight of total fishery mortality of red king crab in the WAI, partitioned into retained catch, bycatch mortality during crab fisheries, and bycatch mortality during federal groundfish fisheries, is provided in 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 non-retained catch given in Table 3. The estimates of bycatch mortality in groundfish fisheries given in Table 6 are from Table 4.

c. ***<u>Catch-at-length</u>:*** Not used in a Tier 5 assessment; none are presented here.

d. ***<u>Survey biomass estimates</u>:*** Not available; there is no program for regular performance of standardized surveys sampling from the entirety of the stock range.

e. ***<u>Survey catch at length</u>:*** Not used in a Tier 5 assessment; none are presented here.

f. ***<u>Other data time series</u>:***

Data on CPUE (number of retained crab per pot lift) during the red king crab in the WAI are available for the 1972/73–2014/15 seasons (see Table 1).

3. <u>Data which may be aggregated over time</u>:

a. <u>Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):</u>

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. <u>Weight-at length or weight-at-age (by sex)</u>:
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. ***<u>Natural mortality rate</u>:*** Natural mortality rate has not been estimated specifically for red king crab in the WAI. NPFMC (2007) assumed a natural mortality rate of M = 0.18 for king crab species.

4. **<u>Information on any data sources that were available, but were excluded from the assessment:</u>**
   - 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 bycatch of red king crab in the WAI red king crab fishery and the Aleutian Islands golden king crab fishery, 1988/89–2013/14 (ADF&G observer database).
   - Summary of data collected by ADF&G WAI red king crab fishery observers or surveys during 1969–1987 (Blau 1993).
   - Retained catch-at-length data for the red king crab fishery in the WAI for the 1984/85–1995/96, 1999/00, 2000/01–2001/02, and 2002/03–2003/04 seasons (data from the 1999/2000 season and the 2000/01–2001/02 seasons collected made during either restricted exploratory fishing or during ADFG-Industry surveys).

E. Analytic Approach

1. **<u>History of modeling approaches for this stock</u>:** This is a Tier 5 stock; there is no assessment model and no history of assessment modelling approaches for this stock.

2. **<u>Model Description</u>:** 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 bycatch estimates 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 retained catch data and bycatch 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 2015/16 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 2015/16 is

$$OFL_{2015/16} = RET_{95/96\text{-}07/08} + BM_{CF,\ 95/96\text{-}07/08} + BM_{GF,\ 95/96\text{-}07/08},$$

where,

- $RET_{95/96\text{-}07/08}$ is the average annual retained catch in the directed crab fishery during 1995/96–2007/08
- $BM_{CF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the directed and non-directed crab fisheries during 1995/96–2007/08, and
- $BM_{GF,\ 95/96\text{-}07/08}$ is the estimated average annual bycatch mortality in the groundfish fisheries during 1995/96–2007/08.

Given the June 2010 SSC recommendations, items ***E.2 a–i*** are not applicable.

3. **Model Selection and Evaluation:** Not applicable; see section ***E.2***.

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 Table 6.

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 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 (0.12 million lb; 56 t) 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." Additionally, the CPT registered its concern with a fishery mortality equivalent to 90% of that OFL: "Discussion further noted to what extent removing 110,000 lbs in perpetuity is reasonable rate of sustainable catch for this stock given its current size."
- 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 specified as the estimated average annual total-catch during the period 1995/96–2007/08; i.e.,

$$OFL_{2015/16} = RET_{95/96\text{-}07/08} + BM_{CF,\ 95/96\text{-}07/08} + BM_{GF,\ 95/96\text{-}07/08},$$

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 $BM_{GF,95/96\text{-}07/08}$, $OFL_{2015/16}$ is,

$$OFL_{2015/16} = 96{,}932 + 3{,}000 + 23{,}935 = 123{,}867 \text{ lb (0.12-million lb; 56 t).}$$

2. **<u>List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan</u>:** Not applicable for Tier 5 stock.

3. **<u>Specification of the OFL</u>:**

a. <u>Provide the equations (from Amendment 24) on which the OFL is to be based</u>:

From **Federal Register** / Vol. 73, No. 116, page 33926, "For stocks in Tier 5, the overfishing level is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information." Additionally, "For stocks where nontarget fishery removal data are available, catch includes all fishery removals, including retained catch and discard losses. Discard losses will be determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the overfishing level is set for and compared to the retained catch" (FR/Vol. 73, No. 116, 33926). That compares with the specification of NPFMC (2007) that the OFL "represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock."

b. <u>Basis for projecting MMB to the time of mating</u>: Not applicable for Tier 5 stock.

c. <u>Specification of F_{OFL}, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring</u>:

See table, below. The OFL and ABC values for 2015/16 are those recommended by the author.

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

a. Millions of lb.
b. Includes bycatch mortality of discarded bycatch.

4. **<u>Specification of the recommended retained-catch portion of the total-catch OFL</u>:**

   a. Equation for recommended retained portion of the total-catch OFL,
   Retained-catch portion = average retained catch during 1995/96–2007/08

= 96,932 lb (0.10-million lb; 44 t).

5. **Recommended F_{OFL}, OFL total catch and the retained portion for the coming year:** See sections ***F.3*** and ***F.4***, above; no F_{OFL} is recommended for a Tier 5 stock.

G. Calculation of ABC

1. PDF of OFL. A bootstrap estimate of the sampling distribution (assuming no error in estimation of bycatch) of the OFL is shown in Figure 6 (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 and CV 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.

- Bycatch mortality rate in each fishery that bycatch occurs. Note that for Tier 5 stocks, an increase in an assumed bycatch 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 bycatch mortality during each fishery that bycatch occurred in during 1995/96–2007/08.
- The time period to compute the average catch relative to assumption that it represents "a time period determined to be representative of the production potential of the stock."

3. List of addititional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.

4. Author recommended ABC. 74,000 lb (0.07-million lb, 34 t). This is the status quo from the ABC for 2014/15 that was recommended by the SSC in June 2014, which was, in turn, based on the SSC's recommended ABC for 2013/14 that was determined as a value "sufficient to cover bycatch and the proposed test fishery catch" (June 2013 SSC meeting minutes, page 10). Note that the lower ABC recommended for 2011/12 by the SSC in June 2011 was based on the estimated average bycatch mortality due to groundfish and the non-directed crab fisheries during 1995/96–2007/08, 26,935 lb (0.03-million lb; 12 t).

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 stock through the history of the fishery would be very valuable.

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 31,417 lb (14 t) of red king crab. In addition, bycatch mortality during the proposed survey was assumed not to exceed 20,000 lb (9 t) based on assumed maximum bycatch and an assumed bycatch mortality rate of 0.2 In 2012 the CPT and SSC recommended an ABC of 0.074-million lb (34 t) for 2012/13 to accommodate the proposed red king crab survey. 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.

The "reconnaissance survey" planned by Industry and ADF&G in the Adak Island area in September 2015 may provide information for the development of future systematic surveys in that area (J. Hilsinger, Aleutian King Crab Research Foundation, *pers. comm.*, 20 April 2015).

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Table 1. Aleutian Islands, Area O, red king crab commercial fishery data, 1960/61–2013/14, partitioned into the Adak Area (west of 172º W longitude prior to 1984/85 and west of 171º W longitude since 1984/85) and the Dutch Harbor Area (from May 2014 draft SAFE, updated for the 2014/15 season).

		Number of							Average		
Season	Location	Vessels	Landings	Crab[a]	Pots lifted	GHL/TAC[b]	Harvest[a,c]	Deadloss[c]	Weight[c]	CPUE[d]	Length[e]
1960/61	East of 172° W	NA	NA	NA	NA		NA	NA	NA	NA	NA
	West of 172° W	4	41	NA	NA		2,074,000	NA	NA	NA	NA
	TOTAL										
1961/62	East of 172° W	4	69	NA	NA		533,000	NA	NA	NA	NA
	West of 172° W	8	218	NA	NA		6,114,000	NA	NA	NA	NA
	TOTAL		**287**				**6,647,000**				
1962/63	East of 172° W	6	102	NA	NA		1,536,000	NA	NA	NA	NA
	West of 172° W	9	248	NA	NA		8,006,000	NA	NA	NA	NA
	TOTAL		**350**				**9,542,000**				
1963/64	East of 172° W	4	242	NA	NA		3,893,000	NA	NA	NA	NA
	West of 172° W	11	527	NA	NA		17,904,000	NA	NA	NA	NA
	TOTAL		**769**				**21,797,000**				
1964/65	East of 172° W	12	336	NA	NA		13,761,000	NA	NA	NA	NA
	West of 172° W	18	442	NA	NA		21,193,000	NA	NA	NA	NA
	TOTAL		**778**				**34,954,000**				
1965/66	East of 172° W	21	555	NA	NA		19,196,000	NA	NA	NA	NA
	West of 172° W	10	431	NA	NA		12,915,000	NA	NA	NA	NA
	TOTAL		**986**				**32,111,000**				
1966/67	East of 172° W	27	893	NA	NA		32,852,000	NA	NA	NA	NA
	West of 172° W	10	90	NA	NA		5,883,000	NA	NA	NA	NA
	TOTAL		**983**				**38,735,000**				
1967/68	East of 172° W	34	747	NA	NA		22,709,000	NA	NA	NA	NA
	West of 172° W	22	505	NA	NA		14,131,000	NA	NA	NA	NA
	TOTAL		**1,252**				**36,840,000**				
1968/69	East of 172° W	NA	NA	NA	NA		11,300,000	NA	NA	NA	NA
	West of 172° W	30	NA	NA	NA		16,100,000	NA	NA	NA	NA
	TOTAL						**27,400,000**				
1969/70	East of 172° W	41	375	NA	72,683		8,950,000	NA	NA	NA	NA
	West of 172° W	33	435	NA	115,929		18,016,000	NA	6.5	NA	NA
	TOTAL		**810**		**188,612**		**26,966,000**				
1970/71	East of 172° W	32	268	NA	56,198		9,652,000	NA	NA	NA	NA
	West of 172° W	35	378	NA	124,235		16,057,000	NA	NA	NA	NA
	TOTAL		**646**		**180,433**		**25,709,000**				
1971/72	East of 172° W	32	210	1,447,692	31,531		9,391,615	NA	7	46	NA
	West of 172° W	40	166	NA	46,011		15,475,940	NA	NA	NA	NA
	TOTAL		**376**		**77,542**		**24,867,555**				
1972/73	East of 172° W	51	291	1,500,904	34,037		10,450,380		7	44	
	West of 172° W	43	313	3,461,025	81,133		18,724,140	NA	5.4	43	NA
	TOTAL		**604**	**4,961,929**	**115,170**		**29,174,520**		**5.9**	**43**	
1973/74	East of 172° W	56	290	1,780,673	41,840	10.0[f]	12,722,660	NA	7.1	43	NA
	West of 172° W	41	239	1,844,974	70,059	20.0[f]	9,741,464	NA	5.3	26	148.6
	TOTAL		**529**	**3,625,647**	**111,899**		**22,464,124**		**6.2**	**32**	

-continued-

Table 1. page 2 of 3.

		Number of					Average			
Season	Locale	Vessels[a]	Landings	Crabs[b]	Pots Lifted	Harvest[b,c]	Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1974/75	East of 172° W	87	372	1,812,647	71,821	13,991,190	7.7	25		
	West of 172° W	36	97	532,298	32,620	2,774,963	5.2	16	148.6	NA
	TOTAL		**469**	**2,344,945**	**104,441**	**16,766,153**	**7.1**	**22**		
1975/76	East of 172° W	79	369	2,147,350	86,874	15,906,660	7.4	25		
	West of 172° W	20	25	79,977	8,331	411,583	5.2	10	147.2	NA
	TOTAL		**394**	**2,227,327**	**95,205**	**16,318,243**	**7.3**	**23**		
1976/77	East of 172° W	72	226	1,273,298	65,796	9,367,965 [f]	7.4	19		
	East of 172° W	38	61	86,619	17,298	830,458 [g]	9.6	5	NA	NA
	West of 172° W	F I S H E R Y C L O S E D								
	TOTAL		**287**	**1,359,917**	**83,094**	**10,198,423**	**7.5**	**16**		
1977/78	East of 172° W	33	227	539,656	46,617	3,658,860 [f]	6.8	12		
	East of 172° W	6	7	3,096	812	25,557 [h]	8.3	4	NA	NA
	West of 172° W	12	18	160,343	7,269	905,527	5.7	22	152.2	NA
	TOTAL		**252**	**703,095**	**54,698**	**4,589,944**	**6.5**	**13**		
1978/79	East of 172° W	60	300	1,233,758	51,783	6,824,793	5.5	24	NA	NA
	West of 172° W	13	27	149,491	13,948	807,195	5.4	11	NA	1,170
	TOTAL		**327**	**1,383,249**	**65,731**	**7,631,988**	**5.5**	**21**		
1979/80	East of 172° W	104	542	2,551,116	120,554	15,010,840	5.9	21	NA	NA
	West of 172° W	18	23	82,250	9,757	467,229	5.7	8	152	24,850
	TOTAL		**565**	**2,633,366**	**130,311**	**15,478,069**	**5.9**	**20**		

		Number of							Average		
Season	Location	Vessels	Landings	Crab[a]	Pots lifted	GHL/TAC[b]	Harvest[a,c]	Deadloss[c]	Weight[c]	CPUE[d]	Length[e]
1980/81	East of 172° W[g]	114	830	2,772,287	231,607	7.0 - 17.0[f]	17,660,620	NA	6.4	12	NA
	East of 172° W[i]	54	120	182,349	30,000		1,392,923		7.6	6	
	West of 172° W	17	52	254,390	20,914	0.5 - 3.0	1,419,513	54,360	5.6	12	149
	TOTAL		**1,002**	**3,209,026**	**282,521**		**20,473,056**		**6.4**	**11**	
1981/82	East of 172° W	92	683	741,966	220,087	7.0 - 17.0[f]	5,155,345	NA	6.9	3	NA
	West of 172° W	46	106	291,311	40,697	0.5 - 3.0	1,648,926	8,759	5.7	7	148.3
	TOTAL		**789**	**1,033,277**	**260,784**		**6,804,271**		**6.6**	**4**	
1982/83	East of 172° W	81	278	64,380	72,924	2.0 - 3.0[j]	431,179		6.7	1	
	West of 172° W	72	191	284,787	66,893	0.5 - 3.0	1,701,818	7,855	6.0	4	150.8
	TOTAL		**469**	**349,167**	**139,817**		**2,132,997**		**6.1**	**3**	
1983/84	East of 172° W	FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
	West of 172° W	106	248	298,958	60,840	0.5 - 3.0	1,981,579	3,833	6.6	5	157.3
1984/85	East of 171° W	FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
	West of 171° W	64	106	196,276	48,642	1.5 - 3.0	1,296,385	0	6.6	4	155.1
1985/86	East of 171° W	FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
	West of 171° W	35	82	156,097	29,095	0.5 - 2.0	868,828	0	5.6	5	152.2
1986/87	East of 171° W	FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
	West of 171° W	33	69	126,204	29,189	0.5 - 1.5	712,543	800	5.7	4	NA
1987/88	East of 171° W	FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
	West of 171° W	71	103	211,692	43,433	0.5 - 1.5	1,213,892	6,900	5.7	5	148.5

-continued-

Table 1. page 3 of 3.

		Number of					Average			
Season	Locale	Vessels[a]	Landings	Crabs[b]	Pots Lifted	Harvest[b,c]	Weight[c]	CPUE[d]	Length[e]	Deadloss[c]
1988/89	East of 171° W	FISHERY CLOSED								
	West of 171° W	73	156	266,053	64,334	1,567,314	5.9	4	153.1	557
1989/90	East of 171° W	FISHERY CLOSED								
	West of 171° W	56	123	193,177	54,213	1,105,971	5.7	4	151.5	759
1990/91	East of 171° W	FISHERY CLOSED								
	West of 171° W	7	34	146,903	10,674	828,105	5.6	14	148.1	0
1991/92	East of 171° W	FISHERY CLOSED								
	West of 171° W	10	35	165,356	16,636	951,278	5.8	10	149.8	0
1992/93	East of 171° W	FISHERY CLOSED								
	West of 171° W	12	30	218,049	16,129	1,286,424	6.0	14	151.5	5,000
1993/94	East of 171° W	FISHERY CLOSED								
	West of 171° W	12	21	119,330	13,575	698,077	5.9	9	154.6	7,402
1994/95	East of 171° W	FISHERY CLOSED								
	West of 171° W	20	31	30,337	18,146	196,967	6.5	2	157.5	1,430
1995/96	East of 171° W	FISHERY CLOSED								
	West of 171° W	4	12	6,880	1,986	38,941	5.7	3	153.6	235
1996/97		FISHERY CLOSED								
1997/98		FISHERY CLOSED								

		Number of							Average		
Season	Location	Vessels	Landings	Crab[a]	Pots lifted	GHL/TAC[b]	Harvest[a,c]	Deadloss[c]	Weight[c]	CPUE[d]	Length[e]
1998/99	West of 174° W	1	CF	CF	CF	0.015	CF	CF	CF	CF	CF
1999/00		FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
2000/01[k]	Petrel Bank[l]	1	3	11,299	496	FC	76,562	0	6.8	23	161.0
2001/02[m]	Petrel Bank[l]	4	5	22,080	564	FC	153,961	82	7.0	39	159.5
2002/03	Petrel Bank[l]	33	35	68,300	3,786	0.5	505,642	1,311	7.4	18	162.4
2003/04	Petrel Bank[l]	30	31	59,828	5,774	0.5	479,113	2,617	8.0	10	167.9
2004/05 - 2010/11		FC	FC	FC	FC	FC	FC	FC	FC	FC	FC
2011/12–2014/15		FC	FC	FC	FC	FC	FC	FC	FC	FC	FC

Note: NA = Not available.

[a] Many vessels fished both east and west of 171° W long., thus total number of vessels reflects registrations for entire Aleutian Islands.

[b] Deadloss included.

[c] In lb.

[d] Number of legal crab per pot lift.

[e] Carapace length in millimeters.

[f] Split season based on 6.5 inch minimum legal size.

[g] Split season based on 8 inch minimum legal size.

[h] Split season based on 7.5 inch minimum legal size.

[i] January/February 2001 Petrel Bank survey (fish ticket harvest code 15, exploratory shellfish harvest).

[j] Those waters of king crab Registration Area O between 179° E long., 179° W long., and north of 51° 45' N lat.

[k] November 2001 Petrel Bank survey (fish ticket harvest code 15, exploratory shellfish harvest).

[m] November Petrel Bank survey (fish ticket harvest code 15, exploratory shellfish harvest).

Table 2. A summary of relevant fishery activities and management measures pertaining to the Western Aleutian Islands red king crab fishery since the 1996/97 season.

Season	Fishery Activities and Management Measures
1998/99	• GHL of 15,000 lb (7 t) for exploratory fishing with fishery closed in the Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) o 1 vessel
1999/00	• Fishery closed
2000/01	• Fishery closed • Catch retained during ADF&G-Industry survey of Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) conducted as commissioner's permit fishery, Jan–Feb 2001 o 1 vessel o 76,562 lb o CPUE = 23 legals/pot lift
2001/02	• Fishery closed • Catch retained ADF&G-Industry survey of Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) conducted as commissioner's permit fishery, November 2001 o 4 vessels o 153,961 lb o CPUE = 39 legals/pot lift
2002/03	• Fishery opened with GHL of 500,000 lb (227 t) restricted to Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) o 33 vessels o 505,642 lb o CPUE = 18 legals/pot lift • ADF&G-Industry survey of the Adak, Atka, and Amlia Islands area conducted as a commissioner's permit fishery o 4 legal males captured in 1,085 pot lifts
2003/04	• Fishery opened with GHL of 500,000 lb (227 t) restricted to Petrel Bank area (i.e., between 179° W longitude and 179° E longitude) o 30 vessels o 479,113 lb o 10 legals/pot lift
2004/05–2014/15	• Fishery closed o 2006 and 2009 ADF&G pot surveys on Petrel Bank

Table 3. Retained catch (lb) of Western Aleutian Islands red king crab, with the estimated non-retained catch (thousands of lb; not discounted for an assumed bycatch mortality rate) and components of non-retained catch (legal males, non-retained sublegal males, and females) during commercial crab fisheries by season, 1995/96–2013/14 (from 2014 Crab SAFE, updated for 2013/14 season).

	WAI red king crab fishery				AI golden king crab fishery			
	Retained	Non-retained						Total
Season	legal male	Legal male	Sublegal male	Female	Legal male	Sublegal male	Female	non-retained
1995/96	38,941	0	20,669	27,624	0	2,047	314	50,654
1996/97	0	0	0	0	3,292	2,024	666	5,982
1997/98	0	0	0	0	178	579	179	936
1998/99[a]	5,900	-	-	-	747	138	186	-
1999/00	0	0	0	0	161	756	93	1,010
2000/01	76,562	0	771	374	365	274	35	1,819
2001/02	153,961	174	6,574	8,369	19,995	0	364	35,476
2002/03	505,642	1,658	6,027	17,432	21,738	355	512	47,722
2003/04	479,113	631	6,597	7,962	9,425	6,352	6,686	37,653
2004/05	0	0	0	0	2,143	210	0	2,353
2005/06	0	0	0	0	189	0	49	239
2006/07	0	0	0	0	323	117	50	491
2007/08	0	0	0	0	615	1,819	561	2,995
2008/09	0	0	0	0	220	20	97	337
2009/10	0	0	0	0	574	249	43	866
2010/11	0	0	0	0	4,312	167	82	4,561
2011/12	0	0	0	0	958	29	92	1,079
2012/13	0	0	0	0	871	75	35	980
2013/14	0	0	0	0	2,945	102	172	3,219
Average	66,322	137	2,258	3,431	3,634	806	538	11,021

a. Data on non-retained bycatch of red king crab during the red king crab fishery not available (see Moore et al. 2000).

Table 4. Estimated annual weight (lb) of discarded bycatch of red king crab (all sizes, males and females) and bycatch mortality (lb) during federal groundfish fisheries by gear type (fixed or trawl) in reporting areas 541, 542, and 543 (Aleutian Islands west of 170° W longitude), 1993/94–2013/14 (assumes bycatch mortality rate of 0.5 for fixed-gear fisheries and 0.8 for trawl fisheries; from 2014 Crab SAFE, updated for 2013/14 season).

	Bycatch		Bycatch Mortality		
Season	Fixed Gear	Trawl Gear	Fixed Gear	Trawl Gear	Total
1993/94	1,312	88,384	656	70,707	71,363
1994/95	2,993	22,792	1,497	18,234	19,730
1995/96	5,804	15,289	2,902	12,231	15,133
1996/97	2,874	44,662	1,437	35,730	37,167
1997/98	3,819	11,717	1,910	9,374	11,283
1998/99	10,143	45,532	5,072	36,426	41,497
1999/00	37,765	27,973	18,883	22,378	41,261
2000/01	2,697	13,879	1,349	11,103	12,452
2001/02	5,340	59,552	2,670	47,642	50,312
2002/03	11,295	73,027	5,648	58,422	64,069
2003/04	3,577	9,151	1,789	7,321	9,109
2004/05	791	12,930	396	10,344	10,740
2005/06	3,546	2,359	1,773	1,887	3,660
2006/07	6,781	617	3,391	494	3,884
2007/08	16,971	2,630	8,486	2,104	10,590
2008/09	10,778	10,290	5,389	8,232	13,621
2009/10	315	14,104	158	11,283	11,441
2010/11	92	4,381	46	3,504	3,551
2011/12	2,632	1,801	1,316	901	2,216
2012/13	20	523	10	418	428
2013/14	29	93	14	75	89
Average	6,170	21,985	3,085	17,562	20,647

Table 5. Estimated lb of bycatch (not discounted by an assumed bycatch mortality) of red king crab during federal groundfish fisheries (all gear types combined) by NMFS Reporting Area, 1993/94–2013/14 (from 2014 Crab SAFE, updated for 2013/14 season).

	Reporting Area			
Season	541	542	543	Total
1993/94	83,752	5,862	82	89,696
1994/95	23,637	1,922	226	25,785
1995/96	13,122	4,056	3,916	21,094
1996/97	4,294	6,810	36,433	47,537
1997/98	2,218	8,739	4,579	15,536
1998/99	14,892	15,798	24,986	55,676
1999/00	36,027	17,755	11,955	65,738
2000/01	3,899	8,056	4,621	16,577
2001/02	7,661	52,986	4,244	64,891
2002/03	24,250	46,980	13,092	84,323
2003/04	4,915	7,778	36	12,728
2004/05	1,164	12,523	34	13,721
2005/06	3,540	87	2,278	5,905
2006/07	6,545	853	0	7,398
2007/08	11,295	6,708	1,598	19,601
2008/09	2,522	16,635	1,911	21,068
2009/10	3,686	8,278	2,455	14,419
2010/11	468	4,004	1	4,473
2011/12	1,933	2,499	0	4,433
2012/13	344	199	0	543
2013/14	0	96	26	122
Average	11,913	10,887	5,356	28,155

Table 6. Estimated annual weight (thousands of lb) of total fishery mortality to Western Aleutian Islands red king crab, 1995/96–2013/14, partitioned by source of mortality: retained catch, bycatch mortality during crab fisheries, and bycatch mortality during groundfish fisheries (from 2014 Crab SAFE, updated for 2013/14 season).

		Bycatch Mortality by Fishery Type		Total Estimated
Season	Retained Catch	Crab	Groundfish	Fishery mortality
1995/96	38,941	10,131	15,133	64,205
1996/97	0	1,196	37,167	38,363
1997/98	0	187	11,283	11,470
1998/99[a]	5,900	1,535	41,497	48,931
1999/00	0	202	41,261	41,463
2000/01	76,562	364	12,452	89,378
2001/02	153,961	7,095	50,312	211,368
2002/03	505,642	9,544	64,069	579,256
2003/04	479,113	7,531	9,109	495,753
2004/05	0	471	10,740	11,210
2005/06	0	48	3,660	3,708
2006/07	0	98	3,884	3,982
2007/08	0	599	10,590	11,189
2008/09	0	67	13,621	13,688
2009/10	0	173	11,441	11,614
2010/11	0	912	3,551	4,463
2011/12	0	216	2,216	2,432
2012/13	0	196	428	624
2013/14	0	643	89	732
Mean, 1995/96–2007/08	96,932	3,000	23,935	123,867
CV of mean	52%	37%	23%	43%
Mean, 1995/96–2013/14	66,322	2,169	18,026	86,517
CV of mean	54%	37%	24%	44%

a. No bycatch 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.

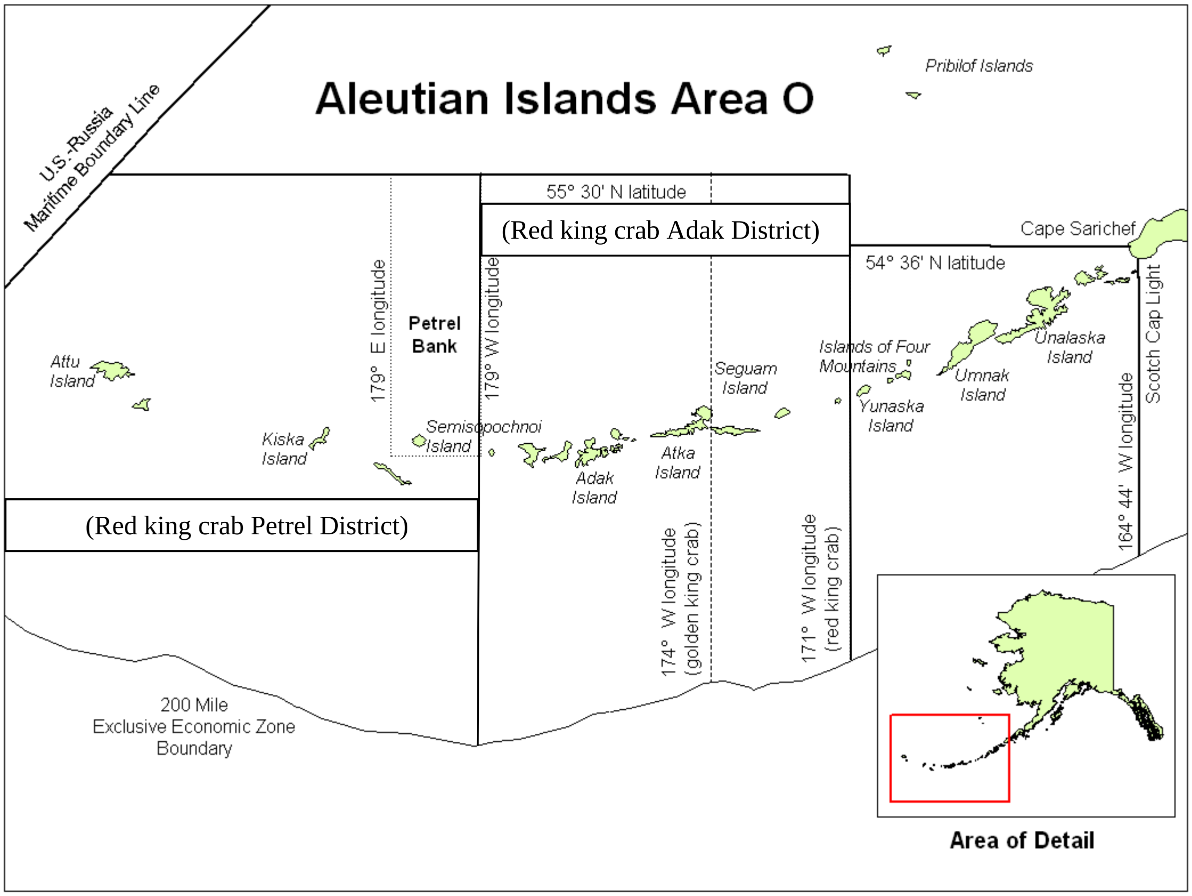


Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Baechler and Cook 2014, updated to show boundaries of the Adak and Petrel Districts for red king crab as established by the Alaska Board of Fisheries in March 2014).

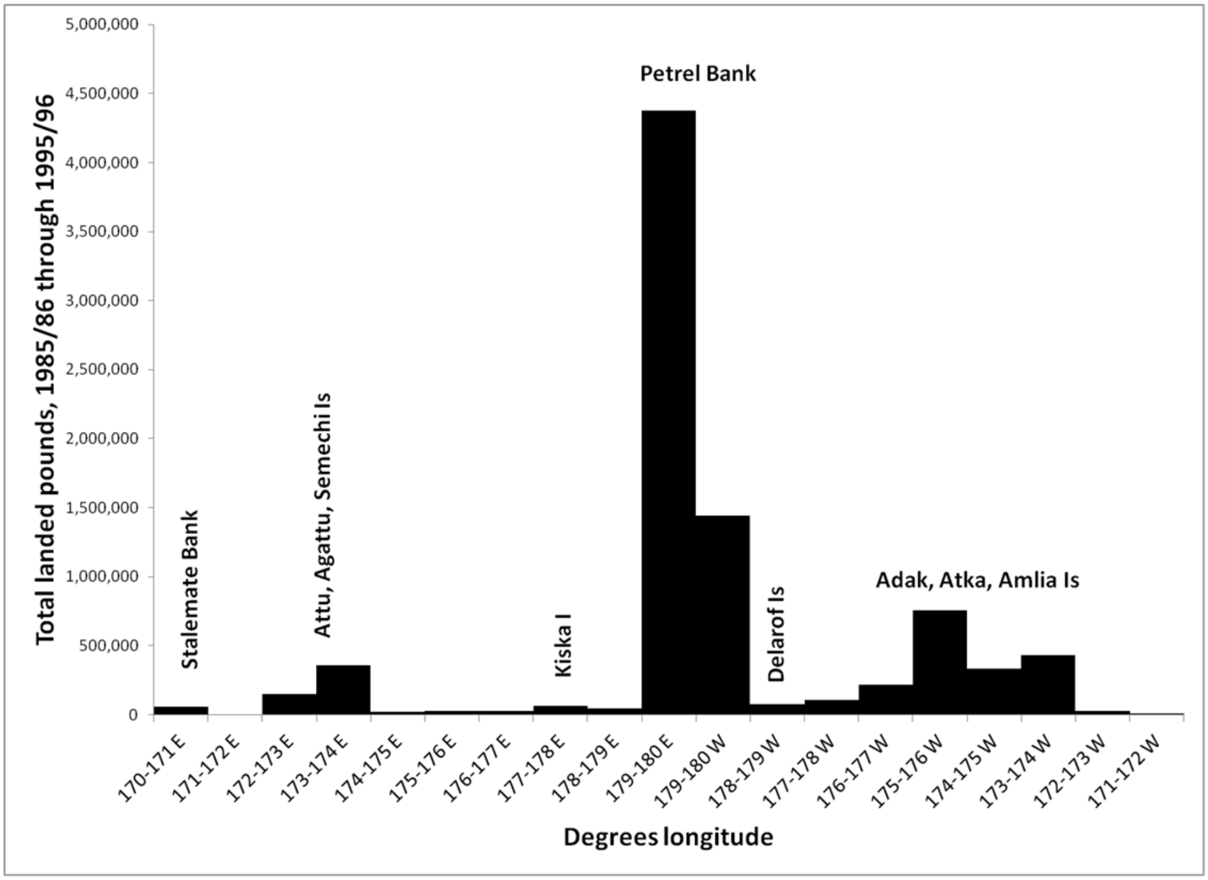


Figure 2. Retained catch (lb) in the Western Aleutian Islands red king crab fishery, 1985/86–1995/96 by 1-degree longitude grouping, summarized from fish ticket catch by state statistical area landing data.

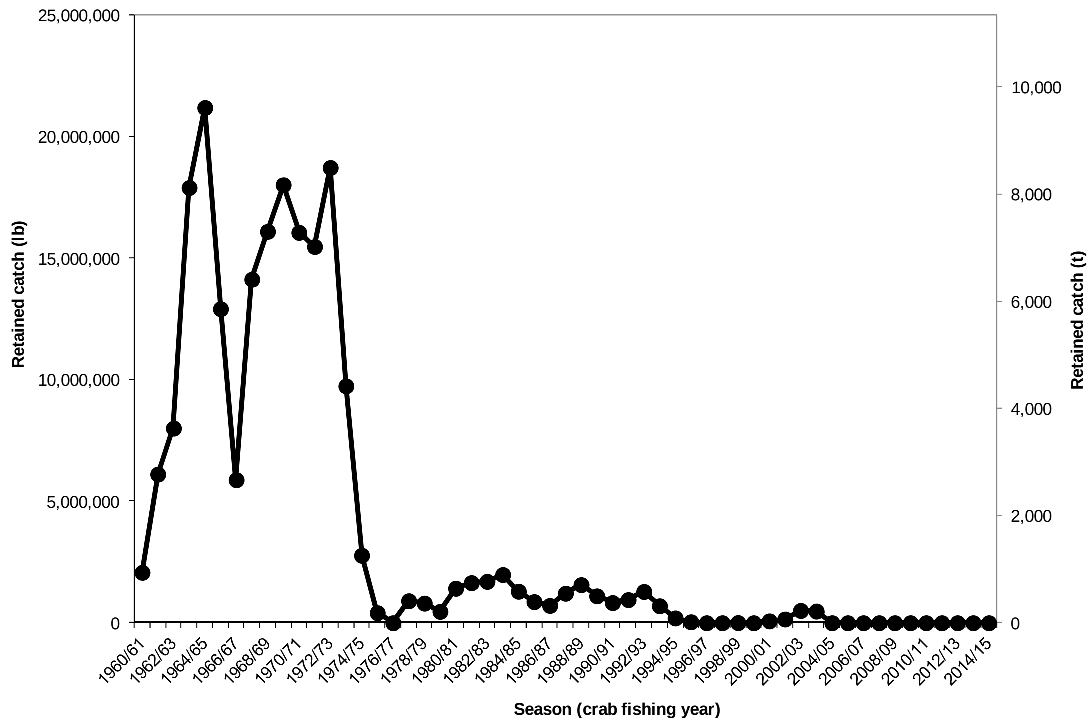


Figure 3. Retained catch (lb on left axis, t on right axis) in the Western Aleutian Islands red king crab fishery, 1960/61–2014/15 (catch is for the area west of 172° W longitude during 1960/61–1983/84 and for the area west of 171° W longitude during 1984/85–2014/15; see Table 1).

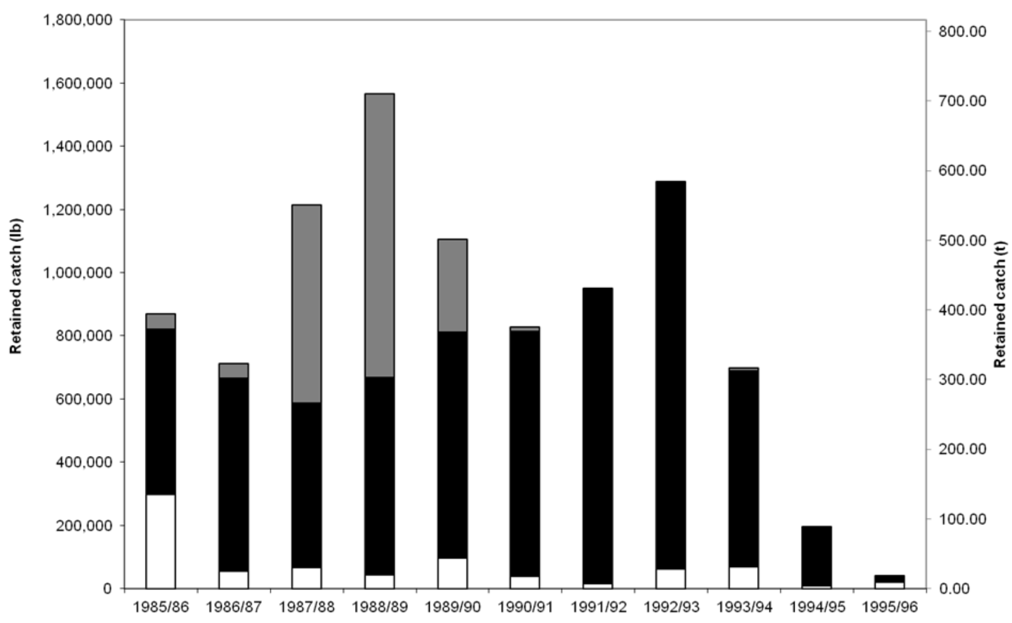


Figure 4. Retained catch (lb on left axis, t on right axis) in the Western Aleutian Islands red king crab fishery for the 1985/86–1995/96 seasons, partitioned into three longitudinal zones: 171º W longitude to 179º W longitude (white bars); 179º W longitude to 179º E longitude (black bars); and 179º E longitude to 171º E longitude (gray bars; data from ADF&G fish ticket summary provided by F. Bowers, ADF&G, March 2008).

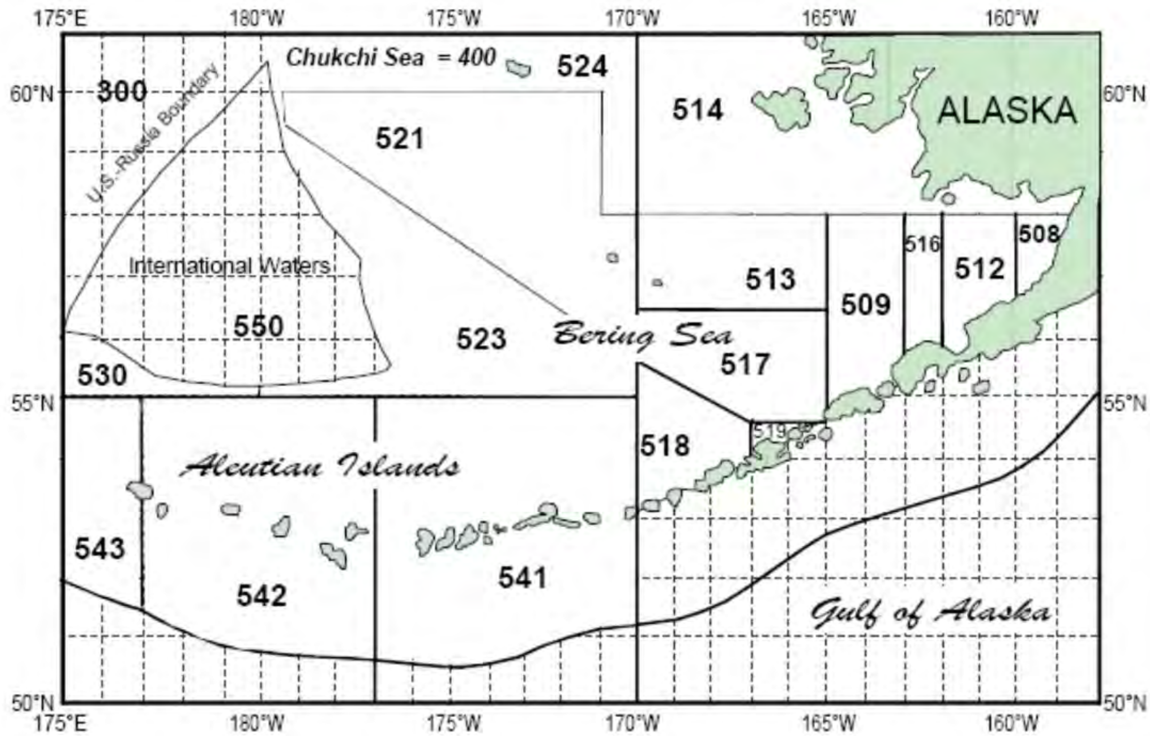


Figure 5. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands showing reporting areas 541, 542, and 543 that are used to obtain data on bycatch of Western Aleutian Islands red king crab during groundfish fisheries (from http://www.alaskafisheries.noaa.gov/rr/figures/fig1.pdf).

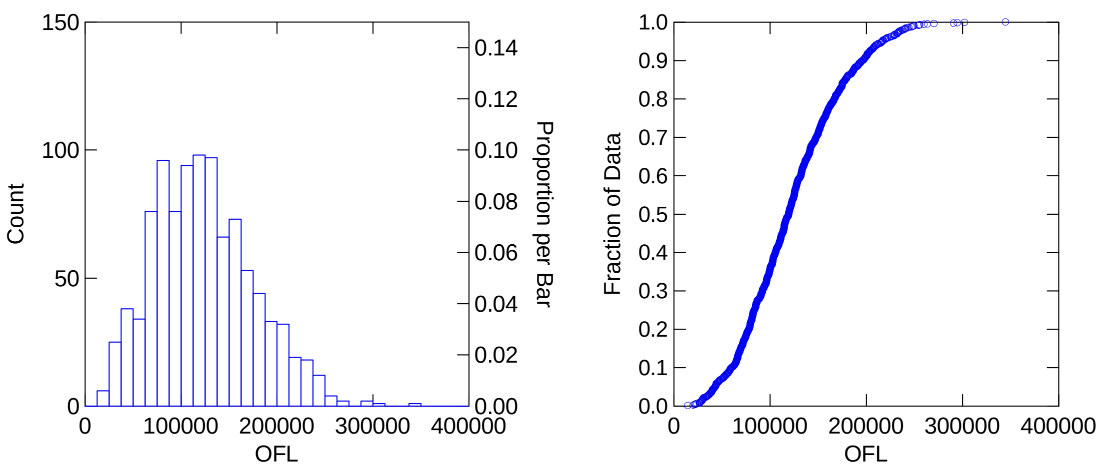


Figure 6. Bootstrapped estimate of the sampling distribution of the recommended 2014/2015 Tier 5 OFL (catch, lb) for the Western Aleutian Islands red king crab stock; histogram in left column, cumulative distribution in right column (from 2014 SAFE).

Economic Status Report Summary: BSAI Crab Fisheries, 2015

This report provides a brief summary of key indicators of economic status and performance of BSAI crab fisheries for the 2010 through 2014 calendar year operations.[1] The Bering Sea/Aleutian Islands (BSAI) crab fisheries managed under the North Pacific Fishery Management Council's Fishery Management Plan (FMP) were prosecuted by an active fleet of 106 catcher vessels and two catcher processors during calendar year 2014, and landed and processed at 17 processing facilities throughout the region. Of the 11 crab fisheries managed under the FMP[2], nine were open to targeted fishing during 2014. The Bering Sea Tanner (BST) crab fisheries were closed for the 2010/11 and 2011/12 seasons, and reopened for targeted fishing for the 2013/14 and subsequent seasons[3], and the Saint Matthew blue king (SMB) crab fishery was closed for the 2013/14 season under the State of Alaska's management strategy and reopened for 2014/15. Pribilof Islands red and blue king, and Western Aleutian red king crab stocks are currently designated overfished and are closed, as detailed in the assessments for these stocks.

Fishery production and economic value

Harvest- and processing sector production statistics by crab fishery, including ex-vessel and first wholesale output, estimated revenue, and average prices are shown in Table 1 for calendar years 2010-2014 and summarized in Figure 1. Across all fisheries managed under the BSAI Crab FMP during 2014, the total volume of ex-vessel landings commercially sold to processors was 72.8 million pounds, and processing sector total finished production volume was 47.9 million pounds, declining by 14 and 10 percent respectively from the previous year. Average prices as reported in both sectors for most BSAI crab produced in 2014 declined for the third year from recent peak 2011 levels, with the result of total gross revenues aggregated over all fisheries declining in 2014: $225[4] million ex-vessel and $303 million first wholesale revenues, both declining 13% from the previous year.

As of 2014, allowable catch quantities in the six largest BSAI crab fisheries currently open to targeted fishing are fully exploited (> 98% of total allocation landed), with the smaller crab fisheries exceeding 80% of total allocation landed; recent inter-annual variation in commercial

[1] A comprehensive presentation of statistical information and analysis regarding economic dimensions of the fishery evaluation is provided in the Economic Status Report for BSAI Crab, prepared annually as an appendix the Crab SAFE Report, and currently being updated for distribution in January, 2016 to incorporate data collected for the 2014 calendar year (the most recent period for which data is available). Note that results for the 2014 year are preliminary pending completion of data validation and additional analyses, and may be revised in the final update of the full Economic Status Report.

[2] For fisheries characterized by a small number of participating entities, individual statistics where indicated in Tables 1-2 are suppressed in this report due to confidentiality restrictions; this includes most values for the Pribilof Island golden king (PIG) crab fishery and the Norton Sound red king (NSR) crab fisheries, and summarized statistics for both Aleutian Islands golden king crab fisheries and both Bering Sea Tanner crab fisheries are reported in aggregate, respectively. Values that are indicated as suppressed in Tables 1-2 are also excluded from values reported in aggregate over all crab fisheries. Except where noted, the suppressed values are sufficiently small that they have minimal effect on the accuracy of information reported over all crab fisheries at the level of precision reported here.

[3] Although opened as of October, 2013, most activity in the reopened BST fisheries occurred during Spring of 2014.

[4] All monetary values are inflation-adjusted to 2014-equivalent dollar value.

landings largely reflects the results of stock assessments and the State of Alaska's specified catch limits rather than changes in fishing capacity or exploitation rate. The decrease in aggregate production during 2014 noted above was driven largely by the 26 percent decrease in commercial landings in the Bering Sea snow crab (BSS) fishery compared to 2013, with 48.6 million pounds sold to processors. Ex-vessel sales of 9.87 million pounds in Bristol Bay red king (BBR) in 2014 increased 16% over 2013, and the BST fishery returned to full production in 2014 after reopening for the 2013/14 season, producing 8 million pounds of ex-vessel sales. Norton Sound red king crab (NSR) landings were 420 thousand pounds, and landings of 5.7 million pounds in Aleutian Islands golden king (AIG) crab fisheries declined from 5.8 million pounds the previous year (-2.6%).

Similar to ex-vessel production, the proportional decrease in processing sector output aggregated over all active crab fisheries was driven by the 32 million pounds of BSS finished production, declining by 26 percent in volume over the previous year. Finished volume in the BBR fishery of 6.7 million pounds reflects an increase of 16% in 2014, and AIG and NSR fisheries produced 3.6 million and 0.32 million pounds of finished volume, respectively, both slightly reduced from 2013 levels. Total 2014 finished volume in the BST fishery was 5.5 million pounds.

Ex-vessel and wholesale Alaska crab prices declined in all 2014 crab fisheries shown in Table 1. Average prices declined most sharply in red king crab fisheries; BBR ex-vessel price dropped 14 percent to $6.64 per landed pound, and first wholesale price dropped 16 percent to $11.94 per finished pound, with NSR ex-vessel and first wholesale prices decreasing to $5.27 (-15%) and $9.20 (-10%) per pound, respectively. Prices in the BST fishery declined to $2.39 ex-vessel (-10%) and $5.82 (-15%) first wholesale. More moderate declines occurred in snow crab prices, with $2.38 average ex-vessel (-4.8%) and $5.03 average first wholesale (-4%) per-pound. Golden king crab ex-vessel price decreased to $4.06 (-7%), and first wholesale to $7.96 (-11%) per-pound.

The third year of decline in both market price and production volume in the BSS fishery reduced gross revenue by 29 percent compared to 2013, to $116 million in the harvest sector and $160 million in the processing sector. Earnings were more stable in the BBR fishery, with ex-vessel revenue of $65 million and wholesale revenue of $80 million only slightly less than 2013. Estimated revenues in the AIG fisheries declined to $23 million ex-vessel (-9%) and $29 million wholesale (-13%). The reopened BST fishery produced gross revenue of $19 million ex-vessel and $32 million wholesale, and the NSR fishery produced gross ex-vessel revenue of $2.2 million (-20%), and $3 million at first wholesale (-16%). The proportional inter-annual variation in gross revenue from 2013 to 2014 was somewhat less than the average degree of variation over the last 15 years in the historically volatile crab fisheries; longer time series for these and other measures of crab fishery performance are available in the full BSAI Crab Economic Status Report

Employment and Income

A summary of selected indicators from the most recent employment data available for Crab Rationalization (CR) program fisheries (including CDQ and ADAK allocation components of these fisheries) is provided in Table 2[5]. The number of distinct vessels operating in one or more of the CR fisheries in 2014 declined from 81 to 74. The AIG fisheries together had one fewer vessel active during 2014 and the BSS fishery had two fewer vessels active during 2014, while 106 additional vessels fished in the BST fishery during 2014 than in the pervious year. Based on the average (mean) number of crew onboard (as reported in eLandings catch accounting records for crab vessels), there were an estimated 1191 crew positions across all 74 vessels and CR fisheries in 2014[6].

Revenue-share payments to crab vessel crew members as a group totaled approximately $31 million in 2014, with an additional $14 million paid to vessel captains[7]. Over both groups, incomes declined by 14 percent in 2014, reflecting the overall decrease in ex-vessel revenue described above. Aggregate crew and captain earnings in the BSS fishery declined by 28 percent to $17.1 million and $7.8 million, respectively. On a median vessel basis, crew and captain pay in the BSS fishery were $236 thousand and $107 thousand respectively, with pay to captains decreasing from 2013 by 29 percent on average compared to 23 percent for crew. While aggregate crew and captain earnings in the AIG and BBR fisheries declined for 2014 (to $3.3. million and $1.4 million in AIG, respectively, and $7.6 million and $3.6 million in BBR), crew payments by the median vessel increased in both fisheries, to $702 million in AIG (+21%) and $104 million in BBR (+3%), while captain pay by the median vessel declined moderately in both fisheries.

Crab processing labor input at processing plants that received IFQ and CDQ crab landings in 2014 is estimated at nearly 843 thousand labor hours, 12 percent less than 2013, and with the number of active plants decreasing from 12 to nine. Aggregate processing labor income generated across all CR fisheries during 2014 was nearly $9 million, declining 16 percent from the previous year. The larger proportional drop in processing labor pay compared to labor hours reflects a downward trend in hourly processing wage rates across all fisheries, with median plant-level hourly wage rate declining from $11.92 in 2012 to $9.48 in 2014 for processors in the BBR fishery, with similar but more moderate changes indicated for other fisheries.

IFQ Leasing

Table 3 shows aggregated results for CR program fishing quota lease volume (in pounds) and cost reported for crab vessels active in recent calendar year BBR and BSS fisheries,[8] by fishing quota type category, including total quantities summed over all reporting vessels, median vessel-

[5] BSAI Crab Economic Data Report (EDR) data are collected for CR fisheries only. The NSR and Pribilof Island golden king (PIG) crab fisheries are managed by the State of Alaska under the FMP, but are not included in the CR program. Crab EDR data for calendar year 2014 are preliminary.

[6] Note that the aggregate count of vessels indicates the total number of distinct vessels, while the count of crew positions counts positions separately by fishery and vessel, such that individual crew members are counted more than once, The reopened BST fishery added 106 positions during 2014, which accounts for the increase in positions across all fisheries despite the reduced number of distinct vessels operating.

[7] In addition to revenue-share payments, income is derived by some crew and many captains from royalties for harvesting quota shares held by either the captain or crew. While this may become an increasingly important source of income as opportunities for investment in QS ownership are advanced, there is no evidence to-date that the proportion of CR fishery quota share pools held by crab crew members has changed in recent years, following a small amount of consolidation occurring during the initial years of the program (see NMFS Alaska Region, Restricted Access Management Program, Bering Sea and Aleutian Islands Crab Rationalization Program Report, Fishing Year 2011/12 for information on quota allocation and transfer activity, and other current CR program administration details).

[8] Note that CR crab fisheries are managed on a July-June seasonal calendar, i.e., 2012 calendar year fisheries include the 2011/2012 BSS season and 2012/2013 BBR season.

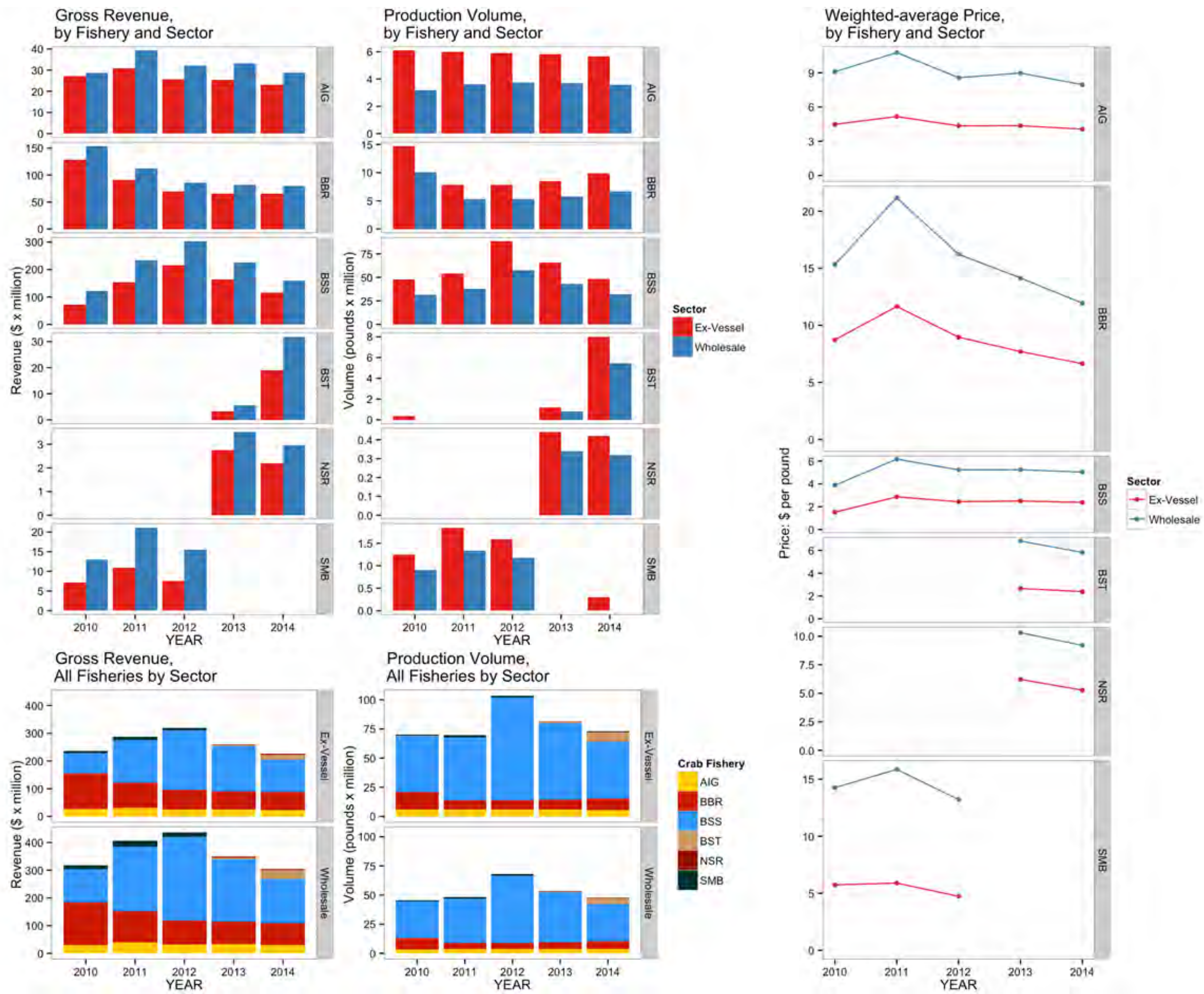
level values for volume and cost of leased quota per vessel, and median lease price paid ($US per pound) and lease rate (lease price as percentage of ex-vessel price) per vessel. Harvest quota types are categorized as the following: catcher vessel owner (CVO) Class A IFQ; catcher vessel owner Class B IFQ and catcher/processor owner (CPO) IFQ; catcher vessel crew IFQ and catcher/processor crew IFQ, and community development quota (CDQ).

The number of vessels reporting quota leases in the 2014 BBR fishery range from 49 vessels leasing CVO Class A shares, to 7 vessels leasing CDQ shares (out of 63 crab vessels active during the 2013 BBR fishery), and from 53 vessels leasing CVO A Class BSS IFQ allocation to 10 vessels leasing CDQ allocation (out of 69 active vessels) in the BSS fishery. Total volume and cost over all vessels leasing the respective quota types during 2014 range from 4.99 million pounds and $21 million for BBR CVO Class A IFQ, to 215 thousand pounds and $942 thousand for BBR CVO and CPC crew IFQ allocation; BSS lease volume and cost ranged from 28.5 million pounds and $31 million for CVO A Class IFQ to 1.1 million pounds and $1.3 million for crew share IFQ allocation.

Median vessel-level values for 2014 BBR quota leased volume and cost ranged from 118 thousand pounds and $503 thousand per vessel for the seven vessels leasing BBR CDQ allocation, 89 thousand pounds and $373 thousand for BBR CVO-A shares, and 7 thousand pounds and $23 thousand for BBR CVO and CPO crew IFQ; BSS per-vessel averages ranged from 442 thousand pounds and $489 thousand per vessel for BSS CVO- A Class allocation to 29 thousand pounds and $38 thousand for BSS crew share allocation.

Median vessel-level lease prices and lease rates (see table footnote regarding calculation of lease rate) shown in Table 3 have remained quite stable over the three years for which data are available, varying slightly year-to year and by quota type within fishery, and with interannual variation in price per pound corresponding to changes in ex-vessel prices. In the 2014 BBR fishery, median lease price ranged from $4.32 per pound for BBR CVO A Class allocation (64% of ex-vessel value) to $4.46 per pound (65% of ex-vessel value) for CDQ allocation. Median lease price and rate in the 2014 BSS fishery ranged from $1.08 for CVO A Class IFQ (46% of ex-vessel value) to $1.23 per pound for BSS CDQ allocation (48% of ex-vessel).

Figure 1: BSAI Crab Ex-vessel and First Wholesale Production, 2010-2014



Source: ADF&G fish tickets, eLandings, CFEC pricing, ADF&G Commercial Operator's Annual Report, NMFS AFSC BSAI Crab Economic Data Report (EDR) database. See Table 1 footnotes for details.

(a) Revenue, (b) Volume, and (c) Weighted Average Price, 2010-2014; gross revenue and production volume by sector are presented in the upper pair of panels by individual crab fishery for comparison of within-fishery variation over time, and summarized over all fisheries in the lower panels to illustrate the variation in aggregate values and relative contribution of each fishery over time. Figure does not display information for PIG fishery due to confidentiality. See Table 1 footnotes for data sources and details.

Table 1: BSAI crab harvest and processing sector output - production volume, gross revenue, and average price, 2010-2014

	Harvest Sector: Ex-Vessel Statistics [a]						Processing Sector: First Wholesale Statistics [b]					
Fishery: Year	**Vessels**	**CFEC permits**	**Landed volume** 1000 *mt*	million lbs	**Gross revenue** $million	**Average price** $/lb	**Plants**	**Buyers**	**Finished volume** 1000 *mt*	million lbs	**Gross revenue** $million	**Average price** $/lb
Total - All BSAI crab fisheries [d]												
2010	102	232	31.88	70.29	$236	$3.36	19	24	20.65	45.53	$318	$6.98
2011	102	235	31.61	69.68	$287	$4.12	18	27	21.85	48.17	$407	$8.44
2012	113	284	46.97	103.55	$319	$3.08	20	26	30.84	68	$436	$6.41
2013	115	238	36.95	81.45	$261	$3.20	22	29	24.27	53.5	$348	$6.51
2014	108	253	33.04	72.84	$225	$3.09	17	24	21.72	47.89	$303	$6.33
Aleutian Islands golden king - Eastern and Western (AIG)												
2010	5	13	2.76	6.09	$27	$4.48	5	9	1.44	3.17	$29	$9.09
2011	5	13	2.72	6	$31	$5.16	7	14	1.65	3.64	$39	$10.77
2012	6	14	2.69	5.92	$26	$4.35	8	14	1.71	3.76	$32	$8.57
2013	6	14	2.64	5.81	$25	$4.36	7	13	1.67	3.69	$33	$8.97
2014	5	11	2.57	5.66	$23	$4.06	5	11	1.63	3.6	$29	$7.96
Bristol Bay red king (BBR)												
2010	65	79	6.68	14.73	$129	$8.73	14	17	4.55	10.03	$154	$15.35
2011	62	71	3.53	7.79	$91	$11.66	14	18	2.41	5.3	$112	$21.18
2012	64	74	3.54	7.8	$70	$8.96	12	17	2.39	5.27	$86	$16.23
2013	63	73	3.86	8.52	$66	$7.70	11	17	2.61	5.75	$81	$14.15
2014	63	72	4.48	9.87	$65	$6.64	9	17	3.02	6.66	$80	$11.94
Bering Sea snow (BSS)												
2010	68	87	21.7	47.84	$73	$1.52	11	13	14.25	31.41	$122	$3.88
2011	68	88	24.52	54.05	$154	$2.86	14	16	17.18	37.89	$234	$6.17
2012	72	109	40.02	88.23	$216	$2.44	13	16	26.21	57.79	$302	$5.23
2013	71	90	29.7	65.49	$164	$2.50	12	15	19.46	42.9	$225	$5.24
2014	69	90	22.04	48.59	$116	$2.38	10	13	14.44	31.83	$160	$5.03

Source: ADF&G fish tickets, eLandings, CFEC pricing, ADF&G Commercial Operator's Annual Report, NMFS AFSC BSAI Crab Economic Data Report (EDR) database. Data shown for all BSAI crab fisheries by calendar year. All dollar values are adjusted for inflation to 2014-equivalent value. Information suppressed for confidentiality where indicated by "--"

[a] Except where noted, ex-vessel results reflect total commercial sales volume and value across all management programs (LLP/open access, IFQ, CDQ, ACA), inclusive of all harvest sector production (CV, CP, and catcher-sellers); ex-vessel value of CP and catcher-seller landings incorporated in revenue total by approximation using average CV ex-vessel sale price; ex-vessel average price results are sourced from CV sector EDR data where available (2010-2014 for CR program fisheries) and secondarily from CFEC gross earnings estimates (2013 for CR fisheries; all years for non-CR fisheries).

Table 1: (continued)

	Harvest Sector: Ex-Vessel Statistics [a]						Processing Sector: First Wholesale Statistics [b]					
Fishery: Year	**Vessels**	**CFEC permits**	**Landed volume** 1000 *mt*	million lbs	**Gross revenue** $million	**Average price** $/lb	**Plants**	**Buyers**[c]	**Finished volume** 1000 *mt*	million lbs	**Gross revenue** $million	**Average price** $/lb
Bering Sea Tanner (BST)[d]												
2009	18	24	0.97	2.14	$4.91	$2.30	10	11	0.63	1.39	6.19	4.46
2010	4	5	0.17	0.37	--	--	7	7	--	--	--	--
2011-2012						CLOSED						
2013	22	26	0.54	1.19	$3	$2.66	9	13	0.37	0.82	$6	$6.82
2014	38	50	3.63	8	$19	$2.39	9	13	2.48	5.47	$32	$5.82
Norton Sound red king (NSR) [e]												
2010	24	37	--	--	--	--	2	3	--	--	--	--
2011	25	38	--	--	--	--	2	2	--	--	--	--
2012	30	64	--	--	--	--	3	3	--	--	--	--
2013	34	52	0.2	0.44	$3	$6.22	5	5	0.15	0.34	$4	$10.31
2014	34	65	0.19	0.42	$2	$5.27	4	4	0.15	0.32	$3	$9.20
Pribilof Island golden king (PIG)												
2010	1	1	--	--	--	--	2	2	--	--	--	--
2011	2	2	--	--	--	--	1	1	--	--	--	--
2012	1	1	--	--	--	--	1	1	--	--	--	--
2013	1	1	--	--	--	--	1	1	--	--	--	--
2014	1	1	--	--	--	--	1	1	--	--	--	--
Saint Matthew blue king (SMB)												
2010	11	14	0.57	1.25	$7	$5.74	5	9	0.41	0.91	$13	$14.26
2011	18	23	0.84	1.85	$11	$5.89	6	11	0.6	1.33	$21	$15.86
2012	17	22	0.72	1.59	$8	$4.73	6	11	0.53	1.18	$16	$13.21
2013						CLOSED						
2014	4	5	0.14	0.3	--	--	1	6	--	--	--	--

[b] Counts of buyers include CPs landing and processing their own crab, but exclude catcher sellers (NSR fishery only); processing sector results inclusive of all CP and shoreside processor output; finished volume sourced from crab processor EDR production reports where available (2010-2011), or eLandings ex-vessel sales volume adjusted by average product recovery rate (PRR) by fishery (2012-2014). Wholesale price results are sourced from crab processor EDR gross earnings reports where available (2010-2011) and secondarily from COAR gross earnings estimates (2012-2014); gross wholesale revenue estimates are derived from price and volume sourced or estimated as described.

[c] Statistics reported for "All BSAI Fisheries" reflect information aggregated over all FMP crab fisheries, excluding fishery-level confidential information suppressed where indicated by "-- ".

[d] Landings and ex-vessel revenue suppressed in years where CDQ fishery landings are confidential.

[e] Data for Norton Sound red king crab are aggregated over the summer and winter commercial fisheries.

Table 2: CR program fisheries crew and processing sector employment and earnings, 2010-2014

		Crab Crew Employment and Earnings							**Crab Processing Employment and Earnings**					
		Crew positions		**Crew share**		**Captain share**			**Processing labor hours**		**Processing labor payment**			
Fishery: Year [b]	Vessels	Total	Vessel mean	Total $million	Vessel median $1000	Total $million	Vessel median $1000	Plants	Total 1000 hrs[d]	Plant median 1000 hrs	Total $million	Plant median $1000	Median $/hour[e]
All CR Program Fisheries [e,g]													
2010	79	964		$29.75		$14.26		15	771.12		$9.28		
2011	77	1014		$38.91		$18.05		16	724.96		$9.42		
2012	83	1081		$43.17		$19.79		13	1261.9		$15.97		
2013	81	1099		$35.94		$16.53		12	955.77		$10.74		
2014	74	1191		$30.95		$14.24		9	842.63		$8.99		
Aleutian Islands golden king - Eastern and Western (AIG) [f,g]													
2010	5	35	7	$3.57	$720.32	$2.03	$310.73	3	--	--	--	--	--
2011	5	36	7.2	$4.31	$730.88	$2.35	$388.79	6	48.97	4.79	$1.23	$83.42	$11.09
2012	6	46	7.67	$3.83	$698.25	$1.97	$349.81	7	53.16	2.6	$1.22	$65.46	$11.25
2013	6	44	7.33	$3.59	$578.94	$1.63	$295.48	6	61.09	5.96	$0.66	$66.46	$10.76
2014	5	35	7	$3.25	$702.44	$1.41	$292.22	4	--	--	--	--	--
Bristol Bay red king (BBR) [g]													
2010	65	422	6.48	$14.69	$217.73	$7.00	$112.60	11	211.56	20.09	$2.69	$217.91	$11.16
2011	62	413	6.66	$11.59	$168.25	$5.38	$91.51	12	104.38	6.71	$1.35	$81.54	$11.28
2012	64	428	6.68	$8.81	$112.00	$3.97	$59.61	10	100.36	6.51	$1.30	$74.49	$11.92
2013	63	418	6.63	$8.09	$101.27	$3.85	$57.02	8	103.96	10	$1.28	$101.13	$10.82
2014	63	422	6.7	$7.58	$104.78	$3.64	$52.50	7	129.98	21.07	$1.41	$76.19	$9.48
Bering Sea snow (BSS) [g]													
2010	68	444	6.53	$10.47	$138.53	$4.70	$66.28	9	534.17	50.9	$6.33	$418.09	$11.38
2011	68	453	6.66	$21.62	$305.06	$9.68	$141.56	12	554.86	45.69	$6.67	$386.73	$11.45
2012	72	502	6.97	$29.59	$410.24	$13.42	$192.62	11	1087.26	77.94	$13.19	$672.78	$11.44
2013	71	481	6.77	$23.78	$305.95	$10.82	$152.66	10	774.12	63.55	$8.63	$520.28	$10.84
2014	69	472	6.84	$17.11	$235.85	$7.79	$106.90	8	590.39	76.01	$6.35	$459.07	$10.64

Table 2: (continued)

		Crab Crew Employment and Earnings							**Crab Processing Employment and Earnings**					
		Crew positions[a]		**Crew share payment**[b]		**Captain share payment**[b]		**Processing labor hours**[c]			**Processing labor payment**		
Fishery: Year [b]	Obs	Total	Vessel mean	Total $million	Vessel median $1000	Total $million	Vessel median $1000	Obs	Total 1000 hrs[d]	Plant median 1000 hrs	Total $million	Plant median $1000	Median $/hour[d]
Bering Sea Tanner (BST)													
2010	4	--	--	--	--	--	--	5	6.43	0.7	$0.07	$7.92	$11.39
2013	22	156	7.09	$0.48	$15.66	$0.22	$8.05	6	16.58	1.86	$0.18	$16.82	$10.40
2014	38	262	6.89	$3.01	$67.71	$1.40	$30.74	7	122.27	8.51	$1.23	$79.52	$9.64
Saint Matthew blue king (SMB)													
2010	11	63	5.73	$1.02	$80.48	$0.53	$48.11	5	18.96	0.4	$0.19	$4.52	$11.10
2011	17	112	6.56	$1.38	$64.31	$0.65	$34.84	6	16.75	0.84	$0.16	$8.72	$10.22
2012	17	106	6.24	$0.94	$48.35	$0.43	$24.64	6	21.12	0.76	$0.27	$8.04	$10.75
2014	4	--	--	--	--	--	--	1	--	--	--	--	--

Source: NMFS AFSC BSAI Crab Economic Data. Crew positions from eLandings. Data shown for CR fisheries by calendar year. All dollar values are adjusted for inflation to 2014-equivalent value. Information suppressed for confidentiality where indicated by "--".

[a] For catcher processors, EDR reporting may be used to adjust eLandings crew size reporting in order to estimate the number of fishing crew and processing positions.

[b] Crew and captain payments reflect amounts paid for labor during the crab fishery and include all post-season adjustments, bonuses, and deductions for shared expenses such as fuel, bait, and food and provisions; payments for IFQ royalties, labor outside of crab fishery, health/retirement or other benefits are excluded.

[c] Processing labor hours for catcher processors are estimated by multiplying processing positions, number of days processing, and an assumed shift length of 12 hours per day.

[d] For all years, pay per hour statistics reflect only the shoreside and floating processing sectors.

[e] Statistics reported for "All CR Program Fisheries" reflect information aggregated over all rationalized crab fisheries, excluding fishery-level confidential information suppressed where indicated by "-- ". Values that are discontinuous with the rest of the series for a given variable due to data suppression are italicized. Average values are reported at the fishery level, but not over all crab fisheries.

[f] Due to confidentiality restrictions, Aleutian Islands Eastern and Western golden king crab fisheries are reported in aggregate. Where an entity reported labor information for both the Eastern and Western fisheries, counts of crew positions are averaged over both fisheries under the assumption that the same individuals are employed in both fisheries.

[g] Sector-level results for 2009 and later reflect combined catcher processor data and catcher vessel/shoreside processor data.

Table 3: Crab Harvest Quota Leasing - Volume, Cost, and Lease Prices and Rates, 2012-2014 Calendar Year BBR and BSS Fisheries

				Pounds Leased (1000 pounds)		Cost ($1000)		Average Lease Price ($/pound)	Average Lease Rate (% of ex-vessel value)[c]
Fishery	Year	Quota type[a]	Vessels[b]	Total	Median	Total ($1000)	Median	Median	Median
BBR	2012	CVO A	50	3,619	65	$19,971	$342	$5.79	64%
		CVO B +CPO	42	539	8	$3,266	$47	$5.98	65%
		CVC + CPC	36	172	4	$1,006	$24	$5.84	63%
		CDQ	5	369	71	$2,445	$485	$6.05	64%
	2013	CVO A	51	4,425	79	$21,974	$372	$4.87	64%
		CVO B +CPO	45	778	10	$4,013	$51	$5.14	65%
		CVC + CPC	37	199	5	$1,056	$23	$5.17	66%
		CDQ	8	713	77	$3,753	$406	$5.27	66%
	2014	CVO A	49	4,988	89	$21,273	$373	$4.23	63%
		CVO B +CPO	40	803	12	$3,505	$55	$4.37	64%
		CVC + CPC	33	215	7	$942	$26	$4.34	65%
		CDQ	7	826	118	$3,700	$503	$4.47	63%
BSS	2012	CVO A	55	42,796	640	$47,706	$736	$1.12	46%
		CVO B +CPO	47	6,990	84	$8,752	$112	$1.22	46%
		CVC + CPC	39	1,880	48	$2,248	$56	$1.22	46%
		CDQ	11	6,464	563	$8,171	$742	$1.26	49%
	2013	CVO A	56	34,353	487	$40,003	$558	$1.15	46%
		CVO B +CPO	50	7,741	78	$10,342	$103	$1.25	47%
		CVC + CPC	41	1,767	35	$2,256	$43	$1.23	46%
		CDQ	11	6,409	564	$8,660	$811	$1.35	54%
	2014	CVO A	55	28,465	442	$31,021	$489	$1.12	46%
		CVO B +CPO	45	5,737	76	$6,821	$98	$1.21	47%
		CVC + CPC	35	1,111	29	$1,376	$36	$1.21	46%
		CDQ	10	5,367	423	$6,338	$510	$1.23	48%

Source: NMFS AFSC BSAI Crab Economic Data (preliminary findings subject to revision following completion of data validation).

[a] Harvest quota types are categorized in this report as the following: CVO A – catcher vessel owner Class A IFQ; CVO B + CPO - catcher vessel owner Class B IFQ and catcher/processor owner IFQ; CVC + CPC – catcher vessel crew IFQ and catcher/processor crew IFQ. Statistics reported represent results pooled over all quota types and/or regional designations within each category.

[b] Vessels column shows total count of vessel-level observations for fishery-year where both pounds and cost of quota leased were reported as non-zero values; in a small number of observations where leased pounds was reported for a given fishery/quota type but lease cost was missing, the mean price over all complete observations was used to impute the missing data in computing the total aggregate lease cost over all vessels.

[c] Average lease rate statistics by fishery and quota type are calculated as the median of the ratio of lease price to ex-vessel price, over all EDR observations where both ex-vessel and lease pounds, and ex-vessel revenue and lease cost, were reported as non-zero values; both ex-vessel and quota-lease price estimates used in calculations are stratified by fishery and quota type, such that lease rate is calculated relative to ex-vessel value of catch landed on the respective quota type, not the average price by fishery over all landings as reported in Table 1.